ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOAL01

MATURITY OF THE MAX IV LABORATORY IN OPERATION AND PHASE II DEVELOPMENT

V. Hardion, P. Bell, M. Eguiraun, T. Eriksson, A. Freitas,
M. Klingberg, M. Lindberg, Z. Matej, S. Padmanabhan, A. Salnikov,
P. Sjöblom, D. Spruce, MAX IV Laboratory, Lund University, Lund, Sweden

Abstract

MAX IV Laboratory, the first 4th generation synchrotron located in the south of Sweden, entered operation in 2017 with the first three experimental stations. In the past two years the project organisation has been focused on phase II of the MAX IV Laboratory development, aiming to raise the number of beamlines in operation to 16. The KITS group, responsible for the control and computing systems of the entire laboratory, was a major actor in the realisation of this phase as well as in the continuous up-keep of the user operation. The challenge consisted principally of establishing a clear project management plan for the support groups, including KITS, to handle this high load in an efficient and focused way, meanwhile gaining the experience of operating a 4th generation light source. The momentum gained was impacted by the last extensive shutdown due to the pandemic and shifted toward the remote user experiment, taking advantage of web technologies. This article focuses on how KITS has handled this growing phase in term of technology and organisation, to finally describe the new perspective for the MAX IV Laboratory, which will face a bright future.

MAX IV GENERAL STATUS

MAX IV Laboratory [1] is a synchrotron based research facility which consists of two storage rings of 1.5 GeV and 3 GeV respectively fed by a full energy linear accelerator. These two rings provide X-rays to 16 beamlines, of which 14 are today in user operation (see Fig. 1) and the remaining two will come online during the period 2022-2023.

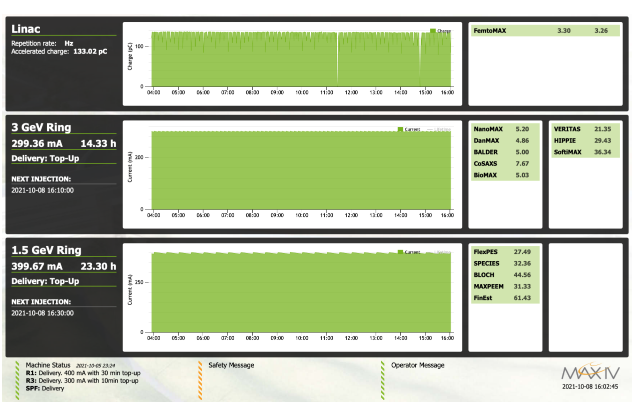

Figure 1: The Machine Status web application accessible for the public, showing all accelerators and beamlines in operation.

Beamlines Status

The first phase beamlines have rolled out into their normal operation and the number of articles published by MAX IV compared to the previous MAX-Lab are rising (Fig. 2). Beamlines already in operation have increased their performance above the baseline, aided by the support from the KITS group.

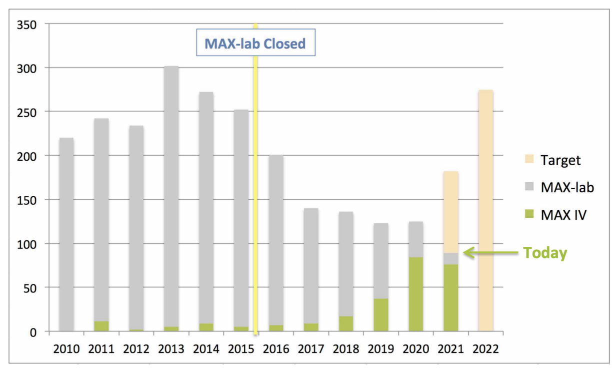

Figure 2: Publication of MAX IV Laboratory vs MaxLab.

For example Balder has achieved a unique performance with a continuous scanning down to 30 s per EXAFS in combination with a powerful analysis software [2], opening up more experiments for environment science.

In the meantime the beamlines which started in 2020 are getting excellent commissioning results while welcoming expert user experiments, in preparation for general users. Four new beamlines have completed the portfolio of full user operation since then. After achieving baseline requirements, FemtoMAX could open its first user call with a time precision of 250 fs and enough signal to complete an experiment in a standard beamtime. Thanks to large resource investment, the X-Ray pulse of the LINAC has been upgraded to 10 Hz operation while on the beamline, a precise data acquisition system has been developed by KITS to acquire all the precious shots while applying a time-over-threshold computation within 10 ms.

In 2021 the new beamlines have started operation early 2021 with limited offer. These new phase II beamlines are increasing the global level of efficiency by profiting on new standards using more stable equipment such as the PandABox [3]. DanMAX has just finished the commissioning phase and started to accept expert Users for the PRXD experiment. In order to guarantee the expected performance of the experiment, KITS have developed a position-based hardware triggered continuous scan [4]. COSAXS started early in 2021 with a basic SAXS experiment based on time

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOAL02

STATUS OF THE NATIONAL IGNITION FACILITY (NIF) INTEGRATED COMPUTER CONTROL AND INFORMATION SYSTEMS

M. Fedorov, A. Barnes, L. Beaulac, G. Brunton, A. Casey, J. Castro Morales, J. Dixon, C. Estes, M. Flegel, V. Gopalan, S. Heerey, R. Lacuata, V. Miller Kamm, M. Paul, B. Van Wonterghem, S. Weaver, Lawrence Livermore National Laboratory, P.O. Box 808, Livermore 94550, CA

Abstract

The National Ignition Facility (NIF) is the world's most energetic laser system used for Inertial Confinement Fusion (ICF) and High Energy Density Physics (HEDP) experimentation. Each laser shot delivers up to 1.9 MJ of ultraviolet light, driving target temperatures to more than 180 million K and pressures 100 billion times atmospheric, making possible direct study of conditions mimicking interiors of stars and planets, as well as our primary scientific applications: stockpile stewardship and fusion power. NIF control and diagnostic systems allow physicists to precisely manipulate, measure and image this extremely dense and hot matter. A major focus in the past two years has been adding comprehensive new diagnostic instruments to evaluate increasing energy and power of the laser drive. When COVID-19 struck, the controls team leveraged remote access technology to provide efficient operational support without stress of on-site presence. NIF continued to mitigate inevitable technology obsolescence after 20 years since construction. In this talk, we will discuss successes and challenges, including NIF progress towards ignition, achieving record neutron yields in 2021.

INTRODUCTION

The National Ignition Facility is a large (3 football fields) and complex (192 laser beams) experimental physics system (Fig. 1) [1] . It is efficiently operated 24x7 by a shift of the 12-14 Control Room operators with the help of the Integrated Computer Control System (ICCS). Over 66,000 devices with rich APIs are distributed over 2,300 front-end-processors (FEPs) and embedded controllers (ECs).

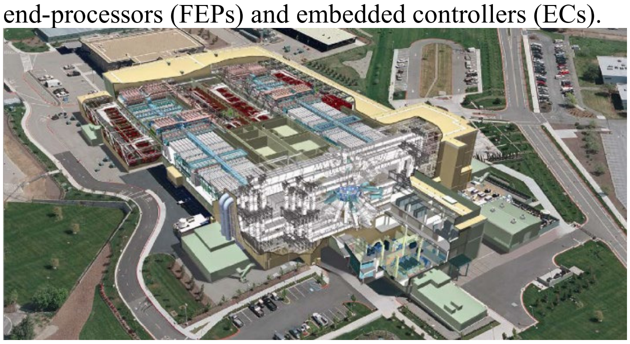

Figure 1: NIF building layout.

NIF experiments are structured around laser shots. Each shot takes 4-8 hours and involves the control system to execute over 2 million device operations.

Experiments at NIF support several programmatic missions, such as Stockpile Stewardship, Discovery Science, National Security Applications, and Inertial Confinement Fusion (ICF). For ICF, thermonuclear ignition has been the long-term goal of the facility, defined as producing more energy from the DT target fusion than the 3w laser energy on the target (for example, 1.9 MJ). The NIF was pursuing the ignition goal for almost 10 years, and it proved to be a scientific and engineering challenge. During 2011-2020, the target energy yield maxed at about 50 kJ, well below the ignition goal.

UNEXPECTED INTERRUPTION

The NIF's quest for ignition and scientific discovery was abruptly interrupted when in March of 2020 a "shelter-in-place" order was issued at our location to quench a spike of COVID-19 infections. Facility shifted to minimal safe operations, shots pauseda, and the Control Room staff reduced from 14 to 3 operators. Controls and IT teams have supported the change, assuring continuity of operations of the networks, hardware and ICCS in a non-shot, monitoring mode.

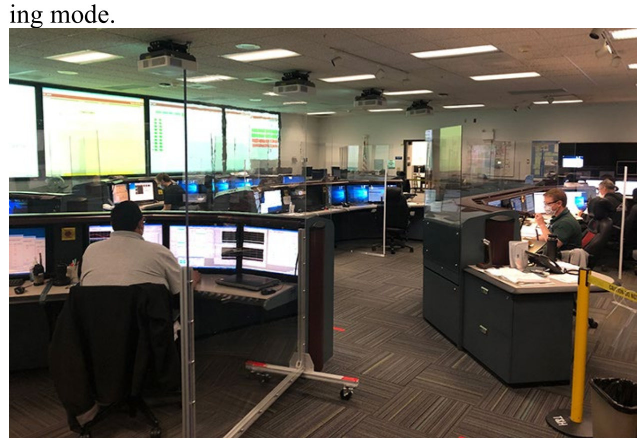

Figure 2: NIF Control with COVID-19 personnel protections: plexiglass screens, masks, traffic barriers.

Soon after the U.S. Center for Disease Control (CDC) recommendations became available, the NIF started to reorganize facility operations. Ventilation flows were adjusted, plexiglass screens between the consoles were installed and personnel traffic was directed with barriers to assure social distancing of at least 7.5ft (Fig. 2,3). Our teams have supported gradual restoration of normal shot operations, by May 2020. Quick restart of experiments was welcomed by the U.S. National Nuclear Security Administration [2,3].

While initially the restarted operations progressed slowly and deliberately, soon the shot rate had ramped up to normal, and control teams had to address the need for support and maintenance activities such as ICCS releases. Traditionally, for major software releases as well as testing and troubleshooting, ICCS software engineers were

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOAL03

FROM SKA TO SKAO: EARLY PROGRESS IN THE SKAO CONSTRUCTION

J. Santander-Vela[1*], M. Bartolini[1,2], M. Miccolis[1], N. Rees[1]
[1]SKA Observatory, SK11 9FT Jodrell Bank, United Kingdom
[2]INAF Istituto Nazionale di Astrofisica, Viale del Parco Mellini 84, 00136 Roma, Italy

Abstract

The Square Kilometre Array telescopes have recently started their construction phase, after years of pre-construction effort. The new SKA Observatory (SKAO) intergovernmental organisation has been created, and the start of construction (T_0) has already happened. In this talk, we summarise the construction progress of our facility, and the role that agile software development and open-source collaboration, and in particular the development of our TANGO-based control system, is playing.

INTRODUCTION

The Square Kilometre Array (SKA) is an international project that has the aim of building two multi-purpose radio telescope arrays. One of them will be built in South Africa in the Karoo desert, and the other will be constructed in the Murchison Shire in Western Australia. The name comes from the initial intention for these telescopes to provide the equivalent collecting area of at least one square kilometre, and thus unprecedented sensitivity, which would allow key questions in modern astrophysics and cosmology to be answered.

The original *Hydrogen Array* concept of an array that was sensitive enough through a very large collecting area of up to one square kilometre was described by Peter Wilkinson in 1991 [1]. One of the main concepts took the name of the Square Kilometre Array project, and several milestones were achieved in order to make this project a reality.

After several forms (from an interest group to the International SKA Project Office, later the SKA Project Office in Manchester University), and several EU framework programs (SKADS, the SKA Design Study; PrepSKA, preparation for SKA), the SKA Organisation was founded in November 2011 as a non-for-profit limited responsibility company established in England and Wales.

As part of SKADS, the first SKA Science book was published in 2004 [2]. After the official start of the SKA Pre-Construction in 2014, an update to the SKA science book was published [3] in 2015 after a decade of development of the SKA concept, incorporating more than 130 scientific use cases that will be possible thanks to the SKA telescopes.

Those science cases cover Galaxy Evolution, Cosmology and Dark Energy[1], Strong-Field Tests of Gravity[2], Cosmic Magnetism[3], The Cosmic Dawn and the Epoch of Reionisation[4], and research on the Cradle of Life[5]. The amount of physical disciplines foreseen to be encompassed by the SKA telescopes is one of the largest for any ground based facility to date.

The SKA project is currently in what is known as SKA Phase 1, or SKA1, in which two telescopes approximately with 10% of the target collecting area are being built, namely SKA1-Mid, and SKA1-Low, in order to prove the feasibility of the techniques and derisk the construction of the next phase of the project, SKA Phase 2, or SKA2.

The goal is to have a single observatory entity, that will construct and operate two SKA1 telescopes (SKA1-Mid and SKA1-Low), with presence in three sites: Australia (SKA1-Low), South Africa (SKA1-Mid), and United Kingdom (Headquarters and central operations).

This talk focuses on the progress and status of the SKA project from our last status report [4] in ICALECPS'17. It starts by describing how we have migrated from the SKA Organisation and pre-construction towards the SKA Observatory (SKAO) in From SKA to SKAO and Start of Construction. We later indicate the role of software in the SKA project in Software in the SKA Project, and we provide an update on the status of our efforts in Current Status. We continue by describing the difficulties that we have been facing up to the start of construction in Challenges, and we describe future work in Next Steps, with some short Conclusions at the end.

FROM SKA TO SKAO AND START OF CONSTRUCTION

As indicated in Sec. Introduction, the Hydrogen Array concept was first published in 1991. Several studies were made to come with a concept for the realisation of that square kilometre array, and in 2008 the EU Framework Programme called SKA Design Studies (SKADS) was started, and then followed by PrepSKA. After PrepSKA, the SKA Organisation was founded as a non-for-profit, limited liability company registered in England and Wales, but it also set in motion the process for finding what would be the ultimate legal form for the SKA Observatory (SKAO), and it was finally decided that an Inter-Governmental Organisation (IGO) was the way to go.

After PrepSKA, which set up the first contacts towards the IGO, the first round of negotiations towards the SKAO IGO took place in October 2015. Several rounds of negotiations

* juande.santander-vela@skao.int
[1] http://skatelescope.org/galaxyevolution/
[2] http://skatelescope.org/gravity-einstein-pulsars/
[3] http://skatelescope.org/magnetism/
[4] http://skatelescope.org/cosmicdawn/
[5] http://skatelescope.org/cradle-life/

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOAR01

MODERNIZING THE SNS CONTROL SYSTEM*

K. S. White†, K. Kasemir, K. Mahoney, K. Vodopivec, D. Williams,
Oak Ridge National Laboratory, Oak Ridge, USA

Abstract

The Spallation Neutron Source at Oak Ridge National Laboratory has been operating since 2006. An upgrade to double the machine power from 1.4 MW to 2.8 MW is currently underway and a project to add a second target station is in the preliminary design phase. While each project will add the controls needed for their specific scope, the existing control system hardware, software, and infrastructure require upgrades to maintain high availability and ensure the system will meet facility requirements into the future. While some systems have received new hardware due to obsolescence, much of the system is original apart from some maintenance and technology refresh. Software will also become obsolete and must be upgraded for sustainability. Further, requirements for system capacity can be expected to increase as more subsystems upgrade to smarter devices capable of higher data rates. This paper covers planned improvements to the integrated control system with a focus on reliability, sustainability, and future capability.

BACKGROUND

The Spallation Neutron Source (SNS) is an accelerator-based neutron facility that provides the world's most intense source of pulsed neutrons for research. The machine was originally commissioned in 2006 and began operating for users in 2007. The facility was constructed by a collaboration of six laboratories who delivered controls along with their systems. The SNS Controls Group was responsible for global systems, control system infrastructure and integration of the partner contributions to create a single Integrated Control System (ICS) [1]. Hardware and software standards were adopted for the control system including the selection of the Experimental Physics and Industrial Control System (EPICS) toolkit for control, communication, and operational services. Using EPICS then allowed a diverse set of hardware to be integrated into a cohesive system.

The client/server architecture of the SNS control system consists of three layers shown in Fig. 1. The front-end layer employs input/output controllers (IOCs) as servers to connect to devices in the field and execute run-time control functions. The communication layer passes data in the form of EPICS process variables (PVs) between front-end IOCs and client applications. The back-end layer uses workstations to execute client applications to provide operational interfaces and tools.

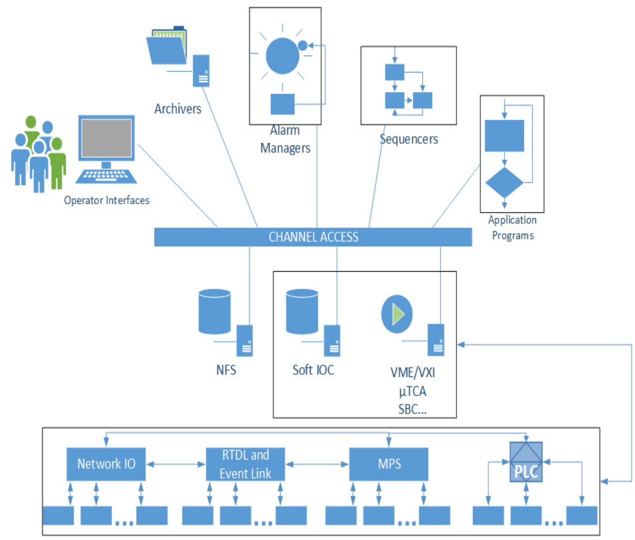

Figure 1: SNS ICS Architecture.

A key advantage of this type of architecture, where control functions, communications, and operational tools are decoupled, combined with the inherently distributed design of EPICS, is the ability to upgrade the layers, or individual components of a layer, independently thus providing a minimally disruptive path for upgrades which is essential for operating facilities.

The ICS, as originally constructed, employed commercial Linux servers and workstations for client layer and standard ethernet networking for communication. EPICS client applications providing operator interfaces included a custom alarm handler, the Extensible Display Manager (EDM) and the Channel Archiver. Several different types of IOCs were used, including VME/VXI Motorola single board computers running VxWorks, Allen Bradley Programmable Logic Controllers (PLCs) interfaced to Linux based (soft) IOCs or VME IOCs, and Windows PCs running Labview for Beam Instrumentation Devices. Table 1 shows the number of IOCs, PLCs, and EPICS PVs during initial operations and the present, pointing out where the system has expanded. While the number of VME IOCs has remained about the same, the number of soft IOCs has tripled supporting requests for new features as well as new devices and subsystems and the number of PVs has grown by ~50%.

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† ksw@ornl.gov

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOAR02

MODERNIZING DIGITAL VIDEO SYSTEMS AT THE NATIONAL IGNITION FACILITY (NIF): SUCCESS STORIES, OPEN CHALLENGES AND FUTURE DIRECTIONS

V. Gopalan, A. Barnes, G. Brunton, J. Dixon, C. M. Estes, M. Fedorov, M. Flegel, B. Hackel, D. Koning, S. Townsend, D. Tucker, J. Vaher,
Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, CA 94550, USA

Abstract

The National Ignition Facility (NIF), the world's most energetic laser, completed a multi-year project for migrating control software platforms from Ada to Java in 2019. Following that work, a technology refresh of NIF's Digital Video (DVID) systems was identified as the next important step. The DVIDs were facing long-term maintenance risk due to its obsolete Window XP platform, with over 500 computers to be individually upgraded and patched, 24 camera types with a variety of I/O interfaces and proprietary drivers/software with their licensing needs. In this presentation, we discuss how we leveraged the strengths of NIF's distributed, cross platform architecture and our system migration expertise to migrate the DVID platforms to diskless clients booting off a single purpose-built immutable Linux image and replacing proprietary camera drivers with open-source drivers. The in-place upgrades with well-defined fallback strategies ensured minimal impact to the continuous 24/7 shot operations. We will also present our strategy for continuous build, test, and release of the Linux OS image to keep up with future security patches and package upgrades.

INTRODUCTION

Digital Video (DVID) systems are an integral part of the NIF control system. They participate in a variety of automatic loops (e.g., automatic alignment), provide critical diagnostics to study the laser, and allow operators to observe the state of the system in real time. The cameras may be used for still captures, streaming video or both. The capture may be precisely timed using triggers, synchronized to the arrival of the laser pulse, or may be manually captured by an operator on demand. It can be used for spatial measurements – e.g., for measuring the spatial aberrations of the NIF beam's optical wavefront. With over 500 DVIDs deployed along the laser path leading to the target, the DVIDs provide machine vision functions to NIF including optics inspection, automation, application-oriented machine vision processing, and vision-guided automatic alignment/positioning systems.

LONG TERM MAINTENANCE CHALLENGE

The NIF Integrated Computer Control System (ICCS) underwent a phase of modernization which concluded in 2019 [1]. As part of that work, the low-level, hardware-facing Front-End-Processors (FEPs) were migrated from Ada to Java based software and associated Java frameworks and libraries. The DVID FEPs also benefitted from the overall NIF ICCS modernization, however, the unique nature of the DVIDs called for further upgrades to DVID hardware and software to counter obsolescence and avoid future maintenance jeopardy. The various challenges specific to DVIDs are described in the following sections.

Obsolete OS

The DVID FEPs run on the unsupported Windows XP Operating System (OS) with inherent security issues and lack of hardware support as newer computer hardware discontinue support for older operating system versions. Non-availability of machines that can install Windows XP on them means that replacing or upgrading hardware will only become a bigger challenge with time. Stop gap measures such as upgrading random access memory (RAM) in existing systems to improve application performance also does not help much due to XP's limitation on maximum supported memory (4GB).

Large Number of FEP Images

Each DVID FEP has its own Windows image installed in the local hard disk and these OS images are required to be individually upgraded and patched. Deployment of OS/driver upgrades and patches are expensive and difficult due to the large number of machines that needs to be individually patched and tested for every modification.

Multiple Camera Interface Types

The DVIDs use several interface types to talk to the different types of cameras. Figure 1 shows how the interface types are split across all the DVID FEPs.

Interface type	No. of FEPs
FireWire	487
GigE	318
Analog-FireWire	110
Analog-PCIe	2

Figure 1: Camera interface types and usage count.

Cameras that use FireWire, also commonly known as IEEE 1394, use DCAM protocol that describes the exchange of data over the FireWire bus interface. GigE based cameras use GigE Vision [2], a standard for video transfer and device control over Ethernet networks. Analog cameras typically provide an RS-170 analog signal, which then

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOAR03

LOFAR2.0: STATION CONTROL UPGRADE

T. Juerges[1,2*], J. D. Mol[2†], T. Snijder[2‡]
[1]Square Kilometre Array Observatory (SKAO),
Jodrell Bank, Macclesfield, SK11 9FT, United Kingdom
[2]Netherlands Institute for Radio Astronomy (ASTRON),
Oude Hoogeveensedijk 4, 7991 PD Dwingeloo, Netherlands

Abstract

After 10 years of operation, the LOw Frequency ARray (LOFAR) telescope is undergoing a significant hardware upgrade towards LOFAR2.0. The hardware upgrade will enable the phased array telescope to observe at 10-90 MHz and at 120-240 MHz frequencies at the same time. With the upgrade comes also the chance to review LOFAR's Control System and to make it ready for the next 10 years of operation at the forefront of low-frequency astronomy. In this work we will give a brief overview over the LOFAR telescope with its more than 50 geographically distributed receiver locations (LOFAR Stations), and the software that is necessary to monitor and control every single one of them. We will then describe the Station Control architecture, with its software design and how it is implemented in Python 3 with Tango Controls, OPC-UA clients and deployed as Docker containers. Lastly we will report on the successful use of open stack software like ELK and, Grafana.

LOFAR TELESCOPE OVERVIEW

LOFAR [1] is a geographically distributed radio telescope array, consisting of around 60,000 dipole antennas. The antennas are grouped into 56 *stations*, 38 of which are deployed in the Netherlands, and the remaining 14 in other countries across Europe. The scientific data from these stations are streamed to our real-time GPU correlator [2] in Groningen, the Netherlands. Thusly correlated (and beamformed) data products are subsequently post processed. We send the end result to our tape archives in the Netherlands, Germany, and Poland. There the data products are made available for download by the scientists.

LOFAR2.0 Station Upgrade

A LOFAR2.0 station will, like the current LOFAR stations, consist of up to 96 high-band dipole tiles (110–250 MHz), and 96 low-band dipole antennas (10–80 MHz). The tiles and antennas are connected to 64 Receiver Control Units (RCUs), which apply a configurable analog filter.

LOFAR2.0 will redesign these RCUs to have improved filters. The new RCUs will also have the ability to process data from all antennas simultaneously [3].

The RCU output is sent to station signal-processing boards, to be beamformed and converted into UDP packets. These packets are streamed over 10 GbE fibres to the correlator.

Station Signal Processing

A station will contain up to 8 Uniboard^2 processing boards [4]. The boards use 32 FPGAs in total to sample and digitise the signal at 200 MHz and calibrate, exchange, beam form, and correlate their input. The end result is a 3–9 GBit/s data stream to the correlator per station, as well as up to 300 Mbit/s of statistical information.

STATION MONITORING AND CONTROL

The hardware in each station exposes tens of thousands of monitoring and control points through various interfaces and protocols. Basically the Monitoring and Control of a LOFAR2.0 station can be condensed into two simple operations at a station:

- Modify the behaviour of our hardware over time, e.g. point at different sources in the sky.
- Verify that the dynamic behaviour has been successfully modified.

In addition to the basic concepts of station operation, the nature of the distributed telescope requires that we also keep track of the system health and let the station autonomously act on extreme scenarios such as overheating of the equipment.

Finally, we are interested in monitoring the quality of the data recorded through our antennas and produced by our processing boards. To this purpose, the signal-processing boards continuously emit statistical information from several points in the signal chain.

OPC UA as a Common Hardware Interface

The hardware that is to be monitored and controlled in a LOFAR2.0 station comes in various shapes and forms. This could imply that a station's Monitor and Control system would have to support a variety of different hardware interfaces and protocols. We have, for example:

- Uniboard^2 processing boards: I^2C
- FPGAs on Uniboard^2: UCP (Uniboard Control Protocol) over IP
- RCUs: I^2C
- Power supplies: PLC interface
- Temperature sensors: PLC interface
- Network switch: SNMP

From prior experience in LOFAR1, as well as in other telescope monitor and control systems (ALMA, WSRT), we

* thomas.juerges@skao.int
† mol@astron.nl
‡ snijder@astron.nl

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOBL01

THE ELT CONTROL SYSTEM: RECENT DEVELOPMENTS

G. Chiozzi, L. Andolfato, J. Argomedo, N. Benes, C. Diaz Cano, A. Hoffstadt Urrutia, N. Kornweibel, U. Lampater, F. Pellegrin, M. Schilling, B. Sedghi, H. Sommer, M. Suarez Valles
European Southern Observatory, Garching bei Muenchen, Germany

Abstract

The Extremely Large Telescope (ELT) is a 39m optical telescope under construction in the Chilean Atacama desert. The design is based on a five-mirror scheme, incorporating Adaptive Optics (AO). The primary mirror consists of 798 segments with 1.4m diameter. The main control challenges can be identified in the number of sensors (~25000) and actuators (~15000) to be coordinated, the computing performance and small latency required for phasing of the primary mirror and the AO. We focus on the design and implementation of the supervisory systems and control strategies. This includes a real time computing (RTC) toolkit to support the implementation of the AO for telescope and instruments. We will also report on the progress done in the implementation of the control software infrastructure necessary for development, testing and integration. We identify a few lessons learned in the past years of development and major challenges for the coming phases of the project.

INTRODUCTION

The ELT is a large segmented telescope, where significant wavefront perturbations are induced by the telescope itself (deformation through gravity, temperature, and wind loads), in addition to perturbations added by the atmosphere. The goal is to control the telescope enabling the delivery of a diffraction limitable beam at each of the ELT Nasmyth foci, i.e. where the light beam is transferred to the instruments. This means the "spectrum of wavefront aberrations induced by the observatory is below that of the free atmosphere." [1].

The ELT Control System implements the overall control of the telescope (and dome), including the computers, communication and software infrastructure. It defines standards for control and electronics hardware and software and data communication. It includes the high-level coordination software, wave front control computer and engineering data archive.

In a system the size of the ELT Control System, decisions on algorithms and computational performance are not the only major design problems. The organization of the overall system, its behavior and interactions represent a significant organizational complexity which must be addressed.

An important factor influencing the architecture of the control software is the procurement strategy, that foresees the outsourcing of all components and services which can be efficiently delivered by industrial partners, while maintaining in-house those tasks for which ESO has a particular domain expertise. Based on this principle, also the overall control system shall be composed of components designed, built and delivered by many industrial partners or in-house. Distributed development and integration of the subsystems demand clear interfaces which should match not only a functional breakdown of the control system, but reflect the organizational boundaries of the many development locations.

CONTROL STRATEGY

The main challenge of ELT is to provide a wavefront with an error in the range of 10th of nm in the presence of perturbations that can be in the range of mm (in the case of gravity deformation when changing the telescope pointing from zenith to horizon). The most important role in the associated control strategy is played by the deformable quaternary mirror (M4). It is controlled in an on-sky loop using stellar light with a large temporal and spatial bandwidth. This requires a deformable mirror of unprecedented size. M4 has 5352 degrees of freedom, with the on-sky loop being closed at rates up to 1 kHz [2]. The limited stroke (100um) of the M4 actuators and the limited capture range of the wavefront sensors exclude that the wavefront can be controlled solely by M4, but require it to be supported by several additional control systems:

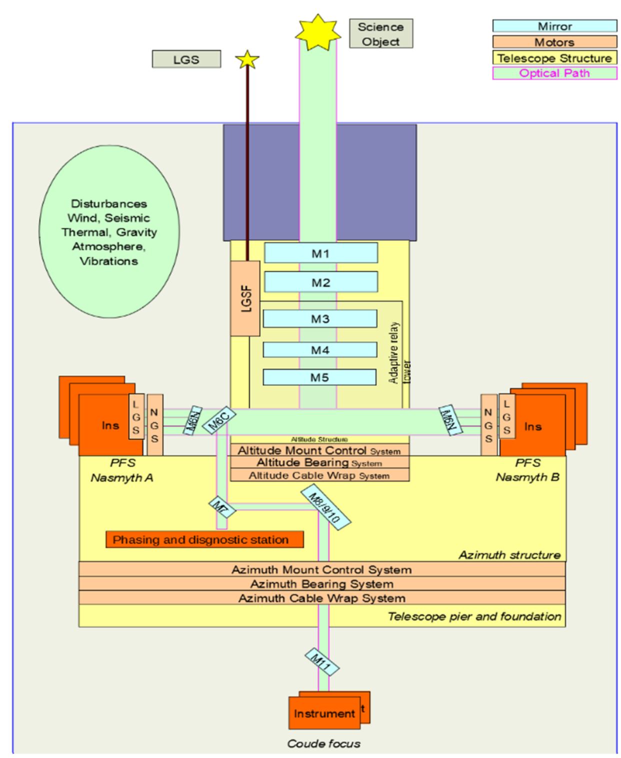


Figure 1: Telescope subsystems following the light path.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOBL02

REAL-TIME FRAMEWORK FOR ITER CONTROL SYSTEMS

W. Lee†, A. Zagar, B. Bauvir, T. Tak, ITER Organization, St. Paul Lez Durance Codex, France
A. Winter, Max Planck Institut für Plasmaphysik, Greifswald, Germany
M. Knap, P. Karlovsek, Cosylab d.d., Ljubljana, Slovenia
S. Lee, Korea Institute of Fusion Energy, Daejeon, Republic of Korea
P. Perek, D. Makowski, Lodz University of Technology, Lodz, Poland

Abstract

The ITER Real-Time Framework (RTF) is a middleware providing common services and capabilities to build real-time control applications in ITER such as the Plasma Control System (PCS) and plasma diagnostics.

The RTF dynamically constructs applications at runtime from the configuration. The principal building blocks that compose an application process are called Function Blocks (FB), which follow a modular structure pattern. The application configuration defines the information that can influence control behaviour, such as the connections among FBs, their corresponding parameters, and event handlers. The consecutive pipeline process in a busy-waiting mode and a data-driven pattern minimizes jitter and hardens the deterministic system behaviour. In contrast, infrastructural capabilities are managed differently in the service layer using non-real-time threads. The deployment configuration covers the final placement of a program instance and thread allocation to the appropriate computing infrastructure.

In this paper, we will introduce the architecture and design patterns of the framework as well as the real-life examples used to benchmark the RTF.

INTRODUCTION

The Plasma Control System is a dominant factor for the ITER pulsed operation, it controls all aspects of the plasma discharge from powering the superconducting magnets up to plasma termination [1]. PCS takes data from sensors and applies sophisticated algorithms to generate commands that are sent to actuators to control plasma parameters, such as position, shape or stability in a real-time context. Design, development and verification of real-time software in general is a complex and often lengthy process requiring multiple iterations until all timing relationships are satisfied and the application is stable and predictable.

The RTF is a flexible high-performance software base that facilitates the development and deployment of complex real-time applications [2]. Originally developed with the aim of control algorithms, the RTF can also be the basis for real-time data processing applications in ITER diagnostic systems.

The architecture design fully considered the modularity and portability of the software, and is applicable and extendable even in none-ITER environments. It hides many details specific to real-time systems (e.g., thread management, inter-thread data transfers, etc.), making the design and development of real-time software much easier and faster.

Strict Quality Assurance (QA) process and code audits enforced software integrity to bring reliable system operation. Along with the EPICS pvAccess interface that enriches functionality for operation, the Simulink wrapper block allows control model transition from the design to the application in an agnostic way.

ARCHITECTURE

Overview

The RTF infrastructure provides a modular, fully abstracted environment with the following key features [3]:

- FBs are self-contained and do not have any dependency on hardware, inputs, and outputs or operating system within the code. All relevant information for the modules is delivered via configuration, fully reusable in any context.
- Full configurability of FBs, which can be chained together at the developer's discretion by configuration.
- Fully data-driven workflow. The FBs can be scheduled automatically based on the availability of input data.
- Configuration-based distribution of processing logic over different threads, processes and computer nodes (hosts).
- Support integrated operability using generated code from graphical system modelling tools (e.g. Simulink [4]).
- Full integration with ITER Control Data Access and Communication (CODAC). Out of the box support for multiple interfaces to other CODAC components (e.g. networks, archive, supervision, etc.).

Figure 1 shows the architecture of the RTF and a Real Time (RT) application including their main elements and how they interact. The main elements are:

- The **RT application** contains the processing logic that runs on different threads, processes or computer nodes (hosts) and contains:
  - The scheduler handling the execution of processing of FBs.
  - The FBs representing an operation with inputs and outputs.
  - The gateways responsible for ensuring that the data is transported between the FBs running in different threads, processes or nodes.
  - The RT applications running within multiple instances of the real-time process.

† email address: woongryol.lee@iter.org

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOBL03

MACHINE LEARNING PLATFORM: DEPLOYING AND MANAGING MODELS IN THE CERN CONTROL SYSTEM

J.-B. de Martel, R. Gorbonosov, Dr. N. Madysa, CERN, Geneva, Switzerland

Abstract

Recent advances make machine learning (ML) a powerful tool to cope with the inherent complexity of accelerators, the large number of degrees of freedom and continuously drifting machine characteristics.

A diverse set of ML ecosystems, frameworks and tools are already being used at CERN for a variety of use cases such as optimization, anomaly detection and forecasting. We have adopted a unified approach to model storage, versioning and deployment which accommodates this diversity, and we apply software engineering best practices to achieve the reproducibility needed in the mission-critical context of particle accelerator controls.

This paper describes CERN Machine Learning Platform (MLP) - our central platform for storing, versioning and deploying ML models in the CERN Control Center. We present a unified solution which allows users to create, update and deploy models with minimal effort, without constraining their workflow or restricting their choice of tools. It also provides tooling to automate seamless model updates as the machine characteristics evolve. Moreover, the system allows model developers to focus on domain-specific development by abstracting infrastructural concerns.

MOTIVATION

Machine learning techniques and in particular neural networks are well suited to the unique challenges of particle accelerator controls [1]. Neural networks are already being used in CERN controls for a variety of use cases including anomaly detection [2], trajectory steering at LINAC4 and AWAKE [3], beam measurements [4] and collimator alignment [5] in the LHC.

In recent years, the rapid expansion of the ML ecosystem and the emergence of MLOps has created a multitude of tools and frameworks to assist data scientists with different aspects of the ML development workflow. These include tooling for experiment tracking and model management (e.g. Neptune [6], Comet [7]), feature storage (e.g. Feast [8]), pipeline and workflow automation (e.g. Pachyderm [9], Airflow [10]), hyper-parameter tuning (e.g. Katib [11], Sigopt [12]), deployment (e.g. Seldon [13]) and monitoring (e.g. Fiddler [14], Evidently [15]). Comprehensive tools which aim to address the whole ML lifecycle also exist, both open source (e.g. MLFlow [16], Kubeflow [17]) and proprietary (e.g. AWS Sagemaker [18], GCP Vertex AI [19]).

However, none of these comprehensive tools fit the use-cases required by CERN controls – they either constrain model developers' workflows or require in-depth knowledge of infrastructural tooling. Furthermore, these tools do not fully address requirements specific to accelerator controls such as high criticality, continuously drifting machine characteristics, variety of use-cases (online and offline, embedded and standalone) and the need to maintain different model configurations for each accelerator beam type.

For these reasons we present a machine learning platform (MLP) specific to CERN controls. It addresses the aforementioned issues by abstracting and simplifying model management, storage, and deployment concerns. In addition, it is open and extensible by design to cope with the rapidly evolving ML landscape and lack of generally accepted industry standard for MLOps. For the same reason, it is designed to be compatible with diverse ML model training environments (local, CERN infrastructure, and public cloud). Helping with rapid development of new models with tools such as experiment tracking or workflow automation are not goals of MLP – instead, it is designed to integrate with existing solutions.

CONCEPTS

We define models as the combination of a model type and model parameters. Model types contain the algorithm and logic of the model, e.g., the neural network architecture, the framework, and data pre- and post-processing. Model parameters are the data which configures the model type, e.g. trained weights of neural networks, and any other configuration variables. As the format of model parameters is highly dependent on the framework used[1], we decided to treat model parameters as opaque data, which we store but don't inspect within MLP.

A given model type can be associated with multiple model parameters. One use case for this is the use of different model parameters for each type of particle beam produced by the accelerators. The opposite is also true, given model parameters can be associated with different model types. For example, a given set of trained neural network weights can be used by a same model surrounded by different pre- and post- processing logic for different use cases.

Model types and model parameters evolve independently and are versioned separately, so we define model type versions (MTV) and model parameters versions (MPV). MTVs and MPVs compatibility follows a many-to-many relationship, as shown in Fig. 1.

The combination of an MTV and a compatible MPV forms a model. Models are fully configured neural networks or

[1] Common formats such as ONNX [20] exist but don't support certain operations such as custom layers or loss functions.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOBL04

KARABO DATA LOGGING: InfluxDB BACKEND AND GRAFANA UI

G. Flucke*, V. Bondar, R. Costa, W. Ehsan, S. G. Esenov, R. Fabbri, G. Giovanetti, D. Goeries, S. Hauf, D. G. Hickin, A. Klimovskaia, A. Lein, L. Maia, D. Mamchyk, A. Parenti, G. Previtali, A. Silenzi, D. P. Spruce[1], J. Szuba, M. Teichmann, K. Wrona, C. Youngman
European XFEL GmbH, Holzkoppel 4, 22869 Schenefeld, Germany
[1]*now at* MAX IV, Fotongatan 2, 22484 Lund, Sweden

Abstract

The photon beam lines and instruments at the European XFEL (EuXFEL) are operated using the Karabo control system that has been developed in house since 2011. Monitoring and incident analysis requires quick access to historic values of control data. While Karabo's original custom-built text-file-based data logging system suits well for small systems, a time series data base offers in general a faster data access, as well as advanced data filtering, aggregation and reduction options. EuXFEL has chosen InfluxDB as backend that is operated since summer 2020. Historic data can be displayed as before via the Karabo GUI or now also via the powerful Grafana web interface. The latter is e.g. used heavily in the new Data Operation Center of the EuXFEL. This contribution describes the InfluxDB setup, its transparent integration into Karabo and the experiences gained since it is in operation.

KARABO AND THE EuXFEL

The European X-ray Free Electron Laser (EuXFEL) facility [1] provides hard and soft X-ray beams at three photon beamlines to six instruments. Up to 27,000 photon pulses per second are arranged into 10 Hz trains with an intra-train pulse repetition rate of 4.5 MHz. The Karabo framework [2–4] has been designed and developed in-house since 2011 for control, online data analysis, and data acquisition at the photon beam lines and the scientific instruments.

In Karabo, so-called devices communicate via a central message broker. All devices using the same broker *topic* form a Karabo installation. Whereas broker communication is considered to be "slow" data, big or "fast" data like images are sent via TCP/IP data pipelines that can be flexibly configured, e.g. for calibration, analysis, or preview purposes. Figure 1 gives an overview of a Karabo installation.

A Karabo device exposes a self-description of its control interface, i.e. its *schema*. Karabo's generic graphical user interface (GUI) uses the schema to render the representation of a device. Devices can have one of manifold tasks:

- interface some hardware like a pump or a motor,
- control a detector and read out its data,
- analyse data,
- orchestrate other devices,

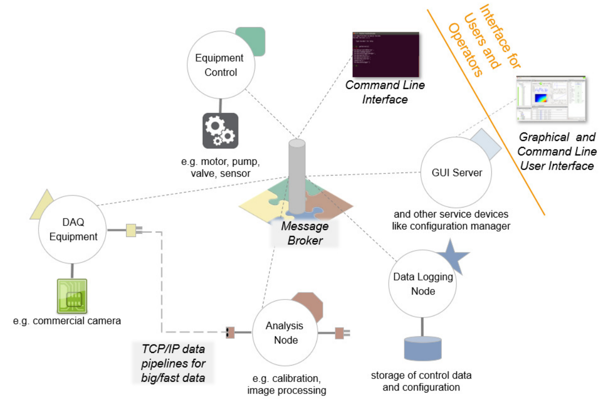


Figure 1: A Karabo installation showing Karabo devices with various tasks. Broker and pipeline communication lines are indicated.

- provide a system service like serving as entry point for the GUI, logging data, managing alarm states, or managing configurations.

To communicate with each other, the Karabo devices expose methods that can be called remotely in the distributed system. Besides being directly called, these *slots* can be subscribed to *signals* of other devices. When such a signal is emitted with arguments, all subscribed slots are called with these arguments. In the process, only a single message is sent to the broker that distributes the message according to the subscriptions, as is shown in Fig. 2. This signal/slot mechanism allows Karabo to be fully event-driven, regular polling of e.g. device properties is not needed. That a single message to the broker is sufficient also for a device with a signal that many other devices have subscribed to, ensures that there is no overhead for such a "popular" device.

FIRST KARABO DATA LOGGING IMPLEMENTATION

Data logging in a Karabo installation is organised via a few dedicated devices. A "data logger" device (or several that share the load) subscribes to the signal for property updates of the other devices. Properties are configuration parameters or read-only values like the reading of a temperature sensor. Via the signal/slot mechanism, the logger is informed about every property update and when this update occurred, i.e. the timestamp of the update, and stores it in the backend of the logger. Similarly, the device schema and its potential

* gero.flucke@xfel.eu

18th Int. Conf. on Acc. and Large Exp. Physics Control Systems ICALEPCS2021, Shanghai, China JACoW Publishing
ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOBL05

PHOTON SCIENCE CONTROLS: A FLEXIBLE AND DISTRIBUTED LabVIEW™ FRAMEWORK FOR LASER SYSTEMS

B. A. Davis*, B. T. Fishler, R. J. McDonald
Lawrence Livermore National Laboratory, Livermore, California, USA

Abstract

LabVIEW™ software is often chosen for developing small scale control systems, especially for novice software developers. However, because of its ease of use, many functional LabVIEW™ applications suffer from limits to extensibility and scalability. Developing highly extensible and scalable applications requires significant skill and time investment. To close this gap between new and experienced developers we present an object-oriented application framework that offloads complex architecture tasks from the developer. The framework provides native functionality for data acquisition, logging, and publishing over HTTP and WebSocket with extensibility for adding further capabilities. The system is scalable and supports both single server applications and small to medium sized distributed systems. By leveraging the application framework, developers can produce robust applications that are easily integrated into a unified architecture for simple and distributed systems. This allows for decreased system development time, improved onboarding for new developers, and simple framework extension for new capabilities.

INTRODUCTION

In contrast to large experimental physics programs, small to medium size experiments and test-beds generally have less resources in terms of manpower, funding, and schedule. Developers are often faced with the task of standing up a distributed control system from scratch under tight deadlines with limited personnel. In these situations, it is imperative to choose a programming language that allows for quick hardware integration and prototyping.

Under these circumstances, NI LabVIEW™ software is often chosen for several reasons. First, it has an extensive hardware ecosystem with options for benchtop, distributed, and embedded hardware systems [1]. Interfacing with these systems from the LabVIEW™ development environment is streamlined and there are offerings for systems across the spectrum of determinism. Simple DAQs provide baseline functionality for non-deterministic applications, and soft and hard real-time situations are handled by RTOS and FPGA applications, respectively.

LabVIEW™ software is also attractive due to its shallow learning curve and low barrier to entry for those without a classical programming background. It uses a graphical programming style combined with a "dataflow" paradigm for organizing functionals and variables and defining execution order [2]. Many workflows for data acquisition, analysis, and logging are built in, and examples and documentation abound. It is simple for novice developers or even end users to create a baseline DAQ system to collect experimental data.

The result is an attractive platform for developing small scale experimental systems. In many cases, control system developers need not get involved at all - scientists and operators can quickly develop the skills to work with LabVIEW™ programming. However, this story becomes less clear when moving from small scale systems to medium scale systems with multiple distributed Front-End Processors (FEPs). Leveraging NI hardware remains an attractive prospect, as it eliminates the need for custom RTOS machines or FPGA boards to handle deterministic applications. However, the very advantage of easy software development can quickly become a burden instead.

Simple LabVIEW™ applications are singular in purpose – they interface with a small number of devices, acquire data, perhaps execute a sequence, and log data to disk. This can be accomplished by a novice developer, or even an end user, as previously mentioned. However, more often than not, such simple systems suffer from a lack of scalability and extensibility. Of course, a piece of software designed to control a single experiment has no need for scaling or extension, provided that system requirements are well-defined before the development begins (a tall assumption, but one we take for granted here).

The disconnect arises when taking similar software development practices and applying them to a larger scale, distributed system. While developing LabVIEW code to control a single system can be accomplished by those with little to no previous software engineering background, developing a distributed, extensible, and scalable system for a larger system requires more experience, skill, and rigor.

Often for a simple system, there is a single developer who creates an application to run the experiment. But for systems of increased complexity, multiple developers of varying skill levels must work together to create a series of interconnected applications across a number of FEPs. In such a situation, a unified architecture must be developed to ensure scalability across the system. Similarly, extensibility becomes key to adding new capabilities over time as the system evolves, as a larger scale system will likely be in operation for longer than a small testbed.

Thus the ideal architecture for developing LabVIEW™ applications for mid-scale distributed control systems must be scalable for any number of devices and FEPs, extensible for adding capabilities across the lifetime of a project (and ideally to future projects as well), and – most importantly – accessible to developers at all skill levels.

To accomplish these goals, we have developed an object-oriented distributed architecture for LabVIEW™ applica-

* davis287@llnl.gov

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOBR01

ROMULUSlib: AN AUTONOMOUS, TCP/IP-BASED, MULTI-ARCHITECTURE C NETWORKING LIBRARY FOR DAQ AND CONTROL APPLICATIONS

A. Yadav, H. Boukabache*, N. Gerber†, K. Ceesay-Seitz, D. Perrin
European Organization for Nuclear Research (CERN), Geneva, Switzerland

Abstract

The new generation of Radiation Monitoring electronics developed at CERN, called the CERN RadiatiOn Monitoring Electronics (CROME), is a Zynq-7000 SoC-based Data Acquisition and Control system that replaces the previous generation to offer a higher safety standard, flexible integration and parallel communication with devices installed throughout the CERN complex. A TCP/IP protocol based C networking library, ROMULUSlib, was developed that forms the interface between CROME and the SCADA supervision software through the ROMULUS protocol. ROMULUSlib encapsulates Real-Time and Historical data, parameters and acknowledgement data in TCP/IP frames that offers high reliability and flexibility, full-duplex communication with the CROME devices and supports multi-architecture development by utilization of the POSIX standard. ROMULUSlib is autonomous as it works as a standalone library that can support integration with supervision applications by addition or modification of parameters of the data frame. This paper discusses the ROMULUS protocol, the ROMULUS Data frame and the complete set of commands and parameters implemented in the ROMULUSlib for CROME supervision.

INTRODUCTION

The Occupational Health & Safety and Environmental Protection (HSE) at CERN obliges to the protection of CERN personnel and the public from any unjustified exposure to ionising radiation. The radiation protection group (RP) at HSE has the mandate to monitor the radiological impact of CERN's accelerators and installations by active monitoring and logging of radiation levels at different experimental sites spanning the CERN complex. To facilitate this, the new generation of CERN RadiatiOn Monitoring Electronics, called CROME [1], was developed by the CROME team of the Instrumentation and Logistics (IL) section within the RP group and is responsible for the design, development, installation and maintenance of these specialised radiation monitoring systems. Starting from Long Shutdown 2 (LS2) of the Large Hadron Collider (LHC) in 2019, the older generation of radiation monitors, namely The Area Controller (ARCON) is being replaced by the new CROME devices and will be operational for the Run 3 of the LHC in February 2022. The consolidation of the current generation of RAdiation Monitoring System for the Environment and Safety (RAMSES) monitors by CROME is planned to be completed by the Long Shutdown 3 (LS3) in late 2027.

The CROME devices consist of the autonomous Monitoring Units, Alarm Units, a Junction Box and an Uninterruptible Power Supply. [2–4] The autonomous monitoring units, called the CROME Measuring and Processing Units (CMPUs), consist of an ionization chamber and an electronic readout system. The CMPU can be either a wall-mounted system where the CMPU is directly attached to the ionization chamber or it can be a rack-mounted system where the CMPU is connected to the ionization chamber with a specialized cable. The rack-mounted system is used for monitoring areas with high radiation levels that can damage the readout electronics. In this case, a custom plastic ionization chamber with graphite coating is placed directly into that area with high radiation levels, whereas the readout electronics are placed in an area of lower radiation for their protection. The ionization chamber detects ionizing radiation and converts it to a readable current value. A read-out chip measures this current, which can be within 2 fA to 1 µA. Because these currents can be so low, a specialized cable SPA6 was developed by the RP team at CERN for the rack-mounted system. The SPA6 cable is used for Signal and High Voltage lines up to one kilometer distance. The CMPU's front-end readout interface transmits the current value to the FPGA programmable logic (PL) of a Zync-7000-based System-on-Chip (SoC), which uses it to calculate the real-time radiation dose rate as well as the total radiation dose received in the monitored area at the ionization chamber location. All safety-critical decisions and actions such as measurement, dose rate calculation, temperature compensation, alarm generation and interlock generation are performed by the PL. This is done to ensure system reliability by implementing operations within a Finite-State Machine. A complex programmable logic device (CPLD)-based watchdog works in tandem with the SoC. It monitors the PL state machine to ensure correct dose rate calculations and overall functionality. It is allowed to reset/reboot the SoC when it is in an undefined state. At the detection of dangerous conditions, e.g. if the radiation dose or dose rate exceeds a defined limit, the CMPU automatically generates local and remote alarms and a beam interlock signal that stops the concerned accelerator or machine. Parameters like dose and dose rate limits, current-to-radiation conversion factors, and many more can be configured remotely by the authorized members of the radiation protection group. A schematic of the CROME devices and it's part is shown in Fig. 1.

* Corresponding author Dr. H.B. (hamza.boukabache@cern.ch)
† N.G. is a former CERN Fellow. He is currently at CSEM, Neuchâtel (CH)

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOBR02

CONTROL, READOUT AND MONITORING FOR THE MEDIUM-SIZED TELESOPES IN THE CHERENKOV TELESCOPE ARRAY

U. Schwanke*[1], T. Murach[2], P. Wagner†[2], G. Spengler[1]
for the CTA MST Project and
D. Melkumyan[2], I. Oya[3] and T. Schmidt[2]
[1] Humboldt-University, Berlin, Germany
[2] DESY, Zeuthen, Germany
[3] CTA, Heidelberg, Germany

Abstract

The Cherenkov Telescope Array (CTA) is the next-generation ground-based gamma-ray observatory. Its design comprises several ten imaging atmospheric Cherenkov telescopes deployed at two sites in the southern and northern hemisphere. The inclusion of various array elements, like large-sized, medium-sized and small-sized telescopes, instruments for atmosphere monitoring, etc, into the Array Control and Data Acquisition System (ACADA) poses a particular challenge which is met by an appropriate software architecture and a well-defined interface for array elements. This paper describes exemplarily how the interface is implemented for the Medium-Sized Telescopes (MSTs, 12 m diameter). The implementation uses the ALMA Common Software (ACS) as a framework for software applications facilitating the readout and control of telescope subsystems like the drive system or the pointing camera; the communication with subsystems takes advantage of the OPC UA protocol.

INTRODUCTION AND OVERVIEW

The Cherenkov Telescope Array (CTA) is the next-generation ground-based observatory for gamma-rays in the energy band between some 10 GeV and several 100 TeV. CTA will comprise two arrays of Imaging Atmospheric Cherenkov Telescopes (IACTs) located in the southern (Paranal, Chile) and northern (La Palma, Canary Islands, Spain) hemisphere, respectively. IACTs with different mirror areas (dubbed Large-Sized Telescopes (LSTs), Medium-Sized Telescopes (MSTs) and Small-Sized Telescopes (SSTs)) ensure proper detection efficiencies for gamma-rays over four orders of magnitude in energy. The stereoscopic observation of showers with numerous IACTs results in an angular resolution and flux sensitivity that constitutes a substantial improvement compared to current IACT arrays (like H.E.S.S., MAGIC, and VERITAS). In CTA's (initial) α-configuration, the northern installation will comprise 4 LSTs and 9 MSTs; 14 MSTs and 37 SSTs will be installed at the southern site.

The readout, control and monitoring of different array elements (telescopes and atmospheric monitoring devices) is the task of the Array Control and Data Acquisition (ACADA) system. The ACADA system is quite complex since it also needs to cope with the concurrent automatic operation of multiple IACT sub-arrays and the rapid re-scheduling of observations in response to science alerts generated internally or by external astronomical facilities. The ACADA software is based on an architecture designed using the Unified Modeling Language (UML) and Systems Modeling (SysML) formalisms [1]. The implementation of applications takes advantage of the ALMA Common Software (ACS [2]) framework.

It adds to the challenge for the ACADA system that the three telescope types (LSTs, MSTs, SSTs) use different optics designs, employ different auxiliary hardware devices (e.g. reference lasers, pointing cameras, light flashers) and implement different operational procedures (observations, calibration, monitoring). A key assumption of the software design is that ACADA can control any telescope without knowing its type and that all telescopes implement a common stateful behaviour via a finite state machine (FSM). This paper describes the software aspects of the interface between ACADA and a telescope. It uses the MSTs as the primary example and starts therefore with a description of the telescope hardware. The implementation of the software interface using ACS and the entire MST software system are detailed as well.

THE MSTS FOR CTA

Telescope Optics

The MSTs [3] are IACTs with a field of view (FoV) of about 8° in diameter and an effective mirror area of about 88 m^2. In the CTA installations, they will be arranged at a typical distance of $O(100)$ m from each other and will cover the central energy range between 100 GeV and 30 TeV. The tesselated mirrors consist of 86 hexagonal spherical mirror facets with a focal length of $f = 16.07$ m that are arranged on a sphere with a radius of curvature of $R = 19.2$ m. The telescope focal length in this so-called modified Davies-Cotton design is $F = 16$ m. The heart of the telescope is a camera[1] with a flat surface that is located in the telescope focal plane and uses about 1800 PMT pixels for the detection of Cherenkov light.

There are two Cherenkov camera projects differing in the number of pixels and the way of storing and processing PMT

* schwanke@physik.hu-berlin.de
† Software for Science (Berlin)

[1] In the following, the term *camera* without further qualification is used only for the Cherenkov camera.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOBR03

HEXAPOD CONTROL SYSTEM DEVELOPMENT TOWARDS ARBITRARY TRAJECTORIES SCANS AT SIRIUS/LNLS

A. Y. Horita *, F. A. Del Nero, M. A. L. Moraes, G. N. Kontogiorgos, LNLS, Campinas, Brazil
G. G. Silva, UNICAMP, Campinas, Brazil

Modern 4th generation synchrotron facilities demand high precision and dynamic manipulation systems capable of fine position control, aiming to improve the resolution and perfomance of their experiments. In this context, hexapods are widely used to obtain a flexible and accurate 6 Degrees of Freedom (DoF) positioning system, since it is based on Parallel Kinematic Mechanisms (PKM). Aiming the customization and governability of this type of motion control system, a software application was entirely modeled and implemented at Sirius. A Bestec hexapod was used and the control logic was embedded into an Omron Delta Tau Power Brick towards the standardization of Sirius control solutions with features which completely fill the beamline scan needs, e.g., tracing arbitrary trajectories. Newton-Raphson numerical method was applied to implement the PKM. Besides, the kinematics was implemented in C language, targeting a better runtime performance when comparing to script languages. This paper describes the design and implementation methods used in this control application development and presents its resulting performance.

INTRODUCTION

Sirius is the 4th generation synchrotron light source being commissioned by the Brazilian Synchrotron Light Laboratory (LNLS), in Brazil [1]. Its low emittance (0.25 nm rad) makes it one of the world's brightest light sources of its kind [2]. In this sense, high precision control systems are required towards better beam quality and stability.

In Sirius IPE Beamline, a Bestec P468 Mirror Unit [3] was chosen as the motion system of a toroidal mirror. This unit contains a hexapod in its structure, which is illustrated in Fig. 1. Hexapods are widely used due to the pararell control capacity of its 6 degree of freedom (DoF), characterized in Pararell Kinematics Machines (PKM) [4].

Together with this unit, a Bestec P494 Motion Control System was also acquired, which embeds a Mint Linux distribution as Operating System (OS), containing a set of proprietary control software which implements the user interface, configuration files, system kinematics and the hexapod system interface.

Although the P494 control system meets the beamline expected stability and motion control accuracy, a customized system developed in-house was desired towards Sirius's systems standardization and independence when implementing new features, such as arbitrary trajectories scans. Under these circumstances, we decided to implement the control logics using an Omron Delta Tau Power Brick LV controller [5].

* augusto.horita@lnls.br

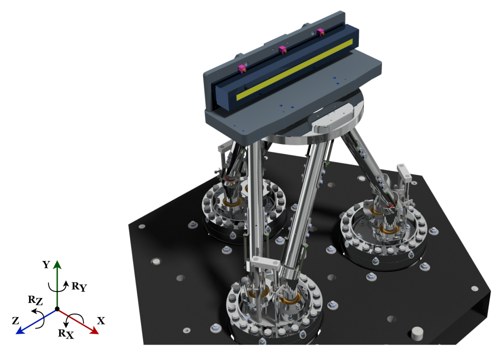


Figure 1: Toroidal mirror supported by hexapod in the Bestec P468 Mirror Unit.

An important portion of the motion control logics consists of its kinematics, which is splitted into two algorithms.The inverse kinematics converts system positions to individual motors' positions and the forward kinematics calculates the system feedback positions based on encoders [6]. Towards a more productive and robust implementation process, the hexapod kinematics was first mathematically modeled using a Jupyter Notebook [7], which provided flexibility using software structures, e.g. mathematical libraries, and optimized the simulation and bugfixes process [8]. Due to the fact that the kinematics of a hexapod is non-linear [6], our model was based on Newton Rhapson for root-finding, as it is widely used and has a fast convergence rate [9].

Based on the validated Jupyter Notebook model, it was possible to implement the control logics in the Delta Tau Power Brick LV system. Its performance was then compared to Bestec's control sytem for validation. Also, an example of arbitrary trajectory was implemented for functionality validation purposes.

The remaining sections of this paper presents in more details the used methods for this control system development and its validation.

MOTION CONTROL DEVELOPMENT

In this section, we present the motion control system development, focusing on the kinematics modeling and implementation.

Kinematics Model

In the presented application, the toroidal mirror is placed inside a vacuum chamber. Towards a more robust and easy

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOBR04

GENERIC DATA ACQUISITION CONTROL SYSTEM STACK ON THE MTCA PLATFORM

J. Krasna, J. Varlec, U. Legat, Cosylab, Ljubljana, Slovenia

Abstract

Cosylab is the world leading integrator of control systems for big physics facilities. We frequently integrate high speed data acquisition devices on the MicroTCA platform for our customers. To simplify this process, we have developed a generic control system stack that allows us to support a large set of MicroTCA hardware boards with minimal firmware and software modifications. Our firmware supports generic data acquisition up to 32-bit sample width and also generic data generation. The firmware modules are implemented in a way so that support for MRF timing modules can be added and allow the board to act as a MRF timing receiver. On the software side we implemented the control software stack in NDS which means that we offer support for EPICS and TANGO control system out of the box.

SYSTEM DESIGN

Cosylab had worked on multiple high-performance data acquisition (DAQ) solutions throughout the years and some of those DAQ solutions, like applications for beam Current monitors, beam profile monitors, LLRF, etc. had overlapping core functionality. Because of this an challenge arose to determine if a generic control system stack that would cover this fundamental, overlapping functionality could be implemented.

The main objective was to design a system that would improve code reusability and reduce time to support new hardware without sacrificing the ability to extend functionality for custom use-cases. Additionally, the requirement was to cover as many control system frameworks as possible and make the system agnostic to specific frameworks. One of the desired outcomes was to reduce expertise needed to support existing and custom use-cases and create a central, standardized, mature codebase that all engineers could learn from.

Hardware

Looking at the generic form-factors currently available on the market that support DAQ use cases, especially for high-end applications, we can safely say that MicroTCA [1] has the most vendors supporting it and it is growing in popularity on the user-side as well. It is in use at different labs around the world for the already mentioned use cases (BCMs, BPMs, LLRF) and is commonly selected as the go-to platform for DAQ applications. The reasoning is high performance, customizability options through rear transition module expansions as well as advanced features, like IPMI [2] support and others. By working with multiple MicroTCA vendors, for example Cosylab and Teledyne developed DAQ drivers that are used at ITER [3], we have gained a lot of experience and insight into the platform. When selecting a hardware platform for our own product, a Dose delivery system used in medical particle accelerators for cancer treatment, the decision to go towards MicroTCA was a straightforward one.

Figure 1: Vadatech AMC523 module.

After careful consideration which hardware was most appropriate for our general DAQ system or gDAQ for short, we decided to use AMC523 [4] from Vadatech as well as the MRT523 rear transition module [5] and MZ523B mezzanine [6], see Fig. 1. The boards support 12 analog input channels with variable gain, 2 analog output channels and can sample at 125 megasamples per second.

Software

The application driver was implemented using NDS3 or Nominal Device Support [7] which is a public, open-source library that was developed at Cosylab to simplify integration of DAQ hardware for a variety of control system frameworks but is targeted mainly for EPICS [8] and TANGO [9]. The first iteration was built with the focus on EPICS, see Fig. 2. All GUI components were developed using Control System Studio Phoebus [10], see Fig. 3.

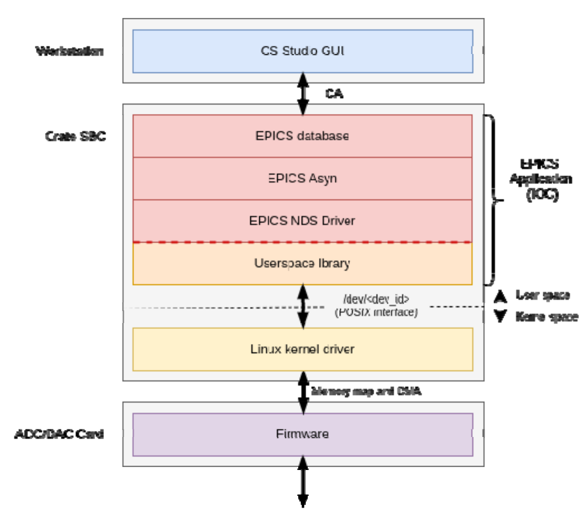


Figure 2: System architecture of the EPICS application.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV001

STATUS OF THE SARAF-PHASE2 CONTROL SYSTEM

F. Gougnaud†, F. Gohier†, P. Bargueden, D. Darde, G. Desmarchelier, G. Ferrand, A. Gaget, P. Guiho, T. Joannem, A. Lotode, Y. Mariette, S. Monnereau, V. Nadot, V. Silva, N. Solenne CEA Saclay IRFU, Gif sur Yvette, France
E. Reinfeld, I. Shmuely, H. Isakov, A. Perry, Y. Solomon, N. Tamim, T. Zchut, SNRC, Yavne, Israel

Abstract

SNRC and CEA collaborate to the upgrade of the SARAF accelerator [1] to 5 mA CW 40 Mev deuteron and proton beams and also closely to the control system. CEA is in charge of the Control System (including cabinets) design and implementation for the Injector (upgrade), MEBT and Super Conducting Linac made up of 4 cryomodules hosting HWR cavities and solenoid packages.

This paper gives a detailed presentation of the control system architecture from hardware and EPICS software points of view. The hardware standardization relies on MTCA.4 that is used for LLRF, BPM, BLM and FC controls and on Siemens PLC 1500 series for vacuum, cryogenics and interlock.

CEA IRFU EPICS Environment (IEE) platform is used for the whole accelerator. IEE is based on virtual machines and our MTCA.4 solutions and enables us to have homogenous EPICS modules. It also provides a development and production workflow. SNRC has integrated IEE into a new IT network based on advanced technology.
The commissioning is planned to start late summer 2021.

CONTEXT OF THE PANDEMIC

Because of the pandemic, the CEA team hadn't been able to go to the SNRC Lab since March 2020. The first impact was for the Injector. The CEA is in charge of the EPICS update of the Injector Control System. Four cabinets were delivered to SNRC in February 2020 as planned but the CEA could no longer go there and install software. Therefore, SNRC installed the four new cabinets and integrated the Injector control software by itself. At that time a remote connection between the 2 labs was not allowed. The CEA support was only by videoconferences and emails. Finally, there was a first beam on the Source on September 2nd 2021.

GENERAL ARCHITECTURE

In summer 2018, our partner SNRC accepted CEA's recommendation to migrate to the CEA MTCA.4 platform for the SARAF control system. This platform was presented at ICALEPCS19 [2] and is based on the very compact NATIVE-R2 crate with this common core on each crate: the NAT-MCH-PHYS80 board offers an 80-port PCIe Gen3 switch and can be combined with the Rear Transition Module CPU NAT-MCH-RTM-COMex-E3.

For semi-fast and fast acquisition, a set of IOxOS boards was also added to this common platform. See Figure 1. The intelligent FMC carrier IFC1410 (AMC form factor featuring an NXP QorIQ T series Power PC processor and one Xilinx Kintex UltraScale FPGA accessible by the user) is used with ADC-3117 and ADC-3111 FMC boards. The fast acquisition board ADC-3111 includes 8 channels with 16-bit/250Msps ADCs. The semi-fast acquisition board ADC-3117, whose sampling frequency is comprised between 1 and 5 Msps, has 20 channels and 2 channels DAC.

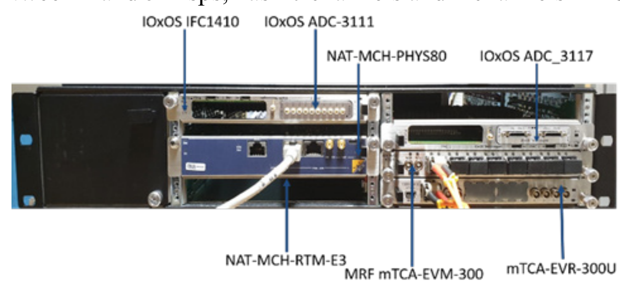


Figure 1: MTCA.4 NATIVE-R2 standardized platform.

The CEA team updated and standardized the IRFU EPICS Environment with MTCA.4 solutions based on IOxOS, MRFand NAT boards.

For the PLC domain essentially used for vacuum, cryogenics, tuning motorizations, current leads and interlocks, Siemens PLC 1500 series (CPU 1516) was selected with TIA Portal by CEA team.

Kontron Industrial PCs are also used in order to run EPICS IOCs for the communication with PLCs. This communication is based on Modbus/Tcp and S7plc.

FARADAY CUPS, ACCTS AND NBLMS

On LEBT and MEBT, this common platform including IOxOS boards is used for Faraday Cups and ACCTs intensity measurement with the IOxOS ADC-3117 board.

An acquisition based on IOxOS ADC-3111 is used for the Neutron sensitive Beam Loss Monitors (gaseous detectors) designed by CEA for SARAF. This CEA design is already used for ESS and gives entire satisfaction.

TIMING SYSTEM

The Timing System distributes trigger signals including the information for each RF pulse and manages timestamping mechanism that allows to date all the actions and events precisely. This timestamping is internally incremented and is periodically resynchronized with the Meridian II GPS by

† francoise.gougnaud@cea.fr , Francis.gohier@cea.fr

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV002

CENBG CONTROL SYSTEM AND SPECIFIC INSTRUMENTATION DEVELOPMENTS FOR SPIRAL2-DESIR SETUPS

L. Daudin†, P. Alfaurt, A. Balana, M. Corne, M. Flayol, A. Husson, B. Lachacinski, CNRS/IN2P3
Université de Bordeaux CENBG, Gradignan, France

Abstract

The DESIR facility will be in few years the SPIRAL2 experimental hall at GANIL dedicated to the study of nuclear structure, astrophysics and weak interaction at low energy. Exotic ions produced by the S3 facility and SPIRAL1 complex will be transferred to high precision experiments in the DESIR building. To guaranty high purity beams to perform high precision measurements on specific nuclei, three main devices are currently being developed at CENBG: a High Resolution Separator (HRS), a General Purpose Ion Buncher (GPIB) and a double Penning Trap named “PIPERADE”. The Control System (CS) developments we made at CENBG are already used to commission these devices. We present here beamline equipment CS solutions and the global architecture of this SPIRAL2 EPICS based CS. To answer specific needs, instrumental solutions have been developed like PPG used to optimize bunch timing and also used as traps conductor. Recent development using the cost efficient Redpitaya board with an embedded EPICS server will be described. This device is used to drive an FCup amplifier and is also used for particle counting and time of flight measurements using our FPGA implementation called “RedPiTOF”.

THE DESIR FACILITY

Overview

In 2024 DESIR [1, 2] is planned to be the new low energy SPIRAL2 facility dedicated to the study of nuclear structure, astrophysics and weak interaction at GANIL (Caen, France). This experimental building will accept low energy (10-60 keV) RIB beams from both historical SPIRAL1 complex [3], delivering heavy ions beams since 1983 and the new SPIRAL2 linear accelerator [4] via the S3 facility [5] delivering high intensity light ion beams since 2019 (see Fig. 1). In DESIR, specific exotic ions will be separated in mass and transferred to high precision experiments to perform decay spectroscopy, laser spectroscopy and mass spectrometry.

CENBG Developments

In order to provide highly purified beams previously introduced, three main devices have been entirely developed and are currently tested and commissioned at CENBG: a High Resolution Separator (HRS) [6], a RFQ-cooler-buncher called “General Purpose Ion Buncher” (GPIB) [7] and a double Penning Trap named “PIPERADE” [8].

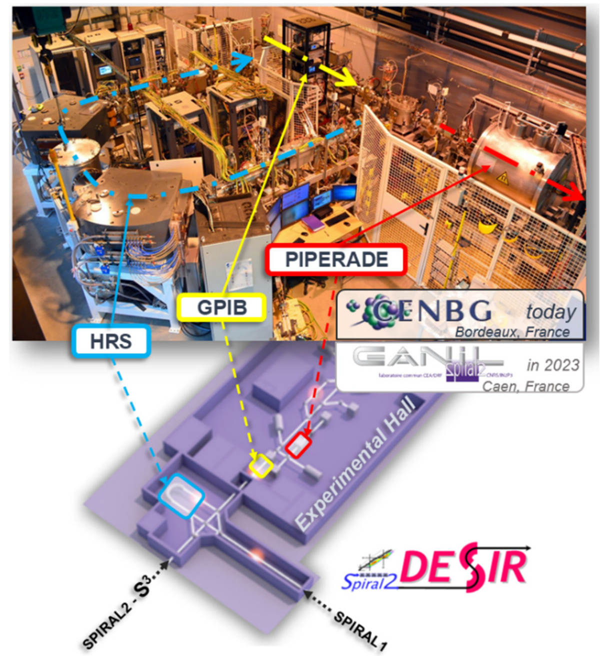


Figure 1: The CENBG setups today at CENBG and the future DE-SIR experimental area, coupling the GANIL building and the new SPIRAL2 facility.

The main concepts of the control system (CS) developed and currently used to test and commission the HRS, the GPIB and PIPERADE is presented in this paper. These CS developments done at CENBG will be extended to the entire DESIR project, meaning to the four DESIR transfer lines (180 meter long):

1. LS: beam transfer from S3 to the DESIR Hall.
2. LT: beam transfer from SPIRAL1 to the DESIR Hall.
3. LHR (High Resolution beamline) including a dedicated RFQ-Cooler SHIRAC (LPC-Caen) and the HRS.
4. LHD (DESIR Hall Beamline): Central delivery “fishbone” line inside the DESIR Hall.

Milestones

The DESIR beam-lines and the experimental Hall equipped with the first group of experiments are expected in 2023. The HRS separator and PIPERADE traps are already in the commissioning phase at CENBG using the first version of the DESIR control system.

DESIR CONTROL SYSTEM (CS)

SPIRAL2 Collaborative Developments

The DESIR CS and Automation developments for the whole beam-lines and purification devices including the

† laurent.daudin@in2p3.fr / ORCID(s) 0000-0002-3007-4217

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV003

LASER MEGAJOULE FACILITY OPERATING SOFTWARE OVERVIEW

J.-P. Airiau, V. Denis, H. Durandeau, P. Fourtillan, N. Loustalet, P. Torrent
CEA, Le Barp, France

Abstract

The Laser MegaJoule (LMJ), the French 176-beam laser facility, is located at the CEA CESTA Laboratory near Bordeaux (France). It is designed to deliver about 1.4 MJ of energy on targets, for high energy density physics experiments, including fusion experiments. The first bundle of 8-beams was commissioned in October 2014. By the end of 2021, ten bundles of 8-beams are expected to be fully operational.

Operating software are used to automate, secure and optimize the operations on the LMJ facility. They contribute to the smooth running of the experiment process (from the setup to the results). They are integrated in the maintenance process (from the supply chain to the asset management). They are linked together in order to exchange data and they interact with the control command system. This paper gives an overview of the existing operating software and the lessons learned. It finally explains the incoming works to automate the lifecycle management of elements included in the final optic assembly (replacement, repair, etc.).

INTRODUCTION

The LMJ facility is still in construction. We are currently mixing assembly, operating and maintenance activities at the same time. The progressive increase of operating activities concerns the laser bundles (10 of 22 expected) and the target chamber diagnostics (14 of 33 expected) (see Fig. 1).

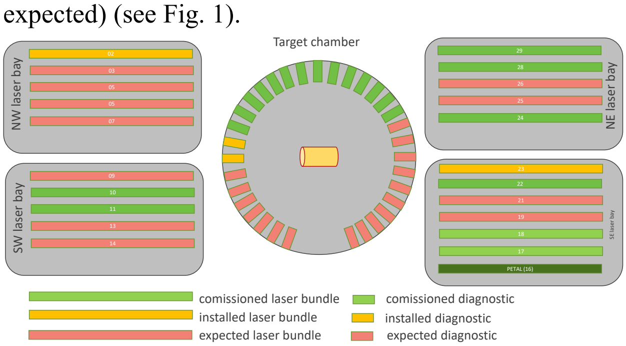


Figure 1: Laser bundles and target diagnostics status.

Laser bundles assembly started in early 2013; the first physics experiment on the facility has been done at the end of 2014 with one laser bundle and two target chamber diagnostics. The end of laser bundle assembly operations is expected for 2025. The full set of target chamber diagnostics is expected later.

Operating software are used to automate, secure and optimize the operations on the LMJ facility. They contribute to the smooth running of the experiment process (from the setup to the results). They are integrated in the maintenance process (from the supply chain to the asset management).

OPERATIONS VS MAINTENANCE

Operating the facility must be still possible while doing assembly and maintenance activities avoiding coactivity issues. These activities must respect safety and security instructions.

Operating such a facility needs to manage many different technical skills (mechanics, electronics, automation, computing and physics). The LMJ is composed of many components. Some of them could be « on the shelves » parts (ex.: pump or motor), others could be specifically designed for the facility and be made of innovative technologies in order to meet the extreme requirements (temperature, pressure and radiation). The supply chain could be very complex for some parts (exclusive know-how, small manufacturing capacity).

The main goal is to fully operate the facility with all the laser bundles and target diagnostic available. But like all complex system, there is sometimes issues on the components (failure, malfunction, etc.). The impact of these issues could be transparent (fault tolerance managed by redundancy), moderated (fault could be bypassed), serious (one laser bundle or one target diagnostic is unavailable) or critical (experiment failure/facility shutdown).

Everything is done to avoid a critical failure and optimize the operation availability. This availability is measure with a Key Performance Indicator (KPI). For example, an availability of 75 % means that quarter of the time the facility could not operate in a nominal way. The time wasted in unplanned maintenance (replacement of faulty parts) downgrade the availability. This KPI is used to measure the technical management of the facility and the ability to anticipate the failures. It is also used for long and mid-term planning.

In order to maximize the availability, it is important to identify all the parts with a Mean Time To Failure (MTTF) lower that the facility's operating life time. It is important to characterize some indicators used to check the "health" status of these parts. By monitoring these indicators, you can anticipate the replacements before the

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV005

TOWARDS A NEW CONTROL SYSTEM FOR PETRA IV

R. Bacher, T. Delfs, D. Mathes, T. Tempel, T. Wilksen
Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany

Abstract

At DESY, an upgrade of the PETRA III synchrotron light source towards a fourth-generation, low emittance machine PETRA IV is currently being actively pursued. The basic concept of the control system of PETRA IV is to exploit synergies between all accelerator facilities operated by DESY. The key figures of PETRA IV's new accelerator control system include the DOOCS control system framework, high-end MTCA.4 technology compliant hardware interfaces for triggered, high-performance applications and hardware interfaces for conventional slow-control applications compliant with industrial process control standards such as OPC UA, and enhanced data acquisition and data storage capabilities. In addition, the suitability of standards for graphical user interfaces based on novel Web application technologies will be investigated. Finally, there is a general focus on improving quality management and quality assurance measures, including proper configuration management, requirements management, bug tracking, software development, and software lifetime management. The paper will report on the current state of development.

INTRODUCTION

With PETRA III, DESY operates one of the best storage ring X-ray radiation sources in the world. PETRA III is a 2300-metre-long storage ring feeding 24 user beamlines. It is operated either in brightness mode (480 equally distributed bunches, 120 mA stored beam) or in timing mode (40 equally distributed bunches, 100 mA stored beam). Research groups from all over the world use the particularly brilliant, intense X-ray light for a variety of experiments - from medical to materials research.

DESY plans to expand it into a high-resolution 3D X-ray microscope for chemical and physical processes. PETRA IV [1] will extend the X-ray view to all length scales, from the atom to millimetres. Researchers can thus analyse processes inside a catalyst, a battery or a microchip under realistic operating conditions and specifically tailor materials with nanostructures. PETRA IV also offers outstanding possibilities and optimal experimental conditions for industry.

PETRA IV will replace the PETRA III facility and will be housed by the existing PETRA III buildings. An additional experimental hall will provide space for additional 18 user beamlines. In addition, a new synchrotron (DESY IV) will serve as booster between the existing electron source LINAC II and PETRA IV.

In 2020, a preparatory phase for the future project PETRA IV was initiated with the aim of submitting a Technical Design Report by mid-2023. Construction work is scheduled to begin in early 2026, followed by a commissioning phase in 2028.

The following chapter will describe the baseline of the accelerator control system of the future PETRA IV facility.

CONTROL SYSTEM DESIGN BASELINE

The development and implementation of the future PETRA IV accelerator control system will be embedded in a long-term process to consolidate the whole accelerator control system landscape at DESY and to take advantage of synergies between the accelerator facilities operated by DESY. The accelerator control system of PETRA IV will closely follow the control system concept implemented at the European XFEL. Consequently, support and maintenance of the existing control system framework used at PETRA III will not be continued beyond its expected lifetime.

Control System Framework

The Distributed Object-Oriented Control System (DOOCS) [2] will form the basis of the future control system of PETRA IV. DOOCS is the established control system framework at FLASH, European XFEL and other conventional accelerator facilities operated by DESY, as well as advanced accelerator projects based on plasma wake field acceleration.

DOOCS is based on a distributed client-server architecture combined with a device-oriented view. Each control system parameter is made accessible via network calls through a device application. Its transportation layer is based on the standardized, industrial RPC protocol. The DOOCS framework is written in C++ and supports a variety of fieldbus and hardware interfaces via device classes. These are accessible through additional libraries which can be linked as needed individually to the server core library. Libraries for creating client applications in C++, Java, Python or MATLAB are available either as a separate implementation or as C-bindings. Through the client API DOOCS provides access to multiple popular control system such as EPICS and TANGO. At DESY, EPICS is used for facility control (electrical power and water distribution, ventilation and air conditioning) and control of the cryogenic systems, while TANGO is the standard control system for operating the beam line components and the experimental equipment.

The initial development of DOOCS dates back to 1993. Since that time, it has steadily developed into a powerful, reliable and versatile control system. Recently, a roadmap was established to meet the increasing user demands over the next decade and to continue to keep pace with the rapid developments in IT technologies.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV006

THE NEW SMALL WHEEL LOW VOLTAGE POWER SUPPLY DCS FOR THE ATLAS EXPERIMENT

Christos Paraskevopoulos[1,2]
[1]National Technical University of Athens, Zografou, Greece
[2]Brookhaven National Laboratory, Upton, NY, U.S.A

Abstract

A series of upgrades are planned for the LHC accelerator to increase it's instantaneous luminosity to $7.5 \times 10^{34}\,\mathrm{cm^{-2}s^{-1}}$. The luminosity increase drastically impacts the ATLAS trigger and readout data rates. The present ATLAS Small Wheel Muon(SW), will be replaced with a New Small Wheel which is expected to be installed in the ATLAS underground cavern by the end of the Long Shutdown 2 of the LHC. Due to its complexity and expected long-term operation, the New Small Wheel (NSW) requires the development of a sophisticated Detector Control System (DCS). The use of such a system is necessary to allow the detector to function consistently and safely and have a seamless interface to all sub-detectors and the technical infrastructure of the experiment. The central system handles the transition between the probe's possible operating states while ensuring continuous monitoring and archiving of the system's operating parameters. Any abnormality in any subsystem of the detector triggers a signal or alert (alarm), which notifies the user and either defaults to automatic processes or allows manual actions to reset the system to function properly. The part that will be described is the modular system of Low Voltage(LV). Among its core features are remote control, split of radiation sensitive parts from parts that can be housed in a hostile area and compatibility with operation in the radiation and magnetic field as in the ATLAS cavern. The new Low Voltage Intermediate Control Station(ICS) will be used to power the Low Voltage Distributor(LVDB) boards of the NSW and through them, the readout and trigger boards of the system providing data and functioning safely.

ATLAS NEW SMALL WHEEL

ATLAS [1] is the largest high-energy physics detector ever built by man. The LHC delivers millions of collisions each second, that take place in the heart of ATLAS. These collisions though, create a dangerous radiation environment, which the detector has to endure. To efficiently handle the increased luminosity of the High-Luminosity LHC (HL-LHC), the Small Wheel (SW) which is the first station of the ATLAS muon spectrometer end-cap system, will be replaced. The New Small Wheel (NSW) [2] will have to operate in a high background radiation region (up to $22\,\mathrm{kHz/cm^2}$) while reconstructing muon tracks with high precision as well as providing information for the Level-1 trigger. The New Small Wheel consists of two detector technologies of gaseous detectors, the first is called small-strip Thin Gap Chambers (sTGCs), and the second comes from the category of micro-pattern gaseous detectors and is named Micromegas (MMG) [3]. The NSW apart from the two new detector technologies is a platform presenting new Custom ASICs and electronic boards. The readout system is based on Front End LInk eXchange (FELIX) housing 2.5 Million readout channels, common configuration, calibration & Detector Control System (DCS) path and new power supply system.

THE NEW SMALL WHEEL DETECTOR CONTROL SYSTEM

In order to monitor and control the operation of the detector, a framework has been devised, which allows for remote supervision and intervention in the detector and its sub-systems: The Detector Control System (DCS) [4].The DCS is simply a Supervisory Control And Data Acquisition (SCADA) system equipped with User Interfaces (UIs), automated scripts and control/monitor functionality. This control scheme is used daily, in the ATLAS Control Room. It is also used by the subdetector experts to guarantee a safe and efficient physics run. The main task of the DCS is to enable the coherent and safe operation of the full detector by continuously monitoring its operational parameters and its overall state.

Finite State Machine Hierarchy

The chosen software used for the back-end system is called WinCCOA [5]. WinCCOA is a highly modular, device oriented product also with event driven architecture. The back-end system, used by all the four LHC experiments, is implemented using this commercial SCADA package. On top of the SCADA package, the Joint Controls Project (JCOP) framework [6] provides a set of software tools and guidelines and assures the back-end homogeneity over the different subsystems, sub-detectors and LHC experiments. The projects are mapped onto a hierarchy of Finite State Machine (FSM) elements using the JCOP FSM toolkit . The FSM is conceived as an abstract machine that is able to be in only one of a finite number of states at a time. The state can change when initiated by a triggering event or condition (transition state).

System Architecture

The NSW DCS projects closely follow the existing look, feel and command structure of MUON DCS, to facilitate the shifter and expert operations. The top node of both MMG and sTGC will propagate its state and receive commands from the ATLAS overall DCS. Shifters will mainly use the

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV009

THE HV DCS SYSTEM FOR THE NEW SMALL WHEEL UPGRADE OF THE ATLAS EXPERIMENT

E. Karentzos* on behalf of ATLAS Collaboration,
Albert-Ludwigs-University Freiburg

Abstract

The background radiation at the HL-LHC is expected to exceed the one designed for the ATLAS muon spectrometer. In order to cope with the foreseen limitations, the collaboration decided to replace the Small Wheel (SW) with a New SW (NSW) by combining two prototype detectors, the small-strip Thin Gap Chambers or sTGC (STG) & and resistive Micromegas (MMG). Both detector technologies are "aligned" to the ATLAS general baselines for the NSW upgrade project [1], maintaining in such way the excellent performance of the system beyond Run-3. Complementary to the R&D of these detectors, an intuitive control system was of vital importance. The Detector Control System (DCS) for both the MMG and the STG High Voltage (HV), have been developed, following the existing look, feel and command architecture of the other sub-systems. The principal task of the DCS is to enable the coherent and safe operation of the detector by continuously monitoring its operational parameters and its overall state. Both technologies will be installed in ATLAS and will be readout and monitored through the common infrastructure. Aim of this work is the description of the development and implementation of a DCS for the HV system of both technologies.

OVERALL VIEW OF THE NSW HV DCS SYSTEM

Figure 1 illustrates a simplified sketch of the New Small Wheel. The wheel consists of 16 sectors equally divided into large and small sectors. However, the detector geometry is different for each sector type. The numbering of the sectors begins at the left large sector with number 1 and continues clockwise, similarly to the realization in DCS. All large sectors have odd numbers (1,3,5,7,9,11,13,15) while the small ones have even numbers (2,4,6,8,10,12,14,16). Each sector is equipped with the so-called quadruplets of both detector technologies. One quadruplet consists of four layers of a certain detector type.

MMG Scheme

The Micromegas sectors are divided into two quadruplets in radial direction. The quadruplets close to the beam axis defined as xM1, and the outer ones with xM2. Small and large quadruplets just differ in dimension, while similar size layers (xM1, xM2) differs in the number of Printed Circuit Boards (PCB). The larger ones consist of five single readout PCB's which are mounted together to form a detector layer of a quadruplet. On top of the PCB the readout lines are located.

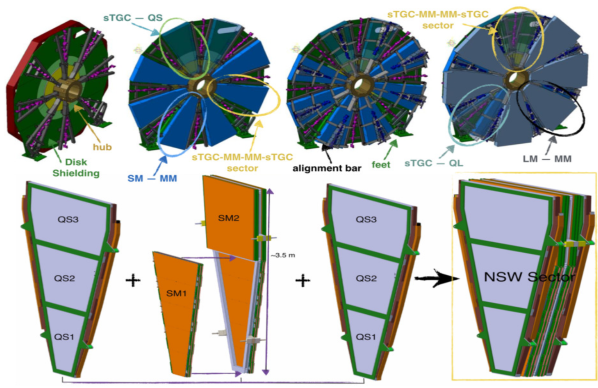


Figure 1: Representation of the NSW (top) with the relevant positions of the NSW sectors, (sTGC and MMG, Small & Large). The different sTGC and MMG modules composing a small sector of the NSW (bottom).

HV Modules Requirements: For both MM quadruplet types a nominal voltage of 570 V/128 µm for the readout is foreseen. The drift boards are supplied by a voltage of 300 V. The current is expected to be less than 1 µA for a readout HV channel. One channel serves one PCB, while the number of channels of all modules sum up to 1024.

sTGC Sheme

The sTGC detectors are divided into 3 quadruplets in the radial direction. The quadruplets naming in radial direction uses the partition definition of inner, middle and outer. A special characteristic is that the innermost quadruplet of the sTGC is divided into two HV sectors in radial direction, due to higher particle flux close at the beam pipe.

HV Modules Requirements: The sTGC quadruplets are operated only with one voltage of around 2.8 kV. There is no aggregation of channels planned, as the number of channels of all modules sum up to 1024. The chosen limits are 1 mA for the innermost HV sector of the inner quadruplets and 0.5 mA for the remaining ones.

Overview of the DCS Internal Structure

In order to incorporate the hardware information into the DCS, several components have been used or developed within the scope of the JCOP Framenwork [2]. Datapoint Types (DPT) have defined for each hardware component, device and detector segment. Their instances, namely the

* efstathios.karentzos@cern.ch

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV010

WORKING UNDER PANDEMIC CONDITIONS: CONTACT TRACING MEETS TECHNOLOGY

E. Blanco Viñuela*, T. Previero, E. Matli, B. Copy, S. Danzeca,
R. Sierra, R. Losito, Ch. Delamare, A. Masi
CERN, Geneva, Switzerland

Abstract

COVID-19 has dramatically transformed our working practices with a big change to a teleworking model for many people. There are however many essential activities requiring personnel on site. In order to minimise the risks for its personnel CERN decided to take every measure possible, including internal contact tracing by the CERN medical service. They performed manual procedures which relied on people's ability to remember past encounters. To improve this situation and minimise the number of employees who would need to be quarantined, CERN approved the design of a specific device: the Proximeter. The project goal was to design a wearable device, built in a partnership with industry (*Terabee* and CERN), fulfilling the contact tracing needs of the CERN medical service. The proximeter records other devices in close proximity and reports the encounters to a cloud-based system. The service came to operation early 2021 and more than 8000 devices were distributed to CERN members of personnel. This publication reports on the service offered, with emphasis on the overall workflow of the project under exceptional conditions and the implications data privacy imposed on the design of the software application.

INTRODUCTION

COVID-19 has dramatically modified working conditions hence affected largely to global economies and enterprise businesses. However, during the pandemic situation essential activities still required personnel on site. In order to keep production stability but ensuring workers safety there was an increased focus on finding solutions to comply with COVID-19 social distancing recommendations [1].

Initially, most of CERN activities adapted and were executed remotely (teleworking), but still some critical activities required work on site. The Health, Safety and Environmental (HSE) unit at CERN introduced a series of measures following the recommendations issued by the Host States. Social distancing and contact tracing have been some of the measures implemented. Contact tracing is defined as the capability of identifying persons who have been in the vicinity of an infected person so their isolation would avoid the spread of the virus. This tracing process was manually conducted by the medical service and required a large effort to keep up with the rate of infection. The process was mostly relying on memories of the infected individuals who should remember with whom they may be in close contact hence does not guarantee perfect traceability.

Two main challenges appeared: (1) help individuals in keeping a **social distance** and (2) timely **identify individuals** who were in close contact with an infected person, the so-called contact tracing.

To tackle the mentioned challenges CERN approved the design of a specific device: the proximeter. The overall project goal was to design a wearable device able to record other devices in close proximity. Additionally an application provides only the close contacts under the request of the medical service.

This publication reports on the service offered, with emphasis on the overall workflow of the project under exceptional conditions and the implications data privacy imposed on the design of the overall service.

THE PROXIMETER

First of all, the definition of two essential terms representing key events widely used during this publication is introduced here: **encounter** as the event of two individuals being within 2 meters distance for more than 30 seconds and **close contact** as the event of an encounter lasting more than 15 minutes which must be traced if required by the medical service.

The device was created with two main objectives: (1) **warning**: so the users are warned once they are not keeping the expected social distancing (2) **contact tracing**: timely provide potential close contacts in case of a positive appears.

Several similar devices with these characteristics were available on the market, but none presenting at the same time the desired precision, scalability to 10000 and more devices, timely data availability and more importantly adaptability in order to protect the sensible data collected at all moments of use and transfer. CERN decided then to issue a competitive tender with those specific requirements.

The company that was awarded the contract, *Terabee* [2], adapted one of its products, the *Terabee mobile robotics positioning system*, to comply with the specifications. In particular, for the connection to the CERN infrastructure *Terabee* implemented the CERN's *miniIoT* (Internet of Things) technology, under licence from CERN, while using its own technology for the encounters tracking based on the accurate Ultra Wide Band (UWB) radiofrequency.

Then, *Terabee* engineered a device that CERN called the **proximeter** (Fig. 1) which become a commercialised wearable product in *Terabee*'s portfolio [3].

* Enrique.Blanco@cern.ch

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV011

THE INCLUSION OF WHITE RABBIT INTO THE GLOBAL INDUSTRY STANDARD IEEE 1588

M. Lipiński*, CERN, 1211 Geneva 23, Switzerland

Abstract

White Rabbit (WR) is the first CERN-born technology that has been incorporated into a global industry standard governed by the Institute of Electrical and Electronics Engineers (IEEE), the IEEE 1588 Precision Time Protocol (PTP). This showcase of technology transfer has been beneficial to both the standard and to WR technology. For the standard, it has allowed the PTP synchronisation performance to be increased by several orders of magnitude, opening new markets and opportunities for PTP implementers. While for WR technology, the review during its standardisation and its adoption by industry makes it future-proof and drives down prices of the WR hardware that is widely used in scientific installations. This article provides an insight into the 7-year-long WR standardisation process, describing its motivation, benefits, costs and the final result. After a short introduction to WR, it describes the process of reviewing, generalising and translating it into an IEEE standard. Finally, it retrospectively evaluates this process in terms of efforts and benefits to conclude that basing new technologies on standards and extending them bears short-term costs that bring long-term benefits.

INTRODUCTION

White Rabbit

White Rabbit (WR, [1]) is an open-source [2] technology developed to provide the Large Hadron Collider (LHC) accelerator chain with deterministic data transfer, synchronisation with sub-nanosecond accuracy and a precision of a few picoseconds. First used in 2012, the technology has since then expanded its applications [3] outside the field of particle physics and is now deployed in numerous scientific infrastructures worldwide. Moreover, it has shown its innovative potential by being commercialised and introduced into different industries, including telecommunications, financial markets, smart grids, the space industry and quantum computing. On 16 June 2020, the WR synchronisation method was recognised by being included in the worldwide industry IEEE 1588 standard called Precision Time Protocol (PTP, [4]), governed by the Institute of Electrical and Electronics Engineers (IEEE, [5]), the world's largest technical professional organisation dedicated to advancing technology.

WR's wide-spread use in scientific installations and its adoption into industry can be attributed to 3 factors:

1. The open-source and commercial nature.
2. The collaborative and welcoming community.
3. Basing it on standards, extending them if needed.

This article focuses on the third factor to the success of WR.

* maciej.lipinski@cern.ch

Standards and Standard-Defining Organisations

A technical standard is usually a formal document that establishes uniform engineering or technical criteria for externally visible operational aspects of a technology. While independently developed products (e.g. devices, software) that follow the same standard are meant to inter-operate, innovation is made possible in the internal implementation of these standard-based solutions.

Technical standards are prepared by groups that gather expert representatives of industry and academia specialised in a given domain. These groups are referred to as standard-defining organisations (SDOs) and can be organised as international organisations, unions, associations or consortia. Examples of SDOs relevant to this article:

1. International Telecommunication Union (ITU): a specialised agency of the United Nations responsible for information and communication technologies.
2. Institute of Electrical and Electronics Engineers (IEEE): a professional association for electronic engineering and electrical engineering (and associated disciplines).

Our everyday life is heavily dependent on standards prepared by IEEE and ITU. The ITU standards govern the operation of mobile networks. Commonly used means of communication, such as Ethernet, Local Area Networks and WiFi are all defined in IEEE standards.

IEEE1588 Standard

The IEEE 1588 standard defines the Precision Time Protocol (PTP) that provides precise synchronisation of clocks in packet-based networked systems. The standard is commonly used to synchronise devices (e.g. sensors, actuators) in factories, power plants, distributed measurement systems as well as in finance, audio-video and telecommunication. First published in 2002, it was updated in 2008 and 2019.

The operation of PTP is divided into two main actions: establishment of a synchronisation hierarchy in the network and synchronisation of network devices following the established hierarchy. The IEEE 1588 standard is actually a "generic framework" that defines the above-mentioned mechanisms, as well as numerous options and parameters to enhance and fine tune its operation. The configuration of this "generic framework" is called a "PTP Profile". The framework cannot be used without a profile, thus the IEEE 1588 standard includes generic-purpose profiles, called Default PTP Profiles. Many industries define PTP Profiles adjusted to their particular requirements [6]. For example ITU-T defines PTP Telecom Profiles (e.g. G.8265.1) and the IEEE defines PTP Profiles for Power (C37.238) as well as Audio/Video, Automation and Automotive (802.1AS).

Notably, the IEEE 1588 standard purposely does not define requirements with respect to synchronisation perfor-

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV012

THE ESRF-EBS SIMULATOR: A COMMISSIONING BOOSTER

S. Liuzzo*, L.R. Carver, J.M. Chaize, L .Farvacque, A. Götz, D. Lacoste,
N .Leclercq, F. Poncet, E.Taurel†, S. White
ESRF, Grenoble, France

Abstract

The ESRF-Extremely Brilliant Source (ESRF-EBS) [1] is the first-of-a-kind fourth-generation high-energy synchrotron. After only a 20-month shutdown, scientific users were back to carry out experiments with the new source. The EBS Simulator (EBSS) played a major role in the success of the commissioning of the new storage ring. Acting as a development, sandbox and training platform, the machine simulator allowed control room applications and tools to be up and ready from day one. The EBSS can also be seen as the initial block of a storage ring digital twin. The present article provides an overview of the current status of the EBS Simulator and presents the current roadmap foreseen for its future.

INTRODUCTION

The ESRF storage ring was upgraded in 2019 to provide 100 times brigther X-rays [1]. The strong demand for experiments at ESRF imposed a very tight schedule for dismantling, installation and commissioning of the new storage ring. Overall, 20 months of dark time for external users were necessary [2]. Only three of these months were dedicated to Storage Ring commissioning. In order to cope with this schedule, the design and update of the whole software infrastructure had to be brought forward as much as possible. This is particularly true for the high-level applications needed on the first day of commissioning, such as the new magnets control. In addition, several applications specific to the commissioning such as beam threading algorithms [3] had to be prepared and tested to be used effectively, with minimal debug time.

For this purpose a full test of the software from high-level applications to power-supplies level (current input, not hardware level) was realized via an EBS control system simulator (EBSS). This control system simulator was strongly focused on the new EBS magnets control system that needed to be completely redesigned, but included as well all the frequently used diagnostic devices (beam position monitor (BPMs), tunes, emittances, etc..) needed for the development of the tools used for the commissioning. The output values of the simulated diagnostic devices are generated from a given lattice optics model that is updated upon a magnetic strength or RF frequency variations in the simulated control system - as depicted in Fig. 1.

From the user's point of view, the simulator is identical to the "physical" control system. The devices providing the information on the beam position have identical names for

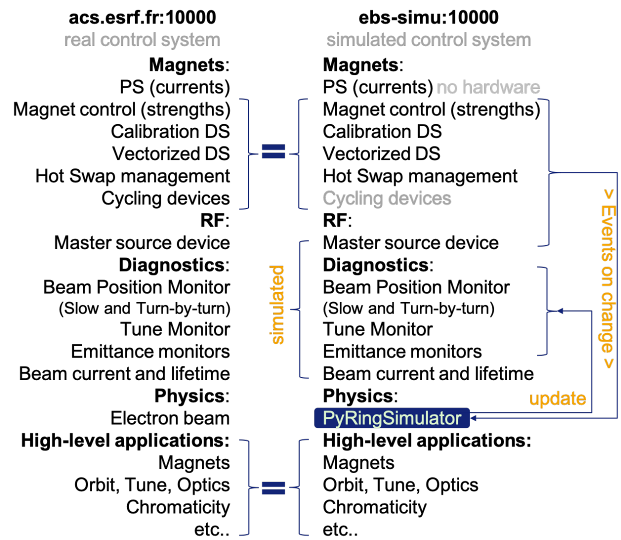


Figure 1: Real control system vs EBS simulator.

attributes and properties as their physical counterparts. This allows to port the applications from the simulator environment to the real machine by simply changing the environment variable pointing to the TANGO [4] database.

EBSS is a clone of a subset of the EBS control system that allows to interact with a simulated beam and to visualize the expected behaviour of most of the relevant electron beam and lattice observables: orbit, tunes, emittances, optics and coupling.

In the past, the ability to run off-line control room applications was already available, for example via toolkits such as the Matlab-Middle-Layer [5], used in many 3rd generation light sources or specific solutions - like the one on which the Virtual XFEL [6] relies.

For storage-rings, Matlab-Middle-Layer provides a high level switch from simulations to real beam experiments. This limits the development to anything above the matlab-middle-layer software infrastructure. The EBSS instead acts at a lower level, replacing directly the beam, thus giving access to all control levels. It notably enables real-time tests of features (1-2s/loop) not only for beam dynamics experts but also for control system engineers.

STRUCTURE OF THE SIMULATOR

The core of an EBSS instance [7] is composed of more than ~ 4000 Tango devices compared to ~ 25000 in the physical accelerator complex (including the 3 accelerators - linac, booster + storage ring). Each EBSS instance runs on its own Tango control system - the associated Tango database

* simone.liuzzo@esrf.fr
† taurel@esrf.fr

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV013

A DYNAMIC BEAM SCHEDULING SYSTEM FOR THE FAIR ACCELERATOR FACILITY

S. Krepp*, J. Fitzek, H. Hüther, R. Mueller, A. Schaller, A. Walter
GSI Helmholtz Centre for Heavy Ion Research, Darmstadt, Germany

Abstract

The new Accelerator Control System for GSI/FAIR is now being used productively for the GSI accelerator facility. As the central component for online beam orchestration, the Beam Scheduling System (BSS) is situated between the FAIR Settings Management System and the FAIR Timing System. Besides device settings, the Settings Management System provides timing schedules for beam production. The primary purpose of BSS is to define which of the beam schedules are executed by the Timing System, how often and in which order. To provide runtime decisions in pre-planned execution options (e.g. skipping of a particular beam), it processes external signals like user input, experiment requests or beam prohibits provided by the interlock system. More recently, advanced features have been added that allow for dynamic execution control required by Storage Ring Mode features such as breakpoints, repetitions, skipping and manipulations. This contribution gives an overview of the Beam Scheduling System including its interfaces.

INTRODUCTION

One of the major building blocks of the new Accelerator Control System for GSI/FAIR is the Beam Scheduling System (BSS). Residing in the middle tier of the FAIR Control System, its core functionality is the orchestration of beams based on user requests. Figure 1 shows how BSS is embedded into the overall Control System architecture.

In the FAIR Settings Management System LSA, beams are represented as Beam Production Chains and are put together to Patterns for defining an execution sequence. This includes both, settings for hardware devices, as well as an execution schedule defining which Timing Events are to be sent to which parts of the facility. Additionally, by assigning Patterns to Pattern Groups, LSA defines which Patterns must be executed sequentially and which Patterns may run in parallel. The schedule for each Pattern and the information about Pattern Groups is provided to the BSS system, which creates an overall schedule for the accelerator facility and sends it to the Timing System's Generator component. The Generator then translates this schedule to the low-level programming of the Data Master.

Operators and experimenters define, which beams they would like to have produced using applications and services, that in turn send these requests to BSS. At the same time, the Master Accelerator Status Processor (MASP) determines whether a certain Pattern can be executed, by collecting status and interlocks of all required devices and services. BSS then combines both of these inputs and sends commands to

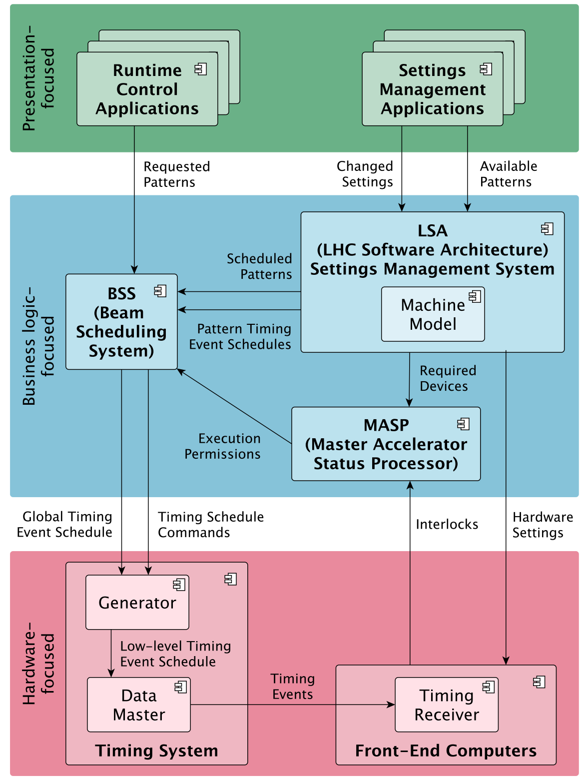


Figure 1: BSS in the FAIR Control System.

the Generator, that dynamically modifies the overall schedule accordingly. At runtime, the Data Master sends out timing events via the White Rabbit-based timing network. Those events lead to synchronous execution of settings in devices as calculated and provided by LSA.

As shown, BSS is the central instance that decides which of the preconfigured schedules are executed. This contribution presents technical details of the BSS system and its interfaces to give an insight, of how beam orchestration is realized within the GSI/FAIR Accelerator Control System.

SCHEDULE REPRESENTATION

Schedules within BSS are represented as schedule graphs that can be executed by the Timing System [1]. The graph itself is represented in the .dot format [2]. The vertices in this directed graph can roughly be interpreted as executable units linked together by a set of edges. Once started, a control thread walks over those vertices one after another in order to execute them. The actual sequence of vertices is defined by a set of edges marked as default destinations. Alternative routes through the schedule are defined by a set of alternative destinations.

* s.krepp@gsi.de

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV014

UPGRADE OF THE NewSUBARU CONTROL SYSTEM

N. Hosoda†[1,2], T. Fukui[2], Y. Hamada[1], M. Ishii[1,2], A. Kiyomichi[1], K. Okada[1], T. Sugimoto[1,2]
[1]Japan Synchrotron Radiation Research Institute, Hyogo, Japan
[2]RIKEN SPring-8 Center, Hyogo, Japan

Abstract

A new dedicated electron injector linear accelerator (linac) was constructed for the soft X-ray synchrotron radiation facility, NewSUBARU. The SPring-8 linac was used as the injector at the facility since its operation started. However, the new linac enabled NewSUBARU to operate independently from the SPring-8. The control system of the new linac and the existing storage ring must be constructed as a unified system for seamless operation. The control framework already used for the SACLA/SPring-8 was also used for the NewSUBARU. MicroTCA.4 (MTCA.4), EtherCAT, and GigE vision camera were used for the new linac control. For the storage ring control, the existing VMEbus system (VME) was used with virtually no changes. The open source version of Qt5 was selected to create a graphical user interface program (GUI). Additionally, the design of the new linac is planned to be used in the 3 GeV synchrotron radiation facility project currently under construction in eastern Japan. Similar kind of hardware and control framework will be utilized for the project.

INTRODUCTION

NewSUBARU is a soft X-ray synchrotron radiation facility with a 1.5 GeV electron storage ring having a circumference of 118 m [1]. It was built at the SPring-8 site and shared a linac of SPring-8 as an injector. The NewSUBARU started user experiments in January 2000. SPring-8 is a hard X-ray synchrotron radiation facility with an 8 GeV electron storage ring having a circumference of 1,436 m. It has a 140 m-long 1 GeV linac and an 8 GeV booster synchrotron having a circumference of 396 m as injectors and has been in service for user experiments since October 1997. SACLA is an X-ray free electron laser facility with a 400 m-long 8 GeV linac that was constructed at the SPring-8 site. The SACLA has been in service since March 2012.

In the SPring-8 upgrade project (SPring-8-II), a method for realizing an ultra-low emittance ring was studied. The plan consisted of drastically modifying the SPring-8 storage ring and injecting a low emittance beam of SACLA directly into the ring. This required the existing injectors, the linac, and the booster synchrotron of SPring-8, to be shut down. However, this would further show that NewSUBARU would no longer be operational. Therefore, a new 1 GeV linac had to be built exclusively for NewSUBARU. As it had to be installed in the existing beam transport tunnel, the linac was designed to be compact with a total length of 70 m and used C-band accelerating structures developed at the SACLA [2]. In July 2020, a beam injection from the SPring-8 linac to the NewSUBARU was completed and the installation of the new linac was started. The commissioning of the linac started in February 2021, and two months later, in April, the user experiments at NewSUBARU were resumed. Figure 1 shows the layout before and after the new linac was installed at the NewSUBARU. A picture showing the NewSUBARU building and the new annex building for the new linac is illustrated in Figure 2.

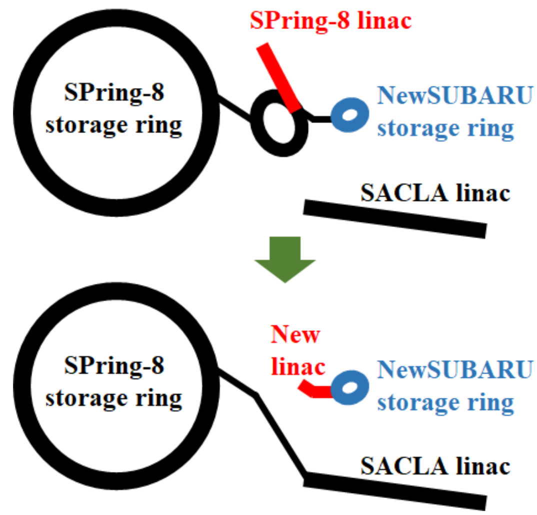


Figure 1: Layout of the NewSUBARU before and after installation of the new linac.

Figure 2: NewSUBARU building and new annex building for the new linac.

Since 1995, MADOCA control framework has been developed and used for the SPring-8 and the SACLA [3]. In 2018, the MADOCA was upgraded for integrated operation of the SACLA and SPring-8 as part of the SPring-8-II [4-6]. Using this new control system, beam injection from the SACLA to the SPring-8 storage ring was started in 2020.

The NewSUBARU has adopted MADOCA as its control system since its introduction. With the construction of the new linac, it was natural to completely shift from the first MADOCA to the upgraded one. To operate the new linac and the existing storage ring together, a file server, the database servers, and the computer networks required further upgrading.

When upgrading an existing facility, the shutdown period must be as brief as possible. To achieve this, advance

† hosoda@spring8.or.jp

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV015

CONTROL SYSTEM OF THE SRILAC PROJECT AT RIBF

A. Uchiyama†, M. Fujimaki, N. Fukunishi, Y. Higurashi, E. Ikezawa, H. Imao, O. Kamigaito, M. Kidera, M. Komiyama, K. Kumagai, T. Nagatomo, T. Nakagawa, T. Nishi, J. Ohnishi, K. Ozeki, N. Sakamoto, K. Suda, T. Watanabe, Y. Watanabe, K. Yamada,
RIKEN Nishina Center, Wako, Japan
A. Kamoshida, National Instruments Japan Corporation, Tokyo, Japan
K. Kaneko, R. Koyama, T. Ohki, K. Oyamada, M. Tamura, H. Yamauchi, A. Yusa,
SHI Accelerator Service Ltd., Tokyo, Japan

Abstract

The RIKEN linear accelerator (RILAC), an injector of the Radioactive Isotope Beam Factory (RIBF) project, was upgraded by installing a superconducting RIKEN linear accelerator (SRILAC) and a 28-GHz ECR ion source (SRILAC project). In addition to controlling these two new apparatuses, the control system of the updated RILAC requires various improvements to the shortcomings of the previous RILAC control system, for example, control methods for electromagnet power supplies using GPIB, a low-performance machine protection system. Moreover, there were issues regarding the integration of small LabVIEW-based systems into the main part of the control system. For efficient operation in the SRILAC project, a distributed control system utilizing the Experimental Physics and Industrial Control System (EPICS) should be adopted in the other parts of RIBF. A higher-level application protocol needs to be integrated into the EPICS channel access protocol. We developed new systems to solve the issues mentioned above and introduced systems that have been proven in other facilities, such as Archiver Appliance as a data archive system. The control system was successfully upgraded and used in the SRILAC beam commissioning completed in 2020. The new control system is currently in its operational phase.

INTRODUCTION

The RIKEN Radioactive Isotope Beam Factory (RIBF) accelerator facility comprises five cyclotrons and two linear accelerators. One of the linear accelerators, the RIKEN linear accelerator (RILAC) [1], has been utilized not only as an injector for cyclotrons but also for stand-alone experiments such as the synthesis of superheavy elements. As an upgrade project, to perform search experiments for superheavy elements with atomic numbers of 119 and higher [2], the superconducting RIKEN linear accelerator (SRILAC) has been introduced downstream of RILAC to enhance beam energy, and a 28-GHz superconducting electron cyclotron resonance ion source (28-GHz SC-ECRIS), similar to the existing RIKEN 28-GHz ECRIS[3], has been introduced at the frontend of RILAC to increase beam intensity [3].

The RIBF control system was constructed using a distributed control system based on the Experimental Physics and Industrial Control System (EPICS) [4]. The new control system for the RILAC upgrade project should be constructed using the EPICS-based control system, and it should be integrated into the existing RIBF control system. The RILAC upgrade project includes various types of hardware such as a 28-GHz SC-ECRIS, beam energy position monitors (BEPM) [5], N2 gas-jet curtain systems [6], and superconducting cavities [7]. Furthermore, the new control system requires improvements to the existing RILAC control system, such as a control method for electromagnet power supplies, a machine protection system, and a data archive system. The protocol for a higher-level application environment should be unified with the EPICS channel access (CA) protocol to enhance operational efficiency. We decided to mainly adopt programmable logic controllers (PLCs) to construct the system and utilize other methods for areas where application of PLCs is difficult considering our limited manpower and resources.

RIKEN 28-GHZ SC-ECRIS CONTROL

The 28-GHz SC-ECRIS was commissioned in advance of the commissioning of other apparatuses. The control system comprises the following: control of ion-source-specific devices (e.g., gas flow controllers, an insertion device of material rods, a high-voltage power supply, and a gyrotron), control of superconducting electromagnet power supplies, and vacuum control [8]. The superconducting electromagnet power supplies embedded MELSEC-Q series as a PLC are connected via NetDev[9], which is an EPICS device support, and controlled by a PC-based EPICS input/output controller (IOC). On the contrary, the control of the ion-source-specific devices and the vacuum control mainly comprised FA-M3 PLCs manufactured by Yokogawa Electric Corporation. These systems have a multi-CPU configuration, a sequence CPU (F3SP71), and a Linux CPU (F3RP61-2L)[10]. Mainly, interlock logic is implemented on the sequence CPU, and EPICS required for higher-level applications is implemented on the Linux CPU.

In contrast to other control systems, some control stations with digital and ana-log modules need to be installed on the high-voltage stage with several tens of kilovolts. Therefore, the connection is insulated between the devices in the high-voltage stage and some devices on the ground level. The control system of the existing 28-GHz SC-ECRIS uses TCP/IP to ex-change interlock signals between

† a-uchi@riken.jp

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV016

DESIGN AND IMPLEMENT OF WEB BASED SCADA SYSTEM FOR HUST FIELD-REVERSED CONFIGURATION DEVICE

F. Wu†, Y. Jiang, S. Li, B. Rao, W. Wang, X. Xie, Y. Yang, M. Zhang, P. Zhang, W. Zheng
International Joint Research Laboratory of Magnetic Confinement Fusion and Plasma Physics,
State Key Laboratory of Advanced Electromagnetic Engineering and Technology,
School of Electrical and Electronic Engineering,
Huazhong University of Science and Technology, Wuhan, 430074, China

Abstract

As a large complex fusion research device for studying field reversed configuration (FRC) plasma, HUST FRC (HFRC) is composed of many subsystems. In order to coordinate all systems and ensure the correct, orderly and stable operation of the whole experimental device, it is very important to have a unified and powerful control system.

HFRC SCADA (Supervisory Control And Data Acquisition) system has selected the in-house developed CFET (Control system Framework for Experimental Devices Toolkit)as the control framework, with advantages of strong abstraction, simplified framework, transparent protocol and flexible extension due to Web technology.

Introduction

Growing worldwide demand for energy, and problems of scarcity and environmental impact associated with conventional sources are the challenges facing humanity [1]. The energy industry is facing decades of transformation. On a longer scale, nuclear fusion will be part of a catalog of more sustainable energy sources [2].

Field-reversed Configuration (FRC) has the advantages of complete axis symmetry, relatively simple structure, β~1 and so on [3]. Therefore, it is of great significance for the research of new fusion configuration, and the future exploration of miniaturization and economization of the fusion reactors [4, 5]. HUST Field-Reversed Configuration (HFRC) is a pre-research platform for field-reversed configuration research device based on plasma's colliding and merging, which is under development.

HFRC is composed of many subsystems such as magnets, vacuum, power, and diagnostics. It's important to have a unified control system considering the diversity and complexity of the subsystems. This paper describes the design and implementation of control system specially designed for HFRC.

HFRC SCADA (Supervisory Control And Data Acquisition) system includes the global control system, which coordinate all subsystems, and control systems in various subsystems such as the pulse power supply control system. It also offers a customizable and pluggable web based HMI for better operation. Users can design the HMI by simply dragging and dropping widgets in the browser.

At present, HFRC SCADA has been initially deployed in daily experiments of HFRC, which will provide valuable experiences for future control system design of large experimental device.

* Work supported by No. 2017YFE0301803 and No.51821005
† email address: wfy@hust.edu.cn

Design of HFRC SCADA

Micro Service HFRC SCADA adopted the decentralized model on the whole, and it can mainly be divided into two parts: central control system and subsystems. The main function of central control system is to coordinate the run of whole experimental device, and all subsystems need access plant operate network and accept the monitoring and the dispatch from central control system. The main subsystems are charger control system, pulse power control system, central timing control system, distributed timing control system and data acquisition system. Each subsystem offers different service to others. Fig.1 shows the overall structure of the whole system.

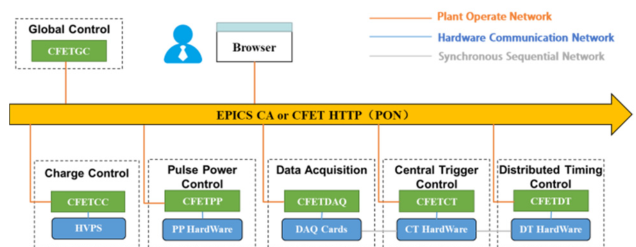


Figure 1: Overall structure of the whole system.

HFRC SCADA builds the whole system as a suite of small services, each running in its own process and are independently deployable. Adopting micro services makes HFRC SCADA simpler to deploy and understand, and minimizing the risk of change.

FSM (Finite State Machine) Pattern The discharge process of HFRC can be seen as a sequential transitions of states. HFRC SCADA uses FSM mode to control the flow of discharging and handle exceptions.

FSM is reliable, easy to understand, predictable and safe. There is only one state active at any one time, which drastically reduces the chance of unforeseen errors or unexpected behavior in the system.

Observer Pattern In observer pattern, any other object can be registered on an observed object, which will function as an observer. The first object, also called the subject, informs registered observers each time it is modified [6].

As HFRC SCADA is a distributed event handling system, observer pattern works well in implementing coordination of subsystems. Each subsystem can act as both an observer and a subject.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV017

CERN SCADA SYSTEMS 2020 LARGE UPGRADE CAMPAIGN RETROSPECTIVE

Lukasz Goralczyk†, Alexandros Foivos Kostopoulos, Brad Schofield, Jean-Charles Tournier
CERN, Geneva, Switzerland

Abstract

In this paper we report the experience from a large-scale upgrade campaign of SCADA control systems performed during the second LHC Long Shutdown at CERN. Such periodical upgrades are dictated by the ever evolving SCADA WinCC OA system and the CERN frameworks evolution used in those control systems. These upgrades concern: accelerator control systems, e.g. quench protection system, powering interlocks, magnet alignment; control systems devoted to accelerator facilities such as cryogenics, vacuum, gas and other global technical infrastructure systems as well as the CERN electrical distribution system.

Since there are more than 200 SCADA projects covering the CERN accelerator complex and technical infrastructure, any disruption requires careful coordination, planning and execution with process owners. Having gained experience from previous campaigns and reaching a new level of automation we were able to make visible improvements by shortening the required time and reducing the personnel required. Activities, lessons learned and further improvements are presented as well as a comprehensive statistical insight of the whole campaign.

INTRODUCTION

Software upgrades are an inherent process in modern computing which also applies for present-day SCADA (Supervisory Control And Data Acquisition) applications and the infrastructure in which they run. Upgrades are a necessity to keep systems secure, provide new features and avoid software obsolescence.

At CERN there are numerous industrial control systems in different domains such as machine protection, cryogenics, cooling and ventilation and the electrical distribution system. Together they account for a total of around 200 SCADA applications. These applications are often critical for the operation of CERN's accelerator complex and experiments. The large number and broad scope of these applications poses several challenges with respect to upgrades, a key challenge being the creation of an upgrade plan which does not interfere with the operation schedule.

At the end of 2018 CERN entered its second Long Shutdown (LS2) period that normally lasts around two years (in 2020 due to COVID-19 pandemic, it was extended). This was a perfect opportunity to perform a large-scale campaign to upgrade SCADA applications to the latest software packages, as well as to perform some housekeeping activities (e.g. server maintenance). In most cases, operational constraints are not as strict as is normally the case outside of long shutdown periods.

In this paper we give an insight into the upgrade campaign that took place in 2020. We start by giving details about the motivation behind the upgrades, planning goals and the scope. Differences with the previous campaign, carried out in 2017, will be also discussed. Improvements implemented from that campaign, as well as new enhancements are a topic of another chapter. We follow by presenting details about our experiences – the good and the bad. We conclude with proposals for further improvements.

For details about the SCADA service at CERN as well as software and infrastructure details, the reader is referred to [1].

MOTIVATION, SCOPE AND PLANNING

For the 2020 campaign the motivation was:

1. Siemens/ETM has decided to stop providing support for the version 3.15 of WinCC OA [2], the software used for most of the SCADA applications at CERN. It was, therefore, necessary to upgrade all the CERN WinCC OA-based SCADA systems to the latest version of WinCC OA.
2. New features that came with the updated JCOP [3] and UNICOS frameworks [4] depended on newer releases of WinCC OA.
3. Relaxed intervention restrictions given by the LS2 period.

Planning activities started several months before LS2 began. Similarly to the 2017 upgrade campaign all control domain representatives were interviewed to gain information about the planning restrictions, acceptable downtime and any additional requests. It was also an opportunity to present how the upgrades would be executed.

With this data gathered, an initial schedule was proposed and later agreed upon with the representatives. The upgrade calendar had to take into account some restrictions as: criticality, overlap with other upgrades, operation schedule and availability of experts.

Despite the long duration of LS2, the initial assumption was to finish all upgrades in less than 6 months, with the majority of applications upgraded in the first quarter of 2020. The COVID-19 pandemic forced us to put all pending upgrades on hold, abandon the initial schedule and, later, adjust it again conditioned by the COVID-19 protective measures (e.g. teleworking). This resulted in the upgrades being spread throughout the year.

† lukasz.goralczyk@cern.ch

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV018

LINAC-200 GUN CONTROL SYSTEM: STATUS AND PLANS

M. Nozdrin*, V. Kobets, V. Minashkin, A. Trifonov
Joint Institute for Nuclear Research, Dubna, Russia

Abstract

Due to the development of the global Tango-based control system for Linac-200 accelerator, the new electron gun control system software was developed. Major gun electronics modification is foreseen. Current gun control system status and modification plans are reported.

INTRODUCTION

Linac-200 accelerator [1] is the core of the new electron test beam facility in JINR. It's quite hard to obtain necessary beam quality with standalone control subsystems, so the new global control system based on Tango is being developed [2]. In the frame of this work the existing gun control system part based on a standalone PC should be exchanged to a new one (Tango device & corresponding client).

HARDWARE

Electron Gun

Triode MIT-designed DC gun is used [3, 4]. Gun is placed in the SF_6 filled tank (pressure 6 atm) for better electric durability. Gun and cathode parameters are given in Tables 1 and 2 correspondingly.

Table 1: Parameters of the Linac-200 Gun

Type	Thermionic
Max. energy	400 keV
Beam intensity (peak)	200 mA
Normalized emittance	8π mm mrad
Pulse duration	200 mA

Table 2: Parameters of the Linac-200 Gun Cathode

Type	Dispenser
Max. energy	W + 20% Ba, Ca & Al oxides
Diameter	8 mm ($S = 50\,\text{mm}^2$)
Working I & U range	6.5 V / 4 A to 8.8 V / 5 A
Lifetime	15000–20000 hours

Cathode is mounted at the end of the HV column — multisectional vacuum insulator separating the vacuumed beam chamber and the gas-filled gun tank. Gun electro-optical system consists of the extractor electrode and 15 anodes with forced resistive ($R = 200$ M) potential distribution (about 30 kV per gap).

First focusing anode voltage can vary in the range from 8 to 20 kV. Extractor electrode pulse is generated by Marx generator. Possible voltage is from −400 V (turnoff voltage) to 5 kV, pulse length—from 100 ns to 50 µs.

Schematic view of the Linac-200 electron gun control system structure is presented at Fig. 1. Controller board architecture is shown at Fig. 2. Gun optics and electronics scheme is shown at Fig. 3.

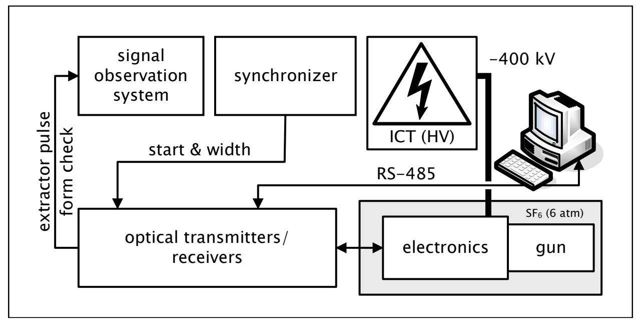


Figure 1: Linac-200 gun control system structure.

Gun Electronics

Cathode electronics is housed on the hot deck inside the tank. All cathode electronics assembly is "suspended" at a potential of −400 kV while the accelerator beamline is grounded.

Electronics consists of the following boards:

- Controller board acts as interface between the cathode electronics and the control computer.
- 50 kHz board supply transfiorms input voltage of 187 V / 50 Hz to 2 × 65 V / 50 kHz.
- Filament supply board sets the cathode filament current.
- Extractor pulser ensures the gun extraction pulse with necessary parameters.
- 1st focusing electrode voltage board is self-explanatory.

Controller Board

Board includes ATmega32 microcontroller, 4 DAC and 16 ADC channels, input register with 8 inputs, and output register with 8 outputs (TTL).

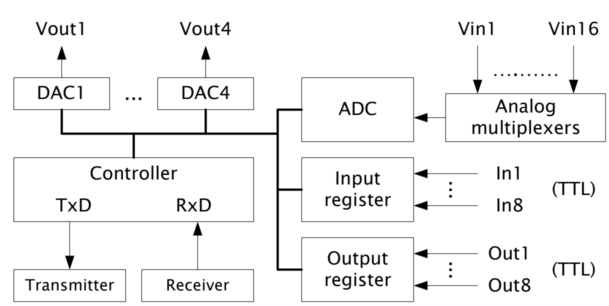


Figure 2: Controller board architecture.

* nozdrin@jinr.ru

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV019

PVEcho: DESIGN OF A Vista/EPICS BRIDGE FOR THE ISIS CONTROL SYSTEM TRANSITION

K.R.L. Baker*, I.D. Finch, G.D. Howells, A. Saoulis,
ISIS Neutron and Muon Source, Didcot, United Kingdom
M. Romanovschi, University of Manchester, United Kingdom

Abstract

The migration of the ISIS Accelerator Controls System from Vsystem to EPICS presents a significant challenge and risk to the day-to-day operations of the accelerator. An evaluation of potential options has indicated that the most effective migration method to mitigate against this risk is to make use of a 'hybrid' system running Vsystem and EPICS simultaneously. This allows for a phased porting of controls hardware from the existing software to EPICS. This work will outline the prototype Vsystem/EPICS bridge that will facilitate this hybrid operation, referred to as PVEcho. The bridge has been developed in Python, utilising existing communication from Vsystem to an MQTT broker developed as part of a previous project. Docker containers have been used for its development to create a test environment that allows the software to communicate with other active services currently used at ISIS.

INTRODUCTION

The ISIS Neutron and Muon Source [1] has been operated using Vista Control Systems' commercial product Vsystem [2], colloquially referred to as Vista, since 1998. Recently, a study was undertaken to evaluate its use against that of the Experimental Physics and Industrial Control System [3] (EPICS) at ISIS. The study determined that the control system should be migrated to EPICS [4]. One of the key benefits of the migration will be to promote collaboration with other facilities at Rutherford Appleton Laboratory, such as ISIS Instrumentation [5], Central Laser Facility [6] and Diamond Light Source [7], also using EPICS.

In order to minimise the impact on business-as-usual at the facility, a phased porting of control of hardware is the desired option for the transition. This requires the development of bridging software that will map approximately 33,000 channels that exist in Vsystem to an equivalent EPICS Process Variable (PV). This will allow a progressive migration of the operator control screens in the main control room (MCR) alongside a gradual transition of hardware without interrupting operator control. The current control screens are produced using Vsystem's Vdraw [8] tool but will be migrated to screens created using CS-Studio Phoebus [9] as part of the transition. Phoebus is the suite of applications that can be used to display screens as well as probe EPICS PVs.

The use of a bridge also elegantly permits some legacy hardware that cannot be converted to EPICS to still be run using Vsystem but using Phoebus control screens. PVEcho will serve as this bridge, responsible for replicating the behaviour of the current control system in EPICS.

* k.baker@stfc.ac.uk

PVEcho

Each component of hardware that comprises the accelerator controls system is associated with a group of unique channels through which value changes in the hardware can be communicated. During the migration, we will need to exactly replicate each of these channels that currently operate through Vsystem as an equivalent EPICS PV, including their value, alarm and display configuration. Each Vsystem channel and corresponding mirrored EPICS PV needs to be kept synchronised. This in turn will allow the control system to operate with either the Vsystem channel or the EPICS PV acting as the source of truth.

In the early stages of the transition, the majority of channels will still be operated through Vsystem while long-term EPICS equivalents are being developed. In this case, the source of truth will be the Vista channels and changes in their values and alarm limits will be broadcast from Vista to EPICS, handled by the vistatoepics (v2e) program. Once the control of hardware of specific channels has been ported to EPICS, the source of truth will transfer. Now, changes to the PV will be monitored and transferred from EPICS to Vista via MQTT [10] messages. This is handled by the epicstovista (e2v) program. The vistatoepics and epicstovista applications work in tandem to make up the PVEcho bridge, a visual representation of which can be seen in Fig. 1. The long-form names are used for descriptions of the applications, while the shorthand versions (v2e and e2v) are used for simplicity in the codebase and in diagrams. More details about the individual programs will be given in subsequent sections of this paper.

To track which channels have Vista or EPICS representing their true value, we have created a `PVMonitor` utility class to use in both programs. A list of channels to monitor are defined in a file which the `PVMonitor` regularly checks for changes (in our case once per second). When a change is noted, the monitor determines which channels have been added or removed relative to the file's previous state, and starts or stops tracking those channels accordingly. This method allows a lot of control and flexibility over the channels to be replicated in EPICS, allowing the transition of individual channels at a time. As the same class is used in both applications, "channel" may be substituted for PVs when referring to epicstovista, where the same approach is used.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV020

DIGITISATION OF THE ANALOGUE WAVEFORM SYSTEM AT ISIS

W. A. Frank*, B. R. Aljamal†, R. Washington
STFC Rutherford Appleton Laboratory, Didcot, Oxfordshire, UK

Abstract

The Analogue Waveform System (AWS) at the ISIS Neutron and Muon Source is a distributed system that allows operators to select and monitor analogue waveforms from equipment throughout the facility on oscilloscopes in the Main Control Room (MCR). These signals originate from key accelerator systems in the linear accelerator and synchrotron such as the ion source, magnets, beam diagnostics, and radio frequency (RF) systems. Historical data for ISIS is available on the control system for many relevant channels. However, at present, to avoid disrupting the oscilloscope displays in the MCR, only an hourly image capture of the AWS waveforms is stored. This is largely inadequate for potential data-intensive applications such as anomaly detection, predictive maintenance, post-mortem analysis, or (semi-)automated machine setup, optimization, and control. To address this, a new digital data acquisition (DAQ) system is under development based on the principle of large channel count, simultaneous DAQ. This paper details the proposed architecture of the system and the results of initial prototyping, testing, and commissioning.

INTRODUCTION

The Analogue Waveform System has been a key part of accelerator operations since the inception of the ISIS Neutron and Muon Source in 1984 [1]. At present, it is a distributed analogue waveform switching system that allows operators to select and monitor signals from equipment throughout the facility from the Main Control Room (MCR).

Recently the particle accelerator community has been turning to the increasingly mature fields of machine learning and data science to help manage the inherent complexity of these facilities [2]. Therefore, to modernise the current system in order to meet the data needs of these techniques, a new digital data acquisition system (DAQ), called the Digitised Waveform System (DWS), is under development. The new system aims to increase the signal capacity, improve flexibility, as well as signal integrity of the system. Further benefits are expected from the ability to store and archive descriptive statistics of the waveforms and raw waveforms for specific applications.

EXISTING AWS SYSTEM

The AWS consists of three main cable trunks. Each trunk can, in principle, connect any number of ISIS Controls CPCI System (CPS) crates [3] using a daisy chain topology. Each CPS crate provides 32 analogue inputs to the system. However, at most six signals from all the CPS crates connected on a single trunk can be multiplexed to a bank of Tektronix TDS3014B oscilloscopes in the MCR.

The CPS crates contain a Kontron CP3004-SA CPU board, Pickering PXI switching matrix modules (40-531-022/40-531-023), a custom six channel fully differential amplifier board, and a seven segment I/O display board. Inter-crate communication is over the CompactPCI [4] backplane. The direct analogue trunks provide negligible signal transmission latency but limit the flexibility of the system and make expanding the signal capacity difficult. The fast update rate of the oscilloscopes ensure real-time capture of each 50 Hz acceleration cycle.

There are currently 13 AWS CPS crates installed across the facility, providing 416 inputs to the system. Control and status monitoring of the AWS as well as triggering from the ISIS Timing System is provided by the ISIS Control System [5], based on the VSystem SCADA/HMI toolbox from Vista Control Systems [6] .

DWS SYSTEM OVERVIEW

Hardware

Recent technological developments have brought down the cost of high-performance and high channel count digitisers. This has made possible the option to replace the multiplexed analogue approach with a largely digital paradigm consisting of network connected digitisers. A similar one-digitiser-per-device approach with the DAQ placed as close to the accelerator device as possible has recently been proposed and implemented at the Facility for Antiproton and Ion Research (FAIR) [7].

For the DWS, the selected DAQ hardware is the ACQ2106 carrier units from D-TACQ Solutions fitted with two or three ACQ482 ELF modules [8]. These digitisers provide excellent analogue and digital performance at a competitive cost per channel. In addition, it has built-in EPICS support, providing extensive monitoring, supervisory and control features that reduces integration efforts for the new EPICS based control system at ISIS [9]. Each ACQ482 has 16 differential inputs with an analogue bandwidth of 10 MHz and ADC clock speeds up to 80 MSPS. The bandwidth is sufficient to digitise the ≤1 MHz analogue bandwidth of the existing AWS. The signals from the AWS are connected to the VHDCI input connectors of the ACQ482 with 32 channel dual pin LEMO 1U, 19" panels. A total of nine ACQ2106 units will cover the existing system capacity of 416 channels, with the option to install additional units to cover any future capacity requirements.

The Rear Transition Module (RTM-T) in the ACQ2106 units connects to the DAQ server fitted with AFHBA404 PCI Express Host Bus Adapters via LC terminated OM3

* william.frank@stfc.ac.uk
† basil.aljamal@stfc.ac.uk

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV021

UPGRADING THE NATIONAL IGNITION FACILITY'S (NIF) INTEGRATED COMPUTER CONTROL SYSTEM TO SUPPORT OPTICAL THOMPSON SCATTERING (OTS) DIAGNOSTIC

A. Barnes, A. Awwal, L. Beaulac, B. Blackwell, G. Brunton, K. Burns, J. Castro Morales, M. Fedorov, R. Lacuata, R. Leach, D. Mathisen, V. Miller Kamm, S. Muralidhar, V. Pacheu, Y. Pan, S. Patankar, B. P. Patel, M. Paul, R. Rozenshteyn, R. Sanchez, S. Sauter, M. Taranowski, D. Tucker, K. C. Wilhelmsen, B. Wilson, H. Zhang
Lawrence Livermore National Laboratory, Livermore, USA

Abstract

With the ability to deliver 2.1 MJ of 500 TW ultraviolet laser light to a target, the National Ignition Facility (NIF) is the world's most energetic laser. This combination of energy and power allows the study of materials under conditions similar to the center of the sun. On fusion ignition experiments, plasma generated in the interior of the target shell can detrimentally impact the implosion symmetry and the resulting energy output. We are in the final stages of commissioning a significant new diagnostic system that will allow us to better understand the plasma conditions and improve our symmetry control techniques. This Optical Thompson Scattering (OTS) system consists of two major components: a probe laser beamline capable of delivering a world first 1 J of energy at 211 nm, and a diagnostic that both reflects the probe laser into the target and collects the scattered photons. Between these two components, the control system enhancements required integration of over 450 components into the existing automation suite. This talk will provide an overview of the system upgrade approach and the tools used to efficiently manage and test changes to both our data and software.

BACKGROUND INFORMATION

The purpose of the NIF is to continue research into nuclear fusion, specifically laser driven inertial confinement fusion (ICF). To accomplish this, NIF uses 192 lasers. When combined, the lasers can deliver up to 2.1 MJ of energy at 351 nm. For a sense of scale, the NIF building containing the lasers stands four stories tall and can fit three American football fields on the roof.

Responsibility for driving the NIF through its experiments lies with the Integrated Computer Control System (ICCS). At the lowest level, ICCS provides direct control of devices for manual operations during maintenance and troubleshooting tasks. On top of that, it provides multiple layers of automation which allow less than a dozen operators to configure and control more than 66,000 control points on over 2,300 processors and embedded controllers through the course of a shot cycle.

Behind the scenes ICCS has chosen a data driven architecture to keep things manageable. A predominantly Java code base of over 3 million lines of code provides the basic implementation of each control type, the hooks to communicate via Common Object Request Broker Architecture (CORBA) protocols, and the automation frameworks. Going along with this, an Oracle database stores all information needed to instantiate the control points, automation scripts, and the experiment configurations.

OTS LASER SYSTEM UPGRADE

As part of the NIF team's continued effort to improve our understanding of the plasma conditions, we recently deployed a diagnostic capable of measuring OTS from the imploding target. This method significantly improves the precision at which we can measure the plasma's temperature, density, and flow velocity. From this we'll gain a better understanding of how the laser interacts with the plasma, and how we can further reduce unwanted interactions. This in turn will lead to even better symmetry during the implosions and higher fusion yields. [1]

This upgrade consists of two large scale pieces: the OTS Laser (OTSL) and the OTS Diagnostic (OTSL-D). Unlike previous upgrades such as the Advanced Radiographic Capability (ARC), OTSL did not reuse any of the existing NIF beam path. Instead, we built a new room in NIF's switchyard 1 to house the front end and amplification components. The laser light follows a new beam path into the target area. Just outside the target chamber wall, we convert the laser light from the front end's 1053 nm to 211nm.

OTSL-D consists of two primary components. Frist you have the diagnostic package consisting of a spectrometer and alignment cameras. This package was specifically designed to work with either OTSL at 211 nm or a standard NIF 351 nm beamline as the probe laser. This allows us to install the diagnostic in multiple locations and inspect the target from multiple angles. In addition to the diagnostics, OTSL-D contains a separate set of alignment mirrors and cameras in a laser launch package. Due to the location where OTSL enters the target chamber, it cannot fire directly into the hohlraum's laser entrance holes. To get around this, we reflect OTSL off the laser launch mirrors and into the target.

OTS Software Upgrade Scope

To support the OTSL system, we needed to modify every layer of the ICCS system. Down at the Front-End Processor (FEP) layer, we made code changes to support multiple new device types, such as energy diagnostics,

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV024

VSCODE-EPICS, A VSCODE EXTENSION TO ENLIGHTEN YOUR EPICS CODE

Victor Nadot†, Alexis Gaget, Francis Gohier, Françoise Gougnaud, Paul Lotrus, Stéphane Tzvetkov, *IRFU, CEA, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France

Abstract

vscode-epics is a Visual Studio Code extension developed by CEA Irfu that aims to enlighten your EPICS code. The development was originally initiated by one of our students in 2017.

This module makes developer life easier, improves code quality and helps to standardize EPICS code.

It provides syntax highlighting, snippets and header template for EPICS files and snippets for WeTest[1].

vscode-epics module is based on Visual Studio Code language Extension and it uses basic JSON files that make feature addition easy.

The number of downloads increases, version after version, and the various feedbacks we receive motivate us to strongly maintain it for the EPICS community. Since 2019, several other laboratories of the EPICS community have participated in the improvement of the module and it seems to have a nice future (linter, snippet improvements, specific language support, …).

The module is available for free on Visual Studio Code marketplace[2] and on EPICS extension GitHub[3]. CEA Irfu is open to bug notifications, enhancement suggestions and merge requests, in order to continuously improve vscode-epics.

FEATURES

The syntax highlighting (Figure 1) provides the function-ality to detect the EPICS keywords for a large scope of EP-ICS files (“.db”, “.template”, ".substitutions”, “.cmd”, “.st”, “.proto”, “.c”). As a concrete example, record types, record fields, macros and comments are supported for “.db” files.

Figure 1: With and without syntax highlighting.

Snippets are yet an even more powerful feature of the extension (see Figure 2). It makes it possible to generate any records with the basic EPICS fields. They are very val-uable for new EPICS developers.

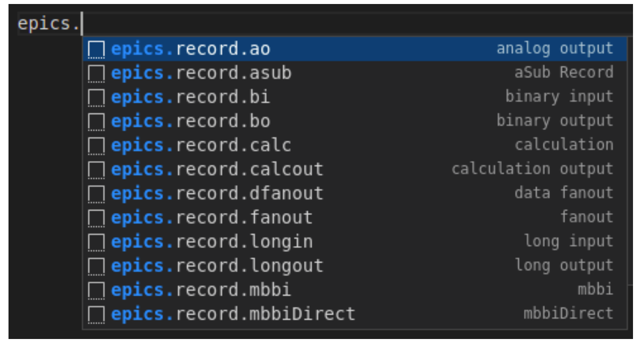


Figure 2: Scrollable list of available snippets.

Another interesting feature is the header template gener-ation (see Figure 3). Largely inspired from our collabora-tion with ESS, the headers are composed of the following fields:

1. “file”: the file name is automatically written at the top of the header. This is useful when you use substitution files that generate a large “.db” file with all your templates inside. Thus, you can easily see the different template demarcations in the generated “.db” file.
2. “author”: the author and company references.
3. “description”: a short presentation describing the file scope.
4. “macros” :in order to improve code readability, it is strongly advised to add the list of the macros used in the file with a short description. They are split in two types. Mandatory: they are required to be defined at higher level to use the template. Optional: they have default values so they are not required to be defined at higher level to use the template;

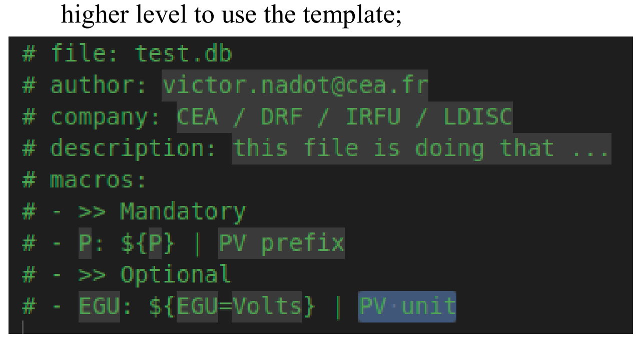


Figure 3: File header provided by vscode-epics extension.

More snippet can be added as long as the language you are using is part of the EPICS extensions[4]. For instance WeTest, a software developed by CEA/Irfu to automate acceptance tests and shared with EPICS extension, has snippets integrated to epics-vscode module.

Besides making developer life easier, vscode-epics extension improves your code quality and code homogeneity

* † victor.nadot@cea.fr

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV025

TangoGraphQL: A GraphQL BINDING FOR TANGO CONTROL SYSTEM WEB-BASED APPLICATIONS

J.L. Pons, European Synchrotron (E.S.R.F), Grenoble, France

Abstract

Web-based applications have seen a huge increase in popularity in recent years, replacing standalone applications. GraphQL provides a complete and understandable description of the data exchange between client browsers and back-end servers. GraphQL is a powerful query language allowing API to evolve easily and to query only what is needed. GraphQL also offers a WebSocket based protocol which perfectly fits to the Tango event system. Lots of popular tools around GraphQL offer very convenient way to browse and query data. TangoGraphQL is a pure C++ http(s) server which exports a GraphQL binding for the Tango C++ API. TangoGraphQL also exports a GraphiQL web application which allows to have a nice interactive description of the API and to test queries. TangoGraphQL has been designed with the aim to maximize performances of JSON data serialization, a binary transfer mode is also foreseen.

INTRODUCTION

Today, at the ESRF [1], we use mainly Java standalone applications for the accelerator control system. These applications are built on top of the Java Swing ATK framework [2] and Tango java APIs. Today, regarding GUI technologies, we see almost only development around web technologies such as React, Angular, Vue.js, Bootstrap, Material UI, etc... It is natural that we migrate our GUIs to web based applications. Java ATK is based on the Model View Controller model. React (Facebook) offers a very convenient way to implement this model using hooks. GraphQL [3], initially developed by Facebook in 2012, was moved as open source to the GraphQL foundation. A JavaScript Tango Web ATK built on top of React and GraphQL is currently under development at the ESRF. This framework is designed in order to ease as much as possible the migration of our Java applications.

ARCHITECTURE

MVC Model using React

React function components offer hooks that can be used to implement the MVC model. The key idea is to use the state hook and to pass the setState function handle as a dispatcher to the model. A layoutEffect hook handles the subscription in the listener list of the model as shown in Fig. 1.

The model (the GraphQL client) makes access to Tango devices using the TangoGraphQL server either through basic HTTP requests or through WebSocket as shown in Fig. 2.

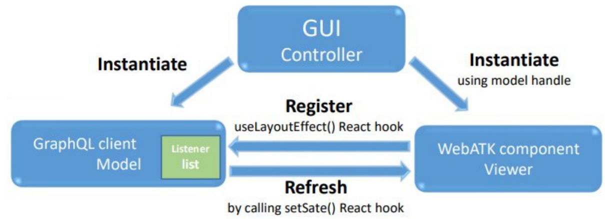


Figure 1: MVC using React.

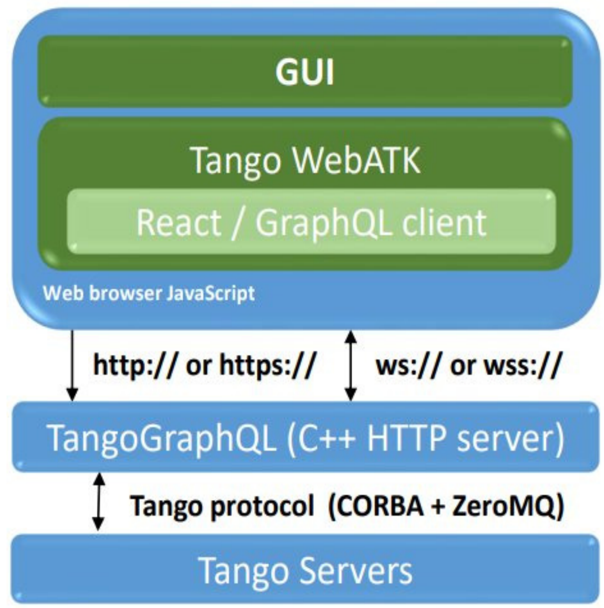


Figure 2: Architecture.

GRAPHQL

GraphQL vs REST

Compared to a REST API, GraphQL is a true query language allowing clients to query only what is needed in a single HTTP request. GraphQL also provides an introspection system giving information about the supported schema. GraphQL uses GraphQL query to perform introspection. The GraphQL foundation provides a web application called GraphiQL, based on this introspection system, enabling users to write query using modern tools such as completion, syntax checking and documentation browsing. It uses the Tango GraphQL schema definition [4] to provide all these features to the Tango GraphQL API. TangoGraphQL C++ server also exports a GraphiQL interface.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV026

INTEGRATING OPC UA DEVICES IN EPICS

R. Lange†, ITER Organization, 13067 St. Paul lez Durance, France
R. A. Elliot, K. Vestin, European Spallation Source, 221 00 Lund, Sweden
B. Kuner, C. Winkler, Helmholtz-Zentrum Berlin, 14109 Berlin, Germany
D. Zimoch, Paul-Scherrer-Institut, 5232 Villigen PSI, Switzerland

Abstract

OPC Unified Architecture (OPC UA) is an open platform independent communication architecture for industrial automation developed by the OPC Foundation. Its key characteristics include a rich service-oriented architecture, enhanced security functionality and an integral information model, allowing to map complex data into an OPC UA namespace.

With its increasing popularity in the industrial world, OPC UA is an excellent strategic choice for integrating a wealth of different COTS devices and controllers into an existing control system infrastructure. The security functions extend its application to larger networks and across firewalls, while the support of user-defined data structures and fully symbolic addressing ensure flexibility, separation of concerns and robustness in the user interfaces.

In an international collaboration, a generic OPC UA support for the EPICS control system toolkit has been developed. It is used in operation at several facilities, integrating a variety of commercial controllers and systems. We describe design and implementation approach, discuss use cases and software quality aspects, report performance and present a roadmap of the next development steps.

INTRODUCTION

Open Platform Communications Unified Architecture (OPC UA) is an open standard architecture intended to improve and expand interoperability in the Industrial Automation industry. It is a machine-to-machine communication protocol for industrial automation developed by the OPC Foundation [1] and released in 2008.

While its predecessor, OLE for Process Control (OPC; re-branded as OPC Classic) was developed by Microsoft and used a transport layer based on proprietary Microsoft software (e.g., OLE, DCOM), OPC UA focuses on platform independence and uses well-known open standards like TCP and TLS.

Over the last years, OPC UA has become increasingly popular in the world of Industrial Automation. Across all vendors, framework and device types, it is a key word for interoperability and integration, boosted by the OPC Foundation's certification program that ensures high levels of compliance.

OPC UA ARCHITECTURE

Features

OPC UA integrates all functionality of the OPC Classic specifications into a single extensible framework, providing (see [1]):

- Functional equivalence: all OPC Classic specifications are mapped to Unified Architecture.
- Platform independence: hardware and operating system portability covers everything from embedded systems to cloud-based infrastructure.
- Security: encryption, signing, authentication and auditing allow messages to be transmitted securely with verifiable integrity.
- Extensibility: new features can be added without affecting existing applications.
- Information modelling: a framework helps defining complex information.

Core Concepts

The client-server communication model of OPC UA is layered: on top of a *transport*, which can be secured, the client opens a *session* to a server. Within that session, every piece of information is an *item* that can be written or read. Items are uniquely identified by a *nodeID*, consisting of a *namespace* number and an *identifier*, which can be numerical or a name string. To overcome the disadvantage of having to look up nodes by their name with every access, the client can *register* nodes with the server, to allow optimizing their name resolution.

Each item has a typed value, which can be of a basic data type, an array thereof, a union, or a structure consisting of multiple named elements, which are themselves of basic type, arrays, unions or structures.

Opening *subscriptions* in the session allows monitoring items for changes in their values. The subscription has a configurable *publishing period*, but any monitored item in the subscription can use a different *sampling period* for updating the value from the underlying device. For values that are sampled faster than their subscription is published, data loss can be avoided by defining a server-side queue.

OPC UA *methods* are basically remote procedure calls. They allow the client to send parameters (which can be of structured data types) and can return results to the client. All handshake and synchronization is part of the protocol specification and done within the client and server libraries.

† ralph.lange@iter.org

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV027

THE EVOLUTION OF THE DOOCS C++ CODE BASE

L. Fröhlich*, A. Aghababyan, S. Grunewald, O. Hensler, U. F. Jastrow, R. Kammering, H. Keller†, V. Kocharyan, M. Mommertz, F. Peters, A. Petrosyan, G. Petrosyan, L. Petrosyan, V. Petrosyan, K. Rehlich, V. Rybnikov, G. Schlesselmann, J. Wilgen, T. Wilksen,
Deutsches Elektronen-Synchrotron DESY, Germany

Abstract

This contribution traces the development of DESY's control system DOOCS from its origins in 1992 to its current state as the backbone of the European XFEL and FLASH accelerators and of the future Petra IV light source. Some details of the continual modernization and refactoring efforts on the 1.5 million line C++ code base are highlighted.

INTRODUCTION

DOOCS [1, 2] started out at DESY in 1992 as a control solution for vacuum devices – ion getter pumps and similar equipment – for superconducting cavity test stands. Later it was ported to the HERA [3] proton storage ring to replace an older predecessor. It was built around Sun Microsystem's remote procedure call protocol (*SunRPC*) that continues to be used today in many well-known services such as the Network File System (NFS) under the newer name Open Network Computing RPC (*ONC RPC* [4]).

At the time, object-oriented programming was quickly establishing itself as the dominant programming paradigm, which lead to the new system being called the "distributed object-oriented control system", DOOCS. It was implemented in C++, the natural choice for developing reliable software that could use high-level abstractions, work with limited resources, and access hardware efficiently. Java, the next "big" language to champion object-orientation, would not be released to the public until 1994/1995 [5].

The C++ of the year 1992 was quite different from modern versions of the language. It was six years before the first ISO standardization of the language [6], and many features taken for granted today were still in their infancy: Templates, namespaces, and exception handling had just been specified [7] but were not or only partially available on the compilers of the time. The standard template library (STL) and even the `bool` type would not be standardized until 1998. It is therefore only natural that early DOOCS sources, although heavily using classes and inheritance, look more like low-level C than modern C++ from today's perspective.

These first years established the backbone of DOOCS and formed many of the conventions that shaped the development of the code over the following two decades. Although the code was continually extended and maintained, its basic style changed relatively little until some years after the introduction of C++11 [8]. Although the new standard could not be adopted for the core libraries until 2018 due to lack of compiler support on the Solaris platform, it lead to renewed interest in C++ and modern programming styles and attracted new developers. Gradually, more and more effort was put into the modernization of the code base. We are going to highlight a few of the changes made during this ongoing modernization effort below. For orientation, we first give a brief overview of the DOOCS code base.

CODE ORGANIZATION

DOOCS consists of multiple libraries, tools, and servers, the biggest part of which is written in C++[1]. Two libraries form the core of almost every DOOCS application:

- The DOOCS client library (*clientlib*) provides the basic functionality to list `names()` from the DOOCS namespace and to send `get()` and `set()` requests over the network. It also offers interoperability with other control systems such as EPICS [10] and TINE [11, 12] by exposing some of their native functionality via the DOOCS API.
- The DOOCS server library (*serverlib*) provides the building blocks for a DOOCS server which accepts requests from the network. It contains classes for *properties* of various data types and allows instantiating these properties as members of *locations* with user-defined functionality. It also handles archiving, configuration management and related tasks.

These two libraries are complemented by approximately one hundred other DOOCS-related libraries of various purposes, ranging from support for specific hardware like cameras over interfaces to data acquisition (DAQ) systems to high-level algorithms for particle tracking.

Most of the DOOCS applications are servers. They connect hardware devices such as beam position monitors or vacuum pumps to the network, process and archive data, run feedback loops, and execute complex algorithms for advanced data evaluation. Currently, our repositories contain source code for more than 500 different server types. For most of these, multiple instances are running at one or more of DESY's accelerator facilities. Between libraries and servers, the C++ code base consists of ~8000 source files with a total of ~1.5 million lines of code[2].

Figures 1 and 2 show the development of the number of lines of code in the client- and serverlib over time. It is worth noting that the clientlib was dominated by C code between

* lars.froehlich@desy.de
† retired

[1] Notable exceptions are the JDOOCS client library for Java and tools based on it such as the graphical user interface builder *jddd* [9]. Client libraries for Python, Matlab, and LabView also exist and have spawned a multitude of tools in these languages.

[2] We count lines of code excluding comments and blank lines using the `cloc` [13] utility.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV030

APPLICATION OF EPICS SOFTWARE IN LINEAR ACCELERATOR

Yuhui Guo†, Nian Xie, Rui Wang, Haitao Liu, Baojia Wang
Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou, China

Abstract

The institute of modern physics (IMP) has two sets of linear accelerator facilities, they are CAFe (China ADS front-end demo linac) and LEAF (Low Energy Accelerator Facility). The Main equipment of LEAF facility consists of ion source, LEBT (Low Energy Beam Transport), RFQ (Radio Frequency Quadrupole) and some experiment terminals. Compare with LEAF, CAFe equipment has more and adds MEBT (Medium Energy Beam Transport) and four sets of superconducting cavity strings at the back end of RFQ. In the process of commissioning and running linac equipment, The EPICS Archiver application and Alarm system are used. According to the refined control requirements of the facility sites, we have completed the software upgrade and deployment of the archiver and alarm systems. The upgraded software system have made the operation of linac machines more effective in term of monitoring, fault-diagnostic and system recovery, and becomes more user-friendly as well.

INTRODUCTION

The CAFe is a prototype of ADS proton superconducting linear accelerator. It mainly includes a compact ECR (Electron Cyclotron Resonance) ion source, a low energy beam transport LEBT section, a radio frequency quadrupole acceleration system RFQ , a MEBT, 4 sets of CM superconducting cavity strings, a HEBT (High Energy Beam Transport) and a beam dump with the function of measuring current intensity and absorbing the energy from ion beam [1,2]. The layout of CAFe facility is shown in Fig. 1.

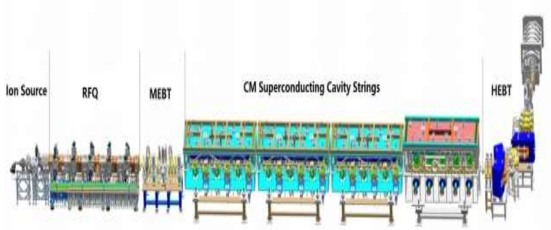


Figure 1: The layout of the CAFe facility.

The CAFe facility can provide a high power beam with the beam intensity of several mA. At the same time, CAFe, as a new research device, needs to do some research on the operation mode of the machine.

The LEAF contains a 45 GHz fourth-generation superconducting high-charge state ECR ion source, a 300 kV high-voltage platform, an advanced RFQ heavy ion accelerator capable of accelerating a variety of ions, and a DTL energy regulator. LEAF is a research facility of the low-energy, high-current and high-charged heavy ion [3]. The layout of the LEAF is shown in Fig. 2.

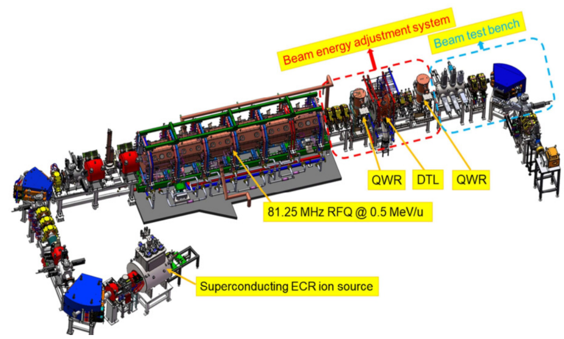


Figure 2: The layout of the LEAF facility.

LEAF can provide pulse (beam energy range of 0.1-20 MeV) and continuous beam with high beam intensity, high charge state and many kinds of ions. The core parts of the LEAF are superconducting high charge ECR ion source and RFQ accelerator. They are the most key equipment of the front-end injector for the next generation large heavy ion accelerator. Therefore, the development of the LEAF will build a good foundation for the development of the next generation high-power high current heavy ion accelerator.

During the commissioning and operation of the LEAF and CAFE accelerator systems, the upper-level applications have a similar requirement for both systems. For example, the alarm system needs to monitor whether values of the defined PV variables exceed their safety threshold ranges, and the data archiving system needs to store the historical relevant PV data from the systems for fault location diagnosis and error analysis.

For the alarm system, the BEAST software package is used for the LEAF, which is mainly composed of AlarmConfigTool, Alarm Server, JMS (Java Message Server) and Alarm Client GUI. In the control system of the CAFe facility, we use the alarm module from the EPICS Phoebus software to upgrade the BEAST-based alarm system. Compared with ActiveMQ message publishing technology, Kafka with its own alarm message publishing technology has much higher data throughput and is more suitable for processing large-scale real-time data streams.

For the data archiving system, we used the Channel Archiver and Archiver Appliance software packages in the EPICS software tool to build two data archiving systems with redundant functions. The Channel Archiver software package was released earlier, and its client software is relatively rich. The Archiver Appliance is a new data archiving system and adopts a multi-level storage method. It also provides a Web front-end management interface, allowing

†Email address: guoyuhui@impcas.ac.cn

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV031

THE DEPLOYMENT TECHNOLOGY OF EPICS APPLICATION SOFTWARE BASED ON DOCKER

R. Wang†, Y. H. Guo, B. J. Wang, N. Xie, IMP, Lanzhou 730000, P. R. China

Abstract

StreamDevice, as a general-purpose string interface device's Epics driver, has been widely used in the control of devices with network and serial ports in CAFe equipment. For example, the remote control of magnet power supply, vacuum gauges and various vacuum valves or pumps, as well as the information reading and control of Gauss meter equipment used in magnetic field measurement. In the process of on-site software development, we found that various errors are caused during the deployment of StreamDevice about the dependence on software environment and library functions, which because of different operating system environments and EPICS tool software versions. This makes StreamDevice deployment very time-consuming and labor-intensive. To ensure that StreamDevice works in a unified environment and can be deployed and migrated efficiently, the Docker container technology is used to encapsulate its software and its application environment. Images will be uploaded to an Aliyun private library to facilitate software developers to download and use. At the same time, some technical implementations, to ensure the safety of containers and host, for communication security between containers and system resource management should be taken on our host. In the future, the large-scale efficient and stable deployment of StreamDevice software can be realized by pulling images on the server installed with Docker, avoiding a lot of repetitive work and greatly saving the time of control technicians.

INTRODUCTION

CAFe equipment, the CiADS superconducting linear accelerator prototype, was built in 2018 to validate the superconducting linear accelerator for CiADS with 10 mA continuous beam current. The equipment consists of the ion source, low-energy transmission section, RFQ, medium-energy transmission section, superconducting linear accelerator, high-energy transmission section, and beam terminal collector. The equipment layout is shown in Fig. 1. The overall parameters of the equipment include the beam intensity of 10mA, the beam energy of 25-40MeV, the RF frequency of 162.5MHz, as well as the temperature of 4.5k [1-3].

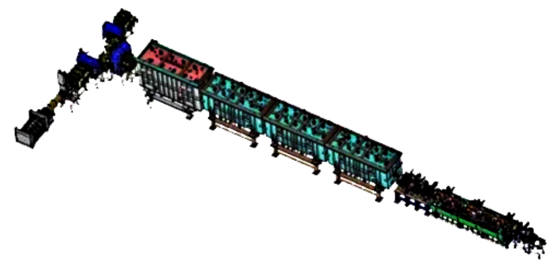


Figure 1: Layout of CAFe superconducting proton linear accelerator.

At present, EPICS is mostly used in the CAFe equipment control software of the Institute of Modern Physics, Chinese Academy of Sciences. The experimental physics and industrial control software adopt the standard distributed control system model and run stably. The device driver is developed with unified system architecture. It has gradually replaced LabVIEW as the mainstream software architecture and development tool for the accelerator control system in China and abroad. StreamDevice module is needed to realize serial communication equipment and drive control, which has the interface of the asynchronous drive module (ASYN) and can provide equipment support for EPICS [4].

With the upgrading of CAFe equipment, the servers have also been updated. In practice, it is found that there are often encountered unknown errors in the installation of EPICS on each new server. A lot of manpower and time will be paid to find the cause of the problems and solve methods. But the solutions do not possess universality. In order to improve the deployment efficiency and reduce the difficulty of application migration, Docker [5] is used to encapsulate EPICS + StreamDevice to assure the unification of the operating environment on different machines. At the same time, a series of security problems existing in the current container should be optimized and improved.

FUNCTIONALITY AND REQUIREMENTS

An asynchronous drive module (ASYN) interface was integrated with StreamDevice, which supports serial ports (RS485, RS232), IEEE-488 (GPIB or HP-IB), and Ethernet interfaces. It can realize the communication between serial ports and Gaussian power supply. The communication rules are specified by writing protocol files, and PV information is defined by DB files [6]. The result of the EPICS reads and sets the equipment information was achieved. Because the StreamDevice, a model of EPICS, was used to develop of I/O IOC for power and Gauss meter.

StreamDevice can analyze web pages by regular expressions, as well as read this important information in real

† wangrui@impcas.ac.cn

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV032

DESIGN OF A COMPONENT-ORIENTED DISTRIBUTED DATA INTEGRATION MODEL

Z. G. Ni†, L Li, J. Luo, J. Liu, X. W. Zhou, Institute of Computer Application, China Academy of Engineering Physics, Mianyang City, China

Abstract

The control system of large scientific facilities is composed of several heterogeneous control systems. As time goes by, the facilities need to be continuously upgraded and the control system also needs to be upgraded. This is a challenge for the integration of complex and large-scale heterogeneous systems. This article describes the design of a data integration model based on component technology, software middleware (The Apache Thrift*) and real-time database. The realization of this model shields the relevant details of the software middleware, encapsulates the remote data acquisition as a local function operation, realizes the combination of data and complex calculations through scripts, and can be assembled into new components.

INTRODUCTION

Large scientific experimental devices generally consist of dozens of heterogeneous systems, each of which is also an independent control system. The control system architecture of a typical large scientific facilities is a two-tier architecture consisting of a monitoring layer of the network structure and a control layer of the fieldbus structure. The monitoring layer is deployed on the virtual server and the console computer to provide centralized operations for control, status, and data storage. The control layer is deployed on the virtual server or embedded controller to provide real-time collection and control of the device.

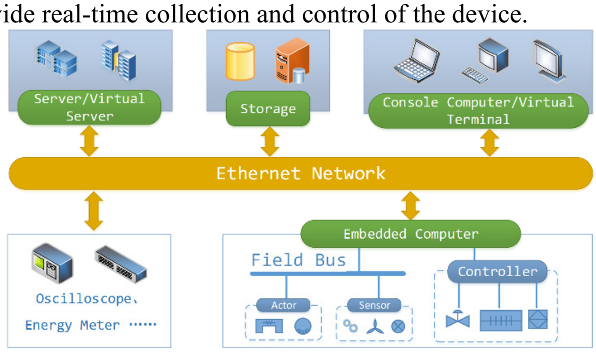


Figure 1: The control system architecture of the typical large scientific facilities [1].

As provided in Fig. 1, the monitoring layer is a software system based on Ethernet structure. It consists of a network switching system, a server system, and a console computer. It provides system services and human-machine interfaces for the facility control system, including control, monitoring, and data management.

At present, the integrated control system mainly used by large-scale laboratories and scientific research institutions around the world is EPICS or TANGO. In the automation industry, excellent instrument manufacturers will not only provide corresponding secondary development libraries, but also corresponding EPICS interfaces or TANGO Devices.

EPICS[2] is a set of software tools and applications which provide a software infrastructure for use in building distributed control systems to operate devices such as Particle Accelerators, Large Experiments and major Telescopes. Such distributed control systems typically comprise tens or even hundreds of computers, networked together to allow communication between them and to provide control and feedback of the various parts of the device from a central control room, or even remotely over the internet.

Tango[3] is an Open Source solution for SCADA and DCS. Open Source means you get all the source code under an Open Source free licence (LGPL and GPL). Supervisory Control and Data Acquisition (SCADA) systems are typically industrial type systems using standard hardware. Distributed Control Systems (DCS) are more flexible control systems used in more complex environments. Sardana is a good example of a Tango based Beamline SCADA.

Of course, many earlier control system software was built using CORBA software middleware, or implemented using the TCP custom protocol.

QUESTION

A few years later, the scientific experimental device will inevitably bring about the continuous upgrading of the system. How to adapt the control system and software to this change is a great challenge. The control system software constructed first needs to have a certain degree of scalability. Secondly, as technology evolves, the control system software needs to have a certain degree of compatibility; the early and current systems need to communicate and communicate, how to realize the communication between the early and current systems is a technical problem, which is a problem that this article needs to solve.

Another feature of the scientific experimental device is that the operator's demand is unstable. Users will constantly adjust their requirements based on their experience. We have to modify the code, compile, and test run, and the debugging time for software developers is very short, so the skills of software technicians are very high. If you can adapt to changes in requirements with zero programming, this is a great thing.

Therefore, we propose a component-oriented distributed data integration model, which is used to construct an implementation method of data acquisition and control from the device to the user interface.

In the following chapters, we first introduce the technologies that may be involved.

† email address: drops.ni@caep.cn.

18th Int. Conf. on Acc. and Large Exp. Physics Control Systems ICALEPCS2021, Shanghai, China JACoW Publishing
ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV033

WEB CLIENT FOR PANIC ALARMS MANAGEMENT SYSTEM

M.Nabywaniec*, M.Gandor, P.Goryl, Ł.Żytniak S2Innovation, Cracow, Poland

Abstract

Alarms are one of the most important aspects of control systems. Each control system can face unexpected issues, which demand fast and precise resolution. As the control system starts to grow, it requires the involvement of more engineers to access the alarm's list and focus on the most important ones. Our objective was to allow users to access the alarms fast, remotely and without special software. According to current trends in the IT community, creating a web application turned out to be a perfect solution. Our application is the extension and web equivalent to the current Panic GUI application. It was developed to be integrated with EPICS and TANGO control systems. It allows constant remote access using just a web browser which is currently present on every machine including mobile phones and tablets. In that paper the status of application will be presented as well as key features.

ALARM SYSTEM IN TANGO CONTROL SYSTEM

TANGO Control System is object-oriented control system based on CORBA. It is widely used in order to create Supervisory Control and Data Acquisition system architecture. One of the most important advantages is that it is available under Open Software free license. TANGO is widely used in scientific facilities e.g. Max IV (Lund, Sweden), ALBA (Barcelona, Spain) or SOLARIS (Cracow, Poland) as well as in industry [1]. In institutes like synchrotrons the scientists and engineers are dealing with thousands of signals per second coming from different types of devices. It is clear that there is a need to monitor non-typical situations. Here comes the idea of alarm. It is asynchronous notification that some event happened, or a given state was reached. In scientific facilities using TANGO Controls the idea of creating a set of tools to manage alarms led to the creation of an alarm system. One of the most popular systems are PANIC and Tango Alarm System.

PANIC

PANIC (Package for Alarms and Notification of Incidences from Controls) was developed in ALBA Synchotron. It is a set of tools including API, Tango device and user interface for evaluation of a set of conditions and user notification. [2]

PyAlarm

One of key elements of PANIC toolkit is PyAlarm device server [3]. According to documentation, it connects to the list of alarms provided and verifies their values. Each alarm is independent in terms of formula, but all alarms within the same PyAlarm device will share a common evaluation environment. PyAlarm device allows also to configure mail or SMS notification as well as logging. That features are needed to ensure convinient alarm management for user.

Panic GUI

Panic GUI is a desktop application implemented using Taurus library. It allows checking existing alarms and manipulate them.

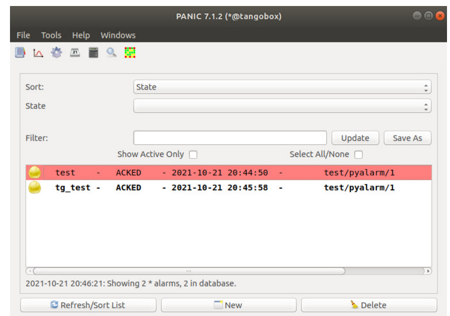


Figure 1: Alarm dashboard in PANIC GUI

Moreover, PANIC allows user to modify alarm formula, acknowledge or disable alarm.

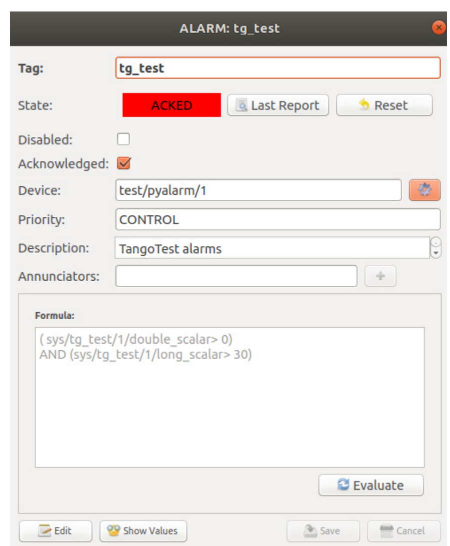


Figure 2: Alarm modification in PANIC GUI

IC@MS

Although PANIC GUI is a useful application, it has some drawbacks. First, it is desktop application what means it requires installation, and it can be only run on a desktop Nowadays, there is a trend to move desktop applications to web.which can easily by open on wider range of different devices including mobile phones, tablets and desktop

* mateusz.nabywaniec@s2innovation.com

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV034

MIGRATION OF Tango CONTROLS SOURCE CODE REPOSITORIES

M. Liszcz, K. Kedron, P.P. Goryl, M. Celary, S2Innovation, Kraków, Poland
C. Pascual-Izarra, S.Rubio, A. Sánchez, ALBA-CELLS Synchrotron, Cerdanyola del Vallès, Spain
B. Bertrand, MAX IV Sweden, Lund, Sweden
R. Bourtembourg, A. Götz, ESRF, Grenoble, France
L. Pivetta, Elettra-Sincrotrone Trieste S.C.p.A., Basovizza, Italy
G. Abeille, SOLEIL, Gif-sur-Yvette, France
A.F. Joubert, SARAO, Cape Town, South Africa
T. Braun, Byte Physics, Berlin, Germany

Abstract

At the turn of 2020/2021, the Tango community faced the challenge of a massive migration of all Tango software repositories from GitHub to GitLab. The motivation has been a change in the pricing model of the Travis CI provider and the shutdown of the JFrog Bintray service used for artifact hosting. GitLab has been chosen as a FOSS-friendly platform for storing both the code and build artifacts and for providing CI/CD services. The migration process faced several challenges, both technical, like redesign and rewrite of CI pipelines, and non-technical, like coordination of actions impacting multiple interdependent repositories. This paper explains the strategies adopted for migration, the outcomes, and the impact on the Tango Controls collaboration.

INTRODUCTION

Tango Controls [1] is a free and open-source software ecosystem for building distributed SCADA systems. Nowadays Tango Controls consists not only of the middleware libraries providing the core functionality but also of many supporting applications, GUI toolkits, and other utilities. Tango Controls is developed by numerous contributors and members of the Tango community.

Maintaining such a large and complex project requires best-in-class tools for planning, development, testing, packaging, and version control. From 2016 till 2021 Tango Controls was using GitHub [2] for source code management and various other services, including Travis CI for continuous integration and JFrog Bintray for publishing release artifacts. At the end of 2020, Travis CI announced the shutdown of `travis-ci.org` [3], while `travis-ci.com`, previously focused on commercial software, received a new pricing model [4]. Soon after that, JFrog announced the shutdown of Bintray service [5]. These events resulted in a mass migration of Tango Controls software repositories from GitHub, Travis CI, Bintray, and other previously used service providers. The following sections describe the migration strategy, the challenges faced during the process, the outcomes of the migration, and the impact on the whole Tango Controls collaboration.

MOTIVATION AND STRATEGIC DECISIONS

When in 2015 the tango-controls project was planning its migration out of SourceForge [6], both GitHub.com and GitLab.com were considered as its destination. In favour of GitLab was its licensing policy (GitLab maintains an Open Source Community Edition while GitHub is proprietary software), but GitHub was chosen because, it was then reasoned, its larger popularity would increase the visibility of Tango and facilitate the integration of third party services such as Travis-CI. Over the years, however, GitLab increased its user base considerably–in particular within the Tango developers because of GitLab being installed on-premises in many Tango Collaboration facilities. GitLab also greatly improved its CI integration, making it much more attractive than Travis CI (e.g. for its native support of Docker containers). Meanwhile, in 2018 Microsoft acquired GitHub –an event that already prompted many projects to move from GitHub to GitLab– and launched its own CI service called "GitHub Actions" [7] which also overcame many limitations of Travis CI. The definitive trigger for considering the migration of the tango-controls organization came at the end of 2020 with the announcement that Travis CI would start charging for CI time also to FOSS projects [4], which directly affected the key repositories in tango-controls.

GitHub Actions or GitLab CI?

At this point, two alternatives were considered: either move the CI of the Tango projects to GitHub Actions or move the whole project to GitLab (other possibilities such as using GitLab for the CI but keeping the project infrastructure in GitHub were also considered but quickly discarded as impractical).

Obviously, staying in GitHub and only adapting the CI would entail less effort and, from the technical point of view, the GitHub Actions service was considered to be on-par with GitLab CI in terms of integration and features. However, the proprietary nature of GitHub weighted against investing effort on further integrating with it because of concerns about potential vendor lock-in. In contrast, the fact that GitLab's Community Edition is Open Source and that the Tango Collaboration members are already experienced in both using and maintaining their own GitLab instances, eased the concerns even about the eventuality that GitLab.com

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV035

DEVELOPMENT OF ALARM AND MONITORING SYSTEM USING SMARTPHONE

W.S Cho*, Pohang Accelerator Laboratory, Pohang, Republic of Korea

Abstract

In order to find out the problem of the device remotely, we aimed to develop a new alarm system. The main functions of the alarm system are real-time monitoring of EPICS PV data, data storage, and data storage when an alarm occurs. In addition, an alarm is transmitted in real time through an app on the smartphone to communicate the situation to machine engineers of PLS-II. This system uses InfluxDB to store data. In addition, a new program written in Java language was developed so that data acquisition, analysis, and beam dump conditions can be known. furthermore Vue.js is used to develop together with node.js and web-based android and iOS-based smart phone applications, and user interface is serviced. Eventually, using this system, we were able to check the cause analysis and data in real time when an alarm occurs. In this paper, we introduce the design of an alarm system and the transmission of alarms to an application.

INTRODUCTION

The off-line method of the past alarm system sets threshold points for Low, High, and Interlock information, outputs a sound through the speaker when the range is out of range, and the operator immediately analyses the contents and solves the cause. This is a useful solution in field situations. However, engineers cannot see real-time data or alarm information generated by the device.

The new real-time online alarm method selects the EPICS PV [1] data requested by engineers or users in addition to the specified threshold and checks the data or receives an alarm with their smartphone. The new alarm system uses multiple user subscriptions based on EPICS PV. If the user wants to receive an alarm or there is data that he wants to monitor in real time, the PV is registered in the alarm system through the smartphone application. For example, the beam current data of the storage ring is unique. However, individual users may have different desired alarm setting conditions. That is, some users may want to be notified when the current is less than 100mA, and another user may want to receive an alarm when the current is less than 50mA. The alarm system is completely individualized for each user so that alarms are sent or stopped according to different conditions required for each as shown in Figure 1. And when an unexpected failure occurs, the PV connection of the EPICS IOC may be disconnected, so the EPICS PV connection information can also be included in the alarm. The smartphone application to receive the alarm can be used in both Android and iOS environments. We chose Web App because it is important to reduce development time and simplify maintenance. Among the many frameworks used in Web App, Vue.js [2] is applied. HTML5 and Java script can be easily handled, templates are modular, and switching to mobile or desktop environments is simple. Data can be checked up to 5 hours ago from the present using a line chart. In addition, to check the data of EPICS PV, the data value displayed in the application is updated in real time once every 3 seconds using Web Socket.

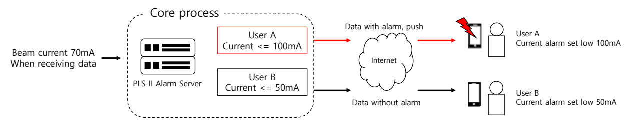


Figure 1 : Alarm system operation overview.

ALARM SYSTEM

Each embedded device provides the user with the necessary data. These data are integrated through the EPICS Gateway server. The alarm system connects to the gateway server through a network by a process called the integrated alarm system core and collects data at a rate of up to 10Hz according to the data cycle updated for each device.

The EPICS JCA library was used to collect PV connection status and data by connecting to the IOC through the network. Users who use the alarm system select a PV to receive real-time monitoring and alarm services through a smartphone application. And when parameters linked to PV are set and saved, data monitoring starts immediately in the core process. All data is stored in InfluxDB while monitoring data. And the data is processed by analysing the parameters set by each user, and if the alarm condition is met, an alarm is immediately prepared to be sent to the user. Alarm information is stored in an event queue running as an asynchronous thread inside the core process. When data exists in the event queue, it immediately analyses the event contents and stores the event log and data from the last hour or so in SQL and the file system. When all processing is completed, a PUSH notification service is sent to an Android or iOS smartphone through Google Firebase service. When the user receives the PUSH notification service, the notification of the installed application is generated, and when the user selects the corresponding event, analysis can be performed together with the past data.

Integrated Alarm System Core

Integrated alarm system core is developed in Java language and executed as a process inside O/S. This process is composed of 5 functions, and the role is divided for each function as shown in Table 1.

* wscho@postech.ac.kr

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV036

PORTING CONTROL SYSTEM SOFTWARE FROM PYTHON 2 TO 3 - CHALLENGES AND LESSONS

A. F. Joubert, M.T. Ockards, S. Wai, SARAO, Cape Town, South Africa

Abstract

Obsolescence is one of the challenges facing all long-term projects. It not only affects hardware platforms, but also software. Python 2.x reached official End Of Life status on 1 January 2020. In this paper we review our efforts to port to the replacement, Python 3.x. While the two versions are very similar, there are important differences which can lead to incompatibility issues or undesirable changes in behaviour. We discuss our motivation and strategy for porting our code base of approximately 200k source lines of code over 20 Python packages. This includes aspects such as internal and external dependencies, legacy and proprietary software that cannot be easily ported, testing and verification, and why we selected a phased approach rather than "big bang". We also report on the challenges and lessons learnt - notably why good test coverage is so important for software maintenance. Our application is the 64-antenna MeerKAT radio telescope in South Africa — a precursor to the Square Kilometre Array.

INTRODUCTION

The MeerKAT radio telescope [1] is operational in the Karoo region of South Africa, with its 64 dish antennas. It is a precursor to the larger Square Kilometre Array project [2], and will be integrated into the mid-frequency array, SKA1 MID.

The focus of this work is to report back on our approach, and progress related to the effort of porting our codebase from Python 2 to Python 3 [3]. The telescope has many subsystems with their own teams and software codebases — here we look at the control and monitoring software system.

This paper is organised as follows. First, we briefly compare Python 2 and Python 3. We then discuss the motivation for change and strategies considered. The actual approach taken, and the results are then presented, before concluding.

PYTHON 2 VS. 3

The main driver leading to the creation of Python 3 was to clean up problems with the language [4]. These changes were backwards incompatible by design. The most fundamental change is the representation of strings using Unicode by default, rather than 8-bit ASCII. This resulted in a clear split between binary data and text data.

There are a number of other changes [5], including: `print` became a function, module imports are now absolute, rearrangement/renaming of the standard libraries, more use of generators instead of concrete containers, division automatically promotes to floating point, classical classes are removed, and first-class support for asynchronous coroutines with `async` and `await`.

MOTIVATION FOR CHANGE

Porting a codebase requires significant effort, and any changes introduces risks like bugs, downtime, and degraded performance. The benefits of porting need to outweigh these negative factors.

Positive factors:

- Python 2 is end-of-life since January 2020. This means no further changes or fixes to the interpreter will be provided.
- The ecosystem of Python packages are dropping Python 2 support. This also means no fixes, no security updates, an inability to benefit from future improvements in existing packages, and new packages. Another problem is that dependencies with unpinned requirements start to break, when a new version of a package adds Python 3-only features incorrectly.
- Linux distributions are no longer including packages for Python 2 [6]. While there are ways of installing Python 2 now, this is likely to get more and more difficult. A lack of Python 2 support on future Linux releases, means that we cannot upgrade our servers, and are "stuck" on old operating systems.
- In our opinion, software engineers tend to favour newer tools, and Python 2 is now considered "legacy". There are new features in Python 3 that improve the development experience. Software engineers that enjoy the work they do are more motivated and committed to their projects.
- The remaining lifespan of MeerKAT, before it is consumed by SKA, is at least 5 years, so we need to be able to continue improving the software for at least that long.
- Revisiting the whole codebase while porting helps to increase the knowledge and understanding of the codebase, and can result in old bugs being discovered and fixed.

Negative factors:

- A huge amount of work is required, so other software features/improvements have be delayed in order to allocate human resources to the porting project.
- Risk of introducing bugs which lead to incorrect operation, downtime or degraded performance.

Overall, we believed that the positive aspects make the exercise worth doing.

STRATEGIES FOR PORTING

The Python porting book [7] outlines a few strategies for porting to Python 3.

Unfortunately, most of the projects in our codebase are libraries and therefore coupled during runtime (they must run

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV037

ALBA CONTROLS SYSTEM SOFTWARE STACK UPGRADE

G. Cuni, F. Becheri, S. Blanch-Torné, C. Falcon-Torres, C. Pascual-Izarra,
Z. Reszela, S. Rubio-Manrique, ALBA-CELLS, Barcelona, Spain

Abstract

ALBA, a 3rd Generation Synchroton Light Source located near Barcelona in Spain, is in operation since 2012. During the last 10 years, the updates of ALBA's Control System were severely limited in order to prevent disruptions of production equipment, at the cost of having to deal with hardware and software obsolescence, elevating the effort of maintenance and enhancements. The construction of the second phase new beamlines accelerated the renewal of the software stack. In order to limit the number of supported platforms we also gradually upgraded the already operational subsystems. We are in the process of switching to the Debian OS, upgrading to the Tango 9 Control System framework including the Tango Archiving System to HDB++, migrating our code to Python 3, and migrating our GUIs to PyQt5 and PyQtGraph, etc. In order to ensure the project quality and to facilitate future upgrades, we try to automate testing, packaging, and configuration management with CI/CD pipelines using, among others, the following tools: pytest, Docker, GitLab-CI and Salt. In this paper, we present our strategy in this project, the current status of different upgrades and we share the lessons learnt.

ALBA CONTROLS SYSTEM DEVELOPMENT AND EARLY OPERATION

When building ALBA controls system, the main goal from the software (and hardware) point of view was to use standard tools and be as homogeneous as possible in order to ease development, training, and troubleshooting. Beamlines and accelerators have the same software structure and use the same applications wherever it is possible, for example, vacuum or motion control.

Controls Software Stack Overview

ALBA controls system uses Tango as middleware, a distributed control system framework based on CORBA [1]. It is characterized by a client-server architecture, its object-oriented design, and the use of the database as a broker and name service. The ALBA Controls Group chose Python as the main programming language and strongly invested in developing and supporting PyTango, a Python binding to C++ Tango library [2].

The vast majority of GUIs at ALBA are developed using Taurus [3], a library for building desktop applications in PyQt. Taurus was initially connecting only to Tango models but over years its architecture evolved towards a highly modular and data source agnostic solution broadly used in numerous scientific installations.

Apart from Taurus, other generic and transversal services, initially implemented as Tango device servers interfaced from GUIs, gradually evolved into projects used not only at ALBA beamlines and accelerators but also at many other institutes of the Tango community. These are, among others:

- Sardana, a scientific SCADA suite [4], which consists of Taurus-based widgets for experiment control and IPython based CLI called Spock on the client-side, and a powerful sequencer called MacroServer and Device Pool for interfacing with the hardware on the server-side.
- Panic, an IEC62682 compliant Alarm Handling suite (Alarm Handling Panic GUI and PyAlarm) [5] capable of messaging and automated execution of control system actions.
- Generic tools and device servers (Tango import/export scrips, calculation device servers, vacuum controllers, diagnostics tools) [6]

Apart from the generic services and user interfaces, every sub-system has its specific applications, e.g. MXCuBE control application for macromolecular crystallography experiments used at BL13, TXM control application for tomography experiments used at BL09, or the accelerator timing system controls stack (Linux drivers, Tango device servers and GUIs).

The ALBA Controls Group used to manage all the software under maintenance with the “bliss” system. The bliss system, developed by the ESRF, is an rpm-based packaging and Software Configuration Management (SCM) tool. It comprises two applications: the blissbuilder and the blissinstaller, both offering intuitive to “non-packaging experts” graphical way of defining and creating packages, and installing them, at the same time being limited in terms of automatic package creation and deployment.

The different pieces of software run on diskless compact PCI (only for the accelerators) and industrial PCs, distributed in the service area or experimental hall with direct access to the hardware devices. The boot servers, archiving, Tango databases, CCD data acquisition, and various other services run on VMs centralized in the computing room. Most of the controls hosts run a standard Linux distribution which at the beginning was openSUSE but there are also some Windows hosts, mainly workstations for data analysis.

ALBA CONTROLS SYSTEM SOFTWARE OBSOLESCENCE

A control system for a scientific facility such as ALBA is not a static system: new hardware needs to be suppor-

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV039

UCAP: A FRAMEWORK FOR ACCELERATOR CONTROLS DATA PROCESSING @ CERN

L. Cseppentő*, M. Büttner, CERN, Geneva, Switzerland

Abstract

The Unified Controls Acquisition and Processing (UCAP) framework provides a means to facilitate and streamline data processing in the CERN Accelerator Control System. UCAP's generic structure is capable of tackling classic "Acquisition - Transformation - Publishing/Presentation" use cases, ranging from simple aggregations to complex machine reports and pre-processing of software interlock conditions.

In addition to enabling end-users to develop data transformations in Java or Python and maximising integration with other controls sub-systems, UCAP puts an emphasis on offering self-service capabilities for deployment, operation and monitoring. This ensures that accelerator operators and equipment experts can focus on developing domain-specific transformation algorithms, without having to pay attention to typical IT tasks, such as process management and system monitoring.

UCAP is already used by Linac4, PSB and SPS operations and will be used by most CERN accelerators, including LHC by the end of 2021.

This contribution presents the UCAP framework and gives an insight into how we have productively combined modern agile development with conservative technical choices.

INTRODUCTION

The Unified Controls Acquisition and Processing (UCAP) Framework is a recent product in the CERN Controls Software & Services (CSS) group's portfolio. This generic, self-service online Controls data processing platform, enables clients to easily implement and run Controls Device data acquisition and processing in Java or Python.

The main objective of the project is to provide a common approach to solve problems where:

1. data is acquired and grouped from several sources (*Acquisition*),
2. based on these inputs, and optionally internal state, a result is calculated (*Transformation*),
3. the result is made available to clients (*Publishing/Presentation*).

Such "Acquisition - Transformation - Publishing/Presentation" problems are regularly featured in many Controls products, such as data concentrators, software interlocks, logging adaptations and autopilot-style Controls software.

At CERN, Controls software development responsibilities are often split between the CSS group (mainly computing engineers providing frameworks and generic services), and equipment and operations groups (typically experts in their specialised domains). Experience showed that in order to effectively tackle certain problems, collaboration of teams with different backgrounds is essential, as the expertise of Controls framework libraries and accelerator domain knowledge are distributed. The UCAP service aims to streamline development and maintenance by splitting responsibilities:

- the UCAP team provides infrastructure, tools, training and support for development, testing and deployment of transformations,
- while the transformation code and configuration stays under the responsibility of the end-user (typically a domain expert).

This *self-service* model enables end-users to focus on realising their business logic, while the service takes care of secondary tasks, such as process management and monitoring. It is also *scalable*: as service usage increases, only new machines and UCAP nodes need to be added to the system.

Nevertheless, this set up brings other challenges, such as isolating user groups on shared hardware, ensuring dynamic server-side code loading, providing substantial documentation and user-friendly access. At this scale, a high level of *automation* is essential

The "UCAP-idea" originates from 2016, with a first prototype started in 2018. During this phase, the first use case was satisfied, providing transformations on approximately 1000 data streams. The following year, in the beginning of Long Shutdown 2, development started on the operational product – in close collaboration with stakeholders. A few months later, still in early 2019, the system went to production while iterative development continued. As of 2021 Q3, the UCAP service is composed of 105 nodes (isolated deployment units), running on 6 physical servers, performing around 20 000 data transformations.

UCAP IN A NUTSHELL

The UCAP service is a *multitenant* system. *Nodes* are assigned to client groups or use cases for isolation purposes. All nodes are fully functional data processing services, differing only in basic configuration parameters, such as name, description and responsible. The layered architecture, presented in Fig. 1, mirrors the "Acquisition - Transformation - Publishing/Presentation" chain – each layer being responsible for dealing with one aspect of data processing. UCAP complies with this model on the architecture level, avoiding the introduction of any new structural elements in the data representation.

The CERN Control System uses the *Device-Property model* [1], meaning that all endpoints providing data are

* lajos.cseppento@cern.ch

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV040

INTRODUCING PYTHON AS A SUPPORTED LANGUAGE FOR ACCELERATOR CONTROLS AT CERN

P. Elson, C. Baldi, I. Sinkarenko, CERN, Geneva, Switzerland

Abstract

In 2019, Python was adopted as an officially supported language for interacting with CERN's accelerator controls. In practice, this change of status was as much pragmatic as it was progressive - Python has been available as part of the underlying operating system for over a decade and unofficial Python interfaces to controls have existed since at least 2015. So one might ask: what really changed when Python adoption became official?

This paper will discuss what it takes to officially support Python in a controls environment and will focus on the cultural and technological shifts involved in running Python operationally. It will highlight some of the infrastructure that has been put in place at CERN to facilitate a stable and user-friendly Python platform, as well as some of the key decisions that have led to Python thriving in CERN's accelerator controls domain. Given its general nature, it is hoped that the approach presented in this paper can serve as a reference for other scientific organisations from a broad range of fields who are considering the adoption of Python in an operational context.

INTRODUCTION

The Python language, and specifically the cPython implementation for which this paper concerns itself, has one of the largest and fastest growing developer communities of any programming language [1]. It has been jokingly described as “the second best programming language for anything” [2] on the basis of its ability to adapt to a broad array of problems, including domains of particular interest to accelerator controls such as system automation, data analytics & machine learning, web services, and graphical user interfaces (GUIs). This flexibility comes less from the “batteries included” Python standard library, and is more a reflection of a rich suite of third-party packages available from the Python Package Index (PyPI).

CERN’s Accelerator & Technology sector, referred to as simply “accelerator sector” in this paper, is responsible for the operation and exploitation of the whole accelerator complex, including the LHC, and for the development of new projects and technologies [3]. Python has been in use in the accelerator sector for a number of years, solving a diverse set of problems including fundamental physics simulations, gathering and analysis of data for machine development (MD) studies, rapid prototyping of services, GUI applications, and much more. For high-level operational accelerator controls at CERN, Java was the only supported programming language until the adoption of Python in 2019. The growth of Python has meant that more people are joining CERN with prior Python experience, and the simplicity of the language is compelling for the large user base of domain specialists for whom software development is a tool to achieve a specific task rather than being the main focus of their work.

Promotion of Python to “supported” status includes the provision of a software infrastructure to allow the operational 24/7 running of Python for mission-critical high-level accelerator controls, as well as infrastructure, such as tooling and a support service, to aid with effective development of such applications & services. Much inspiration was drawn from the existing Java service for accelerator controls, though to directly emulate the Java experience in Python would be to suffer the worst of both worlds and to risk missing the advantages of Python adoption. Therefore, a key objective was to preserve the spirit of Python in the service provided.

The objectives of this paper are to outline some common practices observed before the adoption of Python; to highlight some of the idiomatic Python practices that should be preserved; and at a high level, to present some of the infrastructure put in place to facilitate the use of Python in the accelerator sector at CERN. With this, it is hoped that other scientific organisations may be able to identify existing practices and potential areas of improvement in their own journey to bring Python into an operational context.

As a reflection of the computers in use for high-level controls in the accelerator sector, this paper predominantly focuses on x86-64 architecture, variants of Linux operating systems (OS) such as CentOS, and bare-metal deployments to machines which are often multi-purpose and multi-user.

A TYPICAL PYTHON STARTING POINT

Python Already in Use for Many Years

Python isn’t new, and is almost certainly in use in most medium to large scientific organisations today. Typically installed by default in Linux-based operating systems, the barrier to first use of Python is relatively low – scripts can be executed directly by the Python interpreter for a rapid and iterative development experience. As they develop, re-use of functions and other definitions by gathering scripts together into a library of modules becomes desirable. Historically, this was achieved by setting the PYTHONPATH environment variable to point to a directory of packages for consideration in the Python import machinery. At the same time, it is common to want to make use of the rich set of 3rd party, open-source software (OSS) Python packages. On a machine dedicated to a particular task, it is likely that the OS package manager will suffice for the most popular libraries, but eventually

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV041

MODERNISATION OF THE TOOLCHAIN AND CONTINUOUS INTEGRATION OF FRONT-END COMPUTER SOFTWARE AT CERN

P. Mantion†, S. Deghaye, L. Fiszer, F.Irannejad, J. Lauener, M. Voelkle
CERN, 1211 Geneva 23, Switzerland

Abstract

Building C++ software for low-level computers requires carefully tested frameworks and libraries. The major difficulties in building C++ software are to ensure that the artifacts are compatible with the target system's (OS, Application Binary Interface), and to ensure that transitive dependency libraries are compatible when linked together. Thus developers/maintainers must be provided with efficient tooling for friction-less workflows: standardisation of the project description and build, automatic CI, flexible development environment. The open-source community with services like Github and Gitlab have set high expectations with regards to developer user experience. This paper describes how we leveraged Conan and CMake to standardise the build of C++ projects, avoid the "dependency hell" and provide an easy way to distribute C++ packages. A CI system orchestrated by Jenkins and based on automatic job definition and in-source, versioned, configuration has been implemented. The developer experience is further enhanced by wrapping the common flows (compile, test, release) into a command line tool, which also helps transitioning from the legacy build system (legacy makefiles, SVN).

INTRODUCTION

Front-End Computer Software Development at CERN

CERN's Front-End Computers (FECs) are disk-less computer crates which host electronic cards connected on a back-plane. The software running on these computers typically uses a framework such as Front-End Software Architecture (FESA) [1,2] to interface with:

- The upper layer of the control system (settings management, timing, network (Remote Device Access (RDA3) protocol [3]), logging, post-mortem, machine protection, etc.)
- The cards' driver (C library) to drive the equipment.
- The OS (Linux, CentOS 7 with RT kernel) and framework (FESA) are designed to provide near real-time execution of the tasks through scheduling, thread priorities, and optimisation: this is a strong reason (amongst others), for using a performance-oriented language like C++ to build the software.

The production FECs run on CentOS 7, so the software must be built for that target, ensuring compatibility with the system's libraries (especially libc) and ABI (changes in ABI for *C++11 support*).

Software built using the FESA framework consists of an executable that is statically linked against the framework's libraries (versioned headers and *.a* archive files). The framework libraries themselves depend on a collection of middleware libraries provided by different teams across different groups.

† pierre.mantion@cern.ch

The FESA framework is mostly used by equipment developers who are not full-time software engineers. As such, the framework providers aim to offer tooling that promotes best practices (e.g. source code versioning, releasing, tagging) and minimises human errors.

NEED FOR MODERNISATION

After almost two decades of building C++ software with Makefiles, a well-deserved modernisation was needed. A Continuous-Integration (CI) solution, based on a shared central Bamboo Server instance, was put in place almost ten years ago. A general move away from Bamboo to Jenkins or Gitlab CI for Controls software also needed to be taken into consideration. Additional objectives were to ensure that the new solution provides a better dependency management and ensure a smooth transition for our users.

Dependency and Toolchain Management

The correct execution of FEC software requires the binaries to be built using consistent versions of the dependencies. At the lowest level, this means that versions of the dependent libraries should be both binary and functionally compatible. However, a complex dependency graph means it is not easy to ensure, especially if no compilation/linking errors are raised at build time. Dependency management entails two aspects:

1. Knowing where to find/store artifacts (header / library files) from the build system.
2. Being able to check the consistency of dependencies and versions in the dependency graph.

Beyond ensuring production software is built correctly, strong dependency management is very useful to the developer. When working with local copies of a sub-set of a dependency graph, developers are one step away from so-called "dependency hell". Without automatic dependency management developers need to ensure that all libraries used locally are compatible, which entails editing makefiles and building/rebuilding lots of dependencies before having a working setup. Compilation time in such cases is not negligible. The process is also error prone, often requiring to re-build several dependencies after each correction. Figure 1 highlights the difficulty of modifying dependencies by hand by showing the complexity of the dependency graph for a representative example of FEC software.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV042

PLCverif: STATUS OF A FORMAL VERIFICATION TOOL FOR PROGRAMMABLE LOGIC CONTROLLER

I. D. Lopez-Miguel*, J-C. Tournier, B. Fernandez, CERN, Geneva, Switzerland

Abstract

Programmable Logic Controllers (PLC) are widely used for industrial automation including safety systems at CERN. The incorrect behaviour of the PLC control system logic can cause significant financial losses by damage of property or the environment or even injuries in some cases. Therefore ensuring their correct behaviour is essential. While testing has been for many years the traditional way of validating the PLC control system logic, CERN developed a model checking platform to go one step further and formally verify PLC logic. This platform, called PLCverif, was first released internally for CERN usage in 2019, is now available to anyone since September 2020 via an open source licence. In this paper, we will first give an overview of the PLCverif platform capabilities before focusing on the improvements done since 2019 such as the larger support coverage of the Siemens PLC programming languages, the better support of the C Bounded Model Checker backend (CBMC) and the process of releasing PLCverif as an open-source software.

INTRODUCTION

Programmable Logic Controllers (PLC) are widely used for industrial automation including safety systems at CERN. The incorrect behaviour of the PLC control system logic can cause significant financial losses by damage of property or the environment or even injuries in some cases. Therefore ensuring their correct behaviour is essential. While testing has been for many years the traditional way of validating the PLC control system logic, it is often not sufficient as the sole verification method: testing, even when automated, can not be exhaustive, thus can not guarantee the correctness of a logic. Some types of requirements, such as safety (i.e. an unsafe state can never be reached) or invariant (formulas which shall be true over all possible system runs), can be very difficult, if not impossible, to test. Model checking is a formal verification technique which complements the testing activities in order to fully validate and verify a PLC control system logic. Model checking assesses the satisfaction of a formalised requirement on a mathematical model of the system under analysis. It checks the requirement's satisfaction with every input combination, with every possible execution trace. In addition, if a violation is found, a trace leading to the violated requirement is provided. The main hurdle to the widespread usage of model checking within the PLC community is twofold: (1) the mathematical model representing the system under analysis can be difficult to write and requires in-depth understanding of the model checking tools; and (2) many real-life PLC logics are too complex and face the state-space explosion problem, i.e. the number of possible input combinations and execution traces is too big to be exhaustively explored.

In 2019 CERN developed the PLCverif platform with the goals of easing the usage of model checking tools for the PLC developers community by automating the translation of the PLC programs to their mathematical models and to implement several abstraction algorithms to limit the state-space explosion problem. Since September 2020, the platform has been released under an open source license to foster the usage and the development of the tool within the PLC community. The objective of this paper is to give a status of the PLCverif platform focusing on the latest developments improving the usability and performance of the tool.

The rest of the paper is organized as follows: Section *PLCverif Overview* gives an overview of PLCverif to better understand the scope and the architecture of the platform. Section *Open Source Release* focuses on the open source release of PLCverif by describing the process of releasing the source code and presenting the code organization. Finally sections *Latest developments* and *On-going Challenges and Developments* present respectively the latest and ongoing developments.

PLCverif OVERVIEW

This section gives an overview of the PLCverif platform [1] before presenting the latest developments.

Verification Workflow

Out of the box, PLCverif offers a model checking workflow for the analysis of PLC programs. The verification workflow is shown in Fig. 1 and it has the following main steps:

1. **PLC program parsing.** PLCverif parses the PLC program (located in one or several files) to be analysed. By choosing the entry point of the verification, the analysis can be limited to a part of the program. The parsed PLC program is automatically translated into a mathematical, control flow-based representation, producing so-called Control Flow Automata (CFA). This precise description will serve as the basis for the analysis.

2. **Requirement representation.** The user should describe the precise requirement to be checked. This, however, does not mean that the user needs to describe the requirement using mathematical formulae. Currently, two requirement description methods are supported:

    - Assertion-based requirements: special comments in the source code (e.g. `//#ASSERT On<>Off`)

* ignacio.david.lopez.miguel@cern.ch

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV043

CERN CONTROLS CONFIGURATION SERVICE – EVENT-BASED PROCESSING OF CONTROLS CHANGES

B. Urbaniec, L.Burdzanowski, CERN, Geneva, Switzerland

Abstract

The Controls Configuration Service (CCS) is a core component of the data-driven Control System at CERN. Built around a central database, the CCS provides a range of client APIs and graphical user interfaces (GUI) to enable efficient and user-friendly configuration of Controls. As the entry point for all the modifications to Controls system configurations, the CCS provides the means to ensure global data coherency and propagation of changes across the distributed Controls sub-systems and services. With the aim of achieving global data coherency in the most efficient manner, the need for an advanced data integrator emerged.

The "Controls Configuration Data Lifecycle manager" (CCDL) is the core integration bridge between the distributed Controls sub-systems. It aims to ensure consistent, reliable, and efficient exchange of information and triggering of workflow actions based on events representing Controls configuration changes. The CCDL implements and incorporates cutting-edge technologies used successfully in the IT industry. This paper describes the CCDL architecture, design and technology choices made, as well as the tangible benefits that have been realised since its introduction.

INTRODUCTION

The Controls Configuration Service (CCS) is a core component of CERN's Control system, serving as a central point for the configuration of all Controls sub-domains. CCS ensures that the data provided to other services is done in a coherent and consistent way. CCS is used by a diversified group of users, including installation teams (configuring Controls hardware), equipment experts (configuring processes and applications), and Accelerator operators. All CCS users interact with the service at various points in time, to verify or define appropriate configurations.

The service is built around a centralised Oracle database server. To minimise downtime of the system and risks of negative impact to the users, the server is deployed in a cluster as 2 redundant nodes, providing 99.9% availability. The data stored in the CCS database (CCDB) may be accessed via a dedicated high level web-based editor - Controls Configuration Data Editor (CCDE) [1]. At the same time the service also provides advanced Java and Python REST APIs which allow users to efficiently configure, modify and maintain configuration data in a programmatic way.

The CCS service has been an integral part of the Controls system for many years. The first version was created in the late 80s, during operations of the Large Hadron Collider's predecessor - The Large Electron-Positron Collider (LEP). Since that time the service has evolved and been consolidated multiple times. The last renovation started 4 years ago [2] to match the CCS technology stack with technologies widely used in the software industry. All CCS components are based on Java (currently version 11) and the Spring framework. From the Spring framework, Spring Boot has been selected as a solution to establish a common architecture among all the applications in a simplified and unified way. As mentioned, CCS also provides a high-level web interface - CCDE. The CCDE is based on the AngularJS framework (provided by Google) and is augmented with a web components framework developed in-house and encapsulating common functionality and integration with CERN services such as SSO. Communication between the Java back-end and the AngularJS front-end is implemented using the REST architectural pattern.

CERN CONTROLS CONFIGURATION SERVICE

As a core Controls service, the CCS must exhibit a high level of availability. Even though CCS downtime does not directly impact beam operation, it severely limits the means to verify or modify core system configurations. To provide the highest possible availability and quality of service, each CCS component is implemented with some degree of redundancy. For example service-side processes are stateless and deployed in a multi-node set-up. In the rare case of a failure for one of the nodes, the system remains operational without impacting users. Advanced monitoring and notification mechanisms continuously check the consistency and status of all service components and send alerts in case of any abnormality. This allows service managers to react before the CCS becomes unavailable.

Since its inception, the CCS has evolved regularly, in-synch with the significant evolution of CERN's accelerator complex and multiple sub-systems. During the last 30 years, new advanced accelerators and major upgrades have triggered a need for a more sophisticated and powerful configuration platform. The global Controls architecture is realised as a layered system, reflected in CCS configuration domains, which can be simplified as follows:

- Low-level aspects covering kernel driver configurations and hardware types.
- Front-End Computers (FEC) with their modules (of hardware types, mentioned above), on which,

18th Int. Conf. on Acc. and Large Exp. Physics Control Systems ICALEPCS2021, Shanghai, China JACoW Publishing
ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV044

LESSONS LEARNED MOVING FROM PHARLAP TO LINUX RT

Cédric Charrondiere, Odd Oyvind Andreassen, Diego Sierra Maillo Martinez, Joseph Tagg, Thomas Zilliox, CERN, Geneva, Switzerland

Abstract

The start of the Advanced Proton Driven Plasma Wakefield Acceleration Experiment (AWAKE) [1] facility at CERN in 2016 came with the need for a continuous image acquisition system. The international scientific collaboration responsible for this project requested low and high resolution acquisition at a capture rate of 10Hz and 1 Hz respectively. To match these requirements, GigE digital cameras were connected to a PXI system running PharLap, a real-time operating system, using dual port 1Gbps network cards. With new requirements for a faster acquisition with higher resolution, it was decided to add 10Gbps network cards and a Network Attached Storage (NAS) directly connected to the PXI system to avoid saturating the network. There was also a request to acquire high-resolution images on several cameras during a limited duration, typically 30 seconds, in a burst acquisition mode. To comply with these new requirements PharLap had to be abandoned and replaced with NI Linux RT.

This paper describes the limitation of the PharLap system, and the lessons learned during the transition to NI Linux RT. We will show the improvement of CPU stability and data throughput reached.

INTRODUCTION

A plasma wakefield is a type of wave generated by particles travelling through a plasma. By harnessing these wakefields, accelerating gradients hundreds of times higher than those produced in current radiofrequency cavities can be achieved [2], allowing for more compact accelerators. AWAKE is a proof of principle experiment that aims to demonstrate this in a scalable way, sending proton beams through plasma cells to generate these fields, which subsequently accelerate electrons to high energy over a short distance.

One important observable is the shape and position of the proton beam halo along the beamline, that must be acquired in real-time. To handle the 10Hz image acquisition on 10 cameras simultaneously it was decided to use a PXI running PharLap.

Due to the lack of supported drivers, issues with timing and performance, the system was later upgraded to NI Linux RT to benefit from its flexibility.

Motivation

The cameras are positioned along the beam line for several purposes (Fig. 1). The cameras that are on the virtual laser diagnostic line are used to measure the characteristics of the laser used to initiate the plasma. Other cameras are used to image the path of the laser and proton beams to align them in the plasma cell. Finally, some cameras are positioned to visualize the low energy electron beam at different points of its path before it is accelerated by the proton generated wakefield in the plasma cell.

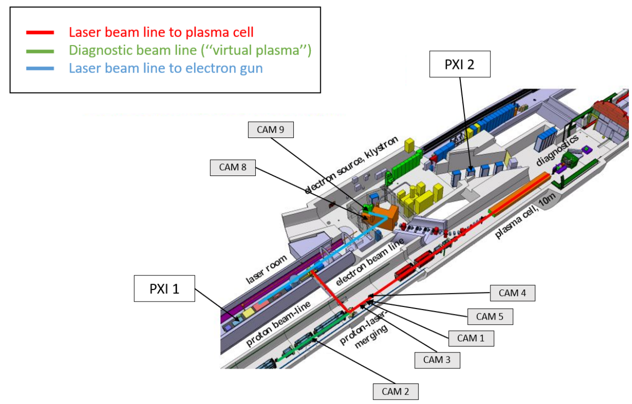


Figure 1: Camera locations in the Awake Experimental Area.

HARDWARE TOPOLOGY

The AWAKE camera acquisition system acquires images from ethernet based, digital GigE cameras. The system publishes resampled images (resampling factor 5x5) at 10 Hz and publishes the full-size images on an SPS extraction event (once per AWAKE cycle). The basic system topology is shown below (Fig. 2)

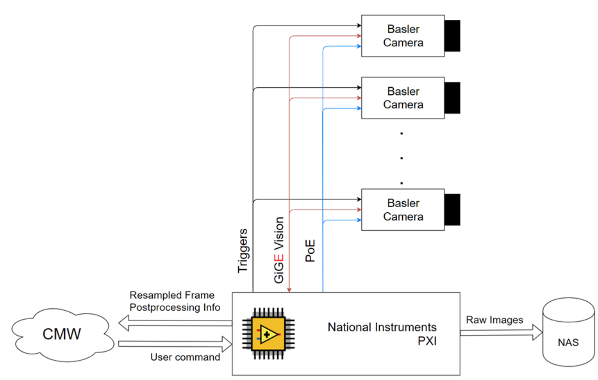


Figure 2: System topology.

Each camera is connected to the PXI system and powered by a PoE (Power over Ethernet) module. The triggering is handled through the FPGA as shown in the hardware architecture (Fig. 3)

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV045

DATA-CENTRIC WEB INFRASTRUCTURE FOR CERN RADIATION AND ENVIRONMENTAL PROTECTION MONITORING

Adrien Ledeul*, Catalina Cristina Chiriac, Gonzalo de la Cruz, Gustavo Segura, Jan Sznajd
CERN, Geneva, Switzerland

Abstract

Supervision, Control and Data Acquisition (SCADA) systems generate large amounts of data over time. Analyzing collected data is essential to discover useful information, prevent failures, and generate reports. Facilitating access to data is of utmost importance to exploit the information generated by SCADA systems.

CERN's occupational Health & Safety and Environmental protection (HSE) Unit operates a web infrastructure allowing users of the Radiation and Environment Monitoring Unified Supervision (REMUS) to visualize and extract near-real-time and historical data from desktop and mobile devices. This application, REMUS Web, collects and combines data from multiple sources and presents it to the users in a format suitable for analysis.

The web application and the SCADA system can operate independently thanks to a data-centric, loosely coupled architecture. They are connected through common data sources such as the open-source streaming platform Apache Kafka and Oracle Rdb. This paper describes the benefits of providing a feature-rich web application as a complement to control systems. Moreover, it details the underlying architecture of the solution and its capabilities.

INTRODUCTION

Radiation protection and environmental monitoring are fundamental aspects of the CERN Safety Policy. CERN's occupational Health & Safety and Environmental protection (HSE) Unit conducts a program in charge of monitoring the radiological and environmental impact of the organization. The aim is to ensure workplace safety for CERN employees and visitors, minimize the environmental impact of CERN, and provide regulatory authorities with comprehensive reports.

In order to achieve these objectives, a geographically distributed and heterogeneous set of instruments is continuously measuring the nature and quantity of ionizing radiations produced by the accelerators, possible contamination as well as conventional environmental parameters.

Radiation and Environment Monitoring Unified Supervision (REMUS) [1], based on WinCC Open Architecture (WinCC OA) [2] is the Supervision, Control And Data Acquisition (SCADA) system controlling this infrastructure. It is accessed from various control rooms across the Organization and has more than 200 active users.

At the time of writing, REMUS is interfacing 86 different types of devices. It contains 850 000 tags, manages 120 000 alarms and handles a throughput of 25 000 Input/Output operations per second. REMUS archives roughly 80 billion measurements per year.

One of the main challenges of such a system is to provide comprehensive yet accessible means to extract and exploit the data. REMUS itself allows users to display a large variety of synoptic views and control panels designed for the operation in control rooms. However, such user interfaces are not the most suitable for data extraction at a higher level of abstraction, and typically require physical access to terminals in a protected network.

Two use cases are particularly challenging to handle. The first one is that CERN radiation and environmental protection experts are in charge of transforming the data generated by REMUS system into business-specific reports. Such reports are used for further internal analysis and to consolidate CERN's communication with the host states and with the general public. The second one is to provide the CERN's Fire and Rescue service and other emergency response teams with access to near-real-time data on remote terminals. This is particularly useful at CERN, where installations for environmental monitoring are geographically scattered. The installation of dedicated monitoring screens is not always possible at the location where the access to the data is needed.

This paper describes the approach taken to make radiation and environmental monitoring data accessible to third party applications as well as why web technologies were chosen for the presentation of this data.

A DATA-CENTRIC APPROACH

This section introduces the approach taken for the consolidation and homogenization of the data layer.

The Data-Centric Manifesto

The data-centric mindset, as opposed to the application-centric one, considers the data to be the permanent assets, and the applications the temporary ones. The key principles, as expressed in the Data-Centric Manifesto [3], can be summarized as follows:

- Data is the key asset.
- Data is self-describing.
- Data is stored in non-proprietary formats.
- Data access control and security is the responsibility of the data layer itself.

This approach suits well REMUS use case, as radiation and environmental protection data must be kept for an indefinite amount of time, as requested by regulatory authorities. On the other hand, the applications publishing

* adrien.ledeul@cern.ch

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV047

UPGRADING ORACLE APEX APPLICATIONS AT THE NATIONAL IGNITION FACILITY

A. Bhasker, R. D. Clark, R.N. Fallejo
Lawrence Livermore National Lab, CA, USA

Abstract

As with all experimental physics facilities, NIF has software applications that must persist on a multi-decade timescale. They must be kept up to date for viability and sustainability. We present the steps and challenges involved in a major Oracle APEX application upgrade project from Oracle APEX version 5 to Oracle APEX version 19.2. This upgrade involved jumping over 2 major versions and a total of 5 releases of Oracle APEX. Some applications - that depended on now legacy Oracle APEX constructs required rearchitecting, while others that broke due to custom JavaScript needed to be updated with compatible code. This upgrade project, undertaken by the NIF Shot Data Systems (SDS) team at Lawrence Livermore National Laboratory (LLNL), involved reverse-engineering functional requirements for applications that were then redesigned using the latest APEX out-of-the-box functionality, as well as identifying changes made in the newer Oracle APEX built-in "plumbing" to update custom-built functionality for compatibility with the newer Oracle APEX version. As NIF enters into its second decade of operations, this upgrade allows for these aging Oracle APEX applications to function in a more sustainable way, while enhancing user experience with a more modernized GUI for existing and future Oracle APEX webpages.

INTRODUCTION

The National Ignition Facility (NIF) made history when it first fired all 192 of its laser beams at a single point inside the vast, spherical target chamber in 2009. Now, over 10 years and more than 2,700 shots later, NIF still dominates the world of high-energy lasers by a factor of 10 and continues to help the Laboratory achieve its mission objectives, offering unparalleled laser performance and precision [1]. As NIF enters into its second decade of operations, it must continue to maintain its various software applications in a sustainable and viable way. Two such applications that the Software Data Systems (SDS) team at NIF recently upgraded are the *Production Optics Reporting and Tracking* and the *Shot Planner* applications. At the time of this undertaking, these applications were running on Oracle APEX version 5.0. Oracle APEX is a web-application development tool for the Oracle databases [2], that supports utilization of JavaScript and JQuery components as well. In this paper, we discuss the steps involved in upgrading these NIF applications from Oracle APEX version 5.0 to Oracle APEX version 19.2 – a jump spanning 2 major versions and a total of 5 releases of Oracle APEX.

The Oracle APEX Applications

The original *Production Optics Reporting and Tracking (PORT)* and the *Shot Planner* applications were developed in very early versions of Oracle APEX when NIF was in the process of being built, over a decade ago. The PORT application covers a wide domain of capabilities – ranging from reporting and analysis to task-scheduling and optics installation. The Shot Planner application functions as a scheduling app, providing reports and forms to plan the sequencing of shots on NIF. At the time of the Oracle APEX upgrade, both these applications were running on legacy Oracle APEX themes and utilizing certain Oracle APEX constructs (such as AnyChart/Flash Charts [3]) that are no longer supported by the latest Oracle APEX versions.

METHODOLOGY

The PORT application comprised of ~500 application pages, and the Shot Planner application comprised of ~200 application pages at the time of this upgrade. The following are the steps that the team undertook as a part of the Oracle APEX upgrade for these applications (Figure 1).

1. Identify all Obsolete Application Pages
2. Set up an APEX 19.2 environment for testing
3. Fix Forward Incompatibility
4. Deploy Pre-Upgrade Fixes
5. Line Up Post-Upgrade Fixes
6. Oracle APEX Upgrade Utility Recommendations
7. Upgrade and Deploy Post-Upgrade Fixes

Figure 1: Methodology followed.

Identify Obsolete Webpages

The SDS team worked with the various users to identify any application pages that were no longer used. Given the age of these applications, several application functionalities were no longer required as the program evolved with time. Identifying these application pages gave the team an opportunity to prune out the deprecated functionalities. To be sure that a functionality could be deprecated, all visits of the various application pages on these applications were recorded for a period of one year before beginning the actual upgrade. To achieve this, a new Oracle database table was created to record this information from the APEX_WORKSPACE_ACTIVITY_ LOG view [4].

A Sandbox Environment with Oracle APEX 19.2

The next step was setting up a test environment with the target Oracle APEX version 19.2 installed. Copies of the application were imported into this *sandbox* environment. The team meticulously tested all the functionalities on each Oracle APEX application page and identified features that were no longer working in the new upgraded environment. This was done by comparing each application page in the

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV048

FAST MULTIPOLE METHOD (FMM)-BASED PARTICLE ACCELERATOR SIMULATIONS IN THE CONTEXT OF TUNE DEPRESSION STUDIES *

M. Harper Langston† [1], Richard Lethin[1], Pierre-David Letourneau[1], Julia Wei[1]
[1]Reservoir Labs Inc., New York, NY 10012, USA

Abstract

As part of the MACH-B (Multipole Accelerator Codes for Hadron Beams) project, Reservoir Labs has developed a Fast Multipole Method (FMM [1–7])-based tool for higher fidelity modeling of particle accelerators for high-energy physics within Fermilab's Synergia [8, 9] simulation package. We present results from our implementations with a focus on studying the difference between tune depression estimates obtained using PIC codes for computing the particle interactions versus those obtained using FMM-based algorithms integrated within Synergia. In simulating the self-interactions and macroparticle actions necessary for accurate simulations, we present a newly-developed kernel inside of a kernel-independent FMM, where near-field kernels are modified to incorporate smoothing while still maintaining consistency at the boundary of the far-field regime. Each simulation relies on Synergia with one major difference: the way in which particles interactions are computed. Specifically, following our integration of the FMM into Synergia, changes between PIC-based computations and FMM-based computations are made by simply selecting the desired method for near-field (and self) particle interactions.

INTRODUCTION

The majority of numerical approaches for accelerator multiparticle-tracking solve the macroscale problem by employing Particle-In-Cell (PIC) methods [8–14]. These methods incorporate an Eulerian method for solving the necessary equations and Lagrangian techniques to advect particles through the domain (e.g., see Fig. 1).

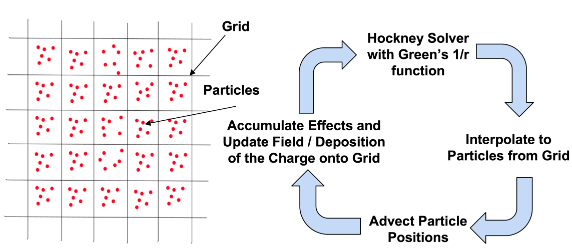


Figure 1: PIC-based Hockney solver. Given a cloud of charged particles, iterate (1) Grid charge deposition; (2) Compute potential; (3) Compute forces at grid points; (4) Compute forces at particle locations.

Since space-charge modeling in high-intensity hadron beams for the accelerator physics community requires scalable and high-fidelity algorithmic approaches, all new computational approaches must **(1)** be inherently multiscale, **(2)** exploit locality, **(3)** reduce expense of non-locality while handling accuracy, **(4)** guarantee high accuracy when needed, and **(5)** handle a variety of complex geometries.

Reservoir Labs' MACH-B (Multipole Accelerator Codes for Hadron Beams) project addresses the above five key elements, maintaining the strengths of PIC codes and approaches while further improving upon some of their weaknesses, allowing domain experts to evaluate and optimize various scenarios for complex high-energy physics experiments. The MACH-B technology is based on both existing and novel mathematical frameworks, providing scalable, high-performance algorithms that will assist in accurately and rapidly computing a variety of complex particle accelerator simulations; specifically, (1) **Fast Multipole Methods (FMM)** and (2) **Boundary Integral Solvers (BIS)**.

Introduction to Fast Multipole Methods

FMM approaches achieve linear scaling by separating near- and far-field interactions (e.g., see Fig. 2) on a spatial hierarchy using tree data structures. As they achieve arbitrary precision at modest cost with straightforward error estimates [1, 2, 4–6, 15–20], FMM techniques are well-suited for problems requiring high accuracy at large scales, such as in particle accelerator simulations.

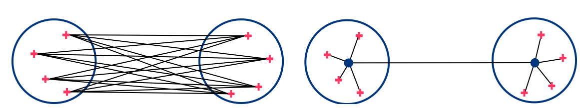


Figure 2: (*Left*): A naive $O(N^2)$ approach for computing the interactions between well-separated sources and targets. (*Right*): Using multipole and local expansions to reduce far-field costs, based on refinement.

FMMs are **inherently multiscale**, separating a regular domain into disjoint sets, using a tree structure to **exploit locality** as well as **reduce the expense of non-locality** through low-rank approximation multipole expansions [1, 4]. FMMs compute the total field at a domain B as the sum of (a) the field due to the sources contained in its near field $\mathscr{N}^B$ and (b) its far field $\mathscr{F}^B$. Contributions from $\mathscr{N}^B$ are computed using direct, dense summations, while contributions from $\mathscr{F}^B$ are obtained by evaluating approximating expansion coefficients, constructed to achieve far-field low-rank approximations at computationally-efficient and provably-accurate levels of accuracy. Through two parameters ((1) for points per smallest grid in the hierarchy and (2) for number of coefficients in the expansions), **high accuracy is guaranteed** [2, 3, 21].

* This work was supported by the U.S. Department of Energy as part of the SBIR Phase I Project DE-SC0020934.
† langston@reservoir.com

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV049

STANDARDIZING A PYTHON DEVELOPMENT ENVIRONMENT FOR LARGE CONTROLS SYSTEMS *

S. Clark, P. Dyer, S. Nemesure, BNL, Upton, NY 11973, U.S.A.

Abstract

Python provides broad design freedom to programmers and a low barrier of entry for new software developers. These aspects have proven that unless standardized, a Python codebase will tend to diverge from a common style and architecture, becoming unmaintainable across the scope of a large controls system. Mitigating these effects requires a set of tools, standards, and procedures developed to assert boundaries on certain aspects of Python development — namely project organization, version management, and deployment procedures. Common tools like Git, GitLab, and virtual environments form a basis for development, with in-house utilities presenting their capabilities in a clear, developer-focused way. This paper describes the necessary constraints needed for development and deployment of large-scale Python applications, the function of the tools which comprise the development environment, and how these tools are leveraged to create simple and effective procedures to guide development.

GOALS

Python has grown in popularity since its 1991 inception, with wide use in scientific and analytic applications. The myriad libraries released to simplify complex tasks — such as Numpy and SciPy for scientific calculations, and the PyQt5 user interface toolkit for application development — have driven increased adoption within the Collider-Accelerator Department (C-AD) Controls Group at BNL. As this adoption began, many developers created simple scripts scattered across the filesystem, which grew into operation-critical applications over many years. Long-term maintenance of these scripts is difficult for future developers who must now not only learn the codebase, but also the unique project structure and procedures of dozens of disparate programs. The primary goal of the Python development environment is to alleviate the manageability issues described above.

PYTHON DISTRIBUTION

An essential requirement for Python usage in a large complex must be to establish a common base across all workstations. The Anaconda Python distribution provides exactly this, with each version containing a specific set of Python binaries and packages. Additionally, Anaconda is well-supported with first- and third-party tools to ease maintenance and deployment of distribution upgrades.

Initially, the Anaconda distribution was installed to a network mount which was globally available to all hosts, and any necessary packages (in addition to the standard set) were installed directly upon request. However, two primary issues were encountered with this method: performance and maintainability. Performance issues appeared shortly after the adoption, which manifested in slow application launch times. Latency and bandwidth limitations over the network were discovered as the probable cause. Maintainability was further impacted by cascades of package upgrades triggered by new package installations, leading to previously-working scripts and programs breaking due to backwards incompatibilities unless careful intervention was taken during the process.

The deployment philosophy for the Anaconda distribution was changed to account for both issues. As mentioned above, inhibited performance was found to stem from network latency. During investigation, locally-installed copies of the Anaconda distribution showed a marked decrease in application launch time. Resulting from the discovery, the Anaconda distribution was moved from the network share to local disk on each host requiring Python. The tool `conda-pack` [1] facilitates this by allowing system administrators to create a portable clone of the Anaconda distribution which then can be extracted and installed locally on machines for use.

On a yearly schedule, the Anaconda distribution is rebuilt and redistributed. This provides an opportunity for Python and package upgrades, base package additions, as well as other general maintenance of the distribution. The newest distribution is constructed on a machine, tested for general compatibility, and finally deployed to all machines using the `conda-pack` tool as described above. Two local copies of Anaconda are maintained upon release of a new distribution — the new version and the prior version – guaranteeing Applications two years of first-class support, allowing developers to migrate to newer Anaconda releases at their own pace. Distributions prior to the two locally-kept copies are available on the network share. This limits the local disk usage by Anaconda versions, but reintroduced issues with network latency. This, however, should be mitigated if applications are regularly maintained and released using the latest available distribution.

PROJECT CREATION & ORGANIZATION

A unified project architecture is key for ongoing maintainability and standardization of development procedures. The details of how projects are structured at the file level are equally important as aspects of development such as a standard package base, ensuring that developed procedures work equally across any project created within the development environment.

* Work supported by Brookhaven Science Associates, LLC under Contract No. DE-SC0012704 with the U.S. Department of Energy

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV050

DevOps AND CI/CD FOR WinCC OPEN ARCHITECTURE APPLICATIONS AND FRAMEWORKS

R. P. I. Silvola, CERN, Geneva, Switzerland
L. Sargsyan, A. Alikhanyan National Laboratory (former YerPhI), Yerevan, Armenia

Abstract

This paper presents the Continuous Integration and Continuous Deployment (CI/CD) tool chain for WinCC Open Architecture applications and frameworks developed at CERN, enabling a DevOps oriented approach of working. By identifying common patterns and time consuming procedures, and by agreeing on standard repository structures, naming conventions and tooling, we have gained a turnkey solution which automates the compilation of binaries and generation of documentation, thus guaranteeing they are up to date and match the source code in the repository. The pipelines generate deployment-ready software releases, which pass through both static code analysis and unit tests before automatically being deployed to short and long-term repositories.

The tool chain leverages industry standard technologies, such as GitLab, Docker and Nexus. The technologies chosen for the tool chain are well understood and have a long, solid track record, reducing the effort in maintenance and potential long term risk. The setup has reduced the expert time needed for testing and releases, while improving the release quality.

INTRODUCTION

The CERN Industrial Control Systems Group of the Beams Department (CERN BE/ICS) [1] provides support and software solutions to the SIMATIC WinCC Open Architecture (WinCC OA) [2] community for setting up SCADA applications. This includes general infrastructure (cryogenics, electricity, radiation protection, etc) as well as controls for the experiments, and associated institutes. The group provides a CERN specific distribution of WinCC OA, repackaging the software released by ETM Professional Control, a Siemens AG subsidiary. In addition, the group develops and maintains WinCC OA applications, as well as frameworks for building such applications, and for connecting them to the CERN IT infrastructure.

The WinCC OA software catalogue supported by the group spans hundreds of applications and two frameworks composed of a large set of components, totalling up to millions of lines of source code written in multiple languages, including C++, PL/SQL, CTRL – which is a WinCC OA proprietary scripting language, and others. Many of these projects are required to run on both Linux and Windows, increasing their complexity.

While the code itself has always been kept in a central repository, the procedures for building a release, including compilation, packaging and deployment to our package repositories, were left to the developer in charge of each individual project. This approach meant that each component was built in a different way, and releases were only possible to be done when the expert was present. Much of this was standardized by the introduction of ARES [3], yet the approach taken was in a way upside down, requiring many manual steps for releases, leading to automated commits to the repository. This required developers to change contexts each time a release was to be prepared, be it for validation or for production, and the automated commits resulted in unnecessary pollution of the commit log, making it hard to read.

While ARES greatly simplified and automated releases, there was a disconnect between development and releases. The tools used for the release infrastructure were based on technologies poorly understood by framework developers, which lead to recurrent delays while debugging issues as the ARES expert intervention was required. The tooling, while advanced, was designed with Java projects in mind, which differ radically from WinCC OA and Frameworks development.

To alleviate these issues, a deep look was taken into the development processes, and based on it, a new set of tooling was designed and put in place. The resulting DevOps processes and CI/CD infrastructure are described in the next sections.

WORKFLOW

Deciding on a workflow (see Fig. 1) for development with git, the industry "standard" git flow was adopted, later morphing closer to the GitHub flow [4]. For any given project the master branch is considered stable, yet not necessarily production quality. There is no development branch, simply bug fix and feature branches, all of which tend to be short-lived. The frequent merges promote targeted and granular development, reducing the occurrence and probability of complicated and time-consuming merge conflicts.

To start development for a bug fix or a feature, the developer manually creates a ticket in the ticketing system. The name of that ticket is then used as the branch name. On that branch each commit produces a release that can be passed on for validation by users. Once a merge request is created, unit tests are automatically run, and each subsequent push will trigger a new set of tests to be executed. After a review and with the tests successful, the branch is merged into master, resulting in a snapshot build. A tag produces a release that is automatically deployed into an array of repositories. All the steps of the process can be performed either from the command line interface, or from a single browser tab.

For a developer this is a natural workflow, while GitLab [5] allows for less technically minded people to create releases as well, after a short training session.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUAL02

DEVELOPMENT OF A SINGLE CAVITY REGULATION BASED ON MicroTCA.4 FOR SAPS-TP

W. Long†, X. Li, Y. Liu, S. H. Liu
Institute of High Energy Physics Dongguan Campus, Chinese Academy of Sciences, Dongguan, China

Abstract

A domestic hardware platform based on MTCA.4 is developed for a single cavity regulation in Southern Advanced Photon Source Test Platform (SAPS-TP). A multi-function digital processing Advanced Mezzanine Card (AMC) works as the core function module of the whole system, it implements high speed data processing, Low-Level Radio Frequency (LLRF) control algorithms and an interlock system. Its core data processing chip is a Xilinx ZYNQ SOC, which is embedded an ARM CPU to implement EPICS IOC under embedded Linux. A down-conversion and up-conversion RTM for cavity probes sensing and high-power RF source driver can communicate with AMC module by a ZONE3 connector. A hosted tuning control FPGA Mezzanine Card (FMC) combines both the piezo controlling and step-motor controlling functions for independent external drive devices. The design of the hardware and software of the platform electronics and some test results are described in this paper. Further test and optimization is under way.

INTRODUCTION

The SAPS-TP is next to the China Spallation Neutron Source (CSNS) which is located at Dongguan City, Guangdong Province in China. It is an innovative research platform for advanced accelerator and X-ray technologies serving Southern Advanced Photon Source (SAPS) which will be built as a 4th generation light source based on diffraction limit storage ring, and the CSNS II which is the upgrade of the CSNS. It is mainly composed of a superconducting RF hall, an optical experiment hall, a low temperature hall, a high-accuracy measurement hall and a comprehensive laboratory [1].

The superconducting RF hall is about 3500 m^2. It has 2 vertical test pits and a horizon test station can be applied for assembling and test of the 324 MHz spoke cavity, 648 MHz elliptical cavity, 500 MHz elliptical cavity and 1.3 GHz elliptical cavity, etc.

The function of the single cavity regulation includes amplitude and phase stabilization controlling of cavity field, resonance controlling, continue waveform (CW) or pulse mode conversion and fast interlocking, etc.

MTCA.4 system is the new generation embedded digital hardware platform specifically for high energy physics applications. It is a modular, open standard architecture with high reliability, which is becoming more and more popular, and widely used in European X-ray Free Electron Laser (EXFEL), European Spallation Source (ESS) and Stanford Linear Accelerator Center (SLAC), and so on.

A domestic hardware platform based on MTCA.4 is developed for SAPS-TP single cavity regulation. The system architecture and the development of hardware platform based on MTCA.4 are described in this paper.

SYSTEM ARCHITECTURE

The single cavity regulation for SAPS-TP is mainly used to control to RF field and the resonance frequency of the cavity. The block diagram of the system design is shown in Fig. 1.

Dedicated RF power source (klystrons or solid-state amplifier (SSA)) is used to feed the cavity with required input power. In the RTM module, the forward and reflected power signals, the cavity pick-up signal and the reference RF signal are down-converted to intermediate frequency signals using analog mixers driven by local oscillator signal (LO).

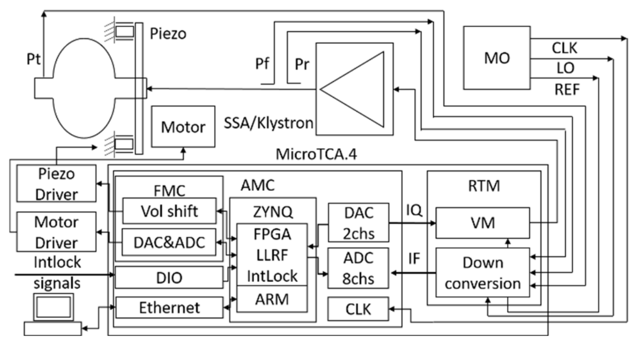


Figure 1: Design of single cavity regulation for SAPS-TP.

The LLRF system implements the cavity RF field controlling feedback loop to keep the RF field amplitude and phase stability [2, 3].

The master oscillator provides RF synchronization signals, such as the reference signal (REF), LO signal and the clock (CLK). In the AMC module, the intermediate frequency signals are sampled by ADCs with the frequency of CLK. Next, the raw data are demodulated to in-phase (I) components and quadrature (Q) components with the IQ or no-IQ algorithm. Errors between setpoint values and detected values are sent to PI controller. The digital I/Q output of PI controller are sent to DACs and are converted to analog I/Q signals. The baseband I/Q signals are then mixed with the in-phase and quadrature-phase components of a REF signal whose frequency is located at the required RF frequency to generate final RF excitation signal. This process is called up-converted which implemented by the vector modulator device of the RTM module.

The superconducting cavity is very susceptible to small changes in dimension, because of its very narrow RF resonance bandwidth. The equipped mechanical tuners can tune the cavity to a resonance frequency. There are two types of tuners, the slow tuners are based on step motors, and the fast tuners are based on piezo elements. The LLRF

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUAL03

R&D STUDIES FOR THE ATLAS TILE CALORIMETER DAUGHTERBOARD * †

Eduardo Valdes Santurio‡, Samuel Silverstein, Christian Bohm,
Suhyun Lee, Katherine Dunne, Holger Motzkau
Stockholm University, Stockholm, Sweden

Abstract

The ATLAS Hadronic Calorimeter DaughterBoard interfaces the on-detector with the off-detector electronics. The DaughterBoard features two 4.6 Gbps downlinks and two pairs of 9.6 Gbps uplinks powered by four SFP+ Optical transceivers. The downlinks receive configuration commands and LHC timing to be propagated to the front-end, and the uplinks transmit continuous high-speed readout of digitized PMT samples, detector control system and monitoring data. The design minimizes single points of failure and mitigates radiation damage by means of a double-redundant scheme. To mitigate Single Event Upset rates, Xilinx Soft Error Mitigation and Triple Mode Redundancy are used. Reliability in the high speed links is achieve by adopting Cyclic Redundancy Check in the uplinks and Forward Error Correction in the downlinks. The DaughterBoard features a dedicated Single Event Latch-up protection circuitry that power-cycles the board in the case of any over-current event avoiding any possible hardware damages.

We present a summary of the studies performed to verify the reliability if the performance of the DaughterBoard revision 6, and the radiation qualification tests of the components used for the design.

INTRODUCTION

The instantaneous luminosity at HL-LHC will be increased by a factor of five compared to the LHC. Consequently, the read-out systems of the ATLAS detector [1] will be exposed to higher radiation levels and increased rates of pileup. The current electronics for the read-out system of the ATLAS Tile Calorimeter (TileCal) will not be able to handle the new requirements imposed by the HL-LHC. R&D work is ongoing to upgrade the TileCal electronics with a new design that will provide continuous digital read-out of all the calorimeter cells with better energy resolution, improved timing and less sensitivity to out-of-time pileup [2]. The upgrade R&D work requires Total Ionizing Dose (TID), Non Ionizing Energy Loss (NIEL) and Single Event Effects (SEE) tests to be performed on the upgraded on-detector electronics, to qualify the design as reliable for the HL-LHC radiation environment.

* Work supported by Stockholm University and CERN.

‡ eduardo.valdes@fysik.su.se, eduardo.valdes@cern.ch

ATLAS TILE CALORIMETER

TileCal is a sampling calorimeter with plastic scintillator tiles and steel plates as active and absorber materials, respectively. TileCal is longitudinally divided into four cylindrical barrels (Fig. 1b) each comprising 64 wedge-shaped modules (Fig. 1c). Scintillator light is collected on each side of a pseudo-projective cell by wavelength shifting fibers and read out by a pair of PMTs.

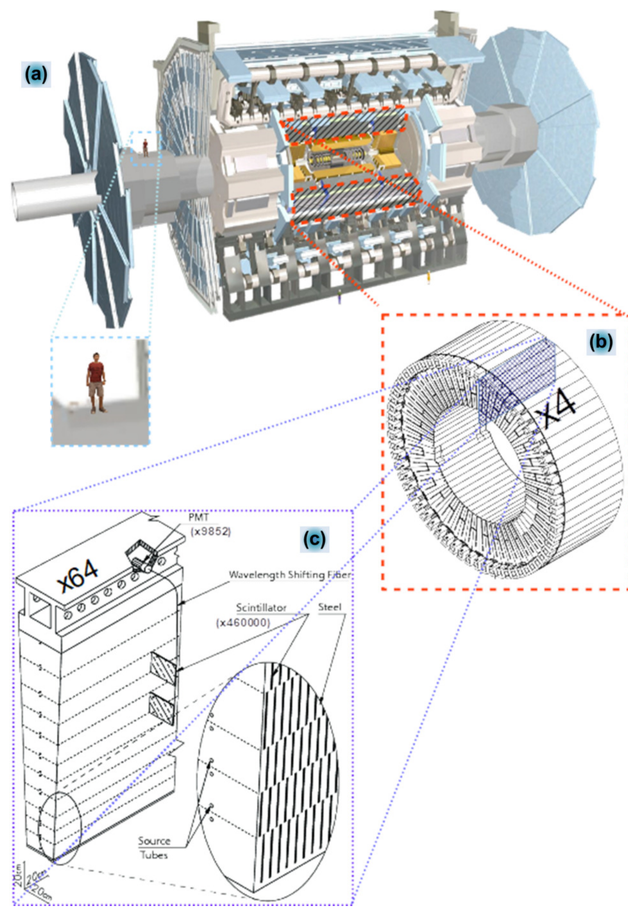


Figure 1: (a) The ATLAS detector. (b) A TileCal barrel. (c) Depiction of a TileCal wedge-shaped module.

THE TILECAL HL-LHC UGPRADE SYSTEM

The TileCal HL-LHC upgrade on-detector electronics will continuously sample data from all TileCal PMTs at 40 MHz by means of 896 independent modules, so-called MiniDrawers (MD). Each MD servicing up to six pairs of

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUAR01

UPGRADE OF THE CMS ECAL DETECTOR CONTROL SYSTEM DURING THE CERN LARGE HADRON COLLIDER LONG SHUTDOWN II*

L. Marchese†, D. Di Calafiori, G. Dissertori, L. Djambazov, R. J. Estupiñán, W. Lustermann,

ETH Zürich, Zürich, Switzerland

Abstract

As part of the Compact Muon Solenoid (CMS) experiment, the Electromagnetic Calorimeter (ECAL) Detector Control System (DCS) is undergoing a large software and hardware upgrade during the second long shutdown (LS2) of the CERN Large Hadron Collider (LHC). The DCS software running under the WinCC Open Architecture (OA) platform, required fundamental changes in the architecture as well as several other upgrades on the hardware side. The extension of the current long shutdown (2019-2021) is offering a unique opportunity to perform more updates, improve the detector safety and robustness during operations and achieve new control features with an increased modularity of the software architecture. Starting from the main activities of the ECAL DCS upgrade plan, we present the updated agenda for the LS2. This covers several aspects such as the different software migrations of the DCS, the consolidation of toolkits as well as some other improvements preceding the major ECAL upgrade foreseen for the next long shutdown (2025-2026).

INTRODUCTION

The CMS (Compact Muon Solenoid) [1] experiment at the CERN Large Hadron Collider (LHC) is a general multi-purpose detector designed primarily to probe proton-proton and heavy ion collisions. The detector is built around a huge superconducting solenoid of 6m internal diameter providing a magnetic field of 3.8 T. A silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter and a brass scintillator hadron calorimeter are located within the solenoid volume. Muon detectors are embedded in the steel flux-return yoke outside the solenoid.

The electromagnetic calorimeter consists of about 76,000 $PbWO_4$ scintillating crystals and a lead/silicon preshower. The detector is conventionally sub-divided in three main partitions: Barrel (EB), Endcaps (EE) and preshower (ES). The EB is organised in 36 super-modules forming a cylinder around the proton-proton interaction point. Each super-module contains 1700 crystals arranged in four modules. The EEs are the structures which close both ends of this cylinder with each of them formed by two half disks named DEEs and containing 3662 crystals. The ES consists of two circular structures placed in front of the EEs. More details on the CMS ECAL detector can be found in [2].

The challenging constraints on the design of the ECAL required the development of a complex sophisticated Detector Control System (DCS). The ECAL DCS has successfully supported ECAL operations since the commissioning phase of the detector contributing to an efficient data collection during Run 1 and Run 2 operations. Detector maintenance at CMS closely follows the LHC calendar with major upgrades postponed to special times, known as the Extended Year-End Technical Stops (EYETS) and the LHC Long Shutdowns (LS). We are currently in the second major long shutdown LS2 [3] since the start of the LHC. Initially planned to last two years until April 2021, due to the ongoing COVID-19 pandemic the LS2 was extended by one year. During the LS2 both hardware and software upgrades were performed, as described in [4]. In this paper we focus on the software upgrades, including the software migration which allowed the ECAL DCS to be up-to-date with the latest versions of the control platform and frameworks.

This paper is organized as follows. After describing the CMS ECAL DCS, we describe the software upgrade performed during LS2 where different upgrades are reported in four subsections. An additional section reports on the reorganization of the notification system of the ECAL DCS, which also took place during LS2. Finally, we summarize the contents in the last section.

THE CMS ECAL DCS

The ECAL DCS was designed to ensure an autonomous control and monitoring of the working conditions of the ECAL detector and to guarantee the detector is properly powered and able to collect data when the LHC is operational. The ECAL DCS is organised according to the detector services it provides, where the latter can be categorized in four different groups: powering services, safety services, environmental monitoring services (humidity and temperature) and external services. The ECAL DCS architecture is schematically shown in Fig. 1.

The DCS software supervises the interaction among the different subgroups mentioned above and runs on three DELL blade servers installed with the Windows Server 2008 R2 operating system. A redundant software replica is also available in the event of a critical failure of the primary system. The DCS software is assembled via the commercial WinCC Open Architecture (WinCC OA) control system toolkit from ETM [5] along with CERN software frameworks known as JCOP Framework [6] and components developed by the Central CMS DCS team [7]. Industry standards, as OPC Data Access (OPC DA), Modbus and

* on behalf of the CMS Collaboration

† luigi.marchese@cern.ch

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUAR03

THE CONTROL SYSTEM OF THE LINAC-200 ELECTRON ACCELERATOR AT JINR

A. Trifonov*, M. Gostkin, V. Kobets, M. Nozdrin, A. Zhemchugov, P. Zhuravlyov,
Joint Institute for Nuclear Research, Dubna, Russia

Abstract

The linear accelerator Linac-200 at JINR is constructed to provide electron test beams with energy up to 200 MeV to carry out particle detector R&D, to perform studies of advanced methods of beam diagnostics, and to work as an irradiation facility for applied research. While the accelerator largely reuses refurbished parts of the MEA accelerator from NIKHEF, the accelerator control system is completely redesigned. A new distributed control system has been developed using the Tango toolkit. The key subsystems of the accelerator (including focusing and steering magnets control, vacuum control system, synchronization system, electron gun control system, precise temperature regulation system) were redesigned or deeply modernized. This report presents the design and the current status of the control system of the Linac-200 machine.

INTRODUCTION

Linear electron accelerator Linac-200 (Dzhelepov Laboratory of Nuclear Problems, JINR, Dubna, Russia) is a unique facility intended for scientific and methodological research in the field of accelerator physics and technology, elementary particles detectors research and development, as well as fundamental and applied research in the fields of materials science and radiobiology. It is based on the MEA linear electron accelerator which was transferred to JINR from NIKHEF in the end of 90s.

Main accelerator structure unit is a station. The injector station A00 includes the electron gun, chopper, prebuncher and buncher. First accelerator station A01 includes one accelerating section and a klystron, which also feeds the RF equipment of the A00 station. All the rest stations include two accelerating sections and a klystron each.

Current setup (Fig. 1) consists of 5 stations, A00–A04, and allows generation of the 200 MeV electron beam. In the future it is planned to increase the number of stations up to thirteen, and the energy will accordingly increase up to 800 MeV [1].

Almost all MEA equipment is in good condition and has reasonable operating resource. However, control systems hardware and software, as it is the most rapidly developing sphere, were mostly out-of-date already at the moment of accelerator transfer from NIKHEF to JINR. Therefore, two major accelerator control system upgrades took place. The first one was continuous, when necessary control subsystems were developed when they were needed [2]. The second one started in 2018 when development of the new global control system began [3].

The global control system automatically collects, processes, stores and displays information about the operation of the accelerator, as well as about the state of the technological equipment involved in the operation of the accelerator. Also, the global control system provides the ability to automatically control individual accelerator subsystems.

The main requirements for the Linac-200 global control system is high reliability, safety, simplicity of software development, and ease of technical support. There should be an opportunity for future modifications and extensions. The software of the global control system should use standard interfaces for interaction between components and be able to use existing developments of the world community.

Tango Controls allows to create control systems that meet these requirements. It is also worth mentioning that the control system for the NICA collider at JINR is being developed using Tango [4]. Therefore, it was decided to implement a new global control system for the Linac-200 accelerator based on Tango.

CONTROL SYSTEM CONCEPT

Tango Controls

Tango Controls is a free open source device-oriented controls toolkit for controlling any kind of hardware or software and building supervisory control and data acquisition (SCADA) systems. The fundamental unit of Tango is a device, which is an abstraction hiding real equipment or program component behind the standard interface. Tango provides high level client application interface which has necessary programming classes to implement client-server communications – synchronously or asynchronously execute commands, read or write attributes, or use events to acquire the data from the Tango devices. Tango incorporates a number of tools to build efficient control system environment including centralized administration and monitoring, access control, logging system, data archiving and code generation for rapid development of the Tango device servers using C++, Java and Python [5].

* trifonov@jinr.ru

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUBL01

DISTRIBUTED CACHING AT CLOUD SCALE WITH APACHE IGNITE FOR THE C2MON FRAMEWORK

T. Oliveira*, D. Martin Anido, M. Braeger, B. Copy, S Halastra, A. Papageorgiou Koufidis
CERN, Geneva, Switzerland

Abstract

The CERN Control and Monitoring platform (C2MON) [1] is an open-source platform for industrial controls data acquisition, monitoring, control and data publishing. Its high availability, fault tolerance and redundancy make it a perfect fit to handle the complex and critical systems present at CERN. C2MON must cope with the ever-increasing flows of data produced by the CERN technical infrastructure, such as cooling and ventilation or electrical distribution alarms, while maintaining integrity and availability. Distributed caching [2] is a common technique to dramatically increase the availability and fault tolerance of redundant systems. For C2MON we have replaced the existing legacy Terracotta [3] caching framework with Apache Ignite [4]. Ignite is an enterprise grade, distributed caching platform, with advanced cloud-native capabilities. It enables C2MON to handle high volumes of data with full transaction [5] support and makes C2MON ready to run in the cloud. This article first explains the challenges we met when integrating Apache Ignite into the C2MON framework, and then demonstrates how Ignite enhances the capabilities of a monitor and control system in an industrial controls environment.

INTRODUCTION TO C2MON

C2MON is an open-source monitoring platform developed at CERN. C2MON acts as the backbone of the Technical Infrastructure Monitoring system (TIM) that is used to monitor and control CERN's technical services from the CERN Control Centre (CCC) [6]. The main function of TIM is to provide reliable and real-time data to CCC operators about the state of CERN's widely distributed technical infrastructure. To handle such a large volume of information while maintaining data integrity, C2MON uses Java Message Service (JMS) [7] technologies together with caching technologies. Caching involves storing information in a separate low-latency data-structure for a period of time to be reused and consequently minimizing the cost of re-accessing it [2]. The existing C2MON caching layer relied on a legacy Terracotta Ehcache framework [3]. Ehcache is a widely-used Java-based cache that is fast, lightweight and can be scalable through the use of a Terracotta Server that provides distributed caching capabilities [3].

C2MON uses a 3-tier architecture, as presented in Fig. 1, that composes a Data Acquisition (DAQ) Layer, the Server Layer and a Client Layer. The DAQ layer is responsible for acquiring data from specific sources and publishing it to the C2MON server tier. The Client layer provides various

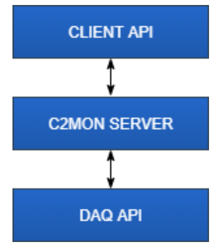


Figure 1: C2MON Architectural Overview.

service classes that allow to interact with the server. The Server layer, which is the core part of C2MON, is responsible for receiving and handling the data.

Most of the information in C2MON is stored and used in the form of Tag which changes frequently as new data from the DAQ is received and evaluated by the system. In order to evaluate the correct and normal values of each Tag, C2MON provides an Alarm mechanism. The Alarm is a declaration associated with a Tag and contains a condition specifying the legal values of that Tag. If the new value received is outside the legal value range, the Alarm is activated and pushed to the client. Finally, the C2MON server layer also provides a rule engine with a set of operations, that allows expressing complex computations, comparisons and conditions.

INTRODUCTION TO APACHE IGNITE

"Apache Ignite is an open-source memory-centric distributed database, caching and computing platform" [4].

Ignite provides a simple interface to work with large data sets in real time. It is written in pure Java, based on Spring and supports different technologies like Java, C# and C++. The main capabilities that Apache Ignite provides are

- Elasticity: The Ignite cluster can grow horizontally simply by adding new nodes over a TCP connection.
- Persistence: Cache entries can be persisted on a file system or in an RDBMS (Relational Database Management System).
- Distributed computing: Apache Ignite provides a set of APIs that facilitate the distribution of computation and data processing across the nodes in the cluster for better performance; it simplifies greatly the development of a microservice-based architecture.
- Streaming: Ignite allows the processing of continuous streams of data (which C2MON uses to receive cache events asynchronously through continuous queries).

Ignite includes the notion of client and server nodes, where a node is a single Ignite instance running in a JVM (Java Virtual Machine). In a client server architecture both client and server nodes are interconnected with each other. The server, which can be constituted by a single node or a group

* tiago.marques.oliveira@cern.ch

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUBL02

IMPLEMENTING AN EVENT TRACING SOLUTION WITH CONSISTENTLY FORMATTED LOGS FOR THE SKA TELESCOPE CONTROL SYSTEM

S.N. Twum*, W. Bode, A. F. Joubert, K. Madisa, P.S. Swart, A. J. Venter
SARAO, Cape Town, South Africa
A. Bridger, UKATC, Edinburgh; SKAO, Macclesfield

Abstract

The SKA telescope control system comprises several devices working on different hierarchies on different sites to provide a running observatory. The importance of logs, whether in its simplest form or correlated, in this system as well as any other distributed system is critical to fault finding and bug tracing. The SKA logging system will collect logs produced by numerous networked kubernetes deployments of devices and processes running a combination off-the-shelf, derived and bespoke software. The many moving parts of this complex system are delivered and maintained by different agile teams on multiple SKA Agile Release Trains. To facilitate an orderly and correlated generation of events in the running telescope, we implement a logging architecture which enforces consistently formatted logs with event tracing capability. We discuss the details of the architecture design and implementation, ending off with the limitations of the tracing solution in the context of a multiprocessing environment

PREVIEW TO THEORY AND SKA SYSTEM ARCHITECTURE

Observability and Monitoring in a Distributed System

Logs have long been the de facto approach used to sample parts and peek into the internal state of a running program. Coupled with metrics, monitoring can be done across a system to understand its health at any given time. Inasmuch as this age old approach has been very beneficial to developers, especially for debugging purposes, it is limited in its diagnostic ability in distributed environments. Monolithic applications are easily observable using only logs and metrics. But in the dawn of the era of microservice architecture, logging alone is not adequate to debug and probe the internal state of such a system. Distributed systems with different services and multiple instances of these services need a correlated view of events to troubleshoot errors. It now requires the use of logs, metrics and traces, all together producing the emergent quality of this new buzz word, “observability”. J. Heather explains observability as inferring the internal state of a system from its external outputs. But it is not just the ability to see what is going on in your systems. It’s the ability to make sense of it all, to gather and analyze the information you need to prevent incidents from happening, and to trace their path when they do happen, despite every safeguard, to make sure they don’t happen again[1]. Full observability of a distributed system is a function of three pillars [2], namely:

- Logs: a snapshot of an event in a running system.
- Metrics: measurement of activities on a running system, e.g. CPU load.
- Tracing: A trace is a representation of a series of causally related distributed events that encode the end-to-end request flow through a distributed system [2].

An Overview of the SKA Telescope Control System Architecture

The SKA telescope control system will be a collection of software and services running from two sites which will be controlled from HQ in Jodrell Bank. The software consists of Tango Devices managing specific telescope hardware, and processes running all manner of software which are maintained by 17 or more teams on our Agile Release Trains (ARTs) [3]. The control system has a hierarchical structure to reduce complexity. The TANGO device is an abstraction hierarchy that has functional purpose at the top, and that goes down to physical form at the bottom. The frequency of intervention required at the different levels are different, increasing as you go downward the hierarchy (the Telescope Operator will exercise low frequency supervisory control, while at the lowest level you find real-time, closed loop feedback control) [4]. Control propagates downward (with fan-out) through this hierarchical structure. This is one source of causal path for events to propagate through the system.A specialisation of this hierarchical structure is that of the sub-array, an aggregation of telescope resources that are engaged for use in an observation [5]. Figure 1 illustrates the usage of sub-array nodes to control of the Mid telescopes.

During the lifetime of a running telescope, commands are triggered, events are fired, threads are spawned, several things are happening at the same time and it is not a trivial task to have end to end observability of the running system. This complex network exudes all the characteristics and challenges that are inherent in distributed systems. Though the various moving parts of the system are well tested, they are susceptible to faults and the ability to pin point a glitch to an exact root cause, following it through the various parts can only be provided in a distributed tracing system.

* stwum@sarao.ac.za

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUBL03

Tango CONTROLS RFCs

V. Hardion, MAXIV Sweden, Lund, Sweden
A. Götz, R. Bourtembourg, ESRF, Grenoble, France
S.Blanch-Torné, ALBA-CELLS Synchrotron, Cerdanyola del Vallès, Spain
L. Pivetta, Elettra-Sincrotrone Trieste S.C.p.A., Basovizza, Italy
P.P. Goryl, M. Liszcz, S2Innovation, Kraków, Poland

Abstract

In 2019, the Tango Controls Collaboration decided to write down a formal specification of the existing Tango Controls protocol as Requests For Comments (RFC). The work resulted in a Markdown-formatted specification rendered in HTML and PDF on Readthedocs.io. The specification is already used as a reference during Tango Controls source code maintenance and for prototyping a new implementation. All collaborating institutes and several companies were involved in the work. In addition to providing the reference, the effort brought the Community more value: review and clarification of concepts and their implementation in the core libraries in C++, Java and Python. This paper summarizes the results, provides technical and organizational details about writing the RFCs for the existing protocol and presents the impact and benefits on future maintenance and development of Tango Controls.

INTRODUCTION

The TANGO control system is a device-oriented controls toolkit for controlling any kind of hardware or software and building SCADA systems.

The first version of the Tango Controls was designed and developed more than 20 years ago [1]. Since then, it has evolved to follow technology progress and needs of new features and improve its quality. There are still some technical challenges that relate to the legacy of the source code and dependency.

One of the challenges is concerning the heart of TANGO, which use CORBA for all the client/server communication. This open architecture allows distributed objects to communicate with each other, which is a perfect match for a scientific and heterogeneous control system like Tango, considering each hardware as an object.

From its date of creation, CORBA has seen different support from big names in the industry, even being part of the standard library of programming languages like Java. This architecture was the seed of many other types of architecture like web services (JBOSS).

Motivation

Nowadays, CORBA is still used by very specific domains but not maintained to face the evolution of computer science. In 2013 the Tango Community mentioned for the first time a study for the replacement of CORBA.

The implementation reference of Tango written in C++ shows a real entanglement inside the source code, in which OmniORB, the C++ CORBA library, is leaking in all the public API. Removing CORBA would mean refactoring the entire Tango C++ library by abstracting at many different levels.

Backward compatibility in Tango is essential, and the idea to replace the library would generate a lot of uncertainty regarding the fundamentals of Tango. Having a precise specification, an idea that emerged during the 2018 Tango kernel meeting in Krakow and lacking before the RFC project, would have been the best way to remove this risk.

Implementation Agnostic The Community works towards improving the maintainability of Tango Controls. The Collaboration proactively makes the framework immune to obsolesce of libraries and technologies (e.g. CORBA) it is based on. It is expected it may require rewriting all source code-base for a particular language.

Knowledge sharing Another factor to consider is the retirement of the initial Tango Developers. There is a risk of losing a deep knowledge of the Tango protocol implementation. Before the RFCs, the tango library source code was, in fact, the only specification. This could lead to losing the compatibility between versions of the Tango Controls or between libraries for different programming languages after bug fixes or features' implementations.

Compatibility The Community has found that formal documentation of the protocol and Tango Controls concepts is needed [2]. This assures that maintenance and development will not break compatibility.

WRITING RFCS

Writing proper specifications, understandable by software developers and not influenced by the implementation, was not an exercise that the Tango community used to do.

The model of the specification was inspired by the process established by ZMQ [3] which is one of the protocols used by Tango with an open specification and very well documented process called Request For Comments (RFC).

After a presentation at the 2019 Tango Meeting (DESY, Hamburg 2019), it was decided to start writing the specification with the involvement of all major institutes and companies that use Tango Controls.

The Process

The Tango RFC process is a clone of the ZMQ RFC one with a minor adaption to the Tango organisation. The scope

18th Int. Conf. on Acc. and Large Exp. Physics Control Systems ICALEPCS2021, Shanghai, China JACoW Publishing
ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUBL04

CI-CD PRACTICES AT SKA

Di Carlo M.*, Dolci M., INAF Osservatorio Astronomico d'Abruzzo, Teramo, Italy
Harding P.[1], U. Yilmaz, SKA Organisation, Macclesfield, UK
Ribeiro B., Instituto de Telecomunicações Aveiro, Portugal
Morgado J. B., CICGE, Faculdade de Ciências da Universidade do Porto, Portugal

Abstract

The Square Kilometre Array (SKA) is an international effort to build two radio interferometers in South Africa and Australia forming one Observatory monitored and controlled from global headquarters (GHQ) based in the United Kingdom at Jodrell Bank. SKA is highly focused on adopting CI/CD practices for its software development. CI/CD stands for Continuous Integration & Delivery and/or Deployment. Continuous Integration is the practice of merging all developers' local copies into the mainline frequently. Continuous Delivery is the approach of developing software in short cycles ensuring it can be released anytime, and Continuous Deployment is the approach of delivering the software into operational use frequently and automatically. This paper analyses the decisions taken by the Systems Team (a specialized agile team devoted to developing and maintaining the tools that allow continuous practices) to promote the CI/CD practices with the TANGO-controls framework.

INTRODUCTION

When creating releases for end-users, every large software endeavour faces the problem of integrating different parts of their software solution and bring them to the production environment. When many parts of the project are developed independently for some time, an integration problem arises when merging them into the same branch, consuming more developer resources than originally planned. In a classic Waterfall Software Development process this is usual but also happens when following the classic Git Flow — also known as Feature-based Branching, which is when a branch is created for a feature. As an example, considering one hundred developers working in the same repository each of them creating one branch, merging can easily lead to conflicts becoming unmanageable, for a single developer to solve, thus introducing a delay in the releases (in literature this is called ”merge hell”). This problem becomes evident especially working with over a hundred repositories with different underlying technologies. Therefore, it is essential to develop a standard set of tools and guidelines to systematically manage and control different phases of the software development life cycle throughout the organisation.

In the Square Kilometre Array (SKA) project, the selected development process is SAFe Agile (Scaled Agile framework) that is incremental and iterative with a specialized team (known as the Systems Team) devoted to supporting the Continuous Integration, Continuous Deployment, test automation and quality.

* matteo.dicarlo@inaf.it

Continuous Integration (CI)

CI refers to a set of practices requiring developers to integrate code into a shared repository often. Each commit is verified by an automated build, allowing teams to detect problems early in the process, giving feedback about the state of the integration. Martin Fowler [1] states various practices in this regard:

- maintain a single source repository for each system's component, favouring the use of a single branch;
- automate the build (possibly all in one command);
- automated test is run after build process for the software to be self-testing (this is crucial: all benefits of CI rely on the test suite being high quality);
- every commit should build on an integration machine: the more developers commit the better it is (common practice is at least once per day);
- frequent commits reduce potential conflicts: developer workflow is reconciled on short windows of change;
- main branch must always be stable;
- builds must be fast so that problems are found quickly;
- multi-stage deployment: every software build must be tested in different environments (testing, staging, etc);
- make it easy to get the latest version: all programmers should start the day by updating their local copies;
- Everyone can see what's happening: a testing environment with the latest software should be running.

Continuous Delivery & Deployment (CD)

Continuous Delivery [2] refers to a CI extension focusing on sustainably automating the delivery of new software releases. Release frequency can be decided according to business requirements, but the greatest benefit is reached by releasing as quickly as possible. Deployment has to be predictable and sustainable, irrespective of whether it is a large-scale distributed system, complex production environment, embedded system, or app. Therefore the code must always be in a deployable state. Testing becomes the most important activity, needing to cover enough of the codebase.

Often, the unsupported fact that frequent deployment equals lower levels of stability and reliability, is assumed. For software, the golden rule should be "if it hurts, do it more often, and bring the pain forward" — [2], page 26.

There are many patterns around continuous deployment related to the DevOps culture [3], ”the outcome of applying

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUBL05

Pysmlib: A PYTHON FINITE STATE MACHINE LIBRARY FOR EPICS

D. Marcato[1,3,*], G. Arena[1], M. Bellato[2], D. Bortolato[1], F. Gelain[1], G. Lilli[1], V. Martinelli[1], E. Munaron[1], M. Roetta[1], G. Savarese[1],
[1]INFN Legnaro National Laboratories, 35020 Legnaro, Italy
[2]INFN Padova Division, 35131 Padova, Italy
[3]Department of Information Engineering, University of Padova, 35131 Padua, Italy

Abstract

In the field of Experimental Physics and Industrial Control Systems (EPICS) [1], the traditional tool to implement high level procedures is the Sequencer [1]. While this is a mature, fast, and well-proven software, it comes with some drawbacks. For example, it's based on a custom C-like programming language which may be unfamiliar to new users and it often results in complex, hard to read code. This paper presents pysmlib, a free and open source Python library developed as a simpler alternative to the EPICS Sequencer. The library exposes a simple interface to develop event-driven Finite State Machines (FSM), where the inputs are connected to Channel Access Process Variables (PV) thanks to the PyEpics [2] integration. Other features include parallel FSM with multi-threading support and input sharing, timers, and an integrated watchdog logic. The library offers a lower barrier to enter and greater extensibility thanks to the large ecosystem of scientific and engineering python libraries, making it a perfect fit for modern control system requirements. Pysmlib has been deployed in multiple projects at INFN Legnaro National Laboratories (LNL), proving its robustness and flexibility.

INTRODUCTION

The Experimental Physics and Industrial Control Systems (EPICS) [1] is one of the most successful frameworks to develop control systems for physics facilities, being used at major laboratories and experiments all around the world. Its main feature is the implementation of the Channel Access (CA) (and the PV Access in newer versions), a standard protocol where the different parts of the control system can communicate. This provides a standard interface to access all the Process Variables (PV) and works as a hardware abstraction layer. Using this protocol, many components have been developed by the community to provide the core functionalities of a modern control system, like Phoebus [3] and React Automation Studio [4] for Graphical User Interfaces (GUI) or the Archiver Appliance [5] for historical data storage.

The sequencer is the tool proposed by the EPICS core developers to implement high level procedures and Finite State Machines (FSM) for process automation. This is an extension of the core software and was first proposed in 1991 in the EPICS paper [1] and originally developed at the Los Alamos National Laboratory. It defines a C-like language called State Notation Language to develop finite state machines which is transcompiled to C code and then compiled to machine code. The user can define states and transitions, while the sequencer takes care of low-level details like the connection with the Channel Access, the event handling and concurrency. Finally, the code is usually run as part of a EPICS input output controller (IOC), which is the piece of software which defines and publishes the PVs on the Channel Access.

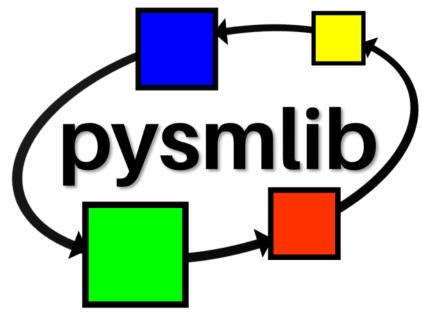


Figure 1: Pysmlib logo.

This software has proved valuable and has been widely adopted thanks to its good performance, seamless integration with the Channel Access and the IOC, and its programming model. Even so, some of its limitations have emerged over time. For example, being C-based was a great advantage at the beginning since it means that one could extend it with any C/C++ library. Today, higher level languages are preferred for this kind of high level tasks, and performance is no longer a limiting factor in most cases. For this reason Python has emerged as one of the most prominent languages for modern scientific and engineering computing, thanks to a large number of dedicated libraries. Also, Python appeals to a broader audience of less-technical programmers.

The PyEpics [2] python library, which wraps the original `libca` C library, became thus a popular alternative to communicate with the Channel Access. This can be used to write both simple scripts and full blown programs. Large experiments or collaborations used this, or similar wrappers, to build tightly integrated high level suites which handle automation and much more at facility level, such as ophyd and bluesky [6]. These are great solutions, but require a big investment into their design model, which could not be ideal for simple tasks or small independent laboratories. Also, at this level there is a lot of fragmentation in the community, with no default go-to solution but many different approaches tailored to the needs of specific laboratories.

* davide.marcato@lnl.infn.it, www.davide.marcato.dev

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUBR01

NOMINAL DEVICE SUPPORT (NDSv3) AS A SOFTWARE FRAMEWORK FOR MEASUREMENT SYSTEMS IN DIAGNOSTICS*

R. Lange†, ITER Organization, St. Paul lez Durance, France
M. Astrain, V. Costa, D. Rivilla, M. Ruiz, Grupo de Investigación en Instrumentación y Acústica Aplicada, Universidad Politécnica de Madrid, Madrid, Spain
J. Moreno, D. Sanz, GMV Aerospace and Defence, Tres Cantos, Spain

Abstract

Software integration of diverse data acquisition and timing hardware devices in diagnostics applications is very challenging. While the implementation should manage multiple hardware devices from different manufacturers providing different applications program interfaces (APIs), scientists would rather focus on the high-level configuration, using their specific environments such as Experimental Physics and Industrial Control System (EPICS), Tango, the ITER Real-Time Framework or the MARTe2 middleware.

The Nominal Device Support (NDSv3) C++ framework, conceived by Cosylab and under development at ITER for use in its diagnostic applications, uses a layered approach, abstracting specific hardware device APIs as well as the interface to control systems and real-time applications.

ITER CODAC and its partners have developed NDS device drivers using both PCI express extension for instrumentation (PXIe) and Micro Telecommunications Computing Architecture (MTCA) platforms for multifunction data acquisition (DAQ) devices, timing cards and field-programmable gate array (FPGA) based solutions. In addition, the concept of an NDS-System encapsulates a complex structure of multiple NDS device drivers, combining functions of the different low-level devices and collecting all system-specific logic, separating it from generic device driver code.

INTRODUCTION

The Instrumentation and Control Systems (I&C) used in big science facilities (BSF) are based on the use of multi-tier software applications. For example, advanced DAQ and timing systems include complex hardware elements that need software elements to configure all their functionalities. In the last years, the use of field-programmable gate arrays (FPGAs), System on a Chip circuits (SoC) and new development tools have demonstrated that software is a key part of implementing these systems [1]. The key points of using software in advanced I&C systems are adaptability, reusability and maintainability over the entire BSF project lifetime.

The Nominal Device Support (NDS) software framework has been implemented to meet these three goals. Initially developed by Cosylab [2], it was recently improved and extended by the ITER Organization, working with Universidad Politécnica de Madrid and GMV Aerospace and Defence. NDS is a driver development software framework for diagnostics measurement systems [3], focusing on data acquisition and timing devices. NDS device drivers are instantiated and configured to build complex systems, designed to solve specific applications. The applied methodology simplifies code reusability and testability, achieving high levels of software quality. Doxygen documentation, automated tests and static code analysis are used in all NDS modules. Specifically, the NDS framework provides a simplified solution for device driver development in I&C systems that use the Experimental Physics and Industrial Control System (EPICS) [4-6].

NDS SOFTWARE LAYERS

Figure 1 shows the basic structure of a device driver in the NDSv3 framework. The application, called "control system", uses the generic NDS control system interface to communicate with NDS device drivers and extensions. The NDS device drivers use the base and helper classes from the NDS-core library to access the hardware through the operating system's low level drivers.

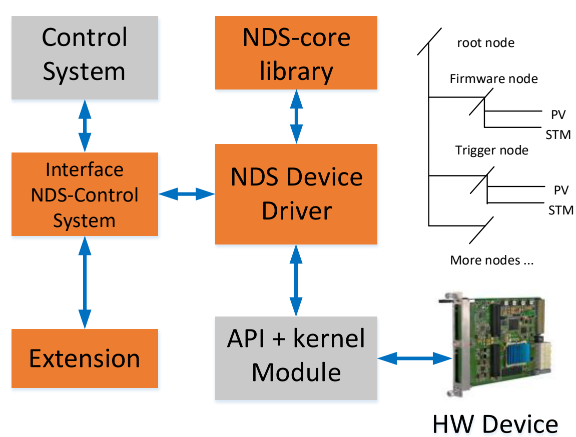


Figure 1: NDSv3 framework elements and basic layers.

NDS-Core

The NDS-core layer (NDS-core library) provides a collection of C++ classes and helpers that standardise and simplify the implementation of the software device driver (NDS device driver) for a specific hardware device or communication interface.

* This work was supported in part by the Spanish Ministry of Science, Innovation, and Universities Projects under Grant ENE2015-64914-C3-3-R and Grant PID2019-108377RB-C33, in part by the Spanish Ministry of Science, Innovation, and Universities Mobility under Grant PRX19/00449, and in part by the Comunidad de Madrid under Grant PEJD-2018-PRE/TIC-8571 and Grant PEJ-2019-AI/TIC-14507.
† ralph.lange@iter.org

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUBR02

DESIGN PATTERNS FOR THE SKA CONTROL SYSTEM

S. Vrcic, SKA Observatory, Manchester, UK

Abstract

Square Kilometre Array Observatory (SKAO) comprises two radio-telescopes: the SKA Low Frequency Telescope, located in the Murchison Region, Western Australia, with the observing range 50 – 350 MHz; the SKA Mid Frequency Telescope, located in the Karoo Region, South Africa, with the observing range 350 MHz – 15 GHz. The SKA Global Headquarters is in the Jodrell Bank Observatory, near Manchester, UK. The SKA Low and SKA Mid Telescopes use different receptors (log-periodic antennas vs offset-Gregorian dishes), otherwise the telescopes share the same design concept, the design of many components, in particular software, is common to both Telescopes. Work on construction, which officially started on the 1. July 2021, was preceded by the extensive design effort which culminated in successful completion of the Critical Design Review (CDR). This paper describes the design patterns defined so far for the implementation of the Telescope Control System (and applies for both Telescopes).

INTRODUCTION

The Square Kilometre Array Observatory (SKAO) is an International Organisation that comprises two radio-telescopes and spans three continents:

- The Global Headquarters (HQ) is located at the Jodrell Bank Observatory near Manchester, UK.
- The SKA Low Telescope, located in Murchison Region in Western Australia operates in the frequency range 50 – 350 MHz.
- The SKA Mid Telescope, located in the Karoo region in South Africa, operates in the frequency range 350 MHz to 15 GHz. The SKA Mid observing range is divided in 6 bands; each receiver can collect and process data for one band at a time; instantaneous bandwidth varies from band to band.

The SKAO was instigated by an idea to build a radio-telescope with a collecting area of 1 km^2. The science goals are described on the SKAO website [1].

Instead of building a single gigantic dish, radio-astronomers use a technique called interferometry. A Radio-Interferometer superimposes electromagnetic waves collected by multiple receivers to amplify the signal of interest and eliminate signals generated by the ground-based sources and by other man-made equipment (including the telescope itself). The signals generated by sources not of interest are generally referred to as radio-interference (RFI). The SKA Telescopes are interferometers.

The SKA Low Telescope comprises 131,072 log periodic antennas, organised in 512 stations. The stations are placed so that the Telescope consist of the densely populated core and three spiral arms with receding density. Signal collected by the antennas is digitized, the beams are formed using input from the antennas the belong to the same station, the beams formed by different stations are aligned in time, and correlated (input from each pair of stations is complex cross-multiplied) to extract information of interest and eliminate RFI. Integration in time and/or frequency may be performed to reduce the amount of output data. Up to this point, data processing is performed in real-time. The output of correlation is then captured, data sets formed and stored for further processing.

The SKA Mid Telescope comprises 197 offset-Gregorian dishes, each with the diameter of 15 meters. To cover the required frequency range, each dish is equipped with several receivers, but only one can be placed at the focus at any given time (consequently, before starting a new experiment a receiver may need to be replaced). The signal captured by the single pixel feed is digitized and processed in the same manner as in the Low Telescope.

After many years of preparation, the construction of the SKA Telescopes officially started on 1. July 2021 (artist impression of the SKA Telescopes shown in Fig. 1).

During the pre-construction phase design were developed and reviewed for each part of the Telescopes, including the Control System. The general principles for the design of the SKA Telescope Control System were established relatively early in the design process. Following the Critical Design Review (CDR), while preparing for transition to construction, work on the detailed design and development of the Control System software started, although with the limited resources. The lessons learned over that period are being applied as we update documentation, improve the development environment, and refine the design, including the design patterns.

This paper provides an overview of the design approach and patterns used in the SKA Control System, with the goal to collect input from the colleagues working on similar projects.

Figure 1: Artist impression of the SKA Telescopes.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUBR03

CONTROL SYSTEM FOR 6 MeV LINEAR ACCELERATOR AT LINAC PROJECT PINSTECH

N. U. Saqib†, M. Ajmal, A. Majid*, D. A. Nawaz‡, F. Sher§, A. Tanvir
LINAC Project, PINSTECH, Islamabad, Pakistan

Abstract

At LINAC Project PINSTECH, 6 MeV electron linear accelerator prototypes are being developed for medical as well as industrial purposes. Control system of the linear accelerators is a distributed control system mainly comprised of EPICS and PLCs. Graphical User Interface (GUI) are developed using Phoebus Control System Studio (CSS) and Siemens WinCC Advanced software. This paper focuses on design, development and implementation of accelerator control system for various subsystems such as RF, vacuum, cooling as well as safety subsystems. The current status of the control system and services is presented.

INTRODUCTION

Particle accelerators are complex machines that have been playing a major role in scientific innovations and discoveries. A particle accelerator is a device that uses electromagnetic waves, in the microwave range, to accelerate charged particles (electrons) to produce high energy charged particle or X-ray beams. In case of electron linear accelerators, electrons are generated from electron source such as electron gun (e-Gun) and are accelerated in a series of accelerating cavities by Radio Frequency (RF) waves, which are fed into the accelerating cavities by an RF source such as a klystron or a magnetron.

LINAC Project at PINSTECH aims at developing indigenous RF linear accelerators for medical and industrial applications. Along with ongoing progressive research and development, prototypes of medical linear accelerator (*Medical Linac*) for radiotherapy application and industrial linear accelerator (*Industrial Linac*) for Non-Destructive Testing (NDT) application are under development. Both of these accelerators are 6 MeV standing wave electron linear accelerators that produce high energy X-rays by striking high energy electron beam onto a tungsten target.

There are several subsystems that are required for operating a linear accelerator: an e-Gun system to produce and extract electrons, an RF system to accelerate the electrons produced by e-Gun, a good vacuum system to avoid arcing or breakdowns, a cooling system to maintain the temperatures of various devices at a desired point for stable operation. As particle accelerators grow more complex, so do the demands placed on their control systems. The complexity of the control system hardware and software reflects the complexity of the machine. Accelerator Controls and Electronics (ACE) Group of LINAC Project is responsible for controls, electronics and IT infrastructure for Medical and Industrial Linac prototypes. Figure 1 shows block diagram of the linear accelerator that contains main subsystems and their interfacing. All these systems need to be controlled and monitored by a sophisticated control system, which enables safe and smooth remote operation of the Linac from control room. Next subsections provide a brief description of Medical and Industrial Linac prototypes.

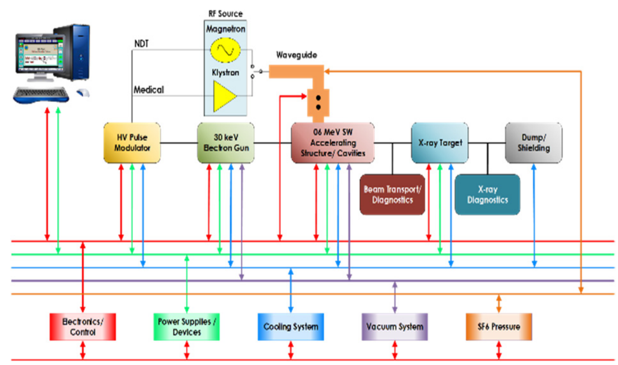


Figure 1: Block Diagram of Linac.

Medical Linac

A medical linear accelerator customizes high energy x-rays or electrons to conform to a tumor's shape and destroy cancer cells while sparing normal tissues. Cancer is a leading cause of death worldwide and its types such as breast, lung, liver, prostate, head and neck carcinoma are most commonly diagnosed in Pakistan. Increasing number of cancer patients has made demand of cancer treatment machines. Therefore, it was need of the time to build an indigenous medical linear accelerator to cope with soaring number of cancer patients in available financial resources. For this purpose, a Klystron based 6 MeV Medical Linac prototype is being developed at LINAC Project PINSTECH. Accelerating cavity was designed indigenously, fabricated and brazed locally. Initially, there was one vacuum port and vacuum didn't sustain to a good pressure, recently a second vacuum port is installed and RF conditioning is under process.

Industrial Linac

Out of several applications of industrial linear accelerators, one is radiography in for Non-Destructive Testing purposes, which provides a method for examination of internal structure and integrity of given specimen/material. Keeping this in view, an indigenous magnetron based 6 MeV Industrial NDT Linac prototype is in final stages at LINAC Project PINSTECH. Accelerating cavity was designed indigenously, fabricated and brazed for this purpose. Most of the parameters of both the linear accelerators are similar as shown in Table 1.

† najm.control@gmail.com
* aaminahmajid@gmail.com
‡ danishplcinc@gmail.com
§ falaksher@gmail.com

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUBR04

CONTROL SYSTEM OF CRYOMODULE TEST FACILITIES FOR SHINE*

H. Y. Wang, G. H. Chen†, J. F. Chen, J. G. Ding,
M. Li, Y. J. Liu, Q. R. Mi, H. F. Miao, C. L. Yu
Shanghai Advanced Research Institute, Chinese Academy of Sciences
Shanghai 201204, P. R. China

Abstract

Shanghai HIgh repetition rate XFEL aNd Extreme light facility (SHINE) is under construction. The 8 GeV superconducting Linac consists of seventy-five 1.3 GHz and two 3.9 GHz cryomodules. A cryomodule assembling and test workshop is established.Multiple facilities have been built for cryomodule and superconducting cavity test, including two vertical test facilities, two horizontal test facility, one multiple test facility and one liquid helium visualization facility.The local control systems are all based on Yokogawa PLC, which monitor and control the process variables such as temperature, pressure, liquid level and power of the heater. PID and other algorithms are used to keep liquid level and power balance. EPICS is adopted to integrate these facilities along with vacuum devices, solid state amplifiers, LLRF and RF measurement system, etc. The details of the control system design, development and commissioning will be reported in this paper.

OVERVIEW

Owing to the wide range of applications of X-rays in the research fields of physics, chemistry and biology, facilities with the ability to generate X-rays were developed continuously in the last century. The free electron laser (FEL) is a novel light source, producing high-brightness X-ray pulses. To achieve high-intensity and ultra-fast short wavelength radiation, several X-ray FEL facilities have been completed or under construction around the world [1].

The first hard X-ray FEL light source in China, the so-called Shanghai HIgh repetition rate XFEL aNd Extreme light facility (SHINE), is under construction. It will utilize a photocathode electron gun combined with the superconducting Linac to produce 8 GeV FEL quality electron beams with 1.003086MHz repetition rate.

CRYOMODULE

Cryomodule (Fig. 1) is the key components of the superconducting linear accelerator, which composes of superconducting cavities, superconducting magnet components, beam position detectors, cryogenic cooling system, vacuum system, and mechanical support system. SHINE requires 75 1.3GHz superconducting cryomodules, which are connected in series to form the accelerator L1, L2, L3, and L4. In addition, two third-harmonic cavities with a frequency of 3.9GHz superconducting modules will be used to linearize the longitudinal emittance of the electron beam [2].

* Work supported by Shanghai Municipal Science and Technology Major Project(Grant No. 2017SHZDZX02)
† chenguanghua@zjlab.org.cn

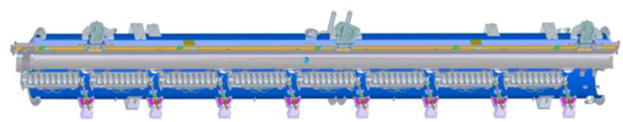


Figure 1: Cryomodule.

CRYOMODULE TEST FACILITY

A superconducting cryomodule workshop is built for SHINE project. The infrastructure(shown in Fig. 2) includes ultra-clean processing and assembly, precision mechanical assembly and testing, cryogenic component multi-functional test facility system, superconducting cavity vertical and horizontal test facility system. They are used for superconducting cryomodule assembly and functional testing.

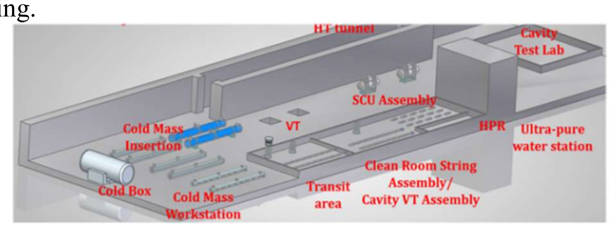


Figure 2: Layout of test facility.

The cryogenic component multi-functional test facility is used to test the working life of the tuner at cryogenic, the vacuum leakage rate and electrical performance at cryogenic of cold BPM, the working stability of superconducting magnet and current lead at cryogenic, the thermal load of each temperature zone, and the vacuum leakage rate of the coupler at cryogenic.

The superconducting cavity vertical test facility is used to test the performance of the superconducting cavity vertically to check whether the cavity has reached the design goal, so that it can meet the needs of engineering. The superconducting cavity horizontal test facility is used to test the performance of the cryomodule, check whether the cryomodule meets the design goal, and make it meet the needs of engineering. it includes cryomodule section and Feed Cap & End Cap.

CONTROL SYSTEM

The control system is responsible for the device control, data acquisition, functional safety, high level database or application, as well as network and computing platform. It will provide operators, engineers and physicists with a comprehensive and easy-to-use tool to control the components of cryomodule test facility.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV001

THE MIRROR SYSTEMS BENCHES KINEMATICS DEVELOPMENT FOR SIRIUS/LNLS*

G. N. Kontogiorgos†, A. Y. Horita, L. M. Santos, M. A. L. Moraes, L. F. Segalla,
Brazilian Synchrotron Light Laboratory (LNLS), Campinas, Brazil

Abstract

At Sirius, many of the optical elements such as mirror systems, monochromators, sample holders and detectors are attached to the ground with high stiffnesses to reduce disturbances at the beam during experiments [1]. Granite benches were developed [2] to couple the optical device to the floor and allow automatic movements, via commanded setpoints on EPICS [3] that runs an embedded kinematics, during base installation, alignment, commissioning and operation of the beamline. They are composed by stages and each application has its own geometry, a set number of Degrees-of-Freedom (DoF) and motors, all controlled by Omron Delta Tau Power Brick LV. In particular, the mirror system was the precursor motion control system for other benches [4 - 6]. Since the mechanical design aims on stiffness, the axes of mirror are not controlled directly, the actuators are along the granite bench. A geometric model was created to simplify the mirror operation, which turn the actuators motion transparent to the user and allow him to directly control the mirror axes.

INTRODUCTION

The latest Sirius mirror bench mechanical design version will be installed in Mogno and Ipê beamlines. They are composed by three stacked granites pieces (Fig. 1), the first one is supported by three levellers on the floor, the second is above the first and it has a ramp to form a wedge with the third granite.

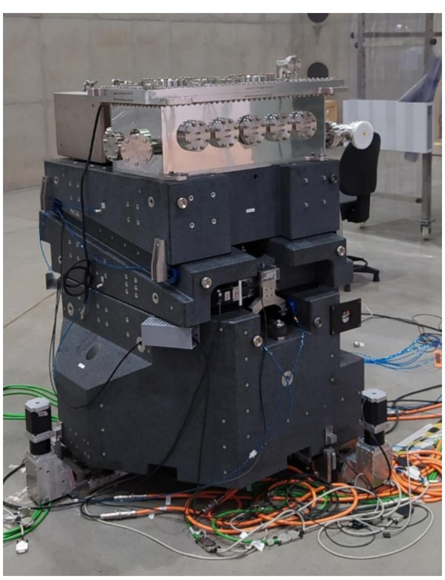


Figure 1: Granite assembly before installation and commissioning.

The mirror positioning depends on the relative motion between those components. Air-bearings were disposed both to guide and lift the granites between interfaces. The pressure, flow and activation of the air-bearings are commanded by a pneumatic panel.

KINEMATICS

Kinematic Model

As mentioned, the hole granite stack is supported by three levellers (The leveller is the component A of Fig. 2). They do not have feedback sensor, the position is measured by three Heidenhain gauges (Component B of Fig. 2) which touch the granites, so the measurement is done at the bench itself, not on the actuator. Although the controller can read the real position of the granite, this mechanical design allows the granite to slide over gauge and the leveller. This result presents incoherence between real position and the controller readback position. Furthermore, the geometry is much more complicated when considering friction and sliding on mechanics. To contour those problems, approximations were done on the geometry (As will be shown now) and an iterative actuation was developed (As will be shown later).

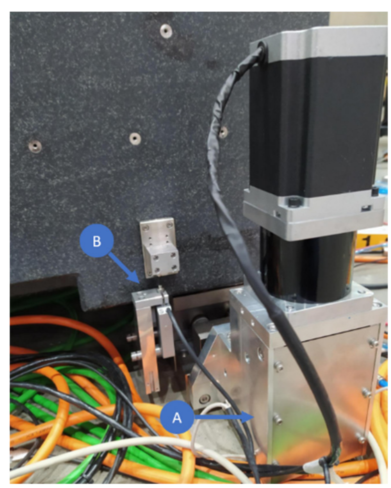


Figure 2: Leveller actuator (A) and feedback encoder (B).

The levellers could be interpreted as a parallel robot called tripod. The tripod was modelled using two reference frames [7], one rigidly coupled to the top platform (S_1), which is the moving one, and the other frame is at rest on the laboratory (S_0). Three vectors $\vec{r}_i(S_1)$ $i = 1, 2, 3$, connect the S_1 origin to the three vertical Heidenhain sensors points that touch the platform. This is the first approximation of this model. Figure 3 illustrates both reference

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV002

MOTION CONTROL IMPROVEMENTS FOR THE KIRKPATRICK-BAEZ MIRROR SYSTEM FOR SIRIUS/LNLS EMA BEAMLINE*

G. N. Kontogiorgos†, C. S. B. N. Roque, M. A. L. Moraes, Brazilian Synchrotron Light Laboratory (LNLS), Campinas, Brazil

Abstract

The Kirkpatrick-Baez (KB) mirror system is composed of a vertical focusing mirror (VFM) and a horizontal focusing mirror. Both concave mirrors focus the X-ray beam by reflecting it at small grazing angles. The relocation of this system from UVX XDS beamline to Sirius EMA beamline facilitated a full revision of the motion control system, whose controller was migrated to Omron Delta Tau Power Brick LV. The beam focus is controlled by bending the mirrors through camshaft mechanisms coupled to low current Faulhaber motors. Although the amplifier is designed for higher currents, controller settings allowed the use of lower currents. Another improvement made is the ability to drive both bender motors in gantry mode and still control the lag between them. Each bender has a capacitive sensor to monitor the position of the center of the mirror, which is read by the analog input of the controller and made available by EPICS [1]. The VFM is supported by a tripod and a new kinematics was developed to reference the center of the mirror as the point of control. This paper presents the implementation of the new motion control KB system and its results at Sirius EMA beamline.

INTRODUCTION

The KB mirror system from XDS beamline at the previous accelerator UVX has been reconditioned for its operation at EMA beamline at Sirius. A full review of mechanisms and optics was done at the system since it was in operation for years at XDS. Some parts were adapted with new concepts brought from other Sirius devices, such as DCM and mirror systems [2,3]. The new parts give the system more repeatability since the backlash is reduced by the substitution of bushing-axis mechanism to parallel leaf spring translator. The mechanical enhancement favoured upgrades on the mirror bending control system.

A closed loop was developed using Power Brick controller for the mirror bending system. Since this controller has more features than the one used previously, the entire system, including its rough positioning by its supporting bench, has been redesigned. A kinematics inspired on mirror systems [4] was developed for a better user experience during commissioning, alignment, and operation because no hand calculation would be necessary to position the mirrors by commanding the actuators one by one.

The present paper is going to present further studies of driving low current stepper motors inspired on [5], the peripherical sensors that offer monitoring during operation and the details of kinematics implementation.

SYSTEM ARCHITECTURE

The KB system is composed of eleven motors with encoders, two piezos for fine pitch and two capacitive sensors. These are divided into two subsystems: VFM and HFM. Each subsystem is composed of a mirror with two motors responsible for driving the bending mechanism, with a capacitive sensor at the center of the mirror, and a base.

The HFM base is composed of one motor for each translation (Ux and Uy) and one for rotation around the X axis. The VFM base is more complex, composed of a tripod responsible for the required rotations (Rx and Ry) and translation on the Y axis.

All motors and encoders are controlled using a Power Brick LV. The capacitive sensors signals are read using the analog input in the same controller after being conditioned through the standard PI device. The piezos are controlled individually using PI servo controllers.

For the final users, all necessary commands are implemented in a graphic user interface (GUI) using process variables (PVs) made available by EPICS.

MIRROR BENDER

Driving Low Current Motors with High Current Amplifier

The Power Brick LV controller was adopted at Sirius for its ability to cover a range of motion control solutions. This controller is integrated with a 5 / 15 A amplifier [6]. The mirror bender motors used in the KB System are 250 mA and although the manufacturer does supply controllers with low current drivers, we opted to adapt the 5 / 15 A amplifier due to cost and time constrains. It has a bending system with two stepper motors AM2224 series model 0250 [7] coupled to a camshaft that pushes the mirror to bend and sets its focus.

Rising the inductance was the first setup to match the motor and controller specifications. To delay the current rising time, different values of inductors were placed in series with a low current test motor and the amplifier circuit could properly control the current on the motor coils.

Adding new components to the motor phases would change the motor properties, increase system cost, and decrease robustness. A detailed analysis led to the conclusion of limiting 48 V amplifier output PWM duty cycle. Since the current rise on the PWM on time and fall on the PWM off time [8], limiting the on-time voltage we chop the maximum reached current.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV003

THE CONTROL SYSTEM OF THE FOUR-BOUNCE CRYSTAL MONOCHROMATORS FOR SIRIUS/LNLS BEAMLINES

L. Martins dos Santos*, J. H. Rezende, M. Saveri Silva, H. C. N. Tolentino, L. M. Kofukuda, G. N. Kontogiorgos, P.D. Aranha, M. A. L. Moraes,
Brazilian Synchrotron Light Laboratory (LNLS), Campinas, Brazil

Abstract

CARNAÚBA (Coherent X-ray Nanoprobe) and CATERETÊ (Coherent and Time-Resolved Scattering) are the longest beamlines in Sirius – the 4th generation light source at the Brazilian Synchrotron Light Laboratory (LNLS). They comprise Four-Bounce Crystal Monochromators (4CM) for energy selection with strict stability and performance requirements. The motion control architecture implemented for this class of instruments was based on Omron Delta Tau Power Brick LV, controller with PWM amplifier. The 4CM was in-house designed and consists of two channel-cut silicon crystals whose angular position is given by two direct-drive actuators. A linear actuator mounted between the crystals moves a diagnostic device and a mask used to obstruct spurious diffractions and reflections. The system is assembled in an ultra-high vacuum (UHV) chamber onto a motorized granite bench that permits the alignment and the operation with pink-beam. This work details the motion control approach for axes coordination and depicts how the implemented methods led to the achievement of the desired stability, considering the impact of current control, in addition to benchmarking with manufacturer solution.

INTRODUCTION

The Four-Bounce Crystal Monochromators (4CM) was in-house designed to compose the set of optical systems in the longest beamlines in Sirius [1]: CARNAÚBA [2] (Coherent X-ray Nanoprobe) and CATERETÊ [3] (Coherent and Time-Resolved Scattering).

The energy is selected by two channel-cut silicon crystals whose angular position is given by two direct-drive actuators. A mask, mounted between the crystals, is used to obstruct spurious diffractions, having as actuator a linear stage.

The system is assembled in an ultra-high vacuum (UHV) chamber onto a motorized granite bench that permits the alignment and the operation with pink-beam.

The adopted motion controller for this system was the Omron Delta Tau Power Brick LV (PBLV) and his PWM amplifier. This works discuss the methods that led to achieve the requirements of stability and coordination, considering current control influence, and compares with manufacturer control solution, Aerotech Ensemble Epaq MR (Epaq).

SYSTEM ARCHITECTURE

Granite Bench

The granite bench is designed to both ensure high stiffness and allow the movement for alignment [4] of the monochromator and operation with pink beam, moving the UHV chamber to a position that the beam passes between the crystals.

Air-bearings in the bottom and top granite interface permits a frictionless motion in the translation in the X direction and rotation in the Y direction.

Furthermore, three levelers that supports the bottom granite compounds the translation in Y direction and rotations in X and Z directions.

The actuators of the granite bench are 2-phase stepper motors. The feedback of the position are made with a Heidenhain's quadrature incremental length-gauge for each leveler and a pair Renishaw's BiSS-C absolute linear encoder.

Figure 1 illustratrates the 4CM granite bench and his UHV chamber installed in CARNAÚBA beamline.

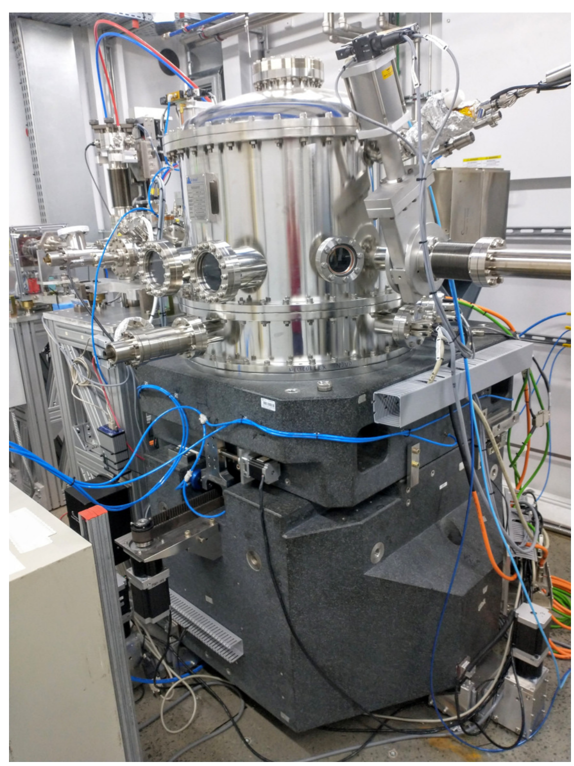


Figure 1: 4CM granite bench and UHV chamber.

* leandro.martins@lnls.br

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV004

THE FPGA-BASED CONTROL ARCHITECTURE, EPICS INTERFACE AND ADVANCED OPERATIONAL MODES OF THE HIGH-DYNAMIC DOUBLE-CRYSTAL MONOCHROMATOR FOR SIRIUS/LNLS

R. R. Geraldes[1]*, J. L. Brito Neto, L. P. Carmo, E. P. Coelho, A. Y. Horita, S. A. L. Luiz, M. A. L. Moraes, Brazilian Synchrotron Light Laboratory (LNLS), CNPEM, Campinas, Brazil
[1]also at the CST Group, Eindhoven University of Technology (TUe), Eindhoven, The Netherlands

Abstract

The High-Dynamic Double-Crystal Monochromator (HD-DCM) has been developed since 2015 at Sirius/LNLS with an innovative high-bandwidth mechatronic architecture to reach the unprecedented target of 10 nrad RMS (1 Hz - 2.5 kHz) in crystals parallelism also during energy fly-scans. After the initial work in Speedgoat's xPC rapid prototyping platform, for beamline operation the instrument controller was deployed to NI's CompactRIO (cRIO), as a rugged platform combining FPGA and real-time capabilities. Customized libraries needed to be developed in LabVIEW and a heavily FPGA-based control architecture was required to finally reach a 20 kHz control loop rate. This work summarizes the final control architecture of the HD-DCM, highlighting the main hardware and software challenges; describes its integration with the EPICS control system and user interfaces; and discusses its integration with an undulator source.

INTRODUCTION

With performance numbers in the range of single nm and tens of nrad, the High-Dynamic Double-Crystal Monochromator (HD-DCM) is a high-end control-based beamline instrument for energy selection with fixed-exit monochromatic beam [1]. It has been developed at the Brazilian Synchrotron Light Laboratory (LNLS/CNPEM) for the 4th-generation Sirius light source [2] to be the first vertical-bounce DCM to reach, even in motion, 10 nrad RMS inter-crystal parallelism over the broad frequency range from 1 Hz to 2.5 kHz, representing improvements by factors between 3 and 100.

Due to its singular architecture, different aspects of the HD-DCM have already been detailed to the community: conceptual design, mechatronic principles and thermal management [3–5]; results of in-air validation of the core, together with system identification and control techniques in the prototyping hardware [6, 7]; offline performance of the full in-vacuum cryocooled system, including scans solutions [8]; dynamic modelling work, updated control design and FPGA implementation in the final NI's CompactRIO (cRIO) [9–11]; and calibration and commissioning procedures, together with the first experimental results with beam [12]. Here, updated schemes of the control system, as a result of operational maturity with two units at the MANACÁ and EMA undulator beamlines, and the emerging control-related strategies and bottlenecks concerning a holistic beamline operation are discussed.

* renan.geraldes@lnls.br

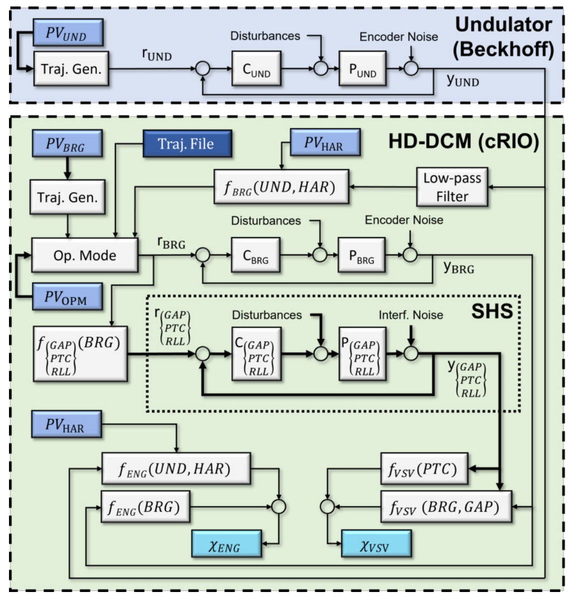


Figure 1: Simplified control diagram for the current HD-DCM integration at Sirius undulator beamlines.

APPLICATION OUTLINE

The application, as currently implemented at the EMA and MANACÁ beamlines, can be briefly introduced via the simplified control diagram in Fig. 1. Planar undulators by Kyma have been provided for the early operation phase, before the definitive Delta undulators that have been developed in-house for Sirius become available. Then, due to the perspective of short-time replacement, only basic features have been specified. Indeed, running on Beckhoff controllers, the systems can be operated by the users only via a limited set (PV_{UND}) of high level *process variables* (PVs) in the EPICS control system [13]. Complementary, the quadrature signal of the phase encoders have been derived to be used as the leading digital signals to the HD-DCMs, if desired.

The HD-DCMs can be defined by four main closed control loops running in NI's CompactRIO (cRIO) hardware. Firstly, BRG, with a bandwidth of 20 Hz, is responsible for controlling the angle of incidence of the beam on the so-called *first crystal*, for energy selection according to Bragg's law of diffraction. Then, GAP, PTC and RLL, with bandwidths between 150 and 250 Hz, are part of the so-called *crystal cage* (CCG), responsible for positioning the so-called *second crystal* with respect to the first one, so that fixed-exit monochromatic outgoing beam can be maintained at

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV005

OPC-UA DATA ACQUISITION FOR THE C2MON FRAMEWORK

E. Stockinger*, B. Copy †, M. Bräger, B. Farnham, M. Ludwig, B. Schofield,
CERN Beams Department, 1211 Geneva, Switzerland

Abstract

The CERN Control and Monitoring Framework (C2MON) [1] is a monitoring platform developed at CERN and since 2016 made available under an LGPL3 open source license. It stands at the heart of the CERN Technical Infrastructure Monitoring (TIM) that supervises the correct functioning of CERN's technical and safety infrastructure. This diverse technological infrastructure requires a variety of industrial communication protocols. OPC UA [2], an open and platform-independent architecture, can be leveraged as an integration protocol for a large number of existing data sources, and represents a welcome alternative to proprietary protocols. With the increasing relevance of the open communication standard OPC UA in the world of industrial control, adding OPC UA data acquisition capabilities to C2MON provides an opportunity to accommodate modern and industry-standard compatible use cases.

This paper describes the design and development process of the C2MON OPC UA data acquisition module, the requirements it fulfills, as well as the opportunities for innovation it yields in the context of industrial controls at CERN.

INTRODUCTION

C2MON must consolidate information from a wide range of sources and so support a diverse set of devices and communication technologies through independent data acquisition modules. OPC UA is considered a key technology to managing heterogeneous machine interoperability and therefore fundamental to developments in advanced industrial environments [3]. As an open protocol, it addresses the common problem of insufficient interoperability by allowing equipment from different vendors to communicate with a host through the same interface [4]. Along with its high data modeling capabilities, OPC UA is a compelling candidate for adapting C2MON to modern use cases.

More generally, trends in industry urge Supervisory Control and Data Acquisition (SCADA) systems towards greater scalability and compatibility with Cloud Computing. While the C2MON server layer has already been adapted to natively support configurability injection and process monitoring [5], the OPC UA data acquisition (DAQ) module presented here pioneers these concepts on the data acquisition layer.

MONITORING OF THE DAQ PROCESS

The continuous monitoring of software plays a key role in ensuring smooth operation. Effective monitoring solutions enable a timely detection and treatment of issues related to quality-of-service and provide insight into system resource management [6]. The states or qualities to be monitored can be inherently complex and multidimensional, and so elude a direct measurement through single metrics. Kaner et al. [7] suggest the use of multidimensional metrics as a more meaningful representation of a complex quality.

C2MON provides extensive functionality for monitoring the elements within the supervised facilities. The connection between these elements and the processes on the C2MON data acquisition layer is also supervised through C2MON as a fundamental function. However, the DAQs are independent Java processes. Their internal states are not monitored through C2MON, but contain information relevant to ensure the availability, security and usability of the data acquisition infrastructure.

The metrics identified to be of relevance are diverse in nature. For example, the health of the machine and the operating system running the DAQ process can among others be tied to CPU, memory or disk usage, and the network load. Other metrics deal with the JVM and cover garbage collection threads and log messages. These are generic metrics which are provided by several external tools and client libraries. Other metrics are tied to the DAQ and the area of data acquisition. For example, these metrics could expose meta-information regarding OPC UA-specific concepts such as OPC UA subscriptions and their respective filter types.

Within the OPC UA DAQ process, metrics representing such internal states are exposed as observable endpoints through the Spring Actuator [8] project and Micrometer [9]. The metrics can be scraped out-of-the-box through the monitoring toolkit Prometheus [10] and be represented by a multi-dimensional data model. They can then be gathered and aggregated into a form enabling a global analysis by administrators and operators.

The choices of technological solutions were largely taken due to the prevalence of Spring within the C2MON infrastructure, and to be in line with the guiding principles of C2MON which prefer the use of proven technologies and of open-source resources where possible to facilitate reusability in other projects [1].

CONFIGURABILITY

There are two distinct aspects to configurability within the OPC UA DAQ. On the one hand, there is the need to configure the data to be monitored through C2MON. This use case is integral to the C2MON platform and impacts all tiers of the software architecture. This configuration data is stateful and managed on the application-level across the different DAQ modules and client applications. On the other hand, C2MON acts in heterogeneous environments with diverse hardware requirements. Operators and administrators

* elisabeth.stockinger@live.at
† brice.copy@cern.ch

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV006

CONTROL SYSTEM OF THE SPIRAL2 SUPERCONDUCTING LINAC CRYOGENIC SYSTEM

A.Trudel, Q.Tura, G. Duteil, A. Ghribi
Grand Accélérateur Nat. d'Ions Lourds (GANIL), Caen, France
P. Bonnay
Commissariat à l'Energie Atomique (CEA/INAC) INAC, Grenoble, France

Abstract

The SPIRAL2 cryogenic system has been designed to cool down and maintain stable operation conditions of the 26 LINAC superconducting resonating cavities at a temperature of 4.5 K or lower. The control system of the cryogenic system of the LINAC is based on an architecture of 20 PLCs. Through an independent network, it drives the instrumentation, the cryogenic equipment, the 26 brushless motors of the frequency tuning system, interfaces the Epics Control System, and communicates process information to the Low Level Radio Frequency, vacuum, and magnet systems. Its functions are to ensure the safety of the cryogenic system, to efficiently control the cooldown of the 19 cryomodules, to enslave the frequency tuning system for the RF operation, and to monitor and analyze the data from the process. A model based Linear Quadratic regulation controls simultaneously both phase separators the liquid helium level and pressure. This control system also makes it possible to perform a number of virtual verification tests via a simulator and a dedicated PLC used to develop advanced model based control, such as a real time heat load estimator based on a Luenberger Filter.

INTRODUCTION

Cryogenic System

Spiral2 accelerator delivers high intensity beams of various ions for research in nuclear fields. It is mainly composed of a LINAC (LINear Accelerator) composed of 26 accelerating cavities installed in 19 cryomodules, made of bulk niobium and immersed in a liquid helium bath.

The cryogenic system, as shown in Fig. 1, is split in two levels: at the ground level stands the cryoplant with its refrigerator and helium collecting system, and in the underground accelerator tunnel, the 19 valves boxes form the cryogenic lines and feed the cryomodules with liquid helium [1].

Type-A and Type-B Cryomodules

The type-A and type-B cryomodules respectively contains one and two accelerating cavities. The helium bath is controlled through three valves shown in Fig. 2. The valve CV001 is used to fill the cryomodule by the bottom during the cooldown whereas CV002 and CV005 ensure respectively level and pressure regulation in the bath, which are measured by the LT200 and PT001 sensors. CV010 serves the shield outlet temperature regulation around 60 K.

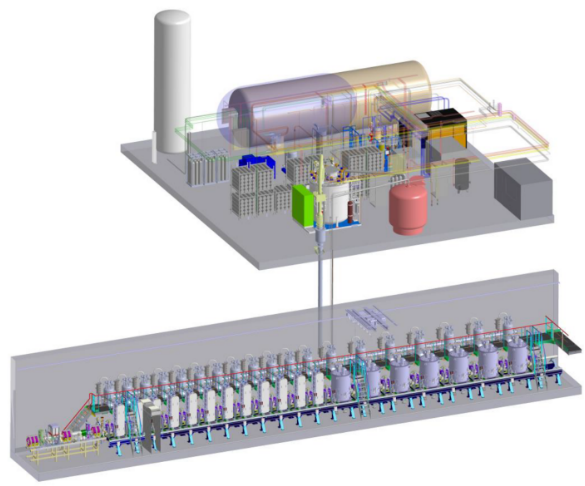


Figure 1: View of the Spiral2 cryogenic system.

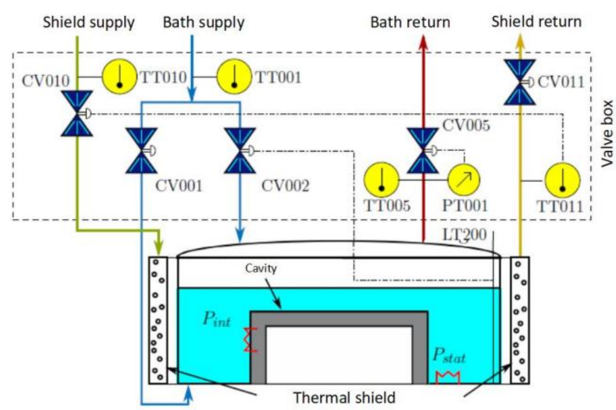


Figure 2: Type-A cryomodule and its associated valves and sensors.

ARCHITECTURE OF THE CONTROL SYSTEM

Liquid helium production and routing, as well as the automated safeties and the controls of the helium liquid bath, are ensured by a PLC-based control system. Data are issued from those PLCs to the Spiral2 Epics system for storage.

The core of the Linac cryogenics control system illustrated in Fig. 3 is made up of a fleet of 20 Siemens PLCs, one for each cryomodule and another one serving as a hub to ensure communication between the cryomodules and the outsides systems, three WinCC Pro supervisions, 1 workshop terminal, 26 brushless motors driving the Frequency Tuning Systems (FTS) of the RF cavities. In addition, there

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV007

MOTORIZED REGULATION FOR THE SARAF PROJECT

T. Joannem*, D. Darde†, CEA Paris-Saclay, IRFU DIS, Saclay, France
F. Gohier, F. Gougnaud, P. Guiho, A. Roger, N. Solenne, P. Lotrus
CEA Paris-Saclay IRFU DIS, Saclay, France

Abstract

Commissariat à l'Energie Atomique et aux Energies Alternatives (CEA) is in charge of the tuning regulation systems for the SARAF-Linac project. These tuning systems will be used with Low Level Radio-Frequency (LLRF) to regulate three rebuncher cavities and HWR cavities of the four cryomodules. These systems were already tested on the Rebuncher and Equipped Cavity Test Stands (ECTS) to test respectively the warm and cold tunings. This paper describes hardware and software architectures. Both tuning systems are based on Siemens Programmable Logic Controller (PLC) and EPICS-PLC communication. Ambient temperature technology is based on SIEMENS motor controller solution whereas the cold one combines Phytron and PhyMOTION solutions.

INTRODUCTION

Context

SARAF particle accelerator is compose of elements to accelerate, control and tune a beam. To work properly, radio-frequency signals are generate by the Low Level Radio-Frequency (LLRF) system.

These signals are used in many parts of the accelerator to correct the beam. We will focus this document about two of these systems that are using motors to reach this goal: rebunchers and cavities.

First motorize tuning system is locate in the Medium Energy Beam Transfer (MEBT) line. It is part of rebunchers. Second motorize tuning system is locate inside cryomodules, next to each cavity, Fig. 1.

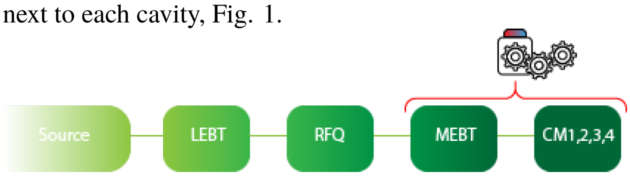


Figure 1: SARAF motors location.

Constraints

Both motorize tuning systems are working in vacuum and radiations environments due to particles accelerator requirements. A third environment parameter have to be taking account and will distinguish two motorizations systems: Temperature.

In fact, motors localize in MEBT, and so rebunchers, will be at ambient temperature therefore cavities motors will be in a cryogenic environment. We will see in next chapters that this difference will heavily impact hardware choice.

Goals

Motors have to be define by taking account of working environment but also processes requirements. In our case motors goals are similar but ways to obtain it are different.

In fact, motors have to move or apply a constraints to an element to obtain required frequency of 176 MHz. Motors movements are done according to frequency feedback measured by the LLRF. Using this feedback provide us a way to regulate movements or constraints to obtain required frequency. Rebunchers motors will linearly translate a beam-inside element to get correct frequency and cavities motors will apply mechanical constraints to cavity in order to obtain required frequency.

REBUNCHERS

Presentation

Rebunchers are dynamic tuning devices located on the MEBT section of the SARAF particle accelerator [1], Fig. 2.

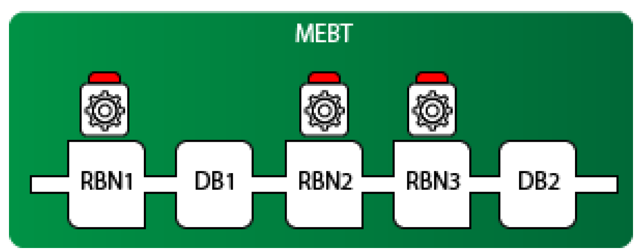


Figure 2: MEBT rebunchers.

They are three similar rebunchers, all located in the MEBT. They are composed of vacuum devices like pumps, gauges and valves but also radio-frequency parts and an outside motorization connected to an internal endless screw that movement radio-frequency passive elements near beam and so gives the possibility to modify feedback frequency.

Movement range of these elements are about thirty millimeters and require a high precision position system and without high-speed response dynamic from the system.

Hardware

According to previously mentioned requirements we will now provide details about hardware used and specifications.

Actuator Rebunchers tuning system requires a position accuracy and speed is not relevant so we choose to use a brushless motor that gives good results for this kind of use.

Moreover due to vacuum high torque requirements motors don't have internal physical brake but are using constant-current to immobilized motor's axis. In fact, motors stator

* tom.joannem@cea.fr
† david.darde@cea.fr

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV009

OpenCMW - A MODULAR OPEN COMMON MIDDLE-WARE LIBRARY FOR EQUIPMENT- AND BEAM-BASED CONTROL SYSTEMS AT FAIR

Ralph J. Steinhagen, H. Bräuning, D. Day, A. Krimm, T. Milosic,
D. Ondreka, A. Schwinn, GSI Helmholtzzentrum, Darmstadt, Germany

Abstract

OpenCMW is an open-source modular event-driven micro- and middle-ware library for equipment- and beam-based monitoring as well as feedback control systems for the FAIR Accelerator Facility.

Based on modern C++20 and Java concepts, it provides common communication protocols, interfaces to data visualisation and processing tools that aid engineers and physicists at FAIR in writing functional high-level monitoring and (semi-)automated feedback applications.

The focus is put on minimising the required boiler-plate code, programming expertise, common error sources, and significantly lowering the entry-threshold that is required with the framework. OpenCMW takes care of most of the communication, data-serialisation, data-aggregation, settings management, Role-Based-Access-Control (RBAC), and other tedious but necessary control system integrations while still being open to expert-level modifications, extensions or improvements.

ARCHITECTURE

OpenCMW is a light-weight modular middle-ware twin-library that combines ØMQ, REST and micro-service design patterns illustrated in Fig. 1. The Majordomo Protocol Broker (MDP) provides reliable (a)synchronous request-reply as well as publish-subscribe (and related radio-dish) communication patterns between external clients and workers, implementing the business logic that may reside either internally or externally to the MDP process. Its core relies primarily on the high-performance and low-latency ØMQ-based transport layer but can, for example, be optionally extended by HTTP to also support REST or HTML-based communication patterns, and optionally secure worker access via RBAC [1–16].

OpenCMW strongly embraces lean-code principles and hence aims at minimising boiler-plate code and to aid light-weight development of network-based, semi- to fully automated real-time feedback applications. It thus provides template implementations for common tasks such as to

a) aggregate, synchronise, and to sanitise data received from multiple devices,

b) allow to inject custom domain-specific user-code to numerically post-process the received data, and

c) derive control signals and forward these to other services using common communication libraries.

This business logic is implemented by workers that cover:

- optional class-based domain-object definitions for the input parameter and return value, and
- two event-handler interfaces that are registered either with the MDP or Event Store, and that implement the call-back functions further described below.

Notably, developers do not need to rely on IDL-type or other proprietary definitions that, based on our experience, may become hard to synchronise and maintain in later development iterations. The interfaces are defined by standard POCO or POJO domain-objects that OpenCMW analyses using `constexpr` compile-time (C++) or run-time (Java) reflection, further described below.

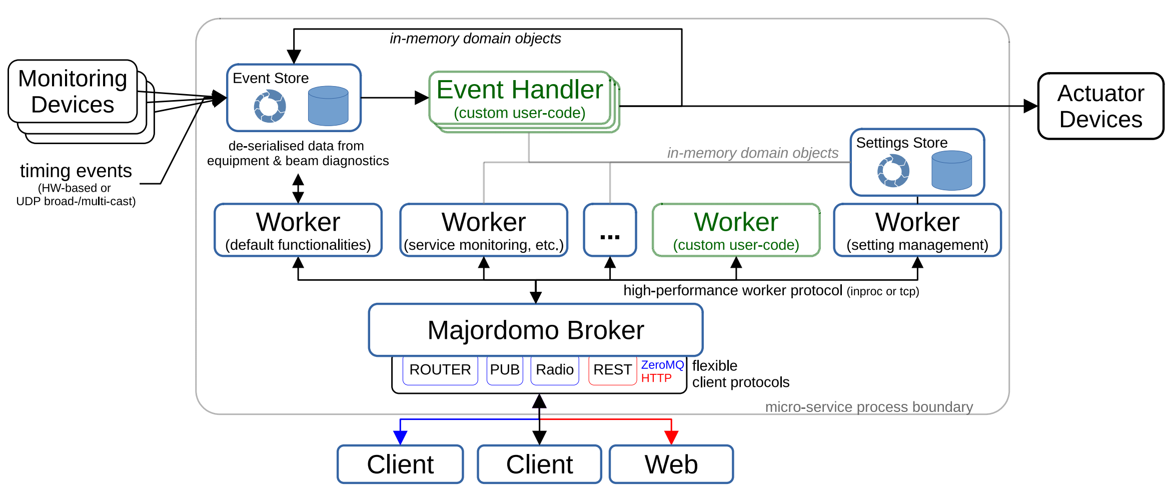


Figure 1: OpenCMW micro-service system architecture combining the Majordomo and event-sourcing design pattern.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV010

INTEGRATION OF OPC UA AT ELBE

K. Zenker*, R. Steinbrück, M. Kuntzsch,
Institute of Radiation Physics, Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany

Abstract

The Electron Linac for beams with high Brilliance and low Emittance (ELBE) at Helmholtz-Zentrum Dresden-Rossendorf (HZDR) is operated using the SCADA system WinCC by Siemens. The majority of ELBE systems is connected to WinCC via industrial Ethernet and proprietary S7 communication. The integration of new subsystems based on MicroTCA.4 hardware, which do not provide S7 communication interfaces, into the existing infrastructure is based on OPC UA using the open source C++ software toolkit ChimeraTK.

This paper discusses OPC UA related contributions to ChimeraTK, that cover an OPC UA backend implementation, development of logging, data acquisition and history modules and improvements of the control system adapter for OPC UA in ChimeraTK. Furthermore, a user data interface based on OPC UA for ELBE is introduced and one ELBE real-life example is described, that makes use of all the afore-mentioned features.

INTRODUCTION

The Electron Linac for beams with high Brilliance and low Emittance (ELBE) at Helmholtz-Zentrum Dresden-Rossendorf (HZDR) is in operation since 2001. It is operated using the SCADA system WinCC by Siemens. The majority of ELBE systems is connected to WinCC [1] via industrial Ethernet and proprietary S7 communication. However, in recent years new subsystems had to be integrated into the existing infrastructure, which do not provide S7 communication interfaces. The Open Platform Communication (OPC) interoperability standard for the secure and reliable exchange of data in industrial automation environments is developed and maintained by the OPC foundation [2]. Its Extension called OPC Unified Architecture (OPC UA) [3] is an open standard for information modeling and machine-to-machine communication, that features e.g. build-in security/authentication and is the foundation of the so-called 4th industrial revolution in industry. It is platform independent and different open source implementations exists that provide support for various development environments like e.g. Python, C/C++, Java and Labview. Because of those features OPC UA has been chosen at ELBE to establish a link between the new subsystems and S7 devices.

As shown in [4] two types of communication were established in the past:

- OPC UA communication between an application and MicroTCA.4 [5] based hardware, i.e. FPGA via direct memory access (DMA) over PICe
- OPC UA communication between an application and Siemens S7-300/400 PLCs

The former communication is established based on the ChimeraTK framework introduced in the following section. The latter communication is based on commercially available OPC UA gateways introduced after. In the following sections OPC UA related components of ChimeraTK and an OPC UA based ELBE machine data interface are presented. Thereafter, the use of the new features is demonstrated by means of an ELBE subsystem as a real-life example.

OPC UA IN CHIMERATK

ChimeraTK [6, 7] is a C++ based open source toolkit for modular control application developments. ChimeraTK provides dedicated libraries for access to devices/data (DeviceAccess library [8]), the application itself (ApplicationCore [9]) and a control system server (ControlsystemAdapter [10]). Both, the Device Access Library and the Control System Adapter library, can be used to implement additional so called device backends and control system adapter implementations. The general structure is shown in Fig. 1. Highlighted in green are parts of ChimeraTK that were contributed as part of the OPC UA developments at ELBE.

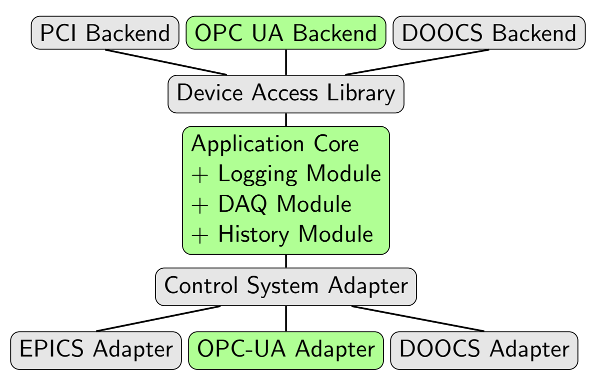


Figure 1: Overview of ChimeraTK. Only selected control system adapters and backends are shown. Contributions discussed in this paper are shown in green.

In general, so far the OPC UA communication in ChimeraTK is implemented using client/server communication, based on TCP/IP. This means no real-time communication can be realized using this approach. Real-time communication would only be possible using the Publish/Subscribe mechanism of OPC UA in combination with Time-Sensitive Networking (TSN) and hardware that supports TSN.

* k.zenker@hzdr.de

18th Int. Conf. on Acc. and Large Exp. Physics Control Systems ICALEPCS2021, Shanghai, China JACoW Publishing
ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV011

INTERFACING EPICS AND LabVIEW USING OPC UA FOR SLOW CONTROL SYSTEMS

Jalal Mostafa, Armen Beglarian, Suren A. Chilingaryan, Andreas Kopmann
Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany

Abstract

The ability of EPICS-based control systems to adapt to heterogeneous architectures made EPICS the defacto control system for scientific experiments. Several approaches have been made to adapt EPICS to LabVIEW-based cRIO hardware, but these approaches, including NI EPICS ServerI/O Server: (1) require a lot of effort to maintain and run, especially if the controllers and the process variables are numerous; (2) only provide a limited set of metadata; or (3) provide a limited set of EPICS features and capabilities. In this paper, we survey different solutions to interface EPICSwith LabVIEW-based hardware then propose EPICS OPCUA device support as an out of the box interface between LabVIEW-based hardware and EPICS to preserve most of EPICS features and provide reasonable performance for slow control systems.

INTRODUCTION

The KArlsruhe TRItium Neutrino (KATRIN) experiment is a large-scale scientific experiment to determine neutrino mass using Tritium beta decay [1]. Large-scale scientific experiments like KATRIN employ diverse hardware from different vendors to support the control system infrastructure, e.g., NI cRIO, Siemens S7, custom hardware chips, etc. For instance, KATRIN employs around 10,000 process variables that are distributed in bunches of 100 to 300 process variables on different NI cRIO, NI cFieldPoint, and Siemens S7 devices. The heterogeneity of such systems imposes a new challenge of providing a unified layer of control and interoperability between these heterogeneous systems and other services like alerts, data archiving, and analysis. The Experimental Physics and Industrial Control System (EPICS) solves this problem using an intermediate C++ software layer.

EPICS is a set of tools and libraries to develop distributed server-client control systems for large-scale scientific experiments e.g. particle accelerators. It can solve the challenge of heterogeneity by acting as an abstract software layer for all devices through implementing a C++ abstraction interface called Device Support. Operator's setpoints and sensor measurements are then channeled through EPICS server or Input/ Output Controller (IOC) using one of EPICS network protocols: Channel Access (CA) and its successor Process Variable Access (PVA). Figure 1 shows a simplified illustration of the EPICS server architecture of the EPICS server. An EPICS server keeps all process variables in in-memory structures called Database. When a client asks for a process variable, the EPICS server access these structures using a module called Database Access. The EPICS server can read data from the hardware using the device support layer where the data is mapped to the corresponding process variable through database access and then published on the network using CA or PVA. Operator's setpoints work similarly, but in the opposite direction: an EPICS client (the operator) sets a process variable on an EPICS server using CA or PVA, which is implemented on the hardware using Device Support.

This architecture imposes new challenges on the interoperability between EPICS and NI LabVIEW-based cRIOs. The LabVIEW programming environment offers very tight integration with EPICS. Several approaches have been made to provide an integration for LabVIEW with EPICS, but they usually require an effort to maintain and run, provide a limited set of metadata, or provide a limited set of EPICS features and capabilities. In this paper, we propose an EPICS-LabVIEW integration based on Open Platform Communications Unified Architecture (OPC UA) protocol.

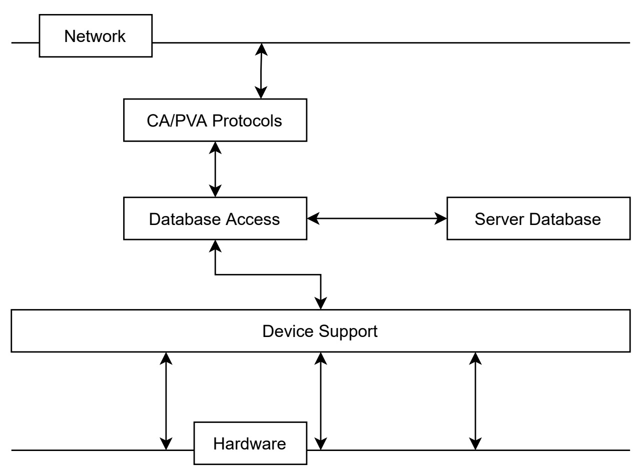


Figure 1: EPICS Server Simplified Internal Architecture.

RELATED WORKS

Several works have been done before to interface LabVIEW with EPICS: most notable is *EPICS Server I/O Server* [2]. *EPICS Server I/O Server* is a complete implementation of EPICS CA protocol for LabVIEW from NI. It allows the developer to create LabVIEW Shared Variables to publish EPICS process variables on the network, a complicated process that involves many clicks to accomplish a simple task, especially when the process variables are numerous. The metadata that EPICS Server I/O Server provides is limited to alarms only leaving behind important metadata like description and engineering units.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV012

AUTOMATED DEVICE ERROR HANDLING IN CONTROL APPLICATIONS

M. Killenberg*, J. Georg, M. Hierholzer, C. Kampmeyer[1], T. Kozak, D. Rothe,
N. Shehzad, J. H. K. Timm, G. Varghese[2], C. Willner,
Deutsches Elektronen-Synchrotron DESY, Notkestr. 85, 22607 Hamburg, Germany
[1]now with Sokratel Kommunikations- und Datensysteme GmbH,
Langenhorner Chaussee 625, 22419 Hamburg, Germany
[2]now with European XFEL GmbH, Holzkoppel 4, 22869 Schenefeld, Germany

Abstract

When integrating devices into a control system, the device applications usually contain a large fraction of error handling code. Many of these errors are run time errors which occur when communicating with the hardware, and usually have similar handling strategies. Therefore we extended ChimeraTK, a software toolkit for the development of control applications in various control system frameworks, such that the repetition of error handling code in each application can be avoided. ChimeraTK now also features automatic error reporting, recovery from device errors, and proper device initialisation after malfunctioning and at application start.

GOALS AND REQUIREMENTS

If the business logic of a control application is intertwined with code for device opening and communication error handling, it becomes hard to read. Hence, this should be avoided. In an ideal case, the application programmer does not have to write any device handling code, and a framework takes care of all the necessary actions, reports faults to the control system and handles the device recovery. For this to work with many different kinds of devices, a sufficient level of abstraction is necessary.

- The framework has to provide a common API for all devices.
- The framework has to guarantee that the user code can always read and write all its variables, and therefore needs to separate read/write operations in the user code from the actual hardware access.

These are the two key places where the framework has to have an appropriate interface. The second point is a consequence of the fact that the framework is taking care of connecting to a device, initialising the device, reporting the connection status to the control system and propagating information about faulty connections.

THE ChimeraTK FRAMEWORK

ChimeraTK, the ***C**ontrol system and **H**ardware **I**nterface with **M**apped and **E**xtensible **R**egister-based device **A**bstraction **T**ool **K**it*, is a framework for writing control applications. [1] An overview is shown in Fig. 1. ChimeraTK consists of three main components:

- The DeviceAccess library provides a common interface to different device types by introducing a backend plugin mechanism.
- The ControlSystemAdapter allows to integrate into various control system middlewares as a native application. [2]
- The ApplicationCore library connects many application modules, which make up the business logic, with the devices and the control system.

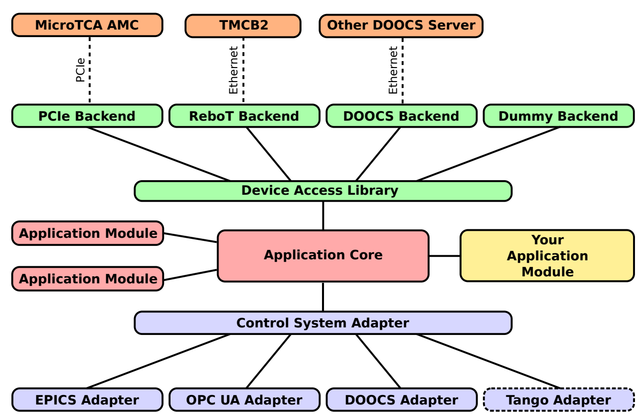


Figure 1: Overview of the ChimeraTK framework. All components connected with solid lines are part of the same executable.

All these components are part of the same executable. The C++-code written by the application programmer consists of application modules for ApplicationCore. ApplicationCore is interfacing to DeviceAccess and the ControlSystemAdapter internally. The user never directly interacts with these libraries on the C++ level. Which devices to use and the parameters for the control system integration are loaded from configuration files at application start.

The DeviceAccess Library

The DeviceAccess library is the interface to various devices. The device usually is a hardware component which is being integrated into the control system, but it can also

* martin.killenberg@desy.de

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV013

BACKEND EVENT BUILDER SOFTWARE DESIGN FOR INO mini-ICAL SYSTEM

Mahesh Punna[1], Narshima Ayyagiri[1], Janhavi Avadhoot Deshpande[1], Preetha Nair[1] , Padmini Sridharan[1],Shikha Srivastava[1], Satyanarayana Bheesette[2], Yuvaraj Elangovan[2], Gobinda Majumder[2], Nagaraj Panyam[2]

[1]BARC, Mumbai, India
[2] TIFR, Mumbai, India

Abstract

The Indian-based Neutrino Observatory collaboration has proposed to build a 50 KT magnetized Iron Calorimeter (ICAL) detector to study atmospheric neutrinos. The paper describes the design of back-end event builder for Mini-ICAL, which is a first prototype version of ICAL and consists of 20Resistive Plate Chamber (RPC) detectors. The RPCs push the event and monitoring data using a multi-tier network technology to the event builder which carries out event building, event track display, data quality monitoring and data archival functions. The software has been designed for high performance and scalability[chronous data acquisition and lockless concurrent data structures. Data storage mechanisms like ROOT, Berkeley DB, Binary and Protocol Buffers were studied for performance and suitability. Server data push module designed using publish-subscribe pattern allowed transport & remote client implementation technology agnostic. Event Builder has been deployed at mini-ICAL with a throughput of 3MBps. Since the software modules have been designed for scalability, they can be easily adapted for the next prototype E-ICAL with 320 RPCs to have sustained data rate of 200MBps.

INTRODUCTION

The Indian-based Neutrino Observatory (INO) collaboration has proposed to build a 50 KT magnetized Iron Calorimeter (ICAL) detector to study atmospheric neutrinos and to make precision measurements of the neutrino oscillation parameters. The detector will look for muon neutrino induced charged current interactions using magnetized iron as the target mass and around 28,800 Resistive Plate Chambers (RPCs) as sensitive detector elements [1]. The mini-Iron Calorimeter (mini-ICAL) detector, a prototype of the ICAL detector is being set up at the Inter Institutional Centre for High Energy Physics' (IICHEP) transit campus at Madurai. The mini-ICAL detector has 20 glass Resistive Plate Chamber (RPC), which act as sensors and are stacked in between 11 iron plates of 4 metre x 4 metre size. The iron plates are magnetised by passing electricity through copper coils wound around. This is expected to serve the purpose of understanding the engineering issues in constructing the main ICAL, and at the same time provide important inputs on the ICAL's operating parameters and physics measurement capabilities. E-ICAL with 320 RPCs is planned to be setup in Madurai, India. Max throughput expected for E-ICAL is around 200MBps with 10% hit rate and 10k trigger rate.

SYSTEM OVERVIEW

The system consists of several sub-systems: RPC DAQs, Backend Data Acquisition System (BDAQ), Trigger System, Calibration System (CAU), Magnet System, Gas System, and LV/HV System as shown in Fig. 1. Description of each system is beyond the scope of the paper [2].

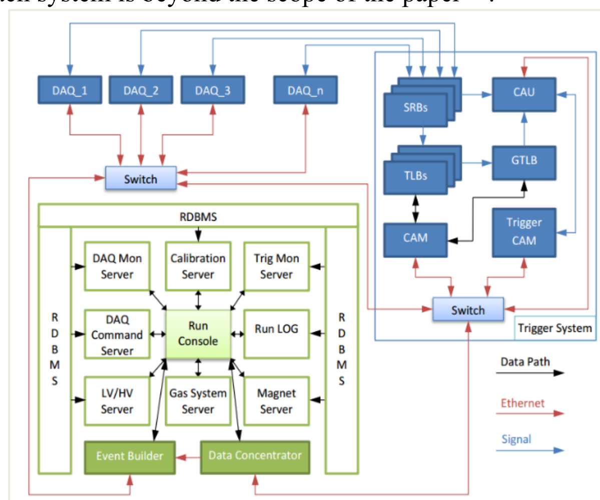


Figure 1: System overview.

Neutrino interacts with the iron plates along its line of travel, triggering events in several RPCs along its path. Orthogonal strip channels (X&Y) on RPCs pick up the charged particles, which are produced from the interaction of neutrino with iron plates. RPC-DAQ modules are connected in hybrid network topology to backend system. Trigger System detects events of interest and notifies RPC-DAQs to transmit event data event data which consists of strips hit and timing information over TCP socket to the designated Data Concentrator (DC) node. Data Concentrator nodes collect event data packets from all the triggered RPC-DAQs and assigns the timestamp and Event Number to the data packet. The updated RPC-DAQ data packets from the data concentrators are pushed to event builder

Backend Data Acquisition System (BDAQ)

The BDAQ system as shown in Fig 2. comprises of several subsystems that are intended to acquire event data and monitor data from the RPC-DAQs. The system also provides event building, event display, data quality monitoring, data archival mechanisms and run manager. BDAQ is a distributed system consisting of several subsystems; Data Concentrator, Event Builder (EB), Run Manager, Data

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV014

CONTROL SYSTEM OF A PORTABLE PUMPING STATION FOR ULTRA-HIGH VACUUM

M.Trevi†, L.Rumiz, E.Mazzucco, D.Vittor, Elettra Sincrotrone Trieste, Trieste, Italy

Abstract

Particle accelerators operate in Ultra High Vacuum conditions, which have to be restored after a maintenance activity requiring venting the vacuum chamber. A compact, independent and portable pumping station has been developed at Elettra to pump the vacuum chamber and to restore the correct local pressure. The system automatically achieves a good vacuum level and can detect and manage vacuum leaks. It has been designed and manufactured in-house, including the mechanical, electrical and control parts. By means of a touch screen an operator can start all the manual and automatic operations, and monitor the relevant variables and alarms. The system archives the operating data and displays trends, alarms and logged events; these data are downloadable on a removable USB stick. Controlled devices include two turbomolecular pumps, one primary pump, vacuum gauges and one residual gas analyser. The control system has been implemented with a Beckhoff PLC (Programmable Logic Controller) with RS-485 and Profibus interfaces. This paper focuses in particular on the events management and object-oriented approach adopted to achieve a good modularity and scalability of the system.

INTRODUCTION

Sometimes sectors of the accelerator vacuum chamber need maintenance or updates requiring venting, but when they have been carried out it is necessary to create ultra-level vacuum conditions to go back to normal operations.

At Elettra, ultra-level vacuum is usually created locally using a pumping station with on electromechanical logics on board (relays, mechanical timers, etc.). The main disadvantage is that it is not programmable and in case of failure it can stop without any information about the reason (for example a mains interruption due to a thunderstorm). Another disadvantage is that, due to its dimensions, the system is not easily moveable inside the accelerator tunnel. These issues led us to design an automatic and autonomous system managing entire parts of the system: alarm management, operator interface, archiving of variables and events like commands, value changed, etc. An important requirement was the compactness of the entire system that has been achieved by suitable choices of mechanical, electrical and automation components. Moreover another feature that we wanted to reach was the possibility to record log and trend.

PLC, I/O boards and wirings are contained in a 3-unit rack (~180 mm height). The controller based on a Beckhoff CX5120 PLC is compact with very good heat dissipation. The Beckhoff development environment feature an IDE and OOP (Object Oriented Programming) capabilities. An Exor panel has been chosen as HMI.

For the development of the software we have taken inspiration from a template on the Beckhoff site based on OOP [1]. We chose to create OOP syntax in order to be independent on that of the manufacturer. In this way it should be possible to move the software to other controllers. We have assumed that these controllers implement structured text and that a function block can be divided in actions.

The OOP paradigm is mainly based on three principles:

- *Encapsulation*: the internal state of an object can be modified by a public method.
- *Inheritance*: a child class can derive and redefine methods from a super class. The inheritance defines a hierarchy between classes; the mechanism is static and defined at compilation time.
- *Polymorphism*: it is a dynamic mechanism used at run time. If a class has a method *m()* and one subclass (child) redefines *m()*, the polymorphism allows executing an *m()* version according to which kind of subclass object is calling it.

In the PLCs software classes are implemented by Function Blocks (FB), as defined in the IEC 61131-3 standard [2]. The instance of a FB is equivalent to the object of a class. The standard mentions typical keywords of OOP like *methods*, *extends*, *implements*, etc. We have not used these elements in order to comply as much as possible with other kinds of controllers that do not implement these keywords. *Methods* are replaced by dividing the FB code in several independent parts called *actions. Extends* are replaced by writing FB I/O interfaces in order to implement the same concepts.

Another important aspect of the design was alarms and commands management. An alarm can be configured in order to allow the following actions: auto-reset, acknowledge and recording. A command can be recorded by means of the PLC logging system or by the *audit trail*, which is a logging mechanism provided by the HMI. In this log the HMI writes setpoint changes, commands sent to the PLC and it tracks who did what. This feature is widely used in industrial systems [3]; adopting it is particularly easy to save and move log files outside the system for data analysis.

All the system configurations can be easily changed many times during the design and commissioning of the software using a form which we have designed in C# VS2015. The result of this form is written in an XML code to be imported in the file system of the HMI project.

† massimo.trevi@elettra.eu

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV015

EPICS BASED HIGH-LEVEL CONTROL SYSTEM FOR ESS-ERIC EMITTANCE MEASUREMENT UNIT DEVICE

M. Giacchini, M. Montis, INFN-LNL, Legnaro, Italy
C. Derrez, J.P.S. Martins, R. Tarkeshian, ESS-ERIC, Lund, Sweden

Abstract

The European Spallation Source (ESS) [1] will be a neutron source using proton beam Linac of expected 5MW beam power [2]. The beam commissioning of low energy beam transport (LEBT) started on 2018 and currently expected to reach to the end of Medium Energy Beam Transport (MEBT). Several diagnostics are installed to characterize the proton beam and optimize the beam matching in radio frequency quadrupole (RFQ) section and rest of accelerator. Among all diagnostics, Allison scanner and Slit-Grid type emittance measurement units (EMUs) will aid by characterizing the beam in transverse plane (both horizontal x and vertical y) in LEBT and MEBT, respectively. Here in this paper the Slit-Grid EMU is explained and the software layer developed in EPICS [3] and realized to orchestrate the entire apparatus and control the different sub-systems will be described.

INTRODUCTION

The emittance measurement unit (EMU) aims to measure the transverse emittance by sampling the transverse phase space. At European Spallation Source (ESS) the Alison Scanner and Slit-Grid EMUs will be used to characterize the proton beam transversely in keV and MeV energy ranges, respectively. The Slit-Grid units, designed and delivered by ESS Bilbao [4], are installed in both transverse directions in MEBT, in order to characterize the beam after RFQ, see Figure 1. According to the baseline parameters, the MEBT will operate with peak current of 62.5 mA, energy of 3.63 MeV and RMS size of 2 mm. The Slit-Grid will be used to optimize matching of the beam to the other sections of the accelerator.

Considering the control system aspect, a single EMU device is composed of different sub-systems (acquisition, motion, etc.) which are harmonized and managed by EPICS, the distributed control system framework adopted as standard for the ESS Project. This article reports the upgraded on low-level and high-level control system.

EMITTANCE MEASUREMENT

The transverse emittance is an invariant quantity describing the distribution of the particle beam in transverse phase space (horizontal *x* and vertical *y*).

The RMS emittance formula commonly used is the following:

$$\varepsilon_{RMS} = \sqrt{\langle x^2\rangle\langle x'^2\rangle - \langle x \cdot x'\rangle^2} \qquad (1)$$

where $\langle x^2\rangle$ is the variance of the particle's position, $\langle x'^2\rangle$ is the variance of the angle the particle makes with the direction of travel in the accelerator and $\langle x \cdot x'\rangle$ represents an angle-position correlation of particles in the beam.

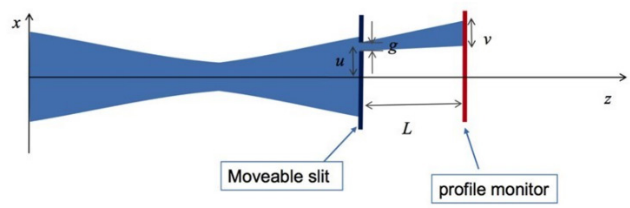


Figure 1: Scheme showing the Emittance measurement using Slit-Grid EMU. Source: Cheymol, R. Miyamoto, *"Preliminary Design of the ESS Slit and Grid System"*

INSTRUMENT DESCRIPTION

A Slit-Grid EMU is composed of a slit and a grid unit, mounted on separate moving actuators to scan the beam entirely. The slit samples small slices from the beam at almost equal position following drift space, the angular distribution of the particles is transformed into a position distribution and sampled using a profile monitor, in our case a secondary emission grid. By scanning the slit across the beam, the whole phase-space is reconstructed, see Figure 2.

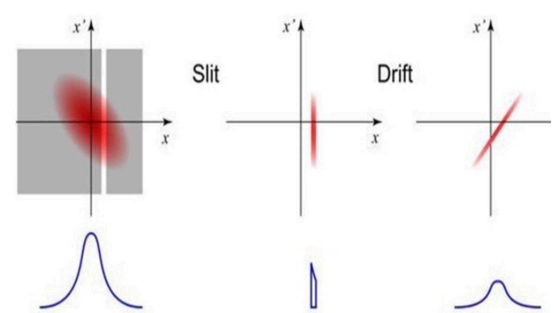


Figure 2: Phase-space sampling using a slit-grid system. Source: B. Cheymol et al., *"Design of a New Emittance Meter for Linac4"*

Particular aspects and design solution adopted are the following [5]:

For the EMU slit, it was shown that graphite is the chosen material to withstand irradiation. As consequence two graphite plates that form the slit are mounted in the slit head

- The EMU slit is designed in order to scan all the beam aperture. Since the beam envelop is ϕ40 mm,

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV016

DESIGN AND DEVELOPMENT OF THE NEW DIAGNOSTICS CONTROL SYSTEM FOR THE SPES PROJECT AT INFN-LNL

G. Savarese*, G. Arena, D. Bortolato, F. Gelain, D. Marcato, V. Martinelli, E. Munaron, M. Roetta
INFN/LNL, Legnaro, PD, Italy

Abstract

The need to get finer data to describe the beam is a relevant topic for all laboratories. For the SPES project at Laboratori Nazionali di Legnaro (LNL) a new diagnostic control system with more performing hardware, with respect to the one used in legacy accelerators based on Versabus Module Eurocard (VME) ADCs, has been developed. The new system uses a custom hardware to acquire signals in real time. These data and ancillary operations are managed by a control system based on the Experimental Physics and Industrial Control System (EPICS) standard and shown to users on a Control System Studio (CSS) graphical user interface. The new system improves the basic functionalities, current readback over Beam Profilers (BP) and Faraday Cups (FC) and handlings control, with new features such as: multiple hardware gain levels selection, broken wires correction through polynomial interpolation and roto-translations taking into account alignment parameters. Another important feature, integrated with the usage of a python Finite State Machine (FSM), is the capability to control an emittance meter to quickly acquire data and calculate beam longitudinal phase space through the scubeex method.

INTRODUCTION

The SPES project, acronym for Selective Production of Exotic Species, is the new leading project of the Legnaro National Laboratories (LNL) an Italian international center for the nuclear and astronuclear physics research. The objective of the SPES project is to study exotic beams made up of ions much more neutron-rich than those we can find in nature. It will exploit the legacy accelerator ALPI (Linear Accelerator for Ions) and will be employed as another ions source in parallel to the existing ones. [1] Since the beam will be post-accelerated in the ALPI accelerator, the beam line is made up of instruments aiming to optimize the beam transport, to reduce the energy spread, to clean the beam from undesired isobaric masses, to boost the beam charge and to pulse the beam. In a transport beam line the fundamental elements to monitor the beam shape, position and intensity are the diagnostics. They are essential to understand how to modify system parameters to obtain the desired beam [2].

The SPES project was the trampoline for the LNL to upgrade the hardware used to acquire and elaborate data and to adopt the Experimental Physics and Industrial Control System (EPICS) standard [3], that is a set of software tools developed to operate particle accelerators allowing information access and exchange between different subsystems. In fact a general upgrade of the legacy diagnostic control system was needed since the computer technologies improvement and the increasingly challenging accelerator data acquisition requested the design of a new modular and maintainable software and a hardware offering better performances.

This paper shows the most significant details and advantages of the new hardware configuration and the EPICS Input Output Controller (IOC) developed to communicate with the hardware components and the other subsystems already developed at the LNL.

THE LEGACY CONTROL SYSTEM

The legacy diagnostic control system is currently mounted in the ALPI and PIAVE (Positive Ions Accelerator for VEry low velocity ions) facilities and its target is to control and display details related to Faraday Cups (FC) and Beam Profilers (BP). Our FCs are copper cups used to collect and measure all the beam current; a metal shield, charged with high negative voltage, avoids that secondary electrons exit the cup. Our BPs are made up of two perpendicular grids (vertical and horizontal) with 40 parallel tungsten wires. Other diagnostic instruments are the collimators (or slits), used to narrow the beam, and the Emittance Meters (EM), which measures the longitudinal phase space and the energy spread.

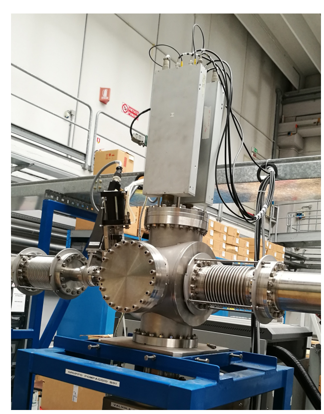


Figure 1: Diagnostic box with the legacy pre-amplifier grids.

Figure 2: VME Rack.

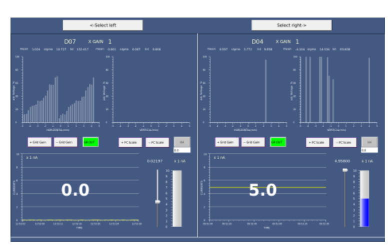


Figure 3: Legacy diagnostic GUI.

* giovanni.savarese@lnl.infn.it

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV019

CONTROL SYSTEM FOR 30 keV ELECTRON GUN TEST FACILITY

D. A. Nawaz†, M. Ajmal, A. Majid, N. U. Saqib*, F. Sher
LINAC Project, PINSTECH, Islamabad, Pakistan

Abstract

At LINAC Project PINSTECH, an electron gun test facility for indigenously developed 30 keV electron guns is developed to control and monitor various beam parameters by performing electron beam tests and diagnostics. After successful testing, electron gun is then integrated into 6 MeV standing wave linear accelerator. This paper presents the control system design and development for the facility.

INTRODUCTION

At LINAC Project PINSTECH, two RF standing wave linear accelerator prototypes are being developed. One is Medical linear accelerator (*Medical LINAC*) for use in medical applications such as cancer treatment, and the other is Industrial linear accelerator (*Industrial Linac*) for use in Non-Destructive Testing (NDT) applications. Electron source is one of the main components of an RF linear accelerator which provides charged particles to be accelerated by means of radio frequency [1]. Indigenously electron guns developed by Beam Transport and Diagnostics Group (BTDG) of LINAC Project are the electron sources for the linear accelerator prototypes at the project. Low energy 30 keV electron guns are designed and fabricated for integration into the 6 MeV linear accelerators. Characterization, testing and validation of electron gun parameters are important tasks that need to be properly done before integration into the accelerator [2]. For this purpose, Electron Source Operation and Characterization lab is developed at LINAC project PINSTECH that contains test facility. Next section describes overview of the experimental setup at the Lab.

OVERVIEW

The Lab is divided into two main areas: Experimental High Voltage (HV) Area and Control Room Low Voltage (LV) Area. Both of these areas are described in following subsections.

Experimental Area

Experimental Area consists of test bench and high voltage components. It consists of a low energy 30 keV electron gun along with beam diagnostic equipment integrated on a CF-63 based test bench. The designed electron gun is diode type based on thermionic emission which incorporates the modern dispenser cathode. The system is evacuated down to 1e-8 mbar with turbo molecular pump. Cold cathode ionization gauge IMG 300 is used for pressure measurement. A Faraday cup is integrated with transitional feed through to measure the beam current and a Ce doped YAG screen is used to measure the beam profile. The cathode of the gun is powered up with low voltage DC power supply, and beam extraction voltage is applied through high voltage DC power supply. Experimental area is remotely monitored and controlled from *Control Room* by means of a PLC-based control system. The schematic picture of experiment is shown in Fig. 1. Due to presence of high voltages, and for elimination of EMI, *Experimental Area* is completely caged, grounded and isolated.

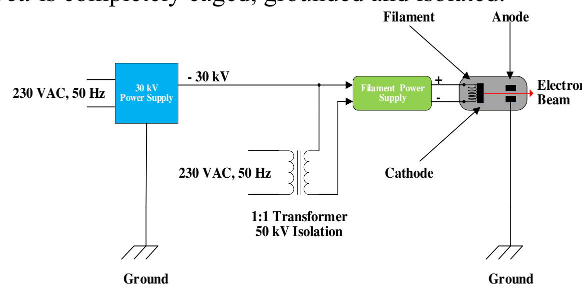


Figure 1: Schematic diagram of experiment.

Control Room Area

Control Room Area consists of two main components: *Operator Computer* and *Control Panel*. Operator computer consists of branded Dell i7 CPU, 24-inch LED monitor, keyboard, mouse and printer. The control panel consists of a C-type rail containing Siemens Simatic S7-300 PLC CPU, input, output and communication modules. The I/O modules allow support for digital inputs, digital outputs, analog inputs, analog outputs and RS-232/422/485 communications. The control panel can be divided into two parts: front panel and back panel. PLC controller along with its power supply, I/O and communication modules, and IPC477D touch panel are installed at the front panel. Circuit Breakers are installed at the back panel which provide protection in case of any short circuit or fault current.

CONTROL SYSTEM DESIGN

Control system acts as brain of the electron gun test facility. It enables operator to remotely monitor and control the complete system in a safe and interlocked environment to avoid any undesirable condition. In order to design the control system, hardware required was to have the following features: modular configuration for scalability, distributed configuration for separating high and low voltage area, Ethernet and serial interfaces for integration of commercial-off-the-shelf equipment, future availability for upgradation, knowledge and expertise for assistance. Keeping in view the above features, Siemens Simatic hardware and TIA-portal software packages were selected to design and develop the control system for electron gun test facility.

† nawazdanishali@gmail.com
* najm.control@gmail.com

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV020

AUTOMATIC RF AND ELECTRON GUN FILAMENT CONDITIONING SYSTEMS FOR 6 MeV LINAC

A. Majid†, D. A. Nawaz, N. U. Saqib*, F. Sher
LINAC Project, PINSTECH, Islamabad, Pakistan

Abstract

RF conditioning of vacuum windows and RF cavities is a necessary task for eliminating poor vacuum caused by outgassing and contamination. Also, startup and shutdown process of linear accelerator requires gradual increase and decrease of electron gun filament voltage to avoid damage to the filament. This paper presents an EPICS based multi-loop automatic RF conditioning system and Electron Gun filament conditioning system for Klystron based 6 MeV Linear Accelerator.

INTRODUCTION

Particle accelerators are a crucial instrument for scientific innovations and knowledge in all fields of research and engineering. As accelerators grow more complex, so do the demands placed on their control systems. The complexity of the control system hardware and software reflects the complexity of the machine. At the very same time, the machine must have simple access and operation, as well as a greater level of stability and adaptability.

Radio Frequency (RF) charged particle accelerators use accelerating RF cavities to accelerate electrons or ions to energies up to hundred mega electron volts. A particle source produces ions or electrons, which inject into the cavity with some minimum initial energy. A significant amount of RF power must be coupled into the accelerating cavity structure to transfer energy to the charged particles. High power klystron amplifiers are commonly employed as a RF power generation source for accelerators. In addition, waveguides and couplers are utilized to transmit RF power from the klystrons to the cavities. Injected RF power resonates with incoming particles, accelerating them to produce a higher energy, faster moving charged particle beam.

Several auxiliary systems, such as a water load and cooling system, vacuum maintenance system, control system and safety interlocks support the entire process. Maintaining a good quality vacuum in the LINAC cavity and connected components is critical for uninterrupted beam transport and smooth operation. When RF power is fed into the cavity during start-up and operation of the accelerator, the vacuum level degrades owing to poor manufacturing of the cavity's internal structures, RF breakdowns, outgassing, and arching. To cope with this issue, an auxiliary vacuum system is employed which consists of one or more series-connected pumps that continually generate a low-pressure zone inside the cavities. Radio frequency (RF) breakdown is a typical problem in accelerating structures and has been widely researched [1, 2, 3]. It is vital to avoid severe RF breakdown since it can harm accelerating structures and microwave devices irreparably. Breakdowns and multipacing restrict the power that the cavity can absorb during the conditioning process [4]. This phenomenon limits the RF structure from working in high-power mode and from producing full-energy beams. The frequency of breakdown is highly linked with the vacuum state and RF power intensity. Outgassing and sparking impact vacuum performance and restrict the RF field level that can be consistently attained.

Therefore, for safe operation, RF power is gradually injected into the cavity, ramping up in multiple stages from the lowest to the highest level while constantly monitoring the LINAC characteristic parameters such as vacuum level, temperature profile, arching, and other system interlocks [5]. The process of gradually "warming up" the LINAC cavity is known as RF conditioning. The amount of time required for conditioning, varies on the nature of cavity and might range from a few days to months.

This paper presents the design and development of a system for automated RF conditioning of electron linear accelerator cavities at the LINAC project PINSTECH. RF power conditioning scheme, hardware setup, logic design and software development techniques have been thoroughly addressed. The suggested structure is implemented with the Experimental Physics and Industrial Control System (EPICS), which is a collection of software components and tools used by developers to create distributed control systems for particle accelerators, big experiments, and massive telescopes [6]. In the last section, test setup developed for automated conditioning of electron gun filament has been discussed.

CONDITIONING STRATEGY

Numerous conditioning strategies have been employed at different accelerator facilities [7, 8, 9]. Linear accelerator prototypes (Medical and Industrial) at the LINAC project PINSTECH comprises of standing wave cavities structure, produces 06 MeV electron beam and runs at 2.5MW input RF power at resonance mode when the cavity is fully tuned. Electrons are injected by a 30keV electron gun and RF power is applied by a klystron that generates an oscillating RF signal of 50Hz frequency, 2.5 MW peak power and 5usec pulse width. The average power effectively delivered into the cavity is determined by three factors: peak amplitude, pulse width, and frequency.

$$P_{inj} = P_{peak} \cdot T_{on} \cdot f$$

Where P_{inj}, P_{peak}, T_{on}, f represent injected power, peak power, pulse width and frequency, respectively. These three parameters can be changed to enhance or reduce injected power.

† aaminahmajid@gmail.com
* najm.control@gmail.com

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV025

CONTROL SYSTEM OF UPGRADED HIGH VOLTAGE FOR ATLAS TILE CALORIMETER

F. Martins[1,*,†], F. Cuim[1], G. Evans[1,2], R. Fernandez[1], L. Gurriana[1], A. Gomes[1,2], J. Soares Augusto[2,3]
[1] Laboratory of Instrumentation and Experimental Particle Physics (LIP), Lisbon, Portugal
[2] Faculdade de Ciências da Universidade de Lisboa, Lisbon, Portugal
[3] Inesc-ID, Lisbon, Portugal

Abstract

The preparation of the upgrade of the ATLAS electronics for the High Luminosity LHC is in full swing. The Tile Calorimeter is preparing the upgrade of its readout electronics and power distribution systems. One of such systems is the High Voltage (HV) regulation and distribution system. The new system is based on HVRemote boards mounted in crates located at the counting room. The HV will be delivered to the on-detector electronics using 100 m long cables. The crates will be equipped with a system-on-chip that will be responsible for the control and monitoring of the HV boards. The control of the HVRemote and its dedicated HVSupply boards is done by means of a serial peripheral interface bus. A SCADA component is under development to communicate with and supervise the crates and boards, and to integrate the HV system in the control system of the detector. The control system will be able to send notifications to the operators when the monitored values are out of range, archive the monitored data and if required, perform automated actions.

INTRODUCTION

Located in the central region of the ATLAS detector [1], the Tile Calorimeter (TileCal) [2] is composed of iron plates interpolated with plastic scintillating tiles that work as active material. The light resulting from the interaction of the particles with the plastic tiles is guided by wavelength shifting optical fibers to the photomultipliers tubes (PMT). The signal generated by the PMT is then processed by the on-detector and off-detector data acquisition electronics. TileCal uses approximately 10^4 PMTs divided over the 256 modules that compose the four TileCal operational barrels (EBA, EBC, LBA and LBC). The operation of TileCal requires a high voltage system able to regulate and monitor the HV set to each individual PMT with a precision within 0.5 V rms. For the High Luminosity Large Hadron Collider (HL-LHC) a new high voltage system is under development [3, 4] for TileCal, along with other hardware upgrades [5, 6]. It will consist of HV source boards, regulation and monitoring boards housed in crates located in the off-detector area, with the HV being delivered to each PMT by 100 m long cables. With the regulation boards located off-detector, they are not required to be radiation hard and they have also the advantage of easier access for repairs which can be executed during data-taking periods.

The Detector Control System (DCS) of TileCal is responsible for the supervision and control of the TileCal electronics and infrastructure, continuously monitoring temperatures, voltages and currents [7].

* Corresponding author fmartins@lip.pt

HIGH VOLTAGE BOARDS

HVSupply

The HVSupply board is responsible for providing the direct current (DC) HV and the three low DC voltage levels, (12 V, −12 V, 3.3 V) required by the HVRemote board to operate. The HV will be supplied by two commercial DC/DC converters (Hamamatsu C12446-12) with a combined maximum output current of 20 mA and adjustable voltages up to −1000 V. The supervision will include the monitoring of the supplied voltages and respective current consumption as well as the readings of on-board temperature probes and on-chip temperature. The digital control and monitoring is achieved by using a dedicated Serial Peripheral Interface (SPI) bus. An analog switch was also implemented in the board which will allow the HV DC/DC converters to be switched off when a hardware interlock signal is removed. The interlock signal can either be interrupted by the TileCal DCS or by the Detector Safety System (DSS).

HVRemote

The HVRemote board is composed of 48 HV channels for regulating and monitoring the individual channels voltages in the range from −500 V to −950 V. Enabling or disabling the output of the HV channel is available by software in groups of 4 channels. However it is possible to disable the output of any of the HV channels by hardware (by means of a jumper) allowing, for example, to isolate it from a short circuit in the long cable or in the HVBus board (located on-detector). Temperature probes are available to monitor the board temperature and assess the cooling conditions. Each of the boards will have an unique serial number allowing the crate controller and the Supervisory Control and Data Acquisition (SCADA) control system to identify each individual HVRemote board. The communication between the on-board circuits and the crate control is done via a dedicated SPI bus. Figure 1 shows a simplified diagram of the HVRemote board control.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV027

EPICS DAQ SYSTEM OF BEAM POSITION MONITOR AT THE KOMAC LINAC AND BEAMLINES

Young-Gi Song†, Jae-Ha Kim, Sung-Yun Cho
Korea Multi-purpose Accelerator Complex, Korea Atomic Energy Research Institute, Korea

Abstract

The KOMAC facility consists of low-energy component, including a 50-keV ion source, a low energy beam transport (LEBT), a 3-MeV radio-frequency quadrupole (RFQ), and a 20-MeV drift tube linac (DTL), as well as high-energy components, including seven DTL tanks for the 100-MeV proton beam [1]. The KOMAC has been operating 20-MeV and 100-MeV proton beam lines to provide proton beams for various applications. Approximately 20 stripline beam position monitors (BPMs) have been installed in KOMAC linac and beamlines. A data-acquisition (DAQ) system has been developed with various platforms in order to monitor beam position signals from linac and beamlines. This paper describes the hardware and software system and test results.

INTRODUCTION

Ten stripline BPMs and nine stripline BPMs were installed in the 350MHz pulse KOMAC Linac and beamline, respectively. Figure 1 shows the BPM installed in Linac and beamlines.

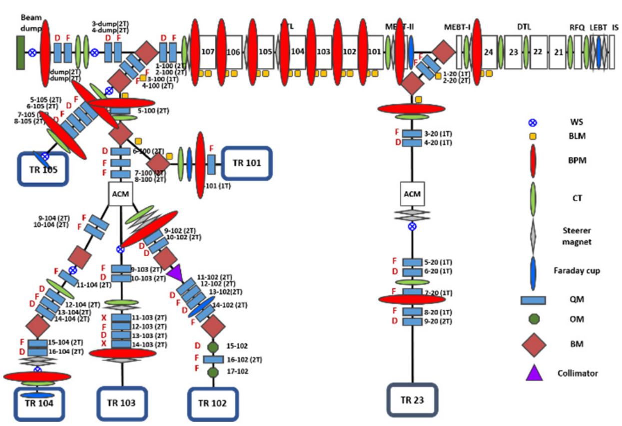


Figure 1: Layout of KOMAC Linac and Beamline.

In addition to the transverse beam position, the BPM is used to measure the beam phase for energy calculation based on flight time measurement. VME-based board was adopted as a major platform for high-performance subsystems. The MVME3100 CPU board has been adopted as a standard control system and is used in beam diagnosis, timing system, and LLRF control systems [2][3].

The DAQ system for BPM measures beam position and phase in pulse mode through IQ-based RF signal measurement. It used a single type of electronic product for all BPMs so that the design of the front electronic device is applied to all type of single-board computers through minor modifications. Table 1 summarizes the main specification of the Linac BPM and beamline BPM. The fabricated BPMs are shown in Fig. 2.

Table 1: Design Parameters of the BPMs

Type	Linac BPM	Beamline BPM
Electrode aperture	20 mm	100 mm
Electrode thickness	2 mm	2 mm
Electrode angle	60 deg.	456 deg.
Electrode length	25 mm	70 mm
Electrode gap	3.5 mm	15 mm
Feedthrough	SMA	SMA
Signal frequency	350/700 MHz	350 MHz

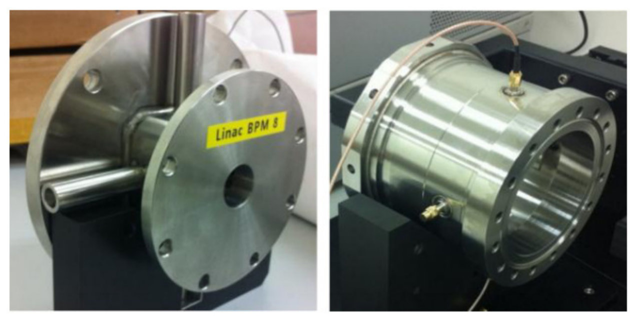


Figure 2: Linac BPM (left) and beamline BPM (right).

The BPM frontend that receives, levels down, and filters BPM signals includes analog parts of some sensitive electrical devices. The signal that has passed the frontend is sampled by the digitizer board and accumulated in memory. The sampled data extracts valid values such as beam position, beam phase, and beam current. KOMAC BPM DAQ has been upgraded to be integrated using EPICS [4] after collecting and processing BPM signals.

SYSTEM CONCEPT

As part of the available electronics platform and electronics standardization strategy, VME has been adopted and used as a major device for KOMAC's high-performance electronics, including BPM, timing and LLRF systems. The main reasons for adopting VME are excellent performance, durability, and cost reduction. In particular, by unifying the platforms of various control system, short development processes and simple maintenance become the biggest advantages.

Figure 3 shows a schematic diagram of the BPM system manufactured by KOMAC for accuracy and calibra-

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV028

THE CONTROL AND ARCHIVING SYSTEM FOR THE GAMMA BEAM PROFILE STATION AT ELI-NP*

G. Chen †, V. Iancu, C. Matei, F. Ramirez, G. Turturica
Extreme Light Infrastructure – Nuclear Physics, IFIN-HH, Magurele-Bucharest, Romania

Abstract

The Variable Energy Gamma (VEGA) System of Extreme Light Infrastructure - Nuclear Physics (ELI-NP) is based on the Inverse Compton Scattering of laser light on relativistic electron bunches provided by a warm radio-frequency accelerator. The system will deliver quasi-monochromatic gamma-ray beams with a high spectral density and a high degree of linear polarization. The Beam Profile Station, which will be used for finer target alignment and spatial characterization of the gamma-ray beam, is one of the diagnostics stations under implementation at ELI-NP.

An EPICS Control and Archiving System (CAS) has been developed for the Beam Profile Station at ELI-NP. This paper describes the design and the implementation of the EPICS CAS for the Beam Profile Station, including the device modular integration of the low-level IOCs for the CCD camera Trius-SX674 and Mclennan PM600 Stepper Motor Controller, the design of the high-level GUI for real-time image acquisition and motion control, as well as the configuration of the archiving system for browsing the historic images and parameters.

INTRODUCTION

The Variable Energy Gamma (VEGA) System of Extreme Light Infrastructure - Nuclear Physics (ELI-NP) will produce intense gamma-ray beams with a spectral density higher than 0.5 x 10^4 photons/eV/s, a relative energy bandwidth better than 0.5%, high degree of linear polarization at more than 95%, and energy continuously variable from 1 MeV up to 19.5 MeV based on the laser Compton backscattering of laser photons off a relativistic electron beam.

The Gamma Diagnostics Stations are designed and under implementation to measure and to monitor the gamma beam diagnostics features [1]. To optimize the operation of the ELI-NP VEGA and its use for experiments, it is necessary to have the proper means to accurately predict the spatial, spectral and temporal characteristics of the gamma beam. The ELI-NP Gamma Diagnostics Stations are dealing with the equipment and techniques meant to optimize the gamma beam in order to make it available for user experiments within required parameters.

As a part of the Gamma Diagnostics Stations, the Gamma Beam Profile Station utilizes a CCD camera to collect the light produced in a scintillator placed in the beam by means of a mirror. The system is designed to be mobile and could be moved to different experimental areas.

The camera will be placed outside vacuum in a special mount, which ensures position reproducibility and easy removal. The scintillator and the mirror will be housed in a light-tight box inside the beam transport pipe. To ensure position reproducibility of the scintillator, a motor controller will be attached to the scintillator.

The CCD camera Trius-SX674 and the Stepper Motor Controller Mclennan PM600 have been chosen to be integrated into the CS of the Gamma Beam Profile Station.

Besides, the archiving system is required to store the PV samples periodically into an RDB.

SYSTEM DESIGN AND CONFIGURATION

The EPICS [2] based CAS for all the diagnostics stations will be designed and implemented by ELI-NP, to provide the machine information connection with the VEGA CS, to collect data from devices in the diagnostics stations, to monitor status of the devices, and to provide the High-Level Software (HLS) for the Gamma Beam Diagnostics.

General Architecture Model

The architecture of the CAS is structured as the standard three-tier structure:

User interface. These are graphical and non-graphical user interfaces. Most or all of these will be in the control room.

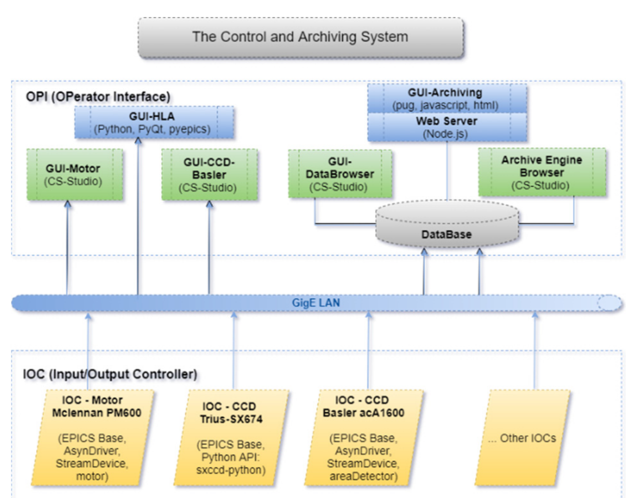


Figure 1: The software architecture of the Control and Archiving System.

Central services. Central services need to be run continuously irrespective of user activities, e.g., for archiving process variables' values, monitoring alarm states, etc.

Equipment interfaces. This tier is responsible for interaction with equipment and devices. It provides an abstract

* The work is supported by ELI-NP Project (http://www.eli-np.ro/)
† guangling.chen@eli-np.ro

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV030

REDESIGN OF THE VELO THERMAL CONTROL SYSTEM FOR FUTURE DETECTOR DEVELOPMENT

S. A. Lunt*, University of Cape Town, Cape Town, South Africa
L. Zwalinski, B. Verlaat, CERN, Geneva, Swizerland

Abstract

The Detector Technologies group at CERN has developed a Two-Phase Accumulator Controlled Loop (2PACL) [1] test system for future detector development, using reused hardware from the LHCb Vertex Locator (VELO) Thermal Control System [2]. The fluid, electrical and control systems have been redesigned and simplified by removing redundant components because it is no longer a critical system. The fluid cycle was updated to allow both 2PACL and integrated 2PACL [3] cycles to be run and the chiller was replaced with an air-cooled unit using hot gas bypass to achieve a high turndown ratio. The electrical systems were upgraded to improve usability and practicality. The control system logic is being developed with the CERN's Unified Industrial Control System (UNICOS) framework. This paper presents the details of the design and implementation.

INTRODUCTION

The Vertex Locator (VELO) Thermal Control System (VTCS) is the first CO_2 detector cooling system used at CERN to cool LHCb's VELO sub-detector. Following the successful use of CO_2 cooling in the VTCS and AMS-02 [4] on the International Space Station the number and capacity of CO_2 based detector cooling systems has increased significantly with installations in the LHCb, ATLAS and CMS experiments at CERN. The VTCS was retired and replaced with a new system in 2019 [5]. The Detector Technologies (DT) group decided that the system could be refurbished and used for the development and testing of future detectors for ATLAS on the surface.

The system was partially redesigned to prepare it for the new role. The electrical system was replaced to ensure it met the department's standards. The control logic has been rewritten with a new program developed under the Unified Industrial Control System (UNICOS) framework [6]. The fluid systems have remained largely unaltered with only the position of the accumulators being changed. All redundant components have been removed and a mode that runs the integrated two-phase accumulator controlled loop (I2PACL) [7] have been added. The chiller has been replaced to make it more suitable for surface applications without available underground infrastructure.

FLUIDIC SYSTEM

The original fluid systems were designed with redundancy in each layer to make sure no single failure would cause the detector's cooling supply to stop because the silicon tracking sensors of the detector degrade quickly at temperatures above 0 °C after they have been exposed to radiation. These redundant elements have been removed from the new system because a failure of the cooling system in a test environment is acceptable because the sensors have not been exposed to radiation [8].

The VELO detector consists of two halves that sit on either side of the beam. The VTCS was designed with two independent, two-phase accumulator controlled loops (2PACL), one for each side. A third pump was installed to act as a backup for either side in the event of a pump failure [2]. This pump along with the pipes and valves that supplied it have been removed. Two valves were left in because they provide mechanical support for the surrounding pipes and convenient access for maintenance of the system.

The new system will retain the two independent 2PACL, shown in Fig. 1, loops to maximise its versatility and minimise the changes that need to be made to the CO_2 system. To improve the responsiveness of the controllers to changes in the process, in-flow temperature sensors are being added. The accumulator heat exchanger previously connected to the backup chiller will be used to allow the system to run in the simpler Integrated 2PACL (I2PACL) mode [7].

Integrated 2PACL

Since the development of the VTCS the DT group has made improvements to the two-phase process: integrated 2PACL. This removes the need to actively cool the accumulator, reducing the complexity of the fluid and control systems. In an I2PACL system, the sub-cooled CO_2 leaving the pump flows through a heat exchanger in the accumulator, shown in Fig. 2.

Removing the need for a controlled external cooling source simplifies the control of the accumulator's saturation pressure, thus allowing the saturation temperature of the accumulator to be controlled with the heater alone. The heater provides the energy equal to the heat capacity of the liquid CO_2 and by controlling the power the pressure is regulated (Fig. 3).

The accumulators contain two condensing spirals, which were used by the main and backup chillers. One of these condensing spirals will now be used for the I2PACL mode; the other will be supplied from the chiller to control pressure in 2PACL mode.

Chiller

The primary water-cooled chiller and backup air-cooled chiller, will not be reused. Cold water is a service supplied in the caverns at CERN but is not readily available in other

* lntstu001@myuct.ac.za; slunt@cern.ch

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV031

LHC VACUUM SUPERVISORY APPLICATION FOR RUN 3

Sebastien Blanchard†, Ivo Ambrósio Amador, Nikolaos Chatzigeorgiou, Rodrigo Ferreira, Joao Diogo Francisco Rebelo, Paulo Gomes, Christopher Viana Lima, Gregory Pigny, Andre Paiva Rocha, Lampros Zygaropoulos
CERN, Geneva, Switzerland

Abstract

The LHC Vacuum Supervisory Control and Data Acquisition application has been upgraded to fulfil the new requirements of Long Shutdown 2 and Run 3.

The number of datapoint elements has been increased from 700k to 1.5M, which constitutes a challenge in terms of scalability. The new configuration of pumping station control hardware has led to an increase in the number of permanently connected PLCs – from 150 to almost 300. A new concept has been developed and deployed, in which the PLC configuration is updated online. The goals were to automate, and to speed up periodic updates of the control system. Integrating of the wireless mobile equipment had led to the acquisition of expertise in dealing with temporary connections and dynamic insertion of device representation in the synoptic.

Other new features include: the introduction of an innovative remote control and representation in synoptic panel of hardware interlocks, the development of a pre-configured notification system, and the integration of asset management into the user interface.

VACUUM SYSTEMS

The Large Hadron Collider (LHC) has two types of vacuum systems:

- The beam vacuum system, which reaches ultra-high vacuum (below 1×10^{-9} mbar).
- The insulation vacuum system, used for thermal insulation of cryogenic components, and which reaches high vacuum (below 1×10^{-5} mbar).

Both systems are divided into sectors delimited by vacuum valves or windows. Vacuum sectors will reduce or entirely prevent the propagation of sudden pressure increases. They also allow for independent venting and interventions.

The beam vacuum system of the LHC has 321 sectors. Only a few sectors have pumping group stations [1] permanently installed. For most sectors, pumping group stations – and sometimes, bake-out cabinets [2] – are temporarily installed during installation or interventions. Pumping group stations achieve high vacuum, after which bake-out cycles decrease the outgassing rate of the vacuum vessel and activate the NEG thin-film coatings. Finally, the permanently installed pumps are started. These include, for example – ion pumps. In addition, every sector has a full set of vacuum gauges.

The insulation vacuum system of the LHC has 235 sectors. These sectors have pumping group stations [1] and vacuum gauges permanently installed.

† sebastien.blanchard@cern.ch

Table 1: List of Remote-controlled Instruments

Type	System	Count
Sector Valves	Beam	324
Sector Valves	Insulation	68
Fixed Pumping Groups	Beam	10
Fixed Pumping Groups	Insulation	193
Ion pumps	Beam	906
Pirani Gauges	Beam	455
Pirani Gauges	Insulation	343
Penning Gauges	Beam	803
Penning Gauges	Insulation	343
Ion Gauges	Beam	196
Membrane Gauges	Insulation	237

Table 1 lists the individual quantities of remote-controlled vacuum instruments in the LHC.

HARDWARE ARCHITECTURE

The automation layer of the vacuum control hardware architecture is PLC-based. Figure 1 shows the hardware architecture.

PLCs and controllers are installed in radiation-free areas of the LHC's underground, while the radiation-tolerant measuring cards [3], for gauges, are installed in the tunnel – close to the instruments. Table 2 lists the individual quantities of PLCs, controllers, measuring cards and hardware interlocks installed in the LHC.

Table 2: List of Controllers

Type	System	Count
PLCs	Beam	40
PLCs	Insulation	253
PLCs for mobiles	Beam/Insul.	350
Commercial controllers	Beam/Insul.	654
Valve controllers	Beam	324
Radiation tolerant cards	Beam/Insul.	881
Hardware Interlocks	Beam	282
Hardware Interlocks for Cryogenics	Insulation	539

After a successful Run 2, the LHC entered into Long Shutdown 2 (LS2). This will have lasted from the end of 2018, to the beginning of 2021.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV032

CHALLENGES OF AUTOMATING THE PHOTOCATHODE FABRICATION PROCESS AT CERN

Cédric Charrondiere, Eric Chevallay, Thomas Zilliox, CERN, Geneva, Switzerland

Abstract

The CERN Photoemission Laboratory was founded in 1989 with the goal of studying laser-driven electron sources, for producing high-brightness electron beams within the framework of the Compact Linear Collider (CLIC) study. To produce these photocathodes, two processes run in parallel. The first process, which is slow and asynchronous, controls and monitors the evaporation of photoemissive material. For this first step several power supplies are controlled to evaporate different metals through the Joule effect, with the power maintained constant in time and the thickness deposited monitored. The second process is synchronized with a laser trigger ranging from 0.1 to 50Hz, where the photocurrent and laser energy are measured to calculate the Quantum Efficiency.

The control system for these processes has recently been renovated to benefit from the modularity of a PXI-based real-time environment using the standard CERN Middle-Ware communication layer (CMW). This paper describes the challenges of the fabrication process as well as the flexibility introduced by using a PXI system.

INTRODUCTION

The CERN Photoemission Laboratory [1] was built with the goal to study and supply the CLIC Test Facilities (CTF 1 and 2) [2] with electron bunches of a few ps in time with a high electrical charge in the range up to 100 nC.

The CERN Photoemission Laboratory apparatus is divided in three parts:

- The Preparation Chamber where the fabrication of our photocathodes (the electron source) is done
- A DC Gun coupled with a beam measurement line for the characterisation of the cathode properties with a real, powerful, electron beam.
- A laser which is used to illuminate the electron sources during the fabrication and characterisation phases.

In the middle of the years 1990, after a few years of R&D, and the validation of the Cs-Te deposition technology, the laboratory received an important upgrade which enable the possibility to supply the CTF, our first client, with electron sources.

FABRICATION PROCESS

Physical Process Involved

The fabrication of the photocathode (Fig: 1) is the process of coating a substrate, the Cu photocathode plug, with a mixture of alkali metals and another element, tellurium or antimony. During this process the cathode is illuminated with a laser. A photoemission reaction occurs and produces an electron current, collected and measured to quantify the cathode's performance. The goal is to maximize the photocurrent and the quantum efficiency of the cathode while ensuring a very good source lifetime.

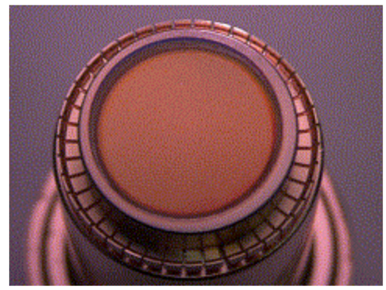


Figure 1: Cs-Te coating visible on the photocathode head.

In order to optimize the process, the system needs to be able to control several power supplies used to heat the evaporators and monitors the applied electrical power, temperature, laser energy, intensity produced by the photoelectron current, thickness of the coatings and vacuum pressure.

Instrumentation

- The Inficon XTM/2 deposition monitor is dedicated to monitor the alkali coating.
- The Inficon XTC/2 deposition controller is used to monitor the thickness of the tellurium coating.
- The Inficon XTC/3S is a spare deposition controller
- The TPG300 is a vacuum gauge controller to monitor the pressure in the vacuum vessel.
- The VIONIC 159 is the vacuum gauge controller for hot cathode gauge.
- The Heidenhain ND 780 is a positioning ruler, as a milling machine gives the position of the evaporator arm and the cathode arm in um.
- The Radiometer RM6600a is used as Joulemeter to monitor the laser energy when the light hits the cathode.
- Power supplies (Delta Elektronika + CERN made electronics) heat the evaporator (Cs or Te) by the Joule effect (control and instrumentation)
- Temperature monitoring with thermocouple and dedicated electronics
- Photocurrent acquisition with a precise laser synchronous timing system and fast sample/hold electronics.

CHALLENGES

Photocathode fabrication in laboratories like CERN is not reproducible because installations were designed for R&D and not for industrial production. Furthermore, with

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV033

DISTRIBUTED TRANSACTIONS IN CERN'S ACCELERATOR CONTROL SYSTEM

F. Hoguin, S. Deghaye, P. Mantion, J. Lauener, R. Gorbonosov, CERN, Geneva, Switzerland

Abstract

Devices in CERN's accelerator complex are controlled through individual requests, which change settings atomically on single Devices. Individual Devices are therefore controlled transactionally. Operators often need to apply a set of changes which affect multiple devices. This is achieved by sending requests in parallel, in a minimum amount of time. However, if a request fails, the Control system ends up in an undefined state, and recovering is a time-consuming task. Furthermore, the lack of synchronisation in the application of new settings may lead to the degradation of the beam characteristics, because of settings being partially applied. To address these issues, a protocol was developed to support distributed transactions and commit synchronisation in the CERN Control system, which was then implemented in CERN's real-time frameworks. We describe what this protocol intends to solve and its limitations. We also delve into the real-time framework implementation and how developers can benefit from the 2-phase commit to leverage hardware features such as double buffering, and from the commit synchronisation allowing settings to be changed safely while the accelerator is operational.

DISTRIBUTED TRANSACTIONS: INTRODUCTION

In CERN's accelerator control system, clients address devices individually with a request made on a property of a device. To modify a property across multiple devices, requires as many requests as there are devices. Until all the requests are made, an accelerator is in an undefined state. Moreover, if any of the requests fail, additional actions are required to understand why it failed and how to fix it, leaving the accelerator in an undefined state for a potentially large amount of time.

In order to solve this problem, distributed transactions were designed and implemented in CERN's accelerator control system.

GOALS, LIMITATIONS, AND DESIGN OF DISTRIBUTED TRANSACTIONS

The goal of distributed transactions is to ensure that a set of modifications occurring on distributed nodes are either completely recorded, or not at all. A node can be anything, but the first example that comes to mind is a database. This behaviour is typically achieved by using a two-phase commit. The generic workflow is as follows:

- A transaction is opened with the different participating nodes;
- Modifications are made on the different nodes in any order and over an unspecified period of time;
- The commit then occurs in two steps:
    1. A commit is sent to all the nodes which perform the required checks and ensure that locally there are no errors;
    2. If no errors are reported by the first commit, a second one, confirming the wish to commit is sent. From then onwards, the modifications are permanently recorded;
    3. If, on the other hand, errors are reported during the first-phase commit, the transaction is rolled back on all the nodes and no modifications are recorded.

DISTRIBUTED TRANSACTIONS IN ACCELERATOR CONTROLS

In the context of CERN's accelerator controls, the nodes are the low-level equipment controllers, the so-called Front-End Computers (FECs). The modifications are changes of the underlying equipment settings. A nominal transaction for CERN accelerator controls contains the following steps:

- The client opens a transaction with a unique transaction ID on all the devices it plans to modify, via a synchronous middleware call to a standardised property;
- The client modifies the settings via a synchronous middleware call. Again, the order and period of time are unspecified;
- The client asks the devices to test their new settings via a synchronous middleware call to a standardised property (TRASACTION.TEST);
- If all the devices report a successful test, the client commands the timing system to broadcast a commit event for the transaction. Upon reception, the FECs permanently commit the new settings;
- Otherwise, if one or more devices report an error during the test, the client asks the timing system to broadcast a roll-back event which will trigger the discard of the settings set with the corresponding transaction ID.

In the workflow described above, several implementation choices are already visible. One key element is the way to transport the final commit and roll-back. CERN's timing system, whose purpose is, among other things, to distribute events to the whole accelerator complex, is used to trigger a commit or rollback of a transaction. Even though the transactions are not meant to synchronise the moments at which the commits are performed, by using the timing system to transport these two events, we combine the possibilities offered by a global commit event with the synchronisation possibilities of the timing system.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV034

DEVELOPMENT OF AN AUTOMATED HIGH TEMPERATURE SUPER-CONDUCTOR COIL WINDING MACHINE AT CERN

H. Reymond, M. Dam, H. Felice, A. Haziot, P. Jankowski, P. Koziol, T.H. Nes, F.O. Pincot, S.C. Richter, CERN, Geneva, Switzerland

Abstract

Within the framework of technology studies on future accelerators, CERN has initiated a five-year R&D project aimed at the evaluation of REBCO (Rare Earth Barium Copper Oxide) High Temperature Superconductors (HTS). The study covers a number of areas from material science to electromechanical properties. The REBCO high-field tape will be tested on different HTS magnet prototypes, such as HDMS (HTS Demonstrator Magnet for Space), GaToroid (hadron therapy Gantry based on a toroidal magnetic field) and other smaller coils that will be fabricated to study the tape's potential. To assemble the HTS coils, a new automatic winding station has been designed and constructed at CERN. A touch panel combined with embedded controller, running software developed in-house provides a sophisticated, yet intuitive and user-friendly system aimed at maintaining perfect coil winding conditions. In this paper, we describe the mechanical choices and techniques used to control the seven HTS spool tapes and the winding machine. We also present the analysis of several coils already produced.

INTRODUCTION

Whether for the next generation of high energy particle accelerators, or for the development of new equipment dedicated to physics or medical research, one of the main decisive factors in the future will be the industry's ability to produce superconducting magnets with a field of at least 20 T [1].

Being one of the world leaders on superconducting magnet technology, CERN has been given responsibility of work-package 10 (WP10) "Future Magnets" as part of their contribution to the EuCARD-2 project [2], supported by the European Commission's Seventh Framework Programme (FP7). WP10's main goal was to manufacture and qualify an HTS cable, within real demonstrator coils and magnets, having useful characteristics for accelerator magnets (dipole field of 20 T, industrialized production, affordable cable, …).

After studying several possible candidates, the REBCO tape was chosen as an appropriate candidate, mainly because of its mechanical properties, but also due to its availability through many different suppliers, and finally because it doesn't require any further treatment before assembly [3].

In 2017, the ARIES European program was launched with the objective of improving the REBCO tape current density [4]. In parallel, CERN initiated a 10-year research program (CERN HTS program) to study and develop dipole magnets with magnetic fields beyond 20 T [5].

The Prototypes and Demonstrators

To test and evaluate the new requirements, several R&D studies were launched, each focusing on different technologies.

- The HTS demonstrator magnet for space (HDMS) aims at validating the feasibility of a new generation of magnet to be used for a spatial spectrometer [6].
- The 20 T HTS Clover Leaf End Coils magnet to study the mechanical and magnetic aspects of so-called overpass / underpass coil end assembly [7].
- The 8.2 T toroidal coils, which would be the basis of the GaToroid CERN proposal, for a new gantry design in the field of Hadron cancer treatment [8].
- The small coils program as a general study of high-field accelerator magnets for Hadrons and Muons (solenoid, undulator) [9].

The Coil Winding Machine

In order to co-wind stacks of REBCO tapes, dedicated tools and custom machinery is needed for its assembly. It was therefore decided that the coil-winding machine would be built in-house, at CERN. As a result, different teams involved in anything from magnets design, mechanical studies to control system development, joined forces to manufacture and assemble the machine in just a few months [10].

THE WINDING MACHINE DESIGN

One of the main requirements of the machine design was the semi-automation of the winding process to be capable of working with up to 7 tapes simultaneously. An important request was the ability to set up and control in a closed loop the tension on the spools, with added monitoring and storage of the results.

The winding station was built as a long table made of aluminium profiles with 7 spools, each connected via a clutch to a dedicated motor (Fig. 1). Next to the spool holder, custom-made tape routing equipment was installed, both guiding and measuring the tension applied to the tapes. In addition, tape alignment tooling with a built-in length encoder was incorporated into the machine to merge and adjust the tape position before winding the coil.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV035

CONTINUOUS INTEGRATION FOR PLC-BASED CONTROL SYSTEM DEVELOPMENT

B. Schofield*, J. Borrego, E. Blanco, CERN, Geneva, Switzerland

Abstract

Continuous Integration/Continuous Deployment (CI/CD) is a software engineering methodology which emphasises frequent, small changes committed to a version control system, which are verified by a suite of automatic tests, and which may be deployed to different environments. While CI/CD is well established in software engineering, it is not yet widely used in the development of industrial controls systems. However, the advantages of using CI/CD for such systems are clear. In this paper we describe a complete CI/CD pipeline able to automatically build Siemens Simatic Programmable Logic Controller (PLC) projects from source files, download the program to a PLC, and run a sequence of tests which interact with the PLC via both a Simulation Unit Profibus simulator and an OPC Unified Architecture (OPC UA) interface provided by Simatic NET. To achieve this, a Google Remote Procedure Call (gRPC) service wrapping the Simatic Application Programming Interface (API) was used to provide an interface for interacting with the PLC project from the pipeline. In addition, a Python wrapper was created for the Simulation Unit API, as well as for the OPC UA interface, which allowed the test suite to be implemented in Python. A particle accelerator interlock system based on Siemens S7-300 PLCs has been taken as a use case to demonstrate the concept.

INTRODUCTION

In software engineering, Continuous Integration (CI) refers to a method of development in which changes are regularly incorporated into a central repository. It is very often associated with the presence of build and test automation, in which code is automatically compiled, and a set of tests run. The objective of the methodology is to provide early detection of bugs introduced by code changes, and to simplify workflows in the case where there are several developers working on a single code base (the alternative is to perform periodic merges of the individual developers' branches, which may be very complex if many changes have been made).

Continuous Deployment (CD) is perhaps less well defined, and entails at least the automatic release of some artefact of the automated build process in the CI stage. It may also involve the fully automatic deployment of the artefact in a production environment.

Software for PLC-based control systems traditionally does not follow CI/CD principles, for a number of reasons. Generally, proprietary engineering tools are used as the development environment, in which code is written, compiled and downloaded to the PLC.

* Corresponding Author. E-mail: brad.schofield@cern.ch

In general there is no support for external version control systems to be used for the source code, at least as far as CERN's standard PLC suppliers are concerned (Siemens, Schneider). Instead, often the full project is included in version control as the collection of files and data used by the engineering tools, provided one is using version control at all. Tracking code changes is difficult, and merging branches is effectively impossible with such a workflow. Automation of the building of PLC projects is not trivial, as not all engineering tools provide easy access from scripting languages to these functionalities. Finally, automated testing proves to be cumbersome for a number of reasons that will be elaborated in later sections.

The question addressed in this article is whether it is technically feasible to implement a CI/CD workflow for PLC-based controls development, and if so, whether such a workflow is practicable and useful in a real-world application.

In order to address the first point, set of tools will be introduced which aim to overcome the obstacles preventing the adoption of CI/CD for PLC-based control system development. Tools for automation of the build process are proposed, with the focus on Siemens Simatic applications, although tooling for other engineering tools has also been developed. An approach for implementing automated testing of the complete PLC program is described, consisting of an interface to a fieldbus simulator, as well as an OPC UA interface to the PLC and Supervisory Control And Data Acquisition (SCADA) layers of the control system.

To demonstrate these tools, and illustrate their potential, a use case consisting of an interlock system for the Large Hadron Collider (LHC) is presented. Major updates and refactoring of this control system have been enabled by employing the CI/CD workflow presented in this article.

The article begins with addressing the question of the tooling required to automate the building of PLC projects. After that, automatic testing is addressed. Finally, the use case is explained and details of the proposed workflow are given within the context of that project.

TOOLS FOR AUTOMATING PLC PROJECT BUILDING

Intended Workflow

In order to implement CI/CD for PLC-based applications, it is necessary to adopt a similar underlying development workflow to that used elsewhere in software engineering. Fundamentally, this means adopting the use of version control for all source code. The source code is then compiled to produce some form of output, for example executable programs or libraries, for one or more target systems. These outputs in themselves do not need to be included in version

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV036

AN EVALUATION OF SCHNEIDER M580 HSBY PLC REDUNDANCY IN THE R744 SYSTEM A COOLING UNIT

D. Teixeira†, University of Cape Town, Cape Town, South Africa
L. Zwalinski, L. Davoine, W. Hulek, CERN European Organization for Nuclear Research, Geneva, Switzerland

Abstract

The Detector Technologies group at CERN has developed a 2-stage transcritical R744 cooling system as a service for future detector cooling. This is the first system in operation at CERN where Schneider HSBY (Hot Standby) redundant PLCs are used. This cooling system provides a good opportunity to test the Schneider redundant PLC system and understand the operation, limitations and probability of failure in a controlled environment. The PLC redundancy is achieved by connecting Schneider M580 HSBY redundant PLCs to the system where one is the primary which operates the system and the other is in standby mode. A series of tests have been developed to understand the operation and failure modes of the PLCs by simulating different primary PLC failures and observing whether the standby PLC can seamlessly take over the system operation.

INTRODUCTION

Previously, most large-scale systems at CERN have made use of multiple small PLCs where there is one running per subsystem and communicating with one leading PLC. The idea behind this is that if one PLC fails, the other subsystems are still able to operate. However, in previous experiences, losing one subsystem can cause erroneous readings fed to the other subsystems or interlocks created in the processes of the other subsystems.

In the context to avoid multiple semi-autonomous PLCs, EP-DT decided to go in the direction of a central powerful PLC connected to the different subsystems which each have communication cards that read and write inputs and outputs. This ensures the centralisation of information inside a single core element. In order to improve the communication availability of such systems the RIO loop was proposed following ring topology. This has been used in the MAUVE system with good results. The ring topology used is shown in Fig 1.

† TXRDAN001@myuct.ac.za

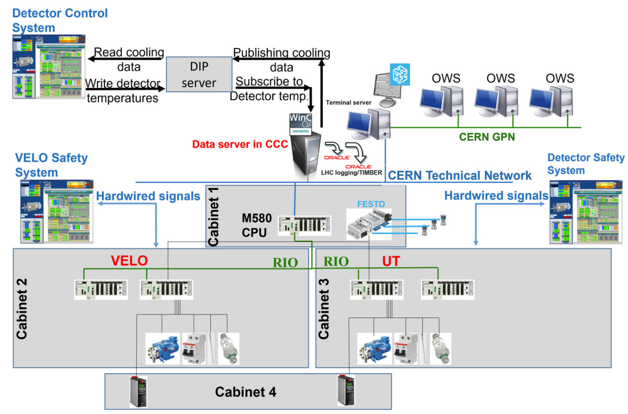


Figure 1: MAUVE control architecture.

For the LHC Phase II upgrade, two different cooling systems, CO_2 based, will be installed, namely the R744 Primary system (2 stages transcritical) [1] and the 2PACL (2 Phase Accumulator Control Loop) system [2], both of which are quite large with a high quantity of inputs and outputs.

The approach of a main core system to control the different remote IO was foreseen to be used in Phase 2. However, following recent technological developments by Schneider, the solution of PLC redundancy was proposed to improve the reliability of the system. Before installing the systems underground, this solution was first implemented on the surface with R744 Primary System A which is currently operational. Following this, it will also be used in the DEMO system which is a 2PACL equivalent currently being installed. The purpose of these surface systems is to gain experience on the process and validate the redundant architecture before installing the final systems underground.

CONTROLS

PLC Selection Following Current Solutions Available on the Market

The Schneider M580 HSBY redundant PLC was chosen for these systems due to satisfactory compatibility with the currently used UNICOS (Unified Industrial Control System [3]) framework as well as the simplicity of implementation. CERN makes use of mostly Schneider and Siemens PLCs, with Schneider being the most commonly used PLC in cooling applications. PLC redundancy has previously been implemented at CERN using Siemens PLCs (S7-400). However, the return of experience from our cryogenics colleague experts was giving a global difficulty with implementation and possibility to update code. There is a new type of PLC from Siemens which proposes a redundant

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV037

MODULAR SOFTWARE ARCHITECTURE FOR THE NEW CERN INJECTOR WIRE-SCANNERS

A. Guerrero†, D. Belohrad, J. Emery, S. Jackson, F. Roncarolo,
European Organization for Nuclear Research (CERN), Geneva, Switzerland

Abstract

In the scope of the LHC injector upgrade, new wire-scanner devices have been installed in the LHC injector circular accelerators. This paper outlines the software architecture and choices taken in order to provide the scanner experts with comprehensive diagnostics as well as operators with straightforward size measurements. The underlying electronics acquire large amounts of data that need to be accessible for expert and machine development use and need to be processed before being presented for daily operational use, in the shape of a beam profile and its derived size. Data delivery and measurement computation are accomplished by means of a modular structure, using functionally distributed real-time processes that handle the different data views, with minimal interference in the processing, and minimal exchange of data among modules.

INTRODUCTION

A wire-scanner is generally based on a thin wire traversing at high-speed circulating particle beams. Monitoring turn by turn the distribution of secondary particles generated by the beam-wire interaction (bottom plot in Figure 1) as a function of the wire position (top plot in Figure 1), allows reconstructing the transverse beam profile.

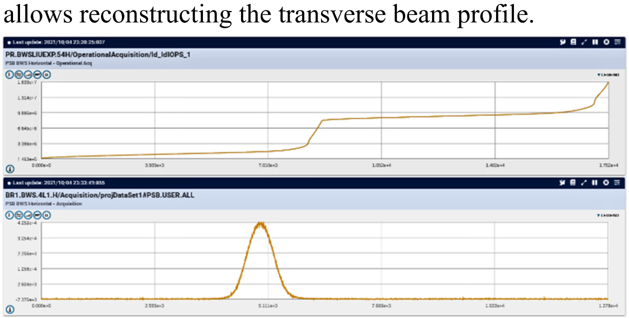


Figure 1: The top plot shows position data for both in and out scan. On the bottom plot beam profile data is displayed.

Such measurements are performed daily by accelerator operators and experts to infer the size of the beam and via the beam optics and beam momentum spread the transverse emittance of the different beams played in the machines.

At CERN a new generation of Beam Wire-Scanners (BWS) has been developed, installed, and recently commissioned [1] in the scope of the LHC injector upgrade (LIU), during the accelerator restart after the long shutdown (LS2). New engineering concepts were applied to build the hardware and electronics of these devices [2] [3] [4] [5], thus giving rise to a new complete software system built and constrained within the available controls infrastructure and underlying standards. In particular, the Front-End Software Architecture (FESA) [6] [7] was chosen as the framework for the design and development of the system modules.

SYSTEM DESCRIPTION

The BWS applies key innovations to its kinematic unit: moving parts located only in vacuum, magnetic and optical techniques to power and air vacuum signal exchange. The unit performs trajectory control of the shaft via a solid rotor resolver [8] and provides carbon wire measurement and a high accuracy position measurement using an optical encoder [9]. Electronics driving the system consist of an Intelligent Drive (BWSIDC) in charge of the powering and wire movement and an acquisition crate collecting data from the different actuation parts as well as from the optical encoder measurements. Diagnostics and tests possible in *local mode* at this level include verification of cabling and parts of the kinematic subsystem, powering and scanning procedures without beam interaction for diagnostics, all without tunnel access.

Communication with kinematic control and acquisition electronics is done through Ethernet by means of the IPbus protocol and associated module and libraries for firmware and software development [10]. The IPbus protocol is a simple packet-based control protocol for reading and modifying memory-mapped resources within FPGA-based IP-aware hardware devices which have a virtual A32/D32 bus, thus enabling the replacement of VME control (a usual standard in our operational instrumentation) in our case.

The secondary particle shower detection is performed by a scintillator coupled to four Photo-Multiplier Tubes (PMT) to acquire four signal amplitude ranges with the aim of covering the large dynamic range of beam energies and intensities across the LHC injectors [11]. The PMT devices are powered with a custom board optimised for large pulse mode and fast recharge. The gain of the PMT is set via a high voltage power supply controlled through a 4-channel commercial board accessed through the VME bus. PMT output currents are amplified in two stages and driven into parallel high-speed digitizers, feeding the so called VFC [12]. The VFC is a CERN FPGA-based multipurpose carrier with VME interface, designed to be the new standard acquisition platform for the Beam Instrumentation Group. The VFC wire-scanner application firmware was built in house and adapts to the different accelerator synchronisation. The acquisition takes place asynchronously to the bunched beam at 500MHz and with a 14-bit resolution. Together with the sensor current outputs, the beam revolution frequency and bunch timing are written into a memory bank composed of two 8Gb DDR chips. On request, acquired digitised beam information is integrated on the fly and placed in the VME bus for the CPU to recuperate

† ana.guerrero@cern.ch

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV039

A RELIABLE MONITORING AND CONTROL SYSTEM FOR VACUUM SURFACE TREATMENTS

J. Tagg, E. Bez, M. Himmerlich, A. K. Reascos Portilla, CERN, Geneva, Switzerland

Abstract

Secondary electron yield (SEY) of beam-screens in the LHC puts limits on the performance of the accelerator. To ramp up the luminosity for the HiLumi LHC project, the vacuum surface coatings team are coming up with ways to treat the surfaces to control the electron cloud and bring the SEY down to acceptable levels. These treatments can take days to weeks and need to work reliably to be sure the surfaces are not damaged. An embedded control and monitoring system based on a CompactRIO is being developed to run these processes in a reliable way [1].

This paper describes the techniques used to create a LabVIEW-based real-time embedded system that is reliable as well as easy to read and modify. We will show how simpler approaches can in some situations yield better solutions.

PROJECT AND BACKGROUND

The objective of the LESS (Laser Engineered Surface Structures) project is the commissioning of an in-situ laser surface treatment conceived to mitigate electron clouds in the Large Hadron Collider (LHC) at CERN. Secondary electrons are multiplied when they interact with the vacuum chamber walls of the accelerator and consequently form electron clouds that can negatively affect its performance.

The secondary electron emission of a surface can be reduced by surface roughening. In this project, pulsed laser processing is applied to generate micro and nanostructures on the inner vacuum chamber surface that surrounds the proton beam. In this way, secondary electrons are captured by the surface geometry. The resulting structures and the performance of the surface strongly depend on the processing parameters, such as the laser power, the scanning speed, and the line distance, as well as on the scanning pattern [2].

The final treatment must be applied in-situ in the already existing accelerator and the system must be capable of treating tens of meters of vacuum pipe autonomously. The dedicated setup to perform this is composed of a picosecond pulsed laser source and a Beam Delivery System (BDS) that shapes and couples the laser beam into an optical fiber, which guides the laser light through an inchworm robot where the beam is decoupled through a rotating nozzle (see figure 1). The translational movements of the robot are driven by a pneumatic clamping system.

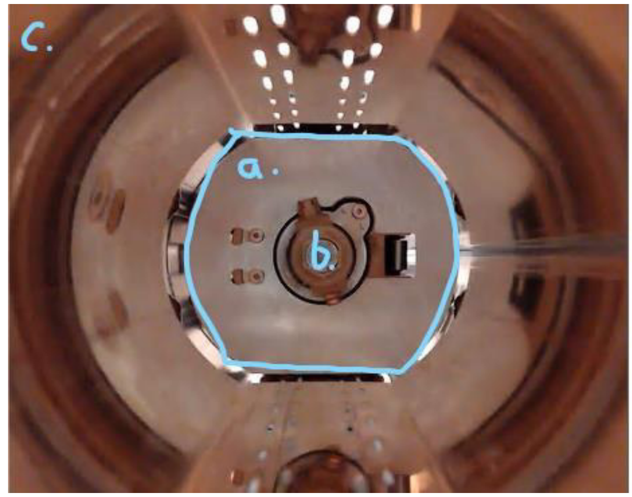


Figure 1: Longitudinal view of the inchworm inside a beam screen. The laser nozzle in the center points upwards. a. inchworm, b. nozzle, c. beam screen.

This setup requires a control system that communicates with each component and allows flexible parameter changes. The system must be reliable enough to run for many days unattended. For example, in a spiral treatment format (described later) we would need to treat 16m of beam screen while advancing by 50µm approximately every 5s. This would take up to 3 weeks. Similar times are expected for other sequences.

The system must also manage concurrent communication with all the components which make up the system and ensure that any issue is either resolved, or the system is safely stopped so the treatment can continue once the issue is resolved.

Movement of the inchworm makes up the bulk of the expected issues because of its mechanical nature. The system must be able to manage and identify movement problems and fix them where possible without affecting the overall process.

HARDWARE

The system consists of multiple hardware components connected to an NI CompactRIO (cRIO) real-time embedded system for control and monitoring. A cRIO was chosen because of successful implementations of cRIO-based control systems for other projects and because it provides a relatively straightforward programming model through LabVIEW.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV040

A PYTHON PACKAGE FOR GENERATING MOTOR HOMING ROUTINES

A. S. Palaha, T. Cobb, G. Knap, Diamond Light Source, Didcot, UK

Abstract

Diamond Light Source uses hundreds of Delta Tau Turbo PMAC2 based motion controllers that control motors with precision and repeatability. Homing is critical to these requirements; it safely moves axes to a well-known position using a high-precision device for detection, leaving the overall system in a well-known state and ready for use. A python package called "pmac_motorhome" has been developed to generate homing routines for multiple motors across multiple motion controllers, allowing the user to write a script that is terse for standard/typical routines but allows for customisation and flexibility where required. The project uses jinja templates as `snippets' to generate the homing routine code written in Delta Tau PLC notation (PLC is the name for logic programs in Delta Tau motion controllers). The snippets can be re-ordered and grouped together, supporting the design of homing routines for multi-axis systems with mechanical limitations that require an orchestrated approach to safely home the axes. The python script using the package is kept terse using a context manager and can group axes together to the same homing group easily.

WHAT IS "HOMING" A MOTOR/AXIS?

Motors, sometimes referred to as "axes", typically turn rotational movement into moving some load. In the operation of an x-ray synchrotron and its associated beamline laboratories, there are many motors used on scales that require precise and repeatable movements.

The position of axes is typically tracked with an encoder that produces signals as the axis turns; these signals are monitored by the motion controller and converted into positions. Assuming no power loss or miscounting of encoder signals (e.g. due to speed or slippage) then the position will remain accurate. However, the counting must start from a known position, and this must be recoverable in the event of power loss or miscounting. This is where homing procedures are critical.

The known position can be provided either by a dedicated home switch, activated when the axis reaches a certain position, or one of the end-of-travel limit switches that are usually present. The manner of activation is also important; sometimes requiring moving to the switch and then in a particular direction to release the switch, or to approach the switch from a particular direction.

Another method of creating a homing signal can be to drive against a hard stop which may generate a following error (the difference between the demanded move and measured move). This is generally used for small axes that can tolerate driving into a hard stop.

Consideration must be made for axes that are coupled; that is when movement in one axis will affect another such as when they are attached to the same load. Such scenarios require homing routines that can act on multiple axes. With the possibility of many different combinations of axis types and multi-axis systems, the ability to create tailored homing routines for each axis or group of axes is a necessity.

WHY IS PMAC_MOTORHOME NECESSARY?

The first homing routine generator written in python for Diamond Light Source (DLS) was called motorhome.py. It generated homing routines as PLC code for Delta Tau motion controllers and started as a single script. As different homing scenarios became necessary, this script grew into a large monolith that was difficult to maintain and became inflexible in some scenarios. The python interface to motorhome.py could not be used to add a custom piece of PLC code that might be used for unique or rare homing scenarios.

PROJECT REQUIREMENTS

The new homing routine generator had to satisfy the following requirements to be a viable replacement for motorhome.py, and to ensure minimal disruption/effort in converting the original generator scripts into the new style:

Maintain the EPICS interface

The EPICS Input Output Controller (IOC) used to control and monitor the Delta Tau motion controller device also monitors the status of the homing routines by polling the program variables, or "p-variables". For instance, the State, Status and Group number of homing routines are accessed through $(PLC)00, $(PLC)01 and $(PLC)02 respectively; where $(PLC) is the number of the PLC program (there can be up to 32 programs stored on the motion controller). So, for the homing routine stored in PLC9, the Status of the routine would be held in p-variable 0901.

The State and Status are enumerations that indicate if a routine is operating, has completed, failed, or been aborted. The Group number indicates whether a particular axis in a group is being homed, or all axes in the group are being homed. The group is configured in the python script that imports the generator module.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV042

COLLISION AVOIDANCE SYSTEMS IN SYNCHROTRON SOLEIL

C. Engblom†, S. Zhang, S. Bouvel[1], D. Corruble, G. Thibaux, S. Akinotcho, P. Monteiro, L. Munoz, B. Pilliaud[2], L. Amelineau, Synchrotron SOLEIL, St. Aubin, France
[1]also at EFOR, Paris, France
[2]also at Mediane Systems, Paris, France

Abstract

Beamlines at Synchrotron SOLEIL are finding that their experimental setups (in respect to their respective sample environments, mechanical systems, and detectors) are getting more constrained when it comes to motorized manoeuvrability - an increasing number of mechanical instruments are being actuated within the same workspace hence increasing the risk of collision. We will in this paper outline setups with two types of Collision Avoidance Systems (CAS): (1) Static-CAS applications, currently being employed at the PUMA and NANOSCOPIUM beamlines, that use physical or contactless sensors coupled with PLC- and motion control- systems; (2) Dynamic-CAS applications, that use dynamic anti-collision algorithms combining encoder feedback and 3D-models of the system environment, implemented at the ANTARES and MARS beamlines but applied using two different strategies.

INTRODUCTION

System actuation in small or limited workspaces can be a delicate matter when taking the risk of collision into consideration. Synchrotron multi-techniques experimental environments are becoming more difficult in this matter as they combine complex beam-focusing setups, sample stages, and detectors – each section often actuated in many Degrees-Of-Freedom (DOF), sometimes with overlapping workspaces, and each section often very fragile and expensive/time-consuming to repair.

The traditional (and most direct) approach to this problem is to introduce workspace limitations (with mechanical hard-stops and/or limit switches to the various actuators) to different subsections, hence assuring non-overlapping workspaces and thus eliminating the risk of collision. This method is however only limited to static (e.g. unchanging) and less constrained environments in the sense that the setup is set in a fixed configuration and no additional systems should be introduced into the workspaces, nor that the different workspaces should ever overlap.

This paper will outline four motorised Collision-Avoidance-Systems (CAS) at SOLEIL that have been adapted to *dynamic or complex workspaces*, particularly where overlapping workspaces are being used. The CAS applications are here classified as:

1. **Static-CAS**: Systems that use proximity- or touch-based sensors coupled with PLC- and motion control-systems.
2. **Dynamic-CAS**: Systems that use motion controllers with integrated dynamic anti-collision algorithms combining encoder feedback and 3D-models of the system environment to avoid collisions.

STATIC-CAS AT THE PUMA BEAMLINE

PUMA [1] is an ancient materials analysis beamline optimised for 2D- imaging with hard X-rays in the 4-23 keV range. The beamline offers its users a range of analytical tools in the form of X-Ray fluorescence (XRF), absorption spectroscopy (XANES), and powder diffraction (XRD). A second experimental stage will be added in the future for 3D imaging with up to 60 keV X-ray beam energy.

This section will focus on the setup situated in the CX-hutch where its beam-focusing section, sample-stage, and detector-support all move in collision-range of each other.

PUMA Experimental Station Overview

The PUMA CX Environment system consists of two motorised table platforms: one holds the Kirkpatrick–Baez (KB) mirror subsystem, its sample goniometer stage, microscope and XRF detectors, while the other table supports the 2D X-ray camera detector. Figure 1 illustrates the overall setup, here each subsystem annotated with the DOF used in the CAS. In total, the complete system holds 41 motorised axes - with overlapping workspaces over 16 DOF for the mirror-chamber, sample stage, and detectors.

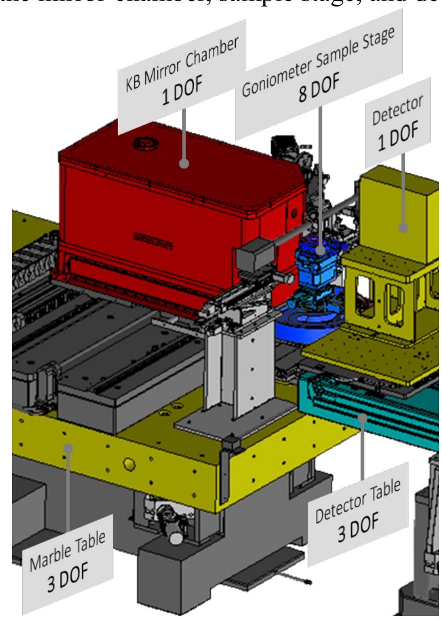


Figure 1: PUMA CX environment overview to be controlled with a CAS, here portraying the five subsystems with a total of 16 degrees of freedom (DOF) used in the CAS.

† christer.engblom@synchrotron-soleil.fr

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV046

MODIFICATION OF DATA ACQUISITION SYSTEM IN HLI-II EXPERIMENTAL STATION*

Zhen Zhang†, Gongfa Liu
University of Science and Technology of
China National Synchrotron Radiation Labor-atory, Hefei, China

Abstract

With the proposal of the concept of super-facility in recent years, users of experimental stations only need to pay attention to data with scientific significance, and the management of massive experimental data are assisted by the super-facility technical support platform to effectively improve user efficiency [1]. Based on this theory, we modified the data acquisition system of the XMCD experimental station in HLS-II. We continue to use LabVIEW software to reduce development workload. Meanwhile, we have added the interaction program with the high-level application in the original data acquisition process under the principle of keeping the user habits of XMCD experimental station. We have modularized the XMCD experimental software and redesigned the experimental architecture into 4 modules: Swiping Card Module, Experimental Equipment Control Module, Storage System Interaction Module and Data Management System Interaction Module. In this way, we have completed the collection of rawdata and metadata, the docking of the data persistent storage system, and the docking of data centralized management.

INTRODUCTION

As a synchrotron radiation light source, Hefei Light Source (HLS-II) provides a basic research platform for collection system will obtain the management metadata related to the user (management metadata) on the HLS-II user platform. The experimental equipment control module is the process control module of the XMCD experiment. This module will record the original experimental data (scientific rawdata) of XMCD and the metadata related to the experiment generated during the experiment (scientific metadata), and transmit them to the data processing module in the form of a data stream. The scientific rawdata and scientific metadata are encapsulated into the standardized format of HDF5 and uploaded to the file storage system through storage system interaction module. The management metadata and scientific metadata are encapsulated into the standardized format of JSON and uploaded to the data management system through data management system interaction module.

* Work supported by Key R & D Project of Hefei Science Center, Chinese Academy of Sciences (No.2019HSC-KPRD003)
†zznsrl@mail.ustc.edu.cn

multi-disciplinary research on cutting-edge topics [2]. Under the important trend of informatization construction [3-5] of large scientific equipment at home and abroad, we have upgraded the data acquisition system of the HLS-II XMCD experimental station.

ARCHITECTURE

Based on LabVIEW experimental system, the data acquisition system (DAQ) of HLS-II XMCD experimental station can accomplish the mission of scientific data acquisition. However, under the information construction trend of centralized data management, experimental data needs to be uploaded to the experimental data management system together with experimental metadata. At the same time, in order to facilitate the management of data, relevant information of the experimenters also needs to be collected. Therefore, based on the development of the existing XMCD experimental station data acquisition system, we upgraded it to meet the above requirements. The acquisition system architecture is shown in the Fig. 1 below.

The data acquisition system is divided into four modules: swiping card module, experimental equipment control module, storage system interaction module and data management system interaction module. After the user swipes the ID card, the data

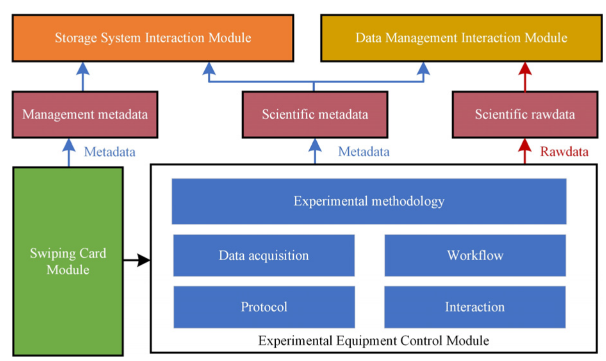


Figure 1: The architecture of DAQ system.

DATA ACQUISITION

User Management Metadata Acquisition

The User management metadata is collected from the HLS-II user platform. The process is shown in Fig. 2: (1)User needs to swipe the ID card at the card reader; (2)The user authentication module sends the collected ID number to the HLS-II user platform via RESTful API, and waits for the HLS-II user platform to return the verification result; (3)If the verification is successful, it means that

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV047

CONTROLLING THE CERN EXPERIMENTAL AREA BEAMS

B. Rae*, V. Baggiolini, D. Banerjee, J. Bernhard, M. Brugger, N. Charitonidis, M. Gabriel, L. Gatignon, A. Gerbershagen, R. Gorbonosov, M. Hrabia, M. Peryt, G. Romagnoli, C. Roderick
CERN, 1211 Geneve 23, Switzerland

Abstract

The CERN fixed target experimental areas are composed of more than 8 km of beam lines with around 800 devices used to define and monitor the beam parameters. Each year more than 140 groups of users come to perform experiments in these areas, with a need to control and access the data from these devices. The software to allow this therefore has to be simple and robust, and be able to control and read out all types of beam devices. This contribution describes the functionality of the beam line control system, CESAR, and its evolution. This includes all the features that can be used by the beam line physicists, operators, and device experts that work in the experimental areas. It also underlines the flexibility that the software provides to the experimental users for control of their beam line, allowing them to manage this in a very easy and independent way. This contribution also covers the on-going work of providing MAD-X support to CESAR to achieve an easier way of integrating beam optics. An overview of the on-going software migration of the Experimental Areas is also given.

INTRODUCTION

The CERN experimental areas are a complex system of beam lines and beam intercepting devices that are able to provide a large variety of different particle beams to different experiments and detector assemblies. They serve both fixed target experiments and test beams [1]. The most important aspect of these unique experimental facilities is the possibility for experimental users to control and to monitor beam parameters from dedicated terminals installed in their respective control rooms. Such parameters include the access to the experimental zones, the beam intensity via collimator settings, the magnet currents, which are defining the beam trajectory and focal properties, the particle species via the use of targets, converters and absorbers, and the instrumentation for monitoring. The beam control system is called CESAR [2], which is an acronym for CERN Experimental areas Software Renovation. Through the past 10 years, CESAR has been continuously developed with new features and devices types being added. With the new secondary beams software migration project, the CESAR scope will be extended to accept optics calculations through MAD-X connectivity, and ideally also with automatic layout updates through the CERN Layout database.

The particularity of CESAR with respect to other control systems of the CERN accelerators is that it is designed to be operated by non-experts, as well. Many of the experimental users are not accelerator physicists and do not know all details of the beam line and its equipment. Therefore the system is made easy and intuitive, yet safe, in order to avoid any unintentional damage to the beam lines and experimental equipment. CESAR is based on Java and constructed around an ORACLE database. It acquires and sets so-called equipment knobs, mainly by subscribing to the Front-End Software Architecture FESA [3] device. In addition, it receives information from other services such as from the access system database (Access-DB) , via DIP (Data Interchange Protocol), and the data logging system NXCALS [4]. All devices are identified in the CESAR database together with their parameters, such as FESA name, element type, beam line, and others. This allows flexible modifications as often needed in secondary beam lines. The architecture of CESAR is shown in Fig. 1.

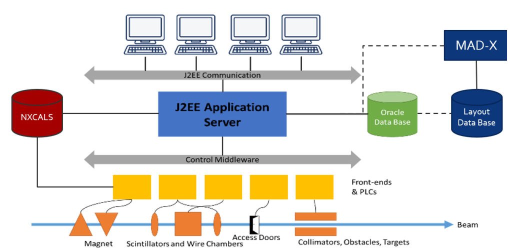


Figure 1: CESAR Architecture and Foreseen Connectivity.

USER TYPES

For both safety and simplicity reasons, there are three user types defined in the database: (1) *Super Users* are allowed to see and change any parameters of all devices in all beam lines. This group is composed of the responsible beam physicists, accelerator operators, and selected equipment specialists. (2) *Main Users* are associated with specific consoles in an experimental control room and are allowed to change most non-safety relevant settings in their beam line up to their experiment. They are set by the super users according to the experiment schedule, which is provided by the SPS/PS Physics Coordinator. (3) *Standard Users* are treated similarly as main users, however they see only their assigned experimental area, for instance to initiate an access procedure. Standard users are able to monitor their beam parameters, but are not allowed to control any devices other than the ones in their assigned user zone.

INTERFACE

The CESAR interface is composed of three main panels, as depicted in Fig. 2: the top menu, the devices panel and the beam line selection tab. The latter is used to change the

* Bastien.Rae@cern.ch

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV048

UPDATES AND REMOTE CHALLENGES FOR IBEX, BEAMLINE CONTROL AT ISIS PULSED NEUTRON AND MUON SOURCE

F. A. Akeroyd, K. V. L. Baker, L. Cole, J. R. Harper, D. Keymer, J. C. King, T. Lohnert, A. J. Long, C. Moreton-Smith, D. Oram, B. Rai, Science and Technology Facilities Council, Rutherford Appleton Laboratory, Chilton, UK

Abstract

IBEX is the EPICS based experiment control system now running on most of the beamlines at the ISIS Neutron and Muon Source, with plans to deploy to all remaining beamlines by the end of the upcoming long shutdown.

Over the last couple of years we have added support for reflectometry and muon instruments, developed a script generator, moved from Python 2 to Python 3, and continued to build on our suite of device emulators and tests. The reflectometry inclusions required the development of a framework to maintain the complex motion control requirements for that science technique.

Whilst it is desirable that IBEX is easily configurable, not all operations should be available to all users, so we have implemented functionality to manage such access.

The COVID-19 pandemic has meant we have also had to adapt to greater amounts of remote experiment access, for which we developed systems covering both IBEX and the old SECI control system.

This presentation will aim to provide a brief update on the recent changes to IBEX, as well as outlining the remote operation solutions employed.

INTRODUCTION

The ISIS pulsed neutron and muon source [1] is a world-leading centre for research in the physical and life sciences and currently has over thirty beamline instruments. The IBEX control system [2, 3] is currently replacing the previous control system, called SECI, and to date about two thirds of instruments have been converted. IBEX is a client-server based system composed of EPICS [4] for the server part, Eclipse/RCP/Control System Studio [5] for the client GUI (see Fig. 1), and utilising Python for scripting.

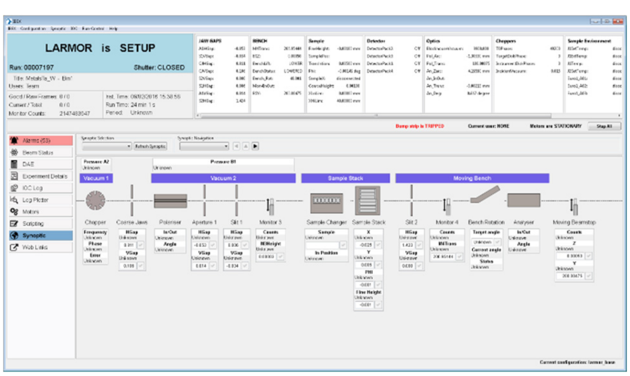


Figure 1: The IBEX user interface.

REMOTE EXPERIMENT ACCESS

Lockdowns and subsequent travel restrictions, social distancing and new safety measures brought about by the COVID-19 pandemic caused disruption to planned operation of the ISIS facility. When systems were put in place to allow the accelerator and instruments (beamlines) to operate again, it was still impossible for most external facility users to travel to ISIS to perform an experiment.

Gathering Requirements

A consultation was undertaken with instrument scientists and technicians, initially with a questionnaire and then follow up meetings with group leaders. The aim was to determine how they foresaw operations with "user not present" experiments and to look for common themes of where best to concentrate our resources. We also needed to cover both IBEX and non-IBEX (SECI) instruments with our solutions.

There were quite a range of levels of user engagement proposed, these were often determined by safety or equipment damage considerations with remote control. Only one instrument group, the muon beamlines, wished their users to have full access. Other instrument groups wished various degrees of read-only access so the user could monitor the experiment remotely, liaising with the local contact when necessary. The support technicians also wished for enhanced remote monitoring, which would allow them to better optimise timing and resourcing of general equipment tasks on site.

Full Remote Experiment Access

For the muon beamlines it was practical to allow remote users full access to the experiment equipment. We were able to achieve this by using the cloud connectivity solution provided by the commercial RealVNC package [6], effectively putting the user in the instrument cabin. The muon beamlines were not fully running IBEX at this point, so this solution also avoided having to modify the old SECI control system.

A dedicated control computer in each instrument cabin was configured for cloud VNC access, instrument scientists then added users to the relevant VNC group granting access only for the duration of their scheduled experiment. Remote users were required to use Two-Factor Authentication (2FA) [7] for access to the VNC system.

In addition the VNC system has proved useful for more than just remote user experiments. An engineer from an overseas external company was also able to take part in commissioning a new chopper system along with local staff.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV049

THE IBEX SCRIPT GENERATOR

James King, Jack Harper, Thomas Löhnert, Aaron Long, Dominic Oram,
STFC/RAL/ISIS, Chilton, Didcot, Oxon, UK

Abstract

Experiment scripting is a key element of maximising utilisation of beam time at the ISIS Neutron and Muon Source, but can be prone to typing and logic errors. The IBEX Script Generator enables collaboration between instrument scientists and users to remove the need to write a script for many experiments, so improving reliability and control.

For maximum applicability, the script generator needs to be easily configurable which is achieved by instrument scientists creating script definitions. Script definitions are Python classes that contain the parameters a user can fill in for each action in the script, and functions to execute, validate and provide a time estimation for each action.

A user organises a table of actions and fills in their values to create their experiment, these action values are validated in real time. With a valid table of actions a user can generate a Python script which can be executed via the IBEX scripting tools.

A key requirement of the script generator is for it to integrate the pre-existing Java based IBEX client. Py4J is used as a bridge between Java and the Python script definitions. An iterative, user-focused approach has been employed with quality assurance techniques such as user interface (UI) testing to achieve a behaviour-driven development workflow.

Further planned development includes dynamically controlling the execution and values of actions whilst the script is running, action iteration and user experience improvement.

INTRODUCTION

IBEX [1] is an EPICS based control system developed and used at the ISIS Neutron and Muon Source to control beamline equipment and experiments. A key feature of IBEX is the Python-based control and scripting library known as genie python [2]. This library provides functions to control experiments in an automated manner, beginning and ending data collection, writing to EPICS process variables (PVs) to control equipment amongst a host of other functionality.

Scripting is an integral part of how ISIS runs experiments, both in IBEX and the previous control system SECI. Giving users the power to write scripts allows them to control and automate experiments in a very customisable and expressive fashion. It also helps improve the reproducibility of experiments and enables maximum utilisation of beam time.

However, there are a few pitfalls when it comes to using scripting extensively. To script an experiment a user needs to understand how to code in Python, this places a steep learning curve ahead of users who have little or no experience in coding. This learning curve distracts user focus away from the science of an experiment. Furthermore, even if a user is proficient in coding they are not familiar with genie python and IBEX, so they must learn a new complex set of commands and logic in order to correctly run their experiment. For users that are familiar with the environment it is certainly easier, but writing scripts is still prone to logic errors and mistyping of commands.

There are attempts to mitigate many of these issues within genie python, such as checking of scripts for programming errors at load time, providing a reduced command set for specific instruments and providing autocomplete for PVs of interest. One of the main roles of the script generator is to mitigate the pitfalls surrounding scripting as well as enhancing the experience of a user at the facility by enabling them to focus on the experiment.

There are a number of script generators in use at ISIS with varying degrees of functionality - some that work with the previous control system SECI. The aim of the IBEX script generator, produced by the experiment controls group [3], is to provide a unified tool – taking inspiration from other script generators currently in use at ISIS – for generating scripts without having to write code for specific experiments.

WORKFLOWS AND FUNCTIONALITY

Many experiments at ISIS follow a regular pattern. Users and scientists often customise previous scripts that follow a similar pattern to the experiment they are creating. The script generator targets this workflow by allowing instrument scientists to create script definitions – which define the parameters an experiment can take and the logic to run the experiment – and users to input experiment parameters. Using these two inputs the script generator can then generate a script (see Fig. 1).

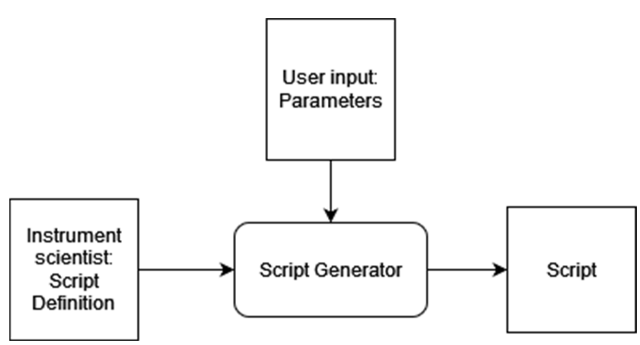


Figure 1: Script Generator inputs and outputs.

18th Int. Conf. on Acc. and Large Exp. Physics Control Systems ICALEPCS2021, Shanghai, China JACoW Publishing
ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-TUPV050

CONTROL SYSTEM UPGRADE OF THE HIGH-PRESSURE CELL FOR PRESSURE-JUMP X-RAY DIFFRACTION

R. Mercado*, N. Griffin, S. Lay, P. Holloway and P. Roberts
Diamond Light Source, Oxfordshire, UK

Abstract

This paper reports on the upgrade of the control system of a sample environment used to pressurise samples to 500 MPa at temperatures between -20°C and 120°C. The equipment can achieve millisecond pressure jumps for use in X-ray scattering experiments. It has been routinely available in beamline I22 at Diamond. The millisecond pressure-jump capability is unique. Example applications were the demonstration of pressure-induced formation of super crystals from PEGylated gold nano-particles and the study of controlled assembly and disassembly of nano-scale protein cages.

The project goal was to migrate the control system for improved integration to EPICS and the GDA data acquisition software. The original control system was based on National Instruments hardware controlled from LabView. The project looked at mapping the old control system hardware to alternatives in use at Diamond and migrating the control software. The paper discusses the choice of equipment used for ADC acquisition and equipment protection, using Omron PLCs and Beckhoff EtherCAT modules, a custom jump-trigger circuit, the calibration of the system and the next steps for testing the system.

INTRODUCTION

Beamline I22 and Imperial College London built and developed a sample environment [1] used to pressurise samples for diffraction experiments. This end-station equipment has been available for several years [2].

This end-station was built using a control system based on Compact DAQ measurement and control modules (National Instruments). Its associated control was realised by the collaborators using LabView.

An initial attempt was made to integrate with EPICS but the integration was not maintained, due to LabView not being an actively supported platform for the controls group at Diamond. User feedback indicated that direct control from GDA and EPICS would make operations less prone to user error.

SYSTEM DESCRIPTION

The high pressure cell has these components (as shown in Fig. 1):

- Pressure generator. This is a motor driven high pressure pump which can generate pressures up to 700 MPa. The drive motor is a high power DC servo operated with a custom built motor controller.

* ronaldo.mercado@diamond.ac.uk

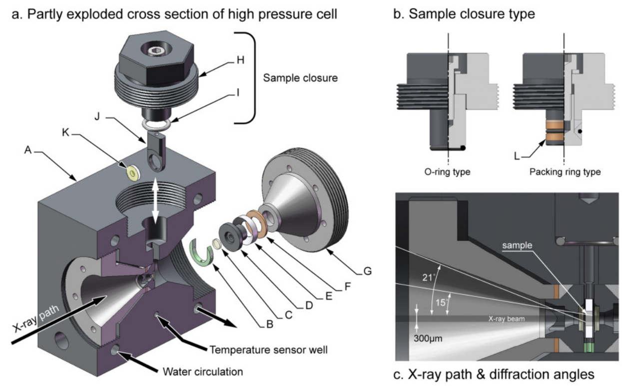


Figure 1: Detail of the pressure cell [1].

- Two remotely operated, normally closed pressure valves.
- Two remotely operated, normally open fast pressure jump valves.
- Three pressure transducers monitoring three sections of the pressure network. The sensors are 700 MPa strain gauge based transducers excited with 10 V and reading 10 mV at full scale.

The pressure network comprises three sections:

- the first section with the pressure generator,
- the second that includes an optional additional tank that can be used particularly for pressure jumps and
- the third section where the pressure cell is installed.

The control system opens and closes valves, allows the syringe pump motor to pressurise and de-pressurise the pressure network.

The pressure network has to be protected from overpressure. Valve operations are inhibited if the pressure differential is larger than 5 MPa (50 bar) between sections, with the exception of pressure jumps.

There are two jump valves, one dedicated to jumps up in pressure and another for jumps down in pressure.

HARDWARE USED IN THE UPGRADE

Diamond standardises on electronics hardware (as shown in Table 1) where possible [3, 4]. A benefit to the facility is the maintainability and support by standardising on a limited set of components.

The majority of the digital I/O signals for the system can be mapped one to one as they are standard and are based

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEAL01

IMAGE PROCESSING ALIGNMENT ALGORITHMS FOR THE OPTICAL THOMSON SCATTERING LASER AT THE NATIONAL IGNITION FACILITY

Abdul A. S. Awwal, Richard R. Leach, Jr., Roger Lowe-Webb, Karl Wilhelmsen, Vicki Miller Kamm, Bela Patel, Siddharth Patankar, Tracy Budge
Integrated Computer Control System, National Ignition Facility, Computational Engineering Division, Lawrence Livermore National Laboratory, Livermore, CA 94551, USA

Abstract

Characterizing plasmas generated in the world's largest and most energetic laser facility, the National Ignition Facility (NIF), is an important capability for experimentalists working to achieve fusion ignition in a laboratory setting. The optical Thompson scattering (OTS) laser has been developed to understand the target implosion physics, especially for under-dense plasma conditions. A 5w probe beams can be set up for diagnosing various plasma densities. Just as the NIF laser with 192 laser beams are precisely aligned, the OTS system also requires precision alignment using a series of automated closed loop control steps. CCD images from the OTS laser (OTSL) beams are analyzed using a suite of image processing algorithms. The algorithms provide beam position measurements that are used to control motorized mirrors that steer beams to their defined desired location. In this paper, several alignment algorithms will be discussed with details on how they utilize various types of fiducials such as diffraction rings, contrasting squares and circles, octagons and very faint 5w laser beams.

INTRODUCTION

The National Ignition Facility (NIF) has made tremendous progress in our understanding of inertial confinement fusion [1]. Recent breakthroughs in fusion performance have attracted worldwide attention to NIF. In NIF, 192 precisely aligned laser beams [2] are designed to irradiate a mm scale fusion target to achieve ignition and produce a net energy gain in a laboratory setting. To achieve this goal, NIF employs several tools to diagnose the plasma condition. The optical Thomson scattering (OTS) laser [3] is such a tool which can deliver a 1 Joule, 5ω (211 nm) probe beam with a 1 ns flat-in-time pulse-shape, for diagnosing the plasma temperature at a user-specified time during the plasma evolution in a NIF experiment.

Experiments on NIF can be designed to utilize all 192 or any subset of laser beams. In every case, accurate beam alignment is essential. Beam positions are monitored in the NIF facility using hundreds of CCD cameras distributed throughout each of the 192 beams path. Feedback control loops form the main engine for the NIF automated alignment control system [2]. Position estimates are generated by image analysis algorithms, which are used to align motorized mirror pairs and other optics to direct NIF beams to their desired locations. Starting from the beam source, or Master oscillator, these alignment loops are responsible for aligning the beams along the complete beam path and finally to the mm size targets located in the target chamber center. In this paper, we will discuss several alignment loops in the OTS laser.

OTSL ALIGNMENT

A total of eight mirror pairs are closed-loop controlled using more than 14 distinct alignment loops to complete the full alignment of the OTS laser. These alignment points are divided into five main sections as shown in Fig. 1. Starting from the pre-amplifier module (PAM) and through the intermediate amplifier, the beam is taken to the Final Optics Assembly (FOA) via an imaging transport telescope section. The FOA contains frequency conversion crystals to convert the beam to the fifth harmonic and motorized, 5ω high-reflecting mirrors to point it to the diagnostic load package (DLP) located in the NIF Target Chamber. Obtaining good OTS data requires precisely overlapping the plasma volume illuminated by the fifth-harmonic probe laser and the plasma-volume imaged by the DLP OTS spectrometer.

The transport vacuum relay telescope (VRT) is used to deliver the conjugate-image of the regen apodization-aperture to the plane of the fifth-harmonic generating crystal; the associated alignment mirror pair ensures the fundamental beam is correctly pointed and centered to the FOA converter line-of-sight for optimum harmonic conversion. Two of the alignment loops discussed here align the ISP laser to the transport telescope input aperture (ISP_TTI_PL loop) and the second one aligns the output of the transport telescope to the input of the FOA (OTS_TTO_FOA_PL). Alignment images for both loops are acquired with the same far-field (FF) alignment camera in the FOA but alignment is completed for each loop using different reference fiducials. Specifically, the physical alignment reference for the OTS_ISP_TTI_PL loop is a pair of precision tooling spheres (pinheads) installed in the output optical aperture of the VRT whereas the OTS_TTO_FOA_PL loop is referenced to a commissioned pixel on the FOA FF alignment camera.

2-D and 3-D images for the OTS_TTO_FOA_PL pointing loop are shown in Figure 2. The beam has a dragonfly-shaped appearance with a distinct head and a tail. The coma-like aberrations seen in this image is caused by diffraction since the alignment beam over-fills the aperture of the intermediate amplifier rod and clips on its edge. The alignment feature for this image is the center of the head of the dragonfly-shaped beam. It was determined that a

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEAL02

A FRAMEWORK FOR HIGH LEVEL MACHINE AUTOMATION BASED ON BEHAVIOR TREES

G. Gaio†, P. Cinquegrana, S. Krecic, G. Scalamera, G. Strangolino, F. Tripaldi, M. Trovò, L. Zambon, Elettra-Sincrotrone Trieste S.C.p.A., Trieste, Italy

Abstract

In order to carry out complex tasks on particle accelerators, physicists and operators need to know the correct sequence of actions usually performed through a large number of graphical panels. The automation logics often embedded in the GUIs prevents its reuse by other programs, thus limiting the level of automation a control system can achieve. In order to overcome this limit, we have introduced a new automation framework for shifting the logics from GUIs to server side, where simple tasks can be easily organized, inspected and stacked up to build more complex actions. This tool is based on Behavior Trees (BT) which has been recently adopted in the gaming industry for in-game AI player opponents. They are able to create very complex tasks composed by simple decoupled self-contained tasks (nodes), regardless how they are implemented. The automation framework has been deployed in the Tango-based control systems of Elettra and FERMI to implement autonomous operations. A dedicated Qt GUI and a web interface allow to inspect the BTs and dynamically go through a tree, visualize the dependencies, monitor the execution and display any running action.

INTRODUCTION

In Elettra and FERMI, a synchrotron light source and a free electron laser located in Italy, it is usual for control room operators or physicists to manually perform long sequences of operations to configure the accelerators in the desired state. These procedures are prone to errors and heavily dependent on the skills of the operators. Over time, many institutes have developed frameworks to automate these lengthy procedures [1,2,3,4]. Therefore, the framework we are going to present in this article is not an absolute novelty.

To be successful a framework must be easy to use, robust and adopted by as many people as possible. These concepts were the basis for the development of this new framework. The originality lies in inheriting the modularity, flexibility and robustness of the Behavior Trees (BT).

Behavior Trees

BTs are very efficient in modelling what an Artificial Intelligence (AI) algorithm can do. They allow designers to define very low-level tasks and combine them to create the set of high-level tasks that the developer wants available to the AI application.

The Behavior Tree is a directed rooted node tree where the internal nodes are called "control flow nodes" and leaf nodes are called "execution nodes" (see Fig. 1). Briefly, the execution flow starts from a root node and go through the tree down to the leaves. The main control flow node is the *sequence node* that can run in parallel or in series to other *sequence nodes* or *action nodes*. An *action node* executes a task and returns to its parent a *success*, *running* or *failure* state. The *sequence* node returns *success* to its own parent if all its children return *success*. The *sequence node* can be configured as *fallback node* to return *success* when at least one of its children return *success*. A *condition node* returns *success* or *failure* depending on the evaluating condition. A *decorator node* can invert a *failure* state into *success* and vice-versa.

There is no canonical implementation of BTs. They are very flexible and suitable to be customized for any application, whether it is an AI algorithm in a computer game [5] or in an Unmanned Aerial Vehicle [6].

Each node executes an instruction after receiving a tick from its parent. In our implementation this aspect has been neglected. The *Action* node start to executes the task at the first tick and completes procedure detached from any external timing signal.

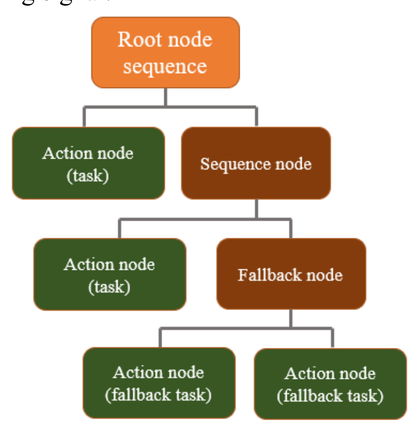


Figure 1: Example of Behavior Tree structure.

THE SEQUENCER

A sequencer (corresponding to a node of the BT) is a Tango device. The core of the sequencer is the sequence which is written in a basic homemade language that has to implement the operations that are performed manually by operators. The language implements macros containing *if/else* conditions and *read/set* instructions, and support basic arithmetic and bitwise operations.

† email: giulio.gaio@elettra.eu

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEAL03

THE STATUS OF FAST OBIT FEEDBACK SYSTEM OF HEPS

P. Zhu†[1], D. P. Jin[1], Y. L. Zhang[1], Z. X. Xie[1], Z. Lei[1], D. Y. Wang[1],
Y. C. He[1], K. J. Xue[1], W. Xuan[1], L. Wang[1]
Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China
[1]also at Spallation Neutron Source Science Center, Dongguan, China

Abstract

The new fast orbit feedback (FOFB) system, a typical multiple-input and multiple-output (MIMO) system, is essential for the storage ring of High Energy Photon Source (HEPS). In order to reduce overall latency and achieve more than 500Hz bandwidth, the FOFB system adopt 16 sub-stations with the same hardware and software function to obtain bias-data from the beam position monitors (BPMs) data using 2.38Gbps in the SFPs and send correct-data to the fast corrector power supplies using a serial point-to-point link around the storage ring, and each sub-station share BPMs data with daisy-chained using of 10Gbps in the SFPs. It is optimized to calculate the large matrix based on the singular value decomposition (SVD) taking the digital signal processing (DSP) modules of V7 field programmable gate array (FPGA) with parallel pipeline. For performance tuning and additional flexibility when adding or removing BPMs and fast corrector power supplies, or downloading new matrix, we implement an independent ethernet controller for remote operation. This article presents details on the design and implementation of the FOFB system, and also the future improvements.

INTRODUCTION

High Energy Photon Source (HEPS), a high-performance and high-energy synchrotron radiation source, is one of the major national scientific and technological infrastructures, mainly composing of accelerators, beam lines and experimental stations, supporting facilities, etc, such as show in Figure 1. HEPS will be an original and breakthrough in the fields of basic science and innovative research.

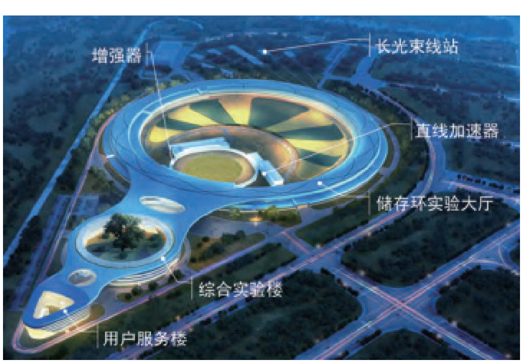


Figure 1: Layout of HEPS.

The size of modern light sources is getting smaller and smaller, and the brightness is getting higher and higher. The performance of the synchrotron radiation photons that finally reach the sample is closely related to the orbital stability of the electron beam. According to the practice of major international laboratories, the stability of the position should be about 10% of the bunch size. For HEPS, the brightest fourth-generation synchrotron radiation source in the world, the bunch vertical emittance should be on the level of 10pm.rad, which corresponds to the vertical bunch size about less than 3μm. Therefore, at the short straight section, the stability of the beam position should be better than 0.3μm.

REQUIREMENT

There are many factors that affect the stability of the beam orbit, including the stability of the magnet power supply, ground vibration, temperature effects, etc. According to ring accelerator physical design and requirements, there are many beam position monitors (BPMs) to monitor the orbit and many correctors to correct the orbit in the storage ring. In order to suppress interference and keep the beam orbit stable, it is we adopt a high-intensity and high-speed orbit feedback system, a typical multiple-input and multiple-output (MIMO)system, to achieve long-term stable operation of the light source based on singular value decomposition (SVD) commonly [1]. The correction algorithm is based on an SVD of the orbit response matrix:

$$\Delta\overline{X} = R\,\Delta\overline{\theta} \quad and \quad R = USV^T$$

$$\Delta\overline{\theta} = VS^{(-1)}U^T\,\Delta\overline{X}\,. \tag{1}$$

Where $\Delta\overline{X}$ is error that the current orbit is compared to the golden orbit, U and V are matrices whose columns form an orthogonal basis in BPM(X) and corrector magnet θ space, S is the diagonal matrix of singular values. The proportional-integrator (PI) control algorithm operates in this diagonal space and the relevant parameters can be adjusted for each mode separately [2]. All multiplication and calculations stages are done for all eigenmodes at one cycle. Therefore, it is necessary to comprehensively consider the whole time consuming, including the speed of BPMs data acquisition, the delay of global BPMs data distribution and calculation, and other factors. According to accelerator physical design and requirements, the fast orbit feedback system should optimize strategies to achieve the low latency response with BMPs and fast corrector power supplies, which is essential to achieve a certain effective bandwidth range for the stable orbit.

† zhup@ihep.ac.cn

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEAR01

THE TANGO CONTROLS COLLABORATION STATUS IN 2021

A. Götz, R. Bourtembourg, D. Lacoste, N.Leclercq, ESRF, Grenoble, France
S.Rubio, C. Pascual-Izarra, ALBA-CELLS Synchrotron, Cerdanyola del Vallès, Spain
V. Hardion, B.Bertrand, MAXIV Sweden, Lund, Sweden
L. Pivetta, Elettra-Sincrotrone Trieste S.C.p.A., Basovizza, Italy
P.P. Goryl, M. Liszcz, S2Innovation, Kraków, Poland
A.F. Joubert, J.Venter, SARAO, Cape Town, South Africa
G. Abeille, SOLEIL, Gif-sur-Yvette, France
T. Braun, Byte Physics, Berlin, Germany
G. Brandl, Forschungszentrum Jülich, Garching, Germany

Abstract

The Tango Controls collaboration has continued to grow since ICALEPCS 2019. Multiple new releases were made of the stable release V9. The new versions include support for new compiler versions, new features and bug fixes. The collaboration has adopted a sustainable approach to kernel development to cope with changes in the community. New projects have adopted Tango Controls while others have completed commissioning of challenging new facilities. This paper will present the status of the Tango-Controls collaboration since 2019 and how it is helping new and old sites to maintain a modern control system.

INTRODUCTION

Tango Controls is a software toolkit for building object oriented control systems. It has been adopted at a large number of sites around the world either as the main toolkit for their control system or for a sub-system or commercially acquired systems. A growing number of commercial products and control systems are now based on Tango Controls. A few commercial companies offer paying support for anyone needing help in integrating Tango Controls into their system.

The main objectives of kernel developments for Tango Controls since 2017 has been to consolidate the continuous integration for all major platforms, maintain the Long Term Support version V9, i.e. bug fixing and add features which are strongly needed by the community but do not break compatibility with V9 release, improve the web development platform, continue to improve the documentation and website, and prepare the next major release of Tango (V10). This paper summarises these developments.

COLLABORATION

The Tango Controls Collaboration is in charge of ensuring the sustainability of Tango Controls. It currently has 11 members who contribute financially and in-kind to the maintenance of Tango Controls as a modern reliable controls toolkit for small and large facilities. In addition to the collaboration members a number of individuals and some companies contribute new developments to the ecosystem e.g. see section Rust binding below.

The Tango Controls Collaboration contract has been in operation since 5 years. The initial collaboration contract ended in 2020. All partners agreed the collaboration was fulfilling an essential role for the sustainability of Tango and should be continued for another 5 years. All partners signed the new contract running from 2021 to 2025. The new contract maintains the objectives and missions of the previous one i.e. all members provide the same financial contribution to maintaining the kernel, while some partners contribute in-kind resources too. The ESRF is in charge of sub-contacting tasks on behalf of the other members. A major change in sub-contracting took place in 2021 with a Call For Tender for sub-contractors who could provide services to Tango for the next 3 to 5 years. After a selection process 4 companies were chosen based on their competence and knowledge of the Tango kernel. Setting up contracts for 3-5 years will help ensure the sustainability of Tango controls. The new collaboration contract foresees a rotation of the role of coordinator amongst the members every year.

New Projects

New projects continue to adopt Tango as their controls toolkit. Some examples of major new projects are the LOFAR 2.0 project (see [1]), the JINR 200 MeV LINAC (see [2]), the PEPC plasma electrode Pockels cell (see [3]) to mention a few. Some of the large projects which are based on Tango have completed successfully, for example the ESRF-EBS, the first 4th generation storage ring (see [4] and [5]). Other large projects like the SKA are ramping up to full speed and are already well advanced in their developments and will soon start construction (see [6]). A number of other 4th generation storage rings which will be based on Tango (e.g. ELETTRA, SOLEIL and CELLS) are in the planning phase. The above projects are only a small subset of projects using Tango: due to the way open source code can be downloaded by everyone without registering not all projects are declared or known to the community. They illustrate how vibrant the Tango Controls community is and the strong need to sustain and continue developing the Tango Controls toolkit for the coming decades.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEAR02

ADAPTATIONS TO COVID-19: HOW WORKING REMOTELY HAS MADE TEAMS WORK EFFICIENTLY TOGETHER

R. Lacuata, B. Blackwell, G. Brunton, M. Fedorov, M. Flegel, D. Koning, P. Koning, S. Townsend, J. Wang, Lawrence Livermore National Laboratory, Livermore, CA , USA

Abstract

The National Ignition Facility (NIF) is the world's largest 192 laser beam system for Inertial Confinement Fusion (ICF) and High Energy Density Physics (HEDP) experiments. The NIF's Integrated Computer Control System (ICCS) team conducts quarterly software releases, with two to three patches in between. Each of these software releases consists of deployment, regression testing, and a test shot. All of these are done with ICCS software team members inside the NIF control room. In addition, the NIF ICCS database team also performs a dry run and verification before each software release. This is to anticipate any issue that may arise on the day of the release, prepare a solution for it, and make sure that the database part of the upgrade will be completed within the allotted time slot. This paper describes how the NIF ICCS software teams adapted when the LLNL workforce began working remotely due to the COVID-19 pandemic. These adaptations led to a better and more efficient way of conducting the NIF ICCS software upgrades.

INTRODUCTION

I joined NIF ICCS back in October of 2017. My background was database development and support for an e-commerce company. A few weeks later, I participated in my first NIF ICCS software release. This is when I realized that updating the control systems for the NIF is different than the software releases I did in my previous job.

The NIF ICCS software releases are done quarterly, with two to three patches in between. It requires a lot of effort from operations, hardware, and software teams.

The software release process is pretty standard. It consists of a database dry run and verification, deployment, regression testing, and a test shot. The big difference from my previous job's software release is with the test procedures done to requalify the changes. The qualification testing in NIF ICCS is more involved that just testing the new version of the application with a web browser.

The pre-pandemic version of our software release process involves a lot of group activities. Most of which requires the software team members to go to the control room to execute the task they needed to do.

For example:

Before the release, we perform the database release dry run. This is done in a team member's office. After a successful dry run, we will go to the control room to verify that the database release scripts have been delivered and the console we will use for deployment is working. This is because the production database is accessible only from the control room.

On the day of the release, we will be in the control room again to apply the database updates. After we are done, members of operational staff will activate the new software that was delivered by our configuration management team.

Once the new software is activated, it will become busy in the control room. Members of the software team will start to come in to do regression testing (Fig. 1). Since only members of the operational staff are qualified to operate the laser, they will have to pair up with an operational staff member to run a series of test procedures for them. The operational staff would sit at their consoles and perform the required operations while they stand behind and observe software behaviour.

Elsewhere in the facility, engineers from other teams will be executing their part of the software release to upgrade various computers, servers, and controls hardware.

All of these release activities and qualification testing are coordinated by the release manager who is also inside the control room. He gets constant updates everybody.

Figure 1: Pre-pandemic, ICCS software engineers inside the control room watching the operators' consoles [1].

When the pandemic started, Lawrence Livermore National Laboratory (LLNL) went into Minimum Safe Operations in March 2020. Only essential personnel are allowed onsite. Most of the laboratory's workforce started working remotely, including the ICCS software team.

Because of this, the software release that was scheduled in April 2020 was cancelled.

After some modifications to control room operations to comply with COVID-19 restrictions, NIF shot operations was able to resume. This required the software team to resume software releases to the NIF control systems as well. But the software release process that required most of the software team inside the control room is not possi-

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEAR03

AGILITY IN MANAGING EXPERIMENT CONTROL SOFTWARE SYSTEMS

K. V. L. Baker, F. A. Akeroyd, T. Löhnert, D. Oram, ISIS Neutron and Muon Source, Didcot, UK

Abstract

Most software development teams are proponents of Agile methodologies. Control system software teams, working at science facilities, are not always just devel-opers, they undertake operations work, and may also be responsible for infrastructure from computer hardware to networks.

Parts of the workflow this team interacts with may be Agile, but others may not be, and they may enforce deadlines that do not align with the typical agile implementations. There is the need to be more reactive when the facility is operating, which will impact any development work plans. Similarly, friction can occur between an Agile approach and more familiar existing long-standing risk-averse organisational approaches used on hardware projects.

Based on experiences gained during the development of IBEX, the experiment control software used at the ISIS Pulsed Neutron and Muon source, this paper will aim to explore what being Agile means, what challenges a multi-functional team can experience, and some solutions we have employed.

WHAT DOES AGILE MEAN?

In its' truest form Agile is a way of working [1] rather than the tools to enable this way of working. What is most important to remember is that the manifesto values certain things over others, but the less valued items are still worth considering, just not at the expense of the more valued items. The Agile Manifesto values are as follows:

- Individuals and interactions over processes and tools
- Working software over comprehensive documentation
- Customer collaboration over contract negotiation
- Responding to change over following a plan

It was software developers that started the use of Agile methodologies, as it is often in the fast-paced world of software that the adaptability is most important in the modern age. However, some of the tools used to support Agile methodologies originated separately from software development, and Agile Project Management is slightly different to Agile Software Development.

What is Agile Project Management?

The Association for Project Management [2] describe Agile Project Management as "an iterative approach to delivering a project throughout its life cycle" [3].

The Agile Manifesto and Principles are generally applied in exactly the same way whether the project in question is software based or not, and instead of working software at each iteration, you aim for working prototypes or solutions.

Is Agile Always the Right Answer?

It is certainly true that not every project is suited to using an agile methodology. Yet, there are very few project teams who would deny that continuous collaboration throughout the project from the customer or their representative, and being able to incorporate any requested, or required, changes over the course of a long term project is beneficial to producing a usable item at the end. Some of the tools which are typically seen in Agile, have other roots. A common tool used to map workflows is a board such as a Kanban board (see Fig. 1) [4].

Initially the use of Kanban was by the assembly lines at Toyota [5], but the tool is used by most Agile methodologies to track progress.

Whilst Agile isn't the answer to everything, aspects of it, and the tool sets it uses are still applicable outside of Agile projects, and vice versa. If using any of the standard toolsets used by Agile Project Management, it is worth making sure you use the one that most suits your team and environment, and to continuously evaluate the tools suitability for use as the project and team develops.

MULTI-FUNCTIONAL TEAMS

Whilst the ideal can be to have teams focussed on just one thing, the practicalities mean that people regularly undertake a variety of tasks.

Types of Function

For the purposes of this paper a function is defined a family of tasks that an individual can undertake.

Development (Dev) The obvious task undertaken by most software developers is development. This mainly covers the introduction of new features to a code base, for example, adding in code to allow a user to change the colour of the interface they are using.

Development covers the full software stack, from the user interface to the lowest levels the team can support, which may even be circuitry. For non-software teams this could be electronic systems, or mechanical ones.

Systems (Sys) The focus for systems tasks is usually the hardware and fundamental aspects of the environment the control system is running in, e.g. computers, network switches, and operating systems. It also covers patching and updating the elements mentioned.

Operations (Ops) Operations tasks are responses to requests for support on problems that need to be solved in a short time frame to keep systems and software running correctly.

It also covers some of the later parts of the process, such as fixing code. For software teams this is hearing about bugs and dealing with them. It is more likely to be failures and faults for those who are not focussed on software, and is the nature of operations for the Systems function. As such

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEBL01

FAIRMAT - A CONSORTIUM OF THE GERMAN RESEARCH-DATA INFRASTRUCTURE (NFDI)

H. Junkes*, P. Oppermann, R. Schlögl, A. Trunschke, Fritz Haber Institute, Berlin, Germany
M. Krieger, H. Weber, Universität Erlangen-Nürnberg, Erlangen, Germany

Abstract

The FAIRmat project, was selected on Friday, July 2, 2021 by the German Joint Science Conference (Gemeinsame Wissenschaftskonferenz – GWK) in a multi-stage competition of the National Research Data Infrastructure (NFDI). The project will receive funding to set up an infrastructure that helps making materials–science data FAIR: Findable, Accessible, Interoperable, and Reusable. This will enable researchers in Germany and beyond to store, share, find, and analyze data over the long term. During the five-year term, a total of 60 project leaders from 34 German institutions will work together in the FAIRmat consortium[1].

FAIRMAT CONSORTIUM

When applying for funding for the FAIRmat project, the following Objectives, work program and research environment were described in the letter of intent:

> Prosperity and lifestyle of our society are very much governed by achievements of condensed-matter physics, chemistry, and materials science, because new products for the energy, environment, health, mobility, and IT sectors, for example, largely rely on improved or even novel materials. The enormous amounts of research data produced every day in this field, therefore, represent the treasure trove of the 21st century. This treasure trove is, however, of little value, if these data are not comprehensively characterized and made available. How can we refine this feedstock, in other words, turn data into knowledge and value? For this, a FAIR data infrastructure is a must.
>
> Here is where FAIRmat ("FAIR Data Infrastructure for Condensed-Matter Physics and the Chemical Physics of Solids") comes in. By building a FAIR research-data infrastructure for the noted fields, the consortium will lift the treasure trove of materials data, and therewith contribute to a disruptive change in the way science and R&D are conducted. Within FAIRmat the acronym FAIR is interpreted in a forward-looking way: Research data should be Findable and Artificial-Intelligence Ready. This new perspective will advance scientific culture and practice. This will not replace scientists, but scientists who use such FAIR infrastructure may replace those who don't.

Projekt Plan

FAIRmat will install a FAIR [1] data infrastructure for the wider area of condensed-matter physics and the chemical physics of solids. This represents a very broad range of different communities that can be characterized by either different classes of condensed matter (e.g. semiconductors, metals and alloys, soft and biological matter, etc.), by different techniques (e.g. ranging from crystal-growth and synthesis to experimental and theoretical characterization by a multitude of probes), or by functionality (exemplified here by battery materials, optoelectronics, catalysts, etc.). As a consequence, the data produced by the community are enormously heterogeneous and diverse in terms of the 4V of Big Data

- Volume (amount of data)
- Variety (heterogeneity of form and meaning of data)
- Velocity (rate at which data may change or new data arrive)
- Veracity (uncertainty of data quality).

Also note that many research data produced today may appear irrelevant in the context they have been produced. Being regarded as *waste*, they are not published. However, they may turn out highly valuable for other purposes.

So, the R in FAIR (reusability) also means "store, share, and recycle the waste!" To cope with all the diversity and complexity, a bottom-up approach that satisfies the needs of the different sub-communities is a must to foster acceptance by the community and participation of a large number of individual researchers and laboratories. FAIRmat sets out to tackle this challenge by a user-driven approach to develop easy-to-use tools and an infrastructure towards FAIR data processing, storage, curation, sharing, and future use of materials data. For the latter, a major goal of FAIRmat is making data artificial-intelligence (AI) ready.

Data obtained by a certain experimental technique for a specific sample of a selected material are only worth keeping if the sample is fully characterized and apparatus and measurement conditions as well as the measured quantity are described in detail. Likewise, computed data are only meaningful when method, approximations, code and

* junkes@fhi.mpg.de
[1] FAIRmat press release

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEBL02

PROTOTYPE OF IMAGE ACQUISITION AND STORAGE SYSTEM FOR SHINE*

Huihui Lv, Huan Zhao†, Danping Bai, Xiaomin Liu
Shanghai Advanced Research Institute, Chinese Academy of Sciences
201204 Shanghai, P.R. China

Abstract

Shanghai HIgh repetition rate XFEL aNd Extreme light facility (SHINE) is a quasi-continuous wave hard X-ray free electron laser facility, which is currently under construction. The image acquisition and storage system has been designed to handle a large quantity of image data generated by the beam and X-ray diagnostics system, the laser system, etc. A prototype system with Camera Link cameras has been developed to acquire and to reliably transport data at a throughput of 1000MB/sec. The image data are transferred through ZeroMQ protocol to the storage where the image data and the relevant metadata are archived and made available for user analysis. For high-speed frames of image data storage, optimized schema is identified by comparing and testing four schemas. The image data are written to HDF5 files and the metadata pertaining to the image are stored in NoSQL database. It could deliver up to 1.2GB/sec storage speed. The performances are also contrasted between a stand-alone server and the Lustre file system. And the Lustre could provide a better performance. Details of the image acquisition, transfer, and storage schemas will be described in the paper.

INTRODUCTION

Motivated by the successful operation of X-ray FEL facilities worldwide and the great breakthroughs in atomic, molecular, and optical physics, condensed matter physics, matter in extreme conditions, chemistry and biology, the first hard X-ray FEL light source in China, the so called Shanghai HIgh repetition rate XFEL aNd Extreme light facility (SHINE), is under construction. SHINE will utilize a photocathode electron gun combined with the superconducting Linac to produce 8 GeV FEL quality electron beams with 1 MHz repetition rate [1].

A myriad of image data will be generated by the beam monitor system, the optical diagnostics system and the laser system, providing the required parameters for the accelerator operation and physics research. In order to measure the laser accurately, CCD cameras in the optical diagnostic system capture images at high speed. In addition, the beam cross section measured by the seed laser system and the drive laser system provides the basis for the commissioning and adjusting the devices ' parameters. Thus the accelerator has need of an efficient data acquisition and storage framework to accommodate the high-speed frames of image data, which is of great value to engineers and physicists to identify errors, component deterioration, poor process optimization, etc. They can also be used for big data analysis to improve control system stability and efficiency, and reduce maintenance cost. We have designed a general image system which is less expensive, using regular commercial hardware. It could acquire, transmit, and store the images at the speed of 1000MB/sec. The relevant tools are also developed to retrieve and display images on real time. Details are described in the following sections.

ARCHITECTURE

The whole system as shown in Fig. 1 can be divided into five functional modules, namely acquisition, transmission, storage, retrieval and online display.

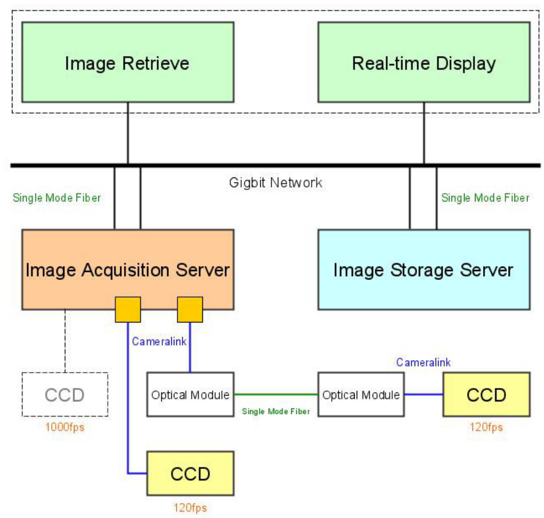


Figure 1: System Architecture.

Two CCD cameras with Camera Link interfaces take images at speed of 120 frames per second. One camera is directly connected to Camera Link Frame Grabber through a cable, while the other is connected to Camera Link Range Extender over a fiber cable, that solves distance limitation of Camera Link. Images are processed and packaged by the acquisition server and then transmitted to the storage server and online-display server through 10 Gigabit Ethernet, using ZeroMQ protocol for communication. After the storage server receives the data stream, it first unpacks it, then saves the image data in files as HDF5 format, and the metadata organized to facilitate searchability in MongoDB database. The web-based retrieval system is based on standard J2EE(Java 2 Platform, Enterprise Edition) Glassfish platform. It is designed to handle remote queries for historical records.

* Work supported by Shanghai Municipal Science and Technology Major Project(Grant No. 2017SHZDZX02)
† zhaohuan@zjlab.org.cn

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEBL04

MANAGE THE PHYSICS SETTINGS ON THE MODERN ACCELERATOR*

T. Zhang†, K. Fukushima, T. Maruta, P. Ostroumov, A. Plastun, Q. Zhao
Facility for Rare Isotope Beams, Michigan State University, East Lansing, USA

Abstract

The Facility for Rare Isotope Beams (FRIB) at Michigan State University is a unique modern user facility composed of a large-scale superconducting linac capable of accelerating heavy-ion beams from oxygen to uranium. An advanced EPICS-based control system is being used to operate this complex facility. High-level physics applications (HLAs) developed before and during the staged commissioning of the linac are one set of the critical tools that resulted in achieving the commissioning goals quickly, within several shifts. Many of these HLAs are expandable to other EPCIS controlled accelerators. Recently developed HLAs deal with the management of extensive data to achieve the repetitive high performance of ion beams in the entire linac measured by non-destructive diagnostics instruments, and open the possibilities to explore the extra values out of the data. This paper presents our recent significant development and utilization of these HLAs.

INTRODUCTION

The LINAC of the Facility for Rare Isotope Beams project at Michigan State University is a unique modern superconducting accelerator, it is designed to deliver all the stable isotope beams with multiple charge states to the kinetic energy higher than 200 MeV per nucleon, and power of 400 kW on the target [1]. Since the mid of 2017, staged commissioning has achieved a series of remarkable successes [2–4]. Now FRIB project is approaching the next milestone, that is to generate and separate the rare isotope beams at and after the production target system.

To expedite the beam commissioning, various kinds of high-level physics applications (HLAs) have been developed and deployed to FRIB controls network. The Python-based software framework called `phantasy` is designed and developed to drive the entire high-level communication between the accelerator and physicists [5]. Based on `phantasy`, the Python interactive scripting environment is implemented and utilized to prototype the physics tuning algorithms, and also used to control the machine in the advanced expert mode. Graphical user interface (GUI) applications have been developed with well-tested physics algorithms to make machine tuning simple and confident. General tools and GUI widgets based on Qt framework [6], together with physics-related widgets have been developed as another major part of `phantasy` framework to streamline the GUI application development.

* Work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661, the State of Michigan and Michigan State University.
† zhangt@frib.msu.edu

To better organize the data generated in the controls network, software applications have been developed to ensure the quality of data, e.g. integrity, reliability, and availability, etc. The next coming sections will present the software development activity of FRIB high-level physics controls, the use cases of the development on the accelerator of FRIB, and the approach of how the physics data is managed.

THE EVOLUTION OF `PHANTASY`

Originally, `phantasy` was designed for the object orient high-level controls for EPICS-based accelerator system. The main goal was to abstract the entire machine to be controllable in the ecosystem of Python, by using the enormous third-party library to fulfill the machine tuning missions [7].

Several critical issues need to be addressed with neat solutions before accomplishing such high-level conrtols environment:

- Properly present the machine in the view of computing environment.
- Properly handle the value of physics quality in different scenarios, either from the view of device control or physics model.
- Properly interface with the physics model, which is usually separately developed to simulate the accelerator behavior.
- Properly manage the development resources, i.e. source code, support data files, testing, deployment, etc.

With `phantasy`, the physics model-independent machine representation could be generated in the view of object-oriented. The machine is represented as a series of devices, each device is an instance of a general abstracted high-level element class, which is composed of controllable and non-controllable attributes. The non-controllable attributes usually present the static properties of the device and the controllable ones are connected to the process variables which are served through EPICS IOCs. The device control is fulfilled via Python object getter and setter operations, through dotted-syntax. All the device information is maintained separately, such a way the core code of `phantasy` could also be working with other accelerator systems, the same strategy has been applied to the GUI application development.

The interpretation of the values for physics qualities is handled in another separated application called UNICORN [8], which is a web application that features REST API. The Python interface "python-unicorn" [9] is also developed to request either value in physics or engineering unit. The mapping rules between physics and engineering world could be defined based on the needs of the physics model, e.g. for

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEBL05

FAIR MEETS EMIL: PRINCIPLES IN PRACTICE

Gerrit Günther*[1], William Smith[1,2], Markus Kubin[1], Marcus Bär[1–4], Nico Greve[1], Rolf Krahl[1], Simone Vadilonga[1], Regan G. Wilks[1,2], Oonagh Mannix[1],
[1] Helmholtz-Zentrum Berlin für Materialien und Energie GmbH (HZB), Lise-Meitner-Campus, Hahn-Meitner-Platz 1, 14109 Berlin, Germany
[2] Energy Materials In-Situ Laboratory Berlin (EMIL), HZB, Albert-Einstein-Str. 15, 12489 Berlin, Germany
[3] Helmholtz Institute Erlangen-Nürnberg for Renewable Energy (HI ERN), Albert-Einstein-Str. 15, 12489 Berlin, Germany
[4] Friedrich-Alexander Universität Erlangen-Nürnberg (FAU), Egerlandstr. 3, 91058 Erlangen, Germany

Abstract

Findability, accessibility, interoperability, and reusability (FAIR) form a set of principles required to ready information for computational exploitation. [1] The Energy Materials In-Situ Laboratory Berlin (EMIL) at BESSY II [2], with its unique analytical instrumentation in direct combination with an industrially-relevant deposition tool, is in the final phase of commissioning. It provides an ideal testbed to ensure workflows are developed around the FAIR principles; enhancing usability for both human and machine agents. FAIR indicators [3] are applied to assess compliance with the principles on an experimental workflow realized using Bluesky. [4] Additional metadata collection by integrating an instrument PID [5], an electronic laboratory book, and a sample tracking system is considered along with staff training. Data are collected in Nexus format and made available in the ICAT repository. This paper reports on experiences, problems overcome, and areas still in need of improvement in future perspectives.

INTRODUCTION

The FAIR principles – findability, accessibility, interoperability and reusability – are well known and serve as guidelines for data curators and data management stewards along with IT professional; people who manage rather than generate data. Here, we apply high-level data management concepts contained in the FAIR principles on the level of granularity of a complex, beamline-based materials research infrastructure – the EMIL infrastructure at BESSY II, that is in its final phase of commissioning. In doing so we clarify the relationship between data generator, research infrastructure, and data infrastructure; demonstrating how the FAIR principles relate to each actor.

To report the present state of work, the remainder of this paper is organized as follows: First, we sketch the complex scientific infrastructure of EMIL at BESSY II focusing on its end station SISSY I (**S**olar energy material **I**n-**S**itu spectroscopy at the **Sy**nchrotron). Since the FAIR principles are independent of each other [1] we continue with a discussion of their implementation following the sequence reusability, interoperability, accessibility, and findability. By balancing user effort and data accuracy we proceed to focus on the sequence of measures taken to find an appropriate workflow. Finally, we apply FAIR indicators and assess the SISSY I end station.

Throughout the paper, the convention of [3] is adopted to distinguish between data and metadata. Here, data refers to the primary output of detectors or other objects of outstanding scientific interest while metadata belongs to information that helps to analyze the primary data such as the sample or the sample's properties. If both types of data are addressed the term (meta)data is used.

OUTLINE OF EMIL INFRASTRUCTURE

The Energy Material In-Situ Laboratory Berlin (EMIL) [2,6,7] is a newly implemented, complex research infrastructure at BESSY II which combines state-of-the-art synthesis and deposition systems on industry-relevant scale with sophisticated in system/in situ/operando x-ray spectroscopy capabilities, outlined in Fig. 1. By focusing on study of the growth of materials and the formation of functional interfaces EMIL tracks the evolution of material properties through successive processing steps. A fully automated ultra-high vacuum multi-chamber system built by PREVAC [8] transfers samples between various production sites, analysis tools, and the SISSY I end station. As a result samples are changing both their state and location within EMIL and may be placed at in SISSY I end station for characterization.

The SISSY I end station houses an electron analyzer able to detect electrons with kinetic energies between 50 eV and 10 keV. Exploiting the full energy range of EMIL's two-color beamline, photon energies between 80 and 10000 eV – delivered by the two canted undulators (UE48 and U17) – can be used to probe the sample properties by soft and hard x-ray photoelectron emission electron spectroscopy. [9] Currently, the SISSY I end station is in the final stages of commissioning and so provides an excellent test bed to implement the FAIR principles during the transition to user operation.

The instrument and beamline are controlled with EPICS [10]. Devices are accessed in a Python environment through

* gerrit.guenther@helmholtz-berlin.de

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEBR01

RomLibEmu: NETWORK INTERFACE STRESS TESTS FOR THE CERN RADIATION MONITORING ELECTRONICS (CROME)

K. Ceesay-Seitz†, H. Boukabache*, M. Leveneur, D. Perrin, CERN, Geneva, Switzerland

Abstract

The CERN RadiatiOn Monitoring Electronics (CROME) are a modular safety system for radiation monitoring that is remotely configurable through a supervisory system via a custom protocol on top of a TCP/IP connection. The configuration parameters influence the safety decisions taken by the system. An independent test library has been developed in Python in order to test the system's reaction to misconfigurations. It is used to stress test the application's network interface and the robustness of the software. The library is capable of creating packets with default values, autocompleting packets according to the protocol and it allows the construction of packets from raw data. Malformed packets can be intentionally crafted and the response of the application under test is checked for protocol conformance. New test cases can be added to the test case dictionary. Each time before a new version of the communication library is released, the Python test library is used for regression testing. The current test suite consists of 251 automated test cases. Many application bugs could be found and solved, which improved the reliability and availability of the system.

INTRODUCTION

The Radiation Protection group within CERN is responsible for measuring levels of ionizing radiation at the CERN sites, experimental areas and in service caverns besides the LHC experiments in order to ensure the radiological safety of the persons on the CERN site as well as the people living in its neighbourhood. The CERN RadiatiOn Monitoring Electronics (CROME) have been developed in-house with the purpose of replacing the older radiation monitoring systems ARCON and RAMSES. In contrast to the old systems, CROME consists of fully independent units, called CROME Measurement and Processing Units (CMPUs), which perform their safety functions autonomously [1]. A CMPU consists of a radiation detector, which is an ionization chamber in most cases, a front-end board for the readout and the processing unit. The latter has at its core a Zynq-7000 System-on-Chip (SoC) with an embedded Linux running on the Processing System (PS) with integrated 32-bit ARM cores and a Programmable Logic (PL) section. Because the PL can operate autonomously and the design architecture is more immune to higher radiation than the PS [2], all the safety critical calculations and decision making are implemented inside the PL.

The CMPU's functionality is entirely configurable at runtime with roughly 150 parameters. This has the advantage that CROME can be deployed for very different usage scenarios – e.g. in service caverns or experimental areas with higher levels of radiation where it can be configured to trigger visible and audible alarms and with the possibility of being connected to machine interlocking systems, or as environmental monitors where the natural background radiation is monitored over long periods for informational purposes.

Figure 1 presents a system overview. During operation the CMPUs are connected to a SCADA supervisory system called REMUS – Radiation and Environment Monitoring Unified Supervision [3]. The CMPUs on the one communication end and the REMUS servers on the other end use the ROMULUS library [4] for communicating with each other. The library implements a custom protocol on top of TCP/IP that can be used to remotely configure the parameters on the CMPU at runtime, to read out its current and historical status, and to receive real time as well as historical measurement values.

The remote parametrization via REMUS is the only dedicated mechanism for users to configure the behaviour of the CROME system during operation. Radiation protection experts use REMUS to configure the CMPUs corresponding to the expected radiation conditions and safety requirements of a zone. Operators in the control room use REMUS to monitor the status and measurement results sent by the CMPUs.

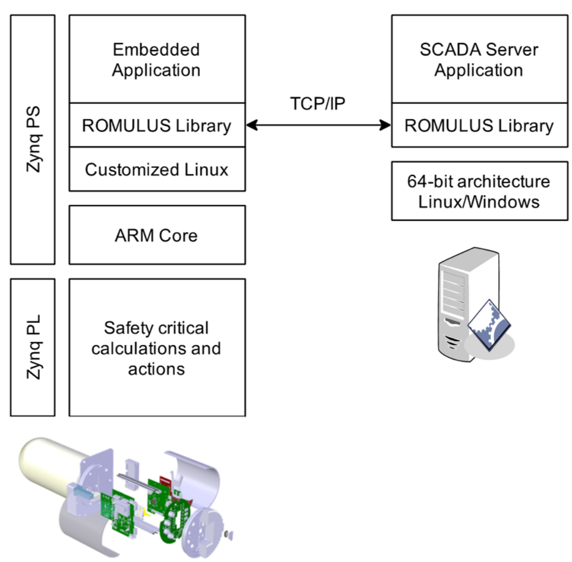


Figure 1: CROME Overview.

Since it influences the functionality as well as the safety function of the system, the communication mechanism needs to be robust and reliable. The RomLibEmu, the ROMULUS Library Emulation and Test Tool, has been developed to test the functionality and robustness of the ROMULUS library as well as of the CMPU's application.

† katharina.ceesay-seitz@cern.ch
* hamza.boukabache@cern.ch

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEBR02

TOWARDS THE OPTIMIZATION OF THE SAFETY LIFE-CYCLE FOR SAFETY INSTRUMENTED SYSTEMS

B. Fernández*, G. De Assis, R. Speroni, T. Otto, E. Blanco,
CERN, Geneva, Switzerland

Abstract

The design and development of Safety Instrumented Systems (SIS) according to the IEC 61511 standard is a long and costly process. Although the standard gives recommendations and guidelines for each phase of the safety life-cycle, implementing them is not a simple task.

Access to reliability data, hardware and systematic safety integrity analysis, software verification, generation of reports, guarantee of traceability between all the phases and management of the project are some of the main challenges. In addition, some of the industrial processes or test benches of large scientific installations are in continuous evolution and changes are very common. This adds extra complexity to the management of these projects.

This paper presents an analysis of the safety life-cycle workflow and discusses the biggest challenges based on our experience at CERN. It also establishes the basis for a selection of the tools for some of the safety life-cycle phases, proposes report templates and management procedures and, finally, describes the roles of the different members in our functional safety projects.

INTRODUCTION

The design, development and maintenance of Safety Instrumented Systems (SIS) requires a lot of resources and time for a company or organization. It is not enough to develop a reliable SIS based on good engineering practices, it is necessary to prove that the Safety Instrumented Functions (SIF) reduce the existing risk to the tolerable region. The functional safety standards provide the guidelines to design and develop such systems and the methods to prove the compliance with the risk reduction target. For industrial processes, the IEC 61511 [1] is the most appropriate standard. It uses the same principles as the IEC 61508 standard with a more specific language and context.

The IEC 61511 Safety Life-Cycle

Figure 1 shows the so-called IEC 61511 safety life-cycle, whose requirements are specified in the Clause 6 of the IEC 61511-1:2016. This Clause defines the different phases, organizes the technical activities and ensures that adequate planning exists for the development of the SIS.

In order to claim conformance with the IEC 61511 standard, all requirements from Clause 5 to Clause 19 from the 61511-1:2016 have to be met and the corresponding reports have to be created. All these requirements are clearly specified, but how to implement them is the real challenge.

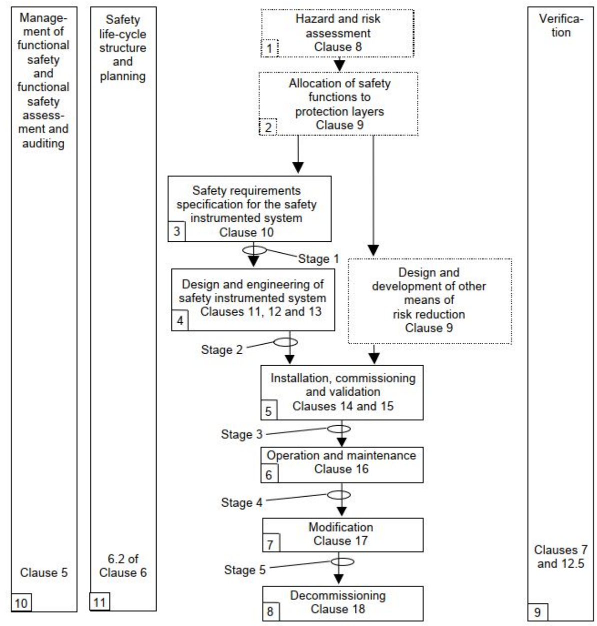


Figure 1: IEC 61511 safety life-cycle.

Challenges

The main challenges related to the implementation of the safety life-cycle are common to most industries. In our experience, proving the compliance with the standard and guaranteeing the traceability between all phases of the safety life-cycle are two of the most critical ones. Compliance is a very costly and time-consuming process, and lack of traceability most certainly would create discrepancies in the project documents, delays and potential errors.

In addition, at CERN (European Organization for Nuclear Research) and most probably in other large scientific installations, some of the industrial processes or test benches are in continuous evolution and changes that influence the safety of the installation are very common.

Objectives

Our goal is to overcome the technical and organizational challenges to optimize the allocated resources for the design, development and maintenance of SIS.

More specifically, we aim to:

- Create report templates that are necessary for the documentation and management of such projects.
- Reuse and integrate the existing tools we have at CERN that can be applied to any of the phases of the safety life-cycle.
- Discuss the management procedures and the roles of the different members in our functional safety projects.

* borja.fernandez.adiego@cern.ch

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEBR03

THE FAST PROTECTION SYSTEM FOR CSNS ACCELERATOR

Y.L. Zhang†, P. Zhu, D.P. Jin
Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China

Abstract

The CSNS (China Spallation Neutron Source) consists of an 80 MeV H^- LINAC, a 1.6 GeV Rapid Cycling Synchrotron, two beam transport lines and one tungsten target and three beam lines. The designed proton beam power is 100 kW in Phase-I [1]. The fast protection system plays an important role to guarantee the safe operation of accelerator. The response time requirement for the CSNS fast protection system is less than 10 µs. The design of CSNS FPS was based on FPGA technology, and the VME bus and SFP connector was adopted for the hardware design. Different beam interlock and mitigation logic was designed so as to fulfil the operation requirements.

INTRODUCTION

CSNS accelerators are designed to accelerate very high intensity proton beam, Fig. 1 shows the schematic layout of the CSNS facility. The uncontrolled beam loss may permanently damage or give a high radiation dose to the accelerator components along the beam line [2, 3]. Therefore, high reliability for machine protection system is the basic requirement. The accelerator protection system must be carefully designed so that we can avoid the unnecessary beam loss. Besides, the availability, scalability, maintainability and the budget were also need to be carefully considered in the design and implementation stage.

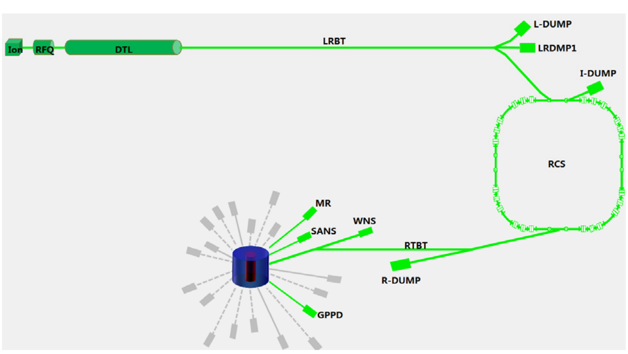


Figure 1: Schematic diagram of CSNS.

CSNS accelerator protection system consists of two protection systems, one is the PLC based slow protection system: NMPS (Normal Machine Protection System), the other is the FPGA based FPS (Fast Protection System). The response time within 20ms and 10µs are required for NMPS and FPS respectively [4]. The overall protection systems for CSNS as shown in Fig. 2. The output signals of PPS (Personnel Protection System) and TPS (Target Protection System) are input into the two NMPS main stations. RMS (Run Management System) can be seen as the beam permit system. Three beam stopping actuators are designed for protection system, which including ion source timing, post acceleration power supply of ion source and RFQ power source.

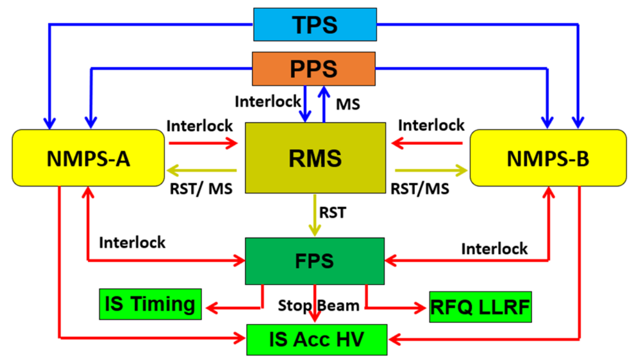


Figure 2: Relations among the protection systems for CSNS facility.

OVERVIEW OF THE CSNS FPS

The FPS for CSNS accelerator was designed based on the FPGA, the hardware was designed in VME form. In order to unify the hardware type, two kinds of boards were designed, one is the main logic board as shown in Fig. 3, the other is the optical signal input board as shown in Fig.4.

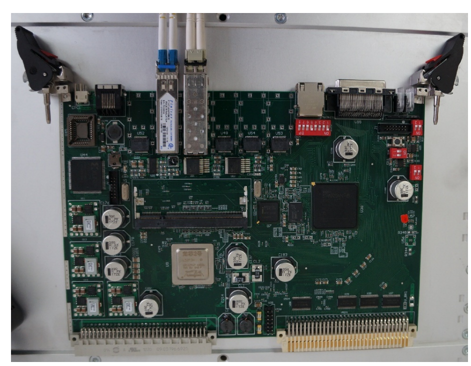


Figure 3: Picture of the FPS main logic board.

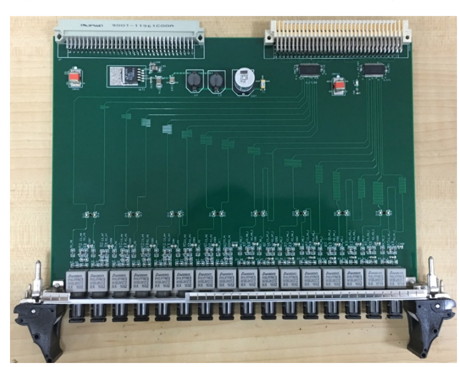


Figure 4: Picture of the FPS signal input board.

The high-speed serial communication technology was adopted by the main logic board, and the common plastic

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEBR04

SAFEGUARDING LARGE PARTICLE ACCELERATOR RESEARCH FACILITY- A MULTILAYER DISTRIBUTED CONTROL ARCHITECTURE

Feng Tao*, SLAC National Accelerator Laboratory, Menlo Park, USA

Abstract

Personnel Protection System (PPS) at SLAC is a global safety system responsible for protecting personnel from radiation hazards. The system's functional design shares similar concepts with machinery safeguarding, though the complexity of PPS is much higher due to its wide geographic distribution, large number of devices, and multiple sources of hazards. In this paper, we will first introduce the multilayer distributed control system architecture of SLAC's PPS, which serves three beam programs, e.g., LCLS, LCLS-II and FACET-II, that co-exist in the same 4km linear accelerator infrastructure. Composed of 50+ sets of redundant safety PLCs and 20+ access control PLCs, SLAC's PPS has five layers: beam program, beam switching and permit, zone access control, zone safety control and sensor/shutoff subsystems. With this architecture, safety functions often involve multiple controllers across several layers, make it a challenge on system analysis, verification, and testing. Therefore, in this paper, we will also discuss functional safety related issues for this type of complex systems.

OUTLINE OF THE PAPER

In this paper, the machinery safeguarding concepts and the introduction of SLAC's PPS are given first. Then different layers of SLAC and their functions are explained. For the representative E-Stop function, how each layer of PPS control contributes to the safety integrity is analyzed in Section 3. The impacts on system integrity for such a large distributed system are discussed in Section 4, with proposed solutions. At last, some remarks are given in the conclusion section.

MACHINERY SAFEGUARDING AND SLAC'S PPS

Machinery safety has been a matured and important field for safety-critical control system applications [1]. With the adoption of IEC 61508 [2] and the concept of functional safety, significant progress has been made in various application fields to formalize requirements on typical safety functions and their integrity levels. System designers should follow those standards and use those formalized requirements as a starting point. In machinery sector, there are two functional safety standards, e.g., IEC 62061 [3] and ISO 13849 [4], using different performance metrics Safety Integrity Level (SIL) and performance Level (PL) respectively. In Europe, ISO 13849 has been widely used as a type B1 standard that many type C specific machine safety standards referred to.

SLAC is a large research facility. It has a 2 miles long linear accelerator (Linac), which is being used to generate either high power electron beam, or extremely bright x-ray laser for scientific experiments. For this reason, the whole facility can be treated as a large "machine" producing electron/x-ray. So those best practice from machinery safety can be applied to SLAC's PPS as well.

There are some similarities and differences between conventional machinery safeguarding with SLAC's PPS.

Common practices include:

- Dual redundant circuitry for system reliability
- Operators' search procedure to secure the area
- Personnel trapped key interlock
- Wide usage of machinery safety certified components, from laser scanner, Emergency stop, trapped keys, circuit breaker, to safety PLCs.

On the other hand, as a large research facility, SLAC's PPS is much more complex than a conventional machinery safety system. The complexity comes from four factors:

- Wide geographical distribution
- Large numbers of field devices to monitor/control
- Multiple sources of hazards to interlock
- Interface to many other complex systems.

Those factors combined altogether pose a design challenge for PPS, which must be a distributed global safety system to meet those challenges.

SLAC's 2-mile long Linac was built in 1960s, and it is the longest linear accelerator in the world. Nowadays, this Linac are serving three different beam programs: LCLS completed in 2009, FACET-II completed in 2020, and the superconducting (SC) LCLS-II, which is under construction and will start operation in early 2021.

Figure 1 shows the locations of three beam programs, each taking up one third of Linac for beam acceleration:

- LCLS-II SC beam: Linac West (Sector 00- Sector 09)
- FACET-II: Linac Middle (Sector 10- Sector 20)
- LCLS-I Cu beam: Linac East (Sector 21- Sector 29)

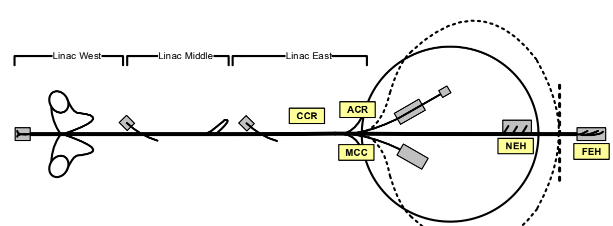


Figure 1: Layout of SLAC's Beam Lines.

* The author currently works for Underwriters Laboratories as a Functional Safety Staff Engineer,
† Feng.Tao@ul.com.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEBR05

INTEGRATED SUPERVISION FOR CONVENTIONAL AND MACHINE-PROTECTION CONFIGURATION PARAMETERS AT ITER

D. Karkinsky†, W. Van Herck, I. Prieto Diaz, J. Soni, A. Marqueta, ITER Organization, St. Paul lez Durance, France

Abstract

Configuration parameters for ITER's I&C systems are predominantly high-coupled due to the nature of the process under control. Subsequently, I&C re-configuration requires an integrated supervision approach that addresses coupling through abstraction, automation, scalability, changeability, robustness and re-usability. Moreover, high-coupling might manifest at any tier of the I&C, and certainly spans configuration parameters across both conventional and investment-protection I&C.

Stemming from ITER design guidelines, the handling of investment-protection configuration parameters needs to meet the goals of IEC61508. These goals are mostly in congruence with the main concerns of integrated supervision identified above. However they also extend requirements that bind the supervision process with traceability and audit capabilities from sources to final self-test (run-time) diagnostics.

This presentation describes the provisions for integrated supervision at ITER and elaborates how these provisions can be used to handle machine-protection parameters in compliance with IEC61508.

INTRODUCTION

The ITER plant configuration system is a component of the Control, Data Access and Communication (CODAC) Supervision and Automation (SUP) system and is tasked to:

- Derive machine parameters from the central planned experiment information contained in the pulse schedule,
- Conduct a multi-stage engineering verification process involving a wide range of codes (e.g. electromagnetic induced forces on mechanical structures, scarce resource budget management, etc.),
- Convert machine parameters to the number and format representation of the various Plant Systems Instrumentation and Control (I&C), and
- Eventually load machine parameters to the Plant Systems Instrumentation and Control (I&C) as part of the experiment preparation.

The ITER plant configuration system interfaces to ITER machine Operation, to a heterogeneous set of data repositories (e.g. pulse schedule queue, machine geometry and condition, operating limits, live measurements, Plant System self-description data, etc.), and the Plant System Instrumentation and Control (I&C) systems that compose the ITER machine.

The ITER plant configuration participates to the ITER defence-in-depth machine protection scheme by ensuring the configuration is as thoroughly verified as deemed necessary before starting lengthy and costly operations.

The baseline design for the Plant System I&C configuration interface is using EPICS records databases and Channel Access (CA). This was challenged during the 2014 CODAC design review. It was then understood that this choice was ill adapted to address the complexity required in the scope of ITER Plant Systems, and in particular in those areas below:

- Large and complex data structures involved.
- Existence of dependencies between parameters.
- Exception handling (e.g. restoration of valid configuration after a failed verification by the Plant System) and reporting.
- Handling of investment protection parameters for the Integrated Control System (ICS).

As a result, the configuration system was designed to support:

- Structured configuration variables,
- Atomicity of loading such, possibly complex, data structures,
- Protection against data corruption.

The protocol for Plant System I&C configuration is defined to follow the sequence outlined in Figure 1. The hash provides protection against data corruption and acts as a digital signature of over a data stream that can encapsulate an arbitrary set of configuration parameters.

In this presentation we report the results from an investigation into how the ITER plant configuration system can integrate with ITERs integrated control system (ICS) for handling investment protection parameters. As per ITER guidelines the ICS needs to meet the goals of IEC61508[1]. We report on the process by which we arrived at an adequate integration point for both systems and the technological solutions that have been put in place in support of this integration.

SUP SYSTEM DESIGN

ITER defence-in-depth principles, and the overall complexity of the machine, dictate that parameters are verified before being loaded to the plant. Distinct verification processes may be used depending on the nature of the task.

Furthermore, high-level operation will define operation goals, from which Plant System parameters must be derived (e.g. required cryogenic cooling capacity derived from predicted thermal loads).

To accommodate these requirements, the SUP configuration framework contains the following subcomponents:

† Damien.Karkinsky@iter.org

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV001

TEMPERATURE CONTROL FOR BEAMLINE PRECISION SYSTEMS OF SIRIUS/LNLS

J.L.N. Brito*, G. S. Baldon, F. R. Lena, M. A. L. Moraes, R. R. Geraldes, M. Saveri Silva, L. M. Volpe, Brazilian Synchrotron Light Laboratory (LNLS), CNPEM, Campinas, Brazil

Abstract

Precision beamline systems, such as monochromators and mirrors, as well as sample stages and sample holders, may require fine thermal management to meet performance targets. Regarding the optical elements, the main aspects of interest include substrate integrity, in case of high power loads and densities; wavefront preservation, due to thermal distortions of the optical surfaces; and beam stability, related to thermal drift. Concerning the sample, nanometer positioning control, for example, may be affected by thermal drifts and the power management of some electrical elements. This work presents the temperature control architecture developed in house for precision elements at the first beamlines of Sirius, the 4th-generation light source at the Brazilian Synchrotron Light Laboratory (LNLS). Taking some optical components as case studies, the predictive thermal-model-based approach, the system identification techniques, the controller design workflow and the implementation in hardware are described, as well as the temperature stability results.

INTRODUCTION

To address strict performance challenges of the new-generation beamlines at the Sirius 4th-generation light source [1], a series of innovative instruments have been developed in-house by the the Brazilian Synchrotron Light Laboratory (LNLS) over the past few years. Considered critical elements, special attention was given to optical systems – such as the High-Dynamic Double-Crystal Monochromator (HD-DCM) [2], the 4-bounce Crystal Monochromator (4CM) [3], mirror systems [4] and experimental stations [5].

These high-performance systems have been developed according to strong precision engineering and mechatronics principles, in which mechanical, thermal, metrology, control, and software aspects must be jointly addressed since early design stage [6]. Within this scope, sub-system functionalities are decoupled as much as possible from each other to minimized crossed effects, such that, as an example, a cooling system aims to be mechanically decoupled from the element of interest, whereas a positioning system/structure tends to be thermally decoupled from it.

Oftentimes, flexural structures are used as predictive solutions for kinematic mounts and fine positioning capabilities, with complementary thermal isolation possibilities [4, 7, 8]. Indeed, thermal decoupling is an essential aspect in many of these systems because cryogenic solutions were extensively adopted, either for sample conditioning [8], or for the silicon-based optical elements [2–4], to benefit from the thermal properties of this material at low temperatures in handling heat dissipation and thermal stresses/deformations.

Next, in addition to thermal decoupling, temperature control becomes an indispensable feature in many of these systems, being used for: 1) coarse static compensation in heat-flow for the desired operation temperatures; 2) heat load compensation (with and without beam, for example); 3) reduction of the time constants in the closed-loop systems as compared to passive or open-loop response; and 4) fine temperature control in drift-sensitive systems.

The following sections present the temperature control architecture that has been standardized for some Sirius beamline systems; the hardware, with appropriate actuators and sensors being critical for robust and high-performance control capabilities; predictive and experimentally derived plant models; and illustrative commissioning examples.

* joao.brito@lnls.br

ARCHITECTURE AND HARDWARE

The hardware architecture adopted to control the temperature of the Sirius precision beamline systems is summarized in the Fig. 1, where a NI CompactRIO (cRIO) implements the control by reading the temperature sensors and acting through heaters present in the system, represented by a mirror. The cRIO also interfaces with the equipment protection system (EPS) [9], closing the beam shutter in case of overheating or disabling the cooling system to prevent overcooling, for example.

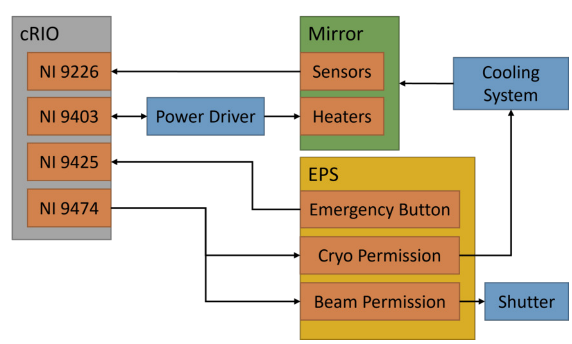


Figure 1: Temperature control hardware architecture.

The elements of the architecture and its characteristics are presented below.

Power Driver

The power driver is a multi-channel heater driver [10] in-house developed with 8 channels that delivers up to 1.5 A at 12 V DC per channel, where the voltage output

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV002

POSITION SCANNING SOLUTIONS AT THE TARUMÃ STATION AT THE CARNAÚBA BEAMLINE AT SIRIUS/LNLS

C. S. N. C. Bueno†, L. G. Capovilla, R. R. Geraldes, L. C. Guedes, G. N. Kontogiorgos, L. Martins dos Santos, M. A. L. Moraes, G. B. Z. L. Moreno, A. C. Piccino Neto, J. R. Piton, H. Tolentino, Brazilian Synchrotron Light Laboratory (LNLS), CNPEM, Campinas, Sao Paulo, Brazil.

Abstract

TARUMÃ is the sub-microprobe station of the CARNAÚBA beamline at Sirius/LNLS. Covering the range from 2.05 to 15keV, the probe consists of a fully-coherent monochromatic beam varying from 550 to 120nm with flux of up to 1e11ph/s/100mA after the achromatic focusing optics. Hence, positioning requirements span from nanometer-level errors for high-resolution experiments to fast continuous trajectories for high throughput, whereas a large flexibility is required for different sample setups and simultaneous multi-technique X-ray analyses, including tomography. To achieve this, the overall architecture of the station relies on a pragmatic sample position-ing solution, with a rotation stage with a range of 220°, coarse stages for sub-micrometer resolution in a range of 20mm in XYZ, and a fine piezo stage for nanometer resolution in a range of 0.3mm in XYZ. Typical scans consist of continuous raster 2D trajectories perpendicularly to the beam, over ranges that vary from tens to hundreds of micrometers, with acquisition times in range of milliseconds. Positioning based on 4th-order trajectories and feedforward, triggering including the multiple detectors and data storage are addressed.

INTRODUCTION

TARUMÃ [1] is the sub-microprobe station of the CARNAÚBA beamline [2] at Sirius/LNLS [3]. The CARNAÚBA beamline was designed to cover the range from 2.05 to 15keV, and is based on an all-achromatic optical design. The probe consists of a fully-coherent monochromatic beam varying from 550 to 120nm, focused by a set of KB (Kirkpatrick-Baez) mirrors, and with flux of up to 1e11ph/s/100mA. TARUMÃ was designed to perform simultaneous multi-technique analyses under a variety of conditions, including *in situ*, *in vivo*, and *in operando* experiments. Thus, it complies a number of customized sample environments [1, 4, 5] and a set of detectors of different types, including: two SDD Vortexes (Xspress 3 and Xspress 3X), two area detectors (MobiPix 45D and PiMega 135D, one XEOL detector, and an in-house spectrometer. Figure 1 shows a detailed view of the sample and the detectors (left) and an overview picture of the TARUMÃ station (right).

The sample stage is composed, from bottom up, of: an Aerotech's 300DL XY, a Newport's IDL280 Z20 wedge-type vertical stage, an Aerotech's ABRS 250MP air-bearing rotary stage, and a PI's P-563.3 XYZ stage. The planar and vertical stages are responsible for the rough alignment of the sample with a range of ±10mm in XYZ. The rotary stage, constrained over 220° due to cable management, is used for tomography, diffraction, and Bragg CDI experiments. A cable carrier system allows additional instrumentation, like special gases, heaters, sensors, and vacuum lines, to be used in the sample environment. The XYZ piezo stage is responsible for the sample scans with nanometer resolution over a 300μm range and has a payload capacity of 5 kg.

Resolutions down to the order of 10nm are desired from the experiment's reconstructions, which sets an upper boundary for the relative positioning errors between the sample and the KB mirrors. Thus, to reach these positioning levels, the KB optics and the sample stage are placed

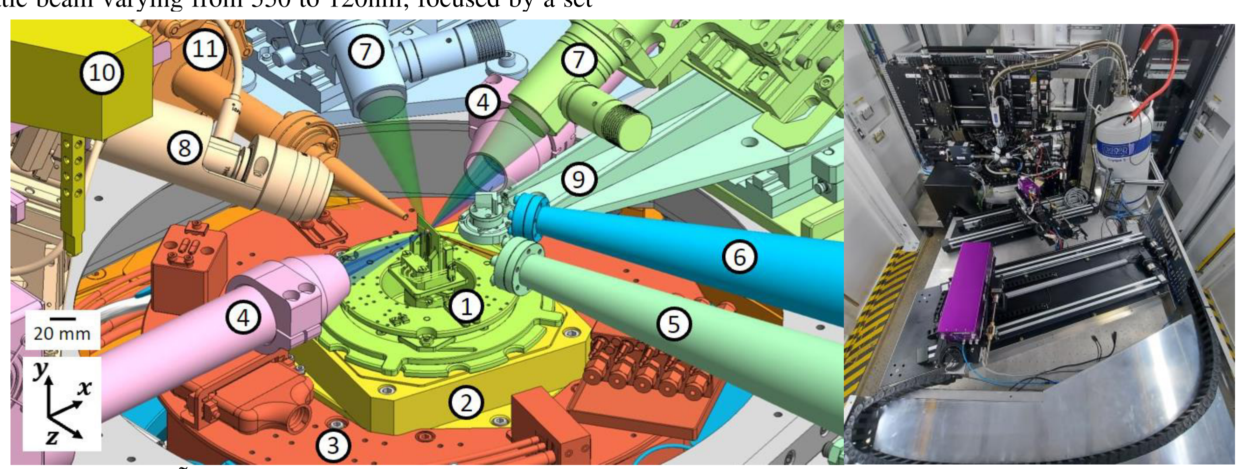


Figure 1: TARUMÃ station: drawing of the region surrounding the sample, detailing: the sample setup(1), the sample stage (2 and 3), the fluorescence detectors (4), the flying paths for the transmission(5) and the diffraction(6)area detectors, the optical microscopes (7), the XEOL optics (8), a crystal analyser spectrometer (9), the pick-and-place gripper (10), and the KB vessel exit port (11). (left) and assembly status on 10/07/2021 (right).

† cassiano.bueno@lnls.br

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV003

THE DYNAMIC MODELING AND THE CONTROL ARCHITECTURE OF THE NEW HIGH-DYNAMIC DOUBLE-CRYSTAL MONOCHROMATOR (HD-DCM-Lite) FOR SIRIUS/LNLS

G. S. de Albuquerque*, A. V. Perna, J. L. Brito Neto, M. A. L. Moraes, M. S. Souza, M. Saveri Silva, R. R. Geraldes[1], LNLS, Campinas, Brazil
[1]also at the CST Group, Eindhoven University of Technology (TUe), Eindhoven, The Netherlands

Abstract

The High-Dynamic Double-Crystal Monochromator (HD-DCM) has been developed since 2015 at Sirius/LNLS with an innovative high-bandwidth mechatronic architecture to reach the unprecedented target of 10 nrad RMS (1 Hz - 2.5 kHz) in crystals parallelism also during energy flyscans. Now, for beamlines requiring a smaller energy range (3.1 keV to 43 keV, as compared to 2.3 keV to 72 keV), there is the opportunity to adapt the existing design towards the so-called HD-DCM-Lite. The control architecture of the HD-DCM is kept, reaching a 20 kHz control rate in NI's CompactRIO (cRIO). Yet, the smaller gap stroke between crystals allows for removing the long-stroke mechanism and reducing the main inertia by a factor 6, not only simplifying the dynamics of the system, but also enabling faster energy scans. With sinusoidal scans of hundreds of eV up to 20 Hz, this creates an unparalleled bridge between slow step-scan DCMs, and channel-cut quick-EXAFS monochromators. This work presents the dynamic error budgeting and scanning perspectives for the HD-DCM-Lite, including discussions on the feedback control via loop shaping, feedforward considerations, and leader-follower control strategies.

INTRODUCTION

After successfully designing, installing and commissioning the High-Dynamic Double-Crystal Monochromator (HD-DCM) [1] at the MANACÁ (crystallography) and the EMA (extreme conditions) beamlines, QUATI (quick absorption spectroscopy) and SAPUCAIA (small-angle-scattering) are two forthcoming Sirius beamlines demanding an HD-DCM at the Brazilian Synchrotron Light Laboratory (LNLS). Since these new beamlines require a smaller energy range (3.1 to 43 keV), the total gap stroke of the instrument can be significantly reduced from 9 mm to about 2.75 mm, such that an opportunity is created to adapt the existing design towards the so-called HD-DCM-Lite.

Removing the long-stroke module (see [1]) for the large gap adjustments allows not only for cost reduction and simplification in the assembly, but also for significant improvement in dynamics. By reducing the main inertia by a factor of 6, the HD-DCM-Lite is expected to deliver energy flyscans of hundreds of eV up to at least 4 to 40 times per second, while keeping fixed exit and the inter-crystal parallelism in the range of a few tens of nrad RMS (root mean square) for the 1 Hz - 2.5 kHz range. Thus, QUATI (superbend-based) may take full advantage of this capability in time-resolved analysis, whereas new science opportunities may be explored for SAPUCAIA. The new design focuses on extending the scanning capabilities while preserving positional accuracy, creating a solution between the current HD-DCM (limited in speed but with fixed-offset and already extremely stable) and fast channel-cut monochromators [2], which suffer from beam walk due to offset variation.

An overview of the mechanical design of the HD-DCM-Lite, with the CAD drawing of its in-vacuum mechanics and a simplified lumped-mass model, is given in Fig. 1. Two crystal sets, with Si(111) and Si(311) orientations for options in energy filtering bandwidth and range, are mounted side by side, being alternatively selected during operation. At the lower side, the so-called 1st Crystals (CR1) (6) are mounted to a common Metrology Frame (MF1) (5), which, in turn, is fixed to an Auxiliary Frame (AF1) (4), that is, finally, fixed to the Goniometer Frame (GOF) (3), which is driven by two rotary stages (ROT) (2) for controlling the angle of incidence of the incoming X-ray beam on the crystals for energy selection according to Bragg's law of diffraction.

At the upper side, the so-called 2nd Crystals (CR2) (7) are used to redirect the beam in the fixed-exit configuration that defines the operational principles of an X-ray DCM. They are mounted to a common metrology frame as well, which, in this case, is a Short-Stroke stage (SHS) (8) that is actively controlled with nanometer level with respect to the MF1 in 3 degrees of freedom (DOF). Indeed, the distance (gap) and parallelism between crystals — or, more precisely, between their metrology frames — can be adjusted via closed-loop control based on 3 voice-coil actuators and 3 laser interferometers. The reaction forces of these actuators act on a Balance-mass (BMS) (10) for dynamic filtering purposes, and both the SHS and the BMS are mounted via flexural folded leaf-springs to the Auxiliary frame 2 (AF2) (9), which is also fixed to the GOF.

The supports of the ROT are stiffly fixed to a vacuum flange, as part of the complete vacuum vessel (VES) (not shown), which, in turn, is stiffly fixed to a granite bench (GRA) (1) for alignment purposes and crystal set selection at the beamline, building the dynamic architecture of the system all the way up from experimental floor (GND).

With the previous experience from the HD-DCM as a high-end mechatronic system, here again a systematic approach based on precision engineering principles and predictive modeling has been adopted to maximize the efficiency in development time and costs, according to a "first-time-right"

* guilherme.sobral@lnls.br

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV005

EXPERIMENT AUTOMATION USING EPICS

D. Cosic†[1], M. Vićentijević, Ruđer Bošković Institute, Zagreb, Croatia
[1]Faculty of Electrical Engineering, Mechanical Engineering and Navel Architecture, University of Split, Split, Croatia

Abstract

Beam time at accelerator facilities around the world is very expensive and scarce, prompting the need for experiments to be performed as efficiently as possible. Efficiency of an accelerator facility is measured as a ratio of experiment time to beam optimization time. At RBI we have four ion sources, two accelerators, ten experimental end stations. We can obtain around 50 different ion species, each requiring a different set of parameters for optimal operation.

Automating repetitive procedures can increase efficiency of an experiment and beam setup time. Currently, operators manually fine tune the parameters to optimize the beam current. This process can be very long and requires many iterations. Automatic optimization of parameters can save valuable accelerator time. Based on a successful implementation of EPICS [1], the system was expanded to automate reoccurring procedures. To achieve this, a PLC was integrated into EPICS and our acquisition system was modified to communicate with devices through EPICS. This allowed us to use tools available in EPICS to do beam optimization much faster than a human operator can, and therefore significantly increased the efficiency of our facility.

INTRODUCTION

Some experiments performed have a standardized procedure which must be repeated on many samples sequentially. In the Laboratory for Ion Beam Interaction at the Ruđer Bošković Institute these experiments are for material analysis purposes and are performed on a dedicated beam line specifically designed for such studies. Materials are studied by applying Rutherford Backscattering (RBS) and Particle Induced X-Ray Emission (PIXE) ion beam analysis techniques. Using these quantitative analysis methods, a precise elemental composition (N_Z) of the target samples can be calculated. Typically, the elemental concentrations of an unknown sample are determined by measuring a standard with a known concentration of an element and comparing it to the sample of interest, using the following formula [2].

$$N_Z = N_A \frac{I_Z m_Z \sigma_A^X eff_A Q_A}{I_A m_A \sigma_Z^X eff_Z Q_Z} \quad (1)$$

where N_Z is the concentration (g/cm^2) of the element in the sample, N_A is the concentration in the standard, I_Z and I_A refer to the integral of the peak in the accumulated spectrum, m is the mass, σ is the cross-section, eff is the efficiency of the detectors, and Q is the integrated projectile charge. The experimental chamber on this beam line consists of two particle detectors and two x-ray detectors that are connected to a custom data acquisition system [3]. The integral of the peak (I) is calculated by constructing a histogram from the data acquired from the detectors. The total charge (Q) is collected by measuring the current from the target if it is a thick sample, or a Faraday cup located behind the sample, if it is thin. This current is measured by an Electrometer and integrated over the time of the experiment to get the total projectile charge on the target.

The measurement procedure consists of the following steps:

1. Setting the target in the beam position.
2. Setting the acquisition system to start recording.
3. Resetting the charge counter.
4. Opening the chamber valve so the ion beam can enter the chamber and hit the target.
5. Waiting for enough statistics to be collected for a well-defined histogram, which typically requires about 1 μC of charge.
6. Closing the valve to the chamber.
7. Stopping the acquisition system.
8. Reading the total charge from the electrometer.
9. Logging the results.

These 9 steps must be repeated for each sample being measured which in one day could be as many as 30 times. Due to this highly repetitive process, errors can occur where the electrometer is not reset, the positioning of the sample is not correct or simply the steps are preformed out of order. Such mistakes result in having to repeat measurements, decreasing beam time utilization efficiency.

Many of these steps can be automated if the various hardware and software components could be controlled remotely. EPICS was used to interconnect all the elements because it creates a common communication framework through which repetitive processes can be automated.

IMPLEMENTATION

As we are still in the preliminary phase of upgrading our accelerator control system to an industrial standard such as EPICS, it was crucial that all implementation for this work were made to work in parallel with our existing system and could easily be disconnected. The existing system utilized

† email address: dcosic@irb.hr

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV006

AUTOMATED OPERATION OF ITER USING BEHAVIOR TREE SEMANTICS

W. Van Herck†, B. Bauvir, G. Ferro, ITER Organization, St. Paul lez Durance, France

Abstract

The inherent complexity of the ITER machine and the diversity of the ways it will be operated in different phases, like commissioning or engineering operation, poses a great challenge for striking the right balance between operability, integration and automation.

To facilitate the creation and execution of operational procedures in a robust and repeatable way, a software framework was designed and developed: the Sequencer. As a supporting framework for tasks that are mostly goal-oriented, the Sequencer's semantics are based on a behavior tree model that also supports concurrent flows of execution [1].

In view of its intended use in very diverse situations, from small scale tests to full integrated operation, the architecture was designed to be composable and extensible from the start. User interactions with the Sequencer are fully decoupled and can be linked through dependency injection.

The Sequencer library is currently feature-complete and comes with a command line interface for the encapsulation of procedures as system daemons or simple interactive use. It is highly maintainable due to its small and low complexity code base and dependencies to third party libraries are properly encapsulated.

Forecasted activities for this year include its use for the commissioning of plant systems, its incorporation as a foundation for ITER CODAC central monitoring and automation functions and the development of a graphical user interface.

INTRODUCTION

During the different phases of the ITER machine, many operational procedures will need to be defined, verified and executed in a traceable and maintainable way.

During regular operation, these procedures are mainly associated with Operational Tasks, e.g. venting, baking, etc. These procedures will very likely need to evolve in the lifetime of ITER, either by:

- changing the content and order of the different steps,
- changing parameters that influence the execution of the steps, or by
- increasing the automation of the execution by removing unnecessary user interactions as the procedure becomes more mature and trusted.

During the testing, calibration and commissioning of plant systems, local procedures will be defined to carry out tasks in a repeatable and traceable way. These procedures will likely be even more often adapted.

The Sequencer is a software tool meant to facilitate the creation, adaptation, approval and execution of those procedures. It also defines the format of these procedures, allowing version control and easy traceability. It provides a means to replace procedural documents with instructions and integrate automatic verification.

It will rely on the configuration, monitoring and control functions of the Supervision and Automation System (SUP) to carry out certain actions defined in the procedure. The Sequencer will thus need to adhere to the protocols defined by SUP.

This tool also has to provide the flexibility to be deployed and used in different environments:

- SUP interfacing with the Sequencer to execute a procedure,
- local activities using a standalone GUI,
- creation and editing can be done in an offline environment.

This paper describes the design and implementation choices and provides an outlook to future enhancements or extensions of the framework.

DESIGN

The language of operational procedures, whether for engineering operations or commissioning tasks, formulates certain goals that need to be achieved at each step. The Sequencer framework was based on behavior tree semantics since, as a formal language, it is generally better adapted to express such goal-oriented procedures than for example finite state machines. Goals can be described by a variety of rules that apply to sub-goals, such as: a Sequence succeeds if all its sub-goals succeed. Another advantage of behavior tree semantics is that it can express parallelism in a natural way. This is often required in operational procedures, where certain goals need to be achieved while maintaining conditions on the machine.

A procedure in the Sequencer library consists of tree structures of instruction objects and a workspace, providing access to variables that need to be shared or communicated between instructions. A procedure is executed by sending 'Execute' commands to a root instruction in the tree until it indicates failure or success. The root instruction is responsible for propagating this 'Execute' command further down the tree.

Figure 1 shows a simplified example of how the goal of starting up a plant system consists of either successfully activating the system (left branch) or, if that fails, executing steps to recover the system to a known and safe state (right branch). Each of those goals can in turn be expressed as a number of actions that need to be carried out sequentially.

† Walter.Vanherck@iter.org

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV007

MACHINE LEARNING PROJECTS AT THE 1.5–GEV SYNCHROTON LIGHT SOURCE DELTA

D. Schirmer*, A. Althaus, S. Hüser, S. Khan, T. Schüngel
Center for Synchrotron Radiation (DELTA), TU Dortmund University, Germany

Abstract

In recent years, several machine learning (ML) based projects have been developed to support automated monitoring and operation of the DELTA electron storage ring facility. This includes self-regulating global and local orbit correction of the stored electron beam, betatron tune feedback as well as electron transfer rate (injection) optimization. Furthermore, the implementation for a ML-based chromaticity control is currently prepared. Some of these processes were initially simulated and then successfully transferred to real machine operation. This report provides an overview of the current status of these projects.

INTRODUCTION

DELTA is a 1.5–GeV electron storage ring facility operated by the TU Dortmund University as a synchroton light source [1] and as a facility for ultrashort pulses in the VUV and THz regime [2, 3]. Due to thermal orbit movements and magnetic field changes caused by different insertion device setups, the beam orbit and the betatron tunes may vary during storage ring operation. Therefore, autonomous local and global beam position corrections as well as self-adjusting tunes controls are important tasks, as otherwise sudden beam losses can occur. For this purpose, conventional, fully connected, shallow feed-forward neural networks (NNs) were investigated and have been successfully implemented. Both machine learning (ML) based controls were first simulated and tested on a detailed storage ring model within the Accelerator Toolbox (AT, [4, 5]) framework and were then successfully applied during real accelerator operation.

So far, the storage ring chromaticity values have been adjusted empirically based on experience. Setting of new values can only be done by time-consuming trial and error. For this reason, a ML-based algorithm for automated chromaticity adjustment is currently being prepared, very similar to the already implemented ML-based betatron tunes control. Classical, non-deep NNs are also used in this case.

At present, the electron transfer efficiency from the booster synchrotron to the storage ring is being optimized with the help of ML techniques, too. Here, NNs as well as Gaussian process regression (GPR) methods are explored.

ORBIT CORRECTION

Extensive studies for a ML-based orbit correction (OC) at the storage ring DELTA started already in 2017. Therefore, initially only the horizontal beam positions were disturbed by horizontally deflection corrector magnets (steerer) and the corresponding data pairs (orbit/steerer changes) were used as training data for supervised learning of fully connected neural NNs. First simulations have shown that already three-layered neural networks were able to learn correlations between beam position deviations and steerer strength changes. The application of such trained networks on the real storage ring results in similarly good beam position correction quality compared to conventional OC methods like SVD-based (singular value decomposition [6]) programs, however, with significantly fewer correction steps [7]. Subsequently, the ML algorithm was extended to both accelerator planes (x/y-coupled orbit), including weighted beam position monitor (BPM) signals. Thus, exposed positions in the DELTA storage ring (e.g., injection region, synchrotron radiation source points) can now be adequately considered in the ML-based OC.

In comparison with a more advanced numerical OC approach (qp-cone [8, 9]), the ML-based version results also in similar correction performance, which is scored by the weighted rms orbit error summed for both planes. On average the ML method still required fewer OC steps in this benchmark.

Exemplarity, some benchmark results are depicted in Fig. 1 (ML-based) and Fig. 2 (conventional). Even beam position deviations provoked by perturbations which were not applied during the training (e-j) could also be compensated equally. In all cases, after each provoked orbit disturbance, the residual weighted orbit error, as a measure for the OC

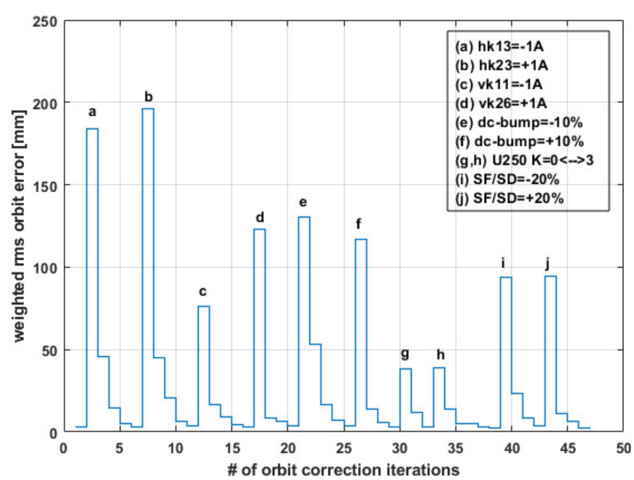


Figure 1: Individual correction steps for different scenarios of orbit deviations (a-j) performed with the ML-based OC program. In comparison to Fig. 2, similar final residual orbit qualities, scored by the weighted rms orbit error, are achieved in significantly fewer iterations.

* detlev.schirmer@tu-dortmund.de

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV008

ONLINE AUTOMATIC PERFORMANCE OPTIMIZATION FOR THE ELETTRA SYNCHROTRON

G. Gaio†, S. Krecic, F. Tripaldi, Elettra-Sincrotrone Trieste S.C.p.A., Trieste, Italy

Abstract

Online automatic performance optimization is a common practice in particle accelerators. Beside the attempts based on Machine Learning, which is effective especially on non-linear systems and images but are very complex to tune and manage, one of the most simple and robust algorithms, the simplex Nelder Mead, is extensively used at Elettra to automatically optimize the synchrotron parameters. It is currently applied to optimize the efficiency of the booster injector by tuning the pre-injector energy, the trajectory and optics of the transfer lines, and the injection system of the storage ring. It has also been applied to maximize the intensity of the photon beam on a beamline by changing the electron beam position and angle inside the undulator. The optimization algorithm has been embedded in a Tango device that also implements generic and configurable multi-input multi-output feedback systems. This optimization tool is usually included in a high-level automation framework based on Behavior Trees [1] in charge of the whole process of machine preparation for the experiments.

INTRODUCTION

Similarly to most of the modern light sources, the Elettra 2-2.4GeV synchrotron relies on feedback systems to keep the beams stable and, more recently, on automatic optimization systems to help operators in maximizing the performance.

Feedback and optimization systems look in some aspects very similar. They have both sensors, actuators and have in common the objective of minimizing the distance between sensors and a reference. In feedback systems the reference is a setpoint of a machine parameter that have to kept fixed no matter the noise or external perturbations affecting the accelerator. In optimization problems the reference is still present but usually set to an arbitrarily very high /very low value if the intention is to maximize / minimize the sensor value.

By the way, excluding the algorithmic part, the software internal components (acquisition, command and control) are the same.

In light sources programmable feedback and/or optimization tools are quite common. Some of them are implemented as high-level applications [2,3] others are server applications [4].

At Elettra a programmable C++ Tango server, called MIMOFB (Multi Input Multi Output Feedback), has been developed to replace legacy applications implementing slow feedback systems and to implement automatic optimization procedures.

† email: giulio.gaio@elettra.eu

MIMOFB

When configured as a feedback, the MIMOFB implements a correction scheme based on a linear model that link sensors and actuators. This relationship is an approximation that is empirically calculated by measuring the perturbation generated on the sensors by one actuator at a time. The result of this process is a matrix, formally a Response Matrix (RM). The product between the inverse of the response matrix, usually inverted using the Singular Value Decomposition (SVD) algorithm, and the error vector returns the values to subtract from actuators to minimize the distance between the sensors and the reference.

Regarding optimization, the MIMOFB implements only model-less optimization schemes. In this case the objective function F (1) is the sum of the normalized distances between N sensor values and corresponding references multiplied by the sensor weights.

$$F = \sum_{i=0}^{N} w_i * \frac{abs(x_i - x_i^{ref})}{x_i^{\max\_thres} - x_i^{\min\_thres}} \qquad (1)$$

The configuration of a MIMOFB device is stored in several device properties.

For each sensor the developer has to configure:

- the sensors Tango attributes
- the number of sensor readings per cycle
- descriptive label
- weight
- minimum threshold value
- maximum threshold value
- dead-band
- sensor update rate in ms
- type of filtering (none, mean, median) when the number of readings per cycle is higher than one
- Tango device allowed states
- list of actuators affecting the sensors

For each actuator it is required to specify:

- the actuator Tango attribute
- descriptive label
- minimum threshold value
- maximum threshold value
- scan range
- RM kick; this value is used in response matrix calculation and as the initial step in optimization algorithms
- maximum backlash (useful when working with motors)
- dead-band
- maximum difference between last read and set value
- RM kick settling time (msec.); this value changes proportionally to RM kick amplitude

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV010

R&D OF THE KEK LINAC ACCELERATOR TUNING USING MACHINE LEARNING

A. Hisano†[1], M. Iwasaki#[1,2,3,4], I. Satake[5], M. Satoh[5,6]
H. Nagahara[4,3], N. Takemura[4,3], Y. Nakashima[4,3], and T. Nakano[3,4]
[1]Osaka City University Graduate School of Science, Osaka, Japan
[2]Nambu Yoichiro Institute of Theoretical and Experimental Physics (NITEP), Osaka, Japan
[3]Research Center for Nuclear Physics, Osaka University (RCNP), Osaka, Japan
[4]Osaka University Institute for Datability Science (IDS), Osaka, Japan
[5]High Energy Accelerator Research Organization (KEK), Ibaraki, Japan
[6]The Graduate University for Advanced Studies (SOKENDAI), Department of Accelerator Science, Kanagawa, Japan

Abstract

We have developed a machine-learning-based operation tuning scheme for the KEK e-/e+ injector linac (Linac), to improve the injection efficiency.

The tuning scheme is based on the various accelerator operation data (control parameters, monitoring data and environmental data) of Linac.

For the studies, we use the accumulated Linac operation data from 2018 to 2021.In this paper, we show the results on our R&Ds of, 1. visualization of the accelerator parameters (~1000) based on the dimensionality reduction, and, 2. accelerator tuning using the deep neural network (DNN). In the latter R&D, estimation of the accelerator parameters using DNN, and the accelerator simulator based on the Generative Adversarial Network (GAN) have been studied.

INTRODUCTION

We have developed an operation tuning scheme for the KEK e-/e+ injector linac (Linac) [1]. The Linac accelerator is a 600m long injector linac to distribute electrons and positrons to four ring accelerators: the Photon Factory (PF), the PF Advanced Ring (PF-AR), the SuperKEKB Electron Ring (HER) and the Positron Ring (LER). The Linac accelerator is capable of operating at up to 50 Hz in two bunches (96 ns apart), which is equipped with 100 beam position monitors (BPM), 30 steering magnets and 60 RF monitors.

Though the precise beam tuning and high injection efficiency are required, there exist several problems on the accelerator tuning as: 1. A lot of parameters (~1000) should be tuned, and these parameters are intricately correlated with each other; and 2. Continuous environmental change, due to temperature change, ground motion, tidal force, etc., affects to the operation tuning.

To solve the above problems, we have developed, 1. visualization of the accelerator parameters (~1000) trend/correlation distribution based on the dimensionality reduction to two parameters, and 2. accelerator tuning using the deep neural network, which is continuously updated with the accelerator data to adapt for continuous environmental change.to adapt the environment changes.

In this paper, we show the results on our R&D. For the studies, we use the electron beam data for Super KEKB injection accumulated in 2018 Nov. - 2021 Jun. This beam data includes the following parameters.

- 500 operating parameters (Steering magnet)
- 732 environmental parameters

In addition, we use the ratio of the upstream (SP_A1_M) and downstream (SP_58_0) charges of the accelerator as a quantitative measure of the injection efficiency of the accelerator.

VISUALIZATION OF THE ACCELERATOR PARAMETERS

In this study, we use dimensionality reduction with a Variational AutoEncoder (VAE) [2] as a visualization method of accelerator parameters. VAE is a neural network consisting of two networks: the encoder, which converts the input data into "latent variables" of arbitrary dimensions, and the decoder, which reconstructs the input data from the latent variables. Here, VAE assumes that "latent variables" are normally distributed, so that latent variables for similar trend input data are closely distributed when they are plotted on a space. Using this property, we can visualize the accelerator parameters by dimensionally reducing them to two-dimensional "latent variables" and plotting them in a two-dimensional space.

To check the visualisation performance by VAE, we created an accelerator parameters dataset containing 1232 parameters (operating params + env params). Figure 1 shows the results of the visualisation of the accelerator parameters accumulated between 2018 Nov. and 2021 Jun. using VAE trained by 2018 Nov to 2021 May data. The output results are coloured according to the injection efficiency of the input accelerator data.

As a result of Figure. 1, the accelerator parameter dataset containing 1232 parameters is visualized by VAE with di-

† m20sa029@uv.osaka-cu.ac.jp
# masako@osaka-cu.ac.jp

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV011

RESEARCH ON CORRECTION OF BEAM BETA FUNCTION OF HLS-II STORAGE RING BASED ON DEEP LEARNING

Yong-Bo Yu*, Ke Xuan, Gong-Fa Liu, Wei Xu,Chuan Li, Wei-Min Li
National Synchrotron Radiation Laboratory, University of Science and Technology of China, Hefei Anhui, China

Abstract

In recent years, artificial intelligence (AI) has experienced a renaissance in many fields. AI-based concepts are nature-inspired and can also be used in the area of accelerator controls. At HLS-II, there are not many studies on these procedures. We focused on HLS-II beam stability in order to get better performance. We have created a deep learning-based approach for correcting beta function. Simulation studies reveal that the method presented in this work performs well in terms of correction outcomes and efficiency, resulting in a new way to adjust the accelerator beam function.

INTRODUCTION

Since the 1980s, artificial intelligence (AI) approaches in accelerator control have been studied [1]. In the light of recent theoretical and practical advances in machine learning and the use of deep neural network-based modeling and controlling techniques, new approaches for the control and monitoring of particle accelerators are emerging. Furthermore, the availability of powerful deep learning programmings frameworks like TensorFlow [2], PyTorch [3], Keras [4], and Matlab allow rapid and optimized implementations of complex algorithms and network architectures. Therefore, we propose a method based on a deep neural network to correct the beta function.

FEEDBACK THEORY

Corrective Theory for the Beta Function

The beta function is the lateral dynamic function of the particle, and it is one of the most important optical parameters of a beam. The focus intensity K of the quadrupole and the change $\Delta Q_{x,y}$ of the storage ring tune at this time are recorded so as to calculate the beta function of the quadrupole. When changing ΔK, the theoretical formula for maintaining the measured value of the ring beta function is

$$\beta_{x,y} = \pm\frac{2}{\Delta Kl}\Big(\cot\left(2\pi Q_{x,y}\right)\left[1-\cos\left(2\pi\Delta Q_{x,y}\right)\right] + \sin\left(2\pi Q_{x,y}\right)\Big) \tag{1}$$

The theoretical formula for the measured value of the function can be simplified as follows when the tune is far from the integer or half-integer resonance line, and the change value is small.

$$\beta_{x,y} \approx \pm 4\pi\frac{\Delta Q_{x,y}}{\Delta Kl} \tag{2}$$

According to the formula,the beta function at the location a quadrupole magnet is calculated using the variation of the quadrupole strength and the measured tune shift.

Using a Deep Learning Model to Conduct Beta Function Correction

The beta function of the storage ring receives feedback correction based on the generated storage ring beam function model. The feedback correction diagram of the HLS beam beta function is shown in Fig. 1. The steps involved in beta function feedback correction are followed: The focus intensity change of the storage ring quadrupole is obtained by feeding the beta function error value into the storage ring beam model. The focus intensity change is sent back to the storage ring to obtain the amended beta function value. This goes back and forth until the beta function is wholly corrected.

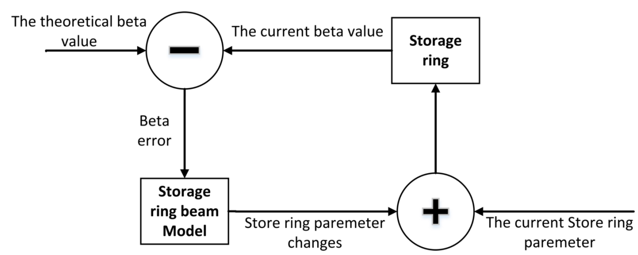


Figure 1: Schematic of the beta function correction system using a Neural network method.

MACHINE LEARNING DESIGN STEPS

Five significant steps are involved in developing an ML-based beat function application (see Fig. 2). Data acquisition and cleaning are the first steps. The topology of the neuron network is then defined and optimized. Finally, the beat function correction application must be tested after multiple training sessions and continuous performance tests. In the following sections, we will go over the most critical development steps.

Data Generation

In order to perform supervised neural network learning, A large number of data pairs must be provided. As a result, we took the Lattice as an object and created the HLS-II virtual storage ring model. The final data is finished with MATLAB's AT toolbox and a python program created with pyAT. After that, 10,000 data pairs were created. Each data pair has 96 data points, with Δbetax (32), Δbetay (32), and Δk (32).

* yybnsrl@mail.ustc.edu.cn

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV012

BEAM FAST RECOVERY STUDY AND APPLICATION FOR CAFe

Jiaosai Li†, Youxin Chen, Jing Wang, Feng Yang, Hai Zheng, Institute of Modern Physics, Chinese Academy of Sciences (IMP/CAS), Lanzhou, China

Abstract

Based on the MASAR (MAchine Snapshot, Archiving, and Retrieve) system [1], a beam fast recovery system was designed and tested in CAFe (Chinese ADS Front-end Demo Superconducting Linac) at IMP/CAS for high current CW (Continuous Wave) beam. The proton beam was accelerated to about 20 MeV with 23 SC (Superconducting) cavities, and the maximum current reaches about 10 mA. The fast-recovery system plays a major role in the 100-hours-100-kW long-term test, during which the average time of the beam recovery is 7 seconds, achieving the availability higher than 90%. The system verifies the possibility for high current beam fast recovery in CiADS (China initiative Accelerator Driven sub-critical System).

INTRODUCTION

The ADS superconducting proton linac prototype (CAFe) led by the Institute of Modern Physics, Chinese Academy of Sciences has continuously improved technology and achieved remarkable innovation in commissioning and operation in recent years: 15~16 MeV@2mA CW proton beam stable operation up to 100 hours in the early of 2019 [2], 100 kW proton beam stable operation at 10 mA in CW mode at the beginning of 2021 [3]. The control system provides an important safeguard for CAFe linac during the stable operation. This paper introduces MASAR and its application in CAFe linac, mainly concerning beam fast retuning.

MASAR

MASAR is an epics V4 service, which is developed based on C++ and python. It was originally proposed and developed by Brookhaven National Laboratory in the United States, and then applied to the second generation synchrotron radiation light source (NSLS-II). The function is just like its name, including the archiving, comparison and restoration of machine snapshots, data archiving and data retrieval [1].

The MASAR consists of client and server: the client has a client Python API library, which can be used by both Python scripting and the GUI. A default PyQt4 GUI is developed for data viewing, snapshot taking, comparing a snapshot with a live machine, and restoring the machine to a particular status using a snapshot. The server has 4 layers: Service communication control; Service: parses a command from the client, implements the desired action, and returns the result to the client; Channel Access Client; DSL (data source layer) and Data layer [3][4]. Figure 1 shows the MASAR Architecture.

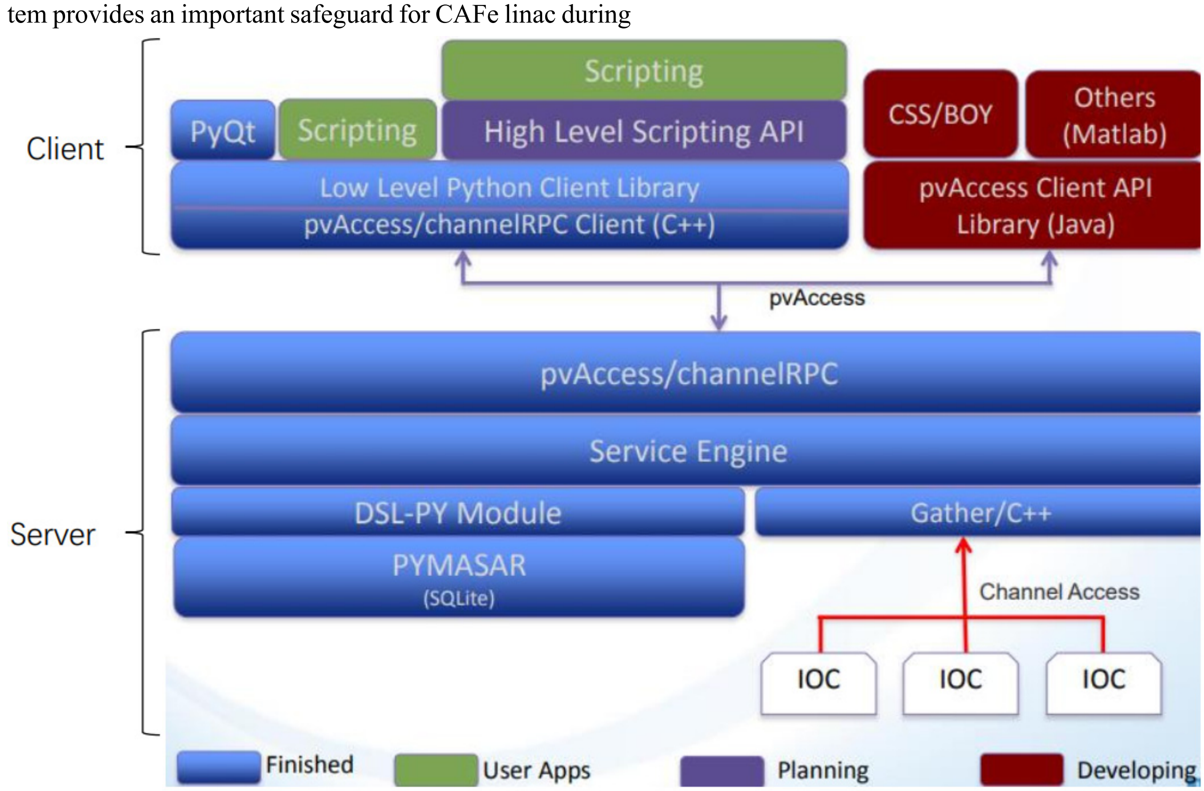


Figure 1: MASAR Architecture.

† ljs@impcas.ac.cn

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV013

DESIGN OF MAGNET MEASUREMENT SYSTEM BASED ON MULTI-HALL SENSOR

B. J. Wang*, Y. H. Guo, N. Xie, R. Wang
Institute of Modern Physics, Lanzhou, China, 730000

Abstract

High-precision magnetic field measurement and control technique significantly guarantees the accurate realization of the magnetic confinement of accelerators. Using real-time magnetic field intensity as the feedback to adjust the magnetic field current input can be a promising strategy. However, the measurement accuracy of the Hall-sensor is hard to meet feedback requirements because of multiple affection from external factors. Meanwhile, the NMR(Nuclear Magnetic Resonance sensor), which can provide high-precision magnetic field measurement, can hardly meet the requirements against the real-time control due to its strict requirements on the uniformity of the measured magnetic field, as well as its low data acquisition speed. Therefore, a magnetic field measurement system based on multi-Hall sensors is designed to solve this problem. Four Hall-sensors are used to measure the target magnetic field in this system. An Adaptive fusion algorithm is used to fused collected values to obtain the best estimate of the magnetic field intensity. This system effectively improves the accuracy of magnetic field measurement and ensures the instantaneity of the measurement.

INTRODUCTION

Magnetic confinement plays a decisive role when stabilizing the accelerator beam. At present, the control of magnetic confinement is mostly based on the feedback of the power supply current to implement of the current input of magnet [1], which indirectly ensures the stability of the magnetic field. However, this method is difficult to ensures the effect of the control of the magnetic field, due to magnet's own factors such as magnet eddy current and iron core aging. Therefore, directly using magnetic field strength, as a feedback signal becomes a more promising solution. Nevertheless, it is limited by the sampling rate and accuracy of magnetic field measurement, which makes the progress of this solution relatively slow.

Present main methods of magnetic field measurement and their accuracy are shown in Fig. 1 [2]. The feedback signal of magnetic field control requires high precision and wide range of measurement. So, NMR, hall, and fluxmeter meets the requirement. However, the NMR sampling frequency is than expected, and it needs a certain period of time to lock the value of non-uniform magnetic field. For instance, the sampling frequency of Metrolab PT2026 is only 33 Hz, and the search time is approx [3]. Thus, NMR is difficult to meet the magnetic field control requirements. Fluxmeter is commonly used for dynamic measurement. But its size is large, which makes it difficult to be broadly deployed on site. Hall sensor advantages of high sampling rate, excellent dynamic characteristics, small volume and easy deployment. So, it is the most suitable magnetic field measurement scheme for feedback control.

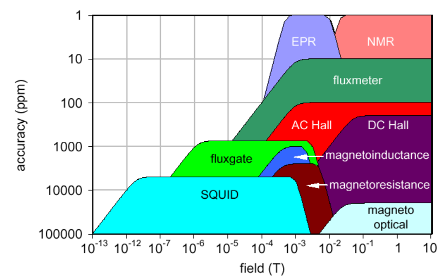


Figure 1: Magnetic field measurement range and accuracy.

SYSTEM DESIGN

Signal Preprocessing

The main noise of the measurement system includes the offset voltage and thermal error of Hall element [4], as well as the gain error, offset voltage and accidental high-frequency noise of the measurement module [5]. To eliminate these noises, the single-channel measurement signal is preprocessed. The high-frequency noise and offset voltage are mainly filtered by pre-filter and differential algorithm within the measurement module. The pre-filter distinguishes signals according to the frequency of the signal and blocks the high-frequency noise. On this basis, differential operation is performed on the input signal. The offset voltage of each ADC in the measurement module is approximately same. Equations (1) and (2) represents signal V_m.

$$V_{m^+} = V_{id} + V_{of} \tag{1}$$

$$V_{m^-} = -V_{id} + V_{of} \tag{2}$$

Where V_{of} is the offset voltage, V_{id} is the ideal signal. V_{m^+} and V_{m^-} represents a pair of measurements with opposite phases.

As shown in Eq. (3), an ideal input signal without offset voltage can be obtained by subtracting the input with opposite phase.

$$V_{m^+} - V_{m^-} = 2V_{id} \tag{3}$$

For Hall thermal error and measurement module gain error, the corresponding calibration parameters need to be obtained and compensated by software. Calibrating gain

* wangbaojia@impcas.ac.cn

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV015

DEVELOPMENT OF THE RF PHASE SCAN APPLICATION FOR THE BEAM ENERGY MEASUREMENT AT KOMAC*

SungYun Cho†, Jeong-Jeung Dang, Jae-Ha Kim, Young-Gi Song
Korea Multi-purpose Accelerator Complex, Korea Atomic Energy Research Institute, Gyeongju, Korea

Abstract

The Korea Multi-purpose Accelerator Complex (KOMAC) has been operating the 100MeV proton linear accelerator. The output beam energy from each drift tube linac (DTL) can be changed by the operation RF phase. The KOMAC linac is consisted of 11 tanks that need to proper setting of RF phase. The phase scan application was developed on the Java eclipse. On the other hand, the analysis program was developed on the Matlab. Since the data analysis processes as soon as finished the scan processing, the application integration need. This paper describes the implementation of the integrated application based on python and Experimental Physics and Industrial Control System (EPICS).

INTRODUCTION

The KOMAC control system has been operating based on the EPICS framework [1]. The distributed system that is an input output controller (IOC) controls the subsystem for each local system. The process variables (PVs) are operation parameters for control and monitoring from the IOC. Several programs can be access to EPICS IOC's parameters by channel access (CA). The RF phase scan application has been developed based on python and can be access to IOC using pyepics library [2]. The scan I/O variables were designed using that. The data processing step has been developed based on python numba library [3]. A scan step and data processing are described separately in order. The below figure is the schema regarding the KOMAC control system.

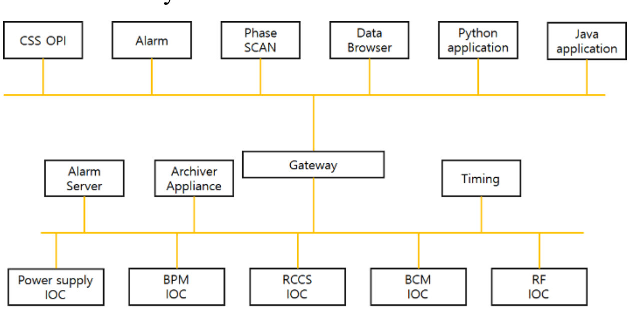


Figure 1: KOMAC distributed control system.

THE STRUCTURE OF THE PHASE SCAN APPLICATION

The basic structure of the application is based on Python Display Manager (PyDM) [4]. The PyDM is a building user interfaces tool based on PyQT5 with plugged in pyepics. The PyDM uses Signal & Slot for calling events. The I/O variables are connected with Slot functions. Some calculation function are developed based on numba. Figure 2 shows the working structure of the phase scan application.

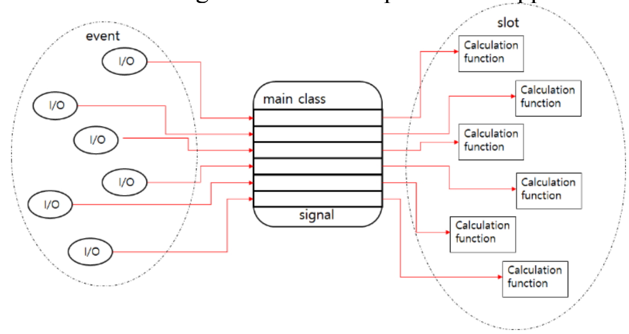


Figure 2: The mechanism of the application.

SCAN CODE DEVELOPMENT

The moving parameter is a phase set value that is different for each tank. After the parameters regarding scan settings are determined, the phase measure experiment will start. The measured phases are from the prior tank and current tank. So the moving parameter is just one and the monitoring parameters are two. Figure 3 shows the concept of process.

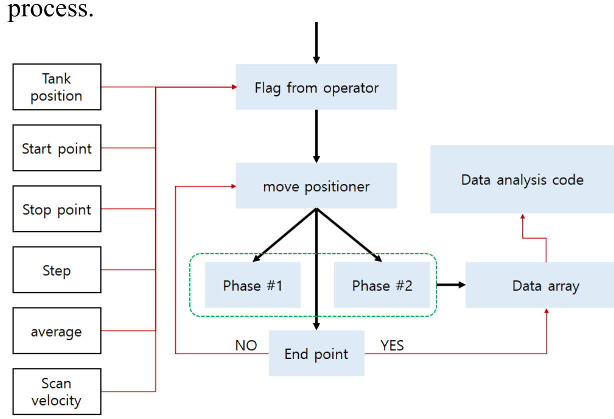


Figure 3: The schematic of scan algorithm.

The original program was developed by the Java language. Since the scan mechanism has to be transplanted to the new program, the EPICS sscan record that's similar to the original algorithm was selected [5]. The sscan record has a function to move positioners and record detector data at each of the positions. The positioner is the moving parameter for the phase setting. When the EXSC field that's a flag signal is executed, sscan record start the process. Many fields work organically during the process. The output signal is sent to positioner PV. If the changing value is finished, the sscan waits the delay time by PDLY field and the detector PV records the target value. The moving step

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV016

THE AUTOMATIC LHC COLLIMATOR BEAM-BASED ALIGNMENT SOFTWARE PACKAGE

G. Azzopardi*, G. Valentino[2], B. Salvachua[1]
[1] CERN, Geneva, Switzerland,
[2] University of Malta, Malta

Abstract

The Large Hadron Collider (LHC) at CERN makes use of a complex collimation system to protect its sensitive equipment from unavoidable beam losses. The collimators are positioned around the beam respecting a strict transverse hierarchy. The position of each collimator is determined following a beam-based alignment technique which determines the required jaw settings for optimum performance. During the LHC Run 2 (2015-2018), a new automatic alignment software package was developed and used for collimator alignments throughout 2018. This paper discusses the usability and flexibility of this new package describing the implementation in detail, as well as the latest improvements and features in preparation for Run 3 starting in 2022. The automation has already successfully decreased the alignment time by 70% in 2018 and this paper explores how to further exploit this software package. Its implementation provides a solid foundation to automatically align any new collimation configurations in the future, as well as allows for further analysis and upgrades of its individual modules.

INTRODUCTION

The CERN Large Hadron Collider (LHC) is the world's largest particle accelerator, built to accelerate and collide two counter-rotating beams towards an unprecedented center-of-mass energy of 14 TeV [1,2]. The LHC is susceptible to beam losses from normal and abnormal conditions, which can perturb the state of superconductivity of its magnets and potentially damage equipment. A robust collimation system handles beam losses of halo particles by safely disposing the losses in the collimation regions, with a 99.998% cleaning efficiency [3].

The collimation system consists of more than 100 collimators [4], each made up of two parallel absorbing blocks, referred to as jaws, inside a vacuum tank. The collimators are installed with a fixed rotational angle, depending on their location and functionality, which allows to clean in either the horizontal (H), vertical (V) or skew (S) plane. The jaws must be positioned symmetrically around the beam to ensure safe machine operation. Each jaw can be moved individually using two stepper motors at the jaw corners, allowing collimators to be positioned at different gaps and angles.

* gabriella.azzopardi@cern.ch

BEAM-BASED COLLIMATOR ALIGNMENT

Two types of beam instrumentation are available to align collimators; the Beam Position Monitoring (BPM) and the Beam Loss Monitoring (BLM) systems. BPM pick-up buttons are installed in 30% of the collimators, embedded in their jaws to provide a direct measurement of the beam orbit at the collimator location [5]. BPMs allow for a safe and fast alignment by analysing the electrode signals without needing to touch the beam. The remaining 70% of the collimators can only rely on dedicated BLMs positioned outside the beam vacuum, immediately downstream from the collimator [6]. BLMs are used to detect beam losses generated when halo particles impact the collimator jaws, such that characteristic spikes recorded in the losses indicate that the reference halo has been touched. The procedure of aligning collimators, with BLMs or BPMs, is referred to as beam-based alignment (BBA).

The beam-based alignment with BLM devices is performed via a four-step procedure established in [6]. This involves aligning a reference collimator in addition to the collimator in question (i). The reference collimator is taken to be the primary collimator (TCP) in the same plane (p) as collimator i. This creates a *reference halo* that extends into the aperture of collimator i. The procedure is to align the reference collimator before and after collimator i, as depicted in Fig. 1.

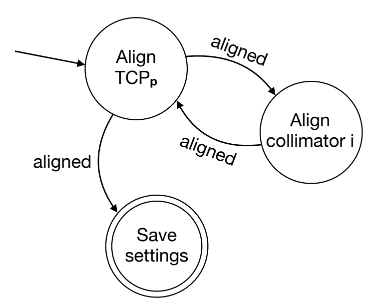


Figure 1: State machine of the beam-based alignment with reference collimator (TCP), from [7].

Once the beam has a well-defined halo amplitude shaped with the primary collimator, the alignment of a collimator can begin. A collimator is aligned by first aligning both jaws simultaneously towards the beam, followed by independently aligning the collimator jaws sequentially. The procedure, as depicted in Fig. 2, involves selecting a BLM threshold to stop the jaw movement when the recorded beam losses

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV018

THE LINAC4 SOURCE AUTOPILOT

M. Hrabia, M. Peryt, R. Scrivens, CERN, Geneva, Switzerland
D. Noll, European Spallation Source, Lund, Sweden

Abstract

The Linac4 source is a 2MHz, RF driven, H- ion source, using caesium injection to enhance H- production and lower the electron to H- ratio. The source operates with 800µs long pulses at 1.2 second intervals. The stability of the beam intensity from the source requires adjustment of parameters like RF power used for plasma heating.

The Linac4 Source Autopilot improves the stability and uptime of the source, by using high-level automation to monitor and control Device parameters of the source, in a time range of minutes to days.

This paper describes the Autopilot Framework, which incorporates standard CERN accelerator Controls infrastructure, and enables users to add domain specific code for their needs. User code typically runs continuously, adapting Device settings based on acquisitions. Typical use cases are slow feedback systems and procedure automation (e.g. resetting equipment).

The novelty of the Autopilot is the successful integration of the Controls software based predominantly on Java technologies, with domain specific user code written in Python. This allows users to leverage a robust Controls infrastructure, with minimal effort, using the agility of the Python ecosystem.

INTRODUCTION

The CERN Linac4 ion source is a 2MHz RF driven H^- ion source, using caesium injection to enhance H^- production and lower the electron to H^- ratio. The source operates for Linac4 with 800µs long pulses at 1.2 second intervals.

The stability of the H^- beam intensity from the source over the period of minutes to days requires adjustment of parameters like the RF power used for plasma heating. Controlling the source on this timescale is the objective of the Autopilot. It is not conceived to work from pulse to pulse, or within a pulse, which would require dedicated systems at the front-end computer level.

The Autopilot Framework was developed in 2019 and used successfully to automatically tune the source during the test runs for Linac4. It is currently operating 24/7 helping the operations team to run the linear accelerator. Another instance has been successfully deployed in the CERN ion linac, Linac3. It replaces a highly specific version developed in 2017 [1], which lacked flexibility.

FRAMEWORK

The Autopilot Framework, henceforth referred to as the framework, is a set of services and tools (see Fig. 1.) that allow the users to deploy and execute the algorithmic tasks in a self-service manner, where the framework provides the necessary tooling and infrastructure. Typical use cases are slow feedback systems and automated procedures (like resetting and restarting equipment that has stopped due to a fault state).

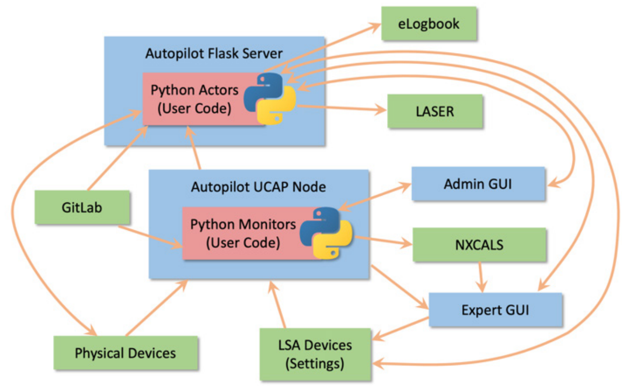


Figure1: Schematic diagram of the Autopilot Framework. Blue boxes signify the Autopilot framework components.

The framework allows the users to subscribe to the Control parameters of their choice, process the received values, and publish the output as properties of Virtual Devices, i.e. Control Devices that are implemented exclusively in software, with no hardware component. Those Virtual Devices can in turn be used like any other Control Device, in particular they can provide inputs to the user-supplied regulation algorithms (subsequently referred to as actors) that interact with the Linac4 H^- ion source.

A particularity of the framework is that although it is based on the accelerator Controls software stack, that is predominantly developed in Java, it allows the user code to be written in Python. Another characteristic of the framework is that it leverages the well-established services and components that form the accelerator Controls, in particular the Controls Configuration Service (CCS) [2], Controls Middleware (CMW) [3], Role-Based Access System (RBAC) [4], the Unified Controls Acquisition and Processing (UCAP) framework [5], LSA (Accelerator Settings Management) [6], LASER (Accelerator Alarms Service) [7], and NXCALS (Accelerator Logging Service) [8], thus reducing the need for developing custom components.

At the core of the framework lies a UCAP node that subscribes to physical and virtual Devices according to the recipes provided by the users. The recipes also contain the triggering conditions. When those conditions occur, the events containing the accumulated data are constructed and forwarded to the user-provided transformation routines, known as "Monitors". The Monitors calculate the output values and give them back to UCAP, for publishing as virtual Device Properties through controls middleware.

Along with the UCAP recipes, and the Monitors, the Flask server also manages the user-provided control tasks called "Actors". These are basically Python scripts whose job is to act upon the updates received from the Monitors

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV019

RENOVATION OF THE BEAM-BASED FEEDBACK CONTROLLER IN THE LHC

L. Grech*, G. Valentino, University of Malta, MSD 2080 Msida, Malta
D. Alves, A.Calia, M. Hostettler, J. Wenninger, S. Jackson, CERN, 1211 Geneva 23, Switzerland

Abstract

This work presents an extensive overview of the design choices and implementation of the Beam-Based Feedback System (BBFS) used in operation until the LHC Run 2. The main limitations of the BBFS are listed and a new design called BFCLHC, which uses the CERN Front-End Software Architecture (FESA), framework is proposed. The main implementation details and new features which improve upon the usability of the new design are then emphasised. Finally, a hardware agnostic testing framework developed by the LHC operations section is introduced.

INTRODUCTION

The Large Hadron Collider (LHC) was designed to handle particle momenta between one and two orders of magnitude higher than previous accelerators [1]. The highly energetic beams inside the vacuum chambers are stripped off of halo particles by a beam cleaning and machine protection system, also known as the collimation system. The collimation system required the machine tolerances to be tightened to work effectively. As a result, the LHC was the first proton accelerator to require automatic feedback control systems on various beam and machine parameters [2].

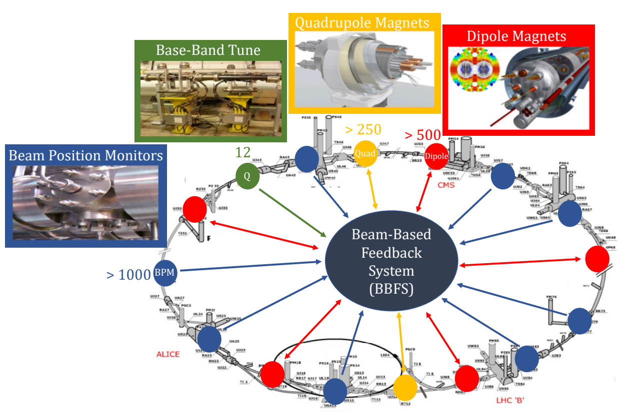


Figure 1: Schematic view of the BBFS in the LHC complex.

In this work, Beam-Based Feedback System (BBFS) denotes the program which was originally responsible for implementing the feedback control of the Radio Frequency (RF) systems, orbit and tune [3]. Figure 1 shows the BBFS within the LHC complex. The systematic beam energy offset from the ideal trajectory can be inferred from the orbit and in turn, the orbit is obtained from the measurements of 1088 Beam Position Monitors (BPMs) placed at different locations in the LHC [2, 4]. The Base-Band Tune (BBQ) systems are responsible for estimating the horizontal and vertical tunes of both beams in the LHC [5]. It is well known that the tune estimates from the BBQ were unstable due to 50 Hz noise harmonics present in the BBQ spectra [6, 7]. This instability also caused the Tune Feedback (QFB) to frequently switch off. As a consequence, the QFB was used intermittently and only when necessary, e.g. at the start of the ramp.

In its original design, the BBFS was foreseen to automatically control the coupling and chromaticity as well. Both these quantities are derived estimates from the BBQ system measurements. Considering that the tune estimates were often unstable, the control of coupling and chromaticity was deemed impractical to be used in operation, despite being implemented in the code.

The BBFS was made up of two components, which were historically named the Orbit Feedback Controller (OFC) and the Orbit Feedback Service Unit (OFSU). The OFC comprised the main program written in C++ and was primarily responsible for communicating with real-time Front-End Computers (FECs) to obtain beam measurements and applying magnetic corrections. The OFSU was implemented using the Front-End Software Architecture (FESA) framework used at CERN [8].

This work will provide a summary of the design and the limitations of the BBFS which was used in operation until the end of Run 2 in 2018. The BBFS underwent renovation during the LHC Long Shutdown 2 (LS2) and the upgraded version is called the Beam Feedback Controller LHC (BFCLHC). The BFCLHC is a FESA-based application which incorporates all the useful functionality of the BBFS, along with new features requested by the LHC operators. During LS2, our colleagues from the LHC operations section also developed a testing framework for the BFCLHC which for the first time allows closed loop tests to be performed on the feedbacks offline.

DESIGN UNTIL LHC RUN 2

Figure 2 illustrates a more detailed view of the BBFS architecture which is comprised of the OFSU and the OFC. The OFSU is connected to the OFC via a private Ethernet connection where Transmission Control Protocol (TCP) is used for lossless communication of the OFC settings and User Datagram Protocol (UDP) is used to stream real-time acquisition BPM, BBQ and magnet data from the OFC to the OFSU. Measurement data coming from the BPM and the BBQ systems is received by the OFC in the form of User

* leander.grech.14@um.edu.mt

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV020

LEARNING TO LASE: MACHINE LEARNING PREDICTION OF FEL BEAM PROPERTIES

A.E. Pollard*, D.J. Dunning, M. Maheshwari
ASTeC, Cockcroft Institute, STFC Daresbury Laboratory, UK

Abstract

Accurate prediction of longitudinal phase space and other properties of the electron beam are computationally expensive. In addition, some diagnostics are destructive in nature and/or cannot be readily accessed. Machine learning based virtual diagnostics can allow for the real-time generation of longitudinal phase space and other graphs, allowing for rapid parameter searches, and enabling operators to predict otherwise unavailable beam properties. We present a machine learning model for predicting a range of diagnostic screens along the accelerator beamline of a free-electron laser facility, conditional on linac and other parameters. Our model is a combination of a conditional variational autoencoder and a generative adversarial network,which generates high fidelity images that accurately match simulation data. Work to date is based on start-to-end simulation data, as a prototype for experimental applications.

INTRODUCTION

Free-electron lasers (FELs) are sources of ultra-short and ultra-bright pulses of light, which are used to reveal the dynamics of important processes across various scientific disciplines [1]. For effective and efficient facility operation, it is necessary to rapidly reconfigure and optimise different setups to meet user needs. Machine diagnostics are essential for this task, and while some measurements can be taken non-invasively and on every shot, others are destructive to the beam, relatively slow, or otherwise constrained. For example, the longitudinal phase space (LPS) of the beam is critically important for FEL performance but this is an invasive measurement that can only be made at locations with dedicated hardware. Simulations are commonly used to supplement the experimental data; however, they can be computationally expensive and often require significant iteration to improve their match to experimental conditions. Machine learning offers the potential to leverage the large volumes of accessible diagnostic and simulation data to build surrogate models that enable accurate modelling with real-time execution, thereby delivering virtual diagnostics and rapid optimisation of beam conditions on demand.

Artificial Neural Networks have shown great utility in the generation of complex data. From synthesised speech to faces of non-existent people, several architectures have been developed to effectively generate artificial data that is indistinguishable from the training data. Autoencoders, autoregressive models, and generative adversarial networks comprise the three main classes of these generative networks and the focus of modern research.

Autoencoders are an excellent choice for generating complex and variable data in an unsupervised manner. Their ability to condense inputs into a significantly lower dimensional representation before reconstructing the input from this representation provides a powerful method of learning the key components of target images, such as input parameters. Variational autoencoders [2] build on this to codify the latent space representation as a series of probability distributions which can be further extended by making those distributions conditional on input parameters. This Conditional Variational Autoencoder(CVAE) model enables effective learning of the parameterised generation of images.

Generative Adversarial Networks [3](GAN) represent the current state-of-the-art approach to image generation and function on a principle of adversarial learning. Adversarial learning functions by one network attempting to generate realistic data, while another network attempts to discern real data from generated data. This technique enables image generation with fidelity orders of magnitude higher than that of generative networks alone, but it is prone to stability issues and is highly sensitive to hyperparameter choices.

Our work combines a CVAE and a GAN into the CVAE-GAN architecture [4] and uses a combination of these powerful techniques to produce high-fidelity longitudinal phase space graphs for arbitrary parameter configurations as a virtual diagnostic for end users. We also demonstrate an ability to search the space of LPS graphs for particular graphs as drawn by an end user, allowing for highly customisable longitudinal beam profiles.

RELATED WORK

The first steps to incorporating image recognition into particle accelerator control using convolutional neural networks were taken in Edelen et al. [5] and developed further in Scheinker et al. [6]. Conversely, machine learning *prediction* of longitudinal phase space from machine parameters has been explored, with good results, as in Emma et al. (2018 and 2019) [7, 8]. While these simple networks seem to lead to artifacts and sub-optimal reconstruction of fine structure details, more complex networks featuring convolutional and upsampling layers do appear to provide some improvement [9]. The use of additional information besides machine settings, in the form of non-invasive shot-to-shot spectral measurements, has also been shown to improve the accuracy of LPS predictions [10]. Additionally, recent work based solely on experimental data has demonstrated LPS prediction at significantly higher resolution to previous studies [11].

* amelia.pollard@stfc.ac.uk

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV021

MACHINE LEARNING FOR RF BREAKDOWN DETECTION AT CLARA

A. E. Pollard*, A. J. Gilfellon[1], D. J. Dunning
ASTeC, Cockcroft Institute, STFC Daresbury Laboratory, Warrington, UK
[1]also at The University of Manchester, Manchester, UK

Abstract

Maximising the accelerating gradient of RF structures is fundamental to improving accelerator facility performance and cost-effectiveness. Structures must be subjected to a conditioning process before operational use, in which the gradient is gradually increased up to the operating value. A limiting effect during this process is breakdown or vacuum arcing, which can cause damage that limits the ultimate operating gradient. Techniques to efficiently condition the cavities while minimising the number of breakdowns are therefore important. In this paper, machine learning techniques are applied to detect breakdown events in RF pulse traces by approaching the problem as anomaly detection, using a variational autoencoder. This process detects deviations from normal operation and classifies them with near perfect accuracy. Offline data from various sources has been used to develop the techniques, which we aim to test at the CLARA facility at Daresbury Laboratory. These techniques could then be applied generally.

INTRODUCTION

There are two main aims with this project. Firstly, we aim to assemble a machine learning (ML) based system that could be used to replace the current mask method of radio frequency (RF) breakdown (BD) detection which is standard in the automated code used in the RF conditioning of accelerating cavities. Secondly, we aim to ensure that the mid-process features of the same mechanism could be used as inputs for an ML algorithm designed to predict whether or not the next RF pulse would lead to a BD.

To this end, we constructed a β convolutional variational autoencoder (βCVAE)[1] with RF conditioning data as inputs. After being trained as an anomaly detector this acted as a live BD detector, in conjunction with a dense neural network (NN), which would act with the capacity to replace the current non-ML based BD detection system. In addition to this, the βCVAE's latent space could act as a viable input for a long short-term memory (LSTM) recurrent neural network (RNN) that could be used to predict BDs, based on the methodology set out by Kates-Harbeck et al.[2] who had success in predicting disruptive instabilities in controlled fusion plasmas.

For this investigation, we used data from the CLARA accelerator (Compact Linear Accelerator for Research and Applications) based at Daresbury Laboratory. CLARA is a dedicated accelerator test facility with the capacity to deliver high quality electron beams for industry and research. In addition to the CLARA data, a larger dataset was provided by the CLIC team at CERN covering a cavity test which took place in CERN's XBOX-2 test stand. The structure tested in this dataset was a T24 high-gradient prototype X-band cavity produced at the Paul Scherrer Institute; further details of this design have been reported previously [3, 4]. The CLARA data was collected as part of the routine RF breakdown detection system.

RELATED WORK

Solopova et al.'s [5] application of a decision tree model to assign both a fault type and cavity-specific location to a collected breakdown signal at CEBAF represents the first foray into using machine learning to classify RF cavity faults. This work was then continued in Tennant et al.[6] where the authors applied a random forest model to the classification of faults and cavity identity for a larger dataset of breakdown events.

Obermair et al. [7] took the first step towards machine learning based detection and prediction of breakdowns. The authors separately applied deep learning on two available data types (event and trend data) to predict breakdowns. In so doing, they were able to predict breakdowns 20ms in advance with good accuracy. In addition, they utilised explainable AI on these models to elucidate the physics of a breakdown. This pointed them towards an increased pressure in the vacuum system before a breakdown, which they indicated as an option for an improved interlocking system. Their analysis of event data alone also reveals the possibility to predict breakdowns with good accuracy, if there has already been a breakdown in the previous minute, i.e. prediction of follow-up breakdowns.

Previous work within our organisation also informed the present studies. Another dataset from XBOX cavity testing was analysed for missed breakdowns using principal component analysis and neural networks [8]. Very high classification accuracy was reported, but there was suspected duplication of traces in the dataset.

METHODOLOGY

CLARA

Here we use data gathered during the RF conditioning of CLARA's 10 Hz photoinjector (Gun-10), which includes both the RF pulse traces themselves and other non-RF, such as the temperature and pressure inside Gun-10. The RF trace data was gathered before ML was taken into consideration and was therefore not ideal for our purposes, but it was deemed to be sufficient for progress to be made. The trace data was only recorded when the RF breakdown detector was activated and a BD identified, then the conditioning script

* amelia.pollard@stfc.ac.uk

18th Int. Conf. on Acc. and Large Exp. Physics Control Systems ICALEPCS2021, Shanghai, China JACoW Publishing
ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV022

SAMPLE ALIGNMENT IN NEUTRON SCATTERING EXPERIMENTS USING DEEP NEURAL NETWORK

A. Diaw *, K. Bruhwiler, J. P. Edelen, C. C. Hall, RadiaSoft LLC, Boulder, CO
S. Calder, C. Hoffmann, Oak Ridge National Laboratory, Oak Ridge, TN

Abstract

Neutron scattering facilities, such as Oak Ridge National Laboratory (ORNL) and the NIST Center for Neutron Research, provide a source of neutrons to investigate a wide variety of scientific and technologically relevant areas, including material science, chemistry, biology, physics, and engineering. In these experiments, the quality of the data collected is sensitive to sample and beam alignment. This alignment changes both between different samples and during measurements. The sample alignment optimization process requires human intervention to tune the beam and sample positions. While this procedure works, it is inefficient, time-consuming, and often not optimized to high precision alignment. This paper uses different neural network architectures on neutron camera images from the HB-2A powder diffractometer beamline at the High flux Isotope Reactor (HFIR) and optical camera images from the TOPAZ single crystal diffractometer at the Spallation Neutron Source (SNS), both at ORNL. The results show that the trained network on a few images accurately predicts the sample position on holdout test images. The resulting surrogate model can then be used via feedback-driven adaptive controls to tune the experimental parameters to get the desired beam and sample position.

INTRODUCTION

Neutron scattering experiments probe the structure and dynamics of materials to provide unique insights into physical, chemical, nanostructured, biological and engineering materials science. At present the US Government operates two premier neutron scattering user centers [1]; one at Oak Ridge National Laboratory and one at the NIST Center for Neutron Research. These large scale facilities offer flagship research capabilities to academia and industry that serve a broad and growing user community which necessitates their improved operational efficiency and capacity. The experiments involve collecting data on samples in a neutron beam on highly optimized neutron instruments. The position of the sample in the beam is often critical to the subsequent data analysis and measurements success, however the need to perform sample alignment and realignment during experiments reduces the amount of time spent collecting data. While there have been efforts to improve sample alignment [2] and to automate switching between samples [3, 4], manual intervention from facility beamline scientists or expert users is still necessary. At present optimization of the experimental environment requires a facility beamline scientist or expert user to interpret image data of the sample either through an optical camera or a neutron camera. A correction is then applied manually based on the data from these images until the sample is aligned in the beam. The automation of this process will result in more efficient and accurate use of neutron facilities and therefore increase the overall quality and reliability of their scientific output. During our studies we have focused on developments for two experimental stations, the HB-2A neutron powder diffractometer and the TOPAZ neutron single crystal diffractometer.

The HB-2A neutron powder diffractometer (as shown in Fig. 1) is located at the High Flux Isotope Reactor at ORNL and is primarily utilized for magnetic structure determination while focusing on experiments at ultra-low temperatures with the options of high external fields or applied pressures. The constant energy neutron beam in a low noise environment and a simple incident beam profile makes HB-2A well suited to a variety of interchangeable environments with minimal calibration required. There are a variety of sample changer options that can allow multiple samples to be loaded at a time. With a focus on weak magnetic signals the sample alignment and beam optimization with adjustable slits and sample stage motors is crucial to reducing unwanted background scattering and to maximise the sample signal. With further optimization of the beamline to include a new detector count rates would increase by over an order of magnitude, resulting in a significant increase in the number of samples being run, further motivating the advancement of automated sample alignment. For more details about the HB-2A instrument and scientific applications see [5].

Figure 1: The HB2A powder neutron diffraction instrument. The sample and detector area is shown on the left, with the neutron camera behind the sample. Middle shows a standard sample holder that the powder sample is loaded into, with the scale shown in millimeters. An example of a neutron image is shown on the right, with the powder appearing as a shadow-like image in the white beam.

* diaw@radiasoft.net

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV023

DEVELOPMENT OF A SMART ALARM SYSTEM FOR THE CEBAF INJECTOR*

Dan Tyler Abell, Jonathan Edelen, RadiaSoft LLC, Boulder, Colorado, USA
Daniel Grady Moser, Brian Freeman, Reza Kazimi, Chris Tennant
Thomas Jefferson National Accelerator Facility, Newport News, Virginia, USA

Abstract

RadiaSoft and Jefferson Laboratory are working together to develop a machine-learning-based smart alarm system for the CEBAF injector. Because of the injector's large number of parameters and possible fault scenarios, it is highly desirable to have an autonomous alarm system that can quickly identify and diagnose unusual machine states. We present our work on artificial neural networks designed to identify such undesirable machine states. Our initial efforts have been focused on model prototyping and data curation. In this paper we present an overview of our initial findings and our efforts to generate a robust dataset for the alarm system. We conclude with a discussion of plans for future work.

INTRODUCTION

A significant aspect of accelerator operations involves identifying the root causes of faulty machine states. For example, the machine trips on a beam loss monitor. But why? What underlying cause trips the machine? Sometimes the reason is obvious, while other times not. Existing alarm systems commonly indicate when specific machine parameters drift outside their normal tolerances. However, operators must still interpret these alarms in the context of many interacting systems and subsystems before they can take the the most appropriate corrective action.

The project described in this paper has at its primary objective the development of a machine-learning-based model with the ability to rapidly identify potential root causes of machine faults (hence the term Smart Alarm). More specifically, given machine readings (defined more precisely later), the system continuously compares the model's predictions of the expected machine settings (also defined later) against actual machine settings. When a discrepancy arises that exceeds some user-defined threshold, the system raises an alarm that directs operators (or subject matter experts) to the "bad" setting (*e.g.*, corrector, solenoid, rf gradient, *etc.*). If this effort succeeds, a more ambitious goal will be to extend the work to monitor the machine for parameter drifts and identify when the machine needs "tweaking" before a fault event occurs.

During our initial efforts at training and validating machine learning (ML) models, we obtained puzzling and disappointing results. The problems at issue we traced back to various difficulties with our data, including some outlier (read nonsensical) vacuum readings. In the process of that investigation, we examined our data more carefully and found

* Work supported, in part, by the US Department of Energy, Office of Science, Office of Nuclear Physics, including grant No. DE-SC0019682.

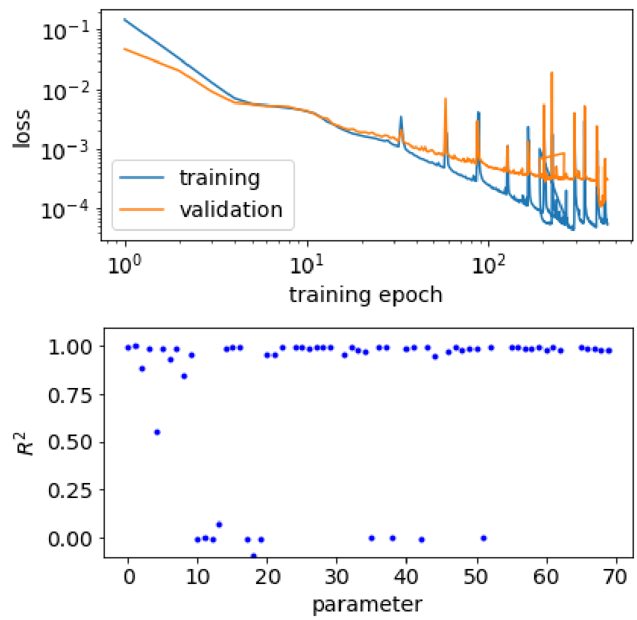


Figure 1: Inverse model trained on operations data from the JLab injector.

other aspects of data collection and selection that required careful consideration. The lesson to learn here is that *understanding one's data*—though time-consuming—*constitutes a critical part of any ML effort.*

In the following sections, we describe briefly some of our early ML efforts and how they led us to make a thorough investigation of our data and the data collection process. We then describe our data, the collection process, and our evolving understanding of how best to curate data that will prove useful for the training and validation of future ML models. We conclude with our plans for future work.

INITIAL ML EFFORTS

Among our first efforts was training an inverse model on data taken from the JLab injector, with the goal of using measurements (readings) to predict machine settings. Figure 1 shows the loss functions and the somewhat disappointing R^2 fit results for one training run with this data. Modifications to the network architecture, number of epochs, choice of optimizer, *etc.*, made relatively little improvement on the overall results.

This circumstance led us to undertake a critical examination of our data, which at the time comprised that taken during (i) regular *operations* of the injector and (ii) a dedicated *study* of the machine. The various parameters (called

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV024

X-RAY BEAMLINE CONTROL WITH MACHINE LEARNING AND AN ONLINE MODEL*

Boaz Nash, Dan Tyler Abell, David Leslie Bruhwiler, Evan Carlin, Jonathan Edelen, Michael Keilman, Paul Moeller, Robert Nagler, Ilya V. Pogorelov, Stephen Davis Webb
RadiaSoft LLC, Boulder, Colorado, USA
Maksim Rakitin, Yonghua Du, Abigail Giles, Joshua Lynch, Jennefer Maldonado, Andrew Walter
Brookhaven National Laboratory, Upton, New York, USA

Abstract

We present recent developments on control of x-ray beamlines for synchrotron light sources. Effective models of the x-ray transport are updated based on diagnostics data, and take the form of simplified physics models as well as learned models from scanning over mirror and slit configurations. We are developing this approach to beamline control in collaboration with several beamlines at the NSLS-II. By connecting our online models to the Blue-Sky framework, we enable a convenient interface between the operating machine and the model that may be applied to beamlines at multiple facilities involved in this collaborative software development.

INTRODUCTION

Electron storage ring based light sources and x-ray FELs provide radiation for a vast array of scientific research. The radiation is created in either undulator or bending magnet sources and then passes down an optical beamline, transporting the radiation to the sample for use in a scientific study.

Although modeling of beamline components and x-ray transport plays an important role in the design and commissioning of x-ray beamlines, these methods are largely unused during day to day operations. In comparison to the electron beam storage ring, in which reduced models combined with diagnostics play a crucial role in electron beam control, little has been done on the x-ray beamline side regarding such methods.

Modeling codes for x-ray beamlines can generally be broken into two classes, either wavefront propagation or ray tracing. The two most widely used codes of these types are Synchrotron Radiation Workshop (SRW) and Shadow. Whereas in principle, either of these codes could be suitable for an online model, there are some deficiencies which we look to improve. In particular, ray tracing methods, though fast and accurate, do not take into account diffraction effects or the effects of partial coherence. Wavefront propagation, on the other hand, while including diffraction effects, is substantially more computationally intensive, particularly when partially coherent computations are required.

We propose two types of simplified models that provide additional tools with which to build fast online models for x-ray beamlines. The first is a physics based model based on what we call a *Matrix-Aperture Beamline*[1]. And the second type of model is a surrogate model using the methods of machine learning on either simulated or measured training data. We describe our progress on the development of each of these types of models and their application to x-ray beamlines at NSLS-II at Brookhaven National Laboratory.

Next, in order to create an accurate online model that ties the beamline and photon beam status to a software model, we must make measurements at beamline diagnostics and take into account beamline component positions using the existing beamline control software. For this purpose, we use the BlueSky software, developed at NSLS-II, but with a goal for wider adoption across the world of synchrotron light sources in the US and beyond.

We document here our continuing efforts to improve this situation by creation of online models in synchrotron light sources that may be used for automated beamline control. We are working with the TES bending magnet beamline at NSLS-II [2], and thus draw our simulations and control examples from this beamline.

REDUCED PHYSICS MODELS

Our reduced physics models are based on the concept of a *Matrix-Aperture-Beamline*. We call the code we are building to implement this concept `MABTrack`, and a diagram for the case of two apertures is shown in Fig. 1. The `MABTrack` code is being developed on GitHub in the `rslight` repository[1] and will be available as an open source package.

The `MABTrack` code starts with a model in SHADOW to compute reference orbit $\vec{Z}_0(s)$, ABCD matrices $M_j(s)$ and physical apertures $t_j(\vec{x})$. Three levels of sophistication in modeling are being developed within `MABTrack`. At the simplest level, one computes the propagation of the radiation second moment matrix $\Sigma(s)$, defined as $\Sigma_{jk}(s) = \langle \vec{\tilde{z}}_j \vec{\tilde{z}}_k \rangle$ with $\vec{\tilde{z}}(s) = \vec{z}(s) - \vec{z}_0(s)$, i.e. subtracting off the reference orbit. The second moments propagate as

$$\Sigma(s) = M(s)\Sigma_0 M^T(s) \tag{1}$$

with Σ_0 as the initial values of the second moments.

As a second level of sophistication, we will use *linear canonical transforms* (LCTs) to transport wavefronts [3]. LCTs have an intimate connection to the so-called *ABCD*

* Work supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, including grant No. DE-SC0020593

[1] `https://github.com/radiasoft/rslight`

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV025

INITIAL STUDIES OF CAVITY FAULT PREDICTION AT JEFFERSON LABORATORY*

L. S. Vidyaratne†, A. Carpenter, R. Suleiman, C. Tennant, D. Turner, Jefferson Laboratory, Newport News, VA, USA
K. Iftekharuddin, Md. Monibor Rahman, ODU Vision Lab, Department of Electrical and Computer Engineering, Old Dominion University, Norfolk, VA, USA

Abstract

The Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Laboratory is a CW recirculating linear accelerator (linac) that utilizes over 400 superconducting radio-frequency (SRF) cavities to accelerate electrons up to 12 GeV through 5-passes. Recent work has shown that given RF signals from a cavity during a fault as input, machine learning approaches can accurately classify the fault type. In this paper, we report initial results of predicting a fault onset using only data prior to the failure event. A dataset was constructed using time-series data immediately before a fault ("unstable") and 1.5 seconds prior to a fault ("stable") gathered from over 5,000 saved fault events. The data was used to train a binary classifier. The results gave key insights into the behaviour of several fault types and provided motivation to investigate whether data prior to a failure event could also predict the type of fault. We discuss our method using a sliding window approach. Based on encouraging initial results, we outline a path forward to leverage deep learning on streaming data for fault type prediction.

INTRODUCTION

The Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Lab is a high power, continuous wave recirculating linac servicing four different experimental nuclear physics end stations [1]. CEBAF completed an energy upgrade in 2017 with a goal of effectively doubling its energy reach from 6 GeV to 12 GeV. The upgrade required the installation of 11 additional cryomodules, named C100s denoting their capability for providing 100 MV of energy gain. A schematic of CEBAF with locations of the new C100 cryomodules is provided in Figure 1. Each cryomodule is composed of 8 superconducting radio-frequency (SRF) cavities. In addition, a digital low-level radio frequency system (LLRF) is implemented to regulate the new cryomodules.

CEBAF experiences frequent short machine downtime trips caused by SRF system faults, particularly when the cavity gradients are pushed to their upper limits. A significant portion of the SRF system faults occur within the C100 cryomodules. Consequently, a data acquisition system is implemented to record data from these cryomodules to investigate the nature and the origin of the SRF faults. The system is configured to record time-series waveform data when any of the C100 cavities fault. These recorded waveform data are analyzed by a subject matter expert (SME) to determine the cavity that caused the trip, and the type of fault. In previous studies we have investigated the possibility of using artificial intelligence (AI) techniques to automate this highly tedious waveform analysis process [2, 3]. It is quite helpful to expedite the beam recovery process with fast automated cavity fault identification after an event. However, it may be further beneficial to investigate the possibility of using AI to predict RF failures beforehand in order to reduce certain faults from occurring. While the data acquisition system is being upgraded for compatibility with such predictive models, we conduct a feasibility study for RF fault prediction using currently available data.

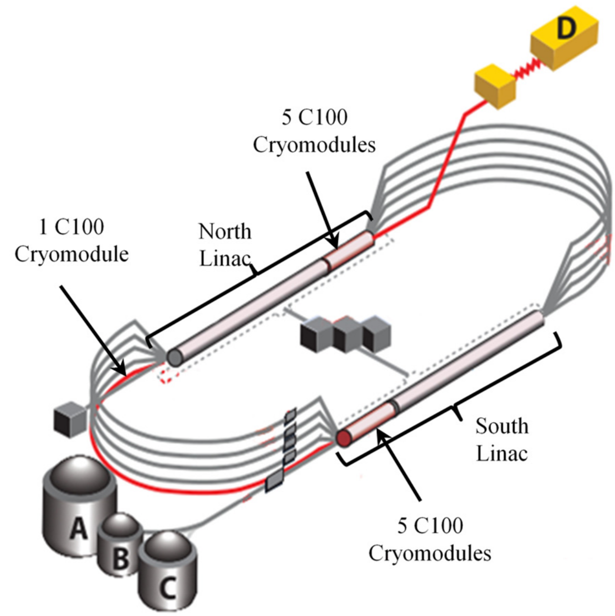


Figure 1: CEBAF schematic with locations of C100 cryomodules.

CAVITY FAULT CLASSIFICATION

The cavity fault classification is posed as a supervised machine learning (ML) problem, with ground truth fault labels for recorded data provided by SMEs. The data used for the classification task is the full time-series waveforms pertaining to each fault event recorded by the data acquisition system. The entire time-series waveform represents approximately 1638.4 ms (from t = −1536 ms to

* This work is supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics under Contract No. DE-AC05-06OR23177.
† lasithav@jlab.org

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV026

MULTI-CHANNEL HEATERS DRIVER FOR SIRIUS BEAMLINE'S OPTICAL DEVICES

M. M. Donatti†, D. H. C. Araujo, F. H. Cardoso, G. B. Z. L. Moreno, L. Sanfelici, G. T. Semissatto, Brazilian Synchrotron Light Laboratory (LNLS), Campinas, Brazil

Abstract

Thermal management of optomechanical devices, such as mirrors and monochromators, is one of the main bottlenecks in the overall performance of many X-Rays beamlines, particularly for Sirius: the new 4th generation Brazilian synchrotron light source [1]. Due to high intensity photon beams some optical devices need to be cryogenically cooled and a closed-loop temperature control must be implemented to reduce mechanical distortions and instabilities. This work aims to describe the hardware design of a multi-channel driver for vacuum-ready ohmic heaters used in critical optical elements. The device receives PWM (Pulse-Width Modulation) signals and can control up to 8 heaters individually. Interlocks and failure management were implemented using digital signals input/outputs available at device rear panel. The driver is equipped with a software programmable current limiter to prevent load overheating and it has voltage/current diagnostics monitored via EPICS (Experimental Physics and Industrial Control System) or an embedded HTTP (Hypertext Transfer Protocol) server. Enclosed in a 1U (rack unit) rack mount case, the driver can deliver up to 2A per channel in 12V and 24V output voltage versions. Performance measurements will be presented to evaluate functionalities, noise, linearity and bandwidth response.

INTRODUCTION

The optical devices design for synchrotron facilities is clear to be one of the most discussed topics to ensure state-of-art beamlines and perform complex experiments, especially for Sirius, the new low-emittance 4th generation Brazilian synchrotron light source [1]. These devices are highly stable thermo-mechanical solutions equipped with cryocooling schemes via cryostats and heaters for temperature control. This work aims to describe the hardware design of a multi-channel heaters drivers for Sirius custom high-performance mirrors [2] and monochromators [3-4]. The driver is also allocated at experimental stations with cryogenic setups, such as Tarumã [5], a sub-microprobe station at CARNAUBA (Coherent X-Ray Nanoprobe Beamline) beamline.

The multichannel driver was designed to simultaneously deliver up to 1.5A at 12V to eight ohmic vacuum-compatible heaters. Each channel can be individually controlled by a TTL (Transistor-Transistor Logic) compatible PWM (Pulse-Width Modulation) signal. Optocoupled interlock inputs were implemented for safety purposes and failure outputs for open load and short-circuit signaling. A current limiter scheme has been included to protect both heater and driver from overload and short-circuits.

Figure 1 shows the internal block diagram and interfaces. Voltage, current and duty cycle are monitored by two multi-channel 12-bit ADC (Analog-to-Digital Converter) AMC7812B [6], also responsible to set current limiter threshold over an internal DAC (Digital-to-Analog Converter). The AMC7812B are connected via SPI (Serial Peripheral Interface) to a NXP LPC1768 [7], an ARM® Cortex-M3 microcontroller.

Ethernet connection is provided to remotely access diagnostics data via an embedded HTTP (Hypertext Transfer Protocol) webserver and a TCP (Transmission Control Protocol) socket for EPICS integration. The current limiter threshold and a software enable control are available remotely. An USB (Universal Serial Bus) connector is provided at front panel for firmware update purpose.

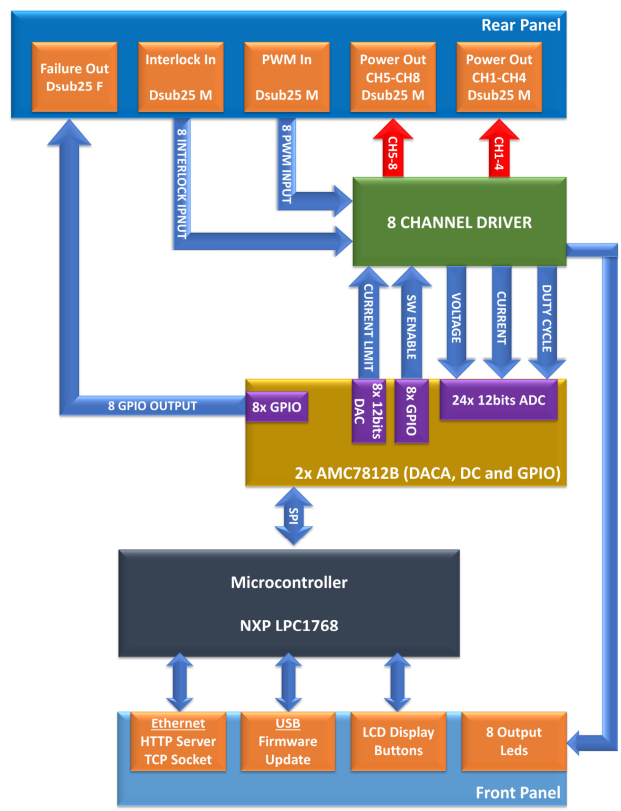


Figure 1: 8-Channel Heaters Driver Block Diagram.

This paper is organized as follows: Section II deals with hardware design details and concepts; Section III presents the embedded firmware architecture; Section IV discuss the mechanical design; Section V presents general results including performance parameters and Sirius'

† mauricio.donatti@lnls.br

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV027

EXPANDABLE AND MODULAR MONITORING AND ACTUATION SYSTEM FOR ENGINEERING CABINETS AT SIRIUS LIGHT SOURCE

P. H. Nallin†, J. G. R. S. Franco, G. F. Freitas, R. W. Polli
Brazilian Center for Research in Energy and Materials, Campinas, Brazil

Abstract

Having multipurpose hardware architectures for controls and monitoring systems has become a need nowadays. When it comes to modular and easily expandable devices, it brings together a system which is easy to maintain and can reach many applications. Concerning Sirius accelerators, which is a 4th generation light source, monitoring environment variables becomes crucial when it comes to accelerator stability and reliability. Several cabinets make up engineering infrastructure, therefore, monitoring, and acting over their environment such as internal temperature, pressure, and fan status, increases overall system reliability. This paper presents an inexpensive hardware topology to deal with multiple sensors and actuators mainly designed to monitor cabinets and prevent beam quality losses due to equipment faults.

INTRODUCTION

Sirius accelerator, the new 4th generation Brazilian synchrotron light source, has been under commissioning since 2019. Some improvements and maintenance have been accomplished for increasing machine performance and reliability in various subsystems.

Although the machine has not reached its project parameters yet, internal, and external scientists can run their experiments in available beamlines infrastructure, along with commissioning and maintenance shifts.

Both commissioning and user shifts require subsystems to work properly. For this purpose, it is necessary to have more information about the environment where equipment is located. The more scalable andeasier to expand the solution is, the more useful it will be regarding future needs. The concept of a multipurpose monitoring and actuating system, which will be initially installed in the Engineering Area, leads to acquiring a large variety of signals, making it easy to prevent, detect or even predict misfunction of a specific device.

OVERVIEW AND MOTIVATIONS

In order tohave a bright and stable photon bean, it is also necessary to keep the accelerators' installation area stable and reliable, which leads to the monitoring of some environment variables, such as the temperature of many different locations, the humidity where each equipment is located, the ambient pressure and several other data.

Sirius' monitoring network, an in-house project called SIMAR (Cabinet Monitoring and Actuation System), has been under development and its main purpose is to obtain data information from the cabinets, which store a large variety of equipment used in Sirius subsystems, such as vacuum, diagnostics and power supply equipment.

SYSTEM ARCHITECTURE

SIMAR is a multipurpose project, based on a Beagle Board single board computer, widely used in Sirius Control System [1]. It aims to handle multiple modular hardware, each one designed to run independently, making it possible to use various sensors and actuatorsin the same system and, also, flexible enough to operate in different conditions. The figure 1 shows the structure of the SIMAR project.

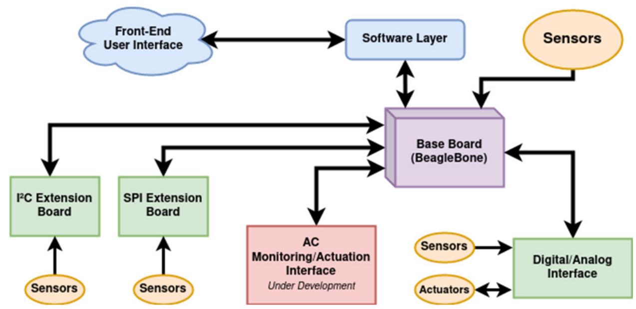


Figure 1: SIMAR conceptual design. It can integrate multiple devices, extend digital communication and easily scalable.

According to the environment to be monitored, additional stacked boards may be added as well as addressable splitters for multidrop digital communication channels. Every board must be hardware-configured prior to any new installation, in order to have a unique address identification.

Considering BeagleBone software integration, it is quite satisfactory to have one single disk image for all nodes in Controls Network, based on Debian. For that purpose, SIMAR has also been integrated into the BeagleBone-functionality-discovery service, which runs at initialization and gets information about hardware and equipment connected to a node. Then, all necessary applications are run.

HARDWARE DEVELOPMENTS

Base Board

The base board is the SIMAR main stack hardware project. It is responsible for functioning as a master on the communication buses and input/output pins. It also integrates the Programmable Real-time Units (PRUs) [2] into SIMAR interface for real-time data processing.

†patricia.nallin@cnpem.br

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV028

CompactRIO CUSTOM MODULE DESIGN FOR THE BEAMLINE'S CONTROL SYSTEM AT SIRIUS

L. S. Perissinotto†, F. H. Cardoso, M. M. Donatti
Brazilian Synchrotron Light Laboratory (LNLS), Campinas, Brazil

Abstract

The CompactRIO (cRIO) platform is the standard hardware choice for data acquisition, controls and synchronization tasks at Sirius beamlines. The cRIO controllers are equipped with a processor running a Real-Time Linux and an embedded FPGA, that could be programmed using Labview. The platform supports industrial I/O modules for a wide variety of signals, sensors, and interfaces. Even with many available commercial modules, complex synchrotron radiation experiments demand customized signal acquisition hardware to achieve proper measurements and control systems integration. This work aims to describe hardware and software aspects of the first custom 8-channel differential digital I/O module (compatible with RS485/RS422) developed for the Sirius beamlines. The module is compliant with cRIO specifications and can perform differential communication with a maximum 20 MHz update rate. The features, architecture and its benchmark tests will be presented. This project is part of an effort to expand the use of the cRIO platform in scientific experiments at Sirius and brings the opportunity to increase the expertise to develop custom hardware solutions to cover future applications.

INTRODUCTION

In a typical synchrotron beamline, a wide variety of electronic devices are employed for controlling and monitoring complex scientific experiments. In a general aspect, these equipment acts to control the beamline components such as shutters, mirrors, monochromators, diagnostic elements, motors, vacuum pumps, etc. These devices have different types of communication interfaces or electrical I/Os in different voltage levels or standards that must be proper integrated to the EPICS control system [1]. The CompactRIO (cRIO) [2] platform is the standard hardware controller used for data acquisition, control and synchronization tasks. The platform supports industrial I/O modules for manipulating a wide variety of signals and interfaces and despite the broad portfolio of commercially available I/O modules, custom hardware designs are often needed. To supply the demand for differential signaling communication, the first in-house C-series module was designed and comprises a 20 MHz max. update rate digital I/O compatible with RS485/RS422 [3] standard.

The hardware and software development were guided by the National Instruments cRIO-9951 [4] development kit, which provides guidelines for design implementation. The developed module will be used for long distance differential communication, triggering and synchronization. The knowledge applied in this development will be useful to develop custom hardware for future applications.

† lucas.perissinotto@lnls.br

HARDWARE

The module has 8 differential channels with configurable direction, compatible with RS485/RS422, and can achieve up to 20 MHz update rate. An external power supply may be required in some conditions, which depends on the channels' directions and data rate. Differential signals and external power supply are available to the user in the front panel through a 37-pin DSUB connector and it has two led indicators that shows the internal powering status and external powering needs. The module is connected to CompactRIO using a high density 15-pin D-SUB connector on the back of the board.

To safeguard the controller from ESD damage, insulation topology [5] was adopted using digital isolators between all internal and external signals to cRIO bus. The circuit is physically separated into the non-insulated side, where compactRIO is attached, and the insulated side where the application signals are available.

The module circuit is divided into three main blocks: power supply, transceivers, and control logic. The power supply block is responsible for insulating, protecting, and managing all power supply sources, internal and external. The transceivers block converts the internal bus single-ended signals into insulated external differential signals, or vice versa, depending on the configured direction. The control logic block identifies compactRIO control signals and implements all internal mode's support logic. The blocks organization in the PCB can be seen in Fig. 1.

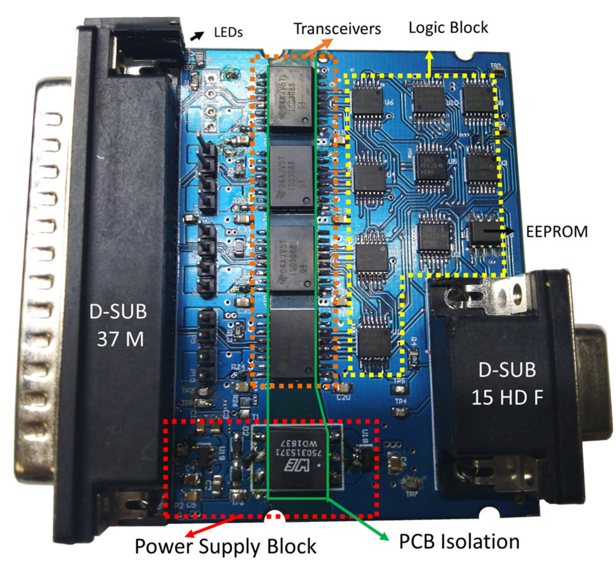


Figure 1: Device blocks on PCB.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV031

STATUS OF THE uTCA DIGITAL LLRF DESIGN FOR SARAF PHASE II

J. S. Fernandez, P. Gil, G. Ramirez, Seven Solutions, Granada, Spain
G. Ferrand, F. Gohier, G. Desmarchelier, N. Pichoff, CEA, Saclay, France

Abstract

One of the crucial control systems of any particle accelerator is the Low-Level Radio Frequency (LLRF). The purpose of a LLRF is to control the amplitude and phase of the field inside the accelerating cavity. The LLRF is a subsystem of the CEA (Commissariat à l'Energie Atomique) control domain for the SARAF-LINAC (Soreq Applied Research Accelerator Facility – Linear Accelerator) instrumentation and Seven Solutions has designed, developed, manufactured, and tested the system based on CEA technical specifications. The final version of this digital LLRF will be installed in the SARAF accelerator in Israel at the end of 2021. The architecture, design, and development as well as the performance of the LLRF system will be presented in this paper. The benefits of the proposed architecture and the first results will be shown.

INTRODUCTION

The SARAF-LINAC project intends to accelerate proton and deuton beam currents from 0.4mA to 5mA up to 40MeV for deutons and 35 MeV for protons. To achieve this, the field in the cavities needs to be controlled and regulated. The LLRF is the device in charge of maintaining the cavity gradient and phase stability in presence of beam. Seven Solutions has designed and implemented the LLRF system including all the hardware, gateware (FPGA code) and software needed to fulfil the specifications derived from [1]. The LLRF channels required for the SARAF-LINAC phase II [2] will drive both normal conducing cavities and superconducting cavities.

The factory acceptance tests (FAT) results will be detailed in this paper.

SPECIFICATIONS

The LLRF must be able to regulate the cavity field both in pulsed mode and in continuous wave (CW). From the simulations and studies performed in [1], the main LLRF system requirements were derived. They are listed in Table 1. The frequency of the full accelerator is 176MHz. This is the reference frequency for the LLRF system.

Table 1: LLRF Requirements

Requirement	Value
Operation frequency range	176MHz +/-100KHz
LLRF delay	< 1us
Input amplitude RMS error	< 0.03%
Input phase RMS error	< 0.03º
Output amplitude stability	< 5%
Output phase stability	< 5º

HARDWARE

The LLRF HW is based on the uTCA.4 technology. The system is composed by two boards (Fig. 1):

The LFE (LLRF Front End) is in charge of conditioning the RF inputs signals to interface them to the ADCs. In addition, the RF drive outputs are amplified and filtered in this board.

The AMC (Advanced Mezzanine Card) digitizer controller board includes all the components (ADCs, DACs, PLL, FPGA, DDR memory…) needed to perform the acquisition and generation of the RF signals as well as all the digital signals processing to implement the different algorithms and features included in a LLRF system. The design based on a FPGA provides the system with a great flexibility making it capable of being adapted to the requirements of different accelerator facilities and to be placed on a rack or in a single standalone mode.

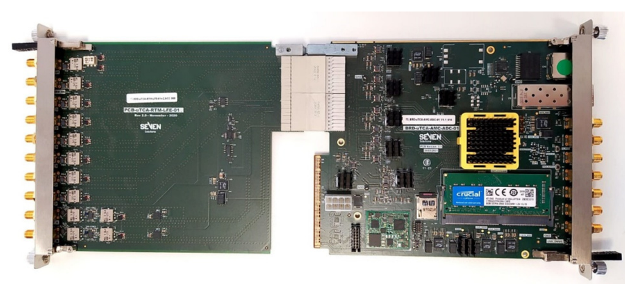


Figure 1: LLRF HW composed of LFE and AMC boards.

The HW is designed to have two LLRF channels making possible to control two cavities with one set of board. Each channel generates one RF drive signal (Uamp) and monitors three RF signals (Fig. 2):

- Ucav: Cavity voltage.
- Uci: Incident voltage.
- Ucr: Reflected voltage.

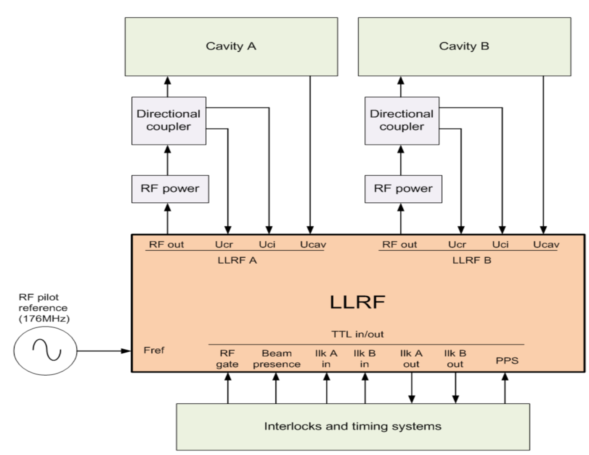


Figure 2: LLRF block diagram.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV033

ARCHITECTURE OF A MULTI-CHANNEL DATA STREAMING DEVICE WITH AN FPGA AS A COPROCESSOR*

J. M. Nogiec†, P. Thompson, FNAL, Batavia, IL 60510, USA

Abstract

The design of a data acquisition system often involves the integration of a Field Programmable Gate Array (FPGA) with analog front-end components to achieve precise timing and control. Reuse of these hardware systems can be difficult since they need to be tightly coupled to the communications interface and timing requirements of the specific ADC used. A hybrid design exploring the use of an FPGA as a coprocessor to a traditional CPU in a dataflow architecture is presented. Reduction in the volume of data and gradual transitioning of data processing away from a hard real-time environment are both discussed. Chief design concerns, including data throughput and precise synchronization with external stimuli, are addressed. The discussion is illustrated by the implementation of a multi-channel digital integrator, a device based entirely on commercial off-the-shelf (COTS) equipment.

INTRODUCTION

One of the typical dilemmas designers face when building a system is whether to buy or build its components. This also applies to test and measurement systems used in High Energy Physics. Readily available, so-called commercial off-the-shelf (COTS) components are ubiquitous and can reduce development cost and offer product support by manufacturers. Unfortunately, the offered instruments or modules may not be precisely what is needed. A solution can be to build an instrument in-house, but from available COTS subcomponents, as is the case for the digital integrator device discussed in this article.

Construction of a multi-channel streaming integrator from COTS subcomponents is presented in the context of using an FPGA as a coprocessor in order to provide predictable and guaranteed data processing performance. The discussed integrator is functionally extensible, thus it has been named the Extensible Digital Integrator (EDI).

Digital integrators have been very successful in testing accelerator magnets, and they are crucial parts of rotating coil systems and single stretched wire systems, the cornerstones of the measurement toolset used in this domain.

FPGA AS COPROCESSOR

A Field Programmable Gate Array (FPGA) allows engineers to design and program data acquisition and control hardware to cater to the specific needs of their applications. Typically, systems employ FPGAs as controllers of hardware and signal preprocessors or conditioners. In these architectures, the FPGA is positioned between the I/O and the higher layers of data processing or control (see Fig. 1a).

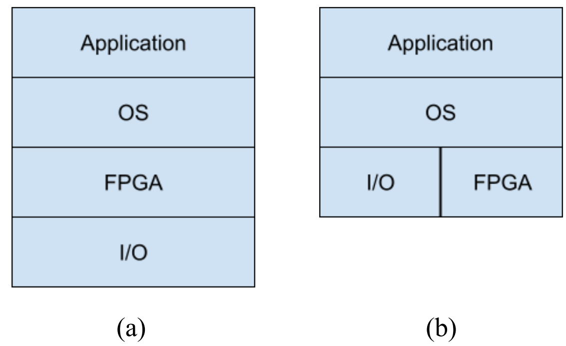


Figure 1: Layers in the system using an FPGA: a) for signal acquisition, b) as a coprocessor.

Another typical application of FPGAs is as a coprocessor offloading computationally intensive functions from a main processor. This solution offers deterministic performance in demanding data processing situations, especially in real-time applications (see Fig. 1b).

The EDI combines both of these hardware organizations into a single architecture. Here, the FPGA serves as both a coprocessor integrating signals and a real-time signal processor acquiring external triggering signals.

The performance of the analog-to-digital converters in dedicated PXI coprocessor modules is inadequate for our needs, and there is no access to the selected DSA ADC boards directly from the FPGA. These factors contributed to some design specifics of the EDI solution.

INTEGRATORS

Digital integrators have proven to be useful in building test systems to measure magnetic fields in accelerator magnets. In fact, they are often a crucial instrument in systems based on the rotating coil and single stretched wire techniques.

These instruments integrate input signals (voltages) over time intervals provided by internal or external triggers, such as a train of pulses or the output of an angular encoder. Historically, these systems evolved from voltage-to-frequency converters connected to up-down counters and trigger boxes [1, 2] to systems using analog-to-digital converters coupled with DSP coprocessors performing integration [3-8]. More recently, FPGAs have offered a very attractive alternative to other integrator hardware

* Work supported by the U.S. Department of Energy under contract no. DE-AC02-07CH11359
† nogiec@fnal.gov

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV034

EQUIPMENT AND PERSONAL PROTECTION SYSTEMS FOR THE SIRIUS BEAMLINES *

L.C. Arruda†, F.H. Cardoso, G.L.M.P. Rodrigues, G.T. Barreto, H.F. Canova, J.V.B. Franca, L.U. Camacho, M.P. Calcanha, Brazilian Synchrotron Light Laboratory (LNLS), Campinas, Brazil
F.A.B. Neto, F.N. Moura, Centro Nacional de Pesquisa em Energia e Materiais (CNPEM), Campinas, Brazil

Abstract

The beamlines and front ends at Sirius, the Brazilian 4th generation synchrotron light source, require monitoring and protection systems for personal and equipment safety in general, due to the high beam power dissipated along the beamline, vacuum safety, secure radiation levels, use of robots, special gases, cryogenic systems, and other highly sensitive and costly equipment throughout the facility. Two distinct programable logic controllers (PLC) were then deployed to create the Equipment Protection System (EPS) and the Personal Protection System (PPS). This work presents an overview of the EPS/PPS - requirements, architecture, design and deployment details, and commissioning results for the first set of beamlines.

INTRODUCTION

The personal protection system (PPS) and equipment protection systems (EPS) are individual per beamline and are implemented in general by two programmable logic controllers (PLCs). The PPS central process unit (CPU) is the Siemens's safety model 1516F-3 and the EPS CPU is Siemens's standard model 1516-3. Both systems use distributed I/Os with Profinet communication with the CPU. The main Graphical User Interface (GUI) is implemented by a Human Machine Interface (HMI) common to other PLC based subsystems and the Input/Output Controller (IOC) [1] is used to allow communication via OPC Unified Architecture (OPC UA) [2, 3] between the PLCs and the Experimental and Industrial Control System (EPICS) [1].

This article is divided into three parts: The first part is about the EPS, the second part is about the PPS and the third is about common subjects related to EPS and PPS.

EPS

Basic Principles

The principles of EPS are low response time, use of positive logic, distributed I/O modules, and simplified detection of the protection logic triggers. The protection logics are very similar among the beamlines, the main protection logics are related to vacuum, temperature, position, and power loss. The program is modularized by hutches, the interface data and functions with the sensors and components form an object's library. The interface with other systems happens through galvanic isolated signals, then the EPS logic and the other system logic actuate together.

There are three checklists for commissioning the EPS: I/Os signals validation, HMI validation, and protection logic validation.

Protection Logics

The protection logic related to vacuum, temperature, position, and blackout fail are following. These protection logics are triggered by an EPS reading or an interface signal with other systems.

Vacuum protection. The vacuum protection system is divided into fast vacuum protection, slow vacuum protection, and low vacuum protection.

Fast vacuum protection is treated individually by the following VAT's devices: Controller VF-2, cold cathode gauge and shutter valve [4]. The shutter valve is installed in the front-end (FE) and the gauge is installed in the vacuum path between FE and the first optical hutch. These devices aim to protect the storage ring (SR) from a high-speed shock wave that could come from the beamline. A detailed description of tests and validation of this matter can be consulted in the article [5].

Slow vacuum protection is used in ultra-high vacuum (UHV) regions, it consists in isolate vacuum paths and interlocks the valve opening in case of high pressure detected. Ionic pump and cold cathode gauge controllers diagnose high pressure through digital signals. Intended to keep the beam on SR, the FE's protection system is triggered if the ionic pump and the cold cathode gauge detect high pressure. Disconnecting the cold cathode gauge connector, it reads a very low pressure, which could indicate a safe condition to FE's protection system even if the ionic pump is turned off. To avoid this unsafe condition, the gate valves opening is allowed only if all ionic pumps before FE's shutter are detecting pressure below the limit, and all cables are connected.

Low vacuum regions are usually situated in experimental stations, with pressures between 1000 *mBar* and $1x10^{-7}$ *mBar*. The protection logics are specific for each region.

From FE's shutter, if a high pressure is detected on a vacuum path by any sensor, the protection logic is triggered closing and interlock the opening of all the gate valves in UHV downstream to the shutter where the trigger occurred. The valves opening logic between shutters are sequential, from downstream shutter to upstream shutter.

Some vacuum paths are specified as critical paths. On these critical paths, due to a fast actuating needed by the

* Work supported by the Brazilian Ministry of Science, Technology and Innovation
† lucas.arruda@lnls.br

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV036

THE LMJ TARGET CHAMBER DIAGNOSTIC MODULE

R. Clot, CEA, Le Barp, France

Abstract

The Laser MegaJoule (LMJ), the French 176-beam laser facility, is located at the CEA CESTA Laboratory near Bordeaux (France). It is designed to deliver about 1.4 MJ of energy on targets, for high energy density physics experiments, including fusion experiments. The first bundle of 8-beams was commissioned in October 2014. By the end of 2021, ten bundles of 8-beams are expected to be fully operational.

Due to the energy levels achieved, the optical components located at the end of the bundles are highly subject to damage stresses. This is particularly the case with vacuum windows whose integrity is critical.

To measure these damages, identify the growth laws, and prevent their degradation (through blockers), the Target Chamber Diagnostic Module (called by its french acronym MDCC) was integrated into the LMJ installation in 2019. This diagnostic, which also measures the windows transmission rate, as well as the spatial energy distribution at the end of the bundles, has been designed to operate automatically at night, between two experiments.

This presentation describes this three years feedback of MDCC. It also presents the areas for improvement which have been identified to optimize its efficiency and reduce its timeline.

INTRODUCTION

The laser Megajoule (LMJ) facility, developed by the “Commissariat à l’Energie Atomique et aux Energies Alternatives” (CEA), is designed to provide the experimental capabilities to study High Energy Density Physics (HEDP). The LMJ is a keystone of the Simulation Program, which combines improvement of physics models, high performance numerical simulation, and experimental validation, in order to guarantee the safety and the reliability of French deterrent weapons. Once fully operationnal, the LMJ will deliver a total energy of 1.4 MJ of 0.35 µm (3ω) light and a maximum power of 400 TW.

The LMJ is sized to accommodate 176 beams grouped into 22 bundles of 8 beams. These will be located in the four laser bays arranged on both sides of the central target bay of 60-meter diameter and 40-meter height. The target chamber and the associated equipment are located in the center of the target bay.

Due to the energy levels achieved, the optical components located at the end of the bundles are highly subject to damage stresses. This is particularly the case with vacuum windows whose integrity is critical as it is a safety component which constitutes the vacuum limit of the chamber where the experiments take place. It’s also an expensive component that we need to take care of.

To measure the damages they suffer, identify the growth laws, and prevent their degradation, the Target Chamber Diagnostic Module (called by its French acronym MDCC) was integrated into the LMJ facility at the end of 2019. This diagnostic inqtrument, which also measures the windows transmission rate, as well as the spatial energy distribution at the end of the bundles, has been designed to operate automatically by night, between two experiments.

This paper reminds the LMJ facility principle before presenting the MDCC and its functionalities with a focus on the measurement of optical component damaging. It also presents the feedback of the measurement sequence timeline and the work achieved to reduce it and make it fit in the facility timeline.

LMJ OPERATING REMINDER

The LMJ 176 beams (37 x 35.6 cm² each) are grouped into 22 bundles of 8 beams. In the switchyards, each individual bundle is divided into two quads of 4 beams, the basic independent unit for experiments, which are directed to the upper and lower hemispheres of the target chamber.

Basically, an LMJ laser beam line is composed of three parts: the front-end, the amplifying section, the switchyard and the final optics assembly.

The front end delivers the initial laser pulse (up to 500mJ). It provides the desired temporal pulse shape and spatial energy profile.

The initial pulse leaving the front end is amplified four times through two amplifiers, in order to obtain the energy required for the experiments (up to 15 kJ at 1ω per beam). Positioned between the two amplifiers, focusing lenses, associated to a diaphragm (spatial filter pinhole), take out the parasitic (noise) beams that may arise. Beyond the two amplifiers is a reflecting mirror (M1), making the four passes possible through angular multiplexing, as shown on Fig. 1. The surface of this mirror is deformable (being controlled by electro-mechanical actuators), allowing beam wavefront distortions to be controlled.

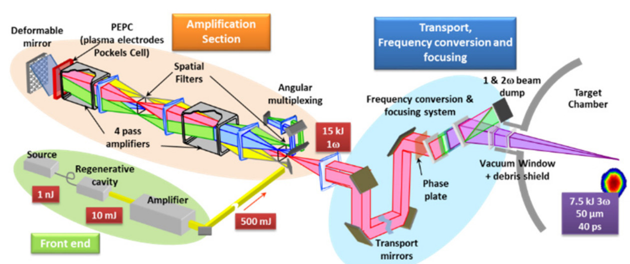


Figure 1: Laser beamline schematic diagram.

The 8 beams coming from the amplification section are divided into two quads. Each quad is transported over more than 40 meters into the target bay and is directed to the upper or the lower hemisphere of the target chamber using six transport mirrors per beam. Each quad arrives into a frequency conversion and focusing system (SCF). Inside the SCF, the beams frequency is changed from infrared (1,053

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV037

DEVELOPMENT OF A VOLTAGE INTERLOCK SYSTEM FOR NORMAL-CONDUCTING MAGNETS IN THE NEUTRINO EXPERIMENTAL FACILITY AT J-PARC

K. Nakayoshi*, K. Sakashita, Y. Fujii
High Energy Accelerator Research Organization (KEK), Tsukuba, Japan

Abstract

We are upgrading the neutrino experimental facility beamline at J-PARC to realize its 1.3 MW operation. One of the upgrade items is to strengthen the machine protection interlocks at the beamline. So far, we have developed an interlock system that monitors the output current of the power supplies for the normal-conducting magnets in the primary beamline. On the other hand, a coil-short in one of the bending magnets at a beam transport line (3-50BT) at J-PARC happened in 2019, and it caused a drift of the beam orbit over time. Our present interlock system cannot detect a similar coil-short in the magnet, while such a change of the beam orbit may cause serious damages. One possible way to detect such a coil-short is to monitor the voltage of the magnet coil. Actually, a significant voltage drop between layers of the coil was observed for the 3-50BT magnet coil-short. Focusing on that fact, we are developing a system that continuously monitors the voltage value of the magnets at the primary beamline and issues an interlock when there is a fluctuation exceeding a threshold value. We report on the progress of the development of this system.

BACKGROUND

At the neutrino experimental facility at J-PARC, a large amount of neutrinos are generated using a high-intensity proton beam extracted from the Main Ring Synchrotron (MR) and sent towards the Super-Kamiokande detector, 295 km away, for a long baseline neutrino oscillation experiment (the T2K experiment) [1]. The MR stopped operation in July 2021 and upgrades, such as replacing the power supplies are ongoing. The beam to the T2K experiment is scheduled to resume in the fall of 2022. Also, the neutrino beamline equipment is being upgraded to support a beam intensity enhancement [2]. Figure 1 shows the primary proton beamline of the neutrino experimental facility. The proton beam extracted from the MR is transported to the graphite target 240 m away by 14 doublet super-conducting magnets (hatched in yellow) and 21 normal-conducting (NC) magnets (hatched in blue). If an abnormality occurs in the transport system of the primary proton beamline during beam operation, the high-intensity proton beam may deviate from the normal orbit and hit the beamline equipment. In that case, the thermal shock of the high-intensity proton beam could cause serious damages to the beamline equipment, which would take a long time to recover. In order to avoid such a situation, we have strengthened the interlock so far. For NC

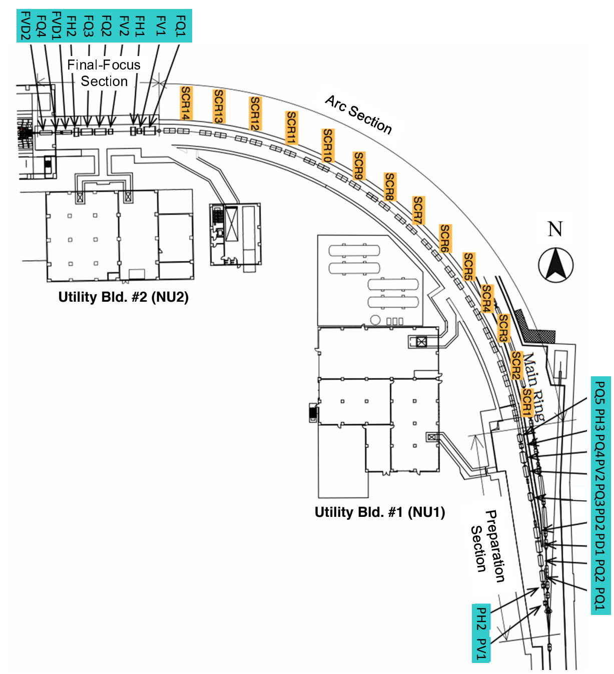


Figure 1: The primary proton beamline of the neutrino experimental facility at J-PARC.

magnets, we have developed an interlock system for detecting current fluctuations in the NC power supplies and have been operating this system from 2012 to the present [3, 4]. When an interlayer short circuit occurred in a dipole magnet coil of J-PARC's beam transport line in 2019, there was no change in the current Value of the power supply, but fluctuations in the voltage of the corresponding magnet coil were observed [5]. This means that our current fluctuation interlock cannot detect an interlayer short circuit of the NC magnets. In order to further strengthen the interlock of the NC magnet system, we are developing a system that detects a voltage fluctuation of the NC magnets and issues an interlock. The target value of the voltage fluctuation detection system was set to 1%.

PRELIMINARY STUDY

How Can We Measure the Magnet Coil Voltage?

Before developing the voltage interlock system, we made a preliminary measurement of the magnet coil voltage. During the accelerator operation, the voltage of the magnet coil

* kazuo.nakayoshi@kek.jp

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV038

PERFORMANCE VERIFICATION OF NEW MACHINE PROTECTION SYSTEM PROTOTYPE FOR RIKEN RI BEAM FACTORY

M. Komiyama†, A. Uchiyama, M. Fujimaki, K. Kumagai, N. Fukunishi, RIKEN Nishina Center, Wako, Saitama, Japan
T. Nakamura, M. Hamanaka, SHI Accelerator Service, Ltd., Shinagawa, Tokyo, Japan

Abstract

We herein report on the performance verification of a new machine protection system prototype for the RIKEN Radioactive Isotope Beam Factory (RIBF) and on the study to improve its performance. This prototype has been developed to update the existing beam interlock system (BIS) that has been in operation since 2006. The new system, as was the BIS, was configured using programmable logic controllers (PLC).

We applied the prototype to a small part of RIBF and started its operation in September 2020. It consists of two separate PLC stations, has 28 digital and 23 analog inputs as interlock signals, and has five digital outputs used to stop a beam. The observed response time averaged 2 ms and 5.4 ms, within one station and with both stations, respectively. When deploying the prototype at the same scale as the BIS, which consists of five PLC stations with roughly 400 signals, the resulting performance would barely meet our requirements. Further, there is a risk that the system cannot protect the hardware when the beam intensity of the RIBF becomes higher. Therefore, we are redesigning a system by adding field-programmable gate arrays to significantly shorten the response time, rather than repeating minor improvements to save a few milliseconds.

INTRODUCTION

The RIKEN Radioactive Isotope Beam Factory (RIBF) consists of two heavy-ion linear accelerators and five heavy-ion cyclotrons. One of the linear accelerators is mainly used for experiments to search for super heavy elements, whereas the other is used as an injector to the cascades of the cyclotrons used for nuclear physics, material science, and life science applications. The cyclotron cascades can provide the world's most intense RI beams over the entire atomic mass range by using fragmentation or fission of high-energy heavy ions [1].

The components of the RIBF accelerator complex (such as the magnet power supplies, beam diagnostic devices, and vacuum systems) are controlled by the Experimental Physics and Industrial Control System (EPICS) [2] with a few exceptions, such as the control system dedicated to RIBF's radio frequency system [3]. However, all the essential operation datasets of the EPICS and other control systems were integrated into an EPICS-based control system [4]. Additionally, two types of independent interlock systems are operated in the RIBF facility: a radiation safety interlock system for human protection [5] and a beam interlock system (BIS) that protects hardware from high-power heavy-ion beams [6].

BIS OVERVIEW AND DEVELOPMENT OF NEW MACHINE PROTECTION SYSTEM

The BIS began operation in 2006, along with the beam commissioning of the RIBF. Figure 1 shows the hardware configuration and process flow of the BIS, which was developed based on Melsec-Q series programmable logic controllers (PLCs) [7]. It was designed to stop beams within 10 ms after receiving an alarm signal from the accelerator and beam line components. Upon receiving an alarm signal, the BIS outputs a signal to one of the beam choppers, which immediately deflects the beam just below the ion source. It also inserts one of the beam stoppers (Faraday cup) installed upstream of the problematic component. The BIS ignores the problems that occur downstream of the beam stopper insertion point. After inserting the relevant beam stopper, the beam chopper can be switched off, and the beam delivery can resume up to the inserted beam stopper. This feature is particularly important because if the problematic component cannot be recovered within a short time, the problem recovery time can be effectively used to readjust the beam to the inserted beam stopper. The inserted beam stopper can then be extracted from the beam line after the problem is fixed.

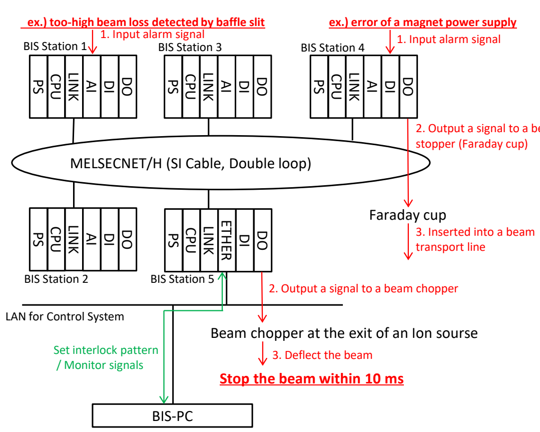


Figure 1: Example of the hardware configuration and process flow in the BIS. The green line signifies communication via Ethernet.

The BIS is still under stable operation; however, its maintenance has become gradually difficult because some

† misaki@riken.jp

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV039

NOVEL PERSONNEL SAFETY SYSTEM FOR HLS-II*

Z. Huang, K. Xuan, C. Li, J. Wang, X. Sun, S. Xu, G. Liu†, NSRL, USTC, Hefei, Anhui 230029, China

Abstract

The Hefei Light Source-II (HLS-II) is a vacuum ultraviolet synchrotron light source. The Personnel Safety System (PSS) is the crucial part to protect staff and users from radiation damages. In order to share access control information and improve the reliability for HLS-II, the novel PSS is designed based on Siemens redundant PLC under EPICS environment which is composed by the safety interlock system, access control system and the radiation monitoring system. This paper will demonstrate the architecture and the specific design of this novel PSS and shows the operation performance after it has been implemented for 2 years.

INTRODUCTION

The Hefei Light Source-II (HLS-II) is a dedicated synchrotron radiation facility which can provide radiation from infrared to vacuum ultraviolet with both Top-Off and Decay operation modes [1].The Personnel Safety System (PSS) is the crucial part of the HLS-II to keep radiation damage away from the staffs and users. The previous PSS in HLS-II was developed by Simens SiPass system which lacked of personnel management function and it's hard to share information. For solving these disadvantages, the novel PSS has been designed for HLS-II.

The Programmable Logic Controller (PLC) and redundant technology are wildly used in the PSS design of big scientific facilities to meet the requirements of the high reliability and stability, such as the European Spallation Source (ESS) [2] and the High Intensity D-T fusion neutron generator (HINEG) [3]. The novel HLS-II PSS is designed based on the Siemens redundant PLC S7-412-5H under the Experimental Physics and Industrial Control System (EPICS). EPICS is a set of open-source software tools, libraries, and applications that are widely used in big scientific facilities [4, 5]. The novel HLS-II PSS contains 3 parts: the safety interlock system, the access control system and the radiation monitoring system. The safety interlock system is used to define the interlock logic to be implemented, the access control system is designed to restrict the access of the staffs and users at HLS-II and provide the personnel management function, and the radiation monitoring system is used to monitor the dose rate in the light source and the surrounding areas.

In this paper, section II introduces the system architecture of the novel HLS-II PSS, section III gives the details about the design of the safety interlock system and the personnel management function in the access control system, and section V shows the operator interfaces (OPIs) design and the operation situation of the novel HLS-II PSS.

* Work supported by National Natural Science Foundation of China (No.11375186)
† Corresponding author, gfliu@ustc.edu.cn

SYSTEM ARCHITECTURE

The novel HLS-II PSS ensures the personal safety by monitoring the radiation dose rate, controlling interlock signals and executing interlock actions. We integrate the safety interlock system, the access control system and the radiation monitoring system into EPICS environments for information sharing. Meanwhile, we can use the existing data archiver and alarm toolkits provided by the EPICS community to archive the historical data and publish the alarm information [6]. The system architecture of the novel HLS-II PSS consists of 3 layers: the EPICS layer, the controller layer and the devices layer as Fig. 1 shown.

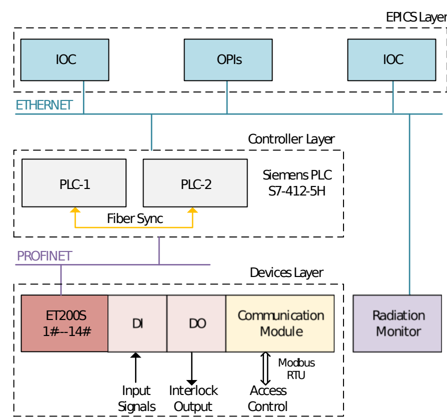


Figure 1: Architecture of the Novel HLS-II PSS.

In the controller layer, there is only one pair of Siemens redundant PLC S7-412-5H. PLC can gather IO signals and access data from 14 IO stations by fiber optic cables, and receive the radiation monitoring signal and commands from other EPICS IOC. The redundant PLC pair has two high performance PLCs that are backed up with each other, one of them takes the role of MASTER PLC and the other one takes the role of SLAVE PLC. During the operation, those two PLCs synchronise programs and real-time data over a high-speed fiber, and the roles between two PLCs can switch over when the MASTER PLC fails.

In the devices layer, 14 Siemens ET200S IO stations are distributed nearby the 14 security doors. The input signals of search buttons, emergency buttons and security doors are collected into the IO stations through the DI modules. The signals of the audible and visual alarm devices, button lamps and the interlock actions are outputted through the DO modules. In addition, the data of card reader is transmitted into the IO station via Modbus-RTU protocol.

According to the design, there are 134 input signals monitored, including 41 search buttons signals, 25 emergency stop buttons signals, 42 security doors signals, and 26 radiation monitoring signals. All the signals are from IO stations, except the radiation monitoring signals. The communication

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV040

DESIGN OF MACHINE PROTECTION SYSTEM FOR SXFEL-UF

Chunlei YU, Jianguo DING, Huan Zhao
Shanghai Advanced Research Institute, Chinese Academy of Sciences, Shanghai, P.R China

Abstract

Shanghai Soft X-ray Free-Electron Laser (SXFEL) facility is divided into two phases: the SXFEL test facility (SXFEL-TF) and the SXFEL user facility (SXFEL-UF). SXFEL-TF has met all the design specifications and has been available in beam operating state. SXFEL-UF is currently under commissioning and is planned to generate 3 nm FEL radiation using a 1.5 GeV electron LINAC. To protect the critical equipment rapidly and effectively from unexpected damage, a reliable safety interlocking system needs to be designed. Machine Protection System (MPS) is designed by Programmable Logic Controller (PLC) and Experimental Physics and Industrial Control System (EPICS) which is based on a master-slave architecture. In order to meet different commissioning and operation requirements, the management and switching functions of eight operation modes are introduced in the MPS system. There are two FEL lines in user facility named SXFEL beamline project (BSP) and undulator (UD) , and the corresponding design of MPS is completed. This paper focuses on the progress and challenges associated with the SXFEL-UF MPS.

INTRODUCTRION

Shanghai Soft X-ray Free-Electron Laser test facility(SXFEL-TF) has been successfully completed in 2020, and the beam energy of the test facility is 840 MeV. The SXFEL user facility (SXFEL-TF) is a critical development step toward the construction of a soft X-ray FEL user facility in China and has been currently undergoing commissioning at the Shanghai Synchrotron Radiation Facility (SSRF) campus[1]. The LINAC accelerator of SXFEL-UF is designed to increase the beam energy to 1.5GeV[2]. Not only the original undulator beam line has been upgrade in SXFEL-UF, but also a new undulator beam line adopts high-throughput working modes such as SASE has been new built.

The requested response time of Machine Protection System (MPS) is less than 20ms, so PLC is employed to execute the underlying logic. Experimental Physics and Industrial Control System (EPICS) is a set of software tools for building distributed control system to operate devices such as particle accelerators and large experiments[3]. The EPICS framework is adopted in the control system in SXFEL-UF and MPS. Due to the hardware structure and function division for test facility, modification and extension has been implemented for new demands of SXFEL-UF.

MPS COMPOMENT

System Structure

The structure of SXFEL machine protection system is shown in Figure 1. The operator interface (OPI) is connected to the input and output controller (IOC) through the local area network, and takes a approach of the EPICS CA protocol. IOC runs on Linux system, and MOXA DA-662 embedded computer is used as IOC server, equipped with 16 serial ports and 4 network ports. Embedded software and hardware technology is applied to complete the development of embedded EPICS IOC.

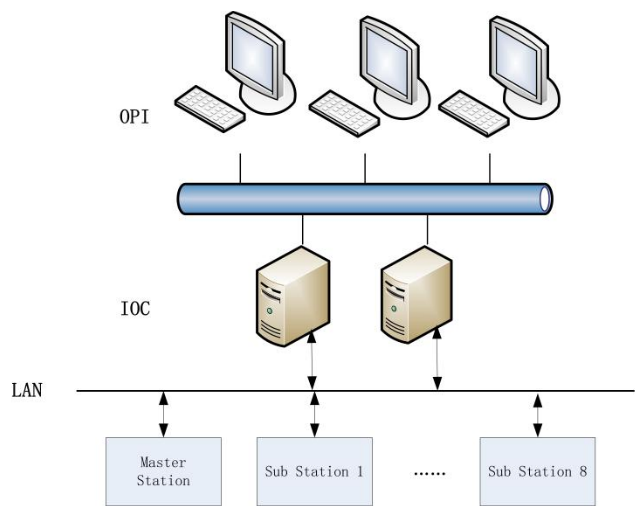


Figure 1: The scheme of SXFEL-UF MPS.

Signal Statistics

Almost all the systems should be assigned the interfaces with MPS, such as radio frequency system, vacuum system, power supply system, water cooling system, timing system and personal safety protection system (PPS) and so on. At present, the number of interlocking input/output signals is aboout 1000, the main equipment interlocking signals are listed in Table 1.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV041

IMPLEMENTATION OF A VHDL APPLICATION FOR INTERFACING ANYBUS CompactCom

S.Gabourin*, S. Pavinato, A. Nordt, European Spallation Source, Lund, Sweden

Abstract

The European Spallation Source (ESS ERIC), based in Lund (Sweden), will be in a few years the most powerful neutron source in Europe with an average beam power of 5 MW. It will accelerate proton beam pulses to a Tungsten wheel to generate neutrons by the spallation effect. For such beam, the Machine Protection System (MPS) at ESS must be fast and reliable, and for this reason a Fast Beam Interlock System (FBIS) based on FPGAs is required. Some protection functions monitoring slow values (like temperature, mechanical movements, magnetic fields) need however less strict reaction times and are managed by PLCs.

The communications protocol established between PLCs and FBIS is PROFINET fieldbus based. The Anybus CompactCom allows an host to have connectivity to industrial networks as PROFINET. In this context, FBIS represents the host and the application code to interface the AnyBus CompactCom has been fully developed in VHDL.

This paper describes an open source implementation to interface a CompactCom M40 with an FPGA.

INTRODUCTION

The European Spallation Source (ESS), an accelerator driven research facility located outside of Lund, Sweden, is currently in its construction and early operation phase, and aims to be the most powerful and bright neutron source in the world by 2025. ESS is a long-pulse neutron source, and consists of a 600 m long proton LINAC, a rotating helium-cooled tungsten target, creating neutrons through the spallation process and 22 different neutron beam ports, equipped with neutron scattering research instruments. The unique time structure of long neutron pulses (2.86 ms) at low frequency (14 Hz) will significantly expand the possibilities for neutron science to probe material structures and dynamics [1]. The proton beam power of 125 MW per pulse (5 MW average) will be unprecedented and its uncontrolled release can cause serious damage of equipment within a few microseconds only. To maximize operational efficiency of ESS, allowing for very high beam availability with high reliability towards the end-users, accidents shall be avoided and interruptions of beam operation have to be minimized and be limited to a short time. Finding an optimum balance between appropriate protection of equipment from damage and high beam availability is the key principle on which the ESS Machine Protection Strategy is being based on [2]. Implementing and realizing the measures needed to provide the correct level of protection in case of a complex facility like ESS, requires a systematic approach, enabling seamless integration of the several 100 protection functions that span over multiple systems. The entity performing the final logic on whether beam operation is allowed or needs to be interrupted, is called Beam Interlock System (BIS), and consists of four PLC based interlock systems and the FPGA based Fast Beam Interlock System (FBIS). The FBIS takes the ultimate decision on safe beam operation and is the only system that can trigger a beam stop. It is designed to stop beam production within 3 µs for the fastest failures at a safety integrity level of SIL2 according to the IEC61508 standard. These requirements result from a hazard and risk analysis being performed for all systems at ESS. The complexity of the ESS machine (multiple beam destinations, beam modes, etc) requires not only transferring binary data from the PLC based interlock systems to the FPGA based Fast Beam Interlock System (Beam Permit OK/NOK), but also to transfer information on e.g. machine configuration, device location, etc.. For that purpose, a so-called datalink has been implemented. It transmits data from the PLCs via PROFINET towards the FPGAs, using an intermediate commercial module, a CompactCom, which communicates via SPI with an ESS in-house developed firmware driver. This paper describes the implementation of this link that was particularly challenging, as the CompactCom is designed to communicate with software entities like microprocessors, but not with FPGA firmware written in VHDL.

ANYBUS CompactCom OVERVIEW

The Anybus CompactCom module is a flexible and cheap way to connect to a PROFINET network. It is already well known and used also in the domain of Machine Protection in laboratories like CERN. In order to understand more in details the following section a brief overview of Anybus CompactCom M40 is done.

As written in the datasheet [3], the Anybus CompactCom M40 for PROFINET is a complete communication module which enables your products to communicate on a PROFINET-RT or IRT network. The module supports fast communication speeds, making it suitable also for high-end industrial devices.

Anybus CompactCom provides different application interfaces to the host: parallel, SPI, with a baudrate up to 20 MHz, shift register interface and UART. At ESS the SPI interface has been chosen as it is faster than UART and shift register interfaces. Also, even if it is slower than the parallel interface, it is less IO consuming. Then the communication is master/slave mode based, where the master, the host, is the FPGA and the slave is the Anybus CompactCom.

Figure 1, shows the interfaces available between an host and the CompactCom with details on its internal structure. In order to interface the PROFINET Network the signals

* stephane.gabourin@ess.eu

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV042

APPLYING MODEL CHECKING TO HIGHLY-CONFIGURABLE SAFETY CRITICAL SOFTWARE: THE SPS-PPS PLC PROGRAM

B. Fernández*, I. D. Lopez-Miguel, J-C. Tournier, E. Blanco,
T. Ladzinski, F. Havart, CERN, Geneva, Switzerland

Abstract

An important aspect of many particle accelerators is the constant evolution and frequent configuration changes that are needed to perform the experiments they are designed for.

This often leads to the design of configurable software that can absorb these changes and perform the required control and protection actions. This design strategy minimizes the engineering and maintenance costs, but it makes the software verification activities more challenging since safety properties must be guaranteed for any of the possible configurations.

Software model checking is a popular automated verification technique in many industries. This verification method explores all possible combinations of the system model to guarantee its compliance with certain properties or specification. This is a very appropriate technique for highly configurable software, since there is usually an enormous amount of combinations to be checked.

This paper presents how PLCverif, a CERN model checking platform, has been applied to a highly configurable Programmable Logic Controller (PLC) program, the SPS Personnel Protection System (PPS). The benefits and challenges of this verification approach are also discussed.

INTRODUCTION

Model checking is a popular verification technique that has been applied in many industries to guarantee that a critical system meets the specifications. Model checking algorithms explore all possible combinations of a system model, trying to find a violation of the formalized specification in the model. This technique is very appropriate for highly configurable projects, since it is necessary to guarantee the safety of the system for all possible configurations.

When model checking shows a discrepancy between the PLC program and the specification, it means that either the PLC program has a bug or the specification is incomplete or incorrect.

In the domain of critical PLC programs, several researchers and engineers published their experiences in the field. To name but a few, in [1] the authors translate the PLC program of an interlocking railway system, written in the FBD (Function Block Diagrams) language, into the input format language of NuSMV to verify their specification written as CTL (Computation Tree Logic) properties. In [2], the PLC program that controls the doors' opening and closing in the trains from the Metro in Brasília, Brazil, was formally verified. In this case, a B model [3] is created automatically from the PLC code. This model is formally verified using the model checker ProB [4].

When applying model checking to PLC programs, three main challenges are faced: (1) building the mathematical model of the program, (2) formalizing the requirements to be checked and (3) the state-space explosion, i.e. the number of possible input combinations and execution traces is too big to be exhaustively explored. In our case, we use the open-source tool PLCverif[5], developed at CERN. It creates automatically the models out of the PLC program and integrates three state-of-the-art model checkers: nuXmv [6], Theta [7] and CBMC [8]. It also implements some reduction and abstraction mechanisms to reduce the number of states to be explored and to speed up the verification. Therefore, challenges 1 and 3 are transparent for the user. There are certainly still limitations and large state-space PLC program models cannot be verified. Regarding challenge 2, PLCverif also provides mechanisms to help the users to formalize their requirements and provide a precise specification. However, this is normally a difficult task, specially for configurable programs. In this paper, we will show examples of functional requirements formalization with PLCverif. More details about PLCverif can be found in [5, 9].

This paper aims to show the benefits of applying model checking to verify highly configurable PLC programs. In such systems, it is usually unfeasible to check all possible combinations by traditional testing methods and model checking is a good complement to these methods, especially for module verification.

In particular, this paper shows how PLCverif was applied to the PLC programs of the SPS Personnel Protection System (PPS) [10] and how it helped to improve their original specification and correct PLC bugs before the commissioning of the system.

SPS PERSONNEL PROTECTION SYSTEM

The SPS-PPS is a large distributed control system in charge of the access control and the personnel protection of the SPS accelerator.

The SPS has 16 access zones divided in different sectors and each access zone has an access point. Several access zones are always interlocked with the same elements inhibiting operation with beam when a hazardous event is detected. This is the concept of a safety chain. Each safety chain contains the "important safety elements" to stop the beam (EISb) when a hazardous event is detected or to avoid access (EISa) when the accelerator is in Beam mode.

All details of the system can be found in [10].

* borja.fernandez.adiego@cern.ch

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV044

BEAM PROFILE MEASUREMENTS AS PART OF THE SAFE AND EFFICIENT OPERATION OF THE NEW SPS BEAM DUMP SYSTEM

A. Topaloudis*, E. Bravin, S. Burger, S. Jackson, F. Maria Velotti, E. Veyrunes,
CERN, Geneva, Switzerland

Abstract

In the framework of the LHC Injectors Upgrade (LIU) project, the Super Proton Synchrotron (SPS) accelerator at CERN is undergoing a profound upgrade including a new high-energy beam dump. The new Target Internal Dump Vertical Graphite (TIDVG#5) is designed to withstand an average dumped beam power as high as 235 kW to cope with the increased intensity and brightness of the LIU beams whose energies in the SPS range from 14 to 450 GeV. Considering such highly demanding specifications, the constant monitoring of the device's status and the characteristics of the beams that are dumped to it is of utmost importance to guarantee an efficient operation with little or no limitations. While the former is ensured with several internal temperature sensors, a Beam Observation system based on a scintillating screen and a digital camera is installed to extract the profile of the beam dumped in TIDVG#5 for post mortem analysis. This paper describes the overall system that uses the BTV images to contribute to the safe and efficient operation of the SPS Beam Dump System (SBDS) and hence the accelerator.

INTRODUCTION

While the accelerators of the proton injector chain at CERN deliver beams to the Large Hadron Collider (LHC) within specification, the requirements for the upgraded High-Luminosity LHC (HL-LHC) exceed their current capabilities. The LHC Injectors Upgrade (LIU) project aims to address this by upgrading the proton injectors to deliver the high brightness beams needed by the HL-LHC [1].

In the framework of the LIU project, the SPS underwent several important upgrades including a new high-energy beam dump [2]. Such a system is meant to dispose of the circulating beam in the accelerator whenever necessary, i.e. in case of emergency, during machine developments (MD), LHC beam setup or LHC filling and after the slow-extraction process to eliminate the remnants of the beam for fixed targets (FT). In order to minimise the associated thermo-mechanical stresses in the dump, the energy density deposited in it is reduced by diluting the beam with the kicker magnets, producing a sinusoidal pattern on the front of the first absorbing dump block [3]. The principle is depicted in Fig. 1 along with a simulation of the expected dilution of a Fixed Target beam.

Until now, the SBDS consisted of two internal dumps, i.e. Target Internal Dump Horizontal (TIDH) and Target Internal Dump Vertical Graphite (TIDVG#4) which used to absorb beams with energy from 14 to 28.9 GeV and between 102.2 and 450 Gev accordingly. During CERN's Long Shutdown 2 (LS2) (2019-2020), the new TIDVG#5 replaced both the aforementioned dumps in order to cope with the increased intensity and brightness of the LIU beams which are expected to produce an average dumped beam power as high as 235 kW instead of 60kW. Consequently, the new system is required to withstand all beam energies in the SPS, i.e from 14 to 450 GeV, including the previously so-called "forbidden" range, 28.9–102.2 GeV; hence, removing this limitation for the beam operation [4].

* athanasios.topaloudis@cern.ch

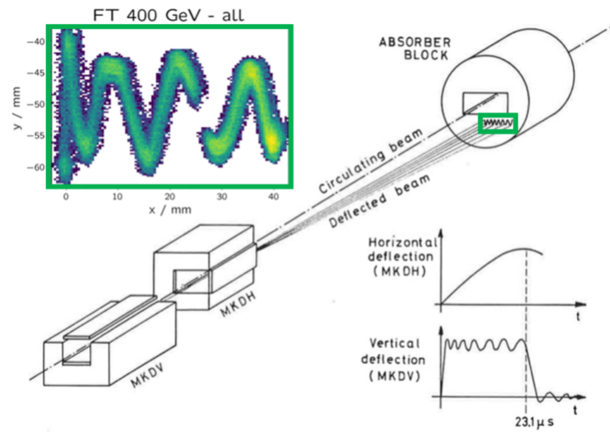


Figure 1: Principle of beam dumping in the SPS and simulation of a Fixed Target diluted beam.

MOTIVATION

In order to reduce the local energy deposition while maintaining the total required beam absorption, several innovations have been implemented in the design of the TIDVG#5, e.g. core materials, cooling and shielding. The design was done base on the most demanding beam dump scenarios taking into account possible failures of the extraction kickers responsible to dilute the particles [4].

However, to ensure the safe operation of the system and its components, the design specifications should be guaranteed. This can be achieved by constantly monitoring the characteristics of the dumped beams, i.e. the exact position of the dumped beam with respect to the dump as well as its shape and inhibit further beam injections in case of operational problems. For this, a Beam Observation system was installed to capture an image of the particles before impacting the dump block [5] to be included in the Post-Mortem analysis that verifies the quality of each dump.

18th Int. Conf. on Acc. and Large Exp. Physics Control Systems ICALEPCS2021, Shanghai, China JACoW Publishing
ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV047

SUPPORTING FLEXIBLE RUNTIME CONTROL AND STORAGE RING OPERATION WITH THE FAIR SETTINGS MANAGEMENT SYSTEM

R. Mueller, J. Fitzek, H. Hüther, H. Liebermann, D. Ondreka, A. Schaller, A. Walter
GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany

Abstract

The FAIR Settings Management System has now been used productively for the GSI accelerator facility operating synchrotrons, storage rings, and transfer lines. The system's core is being developed in a collaboration with CERN [1], and is based on CERN's LHC Software Architecture (LSA) framework [2].

At GSI, 2018 was dedicated to integrating the Beam Scheduling System (BSS). Major implementations for storage rings were performed in 2019, while 2020 the main focus was on optimizing the performance of the overall Control System.

Integrating BSS allows us to configure the beam execution directly from the Settings Management System. Defining signals and conditions enables us to control the runtime behavior of the machine.

The Storage Ring Mode supports flexible operation with features allowing to pause the machine and execute in-cycle modifications, using concepts like breakpoints, repetitions, skipping, and manipulation.

After providing these major new features and their successful productive use, the focus was shifted on optimizing their performance. The performance was analyzed and improved based on real-word scenarios defined by operations and machine experts.

PREFACE

Patterns and Beam Production Chains (Chains) are the central technical concepts within the new LSA-based Settings Management System at GSI [3,4]. Chains are foreseen to provide a beam-oriented view on the facility from source to target, for now this is not utilized and they still represent an accelerator-oriented view. To be able to coordinate multiple beams traversing the facility in parallel, Chains are grouped into Patterns. See Fig. 1.

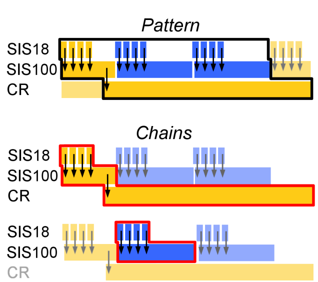


Figure 1: Patterns and Beam Production Chains as concepts for scheduling beams.

The term LSA will be used throughout this paper when the FAIR Settings Management System business logic is referenced.

RUNTIME CONTROL THROUGH BSS

Conceptually, LSA is an offline system which has no information about real-time scheduling, issued beam requests or machine status. BSS is an online system that, at runtime, processes scheduled event sequences and their dependencies on beam requests, accelerator status and beam modes.

Figure 2 shows an overview of the data that is exchanged between the systems.

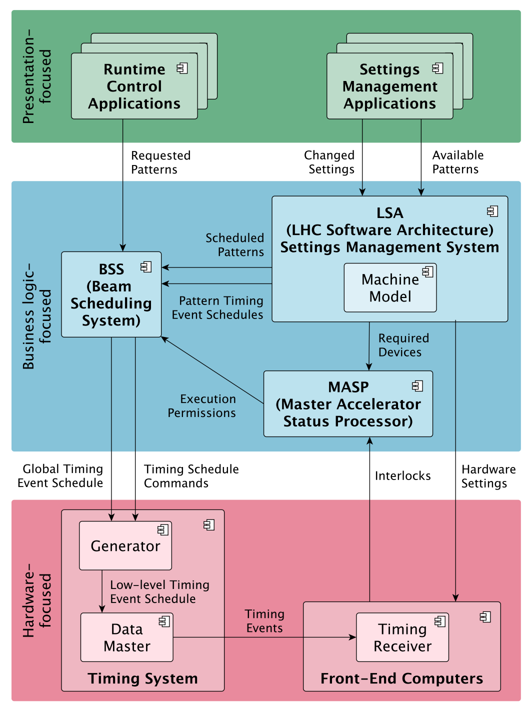


Figure 2: Control system interaction diagram.

The BSS's beam scheduling description is using LSA's own concepts like Patterns, Chains and additionally generated scheduling information like

- description of alternative timing event sequences
- definition of synchronization points
- causal description of branching depending on beam requests, accelerator status and beam-mode
- signal definitions that are used to switch between the aforementioned points

For a detailed description of BSS see [5].

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV048

AN ARCHIVER APPLIANCE PERFORMANCE AND RESOURCES CONSUMPTION STUDY

R. Fernandes†, H. Kocevar, S. Armanet, S. Regnell, European Spallation Source, Lund, Sweden

Abstract

At the European Spallation Source (ESS), 1.6 million signals are expected to be generated by a (distributed) control layer composed of around 1 500 EPICS IOCs. A substantial amount of these signals – i.e. PVs – will be stored by the Archiving Service, a service that is currently under development at the Integrated Control System (ICS) Division. From a technical point of view, the Archiving Service is implemented using a software application called the Archiver Appliance. This application, originally developed at SLAC, records PVs as a function of time and stores these in its persistence layer. A study based on multiple simulation scenarios that model ESS (future) *modus operandi* has been conducted by ICS to understand how the Archiver Appliance performs and consumes resources (e.g. RAM memory) under disparate workloads.

INTRODUCTION

The ICS Division at ESS is mandated to deliver a system to control both its accelerator and end-station instruments. To create the system, the open-source framework EPICS [1] was chosen. With worldwide usage, EPICS allows the creation of Input/Output Controllers (IOCs) which software applications (e.g. Archiver Appliance, CS-Studio) may consume (i.e. connect to) to tackle domain specific businesses (e.g. signals archiving, signals displaying).

Typically, an IOC is an executable (i.e. software process) that utilizes resources from EPICS modules to interface (logical or physical) devices and exposes their input and output signals as Process Variables (PVs). Eventually, an IOC may also implement logic to control these devices.

A PV is a named piece of data, usually associated with devices to represent input and output signals (e.g. status, setpoint). A PV can be read, written or monitored by applications and tools using the Channel Access (CA) library.

Given that a significant number of PVs will be archived by the Archiver Appliance [2] at ESS, the present paper introduces a study to understand how this application performs when storing (i.e. writing) and retrieving (i.e. reading) PV data into and from its persistence layer thanks to a panoply of simulation scenarios designed to stress test it. In addition, the paper explores how the Archiver Appliance consumes resources (e.g. RAM memory) when handling these scenarios.

SIMULATION SCENARIOS

Thanks to discussions with domain experts to understand the type of data and volume important to test the Archiver Appliance with, four dimensions were identified along with relevant ranges of values. This helped specify simulation scenarios close to what ICS will likely face in terms of PV archiving needs and requirements from end-users, thus testing the application in a (more) meaningful way. The dimensions and ranges of values are:

- Number of PV waveforms: 1, 100, 1 000, 10 000
- Data points (per waveform): 1 000, 10 000, 100 000
- Data type: integer (4 bytes), double (8 bytes)
- Update frequency: 1 Hz, 14 Hz

Based on these, 48 simulation scenarios were specified (see Table 1).

Table 1: Simulation Scenarios

Scenario ID	Number Waveforms	Data Points	Data Type	Update Frequency
AAPS-0010	1	1 000	Integer	1
AAPS-0020	1	1 000	Integer	14
AAPS-0030	1	1 000	Double	1
AAPS-0040	1	1 000	Double	14
AAPS-0050	1	10 000	Integer	1
AAPS-0060	1	10 000	Integer	14
AAPS-0070	1	10 000	Double	1
AAPS-0080	1	10 000	Double	14
AAPS-0090	1	100 000	Integer	1
AAPS-0100	1	100 000	Integer	14
AAPS-0110	1	100 000	Double	1
AAPS-0120	1	100 000	Double	14
AAPS-0210	100	1 000	Integer	1
AAPS-0220	100	1 000	Integer	14
AAPS-0230	100	1 000	Double	1
AAPS-0240	100	1 000	Double	14
AAPS-0250	100	10 000	Integer	1
AAPS-0260	100	10 000	Integer	14
AAPS-0270	100	10 000	Double	1
AAPS-0280	100	10 000	Double	14
AAPS-0290	100	100 000	Integer	1
AAPS-0300	100	100 000	Integer	14
AAPS-0310	100	100 000	Double	1
AAPS-0320	100	100 000	Double	14
AAPS-0410	1 000	1 000	Integer	1
AAPS-0420	1 000	1 000	Integer	14
AAPS-0430	1 000	1 000	Double	1
AAPS-0440	1 000	1 000	Double	14
AAPS-0450	1 000	10 000	Integer	1
AAPS-0460	1 000	10 000	Integer	14
AAPS-0470	1 000	10 000	Double	1
AAPS-0480	1 000	10 000	Double	14
AAPS-0490	1 000	100 000	Integer	1
AAPS-0500	1 000	100 000	Integer	14
AAPS-0510	1 000	100 000	Double	1
AAPS-0520	1 000	100 000	Double	14
AAPS-0610	10 000	1 000	Integer	1
AAPS-0620	10 000	1 000	Integer	14
AAPS-0630	10 000	1 000	Double	1
AAPS-0640	10 000	1 000	Double	14

† ricardo.fernandes@ess.eu

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV049

CONTROLS DATA ARCHIVING AT THE ISIS NEUTRON AND MUON SOURCE FOR IN-DEPTH ANALYSIS AND ML APPLICATIONS

I. D. Finch*, G. D. Howells, A. Saoulis, ISIS Neutron and Muon Source, Rutherford Appleton Laboratory, Didcot, United Kingdom

Abstract

The ISIS Neutron and Muon Source accelerators are currently operated using Vsystem control software. Archiving of controls data is necessary for immediate fault finding, to facilitate analysis of long-term trends, and to provide training datasets for machine learning applications. While Vsystem has built-in logging and data archiving tools, in recent years we have greatly expanded the range and quantity of data archived using an open-source software stack including MQTT as a messaging system, Telegraf as a metrics collection agent, and the InfluxDB time-series database as a storage backend.

Now that ISIS has begun the transition from Vsystem to EPICS this software stack will need to be replaced or adapted. To explore the practicality of adaptation, a new Telegraf plugin allowing direct collection of EPICS data has been developed. We describe the current Vsystem-based controls data archiving solution in use at ISIS, future plans for EPICS, and our plans for the transition while maintaining continuity of data.

INTRODUCTION

The ISIS Neutron and Muon Source accelerators [1, 2] are currently controlled using the Vista Control System's software product Vsystem [3] (often colloquially called Vista), while the majority of beamlines and associated instruments [4, 5] are controlled using the Experimental Physics and Industrial Control System (EPICS) [6].

Vsystem and EPICS both originated in work done in the 1980s to create a control system for the Ground Test Accelerator Control System at Los Alamos National Laboratory [7]. While EPICS became an open-source project developed as a collaboration between multiple accelerator organisations, Vista is a closed-source commercial product with paid support. Both are distributed control systems with common features such as databases, and channels (Vsystem) or process variables (EPICS).

At ISIS Vsystem is deployed on four Itanium servers running the OpenVMS operating system. (Vsystem can be deployed on MS Windows, Linux, and OpenVMS, and operated in a hybrid configuration using any combination of these operating systems.) With the announced discontinuation of the Itanium processor architecture [8] a transition to a different processor architecture is required.

A decision has been made to transition the ISIS accelerators control system from Vsystem on OpenVMS / Itanium to EPICS on Linux / x86. This is planned as a gradual transition while ISIS is operating instead of an all-at-once conversion [9]. There will thus be a period in which both Vsystem and EPICS must operate in concert, and an early transition period in which EPICS operates only a small proportion of hardware.

This paper describes the logging functionality included with Vsystem, the software stack developed and deployed at ISIS to improve on this system, and the way in which it has been applied to machine learning and other applications at the facility. Software tools designed to allow EPICS to be used as a data source for this logging framework during the control system transition are then described.

VSYSTEM LOGGING AT ISIS

Vsystem Built-in Logging

Vsystem has an integrated logging subsystem called Vlogger [10] which consists of a Vlogger service that archives data from Vsystem databases to file, Vtrend for visualizing archived data, and utilities to manage and extract data from the generated archive files (including an SQL-like query language allowing CSV export).

At ISIS Vlogger is used to maintain short-term archives of data sampled every 30 seconds for 7 days, and longer-term data sampled every 30 minutes for 7 weeks. Both short- and longer-term archives are circular buffers. Permanent copies of the longer-term data are made at the end of each user cycle. The ISIS archive of this longer-term lower time resolution data begins in 2003, covered key channels by 2005, and subsequently steadily increased in scope.

The main limitations of this Vlogger system at ISIS are that:

- It must be run on a licensed Vsystem installation, with users therefore requiring access to and familiarity with our operations-critical OpenVMS server infrastructure.
- Channels to be logged must be specified in advance.
- It lacks a modern web-based query and visualisation interface.

For these and other reasons a parallel logging system for Vsystem was developed at ISIS.

InfluxDB Logging of Vsystem

Vsystem has an extensive and well-documented API [11] which can be used to access the Vsystem databases and their channels. Specifically, an event based callback API can be used to monitor for changes to live databases or channels.

Python code called vista_mqtt was developed to use the event based callback API to forward the changes in value and alarm states of all channels to an MQTT broker. MQTT is a publish/subscribe messaging standard and was chosen

* ivan.finch@stfc.ac.uk

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THAL01

MACHINE LEARNING TOOLS IMPROVE BESSY II OPERATION

L. Vera Ramírez*, T. Birke, G. Hartmann, R. Müller, M. Ries, A. Schälicke, P. Schnizer
Helmholtz-Zentrum Berlin, Germany

Abstract

At the Helmholtz-Zentrum Berlin (HZB), user facility BESSY II Machine Learning (ML) technologies aim at advanced analysis, automation, explainability and performance improvements for accelerator and beamline operation. The development of these tools is intertwined with improvements of the prediction part of the digital twin instances at BESSY II [1] and the integration into the Bluesky Suite [2, 3]. On the accelerator side, several use cases have recently been identified, pipelines designed and models tested. Previous studies applied Deep Reinforcement Learning (RL) to booster current and injection efficiency. RL now tackles a more demanding scenario: the mitigation of harmonic orbit perturbations induced by external civil noise sources. This paper presents methodology, design and simulation phases as well as challenges and first results. Further ML use cases under study are, among others, anomaly detection prototypes with anomaly scores for individual features.

MOTIVATION

The complexity of a large-scale facility such as the light source BESSY II in Berlin-Adlershof represents a perfect benchmark for the development, implementation and testing of Machine Learning (ML) tools due to the enormous set of use cases that can be identified - some of which were already presented in [4]. An important factor in order to prioritise these applications is the added value that might be gained through ML, which is enormous in the two cases presented in this paper.

We will first focus on a very challenging application: the mitigation of harmonic orbit perturbations. In this case ML tools aim to improve existing correction systems in the frequency domain (beyond the possibilities of current analytical methods), seeking an increase of the electron beam stability - a critical factor in order to achieve light radiation with high quality brilliance and brightness over time. Besides we will also further introduce original developments towards an anomaly detection system with feature anomaly assignation. This automatic system might extend existing preprogrammed alert system in BESSY's control room and provide additional support to human operators.

MITIGATION OF HARMONIC ORBIT PERTURBATIONS

At the light source BESSY II, the stability of the orbit in the storage ring (within the transverse beam dimensions $100 \times 20\,\mu$m) is currently pursued with a system called Fast Orbit Feedback (FOFB, [5]) running at 150 Hz. FOFB correction is based on the linear approximation $\Delta\mathbf{x} \approx S\Delta\mathbf{c}$ with $\mathbf{x}$ relative beam position, $\mathbf{c}$ corrector magnets strength and S the so-called *response matrix* (calculated or measured at the accelerator). Hence, for $\mathbf{x}_{t+1} = \mathbf{0}$ we can apply recursively $\mathbf{c}_{t+1} := \mathbf{c}_t - \alpha S^{-1}\mathbf{x}_t$ with S^{-1} Moore-Penrose pseudoinverse of S and α positive constant (at BESSY $\alpha = 0.8$).

FOFB manages to correct orbit perturbations due e.g. to imprecisions of the magnet positioning in a very efficient way. But beyond that, there are several external elements such as civil noise, main power at 50 Hz and some imperfectly isolated magnetic sources (e.g. booster power supply at 10 Hz) that also produce additional inherent perturbations (see Fig. 1). The correction induced by the FOFB system (Fig. 2) is able to mitigate perturbations at lower frequencies (less than ca. 15 Hz) but beyond that point the FOFB system is not that effective and even induces further perturbations (especially in the region 20-40 Hz).

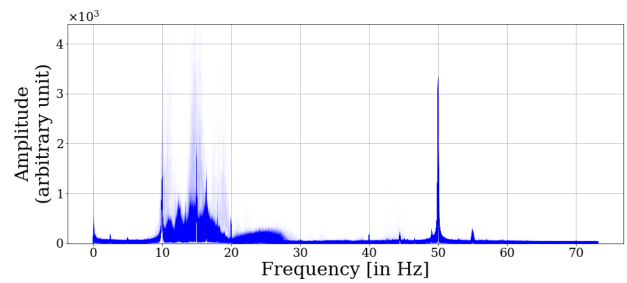


Figure 1: Horizontal beam motion spectra between injections without FOFB (cumulated along 22/04/20, BESSY Archiver data).

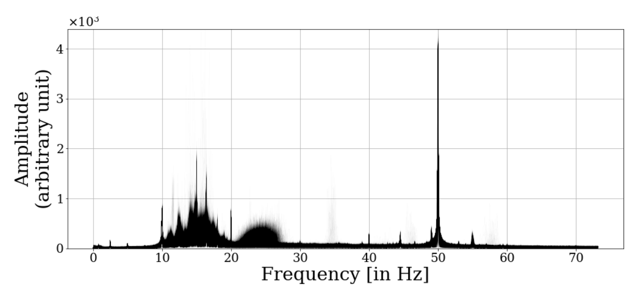


Figure 2: Horizontal beam motion spectra between injections with FOFB (cumulated along 13/05/20, BESSY Archiver data).

A first approach to face this problem was proposed, implemented and tested with simulations in [6]: an explicit correction of the 10 Hz perturbation with a *inverse wave* and an improvement of the PID correction coefficients (proportional-integral-derivative response) in the FOFB algorithm. In this work, we explore the application of ML techniques (in particular Reinforcement Learning, RL) in order to extend the analytical approach with an agent that learns the dynamics

* luis.vera_ramirez@helmholtz-berlin.de

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THAL02

BAYESIAN TECHNIQUES FOR ACCELERATOR CHARACTERIZATION AND CONTROL

R. Roussel*, A. Edelen, C. Mayes, SLAC National Accelerator Laboratory, 94025 Menlo Park, USA
J. P. Gonzalez-Aguilera, Y.K. Kim, University of Chicago, 60637 Chicago, USA

Abstract

Accelerators and other large experimental facilities are complex, noisy systems that are difficult to characterize and control efficiently. Bayesian statistical modeling techniques are well suited to this task, as they minimize the number of experimental measurements needed to create robust models, by incorporating prior, but not necessarily exact, information about the target system. Furthermore, these models inherently take into account noisy and/or uncertain measurements and can react to time-varying systems. Here we will describe several advanced methods for using these models in accelerator characterization and optimization. First, we describe a method for rapid, turn-key exploration of input parameter spaces using little-to-no prior information about the target system. Second, we highlight the use of Multi-Objective Bayesian optimization towards efficiently characterizing the experimental Pareto front of a system. Throughout, we describe how unknown constraints and parameter modification costs are incorporated into these algorithms.

INTRODUCTION

Tuning accelerators to meet operational goals of a given facility is a time-consuming task that limits valuable beam time resources for experimental users. This process represents a difficult to solve optimization problem, where there are many free parameters and limited, expensive to conduct measurements available to diagnose target objectives. Accelerator optimization problems also exist in tightly constrained parameter spaces where large regions of parameter space prevent even simple measurements of the beam. Finally, due to the complexity of accelerator systems, measurements are often noisy and/or have large uncertainties.

Model based optimization methods have been shown to speed up convergence of optimizing black box problems, where derivative information about the target function is not accessible, making routine operations faster and previously impossible to solve problems solvable in realistic settings. Of particular interest is the use of Bayesian optimization (BO) techniques for solving optimization problems [1, 2] including experimental optimization of accelerators [3, 4]. Bayesian statistical models aim to represent measurements as probability distributions, instead of scalar values. This naturally lends itself to characterizing experimental accelerator measurements, which have inherent noise and uncertainty. Bayesian optimization explicitly takes these uncertainties into account when performing optimization, resulting in an algorithm that is robust to noise (an issue faced by many other types of algorithms) [5]. This method is especially proficient at *efficient* global optimization, since the Bayesian surrogate model encodes high level information about the target function behavior (such as function smoothness), allowing it to make accurate predictions about the function with limited data sets, thus significantly improving optimization performance over other methods.

Bayesian optimization consists of two elements, a statistical surrogate model that makes predictions about a given target function and an acquisition function which uses those predictions to choose future points in input space to measure. The surrogate model is usually chosen to be a Gaussian process (GP) [6]. This model treats the value of the target function at each point in input space $\mathbf{x}$ as a random variable taken from a normal distribution $f \sim \mathcal{N}(\mu(\mathbf{x}), \sigma(\mathbf{x})^2)$ where $\mu(\mathbf{x})$ is the mean and $\sigma(\mathbf{x})$ is the standard deviation. Gaussian processes treat the joint probability distribution of the function values at each point in input space as a Multivariate normal distribution, specified by a mean function μ and a covariance matrix $\mathbf{\Sigma}$. We encode the expected behavior of the target function by specifying $\mathbf{\Sigma}$ via a kernel function $K(\mathbf{x}, \mathbf{x}')$ that describes how strongly function values at locations $\mathbf{x}$, $\mathbf{x}'$ are correlated with one another. A common class of kernel functions, known as "stationary kernels", are based solely on the distance between the two points, $||\mathbf{x}-\mathbf{x}'||$. We can then specify the expected smoothness of our function with a length-scale hyperparameter in specific kernels, such as the radial basis function (RBF) or Matern kernels [6]. Once experimental data is incorporated into the model, it can then be used to predict the function mean and corresponding uncertainty everywhere in the input domain.

Once a model is generated, we can then specify an acquisition function $\alpha(\mathbf{x})$ characterizes how valuable future observations are as a function of input parameters. For example, if we have high confidence in our model, we can choose to make measurements where the predicted function mean is at an extremum, thus heavily weighting "exploitation". On the other hand, if we wish to improve our understanding of the target function, we can place a high value on making observations in regions of high uncertainty, thus reducing the overall uncertainty of the model by heavily weighting "exploration". The most popular acquisition functions for single objective global optimization balances these two aspects, either implicitly using expected improvement over the best previously observed function value [7], or explicitly using an optimization hyperparameter [8].

In this work, we describe two acquisition functions that are specifically tailored to solve accelerator control problems. The first example describes "Bayesian exploration", an algorithm that enables automatic, efficient characterization of target functions, replacing the need for grid-like parameter

* rroussel@slac.stanford.edu

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THAL03

MACHINE LEARNING BASED MIDDLE-LAYER FOR AUTONOMOUS ACCELERATOR OPERATION AND CONTROL

S. Pioli*, B. Buonomo, F. Cardelli, P. Ciuffetti, L. G. Foggetta, C. Di Giulio,
D. Di Giovenale, G. Piermarini, INFN-LNF, Frascati, Italy
V. Martinelli, INFN-LNL, Legnaro, Italy

Abstract

The Singularity project, led by National Laboratories of Frascati of the National Institute for Nuclear Physics (INFN-LNF), aim to develop automated machine-independent middle-layer to control accelerator operation through machine learning (ML) algorithms like Reinforcement Learning (RL) and Clustering, integrated with accelerator sub-systems. In this work we will present the actual LINAC control system and the necessary effort to implement the architecture and the middle-layer necessary to develop autonomous operation control with RL algorithms together with the fault detection capability improved by Clustering approach as for waveguides or accelerator sections breakdown. Results of the first tentative operation of Singularity on the LINAC system will be reported.

INTRODUCTION

In this paper we will present our effort to integrate a Machine Learning (ML) based middle-layer integrated in the DAΦNE LINAC in order to demonstrate the feasibility of autonomous operation driven by RL algorithm together with Clustering fault detection methods to identify breakdown activities.

The main obstacle to implement the Singularity project [1] in the DAΦNE LINAC is related to the time available for the development and test the system in an operating accelerator for 4500 hours per year. The COVID periods with the reduced activities permits to implement the necessary step to provides at Singularity the data to implements the algorithms.

In the first part of this work introduction of the LINAC elements will be provided and an overview on the the actual control system is shown to introduce the architecture of the system and the middle layer implemented to provides the data to Singularity.

In the second part of the work description of RL algorithms and Singularity middle layer will presented and related integration and performances obtain on off-line operation will be presented and discussed.

THE DAΦNE LINAC

The DAΦNE injector is composed by a ~60 m long Linac that produces and accelerates up to the collider operation energy (510 MeV) both the positron and electron beams. It has been designed and built by the USA firm TITAN BETA and commissioned by the INFN-LNF staff [2]. In Fig. 1 shows

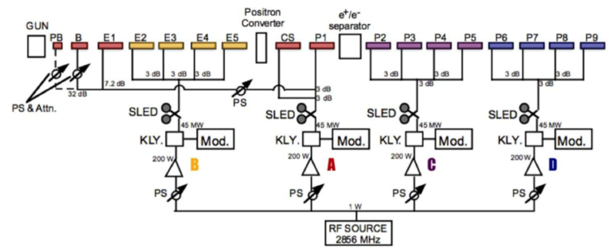


Figure 1: The LINAC layout.

the LINAC RF layout. The injector subsystem includes a thermionic electron gun, a prebuncher and a buncher. The sections performing at S-band working at 2856 MHz, and are powered by 4 klystrons Thomson TH2128C, with nominal output power of 45 MW, each one equipped with a SLED, the SLAC type pulse compressor device. The performances of the LINAC are summarized in Fig. 2.

	Design	Operational
Electron beam final energy	800 MeV	510 MeV
Positron beam final energy	550 MeV	510 MeV
RF frequency	2856 MHz	
Positron conversion energy	250 MeV	220 MeV
Beam pulse rep. rate	1 to 50 Hz	1 to 50 Hz
Beam macropulse length	10 nsec	1.4 to 300 nsec
Gun current	8 A	8 A
Beam spot on positron converter	1 mm	1 mm
norm. Emittance (mm. mrad)	1 (electron) 10 (positron)	< 1.5
rms Energy spread	0.5% (electron) 1.0% (positron)	0.5% (electron) 1.0% (positron)
electron current on positron converter	5 A	5.2 A
Max output electron current	>150 mA	500 mA
Max output positron current	36 mA	85 mA
Trasport efficiency from capture section to linac end	90%	90%
Accelerating structure	SLAC-type, CG, $2\pi/3$	
RF source	4 x 45 MWp sledded klystrons TH2128C	

Figure 2: The LINAC beam performances.

After an upgrade on the gun [3] all the parameters as bunch duration and the other gun parameters and RF power in the RF guide distribution and in the sections could be controlled by klystron voltage set and the low level RF input of each klystron (power and phase) and the prebuncher, buncher, capture section power and phases could be set.

The focusing system varies its conformation according to the requirements of the portion of the LINAC interested.

* stefano.pioli@lnf.infn.it

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THAL04

MACHINE LEARNING BASED TUNING AND DIAGNOSTICS FOR THE ATR LINE AT BNL

J. P. Edelen*, K. Bruhwiler, E. Carlin, C. C. Hall, RadiaSoft LLC, Boulder, CO, USA
K. A. Brown, V. Schoefer, Brookhaven National Laboratory, Upton, NY, USA

Abstract

Over the past several years machine learning has increased in popularity for accelerator applications. We have been exploring the use of machine learning as a diagnostic and tuning tool for the transfer line from the AGS to RHIC at Brookhaven National Laboratory. In our work, inverse models are used to either provide feed-forward corrections for beam steering, or as a diagnostic to illuminate quadrupole magnets that have excitation errors. In this paper we present results on using machine learning for beam steering optimization for a range of different operating energies. We also demonstrate the use of inverse models for optical error diagnostics. Our results are from studies that use both simulation and measurement data.

INTRODUCTION

Machine learning (ML) has seen a significant growth in its adoption for widespread applications. In particle accelerators ML has been identified as having the potential for significant impact on modeling, operation, and controls [1,2]. These techniques are attractive due to their ability to model nonlinear behavior, interpolate on complicated surfaces, and adapt to system changes over time. This has led to a number of dedicated efforts to apply ML, and early efforts have shown promise.

For example, neural networks (NNs) have been used as surrogates for traditional accelerator diagnostics to generate non-interceptive predictions of beam parameters [3,4]. Neural networks have been used for a range of machine tuning problems utilizing inverse models [5,6]. When used in conjunction with optimization algorithms neural networks have demonstrated improved switching times between operational configurations [7]. Neural network surrogate models have also been demonstrated to significantly speed up multi-objective optimization of accelerators [8]. Additionally, ML has been of interest for anomaly detection, using autoencoders, for root cause analysis [9], and for outlier detection, using large data-sets of known good operational states [10].

In this work we seek to apply ML methods — for both tuning and anomaly detection — on the AGS to RHIC transfer line at Brookhaven National Laboratory. Specifically, we employ the use of inverse models for these applications. The application of inverse models for anomaly detection is a burgeoning area of research in many other fields that has not seen much attention in particle accelerators. Here we present our work towards implementing inverse models to detect errors in quadruples using only beam position monitors and corrector data. We will demonstrate the utility of this approach using a toy model, and then show how it scales to a larger system such as the AGS to RHIC transfer line. We will then show results of training inverse models using data from the machine and discuss future work for this effort.

THE ATR LINE

The transfer line between the Alternating Gradient Synchrotron (AGS) and RHIC, or the so-called the ATR line [11, 12], must be retuned for different energies when RHIC changes its operating point. The transfer line controls the orbit matching, optics matching, and dispersion matching of the beam into RHIC. The transfer line is broken down into four sections. The U and W lines are seen by all beams entering RHIC while the X and Y lines are used for injection into the Blue and Yellow rings respectively. In this paper we focus our studies on the UW subset of the ATR line. The length of the transfer line presents challenges for tuning unto itself. The problem is further complicated by a 1.7 m vertical drop in order to get the beam from the AGS to RHIC.

The first part of the ATR (referred to as the U-line) starts with fast extraction from the AGS and stops before the vertical drop from the AGS to RHIC. The U-line consists of two bends. The first bend is 4.25°, consisting of two A-type dipole magnets. The second bend is an 8° bend consisting of four C-type combined-function magnets (placed in a FDDF arrangement), and thirteen quadrupoles. Optics in the U-line are configured to accomplish several goals. The Twiss parameters at the AGS extraction point must be matched, and provide achromatic transport of the beam to the exit of the 8° bend. The beam must be focused at the location of a thin gold foil which is placed just upstream of the quadrupole Q6 of the U-line. The Twiss parameters of the U-line must be matched to the ones at the origin of the W-line. Finally, the beam size should be kept small throughout to minimize losses.

The second part of the ATR (referred to as the W-line) introduces the vertical drop for injection into RHIC, and the matching sections for the injection lines. It contains eight C-type combined-function magnets that each make a of 2.5° bend, followed by six quadrupoles. The eight combined function magnets form a 20° achromatic horizontal bend placed in a (F-D) configuration. The W-Line is also responsible for lowering the beam elevation by 1.7 m. This is accomplished using two dipoles in an achromatic dogleg configuration. Along the line there are also a number of BPMs and correctors that are required to match the orbit of the beam into RHIC.

* jedelen@radiasoft.net

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THAR01

MINT, AN ITER TOOL FOR INTERACTIVE VISUALIZATION OF DATA

L. Abadie, G. Carannante, I. Nunes, J. Panchumarti, S. D. Pinches, S. Simrock, M. Tsalas
ITER Organization, Saint-Paul Lez Durance, France
D. Makowski, P. Mazur, P. Perek, Lodz University of Technology Department of
Microelectronics and Computer Science Wolczanska, Lodz, Poland
A. Neto, Fusion For Energy, Barcelona, Spain
S. S. Kalsi, Tata Consultancy Services, Pune, India

Abstract

ITER will produce large volumes of data that will need to be visualized and analyzed. This paper describes the development of a graphical data visualization and exploration tool, MINT (Make Informative and Nice Trends), for plant engineers, operators and physicists. It describes the early development phase from requirements capture to first release covering the mistakes, lessons learnt and future steps. The requirements were collected by interviewing the various stakeholders. The initial neglect of the architecture and user-friendliness turned out to be key points when developing such a tool for a project with a long lifetime like ITER. A modular architecture and clear definition of generic interfaces (abstraction layer) is crucial for such a long lifetime project and provides a robust basis for future adaptations to new plotting, processing and GUI libraries. The MINT application is based on an independent plotting library, which acts as a wrapper to the choice of underlying graphical libraries. This allows scientists and engineers to develop their own specific tools, which are immune to changes of the underlying graphical library. Data selection and retrieval have also been developed as a separate module with a well-defined data object interface to allow easy integration of additional data sources. The processing layer is also a separate module, which supports algebraic and user-defined functions. The development is based on Python [1] and uses Qt5 [2] as the visual backend. A first release of the 1-D trend tool (MINT) has already started and will be used for the ECH (Electron Cyclotron Heating) system commissioning. Other visualization tools will be developed in the future that build upon the same underlying modules.

INTRODUCTION

ITER is already producing data which need to be plotted and analyzed quickly. This paper describes the requirements and challenges, the development phases and various lessons learnt.

REQUIREMENTS

The top level requirement for data visualization is to be able to plot data for a time range or a pulse identifier.

Stakeholders

To define the detailed requirements, the first thing was to identify the main stakeholders. We identified three basic categories of users:

- Plant engineers whose main objective is to make system investigations; some of them will also perform research activities.
- The science team whose main objective is to analyze pulses and carry out research.
- The operation team whose primary focus will be the analysis of pulses.

Types of Data

The next step was to list the different data types of interest. After interviewing the stakeholders, the following list was constructed:

- Time and profile traces;
- Spectra;
- Fluxes (see Figure 1);
- Images and videos (see Figure 2)

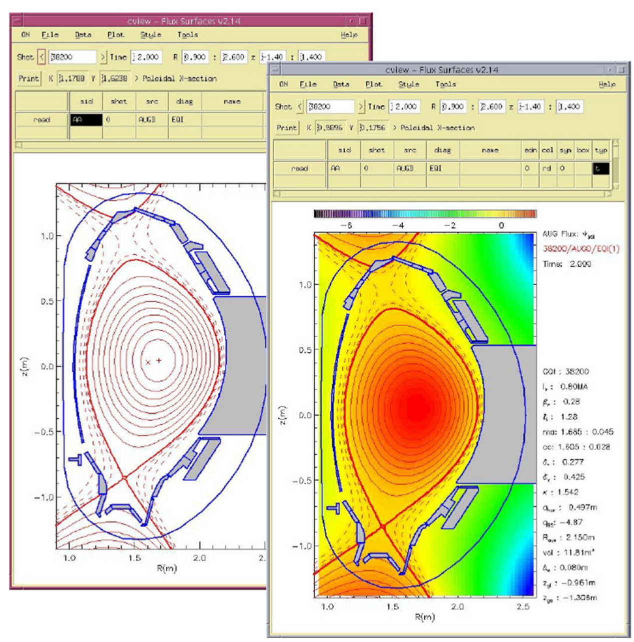


Figure 1: Example of magnetics flux surfaces as represented in CView used at ASDEX (courtesy from G.Conway).

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THAR03

AUTOMATED SCHEDULER SOFTWARE BASED ON METRO UI DESIGN FOR MACE TELESCOPE

Mahesh Punna, Sandhya Mohanan, Padmini Sridharan, Pradeep Chandra, Sagar Vijay Godambe
BARC, Mumbai, India

Abstract

MACE Scheduler software generates automated schedule for the observations of preloaded high energy gamma-ray sources. The paper presents the design of MACE Scheduler software covering; source rise/set time calculation algorithms; auto and manual schedule generation; various data visualizations provided for schedule and source visibility reports. The schedule generation for a specific period is automated using a filter workflow. The sources are selected for scheduling by processing the sources through a series of customizable user defined filters; source visibility filter, priority filter, priority resolution filter. The workflow provides flexibility to apply any user tailored filter criteria that can be loaded dynamically using XML schema. Loosely coupled design allowed decoupling the astronomical timing calculation algorithms from schedule preparation workflow. Scheduler provides metro UI based interface for source filtering workflow generating auto-schedule, updating the generated schedules. Tree-map visualization helped to represent hierarchical multi-dimensional schedule information for the selected date range. WPF flat UI control templates focused more on content than chrome.

INTRODUCTION

Major Atmospheric Cherenkov Experiments (MACE) Telescope (Fig. 1) is a very high energy gamma-ray telescope set up by BARC, at Hanle, Ladakh, India for the study of gamma-ray emissions from various cosmic sources in the energy region of 20GeV-10TeV. The MACE Telescope Control System is a distributed control system which comprises of functionally diverse subsystems like Drive Control system, for moving the telescope towards specific sources at proper orientation; Mirror Alignment system, to focus the Cherenkov light onto the camera; CAMERA system, which recognizes the onset of cosmic events of interest and records the signal acquired. It also consists of Sky Monitoring system, which quantifies the sky transparency level and checks the tracking accuracy of the telescope during observation; Data Archiving System (DAS), and Weather Monitoring system (WMS).

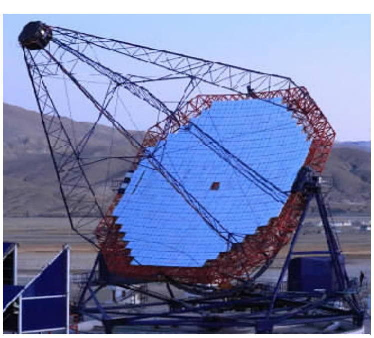
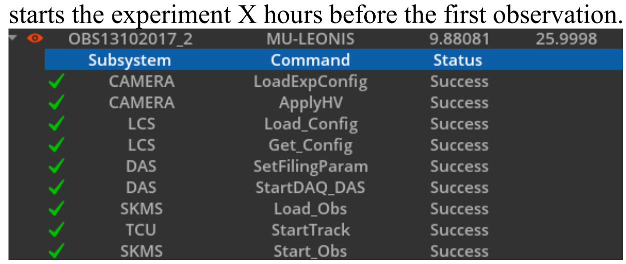


Figure 1: MACE Telescope.

The MACE Operator console holds the responsibility for integrated control and monitoring of these subsystems to conduct a successful observation run. Prior to the experiment an observation schedule selecting astronomical sources to be observed and the configuration of the various subsystems for the experiment is prepared by Astrophysicists.

The start-up sequence from the Operator console powers on the various subsystems in the required sequence and initialise the system and experiment configurations in each subsystem. This is done by running a sequence of commands (Fig. 2) from MACE Operator Console (OC), to bring the different subsystems to a ready state from where data acquisition can be started. These operation sequences are categorized into Initial run, Observation run, and Shut down run having associated pre-setup actions, experiment configuration, data acquisition and final shut down procedures respectively [1, 2]. The time required to carry out the initial run is accounted (X hours). The system automatically completes these activities and the Operator console starts the experiment X hours before the first observation.



OBS13102017_2 MU-LEONIS 9.88081 25.9998

Subsystem	Command	Status
CAMERA	LoadExpConfig	Success
CAMERA	ApplyHV	Success
LCS	Load_Config	Success
LCS	Get_Config	Success
DAS	SetFilingParam	Success
DAS	StartDAQ_DAS	Success
SKMS	Load_Obs	Success
TCU	StartTrack	Success
SKMS	Start_Obs	Success

Figure 2: Observation Command Sequence.

MACE SCHEDULER

The successful operation of the MACE Telescope for observing various high energy gamma celestial source by recording the Cherenkov events produced, highly depends on the schedule.

MACE Scheduler provides an interface to the Astrophysicists to generate observation schedule, which is required to streamline the observations of various sources with MACE telescope. A typical schedule contains 5-10 sources It is the scheduler's task to create a realisable schedule that will then be used in the observations. The challenge is to select one of those possible schedules, which will lead to good results. The schedule file thus created consists of a set of different sources (astronomical) and their coordinates along with the time of observation. Scheduler software generates date-wise schedules and stores in a configured centralized location.

MACE OC loads the schedule file for the current date and picks one source at a time to conduct the Observation Run, wherein respective source co-ordinates are sent to the Drive Control System for positioning the telescope towards the source and data acquisition is done as per the time spec-

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THBL01

CONTROL SYSTEM MANAGEMENT AND DEPLOYMENT AT MAX IV

B. Bertrand*, Á. Freitas, V. Hardion, MAX IV, Lund, Sweden

Abstract

The control systems of big research facilities like synchrotron are composed of many different hardware and software parts. Deploying and maintaining such systems require proper workflows and tools. MAX IV has been using Ansible to manage and deploy its full control system, both software and infrastructure, for quite some time with great success. All required software (i.e. tango devices, GUIs...) used to be packaged as RPMs (Red Hat Package Manager) making deployment and dependencies management easy. Using RPMs brings many advantages (big community, well tested packages, stability) but also comes with a few drawbacks, mainly the dependency to the release cycle of the Operating System. The Python ecosystem is changing quickly and using recent modules can become challenging with RPMs. We have been investigating conda as an alternative package manager. Conda is a popular open-source package, dependency and environment management system. This paper will describe our workflow and experience working with both package managers.

INTRODUCTION

The Controls & IT group, also called KITS, is responsible for the whole IT infrastructure at MAX IV. This includes everything from control system hardware and software to data storage, high performance computing, scientific software and information management systems. Within KITS, the Control System Software team manages all the software linked to the control system. With the accelerator and 16 beamlines, this represents more than 330 physical and virtual machines to configure and maintain. Ansible [1] was chosen for its simplicity of use as detailed in CONFIGURATION MANAGEMENT OF THE CONTROL SYSTEM [2] and is a great help to achieve this. The control system is made of many components that often have dependencies with each other: tango devices, controllers, GUIs. Building and being able to deploy each software individually without breaking another part is not straightforward. This requires some tools and is exactly why package managers were designed. One of their role is to keep track of dependencies between packages to ensure coherence and avoid conflicts. Using a package manager makes it easier to distribute, manage and update software.

PACKAGE MANAGEMENT

RPM

The RPM Package Manager [3] (RPM) is the package management system that runs on Red Hat Enterprise Linux, CentOS, and Fedora. As CentOS is the default Operating System at MAX IV, using RPM to distribute internal software was an obvious choice.

RPM gives us access to a large numbers of high quality packages from the main CentOS repository and others like EPEL [4], the Extra Packages for Enterprise Linux. This provides solid foundation to build on and is one huge advantage of Operating System package managers.

SPEC file RPM creation is usually based on a SPEC file [5]. It is the recipe that rpmbuild uses to build an RPM. It contains metadata like the name of the package, version, license, as well as the instructions to build the software from source with all the required dependencies as seen in Fig. 1.

```
Summary:    Tango device for Linkam T96 heater
Name:       tangods-linkamt96
Version:    1.2.0
Release:    1%{?dist}.maxlab
License:    GPL
URL:        http://www.maxiv.lu.se
Source:     %{name}-%{version}.tar.gz
Requires:   lib-maxiv-linkam-t96
Requires:   linkam-sdk
Requires:   lib-maxiv-common-cpp >= 4.0.0
Requires:   libtango9
BuildRequires: lib-maxiv-linkam-t96-devel
BuildRequires: linkam-sdk-devel
BuildRequires: lib-maxiv-common-cpp-devel >= 4.0.0
BuildRequires: libtango9-devel
# for pogo Makefile templates:
BuildRequires: tango-java

%description
Tango device for Linkam T96 heater

%prep
%setup -q

%build
make

%install
[ -z %{buildroot} ] || rm -rf %{buildroot}

# install bins
pushd bin > /dev/null
for f in *; do
    install -D -m755 $f %{buildroot}%{_bindir}/$f
done
popd > /dev/null

%files
%defattr (-,root,root,755)
%{_bindir}/*
```

Figure 1: RPM SPEC file (extract).

C++ projects are packaged using a SPEC file. RPM creation is handled by a GitLab CI [6] pipeline using maxpkg,

* benjamin.bertrand@maxiv.lu.se

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THBL02

EXPLORING ALTERNATIVES AND DESIGNING THE NEXT GENERATION OF REAL-TIME CONTROL SYSTEM FOR ASTRONOMICAL OBSERVATORIES

T. C. Shen*, J. Sepulveda, ALMA Obervatory, Santiago, Chile
P. Galeas, F. Huenupan, S. Carrasco, R. Augsburger, R. Seguel, U. de La Frontera, Temuco, Chile

Abstract

The ALMA Observatory was inaugurated in 2013; after the first eight years of successful operation, obsolescence emerged in different areas. One of the most critical areas is the control bus of the hardware devices located in antennas, based on a customized version of CAN bus. Initial studies were performed to explore alternatives, and one of the candidates can be a solution based on EtherCAT technology. This paper compares the current architecture with a new proposal compatible with the existing hardware devices, providing the foundation for new subsystems associated with ALMA 2030 initiatives. The progress of a proof of concept is reported, which explores the possibility of embedding the existing ALMA monitor and control data structure into EtherCAT frames, using EtherCAT as the primary communication protocol to monitor and control hardware devices of ALMA telescope subsystems.

INTRODUCTION

The ALMA Observatory was inaugurated in 2013; after the first eight years of successful operation, obsolescence emerged in different areas. One of the most critical areas is the control bus of the hardware devices located in antennas, based on a customized version of CAN bus. Initial studies were performed to explore alternatives, and one of the candidates can be a solution based on EtherCAT [1] technology. This paper compares the current architecture with a new proposal not only compatible with the existing hardware devices, but also provides the foundation for new subsystems associated with ALMA 2030 initiatives. This document reports the progress achieved in a proof of concept that explores the possibility to embed the ALMA monitor & control protocol into a EtherCAT protocol. The main goal of this phase is to obtain the technical assessment of the feasibility to implement the EtherCAT as the communication protocol to monitor and control hardware devices/controller in all the subsystems that comprises the ALMA telescope. This is a collaboration project between ALMA Observatory and the Universidad de La Frontera in the context of a QUIMAL fund (QUIMAL190009) [2], which is sponsored by Chilean National Agency for Research and Development (ANID). The main objective is to design, implement and evaluate an possible alternative of the existing antenna real time computer.

* tshen@alma.cl

THE ALMA DISTRIBUTED CONTROL SYSTEM

The ALMA control software is a distributed system that is divided into several subsystems, each focusing on different stages of the observation process. The subsystems provide software interfaces to transfer communication messages in a coordinated manner between them. Likewise, the control system is also responsible for coordinating, by means of events and/or command messages, all the activities involved in the different observation steps.

The main subsystems are Control, Correlator, Scheduling, Telescope Calibration, Executive and Archive. The software for each subsystem is implemented in one (or more) programming languages (C++, Java, Python) that support the ALMA common software (ACS) [3], CORBA-based framework. The official operating system is Red Hat Enterprise Linux Server release 7.6.

The Antenna Bus Master (ABM)

The ABM is a dedicated real-time computer to monitor and control the antenna hardware devices. The purpose of this computer is to process low level messages from all antenna devices, using a particular implementation of the CAN communication protocol [4]. The scheme of monitor and control conducted by the ABM computer is accomplished with adoption of the ALMA Monitor Bus (AMB) specification. It is a particular ALMA protocol, based on a CAN bus, to communicate with hardware elements, which defines a unique master connected with several slaves in the same bus. The AMB specification promotes a configuration that converts the transaction of CAN messages in a deterministic communication of the command control messages. The master, in a timely manner, is the only agent on the bus that can sends messages and wait responses of the other elements involved in the CAN bus. Similarly, the ABM make uses of five independent ALMA Monitor Bus channels to communicate with the devices spread out in the antenna. In every channel the ABM real-time computer acts as the CAN master and antenna hardware devices are the slaves on the CAN bus.

Hardware Device Interface (AMBSI)

The ALMA Monitor and Control Bus Interface (AMBSI) is a standard interface that defines, on the one side the physical connection of nodes on the bus, and on the other side, the application level protocol that nodes must conform to be monitored and controlled by a software control system. The AMBSI specification outlines that each ALMA device has

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THBL03

THE STATE OF CONTAINERIZATION IN CERN ACCELERATOR CONTROLS

R. Voirin*, T. Oulevey, M. Vanden Eynden, CERN, Geneva, Switzerland

Abstract

In industry, containers have dramatically changed the way system administrators deploy and manage applications. Developers are gradually switching from delivering monolithic applications to microservices. Using containerization solutions provides many advantages, such as: applications running in an isolated manner, decoupled from the operating system and its libraries; run-time dependencies, including access to persistent storage, are clearly declared. However, introducing these new techniques requires significant modifications of existing computing infrastructure as well as a cultural change. This contribution will explore practical use cases for containers and container orchestration within the CERN Accelerator Controls domain. We will explore challenges that have been arising in this field for the past two years and technical choices that we have made to tackle them. We will also outline the foreseen future developments.

CONTAINERS IN CONTROLS SYSTEMS

Containers in a Nutshell

Namespaces started being implemented in the Linux kernel in the 2000s. They provide isolation features on multiple levels: while the mount namespace prevents the process from accessing the rest of the Linux filesystem, the Process ID (PID) namespace creates an independent PID number space where the isolated process is given PID 1. There are eight namespaces in total: mount, PID, network, interprocess communication, time, time-sharing, user and cgroup.

Containers can be seen as industrialization of these isolation mechanisms, where the use of namespaces is concentrated in a single "containerization layer". A containerized application runs in an isolated manner, and requires its dependencies (libraries) to be embedded (Fig. 1).

The Open Container Initiative (OCI) provides three specifications defining how containerized applications are stored (the Image Format Specification), run (the Runtime Specification) and distributed (the Distribution Specification) [1].

CERN Use Cases

Having been used in industry for some time already, it was clear that the benefits brought by containers could translate to CERN's Accelerator Control system. In April 2020, a project was launched to introduce containers to the Accelerator Controls landscape, in order to bring added value in a variety of areas.

Firstly, is the ability to decouple from the underlying host operating system and the flexibility this brings. At CERN,

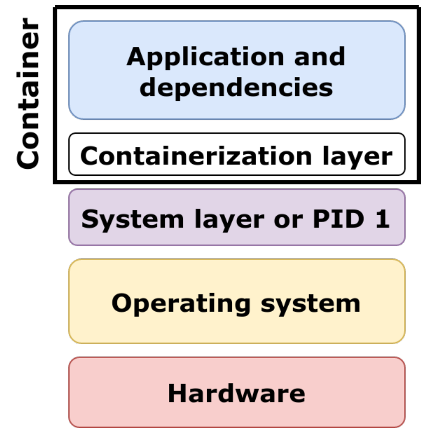


Figure 1: Overview of a containerized software stack.

WinCC OA is used to manage many industrial SCADA systems [2]. Version 3.16 officially runs on CentOS 7 and Red Hat Enterprise Linux (RHEL) 7, while 3.18 will be made to run on Red Hat Enterprise Linux 8. Due to the massive number of WinCC OA applications, many of them for critical systems, migration from version 3.16 to 3.18 must be applied progressively. In contrast, the operating system upgrade from CentOS 7 to the next platform, will concern all hosts at once. For this case, deploying WinCC OA in containers will make it possible to run version 3.16 in a CentOS 7-based container, while the underlying host is already upgraded to RHEL 8 or a derivative.

Containerization is also becoming a *de facto* standard for companies to deliver software to their clients. For example, SourceGraph [3] is used in the CERN Controls software community to index code, quickly search through it, and create statistics. All deployment options for self-hosted instances of SourceGraph are container-based.

Other software are delivered in container images for simpler deployment and upgrades. This is the case for the Nexus Repository Manager, which is used at CERN to manage Python libraries [4].

Another advantage of container-based software delivery is the idempotent behaviour of a product between development and operational environments. This can translate into two ways: streamlining the creation of development and operational releases in a similar way, and easily providing a containerized test setup. For the LHC Orbit Feedback (OFB), the latter has proven cost and time effective. Instead of running many test instances on a dedicated server and configuring them via a database, it is possible to run a local containerized copy and feed it directly with the desired parameters.

Containers are also a way to distribute software that can easily run regardless of the Linux distribution, or even the

* remi.voirin@cern.ch

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THBL04

KUBERNETES FOR EPICS IOCs

G. Knap, T. Cobb, Y, Moazzam, U. Pedersen, C. Reynolds
Diamond Light Source, Oxfordshire, UK

Abstract

EPICS [1] IOCs at Diamond Light Source (DLS) [2] are built, deployed, and managed by a set of in-house tools that were implemented 15 years ago. This paper will detail a proof of concept to demonstrate replacing these legacy tools and processes with modern industry standards.

IOCs are packaged in containers with their unique dependencies included.

Container orchestration for all beamlines in the facility is provided through a central Kubernetes cluster. The cluster has remote nodes dedicated to each beamline that host IOCs on the beamline networks.

All source, images and individual IOC configurations are held in repositories. Build and deployment to the production registries is handled by continuous integration.

Development containers provide a portable development environment for maintaining and testing IOC code.

INTRODUCTION

The approach presented here has 5 main themes:

1. **Containers**: package each IOC with its dependencies and execute it in a lightweight virtual environment. [3]
2. **Kubernetes**: centrally orchestrates all IOCs at the facility [4].
3. **Helm Charts**: deploy IOCs into Kubernetes and provide version management [5].
4. **Repositories**: Source, container and Helm repositories hold all of the assets required to define a beamline's IOCs.
5. **Continuous Integration**: source repositories automatically build containers, Helm charts and deliver them to package repositories.

An initial proof of concept (POC) has been implemented at DLS on the test beamline BL45P. All the source code for the proof of concept, plus documentation and tutorials can be found in the GitHub organization epics-containers [6].

SCOPE

The POC initially targets Linux IOCs. This includes IOCs that communicate with their associated devices over the network, as well as those that connect to local devices through USB, PCIe etc. It does not include provision for Operator Interfaces (OPIs) as these vary greatly between facilities. Future plans include:

1. Support OPIs by having a 2nd container for each IOC instance that serves OPI files over HTTP.
2. Supporting RTEMS hard IOCs: using a containerised developer environment shared with soft IOCs.
3. Support Windows IOC development through a similar approach to RTEMS.

CONTAINERS

A class of IOCs that connect to a particular class of device will all share identical binaries and library dependencies; they will differ only in their start-up script and EPICS database. Thus containerized IOCs may be represented as follows:

1. **Generic IOC**: A container image for all IOCs that will connect to a class of device.
2. **IOC Instance**: a Generic IOC image plus unique instance configuration. Typically the configuration is a single start-up script only.

This approach means that the number of container images is kept reasonably low and they are easier to manage.

Image Layering

Container images are typically built by layering on top of existing images.

For the POC, an image hierarchy is used to improve maintainability as shown in Fig. 1 below.

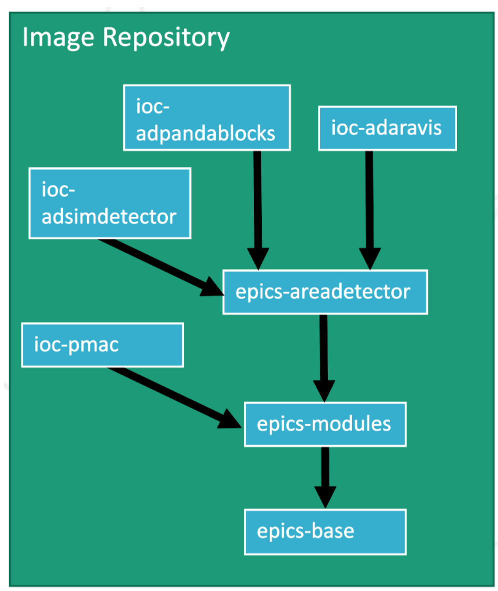


Figure 1: Image hierarchy for the generic IOCs in the current proof of concept.

EPICS base [7] and essential tools are compiled inside one image; the most commonly used support modules (primarily Asyn [8]) and the AreaDetector [9] framework also have their own images. Generic IOC images are then

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THBR01

RENOVATION OF THE TRIGGER DISTRIBUTION IN CERN'S OPEN ANALOGUE SIGNAL INFORMATION SYSTEM USING WHITE RABBIT

D. Lampridis*, T. Gingold, D. Michalik[1], T. Pereira da Silva,
A. Poscia, M. H. Serans, M. R. Shukla, CERN, Geneva, Switzerland
[1]also at Aalborg University, Aalborg, Denmark

Abstract

The Open Analogue Signal Information System (OASIS) acts as a distributed oscilloscope system that acquires signals from devices across the CERN accelerator complex and displays them in a convenient, graphical way. Today, the OASIS installation counts over 500 multiplexed digitisers, capable of digitising more than 5000 analogue signals and offers a selection of more than 250 triggers for the acquisitions. These triggers are mostly generated at a single central place and are then distributed by means of a dedicated coaxial cable per digitiser, using a "star" topology. An upgrade is currently under way to renovate this trigger distribution system and migrate it to a White Rabbit (WR) based solution. In this new system, triggers are distributed in the form of Ethernet messages over a WR network, allowing for better scalability, higher time-stamping precision, trigger latency compensation and improved robustness. This paper discusses the new OASIS trigger distribution architecture, including hardware, drivers, front-end, server and application-tier software. It then provides results from preliminary tests in laboratory installations.

INTRODUCTION

A common need among operators in the European Organisation for Nuclear Research (CERN) is to be able to observe, monitor and record the behaviour of equipment in the accelerator complex. Frequently, this behaviour is represented by analogue electrical signals which mirror physical phenomena, such as the current going through a magnet, the magnetic field, the horizontal and vertical position of the particle beam, and so on. Quite often, there is also the need to correlate these measurements, as for example in the case of transfer lines between accelerators where one might want to observe the currents going into the kicker magnets that are used to displace the beam, together with the beam position monitors detecting the beam passing to the next accelerator.

The Open Analogue Signal Information System (OASIS) [1–3] satisfies all of the above requirements by providing an oscilloscope-like user interface, which offers the possibility to select among more than 5000 available analogue signals, acquired from more than 500 multiplexed devices all across the CERN accelerator complex. This functionality implies the existence of a common trigger source, shared by all acquisition devices participating in a given measurement.

* dimitrios.lampridis@cern.ch

In fact, operators are interested in being able to trigger on different conditions, meaning that there is more than one trigger that needs to reach the acquisition devices. Today, OASIS counts over 250 such triggers which are mostly generated at a single central place, where they are also multiplexed. They are then distributed by means of a dedicated coaxial cable per digitiser, using a "star" topology.

This trigger distribution scheme has served OASIS well for many years, but it is beginning to show its limitations. Trigger multiplexers are located close to the central locations where the triggers are generated, while the connection between the multiplexers and the digitisers is done with long coaxial cables, especially since the digitisers are placed close to the analogue signal sources to preserve the integrity of the signals. Furthermore, there is no compensation for cable length differences, environmental conditions, etc. The fact that all triggers are generated at the same building creates a single point of failure. Last but not least, introducing new digitisers typically involves finding a free trigger multiplexer output and pulling the trigger cable from there to the digitiser, an expensive and not always feasible operation.

This paper presents a new trigger distribution architecture for OASIS based on White Rabbit Trigger Distribution (WRTD) [4, 5]. In this new system, triggers are distributed in the form of Ethernet messages over a White Rabbit (WR) [6,7] network, allowing for better scalability, higher time-stamping precision, trigger latency compensation and improved robustness.

BACKGROUND

OASIS

OASIS is built using a 3-tier architecture:

1. The front-end tier controls the hardware modules (digitisers, multiplexers, etc.) and provides a hardware independent interface to the upper layer. It uses the Front-End Software Architecture (FESA) [8, 9] framework to provide the interface to the server tier.

2. The server tier consists of an application server that manages the resources provided by the front-end layer and assigns them to the connections requested by the clients (the third tier). The server tier intends to maximise the number of concurrent acquisitions based on a sophisticated priority algorithm.

3. The application tier, provides the users with a graphical user interface that displays the signals and their settings, in a familiar oscilloscope-like way.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THBR02

WHITE RABBIT AND MTCA.4 USE IN THE LLRF UPGRADE FOR CERN'S SPS

Tomasz Włostowski*, Andrew Butterworth, Grzegorz Daniluk,
Julien Egli, John Robert Gill, Tristan Gingold,
Juan David González Cobas, Michel Arruat, Grégoire Hagmann, Dimitrios Lampridis,
Maciej Marek Lipiński, Mattia Rizzi, Arthur Spierer,
Maciej Sumiński, Adam Artur Wujek, Karol Adrianek,
Predrag Kuzmanović, Philippe Baudrenghien, Saúl Novel González,
Julien Palluel, CERN, Geneva, Switzerland

Abstract

The Super Proton Synchrotron (SPS) Low-level RF (LLRF) system at CERN was completely revamped in 2020 [1]. In the old system, the digital signal processing was clocked by a submultiple of the RF. The new system uses a fixed-frequency clock derived from White Rabbit (WR) [2]. This triggered the development of an eRTM module for generating very precise clock signals to be fed to the optional RF backplane in MTCA.4 crates. The eRTM14/15 sandwich of modules implements a WR node delivering clock signals with a jitter below 100 fs. WR-clocked RF synthesis inside the FPGA makes it simple to reproduce the RF elsewhere by broadcasting the frequency-tuning words over the WR network itself. These words are received by the WR2RF-VME module and used to produce beam-synchronous signals such as the bunch clock and the revolution tick. This paper explains the general architecture of this new LLRF system, highlighting the role of WR-based synchronization. It then goes on to describe the hardware and gateware designs for both modules, along with their supporting software. A recount of our experience with the deployment of the MTCA.4 platform is also provided.

INTRODUCTION

The High Luminosity LHC (HL-LHC) project at CERN aims to increase the integrated luminosity of the LHC by a factor of 10 in the 10-12 years after its implementation in 2027. As a result of new requirements for the LHC beam, the whole CERN injector complex has undergone an extensive upgrade program. For the SPS, the synchrotron just upstream of the LHC, the new requirement for a beam intensity of 2.3×10^{11} protons/bunch with a bunch spacing of 25 ns resulted in a need to overhaul the complete accelerating system, including cavities, amplifiers and LLRF.

The new LLRF system needed to be ready in a short amount of time and required a significantly higher data transfer rate from the cards to the host PC than the legacy VME platform. A decision was therefore taken to capitalize on the effort of DESY and other institutes, as well as the Commercial-Off-The-Shelf (COTS) components using the MTCA.4 standard. Field Programmable Gate Arrays (FPGA) and System-on-Chip (SoC) solutions were used extensively to speed up the development and provide the flexibility allowing the system to be reused in future applications.

White Rabbit (WR) timing technology plays a key role in several parts of the system:

- It is used to derive a very low-noise base clock signal which is then used to sample the cavity antenna and beam Pick-Up signals, and to synthesize the RF drive signals.
- It is the transmission medium through which the LLRF system receives bending magnetic field information in real time.
- Coupled with Direct Digital Synthesis (DDS) technology, it allows the LLRF system to transmit the RF signals not as physical signals but as messages containing Frequency-Tuning Words (FTW) which allow receivers to replay the RF in synchronism all around the accelerator. This allows distributing the reference RF phase with fixed and very stable latency.

This paper does not aim at describing the upgraded LLRF system in general, but just the synchronization aspects and the use of the WR technology therein. After a quick introduction to the general architecture of the system, we describe the low-noise eRTM14/15 clock signal generation and distribution module. We then move on to the module allowing regeneration of RF signals based on reception of FTWs, the WR2RF-VME. Finally, we share our experience as new users of the MTCA.4 form factor, hoping it can be useful to others in their exploration for optimal platforms to implement LLRF or other types of systems.

GENERAL ARCHITECTURE

The overview of the SPS LLRF system architecture is shown in Fig. 1. Note that it focuses on the usage of WR in the system and omits many details of the RF part.

The renovated system drives six 200 MHz RF cavities and is implemented entirely in the MTCA.4 form factor. Each cavity has a dedicated Cavity Controller (CC), consisting of a Struck SIS8300KU card [3] and a DS8VM1 analog frontend/vector modulator RTM from DESY [4]. The CC's primary role is to maintain stable cavity power and phase, compensating the error introduced by the power amplifier (the Polar Loop) as well as handling the cavity beam loading

* Tomasz.Wlostowski@cern.ch

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THBR03

PROTOTYPE OF WHITE RABBIT BASED BEAM-SYNCHRONOUS TIMING SYSTEMS FOR SHINE*

P.X.Yu, Y.B. Yan†
Shanghai Advanced Research Institute, Chinese Academy of Sciences
201204 Shanghai, P.R. China

G.H. Gong, Y.M. Ye
Tsinghua University
100084 Beijing, P.R. China

J.L. Gu, L. Zhao, Z.Y. Jiang
University of Science and Technology of China
230026 Hefei, P.R. China

Abstract

Shanghai HIgh repetition rate XFEL aNd Extreme light facility (SHINE) is under construction. SHINE requires precise distribution and synchronization of the 1.003086MHz timing signals over a long distance of about 3.1 km. Two prototype systems were developed, both containing three functions: beam-synchronous trigger signal distribution, random-event trigger signal distribution and data exchange between nodes. The frequency of the beam-synchronous trigger signal can be divided according to the accelerator operation mode. Each output pulse can be configured for different fill modes. A prototype system was designed based on a customized clock frequency point (64.197530MHz). Another prototype system was designed based on the standard White Rabbit protocol. The DDS (Direct Digital Synthesis) and D flip-flops (DFFs) are adopted for RF signal transfer and pulse configuration. The details of the timing system design and test results will be reported in this paper.

OVERVIEW

Owing to the wide range of applications of X-rays in the research fields of physics, chemistry and biology, facilities with the ability to generate X-rays were developed continuously in the last century. The free electron laser (FEL) is a novel light source, producing high-brightness X-ray pulses. To achieve high-intensity and ultra-fast short wavelength radiation, several X-ray FEL facilities have been completed or under construction around the world [1].

The first hard X-ray FEL light source in China, the so-called Shanghai HIgh repetition rate XFEL aNd Extreme light facility (SHINE), is under construction. It will utilize a photocathode electron gun combined with the superconducting Linac to produce 8 GeV FEL quality electron beams with 1.003086MHz repetition rate.

* Work supported by Shanghai Municipal Science and Technology Major Project
† yanyingbing@zjlab.org.cn

SHINE timing system is design to provide precise clock pulses (Trigger) for drive laser, LLRF, solid state amplifiers, kicker, beam and optical instruments, etc. It will ensure the electron beam is generated and accelerated to the design energy, to produce the free electron laser, while completing the beam and optical parameters measurement and feedback. The White Rabbit (WR) technology was evaluated and will be adopted.

ARCHITECTURE

SHINE timing system is composed of one master node, WR switchs and more than 500 slave nodes. The master node receives reference signal from the synchronization system. The switches distribute the clock to all the nodes in the network using a hierarchical architecture. The node basic functionality comes in the form of an IP Core called WR PTP Core. They can be standalone trigger fanout modules or FMC boards, which can be embedded in the DBPM and LLRF processor. The system architecture is shown in Figure 1.

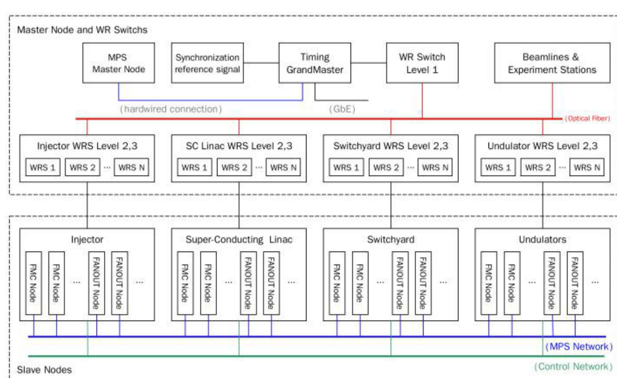


Figure 1: SHINE timing system architecture.

Three functions are designed: beam-synchronous trigger signal distribution, random-event trigger signal distribution and data exchange between nodes. The frequency of the beam-synchronous trigger signal need be divided according to the accelerator operation mode. Each output pulse need be configured for different fill modes.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THPV001

SUPERVISORY SYSTEM FOR THE SIRIUS SCIENTIFIC FACILITIES *

L.C. Arruda†, G.T. Barreto, H.F. Canova, J.V. B. Franca, M.P. Calcanha,
Brazilian Synchrotron Light Laboratory (LNLS) Campinas, Brazil

Abstract

A general supervisory system for the scientific facilities is under development at Sirius, the Brazilian 4th generation synchrotron light source. The data generated by different classes of equipment are generally available via EPICS or industrial protocols such as OPC-UA provided by commercial automation systems. However, as the number of beamlines and laboratories expands, the effort to properly gather, display and manage this data also scales up. For this reason, an aggregating supervisory system is proposed to monitor the systems: power distribution, personal safety, beamline components, cryogenic fluids; mechanical utilities, air conditioning, among others. This work presents the overall system architecture, functionalities, and some user interfaces.

INTRODUCTION

The general supervisory is a Supervisory Control and Data Acquisition (SCADA) system. It aims to provide a simplified web visualization and concentrate the creation of alarms notifications of Sirius' scientific facilities. The system final users are the facilities' support groups.

This article is divided into parts that discuss architecture, information organization, graphical user interface (GUI), and key performance indicators (KPIs).

ARCHITECTURE

The parts that compose the system and the communication protocols used appear in Fig 1. The main server is the Siemens WinCC Unified Runtime [1] and it aims to exchange data with other devices, process information, handle alarms and communicate with the web clients. The Experimental and Industrial Control System (EPICS) [2] data server is used for concentrating the Epics Process Variables (PVs) data from the installations' EPICS servers and provide data to the main server using only one OPC Unified Architecture (OPC UA) [3] connection. The external communication server is intended to expand the way notifications can reach the user, in addition to the web clients alarms tables, providing services like sending emails, Telegram [4] and SMS messages. The SMS messages are sent by the Siemens 3G modem Scalance M874-3 [5] using a Socket protocol between the modem and the external communication server. The connection between the programmable logic controllers (PLCs) and the Main server uses a Siemens proprietary protocol based on TCP/IP, in these set of PLCs are included the equipment and personal protection systems [6].

* Work supported by the Brazilian Ministry of Science, Technology and Innovation
† lucas.arruda@lnls.br

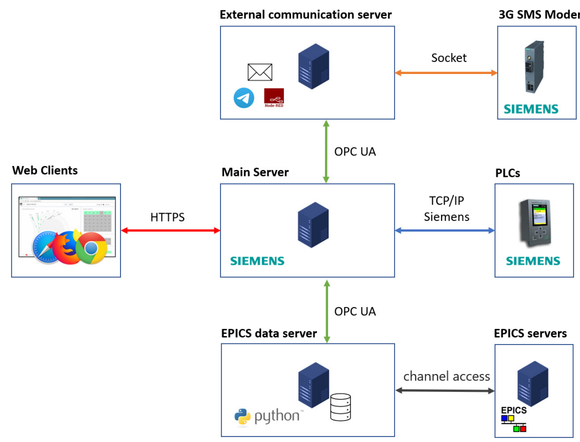


Figure 1: Architecture and communication schema.

Some of the Main server performance characteristics include the capacity to connect with 600,000 external tags, to have 200,000 internal tags, generate 200,000 discrete alarms, connect to 128 Siemens S7 SIMATIC PLCs, 10 OPC UA clients, and 100 web clients [7].

Access to the SCADA system uses password-protected authentication. The system is available only in the internal network, and user credentials needed are the same used to access other computational resources.

A software was developed to run on the EPICS data server using PyEPICS [8]. The update of data obtained from installation EPICs servers is configurable and is set to occur every second, this period is seen appropriated due to the absence of the need for quick diagnoses. Right after the PV is read, the OPC UA variable is updated.

To record trends and to perform more specifics diagnostics, when a correlation is needed, the tool used is the Archiver [9].

INFORMATION ORGANIZATION

Usually, the users are interested in specific parts of the scientific facilities related to their expertise area such as electrical power distribution, mechanical utilities, vacuum, radiological protection, among others. Considering that support groups' work structure may be changed, the supervisory information was organized by the facilities subsystems and the user is responsible for finding their interest area.

The GUI hierarchy pattern is shown in a general form in Fig. 2. The screens are currently grouped in the general view, infrastructure, beamlines, safety, statistics, and support labs. Inside each group, there is a division by subsystem and inside each subsystem, there are one or more personalized screens related to the subsystem and one

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THPV004

OPEN-HARDWARE KNOB SYSTEM FOR ACCELERATION CONTROL OPERATIONS

E. Munaron, M. Montis, L. Pranovi, INFN-LNL, Legnaro, Italy

Abstract

Nowadays technologies in LINAc facilities brought the common Human-Machine Interfaces (HMIs) to be more aligned to the standards coming from the information technology (IT) and the operators started to interact to the apparatus with the common computers' instruments: mouse and keyboard. This approach has both pros and cons. In order to minimize the cons and with the idea of providing an alternative to interact with HMIs, we tried to design and realize an open-hardware knob system solution.

INTRODUCTION

In the market, in addition to the standard devices (such as keyboard, mouse, and so on), there are several HMI controllers used to interact with personal computers. This kind of hardware is based on encoders and buttons and it needs dedicated drivers for specific operating systems (OSs) or software to work.

Sometimes software tools and applications adopted by the control system environment can introduce limitations and constraints in the usage of these commercial devices.

To overcome this limitation (in terms of drivers and OS interface), the need for a new technical solution would be suitable.

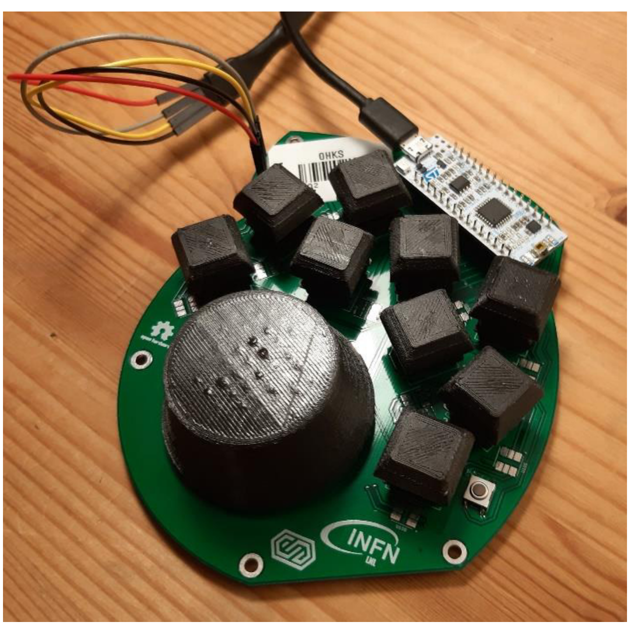


Figure 1: The open-hardware knob controller prototype.

THE OPEN-HARDWARE KNOB CONTROLLER

Because of the heterogeneous situation in terms of hardware and software solutions adopted for the different functional systems composing the facilities at INFN National Laboratories in Legnaro, the new controller should guarantee to be easily interfaced with several kinds of instruments and devices. According to this assumption and based on the talk by Kerry Scharfglass during KiCon 2019 [1], we started to study and design a new knob controller equipped with an encoder and buttons which has to achieve the following goals:

- Easy to configure
- Multi-platform
- Cost-optimized
- Adopt public licenses for both hardware and software

Unlike many proprietary solutions, this hardware interface can be recognized as a USB keyboard from any kind of device and is virtually compatible with any modern operating system. Key buttons and encoder can be programmable and dynamically reconfigurable by the user if needed.

In addition to the technical assumptions previously mentioned, we've chosen to release the project under Open Hardware License (OHL) [2] and GNU General Public License version 3 (GPLv3), so any developer or user interested in this work will be free to reproduce, develop, customize and share his product.

ELECTRONICS

The hardware (Figure 1) has been structured on a Printed Circuit Board (PCB) where the following parts are mounted:

- 9 Cherry-MX type keys
- 1 mechanical encoder
- 1 microcontroller

The keys are used to simulate, at the firmware level, the pressure of one keyboard button or a combination of them. Each key is equipped with anti-bounce circuitry and adequate ESD protection (Human-Body Model - HBM) to prevent a malfunction or breakdown of the electronics.

The microcontroller is devoted to managing the USB HID communication to the target system (such as a personal computer or a control device). To have multiple options in terms of hardware solutions for the microcontroller, the PCB has been realized to be compatible with both ARM STM32 microcontroller [3] and Teensy LC module [4]. This degree of freedom is very useful because it let developers select the preferred software toolchain for firmware implementation: for example, the Teensy LC module

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THPV005

VIRTUAL REALITY AND CONTROL SYSTEMS: HOW A 3D SYSTEM LOOKS LIKE

L. Pranovi, M. Montis, INFN-LNL, Legnaro, Italy

Abstract

Virtual Reality (VR) technology and its derivatives are mature enough to be used in environments like a nuclear research laboratory, to provide useful tools and procedures to optimize the tasks of developers and operators. Preliminary tests were performed [1] to verify the feasibility of this technology applied to a nuclear physics laboratory with promising results. Since this technology is rapidly diffusing in several different professional heterogeneous environments, such as medicine, architecture, the military and industry, we tried to evaluate the impact coming from a new kind of Human-Machine Interface based on VR.

PRELIMINARY WORKS

In a complex environment like a nuclear facility, many tasks can be difficult to execute because of the limitations (in terms of time and availability) due to the normal operations. In this scenario, the usage of Virtual Reality Technology can be an extraordinary way to overcome these limitations.

Among the several possibilities offered by the daily work, we focused on three main aspects: data collection (used to verify the incoherencies among the data provided by the groups involved in specific tasks and projects and to correct them on design and documentation), training (used to train operators to work in parts of the particle accelerator, giving them the opportunity to familiarize with the system despite its real availability) and machine maintenance.

The studies executed and the proof of concept designed and implemented verified the maturity and the versatility of this technology: the application developed gave us preliminary good feedbacks for the areas of interest previously mentioned and the results were very promising and pushed us to extend studies and application functionalities of the prototype, embracing different hardware solutions and integrating heterogeneous data and information.

At the same time, the work done has been consolidated and extended: the training based on VR technology has obtained several good feedbacks (Figure 1) and, accordingly, a new VR experience for radioprotection staff is under discussion.

VIRTUAL REALITY AND AUGMENTED REALITY TECHNOLOGIES

In the last decade, the mayor IT companies invested a lot of effort in VR technology and, as results, several products arrived on the market.

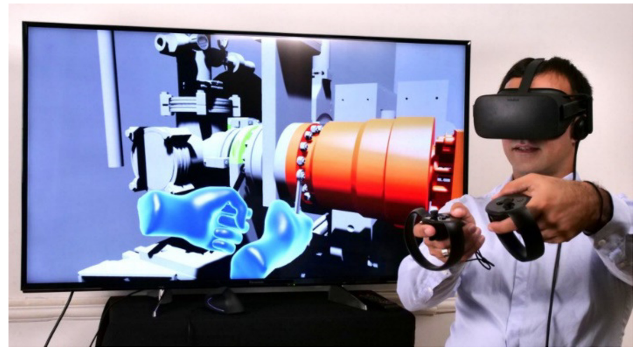


Figure 1: Beta tester for VR training.

At the same time the cost related to this kind of products become more attractive for the end user. In these last years, while VR devices are becoming quite common, first AR (Augmented Reality) type controllers are going to be available on the market (with high costs) [2].

These two kinds of technologies have different characteristics and, as consequence, offer different experiences to the user. Comparing them, it is possible to analyse VR in an interactive computer-generated experience taking place within a simulated environment, that incorporates mainly auditory and visual, but also other types of sensory feedback. It is rapidly diffusing among several different professional environments, such as medical, architecture, military and industry, with different level of interactions, based on the experience required. On the other hand, AR technology is defined as "an interactive experience of a real-world environment where the objects that reside in the real world are enhanced by computer-generated perceptual information, sometimes across multiple sensory modalities, including visual, auditory and haptic, somatosensory and olfactory. AR can be defined as a system that incorporates three basic features:

- a combination of real and virtual worlds
- real-time interaction
- accurate 3D registration of virtual and real objects.

The overlaid sensory information can be constructive (i.e., additive to the natural environment), or destructive (i.e., masking of the natural environment). This experience is seamlessly interwoven with the physical world such that it is perceived as an immersive aspect of the real environment" [3]. It is possible to say that augmented reality alters one's ongoing perception of a real-world environment, whereas virtual reality completely replaces the user's real-world environment with a simulated one.

However, AR technology has a distinct disadvantage compared with virtual reality: visual immersion. While VR completely covers and replaces your field of vision, AR

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THPV006

DESIGN OF REAL-TIME ALARM SYSTEM FOR CAFe

N.Xie,Y.H.Gua, R.Wang, B.J.Wang, IMP, LAN Zhou 730000, P.R. China

Abstract

In accelerator control, the alarm system is a very important real-time monitoring and control system. In order to find specific failures of accelerator-related equipment in time, improve the high availability of the equipment, and ensure the long-term operation of the accelerator. An accelerator alarm system based on Kafka was designed and built on the CAFe. The system uses Phoebus for architecture deployment. Kafka is used as the streaming platform of the alarm system, which effectively improves the throughput of the system and realizes real-time alarms.In order to realize the function of remote monitoring of data in the central control room, CS-Studio is used to draw the opi interface to deploy to the enterprise WeChat platform to realize remote data monitoring. This system greatly improves the response speed of fault handling and saves a lot of valuable time for accelerator fault handling.

INTRODUCTION

China Initiative Accelerator Driven System (CiADS) plays an important role in the safety of spent fuel handling. This is a global challenge that has not yet been resolved by our country and the international nuclear energy community. Chinese ADS Front-end Demo Linac (CAFe) as a CiADS prototype. Figure 1 is the layout of the CAFe superconducting linear accelerator, which consists of nine parts. CAFe as a prototype of CiADS.Its research purpose is to develop clean, efficient and safe nuclear fission energy, and to solve the future energy supply. Therefore, the stable operation of the CAFe equipment is particularly important for the debugging and stable operation of the beam experiment.

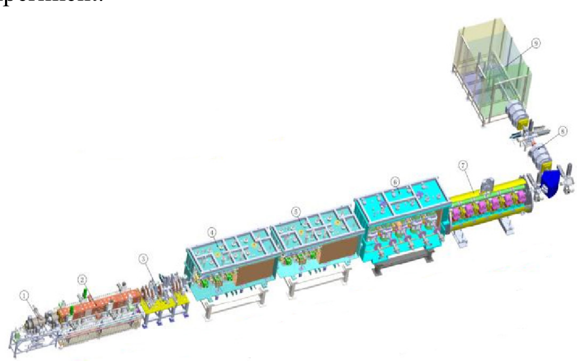


Figure 1: Layout of CAFe Superconducting Linear Accelerator.

SYSTEM STRUCTURE

Figure 2 is the overall framework of the alarm system, which is mainly composed of the control layer, the alarm service layer, the Kafka layer and the application layer.

Control Layer

IOC (input output controller) is the executor of control tasks[1]. It is used to obtain the data of the monitoring equipment and define the alarm threshold of the equipment. The sending of alarm information is based on the setting of the threshold. Each record in the IOC has multiple fields, “SEVR”, “ACKT” “STAT” and “ACKS” are related fields of the alarm and can be customized.

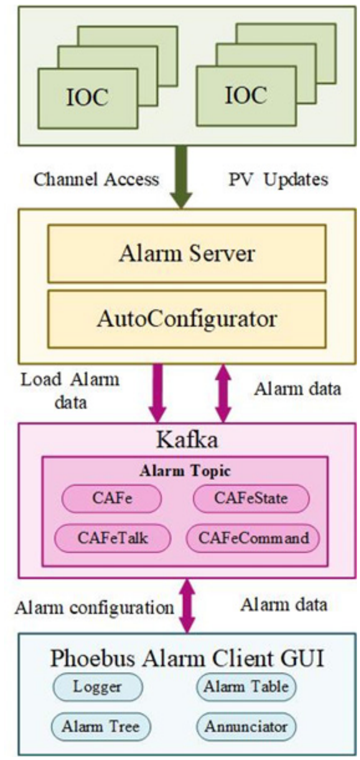


Figure 2: Framework diagram of an alarm system based on Kafka.

Alarm Service Layer

Alarm Server connects all PVs and obtains the records that need to be monitored through the CA protocol and configuration files. At the same time, Alarm Server collects the command information from the upper application “Acknowledge” in the topic "CAFeCommand" in Kafka to confirm the alarm. When the alarm status changes in the records, the Alarm Server will generate a new alarm to update the content in the "AcceleratorState". AutoConfigurator obtains the recorded configuration information and delivers alarm configuration information to the topic “CAFe”.

Kafka Layer

The Kafka layer generates 4 themes: Accelerator,AcceleratorState, AcceleratorCommand, and AcceleratorTalk. Alarm Server obtains current alarm configuration information, real-time alarm status, Acknowledge commands, and voice alarm records from the above 4 topics respectively.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THPV007

FAST CREATION OF CONTROL AND MONITOR GRAPHICAL USER INTERFACE FOR PEPC OF LASER FUSION FACILITY BASED ON ICSFF

Li Li†, Jun Luo, Zhigao Ni
Institute of Computer Application (CAEP) China Academy of Engineering Physics, MianYang, China

Abstract

Plasma electrode Pockels cell (PEPC) is the key unit of the multi-pass amplify system in laser fusion facility, whether the PEPC is effective determined the success rate of the facility experiment directly. The operator needs to conduct remote control and monitor during the facility is running, also can automatically judge whether the pulse discharge waveform is regular online. In traditional design and realization of control and monitor software, the fixed GUI cannot adapt frequent changes of the experiment requirements, and it will consume time and resources once more. We have designed a software framework (ICSFF) that loads all GUI widget elements related to control and monitor into board through plug-ins, and then by setting the respective properties, data source and built-in script of each widget achieve patterns like point control, flow control and other complex combined control, can also achieve data acquisition and varied display effects. It allows the operator drag and drop widget freely and configure the widget properties through the interface in a non-programming mode to quickly build the GUI they need. It not only apply to PEPC in facility, but also to other system in the same facility. ICSFF supports Tango control system right now, and more control systems will be supported in the future.

OVERVIEW

The control system of large-scale scientific experiment equipment is usually a heterogeneous system, including multiple subsystems with special functions, and PEPC of laser fusion facility is also a complex system, which contains a variety of hardware devices with different communication protocol interfaces. The typical large-scale control system like Figure 1. In the past, when developing remote integrated control system, we needed to design different interfaces for each different hardware protocol and design different operating interfaces for users. However, the solidified interface and interface design have great limitations. They are neither adapted to the frequently changing user operation requirements nor to the frequently changing hardware interfaces of experimental systems. Designers often need to spend a lot of time on the repetitive work of modifying and debugging code.

In order to change this situation, we have designed a software framework (ICSFF) that allows users to simply drag and drop and configure control properties through the interface in non-programming mode, and then quickly build the GUI what they need. This is not only applicable to the remote integrated control of the PEPC in facility, but also applicable to other systems in the facility.

FRAMEWORK INTRODUCTION

As mentioned above, we have developed a general control system framework for the integrated control system design of this large-scale facility, and provide editable functional modules for monitoring, control, data acquisition and storage functions with general requirements. The ICSFF software framework is a component-based distributed control system, mainly for non-real-time systems.

The software framework is suitable for the following network systems, and hardware devices are connected to the system through the network. The software of the control layer is deployed on the server or embedded controller to provide the control and data interaction of the hardware device. The monitoring layer software is deployed on the console computer to provide integrated operation, monitoring and other functions.

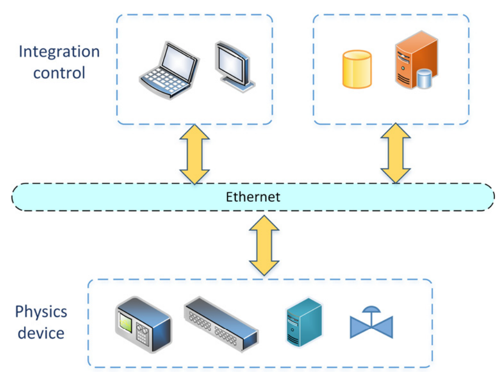


Figure 1: Typical large-scale scientific device control system structure.

The ICSFF software framework is divided into three layers: device service layer, system service layer and integrated monitoring layer [1]. See Figure 2.

The integrated monitoring layer provides a unified integrated operating environment for the control operation of the entire facility, enabling centralized control, monitoring and data management of the entire facility; the integrated monitoring layer can be divided into three different dimensions of integrated control functions according to actual needs: facilities, systems, groups.

The system service layer provides a combined control function for a single system under a bundle group, which is a large-scale control function aggregation of the device service layer, and this layer provides parameter delivery and experimental data archiving.

† lili_top@163.com

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THPV009

WEB GUI DEVELOPMENT AND INTEGRATION IN LIBERA INSTRUMENTATION

D. Bisiach†, M. Cargnelutti, P. Leban, P. Paglovec, L. Rahne, M. Škabar, A.Vigali
Instrumentation Technologies doo, Solkan, Slovenia

Abstract

During the past 5 years, Instrumentation Technologies expanded and added to the embedded OS running on Libera instruments (beam position instrumentation, LLRF) a lot of data access interfaces to allow faster access to the signals retrieved by the instrument. Some of the access interfaces are strictly related to the user environment Machine control system (EPICS/TANGO), and others are related to the user software preferences (Matlab/Python). In the last years, the requirement for easier data streaming was raised to allow easier data access using PC and mobile phones through a Web browser. This paper aims to present the development of the web backend server and the realization of a web frontend capable to process the data retrieved by the instrument. A use-case will be presented, the realization of the Libera Current Meter Web GUI as a first development example of a Web GUI interface for a Libera instrument and the starting point for the Web GUI pipeline integration on other instruments. The HTTP access interface will become in the next years a standard in data access for Libera instrumentation for quick testing/diagnostics and will allow the final user to customize it autonomously.

INTRODUCTION

In the accelerator environment, the data access is usually performed with well-established and standard access using EPICS, TANGO, Labview, and Matlab interfaces. This software does not allow only access to data but also integrates the control system and safety interlocks to prevent damage to the accelerator block unit.

The drawback of this reliable and safe type of implementation is that any new instrument that is placed in the accelerator environment needs to be configured on the server-side and usually this procedure requires time and effort since the connection is not immediate.

The need for a faster way for evaluation and testing of new devices triggered the attention to the Web interfaces that were already developed in-house by the Red Pitaya project [1] that integrates a fast and easy to access interface that can be used for quick data acquisition.

INTERFACE BETWEEN INSTRUMENT AND APPLICATION SOFTWARE

The access to the setting and the data provided by the instrument is allowed by the software structure reported in Fig.1. The lower layer is tightly bonded to the hardware interface and is responsible to communicate at a lower level with the FPGA and the CPU processes. The second layer called Machine Control Interface (MCI) connects all the user interfaces by providing APIs that enable the servers to access the configuration parameters, the status information, and the data acquired by the instrument. The server-side applications expose through the network to the client-side different application protocols: libera-ioc (EPICS), libera-ds (TANGO), libera-telnet (Labiew/Matlab), libera-cli (user access with the bash) and, as a new feature described in this paper, the libera-http interface that enables the Web access.

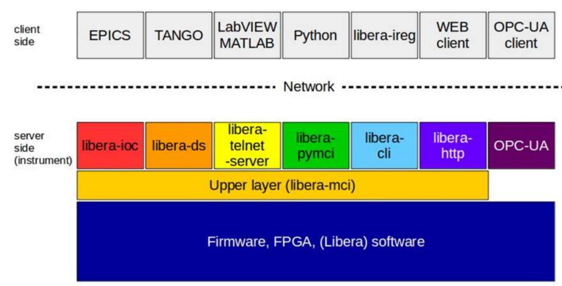


Figure 1: Application stack layer.

Some of these protocols can run in parallel (e.g. EPICS, bash, and HTTP) which makes the troubleshooting of the instrument much easier and more efficient.

HTTP APPLICATION ARCHITECTURE BASED ON REST API

As mentioned in the previous paragraph, access to the instrument can be performed by any device that can access the same network using the HTTP protocol. A typical use case is reported in Fig. 2 where the instrument is accessible using the wired and wireless network:

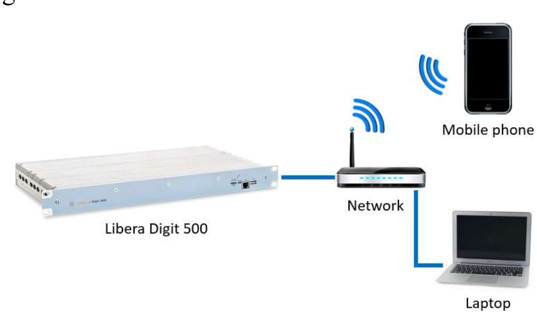


Figure 2: Access to the instrument in a local network.

The system architecture is based on the REpresentational State Transfer (REST) software architectural style and provides the services through Application Programming Interfaces (API) that allow the programmer to easily implement access to the instrument internal interfaces.

The server interface starts during the boot of the instrument and opens a port that is accessible to the other devices

† danilo.bisiach@i-tech.si

18th Int. Conf. on Acc. and Large Exp. Physics Control Systems ICALEPCS2021, Shanghai, China JACoW Publishing
ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THPV010

SCALING UP THE ALBA CABLING DATABASE AND PLANS TO TURN INTO AN ASSET MANAGEMENT SYSTEM

I. Costa†, A. Camps Gimenez, R. Cazorla, T. Fernández Maltas, D. Salvat*
ALBA-CELLS Synchrotron, Barcelona, Spain

Abstract

The "Cabling and Controls Database" (CCDB) is a central repository where the different teams of ALBA manage the information of installed racks, equipment, cables and connectors, and their connections and technical specifications. ALBA has modernized this web application for sustainability reasons and fit new needs detected throughout the last years of operation in our facility. The application has been linked to Jira to allow tracking problems in specific installed equipment or locations. In addition, it also connects to the ALBA Inventory Pools application, the warehouse management system, where the stock of physical equipment and components are maintained to get information on the life cycle of the different devices. These new features, integrated with proprietary products like Jira and Insight, aim to become ALBA's asset management system. This paper aims to describe the main features of the recent application upgrade, currently in continuous development.

INTRODUCTION

During the ALBA's design phase back in 2006, the Management Information Systems section (MIS), under the Computing Division, started to develop the "Cabling and Controls Database" (CCDB) [1]. Since then, this web application has been used as a central repository to keep information of all racks, equipment, connectors and cables used in ALBA. At its early stage, the application was very useful for the cabling tender and the installation phase. Subsequently, other features were implemented in order to ease the maintenance of the Tango Control System [2] and the Equipment Protection System (EPS) [3] by the Controls group, who gets the data through an API or directly from the web interface.

This in-house development has been evolving for years, and in 2019 started a process of technological upgrade. In this upgrade new features have been included, such as the integration between equipment instances and Jira, and also their integration to the ALBA Inventory Pools system. These integrations aim to become a new ALBA's Asset Management System.

CCDB UPGRADE

In origin, the "Cabling and Controls Database" was integrated in the ALBA's Intranet and built in python Plone/Zope which acted as the web interface to ease the visualization of the data stored in a MySQL database. The CCDB provides also an API, which has also been upgraded to a RESTful system.

Along the last years of usage, the Electronics section of ALBA, managers of the application, detected new needs and proposed new features to be developed. Without a first modernization of the technology these new features could not be developed.

Technological Upgrade

Starting on January 2019, the original CCDB application was redefined and migrated to Django Framework [4], a Python-based free and open-source web framework that follows the model–template–views (MTV) architectural pattern. Like in the old application, the new database is also a MySQL.

This upgrade was necessary to decouple the application from the outdated Plone ALBA's Intranet, following the tendency of the other applications developed by the MIS section. In the same direction, the new application's look and feel meets the style guide of the MIS' applications, based on Bootsrap [5] (see Fig. 1).

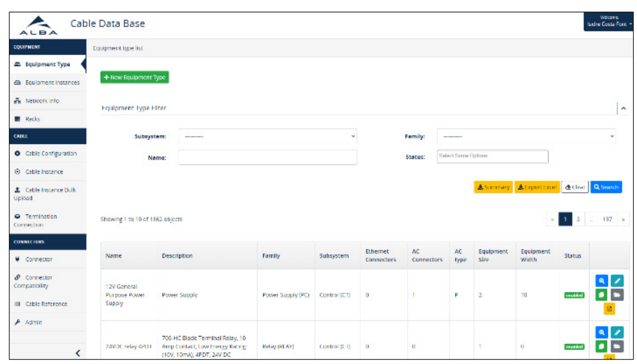


Figure 1: View of the CCDB web application.

To carry out the migration, the new application was developed from scratch and, after a period of coexistence between both the old and the new system, finally on February 2020 all the data was migrated to the new CCDB Django application and the old version was disabled.

New Features

Among the new features introduced after the migration of the application we should highlight two of them, that enable the application to be part of a future Asset Management System.

The first of these features requested by Electronics was the tracking of equipment instances and location using Jira, our issue tracking system. This feature allows to detect dysfunctional equipment or hot locations.

† icosta@cells.es
* on leave

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THPV011

NOTIFICATIONS WITH NATIVE MOBILE APPLICATIONS

B. Bertrand*, J. Forsberg, MAX IV, Lund, Sweden
E. Laface, G.Weiss, European Spallation Source ERIC, Lund, Sweden

Abstract

Notifications are an essential part of any control system. Many people want to be notified of specific events. There are several ways to send notifications: SMS, e-mails or messaging applications like Slack and Telegram are some common ones. Those solutions frequently require some central configuration to record who will receive messages, which is difficult to maintain. ESS developed a native mobile application, both for iOS and Android, to manage notifications. The application allows the users to subscribe to the topics they are interested in, removing the need for a central configuration. A web server is used as gateway to send all notifications following Apple and Google protocols. This server exposes a REST API that is used both by clients to send messages and mobile applications to retrieve and manage those messages. This paper will detail the technical implementation as well as the lessons learnt from this approach.

INTRODUCTION

The European Spallation Source (ESS) is under rapid development in Lund, Sweden. More and more parts of the control system are put into place, which means a growing number of messages and alarms are triggered. People want to be notified to keep track of what is happening and to know if any action is required. There were several ways to send notifications depending on the application. IT had a service to send SMS, some applications were relying on e-mails. We also developed Telegram and Slack bots. The Telegram bot was quite popular as users could check messages on their phone via the native mobile application. The issue was that the configuration was centralized: each new user had to be added manually with the list of topics he was interested in. That was demanding to maintain and didn't scale well. The other problem was the inclusion in existing applications which wasn't trivial. We wanted a general purpose solution that would be easy to use from any application and would unify the user experience.

CONCEPTS

We wanted users to be able to subscribe themselves to the notifications they are interested in. This would remove the need for a central configuration that is laborious to manage. To achieve this, notifications have to be grouped in categories named *services*. The number of *services* doesn't have any limit in theory. In practice, too many services would make it difficult to decide which to subscribe to. With too few services, there is a risk that the user will receive many unwanted notifications. Some services used at ESS are called Logbook On-Call, Logbook TS2, OpenXAL and Prometheus CSI. Those examples show that a service can be linked to an application (like OpenXAL), but that one application can also send messages to different services (like the LogBook).

Smartphones are part of an infrastructure that makes it easy to dispatch notifications. We chose to develop a specific mobile application that we could customize to our need. This application would be used to subscribe to the *services*, receive notifications and read messages. Two clients are available, one for Apple iOS devices [1] and one for Android users [2].

Sending notifications to a mobile phone can be done relying on Apple and Google infrastructure. We decided to design a REST API that is used both to communicate with the mobile clients and to forward the notifications received from the system. Sending a notification only requires a POST to this central server, named Notify server [3], making the integration in existing application simple.

NOTIFY SERVER

The Notify server was developed with FastAPI [4], an async Python web framework, that quickly became very popular in the past years. It is based on Starlette [5], a lightweight ASGI framework, and Pydantic [6], a data validation library using python type annotations. PostgreSQL [7] is used as database. FastAPI was designed to make writing API easy and is based on OpenAPI standard [8]. It automatically generates an interactive API documentation with exploration via Swagger UI [9]. This interface, showed in Fig. 1, is used by admin users to perform basic operation, like creating new services.

Message Sending

As described earlier, a notification has to be linked to a *service*. Only admin users can register a new service. When creating a new service, an UUID is generated and used to identify the service. This id has to be used by clients to send a notification associated to that service. This is done by sending a POST to */services/{service_id}/notifications* with the fields *title*, *subtitle* and *url* in the body. Only the title is required. Other fields are optional. The subtitle usually contains a longer description. The URL can be used to redirect to a specific website, like a LogBook entry, to have more details. This link will make the messages clickable in the mobile app. Figure 2 and Figure 3 show how to send a notification using curl or Python.

As there is no authentication, a filtering based on IP address is performed to avoid receiving messages from an untrusted source. Once received, the message is forwarded to all users who subscribed to this service using Apple and Google push infrastructure.

* benjamin.bertrand@maxiv.lu.se

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THPV012

LHC COLLIMATION CONTROLS SYSTEM FOR RUN III OPERATION

G. Azzopardi*,[1], S. Redaelli[1], G. Valentino[2], B. Salvachua[1], M. Solfaroli Camillocci[1], M. Di Castro[1]
[1] CERN, Geneva, Switzerland
[2] University of Malta, Malta

Abstract

The Large Hadron Collider (LHC) collimation system is designed to protect the machine against unavoidable beam losses. The collimation system for the LHC Run 3, starting in 2022, consists of more than 100 movable collimators located along the 27 km long ring and in the transfer lines. The cleaning performance and machine protection role of the system critically depend on the accurate positioning of the collimator jaws. The collimation control system in place enables remote control and appropriate diagnostics of the relevant parameters. This ensures that the collimators dynamically follow optimum settings in all phases of the LHC operational cycle. In this paper, an overview of the top-level software tools available for collimation control from the control room is given. These tools range from collimator alignment applications to generation tools for collimator settings, as well as collimator scans, settings checks and machine protection sequences. Amongst these tools the key upgrades and newly introduced tools for the Run 3 are presented.

INTRODUCTION

The CERN Large Hadron Collider (LHC) accelerates and collides two counter-rotating beams towards the unprecedented design centre-of-mass energy of 14 TeV [1]. It is made up of eight arcs containing superconducting magnets and eight straight sections that are referred to as insertion regions (IRs) [2].

The quench limit of the LHC superconducting magnets is of the order of 10–30 mW/cm^3 [3] and the damage limit of metal is of a few hundred kJ per cm^3 [4], to be compared to the stored beam energy of more than 300 MJ planned for Run 3. Therefore, a high-performance and robust collimation system is installed to safely dispose of beam losses in the collimation regions, providing a cleaning efficiency of 99.998% of all halo particles [5].

A total of 123 movable collimators are installed in the LHC for the start of Run 3 in 2022, whereby 14 betatron collimators, 6 injection protection collimators and all 12 transfer line collimators have been newly installed/replaced and 2 crystal collimators are planned to be replaced. The LHC ring collimators are mainly concentrated in two dedicated cleaning insertion regions (as shown in Figure 1); IR7 is dedicated to the betatron cleaning, and IR3, where the dispersion is larger, provides off-momentum cleaning [6]. Other collimators are installed in the experimental region to protect the inner triplet magnets, and in the high-luminosity regions IR1 and IR5, to dispose of the collision debris.

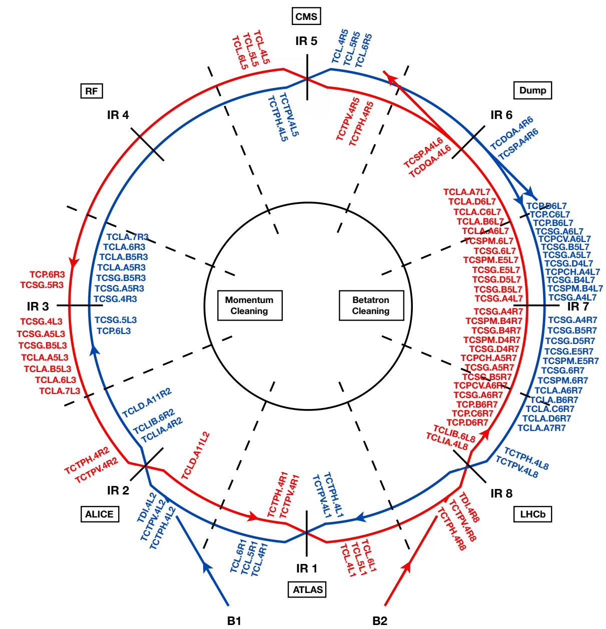


Figure 1: The Run 3 LHC ring collimation system layout.

The collimators have different designs, orientations (horizontal, vertical or skew) and roles for cleaning and protection (refer to Table 1); (1) Primary, secondary collimators, and shower absorbers are located in IR3 and IR7, (2) Tertiary collimators protect the super-conducting triplet quadrupoles in all experimental regions, (3) Injection protection devices (TDI, TCLI) protect the machine in case of injection errors (also the transfer line (TCDIL) collimators), (4) Dump collimators protect against asynchronous or unclean beam dumps in IR6, (5) Crystal collimators, in IR7, enhance ion beam cleaning, (6) Fixed aperture, passive collimators in IR3/7 shield specific magnets from high radiation doses (TCAP).

Table 1: Movable LHC Ring Collimators

Collimator	Description	Number
TCP	Primary	8
TCSG/TCSP/TCSPM	Secondary	28/2/9
TCT	Tertiary	16
TCLA	Shower Absorber	18
TCL	Physics debris	12
TCLD	Disp. Suppressor	2
TDI/TCLI	Injection Protection	6/4
TCDQ	Dump Protection	2
TCPC	Crystal collimator	4

* gabriella.azzopardi@cern.ch

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THPV013

WRAP – A WEB-BASED RAPID APPLICATION DEVELOPMENT FRAMEWORK FOR CERN'S CONTROLS INFRASTRUCTURE

E. Galatas*, A. Asko†, E. Matli‡, C. Roderick§, CERN, Geneva, Switzerland

Abstract

To ensure stable operation of CERN's accelerator complex, many Devices need to be controlled. To meet this need, over 500 custom Graphical User Interfaces (GUI) have been developed using Java Swing, Java FX, NetBeans, Eclipse SWT, etc. These represent a high maintenance cost, particularly considering the global evolution of the GUI technology landscape. The new Web-based Rapid Application Platform (WRAP) provides a centralized, zero-code, drag-n-drop means of GUI creation. It aims to replace a significant percentage of existing GUIs and ease new developments. Integration with the Controls Configuration Service (CCS) provides rich infrastructure metadata to support application configuration, whilst following the associated equipment lifecycle (e.g. renames, upgrades, dismantling). Leveraging the CERN Accelerator Logging Service (NXCALS) and the Unified Controls Acquisition and Processing (UCAP) platform, allows WRAP users to respectively, create GUIs showing historical data, and interface with complex data-stream processing. The plugin architecture will allow teams to further extend the tool as needed. This paper describes the WRAP architecture, design, status, and outlook.

INTRODUCTION

Over the past decade, a large number of expert applications have been developed to provide a way of controlling and monitoring thousands of Devices present within the CERN accelerator complex. The need for control and data visualization applies not only to production equipment, but is also essential for developing and testing new Devices. However, the ecosystem of technologies and platforms used for the development of such applications is quite fragmented. A lot of applications evolved organically based on individual needs. At the same time, the desktop graphical application tool kits traditionally used at CERN have evolved, whilst in parallel facing a major decline of community interest over the years. The Java Swing toolkit has been used since the late 90's, with Java FX coming on the scene several years ago. Most recently, given the direction of Oracle's support for Java as a graphical user interface solution, PyQt has been adopted for some graphical applications [1]. Unsurprisingly, the proliferation of custom Graphical User Interfaces (GUI) combined with an relatively rapid evolution of GUI technologies has lead to a worrying situation backed by extensive technical debt.

Instead of forcing a large and diverse community at CERN to continue learning new GUI technologies and develop their own applications, the following question was raised: "Can we turn the situation around and provide a central, data-driven GUI platform, which experts can use to configure their applications, based on their domain knowledge, without worrying about how to develop, build, deploy, and maintain it, using technologies which will undoubtedly continue to evolve?". A new Web-based Rapid Application Development Framework (WRAP) was designed as the answer to this question, and aims to replace many of the legacy applications over time. WRAP will provide a centralized solution around a common platform, integrated with core Controls sub-systems such as the Accelerator Logging Service (NXCALS) [2] and Controls Configuration Service (CCS) [3]. Since the inception of this project comes after years of application development in the organization, there is a large data-set of use-cases, feedback, and design decisions to analyse and improve upon. Leveraging this knowledge can shape WRAP into a single, unified solution for the vast majority of use-cases.

PROJECT GOALS

There are currently over 500 custom Graphical User Interfaces (GUI) relating to Device control and corresponding to different needs of Operation. Since WRAP encompasses many diverse use-cases and clients, it is important to have a clearly defined set of goals, based on which, decisions can be made regarding individual features.

The most vital attribute WRAP must exhibit, is ease of use. An intuitive User Interface (UI) is required, and beyond improving user productivity, it must encapsulate the complexity of Device modeling and communication. Wherever possible no-code, drag-and-drop configuration should be preferred, allowing experts without a programming background to work at a higher level. This level of abstraction must not, however, come at the cost of performance. Many parallel, real time visualizations should be supported.

Being a centralized service concentrates a lot of complexity on the platform itself, creating a barrier that may inhibit contributions from other teams. To offset this, contributions will instead be supported through a plugin architecture. A stable public application programming interface (API) will be made available giving access to the core functionalities of the platform. Those must in turn have high test coverage and be very conservatively altered.

Lastly, WRAP should leverage device metadata from the CCS to the highest possible degree. Not only does this remove redundant configuration steps, but also enables the restriction of configuration options to only those that are compatible with any given Device. This will help users to configure applications within WRAP whilst avoiding configuration compatibility errors that typically stem from a lack

* epameinondas.galatas@cern.ch
† anti.asko@cern.ch
‡ aemnuele.matli@cern.ch
§ chris.roderick@cern.ch

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THPV014

ADOPTING PyQt FOR BEAM INSTRUMENTATION GUI DEVELOPMENT AT CERN

S. Zanzottera, S. Jensen, S. Jackson, CERN, Geneva, Switzerland

Abstract

As Java GUI toolkits become deprecated, the Beam Instrumentation (BI) group at CERN has investigated alternatives and selected PyQt as one of the suitable technologies for future GUIs, in accordance with the paper presented at ICALEPCS19.

This paper presents tools created, or adapted, to seamlessly integrate future PyQt GUI development alongside current Java oriented workflows and the controls environment. This includes (a) creating a project template and a GUI management tool to ease and standardize our development process, (b) rewriting our previously Java-centric Expert GUI Launcher to be language-agnostic and (c) porting a selection of operational GUIs from Java to PyQt, to test the feasibility of the development process and identify bottlenecks.

To conclude, the challenges we anticipate for the BI GUI developer community in adopting this new technology are also discussed.

INTRODUCTION

The software section of the Beam Instrumentation Group at CERN (SY-BI-SW) has a mandate, to provide expert GUIs allowing hardware experts to manage and diagnose instrumentation. As explained in detail in our preliminary evaluation[1], the software stack consists of several layers, where the most high-level ones, including the GUIs, have been traditionally implemented in Java. However, as Java GUI technologies age and become deprecated, efforts[1,2,3] were made to identify suitable, more modern replacements. As these evaluations concluded, no alternative Java framework could be identified, leading to the option of PyQt.

Adopting PyQt is not trivial: Firstly, tools, services and frameworks must be developed for integration with CERN's control system. Secondly, existing GUIs cannot simply be migrated – they must be rewritten. This represents a massive effort in terms of redesigning and reprogramming. In addition, developers will have to adopt Python as a programming language, which is a challenge in itself, as Python is fundamentally different from Java in many aspects.

As integration with CERN’s control system is addressed by another team at CERN, we have been able to focus on the GUI programming aspect itself (GUI management tools, widgets, proof of concept GUIs) and also on the adaptation of our decade-old Java-oriented GUI development workflow to a more language-agnostic one, supported by more generic tools.

PYTHON TOOLS FOR EXPERT GUIS

Devtools: bipy-gui-manager

Previous integration efforts resulted in a set of tools and environments under the name of Acc-Py[4]. However, none of these tools are oriented towards GUI development: they all target a generalised Python codebase, favouring in practice CLI applications and libraries. Consequently, we proceeded to define a set of best-practices to be followed in order to develop Expert GUIs with PyQt and embarked on the creation of a specific tool, the “bipy-gui-manager” to encourage (and partially enforce) them.

Upon invocation, this command line utility collects some basic project information (project name, author name, author email etc…) and then creates a template project in the desired location, pre-configured with its own GitLab repository (created on the fly), a dedicated virtual environment, a template for Sphinx-based documentation and a workflow that provides Continuous Integration, Continuous Deployment and Continuous Documentation for the project. As a consequence, the setup effort required from the developer to get a fully standard project is close to zero. Even the README is pre-written by compiling a template README with the information gathered by the tool at setup time.

The bipy-gui-manager enables us to enforce group-specific conventions and promote best practices in general. This is valuable in homogenizing the code produced, given the number of short-term developers in the section and their different backgrounds.

One example is how bipy-gui-manager deals with GitLab repositories. In the past, the section had problems with critical pieces of software not checked into version control, or not having their repositories synchronized with the code that was effectively in production. The bipy-gui-manager addresses the issue by 1) setting up the repository for the developers, so even if they don’t know or have no time for version control, the tool takes care of it, and 2) by not allowing the developers to use its simplified release function unless they commit all their changes to GitLab. It is important here to note that bipy-gui-manager does not really block the developer from releasing uncommitted code: a slightly more expert person can still do a release in a single (although longer) command. However, we believe that such small hurdles will make programmers follow conventions, which in turn will help lower our code hand-over and maintenance efforts. This is especially true for projects made by newcomers and interns, who are often tasked with developing or maintaining expert GUIs as a way to

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THPV015

NEW TIMING SEQUENCER APPLICATION IN PYTHON WITH Qt DEVELOPMENT WORKFLOW AND LESSONS LEARNT

Z. Kovari, G. Kruk, CERN, Geneva, Switzerland

Abstract

PyQt is a Python binding for the popular Qt framework for the development of desktop applications. By using PyQt one can leverage Qt's aspects to implement modern, intuitive, and cross-platform applications while benefiting from Python's flexibility. Recently, we successfully used PyQt 5 to renovate the Graphical User Interface (GUI) used to control the CERN accelerator timing system. The GUI application interfaces with a Java-based service behind the scenes. In this paper we introduce the generic architecture used for this project, our development workflow as well as the challenges and lessons we learnt from using Python with Qt. We present our approach to delivering an operational application with a particular focus on testing, quality assurance, and continuous integration.

TIMING CONTROL APPLICATION

Accelerator Timing System

CERN continuously delivers particle beams to a range of physics experiments (end-users), each posing strict, detailed requirements with respect to the physical characteristics of the particle beam to be delivered. Hence, particle beams traverse a number of accelerators while being manipulated in various ways. For this to happen, the accelerators repeatedly "play" pre-defined cycles, which usually consist of an injection-acceleration-ejection sequence. This in turn involves many concurrent beam manipulations including particle production, bunching, cooling, steering, acceleration and beam transfer – all of which must occur at precise moments in time, often with microsecond or even nanosecond precision. The role of the Timing system is an orchestration of all these activities, ensuring that the accelerator complex behaves as expected as a function of time.

Each accelerator at CERN is associated with a Central Timing system (CT) which, based on the configuration provided by the operators and dynamic input such as external conditions, calculates in real time so-called *General Machine Timing (GMT*) events that define key moments in the accelerator cycles such as beginning of the cycle, injection, ramp, extraction, etc.

GMT events are then transmitted to *Front-End Computers (FECs)* via a dedicated cabled network known as the *GMT network*.

On the FEC side, the GMT cables are connected to *Central Timing Receiver* (CTR) modules, which decode the received GMT events and allow generation of derived local events (with optional delay) in the form of software interrupts and physical pulses for the accelerator hardware.

Timing App Suite

The control of the timing system is done via a dedicated GUI application that allows operation crews to define a collection of cycles composing a so-called *beam* (see Fig. 1). A Beam is executed by the central timing to transfer and accelerate a particular particle beam from the source, through the intermediate accelerators, up to the final experiment. Beams are then used to build a *Beam Coordination Diagram (BCD)* that defines sequencing of different particle beams sent to different destinations as illustrated in Fig. 2.

Following the renovation of the central timing itself, it was decided to also renovate the 20-year-old application used to control it, modernizing its architecture, improving usability aspects and taking advantage of the new features provided by the central timing.

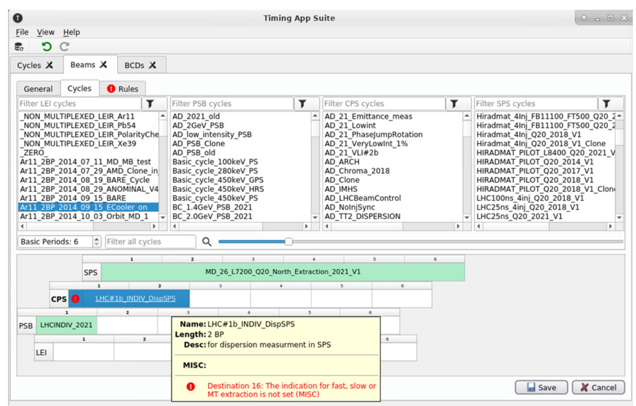


Figure 1: Timing *Beam* editor.

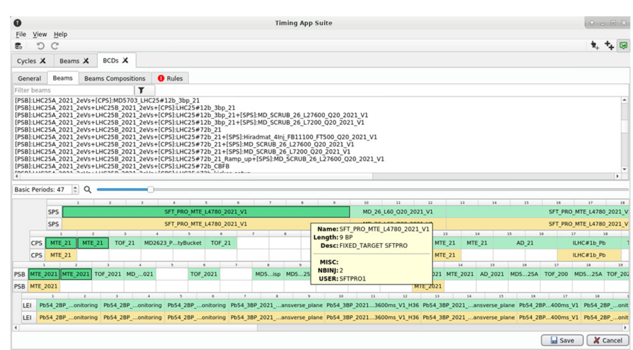


Figure 2: *Beam Coordination Diagram* editor.

ARCHITECTURE

The application was designed and implemented in a 3-tier architecture (see Fig. 3): a GUI, implemented in Python using PyQt toolkit, communicating via HTTP with RESTful services implemented in Java, and with the Cen-

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THPV021

TATU: A FLEXIBLE FPGA-BASED TRIGGER AND TIMER UNIT CREATED ON CompactRIO FOR THE FIRST SIRIUS BEAMLINES

J. R. Piton, D. Alnajjar, D. H. C. Araujo, J. L. Brito Neto,
L. P. do Carmo, L. C. Guedes, M. A. L. de Moraes,
Brazilian Synchrotron Light Laboratory (LNLS), Campinas, Brazil

Abstract

In the modern synchrotron light sources, the higher brilliance leads to shorter acquisition times at the experimental stations. For most beamlines of the fourth-generation source SIRIUS (the fourth-generation particle accelerator in Campinas, Brazil), it was imperative to shift from the usual software-based synchronization of operations to the much faster triggering by hardware of some key equipment involved in the experiments. As a basis of their control system for devices, the SIRIUS beamlines have standard CompactRIO controllers and I/O modules along the hutches. Equipped with an FPGA (Field Programmable Gate Array) and a hard processor running Linux Real-Time, this platform could deal with the triggers from and to other devices, in the order of ms and µs. TATU (Time and Trigger Unit) is an FPGA/real-time software combination running in a CompactRIO unit to coordinate multiple triggering conditions and actions. TATU can be either the master pulse generator or the follower of other signals. Complex trigger pattern generation is set from a user-friendly standardized interface. EPICS (Experimental Physics and Industrial Control Systems) process variables [1], by means of LNLS Nheengatu [2], are used to set parameters and to follow the execution status. The concept and first field test results in at least four SIRIUS beamlines are presented.

INTRODUCTION

LNLS Tatu (Timing and Trigger Unit), being mostly FPGA code running in a CompactRIO (CRIO) device (NI CRIO models 9045/9049/9035/9039), combines C-Series I/O modules to work as trigger detectors, pulse generators and a recorder of analog and digital input readouts. Tatu manages digital signals to detect events and to produce actions for synchronized operations at a beamline. That comprises sequences of operations on shutters, motorized devices and detectors, allowing the data acquisition at beamlines to be as fast as possible (also known as "fly-scan"). An example of signal combination to produce different outputs is shown in Figure 1.

Some premises that have been considered in the pursuing of this project are as follows:

- it was already decided that each hutch in a SIRIUS beamline would count on at least one device to make available TTL signal input/output and CompactRIO was the selected standard.
- additional small pieces of software, either in FPGA or Real-Time, could be included for dedicated jobs (like filtering analog readouts), in parallel to the triggering management.
- the access to the configuration parameters would happen through Nheengatu [2], so their manipulation would be immediately made available under EPICS.
- at least for the initial operation of the first beamlines, a maximum pulse rate of 4 kHz would fully meet the requirements.
- it should be highly flexible to let different conditions and outputs to be combined, just by software configuration (no FPGA recompilation needed).

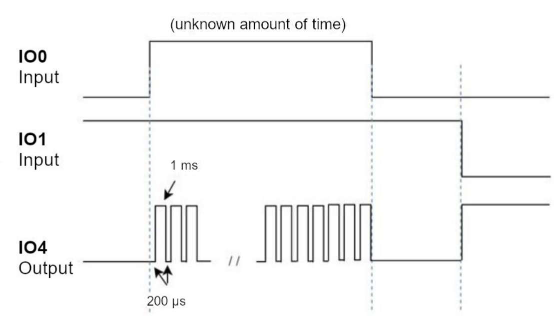


Figure 1: Two cases of output in IO4 port (pulses or "on") depending on the combination of two input ports IO0 and IO1.

THE HARDWARE

Tatu is embedded in an 8-slot CompactRIO controller, under a Real-Time Linux operating system and a programmable FPGA (through LabVIEW). Tatu has been implemented in four different models:

9045 (or 9035) – 1.30 GHz Dual-Core CPU, 2 GB DRAM, Kintex-7 70T FPGA

and the larger

9049 (or 9039) – 1.60 GHz Quad-Core CPU, 4 GB DRAM, Kintex-7 325T FPGA.

The chosen CompactRIO chassis can host C-series modules, a suite of interfaces that provide several analog or digital I/O channels, in a range of different sample rates.

One of two modules can be used under Tatu:

9401 – a 5 V/TTL digital module with 8 bidirectional I/O channels. Four channels are set to input (IO0 to IO3) and four channels to output (IO4 to IO7). In this configur-

18th Int. Conf. on Acc. and Large Exp. Physics Control Systems ICALEPCS2021, Shanghai, China JACoW Publishing
ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THPV022

MRF TIMING SYSTEM DESIGN AT SARAF

A. Gaget†, CEA Saclay IRFU, Gif sur Yvette, France

Abstract

CEA Saclay Irfu is in charge of an important part of the control system of the SARAF LINAC accelerator based in Tel-Aviv. It's including among other the control of the timing system (synchronization and timestamping). CEA has already installed and used successfully timing distribution with MRF on test bench for ESS or IPHI, so it has been decided to use the same technologies. The reference frequency will be distributed along the accelerator by a Rhode & Schwartz oscillator and the UTC time will be based on a Meridian II GPS, these 2 devices, to synchronize MRF cards, will be connected to the Event Master (EVM) card which is the main element of the timing system architecture.

The MRF timing system [1] thanks to an optical fiber network allows to distribute downstream and upstream events with a µs propagation time. Currently we are working on development to also use it for the machine protection system of the accelerator.

In this paper I will present the hardware used, timing architecture, developments and tests we have performed.

INTRODUCTION

SNRC and CEA collaborate to the upgrade of the SARAF accelerator to 5 mA CW 40 MeV deuteron and proton beams (Phase 2) at 176MHz. The timing system is a key part of the accelerator as the machine protection system. The CEA control team is in charge of them and we have selected the MRF products to provide an integrated solution.

TIMING SYSTEM ARCHITECTURE

Overview

The SARAF timing system main functionality is to distribute:

- Trigger events
- Timestamping
- Reference frequency

The main EVM is in charge of distributing these 3 above topics. This EVM generates the trigger events from sequencers, multiplexed counters or external inputs. The timestamping will be defined by the Meridian 2 GPS [2] that distributes the UTC time by NTP and the Pulse Per Second signal (PPS). The PPS consists of a signal sent to the EVM to increment the second of the timestamp with an accuracy of 10ns. The GPS also distributes a 10MHz with ultra-low phase noise to the master oscillator that distributes itself the reference frequency (176MHz) of the accelerator to the EVM and to the RF devices.

Propagation Time

For machine protection system or PostMortem analysis, we use the upstream propagation of events. For machine protection system, the event propagation time associated to a machine issue is an important point to be able to ensure that the system performance is suitable to the requirements. To test this feature, we built a test bench to measure the propagation of an event. The principle of the test is generating a signal on one input of an EVR, and measuring the time for the system to generate an output signal on any other EVR of the bench (see Fig. 1). On this test bench, the propagation time is about 700µs for each additional floor of EVM fan-out.

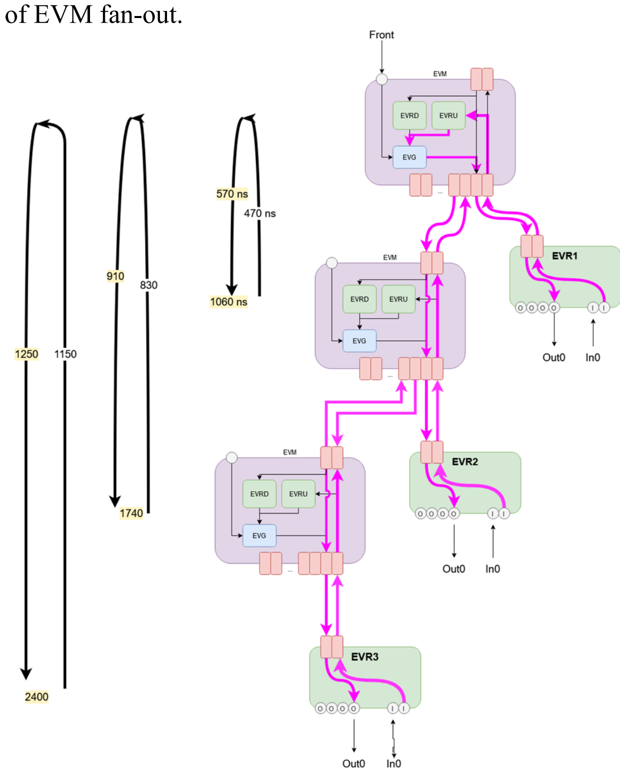


Figure 1: Test bench and result of event propagation.

Topology

The main topology is represented in Figure 2. Due to the propagation time described in the previous paragraph, we need to have as less as possible floors of EVM fan-outs. Therefore the distribution has been divided into 3 distinct parts: Injector, MEBT and SCL.

The Injector EVR has a direct link to the main EVM because it has an important role in protection and has to receive trigger events as soon as possible.

The MEBT (Medium Energy Beam Transport) part is controlled essentially by one EVM fan-out that will only be used as fan-out during beam operation. However for RF conditioning, it will produce events for RF to let cavities as independent as possible.

For the same reason in the SCL (Super Conducting Linac) part, each cryomodule will have a devoted EVM fan-out.

† alexis.gaget@cea.fr

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THPV025

A NEW TIMING SYSTEM FOR PETRA IV

T. Wilksen†, A. Aghababyan, K. Brede, H.T. Duhme, M. Fenner,
U. Hurdelbrink, H. Kay, H. Lippek, H. Schlarb,
Deutsches Elektronen-Synchrotron DESY, Germany

Abstract

The currently ongoing PETRA IV project at DESY proposes an upgrade of the PETRA III synchrotron light source towards a fourth-generation, low emittance machine. The goal is to provide X-ray energies in the regime of 10 keV bringing the electron beam production to its physical limits with respect to the smallest achievable source size, and thus approaching the diffraction limit.

The realization of this new, challenging machine implies a new design of the timing and synchronization system because requirements on beam quality and controls will become significantly more demanding with respect to the existing implementation at PETRA III. Furthermore, the PETRA IV baseline for the fast front-end electronics readout will be based on the MTCA.4 standard. Given the success of the at DESY developed MicroTCA.4-based timing system for the European XFEL accelerator, it has been chosen to utilize the MTCA.4 technology for the PETRA IV timing system as well.

We present in this paper general concepts of the timing and synchronization system, its integration into the control system as well as first design ideas and evaluations of the major timing system hardware component, a MicroTCA.4-based AMC.

THE PETRA IV PROJECT

The PETRA IV project [1] comprises the replacement of the existing 3rd generation synchrotron radiation source PETRA III with a state-of-the-art ultra-low emittance storage ring. This includes the upgrade of the storage ring infrastructure with a circumference of 2304 m as well as the redesign of the current pre-accelerator chain and construction of new beamlines. The 6 GeV storage ring will be operated at an RF frequency of 500 MHz as PETRA III. Currently, the PETRA III facility can run in either the timing mode with 40 equally distributed electron bunches at 100 mA stored beam or in brightness mode with 480 equally distributed bunches and 120 mA of beam current. The bunch pattern options are being under discussion since recent modifications of the lattice design allow now for patterns more similar to the PETRA III ones rather than what was proposed in the PETRA IV CDR.

The present booster synchrotron DESY II will be replaced by a new one, DESY IV, to meet the requirements of a low emittance beam injected into PETRA IV. While the LINAC section will be kept, the gun will be upgraded as well as the transfer section with the PIA accumulator has to be revised. The option of keeping DESY II for test beam production has to be taken into account when designing the timing and synchronization system even if this is not considered to be part of the baseline layout of the PETRA IV project. The entire facility is shown in Fig. 1.

Furthermore, the front-end electronics for diagnostics and instrumentation will be completely overhauled and based on the MTCA.4 standard. At the same time, it has been decided to change over the existing PETRA III control system using the TINE framework to a DOOCS-based one as used at the DESY FEL accelerators. This effectively leads to the necessity to redesign the entire timing and synchronization system and its controls for the storage ring as well as for the pre-accelerator chain.

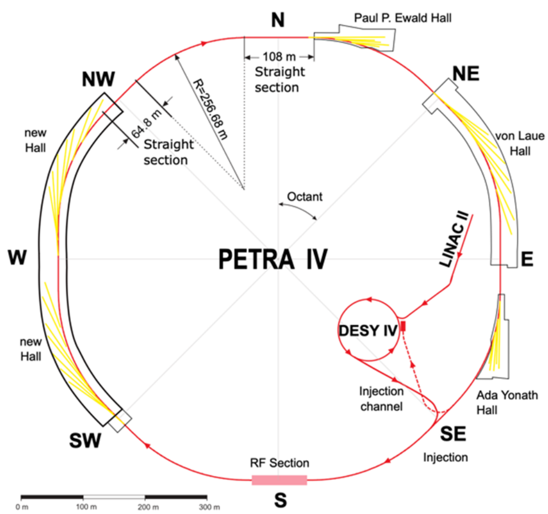


Figure 1: The PETRA IV facility layout with its existing, its new experimental halls and its pre-accelerators.

THE TIMING SYSTEM DESIGN

The overall concept of the new timing and synchronization system has to provide services to at minimum four individual synchrotron, booster, accumulator or LINAC facilities. Namely, the new PETRA IV storage ring, the new DESY IV booster ring, potentially a PIA II accumulator and a LINAC. If it is desired to continue to provide test beam services through DESY II fed by the same new LINAC and PIA II, one has to make sure, these are well enough synchronized with respect to the RF, timing and controls with the pre-accelerator chain for PETRA IV. The idea being pursued at the moment is to provide individual main oscillators and main timing system components for each of the major installations PETRA IV, DESY IV, DESY II and LINAC with PIA together. This would allow for a most flexible way of providing the different required RF frequencies and synchronization signals. Beamlines and experiments would be served by the timing system of PETRA IV, test beams by the DESY II one. The challenge

† Tim.Wilksen@desy.de

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THPV027

APPLICATION OF THE WHITE RABBIT SYSTEM AT SuperKEKB

H. Kaji*, High Energy Accelerator Research Organization (KEK), Ibaraki, Japan
Y. Iitsuka, East Japan Institute of Technology (EJIT), Ibaraki, Japan

Abstract

We employ the White Rabbit system to satisfy the increasing requests from the SuperKEKB operations. The SuperKEKB-type slave node was developed based on the SPEC board and FMC-DIO card. The firmware was customized slightly to realize the SuperKEKB needs. The device/driver for EPICS was developed. The five slave nodes have been operated since the 2021 autumn run. The delivery of the beam permission signal from the central control building to the injector linac is taken care of by new slave nodes. The timing of the abort request signal and the trigger for the abort kicker magnet are recorded with the distributed TDC system. More slave nodes will be installed in the next year to enhance the role of the distributed TDC system.

INTRODUCTION

There are two types of modern timing systems for the large-scale accelerator. One is the event-base system. Its most famous hardware is Event Timing System (EVT) [1]. The other is the timestamp-base system. The famous hardware in this case is White Rabbit (WR) [2].

Both EVT and WR enhance their roles because of the increasing requirements from the accelerator operation. The synchronous control of the distant hardware is indispensable to improve the performance of accelerators.

The SuperKEKB collider [3] at KEK utilizes EVT for the injection control including the delivery of the timing-triggers towards the beamline. It successfully implements the transcendental scheme in the position injections [4, 5].

We consider introducing WR in addition to EVT for taking care of the increasing requirements to the SuperKEKB control system and to replace the devices which close with their lifetime. We especially plan to develop the distributed data acquisition system (distributed DAQ).

NETWORK-BASED CONTROL SYSTEM

In the operation of the modern accelerators, fast and robust communication between the separated hardware is indispensable. In such a case, the accelerator control is realized by synchronously operating modules that are connected via the dedicated optical cable. Often, the cable length becomes more than a kilometer in the large-scale accelerators. Recently, the roles of the timing system are increased for this purpose.

The network-based control system is summarized in Table 1. The module that is employed at SuperKEKB is listed together with the future possibilities of EVT and WR for those purposes.

* E-mail: hiroshi.kaji@kek.jp

Table 1: List of network-based control systems: the module that is employed at SuperKEKB is listed together with the future possibilities of EVT and WR. “Commercial” is a commercial product. “Original” means an original product that is developed at KEK.

	SuperKEKB	Possibility
Trigger delivery	EVT	EVT or WR
Bucket Selection	Commercial	WR
Abort system	Original	EVT or WR
Beam permittion	Original	WR
Distributed DAQ	None	EVT or WR

In the case of SuperKEKB, the trigger delivery for the beam injection is taken care of by EVT. The commercial distributed shared memory is utilized for Bucket Selection [6]. The original modules were individually developed for the Abort Trigger System [7] and the beam permission system.

On the other hand, the WR system has several kinds of modules so that they can take care of all listed systems. We consider replacing the “Commercial” and “Original” devices with WR. Then, all network-based control systems are developed with EVT and WR. Note, the best way is to develop everything with one system. However, to develop with two systems is still better. And this experience becomes important knowledge for future colliders like Higgs factory.

APPLICATION TO SuperKEKB

In this section, we report the WR application at SuperKEKB. The entire system is discussed after introducing the specification of the SuperKEKB-type slave node.

Slave Module

Figure 1 is the pictures of the slave modules which we developed at KEK. The SPEC board [8] is selected as the slave node of WR. Only the FMC-DIO card [9] is employed in the SueprKEKB operation, so far. Two types of nodes are produced at a low cost.

The module in the upper picture of Fig. 1 is a homebuilt computer with a 2.9 GHz 6 core CPU, 8 GB of RAM, and 2.5 inch SATA III SSD. We chose the small-size commercial barebone kit with the PCIexpress slot to mount the SPEC board. All parts are mass-produced goods and can be supplied easily. The size of this module is 20 × 25 × 8 cm^3.

The firmware and software of the starting kit [10] are utilized with small customization. The transition timing of the input or output signals is informed in both higher or lower transitions while that is informed only in higher transition with the original firmware. The software runs on the Ubuntu 18.04 OS. We developed the device/driver for EPICS.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THPV028

ANALYSIS OF AC LINE FLUCTUATION FOR TIMING SYSTEM AT KEK

D. Wang*, K. Furukawa, M. Satoh, H. Kaji, H. Sugimura, Y. Enomoto, F. Miyahara, KEK, Japan

Abstract

The timing system controls the injection procedure of the accelerator by performing signal synchronization and trigger delivery to the devices all over the installations at KEK. The trigger signals is usually generated at the same phase of an AC power line to reduce the unwanted variation of the beam quality. This requirement originates from the power supply systems. However, the AC line synchronization conflicts with the bucket selection process of SuperKEKB low energy ring (LER) which stores the positron beam. The positron beam is firstly injected into a damping ring (DR) to lower the emittance before entering desired RF bucket in LER. A long bucket selection cycle for DR and LER makes it difficult to coincide with AC line every injection pulse. This trouble is solved by grouping several injection pulses into various of injection sequences and manipulating the length of sequences to adjust the AC line arrival timing. Therefore, the timing system is sensitive to drastically AC line fluctuation. The failure of timing system caused by strong AC line fluctuation and solutions are introduced in this work.

INTRODUCTION

The electron/positron collider, SuperKEKB, is upgraded from the KEKB project since 2010 at KEK, whose goal is to update the world highest luminosity record and discover new particle physics by Belle II experiment [1]. The timing system at the 700-m long injector linear accelerator (LINAC) is responsible for the injection of all accelerator complex which consist of a 7 GeV electron high energy ring (HER), a 4 GeV positron low energy ring (LER), a 2.5 GeV Photon Factory (PF) and a 6.5 GeV PF-AR ring (see Fig. 1). During the phase-2 operation in 2018, a 1.1 GeV positron Damping Ring (DR) is constructed at the middle of LINAC to lower the positron beam emittance [2].

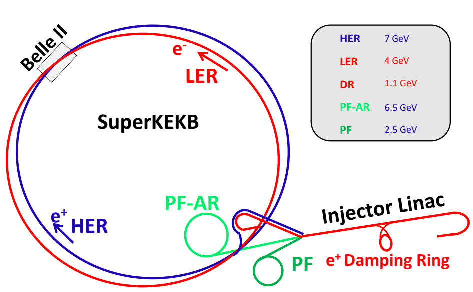


Figure 1: Overview of LINAC, SuperKEKB, and PF/PF-AR.

The event-based timing system at LINAC is required to switch the beam properties at 50 Hz by changing the event codes and additional control data. Totally 12 kinds of beam modes are defined to perform the pulse-to-pulse modulation. The master trigger signal of the timing system comes from the AC line to follow the fluctuation of power line and keep the beam energy stable. The bucket selection is implemented by adding delays to the master trigger signal. However, a long bucket selection cycle which caused by the DR makes it difficult to coincide with the AC line. A scheme called sequence shift is developed to synchronize with the 50 Hz AC line [3]. With the growth of the system complexity, several failures of timing system are observed and analyzed based on the fault diagnosis system [4].

In this paper, the reason of such failures are identified and some efforts to improve the reliability and stability of timing system are introduced.

BUCKET SELECTION FOR LER

The primary task for bucket selection is to provide the ability to select an arbitrary RF bucket in the ring for a single injection pulse. This can be achieved by adding a proper delay time to the gun triggering signal after defining the fiducial bucket in the ring. As the stable phase of RF cavity coincides based on the common frequency (CF) between LINAC and two main rings (MRs), the injection is performed based on the period of the CF [5]. After h times injection, all RF buckets are filled. The period during which all ring RF buckets can be filled is defined as a bucket selection cycle (BSC) and the period of BSC can be represented as

$$T_{\text{BSC}} = h_{MR} * T_{CF} \tag{1}$$

where h is the harmonic number (i.e., the number of RF buckets), T_{CF} is the period of common frequency between LINAC and MR.

According to the requirements of RF synchronization, several significant frequencies for timing system can be calculated in Table 1. Note that the BSC for DR only is practically useful when performing DR-injection-only mode for beam study.

Table 1: Bucket Selection Frequencies at KEK LINAC

Frequency	Period	Remarks
2856 MHz	350 ps	RF frequency for LINAC
508.89 MHz	1.97 ns	RF frequency for DR & LER
114.24 MHz	8.75 ns	Event clock
2.21 MHz	452 ns	DR revolution frequency
99.39 kHz	10.06 µs	LER revolution frequency
45.15 kHz	22.15 µs	BSC for DR only
2.03 kHz	493 µs	BSC for LER only
88.19 Hz	11.34 ms	BSC for DR and LER
50 Hz	20 ms	Beam repetition rate

* sdcswd@post.kek.jp

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THPV029

DEVELOPMENT OF TIMING READ-BACK SYSTEM FOR STABLE OPERATION OF J-PARC

M. Yang†, N. Kamikubota, K.C. Sato, N. Kikuzawa, J-PARC Center, KEK&JAEA, Japan
Y. Tajima, Kanto Information Service, Tsuchiura, Japan

Abstract

Since 2006, the Japan Proton Accelerator Research Complex (J-PARC) timing system has been operated successfully. However, there were some unexpected trigger-failure events, typically missing trigger events, during the operation over 15 years. When a trigger-failure event occurred, it was often tough to find the one with the fault among many suspected modules. To solve the problem more easily, a unique device, triggered scaler, was developed for reading back accelerator signals.

The performance of the module has been evaluated in 2018. In 2021, we measured and observed an LLRF signal as the first signal of the read-back system for beam operation. After firmware upgrades of the module, some customized timing read-back systems were developed, and successfully demonstrated as coping strategies for past trigger-failure events. In addition, a future plan to apply the read-back system to other facilities is discussed. More details are given in the paper.

INTRODUCTION

J-PARC (Japan Proton Accelerator Research Complex) is a high-intensity proton accelerator complex. It consists of three accelerators: a 400-MeV H- Linac (LI), a 3-GeV Rapid Cycling Synchrotron (RCS), and a 30-GeV slow cycling Main Ring Synchrotron (MR) [1-2]. Since the initial beam in 2006, J-PARC has been improving beam power. Concerning MR, recent beam power is about 500-kW (50-kW) by fast (slow) extraction, respectively [3].

There are two time cycles used in J-PARC: A 25-Hz rapid cycle is used at LI and RCS, a slow cycle is used at MR. When MR delivers proton beams to the NU and HD facilities, 2.48-s (fast extraction mode (FX)) and 5.20-s (slow extraction mode (SX)) cycles are used, respectively. Because the slow cycle determines the overall time behavior of the accelerators, it is also called a “machine cycle.”

The control system for J-PARC accelerators was developed using the Experimental Physics and Industrial Control System (EPICS) framework [4]. In addition, a dedicated timing system has been developed [5-6]. The J-PARC timing system consists of one transmitter module and approximately 200 receiver modules. Both types of modules were developed as in-house VME modules. Event-codes, which have information on beam destination and beam parameters, are distributed from the transmitter module to the receiver modules. A fiber-optic cable network is used for event-code distribution using several optical-to-electrical (O/E) or electrical-to-optical (E/O) modules. According to the received event-code, each receiver module generates eight independent delayed trigger signals.

Since the first beam use began in 2006, the J-PARC timing system has contributed to a stable operation of the accelerator beam [6]. Nevertheless, some timing trigger-failure events have occurred during beam operation. During each recovery process against a failure, it was often difficult to find a definite module among the many modules suspected. Such experiences have prompted us to develop a new module that can read back signals generated by the J-PARC timing system. We developed a new module, called a triggered scaler module, for this purpose [7-8].

In this paper, using one of trigger-failure events occurred in J-PARC MR as a case, the working principle, a usage in beam operation, and firmware upgrades of the triggered scaler module, are described. Moreover, a customized read-back system is introduced, followed by a discussion on the plan for future.

PAST TRIGGER-FAILURE EVENTS

Since 2006, we experienced some unexpected trigger-failure events during beam operation [8-9]. Herein, one case is given as an example, a 25-Hz irregular trigger event.

From November to December 2016, an O/E module, which was used to send a 25-Hz trigger signal from RCS to MR, started to produce irregular triggers (Fig. 1). Because the irregular triggers affected a critical beam diagnostic system, the accelerator operation was suspended several times per day [7]. It took 2 weeks to identify the troublesome O/E module.

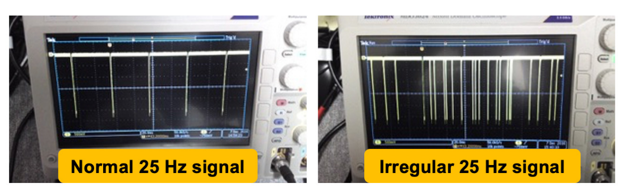


Figure 1: The normal and irregular 25-Hz trigger signals monitored by an oscilloscope during beam operation.

TRIGGERED SCALER MODULE

Introduction

A unique device, triggered scaler (hereafter TS), was designed by J-PARC control group for reading back timing signals. It is a scaler to count number of pulses in a specified accelerator cycle, and it stores the counts in a momentary array [7-8]. The differences between a TS module, a digitizer, and a simple scaler are shown in Fig. 2. Contrast to the simple scaler, the uniqueness of the triggered scaler

† yangmin@post.kek.jp

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THPV031

UPGRADE OF TIMING SYSTEM AT HZDR ELBE FACILITY

Ž. Oven, L. Krmpotić, U. Legat, U. Rojec, Cosylab, Ljubljana, Slovenia
M. Kuntzsch, A. Schwarz, K. Zenker, M. Justus, Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany

Abstract

The ELBE center for high power radiation sources is operating an electron linear accelerator to generate various secondary radiation like neutrons, positrons, intense THz and IR pulses and Bremsstrahlung. The timing system, that is currently in operation, has been modified and extended in the last two decades to enable new experiments. At the moment parts of this timing system are using obsolete components which makes maintenance a very challenging endeavour.

To make the ELBE timing system again a more homogenous system, that will allow for easier adaption to new and more complex trigger patterns, an upgrade based on Micro Research Finland (MRF) hardware platform is currently in progress. This upgrade will enable parallel operation of two electron sources and subsequent kickers to serve multiple end stations at the same time. Selected hardware enables low jitter emission of timing patterns and a long-term delay compensation of the distribution network. We are currently in the final phase of development and with plans for commissioning to be completed in 2022.

SYSTEM DESCRIPTION

Hardware

The new timing system uses hardware from Micro Research Finland [1]. MRF hardware allows a modular approach with highly flexible topology with event master modules (EVMs), which are responsible for timing event generation and distribution, and event receiver modules (EVRs), which are responsible for setting the state of a physical outputs based on the received event.

For the majority of the system hardware used shall be of the MicroTCA form factor wherever possible, but certain user/experiment stations will use PCIe cards, which allow for up to 10 trigger outputs in a smaller package and are more cost effective.

Each of the two ELBE injectors will have an EVM, which will be responsible for generating independent timing pattern, allowing for both independent operation in separate beamlines and also common emission into ELBE accelerator.

Beam diagnostics, low level frequency control (LLRF) and other devices that need coordinated triggering will be connected to the EVRs via MicroTCA backplane trigger lines (if device lives in the same crate as EVR and supports triggering on a backplane signal), front panel output (if TTL level is needed) or through any of the Universal Modules that provide variety of optical and electrical level triggers.

As the number of outputs is limited to 8 per EVR, 4 front panel TTL trigger signals and 4 signals from Universal Modules, MRF offers to extend the number of trigger signals via rear transition module (RTM), where 10 additional trigger output signals can be configured and routed. Type of the input or output signal from the RTM is determined by the type of the Universal Input/Output (I/O) module selected as shown in Figure 1.

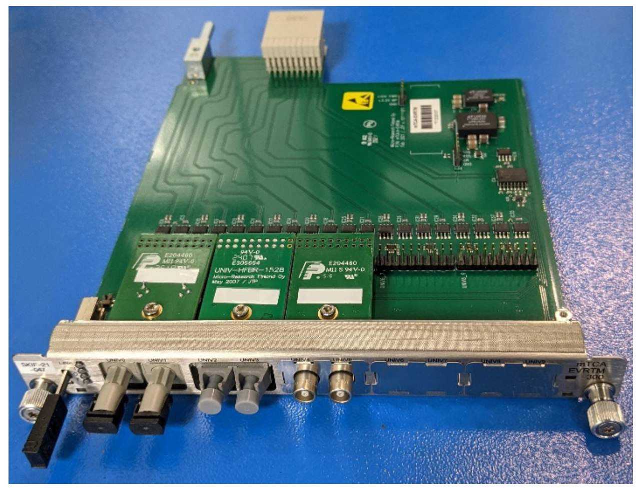


Figure 1: Micro Research Finland timing receiver rear transition module equipped with universal output modules.

All MRF boards (EVMs and EVRs) from the 300 series provide a delay compensation feature, where event propagation delay through whole distribution network is continuously measured and EVRs adjust their internal delay to match a programmed desired target delay. Each of the EVRs can have a different target delay setpoint, but adjusting target delay on an EVR will hold you back for approximately 15 minutes while the measurement and the loopback mechanism stabilizes.

To synchronize new timing system with the accelerator RF we plan to lock the internal oscillator of the master EVM to an externally provided frequency of 130 MHz through the dedicated input on front panel of the master EVM. This external reference frequency will be locked to both 1.3 GHz RF frequency and 26 MHz thermionic gun master oscillator and it will provide a 130 MHz event clock rate with which timing events will be distributed from the EVMs to the EVRs.

ELBE has multiple beamlines (as shown at Figure 2) but at the moment only one kicker is used to split the beam into two beamlines. For each beamline branch a dedicated bunch pattern has to be generated and sent to appropriate gun. A combined interlock and logic block interleaves the pulse trains and allows the machine interlock system to disable individual gun clock signals. As an upgrade to the machine protection system (MPS), an upgrade is foreseen where it will be able to react on interlock events after the kicker and only disable the corresponding pulse train.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THPV032

THE DEMONSTRATOR OF THE HL-LHC ATLAS TILE CALORIMETER

Pavle Tsotskolauri†, on behalf of the ATLAS Tile Calorimeter System*
Tbilisi State University, Tbilisi, Georgia

Abstract

The High Luminosity Large Hadron Collider (HL-LHC) has motivated R&D to upgrade the ATLAS Tile Calorimeter. The new system consists on an optimized analogue design engineered with selected radiation-tolerant COTS and redundancy layers to avoid single points of failure. The design will provide better timing, improved energy resolution, lower noise and less sensitivity to out-of-time pileup. Multiple types of FPGAs, CERN custom rad-hard ASICs (GBTx), and multi-Gbps optical links are used to distribute LHC timing, read out fully digital data of the whole TileCal, transmit timing and calibrated energy per cell to the Trigger system at 40 MHz, and provide triggered data at 1 MHz. To test the upgraded electronics in real ATLAS conditions, a hybrid demonstrator prototype module containing the new calorimeter module electronics, but still compatible with TileCal legacy system was tested in ATLAS during 2019-2021. An upgraded version of the demonstrator with finalized HL-LHC electronics is being assembled to be tested in testbeam campaigns at the Super Proton Synchrotron (SPS) at CERN. We present current status and results for the different tests done with the upgraded demonstrator system.

Introduction

The upgrade of the Large Hadronic Collider (LHC) to the High-Luminosity Large Hadronic Collider (HL-LHC) is aimed to deliver up to ten times peak luminosity [1]. HL-LHC is designed to deliver collisions at the luminosity of 7.5×10^{34} cm^{-2} s^{-1} and up to 200 simultaneous proton-proton interactions per bunch crossing. This environment necessitated a Phase-II upgrade of the ATLAS detector [2]. The Tile Calorimeter (TileCal) is the central section of the hadronic calorimeter of ATLAS. It plays an important role in the measurements of jet and missing transverse momentum, jet substructure, electron isolation, energy reconstruction and triggering, including muon information. To meet the requirements of HL-LHC, upgraded electronics were tested by using The Hybrid Demonstrator in real conditions. The Hybrid Demonstrator combining fully functional upgraded Phase-II electronics with analog trigger signals to be compatible with present and legacy ATLAS interface. Demonstrator comprises four prototype mini-drawers, each equipped with 12 Photo-Multiplier Tubes (PMT) with 3-in-1 cards, Mainboard, Daughterboard and high voltage regulation board. Finger Low Voltage Power supply (fLVPS) is powering all four mini-drawers with 10V. The Hybrid Demonstrator is connected to an off-detector PreProcessor module with a patch panel. PreProcessor modules provide data and control interfaces between on-detector electronics and both legacy and Phase-II Trigger and Data AcQuisitions interface (TDAQi) [3].

Photo-Multiplier Tubes

At every bunch crossing light produced by scintillator plates is transmitted by wavelength shifting fibres. PMTs are responsible for converting this light coming from TileCal cells into analog signal and transfer it to the next stage of a signal chain. Every PMT is equipped with a High Voltage Active Divider (HVAD). The function of HVAD is to divide high voltage coming from high voltage system to 8 PMT dynodes. The high voltage for PMTs is in the range of 600-900 Volts. HVAD is also responsible for linear PMT response. PMT Block consists of PMT, HVAD and 3-in-1 card. For individual PMTs and PMT Blocks, there are two different test benches to ensure their performance and correct functionality. Before PMT Blocks are assembled each PMT is tested to ensure their physical properties. After this PMT Blocks are tested with Portable Readout Module for Tile Electronics (PROMETEO) system which ensures the correct functionality of PMT blocks alongside other demonstrator modules [3].

3-in-1 Card

The 3-in-1 card is part of the PMT Blocks, see Figure 1. They are responsible for shaping, amplification and integration of signal coming from PMT. 3-in-1 cards feature a 16-bit dynamic range, 50ns full width at half maximum (FWHM) time constant, fast readout with two gains (low gain and high gain), integrated slow readout, charge injection for continuous calibration over full dynamic range. Low-gain signals are summed into trigger towers (adder cards) and sent to off-detector electronics. It also consists of an analog trigger to be compatible with the current ATLAS architecture. Data from 3-in-1 cards are read by FPGAs from The Mainboard.

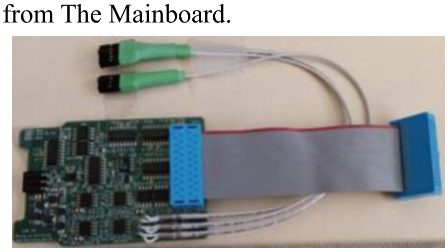


Figure 1: 3-in-1 Card [3].

Mainboard

The Demonstrator consists of four mainboards. The picture of The Mainboard is shown in Figure 2. Currently, Mainboard went through four revisions. The Mainboard is responsible for data transfer between PMT Blocks and Daughterboard. Each of them is connected to 12 PMT Blocks using Field Programmable Gate Arrays (FPGA).

† pavle.tsotskolauri@cern.ch

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THPV033

REUSABLE REAL-TIME SOFTWARE COMPONENTS FOR THE SPS LOW LEVEL RF CONTROL SYSTEM

M. Suminski*, K. Adrianek, B. Bielawski, A. C. Butterworth, J. Egli, G. Hagmann, P. Kuzmanovic, S. Novel Gonzalez, A. Rey, A. Spierer, CERN, Geneva, Switzerland

Abstract

In 2021 the Super Proton Synchrotron has been recommissioned after a complete renovation of its low level RF system (LLRF). The new system has largely moved to digital signal processing, implemented as a set of functional blocks (IP cores) in Field Programmable Gate Arrays (FPGAs) with associated software to control them. Some of these IP cores provide generic functionalities such as timing, function generation and signal acquisition, and are reused in several components, with a potential application in other accelerators.

To take full advantage of the modular approach, IP core flexibility must be complemented by the software stack. In this paper we present steps we have taken to reach this goal from the software point of view, and describe the custom tools and procedures used to implement the various software layers.

INTRODUCTION

The new LLRF system for the SPS has largely replaced old VME-based hardware with a modern installation designed around microTCA crates using PCI-express as the bus.

The update has brought many benefits, one of them being higher hardware density: what used to take a VME crate filled with modules, now is replaced with one or two microTCA cards. It has also affected the control system, as component size has shrunk from a card to an IP core.

Previously, each component was implemented as a VME module, with its own driver, user-space library and application. With the new hardware, the said approach was no longer applicable, therefore a new solution had to be defined.

WORKFLOW

This section will illustrate typical steps needed to develop reusable firmware and software. Overview of the layers constituting a component is presented in Fig. 1.

Memory Map

The process begins with hardware interface definition, starting with individual IP cores and ending with the top level map containing all components used in a card. The interface is called memory map since it defines mapping registers and memories to offsets in a card memory space. Memory map serves as the primary data source for both firmware and software developers.

Each register is described by a number of attributes, such as name, access mode (read-write/read-only), bit width, valid value range or conversion functions between raw register value and physical units.

* maciej.suminski@cern.ch

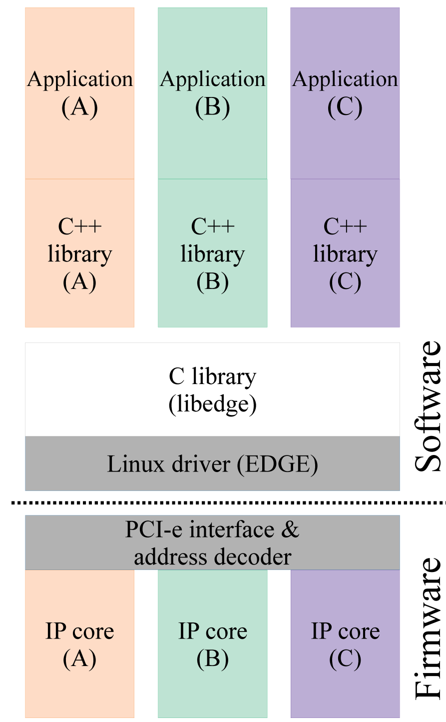


Figure 1: Example of a card implementation with several components. The white block (C library) is common to all cards and components. The grey blocks (Linux driver & address decoder) are card specific. The remaining colors show parts of reusable component stacks, each color representing a different component.

Registers may have subcomponents called fields, providing a way to give different meaning to a set of bits belonging to a particular register. This method is frequently used for status and control registers, where each bit represents a different part of the logic.

Each memory map may also include other memory maps, allowing the designer to reuse existing ones and establish a tree-like structure. The latter method is commonly applied for composing IP cores to define a card interface, also known as the top level map.

Memory maps are edited using a dedicated tool named Reksio (former Cheburashka [1]). The tool offers a graphical user interface aiding the users in memory map creation and validation. It also provides straightforward access to external tools, such as generators for various layers of the component stack.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THPV036

LASER DRIVER STATE ESTIMATION ORIENTED DATA GOVERNANCE

J. Luo†, L. Li, Z. G. Ni, X.W. Zhou, Institute of Computer Application, China Academy of Engineering Physics, Mianyang City, China

Abstract

Laser driver state estimation is an important task during the operation process for the high-power laser facility, by utilizing measured data to analyze experiment results and laser driver performances. It involves complicated data processing jobs, including data extraction, data cleaning, data fusion, data visualization and so on. Data governance aims to improve the efficiency and quality of data analysis for laser driver state estimation, which focuses on 4 aspects — data specification, data cleaning, data exchange, and data integration. The achievements of data governance contribute to not only laser driver state estimation, but also other experimental data analysis applications.

INTRODUCTON

Laser driver state evaluation is an important part of the business process of a laser shooting experiment, which mainly includes physical experiment results evaluation and driver performances evaluation. The energy, pulse power waveform and near-field results of the experimental process are extracted by using the measurement data obtained by acquisition equipments such as energy card meters, oscilloscopes and CCDs in the diagnostic system, and the energy dispersion, power imbalance and other results of a shooting experiment, as well as the gain capacity, output capacity and output stability of the driver are calculated, to evaluate the effectiveness of physical experiments and the performance status of the laser driver.

By adopting the Oracle relational database platform, all the experimental measurement data of the facility are stored [1, 2]. The early database design defined the physical structure and logical structure specification of experimental data storage, but there were no constraints on the storage format of experimental data, so there existed inconsistencies in the storage format of the same type of experimental data. Secondly, there are invalid measurements or missing measurements in the process of experimental data measurement, but such measurement data are not screened when the experimental data are stored in the database, resulting in experimental data quality problems such as missing or abnormal data items. In addition, with the laser facility putting into experimental operations, a large number of experimental measurement data are accumulated, and multiple application systems involving experimental data processing and storage are generated. For these late emerging application systems, most of them do not follow the early database design specifications in terms of data storage. Therefore, the experimental data relationship of the whole facility is complex.

The operational process of a shooting experiment.is described in Figure 1. As an important asset of the facility, the increasingly accumulated experimental data has played an important role in the operation control optimization of the facility in recent years, and the state evaluation of laser driver is one of the main contents. However, limited by the above problems such as inconsistent experimental data storage format, missing experimental data items, abnormal experimental data and complex experimental data relationship, data preprocessing consumes a lot of time, and application systems involving experimental data processing and analysis reveal common problems, such as slow development progress, repeated processing of experimental data, low computational efficiency, and uncertain analysis results, which coincides with the current situation of data preparation mentioned in literature [3].

Data governance aims to improve the efficiency and quality of data analysis and plays an important role in the whole big data analysis process [4]. In recent years, with the rapid development of big data analysis and application research, data governance has played a very significant role in enterprise big data mining, government public data sharing, industrial big data analysis, scientific research data management and other industries [5-12]. The state estimation of a laser driver involves a lot of jobs, like experimental data extraction, transformation, joint calculation and visualization. Considering the current situation of the experimental data quality and the problems faced by the data processing application system, we utilize a framework consisting with data governance and data visualization to implement the laser driver state estimation system. This paper mainly introduces and summarizes our work about the data governance part.

The next section provides an overview of laser driver state estimation. Section III illustrates the data governance. The computation of state parameters of laser driver is discussed in section IV. Finally, we conclude this paper in section V.

LASER DRIVER STATE EVALUATION

The main purpose of state estimation of laser driver is to evaluate the compliance of physical experiment and the performance of the laser driver. The energy, pulse power waveform and near-field results of the experimental process are extracted from the original measurements. And the key technical parameters such as power imbalance, output beam quality, output stability, gain capability and third harmonic efficiency of the laser driver are calculated. Furthermore, their evolution law is visually analyzed.

† luoj1987@caep.cn

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THPV037

THE IMPLEMENTATION OF THE BEAM PROFILE APPLICATION FOR KOMAC BEAM EMITTANCE*

Jae-Ha Kim†, Young-Gi Song, SungYun Cho, Seunghyun Lee, Sang-Pil Yun
Korea Multi-purpose Accelerator Complex, Korea Atomic Energy Research Institute, Gyeongju, Korea

Abstract

Korea Multi-purpose Accelerator Complex (KOMAC) has been operating a 100 MeV proton linear accelerator that accelerates a beam using ion source, a radio frequency quadrupole (RFQ), 11 drift tube linac (DTL). And the accelerated protons are transported to target rooms that meets the conditions required by the users. It is important to figure out the beam profile of the proton linac to provide the proper beam condition to users. We installed 8 wire scanners to measure beam emittance of KOMAC at beam lines. And beam profile application to measure beam emittance has been implemented using EPICS and python. This paper will describe the implementation of the beam profile application for KOMAC beam emittance.

INTRODUCTION

KOMAC has been operating five beamlines and five target rooms for clients. A proton beam that clients require is transported to a target room through a beamline. So it is important to identify the characteristics for the proton linac and a proton beam to provide and appropriate beam. Therefor KOMAC installed Beam profile measurement devices that are Beam Position Monitor, Beam Loss Monitor, Beam Phase Monitor to measure beam characteristics and eight wire scanners at beamlines that are TR23, TR103, TR104, TR105 and straight beamline to figure out the beam profile of the proton beam. Following Fig. 1 shows layout of KOMAC linac and beamlines.

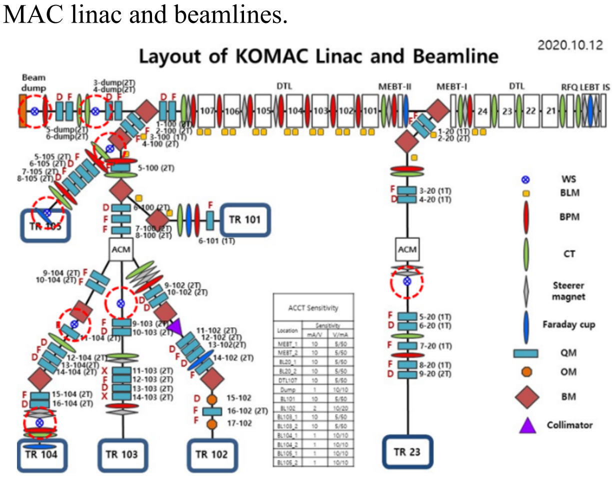


Figure 1: the layout of KOMAC linac and beamlines.

KOMAC control system based on Experimental Physics and Industrial Control System (EPICS) framework has been implemented to control the 100 MeV linac and peripheral devices at the control room [1]. Figure 2 shows the block diagram of KOMAC control system.

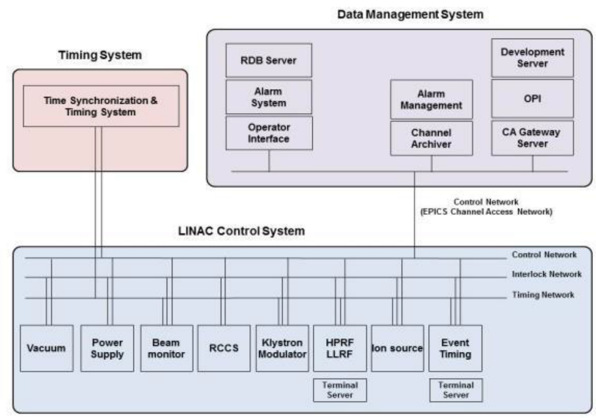


Figure 2: Block diagram of KOMAC control system.

We adopted Control System Studio (CSS) for user interface and Archiver Appliance for data saving system [2], [3]. And we have been developed high level applications that can communicate with the control system to study the beam profile of the linac. To integrate the wire scanner into KOMAC control system, the wire scanner control system was implemented using EPICS to control wire scanner and pyEPICS for data process [4].

WIRE SCANNER

The wire scanner has been developed to measure beam emittance of the KOMAC linac. The specification of the wire scanner is shown in Table 1.

Table 1: The Specification of The Wire Scanner

Specification	
Wire material	W tungsten
Wire diameter	0.1 mm
Moving speed & Range	100 mm/s, 50 mm (± 25 mm)
Spatial accuracy	0.05 mm
Spatial resolution	0.1 mm
Mounting Flange	6” CF

The wire scanner control system is divided into two part: driving wire scanner; data analysis. The layout of the existing wire scanner control system is shown in Fig. 3.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THPV038

PLUG-IN-BASED PTYCHOGRAPHY & CDI RECONSTRUCTION USER INTERFACE DEVELOPMENT

Sang-Woo Kim*, Kyung-Hyun Ku, Woul-Woo Lee
Pohang Accelerator Laboratory, Pohang, South Korea

Abstract

Synchrotron beamlines have a wide range of fields, and accordingly, various open source and commercial softwares are being used for data analysis. Inevitable, the user interface differs between programs and there is little shared part, so the user had to spend a lot of effort to perform a new experimental analysis and learn how to use the program newly.

In order to overcome these shortcomings, the same user interface was maintained using the Xi-cam framework [1], and different analysis algorithms for each field were introduced in a plugin method. In this presentation, user interfaces designed for ptychography and cdi reconstruction will be introduced.

INTRODUCTION

With the development of technology, the amount of data from detectors used for synchrotron radiation facilities is rapidly increasing. Diverse programs for processing the massive data are being developed indivisually at synchrotrons and universities with various languages such as python, matlab, labview, etc. In this situation, Xi-cam [1] proposed to jointly develop data analysis software with standardized framework and to utilize the developed program in other research institutes. Analysis programs using standardized framework have the advantage of being able to easily add necessary functions by loading plugins while maintaining a unified user interface. In addition, since the Xi-cam program handles GUI and analysis code execution, it is possible to focus on the implementation of core functionality. For this reason, we created a ptychography and cdi data processing program using Xi-cam's framework.

Ptychography and CDI are two types of coherent X-ray imaging techniques. As the focused and coherent X-rays pass through the sample, an interference pattern is created and this pattern is recorded by the detector. By using the interference pattern, the wavefunction of the probe, the density distribution of the sample, and the strain information could be obtained. The method estimates the wave function of the probe and the distribution of the sample at the beginning, and repeats the process of updating the probe and sample information to match the measured inteference pattern while repeating propagaion and backward propagation to obtaion a value close to the actual probe and sample. Propagation is mathematicall equivalent to a fourier transformation. When CPU is used to repeatedly perform FFT and inverse FFT of large image data, it takes a long time to obtain a result, whereas GPU could significantly reduce operation time because multiple cores can operate in parallel.

Ptychography and CDI operations were performed using the PyNX [2] developed by ESRF. PyNX was chosen because it is designed to increase the operation speed by using cuda cores of GPU and is designed based on mathematical operator so that the user can modifiy the application of the algorithms to suit their data. Although PyNX provides a script that can apply the reconstruction algorithm from the command line, a graphical user interface was created so that general users who are not familiar with command-line can utilize it.

PTYCHOGRAPHY

Figure 1 shows the intial screen of Xi-cam. A list of installed plugins is displayed in the upper right corner. Currently, ptychography and cdi plugins are displayed, and plugins can be added on demand. Figure 2 is the screen displayed when the Ptychography plugin is selected. Tabs are arranged in the order of data processing, Preprocessing, STXM Viewer, Reconstruction, and Result Viewer. Similarly, CDI plugin (Fig. 6) consists of Preprocessing, Reconstruction, and Result Viewer.

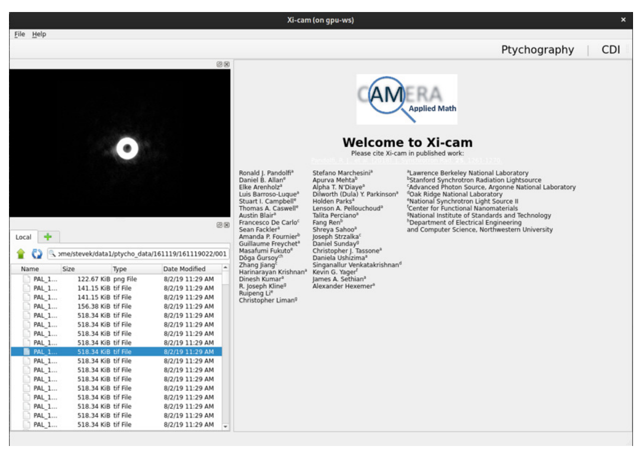


Figure 1: The initial screen of the Xi-cam. Installed plugins can be selected from the upper right corner.

Preprocessing

In preprocessing, meta data such as energy and the distance between the sample and the detector is read from the header file and average, background, substraction, crop, resize, denoising, etc. are performed and then saved as a cxi file. The cxi file format [3] is used as a standard in the field of coherent X-ray imaging and is supported by many programs. Thousands of images are compressed and stored in a single

* physwkim@postech.ac.kr

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THPV040

NEW MACHINE LEARNING MODEL APPLICATION FOR THE AUTOMATIC LHC COLLIMATOR BEAM-BASED ALIGNMENT

G. Azzopardi[*,1], G. Ricci[1,2]
[1] CERN, Geneva, Switzerland,
[2] Sapienza Università di Roma

Abstract

A collimation system is installed in the Large Hadron Collider (LHC) to protect its sensitive equipment from unavoidable beam losses. An alignment procedure determines the settings of each collimator, by moving the collimator jaws towards the beam until a characteristic loss pattern, consisting of a sharp rise followed by a slow decay, is observed in downstream beam loss monitors. This indicates that the collimator jaw intercepted the reference beam halo and is thus aligned to the beam. The latest alignment software introduced in 2018 relies on supervised machine learning (ML) to detect such spike patterns in real-time. This enables the automatic alignment of the collimators, with a significant reduction in the alignment time. This paper analyses the first-use performance of this new software focusing on solutions to the identified bottleneck caused by waiting a fixed duration of time when detecting spikes. It is proposed to replace the supervised ML model with a Long-Short Term Memory model able to detect spikes in time windows of varying lengths, waiting for a variable duration of time determined by the spike itself. This will allow for further speeding up the automatic alignment.

INTRODUCTION

The CERN Large Hadron Collider (LHC) is the largest particle accelerator in the world, built to accelerate and collide two counter-rotating beams towards the unprecedented design center-of-mass energy of 14 TeV [1]. The LHC is susceptible to beam losses which can damage the state of superconductivity of its magnets [2]. A multi-stage collimation system, consisting of 123 collimators [3], is installed in the LHC. Each collimator consists of two parallel absorbing blocks, referred to as jaws, inside a vacuum tank. The collimators must be aligned with the beam by symmetrically positioning the jaws on either side. This provides a 99.998 % cleaning efficiency of halo particles, preventing any LHC damage [4]. Each year of LHC operation begins with a commissioning phase which involves aligning all collimators and ensuring the correct settings for nominal operation [5].

This paper presents an analysis of first-use performance of the latest alignment software, that makes use of machine learning. A comparison with the previous alignment software resulted in identifying a bottleneck that restricts alignment efficiency. This is followed by a detailed analysis of a Long-Short Term Memory model that can be introduced to further improve the performance of the new software.

* gabriella.azzopardi@cern.ch

BACKGROUND

Recap. of Collimator Alignments

Collimation alignment at the LHC is essential for beam performance and is based on different beam-based techniques developed for the specific LHC conditions [6]. While the new generation of collimators feature a design with embedded beam position monitors for a rapid alignment to the circulating beam [7], most of the LHC collimators do not have this feature. For the latter, the alignment relies on dedicated Beam Loss Monitoring (BLM) devices positioned outside the beam vacuum, immediately downstream from each collimator [4].

Collimator jaws are moved towards the beam with a step precision of 5 µm, and the BLMs are used to detect beam losses generated when halo particles impact the collimator jaws. The recorded losses are proportional to the amount of beam intercepted and are measured in units of Gy/s. Collimators are aligned with respect to a reference halo cut generated with the primary collimators. A collimator jaw is considered aligned when a movement produces a clear beam loss spike in the BLM [8]. The observation time to evaluate the quality of the signal and to assess if the spike corresponds to a correct alignment can vary from < 1 s to > 10 s depending on the machine conditions and beam properties. Aligning collimators with BLMs is referred to as the beam-based alignment (BBA), which involves aligning collimators one by one, by moving one jaw at a time towards the beam.

Before moving each jaw, the losses produced by the previous alignment must have decayed in order to decrease possible cross-talk effects between the collimators, whereby the BLM losses at a specific collimator are affected by the signal produced by other collimators around the LHC [9]. A complete alignment campaign at the LHC requires moving each collimator jaw several times, which can produce more than 1000 observation spikes. Therefore, improving the time needed to classify these spikes has a direct impact on the system's alignment time.

Semi-Automatic Beam-based Alignment

Since 2011, LHC collimators have been aligned using a semi-automatic procedure. This involves having the user to select the collimator to align, including the required settings and BLM threshold. The collimator will then automatically move towards the beam until the BLM losses exceed the threshold selected. At this point, the collimator automatically stops moving and the user must determine whether

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THPV041

INNOVATIVE METHODOLOGY DEDICATED TO THE CERN LHC CRYOGENIC VALVES BASED ON MODERN ALGORITHM FOR FAULT DETECTION AND PREDICTIVE DIAGNOSTICS.

A. Amodio, P. Arpaia, Y. Donon, F. Gargiulo, L. Iodice, M. Pezzetti, CERN, Geneva, Switzerland

Abstract

The European Organization for Nuclear Research (CERN) cryogenic infrastructure is composed of many equipment, among them there are the cryogenic valves widely used in the Large Hadron Collider (LHC) cryogenic facility. At present time, diagnostic solutions that can be integrated into the process control systems, capable to identify leak failures in valves bellows, are not available. The authors goal has been the development of a system that allows the detection of helium leaking valves during normal operation using available data extracted from the control system. The design constraints (inaccessibility to the plants, variety of valve models used) has driven the development towards a solution integrated in the monitoring systems in use, not requiring manual interventions. The methodology presented in this article is based on the extraction of distinctive features (analyzing the data in time and frequency domain) which are exploited in the next phase of machine learning. The aim is to identify a list of candidate valves with a high probability of helium leakage. The proposed methodology, which is at very early stage now, with the evolution of the data set and the iterative approach for the test phase presented in the last paragraph, is aiming toward a cryogenic valves targeted maintenance in the LHC cryogenic accelerator system.

INTRODUCTION

The maintenance purpose is to reduce, as far as possible, the occurrence of undesirable events and, consequently, the corrective maintenance interventions. The maintenance campaign of large accelerator systems, such as the LHC at CERN, represents an important factor in terms of financial and manpower resources. At CERN, a large fraction of the cryogenic installation and its control systems are located in areas inaccessible during physic run campaigns. Due to the high complexity of the accelerator, the cryogenic system needs high levels of reliability for its operations. [1]. The cryogenic valves are widely used in the LHC cryogenic facility. The design constraints, such as the inaccessibility to the plants and the variety of valve models used, have driven the development of an integrated solution in the monitoring systems in use, not requiring manual interventions. The authors motivation has been the development of a system that allows the detection of helium leakage during valves operations using available data. In the past, several diagnostic approaches have been developed concerning compressors, electrical motors and cryogenic instrumentation [2, 3]. In literature, diagnostic solutions that can be integrated into the process control systems using only the available data, to identify leak failures in valves bellows, are not available at this time. Although the solution proposed in [4] based on Support Vector Machine (SVM) reaches a very interesting level of accuracy (97 %), it unfortunately requires the use of vibration sensors making this method inapplicable in contexts where the valves are numerous and difficult to access. The state-of-the-art solutions for failure prediction in control valves, cannot fit the context whose constraints are described.

PROBLEM OF CRYOGENIC VALVE BELLOWS LEAKAGE

The helium used in cryogenic systems can, due to its physical characteristic, escape through micro-cracks originated from valve bellows movements after years of operations. The main purpose of the presented work is the development of an innovative tool for maintenance diagnostic. The described algorithm produces a list of designated valves that could potentially present the helium leakage problem. The selected valves are investigated, by cryogenic operators, using local helium sniffing devices and if the leak is validated, a mechanical repair action is undertaken. The cryogenic system uses several valve models for the regulation and the control of cryogenic liquefied gases, being able to be fully functional both at temperatures as low as 1.9 K and at various pressures required by the cryogenic process. The system presented below is focused on these control valves of the cryogenic types (see Fig. 1) fabricated in stainless steel (AISI 316L). The control valve model used at CERN is driven by a Siemens Sipart PS2® positioner which gets a setpoint by the industrial Profibus® PA or by a 4-20 mA current signal (supporting HART® protocol). The control valve has a chamber divided into two parts by a diaphragm.

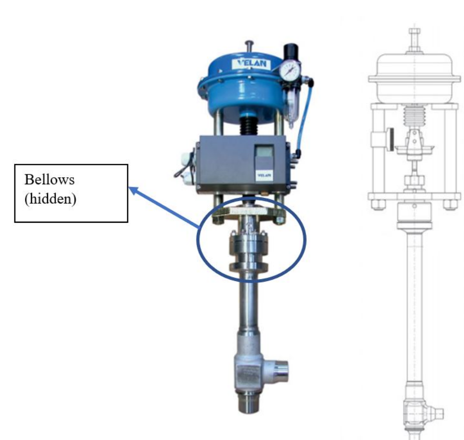


Figure 1: Example of LHC Cryogenic control valve [5].

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THPV042

EVOLUTION OF THE CERN BEAM INSTRUMENTATION OFFLINE ANALYSIS FRAMEWORK (OAF)

A. Samantas, M. Gonzalez-Berges, J-J Gras, S. Zanzottera, CERN, Geneva, Switzerland

Abstract

The CERN accelerators require a large number of instruments, measuring different beam parameters like position, losses, current etc. The instruments' associated electronics and software also produce information about their status. All these data are stored in a database for later analysis. The Beam Instrumentation group developed the Offline Analysis Framework some years ago to regularly and systematically analyze these data. The framework has been successfully used for nearly 100 different analyses that ran regularly by the end of the LHC run 2. Currently it is being updated for run 3 with modern and efficient tools to improve its usability and data analysis power. In particular, the architecture has been reviewed to have a modular design to facilitate the maintenance and the future evolution of the tool. A new web based application is being developed to facilitate the users' access both to online configuration and to results. This paper will describe all these evolutions and outline possible lines of work for further improvements.

INTRODUCTION

Several thousand instruments are installed in the CERN accelerator complex to measure beam parameters (e.g. position, losses, intensity, etc). Table 1 gives an approximate overview of the types of instrument per accelerator. Each instrument is typically composed of a monitor that can be inserted in the beam pipe or installed outside, an analogue/digital electronics system and a software layer.

The complex itself spans over several kilometres, with most of the accelerators installed underground. The regular operation of these instruments is a major challenge. They need to be available for the run periods and their performance has to be guaranteed.

Table 1: Approximate Number of Main Types of Instruments per Type and Accelerator

	LHC	SPS	PS complex	Other
Position	1300	300	300	50
Losses	4200	10	50	30
Intensity	20	10	80	10
Profile	40	10	80	30

The Offline Analysis Framework (OAF) [1,2] was developed some years ago to deal with this challenge. The instruments produce beam physics data as well as status information. Both sets of data are used to monitor the instrument performance and its evolution through time. Our final aim is to fine tune the instruments' performance and introduce predictive maintenance on their mechanics and electronics parts.

CURRENT USAGE

All these instruments measure, regularly or on demand, the different beam observables. Then, they send these values, together with relevant status and setting registers, to the CERN Control Room for the real time operation of the machines and into a centralized logging database (NXCALS) [3] for future offline analysis (Fig. 1).

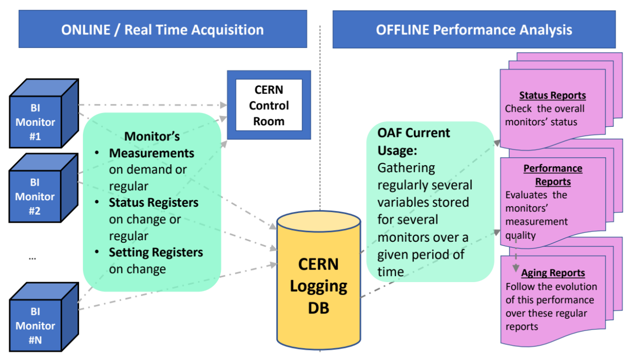


Figure 1: Standard usage workflow.

All this logged information contains too much data to be analysed properly manually. So, in 2013, we decided to develop the Offline Analysis Framework [1] in order to regularly monitor the records stored and automatically produce 3 kinds of reports:

- Status reports that focus on the state of the instrument and monitor humidity, temperatures, logging frequency and more, raising alarms whenever necessary.
- Performance reports will monitor and assess the quality (accuracy, resolution, stability) via device comparisons or regular calibration sequences.
- Aging or long term evolution reports will survey the evolution of the quality evaluations made in the daily performance reports.

Most of these analyses can be derived from the raw DB records via standard data treatment and plotting functionalities directly supported by OAF. However, some analyses require ad-hoc computations or specific plots. To cover these non-standard requirements, OAF offers the possibility, whenever necessary (i.e. when the need is not covered by the build-in OAF features), to add expert python code to this specific analysis that will be

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THPV043

USING AI FOR MANAGEMENT OF FIELD EMISSION IN SRF LINACS

A. Carpenter†, P. Degtiarenko, R. Suleiman, C. Tennant, D. Turner, L. S. Vidyaratne, Jefferson Lab, Newport News, Virginia, USA
K. Iftekharuddin, Md. Monibor Rahman, ODU Vision Lab, Department of Electrical and Computer Engineering, Old Dominion University, Norfolk, Virginia, USA

Abstract

Field emission control, mitigation, and reduction is critical for reliable operation of high gradient superconducting radio-frequency (SRF) accelerators. With the SRF cavities at high gradients, the field emission of electrons from cavity walls can occur and will impact the operational gradient, radiological environment via activated components, and reliability of CEBAF's two linacs. A new effort has started to minimize field emission in the CEBAF linacs by re-distributing cavity gradients. To measure radiation levels, newly designed neutron and gamma radiation dose rate monitors have been installed in both linacs. Artificial intelligence (AI) techniques will be used to identify cavities with high levels of field emission based on control system data such as radiation levels, cryogenic readbacks, and vacuum loads. The gradients on the most offending cavities will be reduced and compensated for by increasing the gradients on least offensive cavities. Training data will be collected during this year's operational program and initial implementation of AI models will be deployed. Preliminary results and future plans are presented.

INTRODUCTION

The Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Lab is a high power, continuous wave recirculating linac that completed an energy enhancing upgrade to 12 GeV in 2017 [1]. This upgrade included the installation of 11 additional higher gradient cryomodules, named C100s for their capability of producing a 100 MeV energy gain. Field emission (FE) is a well-known phenomenon in superconducting radio-frequency (SRF) cavities that can have deleterious impact on accelerator hardware, cryogenic heat loads, and machine operations. Field emitted electrons can be accelerated similarly to CEBAF's electron beam and can generate neutron and gamma radiation on impact. Managing FE in CEBAF's C100 cryomodules has emerged as an on-going operational challenge since the 12 GeV upgrade (Fig. 1).

CEBAF recently designed, built, calibrated, and installed neutron dose rate meters (NDX) [2]. The NDX monitors are deployed around CEBAF with a majority of detectors placed near the newer higher gradient cryomodules. This new system allows for more detailed measurements to be made of the radiation response to RF configurations and is currently being used to minimize the FE-based radiation through manual gradient optimizations.

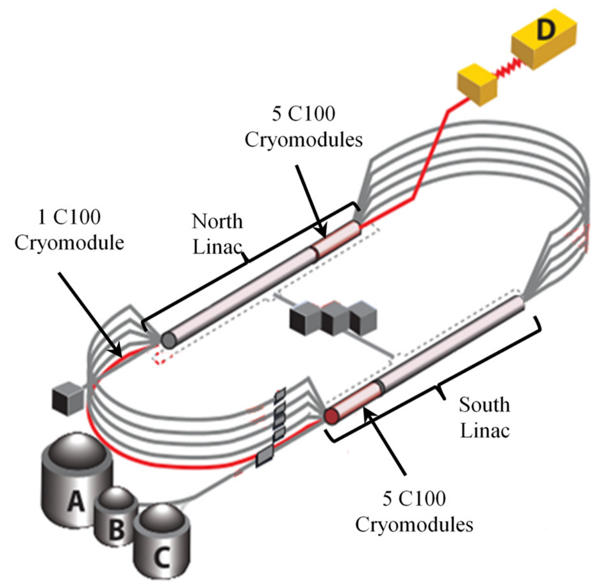


Figure 1: CEBAF schematic denoting the location of C100 cryomodules. One north linac C100 was removed for refurbishment during the time of this study.

Several beam studies were conducted during CEBAF restoration that leveraged the NDX system to measure FE-related radiation response to changes in cavity RF gradients. This data provides an ample training set for the development of artificial intelligence (AI) models to aid operations in maintaining a lower radiation environment. Preliminary attempts at modeling radiation as a function of gradient appear successful.

NDX SYSTEM

Installation and commissioning of the NDX system was completed in August 2021. The system has 21 detectors positioned at strategic locations in the CEBAF tunnel. The majority of these detectors are positioned around the newer higher gradient cryomodules with names corresponding to the adjacent downstream cryomodule. These detectors are primarily designed to measure neutron radiation, but as an ancillary and necessary feature, they also provide measurements of gamma radiation dose rates. The NDX system is now the primary tool for measuring FE-related radiation at CEBAF.

Electrometers associated with the detectors measure the current signal over a variable integration time period, typically set to one second. These signals are converted to

* This work is supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics under Contract No. DE-AC05-06OR23177.
†adamc@jlab.org

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THPV046

VIRTUALIZED CONTROL SYSTEM INFRASTRUCTURE AT LINAC PROJECT PINSTECH

N. U. Saqib†, F. Sher*
LINAC Project, PINSTECH, Islamabad, Pakistan

Abstract

IT infrastructure is backbone of modern big science accelerator control systems. Accelerator Controls and Electronics (ACE) Group is responsible for controls, electronics and IT infrastructure for Medical and Industrial NDT (Non-Destructive Testing) linear accelerator prototypes at LINAC Project, PINSTECH. All of the control system components such as EPICS IOCs, Operator Interfaces, Databases and various servers are virtualized using VMware vSphere and VMware Horizon technologies. This paper describes the current IT design and development structure that is supporting the control systems of the linear accelerators efficiently and effectively.

INTRODUCTION

LINAC Project, PINSTECH aims at developing indigenous RF linear accelerators for medical and industrial purposes. Along with progressive research in this field, prototypes of 6 MeV Medical and Industrial (NDT) linear accelerators are being developed. IT infrastructure provides computing, network and storage resources, as well as several services to the accelerator control system, and also to engineers and scientists involved in research and development tasks. An Ethernet based Local Area Network (LAN) is deployed at LINAC Project. The overall LAN is divided into two segments: *Technical Network* and *Office Network*. Both networks are isolated and contain independent IT infrastructure. Measurement and control devices including commercial-off-the-shelf equipment and related devices are connected to the *Technical Network* while *Office Network* consists of users related devices including scientists' and engineers' PCs, printers, scanners, test equipment etc. For compute resources, Dell EMC PowerEdge servers are configured and installed to provide reliable services for both the networks. Servers are managed remotely via Integrated Dell Remote Access Controller (iDRAC) which eliminates the need of physical presence of server administrator to configure/reconfigure a server. For network resources, Allied Telesis Gigabit Ethernet network switches are installed to provide network connectivity and high bandwidth data transfer between nodes in the networks. Three types of network switches are utilized: unmanaged, web-smart and managed according to purpose of utilization. As multi-core processors become common, virtualization is an important technology to implement full utilization of hardware resources and reduce their footprint [1]. Virtualization enables running multiple virtual PCs simultaneously on one physical machine and allows multiple operating systems to work at the same time and on the same machine. Main advantage of virtual machines is that hardware resources such as processor, memory, hard disk, device controllers, network cards etc. can be dynamically increased or decreased according to the requirements.

† najm.control@gmail.com
† falaksher@gmail.com

SERVER VIRTUALIZATION

Server virtualization divides a physical server into multiple virtual machines by means of a software layer called hypervisor. Virtualization fully utilizes a physical server by distributing workload on virtual servers. Additional benefits include less hardware to buy and manage, more efficient resources usage and improved resilience. Dell EMC PowerEdge servers [2] are virtualized using VMware vSphere 6 [3] technology which is a data center virtualization solution. VMware vSphere consists of two components: VMware ESXi which is a type 1 hypervisor installed on bare metal server and vCenter Server which provides centralized management platform for ESXi hosts, virtual machines and other dependent components. Two Dell R740 servers are deployed in the *Office Network* and one Dell R630 server is deployed in the *Technical Network*. Specifications of both types of servers are provided in Table 1 and Table 2 respectively.

Table 1: Specifications of Dell R740 Server

Component	Specification
CPU	Intel Xeon Silver @ 2.1 GHz x 2
RAM	64 GB (32 GB x 2)
HDD	8 TB (2 TB x 4)
OS	VMware ESXi 6.7

Table 2: Specifications of Dell R630 Server

Component	Specification
CPU	Intel Xeon Silver @ 2.1 GHz
RAM	32 GB (16 GB x 2)
HDD	6 TB (2 TB x 3)
OS	VMware ESXi 6.7

TECHNICAL NETWORK

All components related to control system consisting of servers, desktop computers and commercial-off-the-shelf equipment are connected to the *Technical Network* to pro-

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THPV047

STATUS OF HIGH LEVEL APPLICATION DEVELOPMENT FOR HEPS*

Xiaohan Lu†, Qiang Ye, Hongfei Ji, Yi Jiao, Jingyi Li, Cai Meng, Yuemei Peng, Gang Xu, Yaliang Zhao
Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China

Abstract

The High Energy Photon Source (HEPS) is a 6 GeV, 1.3 km, ultralow emittance ring-based light source in China. The construction started in 2019. In this year, the development of beam commissioning software of HEPS started. It was planned to use EPICS as the control system and Python as the main development tools for high level applications (HLAs). Python has very rich and mature modules to meet the challenging requirements of HEPS commissioning and operation, such as PyQt5 for graphical user interface (GUI) application development, PyEPICS and P4P for communicating with EPICS. A client-server framework was proposed for online calculations and always-running programs. Model based control is also one important design criteria, all the online commissioning software should be easily connected to a powerful virtual accelerator (VA) for comparison and predicting actual beam behaviour. It was planned to use elegant and Ocelot as the core calculation model of VA.

INTRODUCTION

The High Energy Photon Source (HEPS) is a 6 GeV, 1.3km, green-field 4th generation storage ring light source [1]. For this light source, the lattice design and related physics studies were basically finished [2-6], and the construction started in mid-2019. The machine commissioning of LINAC is expected to start in mid-2022. By this time, the high level applications (HLAs) for beam commissioning are indispensable.

To achieve this goal, the development of HLAs started this year. Before the start of development, we investigated the HLA schemes of almost all the running light sources. Most of them use the Matlab Middle Layer Toolkit (MML) [7, 8] as the main commissioning tools, and part of them developed new specific commissioning tools, such python-based aphla of NSLSII [9], and python-based HLA of Sirius [10]. Recently, python becomes more and more popular in every walk of life, due to its powerful modules and easy-to-learn characteristic. And more and more labs use python as the main development tools for control software and data analysis tool. In consideration of future development, economic and time cost, for the HEPS python was chosen as the main development tools, and EPICS as the control system. Python has very rich modules to meet the demands of HLA. PyQt5 was used to develop GUI app, will be update to pyqt6 in near future, PyEPICS and P4P were used as the communication tools. The HLA of HEPS is model-based, we decided to use Elegant [11] and Ocelot [12] as the core calculation models. A client-server framework was proposed for online calculations and always-running programs. All the online commissioning software should be easily connected to a powerful virtual accelerator (VA) for comparison and predicting actual beam behaviour.

APPLICATIONS FRAMEWORK

The development of HLA is collaborative work between the control group and physics group. The whole control system framework is shown in Fig. 1, all the applications were classified into three categories: parameter display and hardware controls, algorithm-based applications for tuning or measurements, model-based applications. The accelerator physics group is responsible for the development of the algorithm-based and model-based applications (the green part in Fig.1), and the control group is responsible for the development of the rest of applications and the construction of the low-level control applications (the blue part in Fig. 1).

The control group chose Control System Studio (CSS) [13] and python display management (PyDM) to build the parameter display and hardware control applications. The accelerator physics group is responsible to develop a brand new platform python accelerator physics application set (Pyapas) to build the HLA, as shown in Fig.2 with the aim of including all necessary tools and modules.

Pyapas is not only a set of applications, but also designed as a platform for the rapid development of HLA. Pyapas learns design philosophy from PyDM [14] and OpenXAL [15]. There are three principles of Pyapas, the first one is that all the applications are physical quantity based. The parameters we work with should be physical quantity. For example, when we do the orbit correction, we should change the magnetic field rather than the current of the correctors. The second one is that most of the applications should be server-based, the calculation process could be running in the background. The third one is that the applications should be model-based, all the applications could be connected to the VA, use the simulation results to tune and predict the behaviour of the beam.

According to the design principles, a clear roadmap was made to develop Pyapas. The drag-and-drop way should be implemented to develop GUI applications quickly. To develop server-based application, a robust and convenient client-server framework is indispensable. The model-based applications and VA require powerful physical models, for the moment we decide to use the exist mature simulation code Elegant and Ocelot as the core physical model. To

*Work supported by NSFC (12005239)
† luxh@ihep.ac.cn

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THPV048

NOVEL CONTROL SYSTEM FOR THE LHCb SCINTILLATING FIBRE TRACKER DETECTOR INFRASTRUCTURE

M. Ostrega, M. Ciupinski, S. Jakobsen, X. Pons
CERN CH-1211 Geneva 23, Switzerland

Abstract

During the Long Shutdown 2 of the LHC at CERN, the LHCb detector is upgraded to cope with higher instantaneous luminosities. The largest of the new trackers is based on the scintillating fibres (SciFi) read out by SIlicon PhotoMultipliers (SiPMs). The SiPMs will be cooled down to -40°C to minimize noise. For performance and integration compatibility, the cooling lines are vacuum insulated. Ionizing radiation requires detaching and displacing the readout electronics from Pirani gauges to a lower radiation area. To avoid condensation inside the SiPM boxes, the atmosphere inside must have a dew point of at most -45°C. The low dew point will be achieved by flushing a dry gas through the box. 576 flowmeters devices will be installed to monitor the gas flow continuously. A Condensation Prevention System (CPS) has been implemented as condensation was observed in previous detector operation tests. The CPS powers heating wires installed around the SiPM boxes and the vacuum bellows isolating the cooling lines. The CPS also includes 672 temperature sensors to monitor that all parts are warmer than the cavern dew point. The temperature readout systems are based on radiation tolerant multiplexing technology at the the front-end and a PLC in the back-end.

INTRODUCTION

SciFi Tracker

The SciFi tracker consists of three stations each with four detection planes. The detector is built from individual modules (0.5 m ×4.8 m), each comprising 8 fibre mats with a length of 2.4 m as active detector material. The fibre mats consist of 6 layers of densely packed blue-emitting scintillating fibres with a diameter of 250 µm (see Fig. 1). The scintillation light is recorded with arrays of state-of-the-art multi-channel silicon photomultipliers (SiPMs). A custom ASIC is used to digitize the SiPM signals. Subsequent digital electronics performs clustering and data-compression before the data is sent via optical links to the DAQ system. To reduce the thermal noise of the SiPM, in particular after being exposed to a neutron fluence of up to 10^{12} neq/cm^2, expected for the lifetime of the detector, the SiPM arrays are mounted in so called cold-boxes and cooled down by 3D-printed titanium cold-bars to −40˚C. The detector is designed to provide low material budget (1 % per layer), hit efficiency of 99 % and a resolution better than 100 µm. These performance figures must be maintained over the lifetime of the detector which will receive radiation dose up to 35 kGy near the beam pipe. The full detector, comprising 590 000 channels, is read out at 40 MHz [1].

Detector Infrastructure

Three control systems have been developed in order to allow the operation with correct environmental parameters for the SciFi infrastructure were developed. In this paper, the vacuum system, condensation protection system and flowcells monitoring system were described.

Figure 1: LHCb SciFi Tracker assembly.

VACUUM SYSTEM

System Overview

The SciFi vacuum system consists of two subsystems that serve two detector sides (A & C). Each subsystem consists of a scroll pump (primary) and two turbomolecular pumps connected parallel for redundancy purposes. "Turbo" pumps set is connected to the central manifold, where are the manual valves. Those valves can insulate every C-Frame in case of maintenance. There are 48 vacuum lines (12 supply and 12 return lines per side), connecting two main manifolds with the 12 detector C-frames.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-THPV049

VIRTUALISATION AND SOFTWARE APPLIANCES AS MEANS FOR DEPLOYMENT OF SCADA IN ISOLATED SYSTEMS

P. Golonka†, L. Davoine, M. Zimny, L. Zwalinski, CERN, Geneva, Switzerland

Abstract

The paper discusses the use of virtualisation as a way to deliver a complete pre-configured SCADA (Supervisory Control And Data Acquisition) application as a software appliance to ease its deployment and maintenance. For the off-premise control systems, it allows for deployment to be performed by the local IT servicing teams with no particular control-specific knowledge, providing a "turnkey" solution. The virtualisation of a complete desktop allows to deliver and reuse the existing feature-rich Human-Machine Interface experience for local operation; it also resolves the issues of hardware and software compatibilities in the deployment sites. The approach presented here was employed to provide replicas of the "LUCASZ" cooling system to collaborating laboratories, where the on-site knowledge of underlying technologies was not available and required to encapsulate the controls asa "black-box" so that for users, the system is operational soon after power is applied. The approach is generally applicable for international collaborations where control systems are contributed and need to be maintained by remote teams.

MOTIVATION

For the past two decades industrial controls technologies have been applied with success at CERN to build control systems for a vast range of applications, ranging from laboratory setups through technical infrastructure up to the ones for accelerators and large particle detectors counting millions of I/O channels. Applying the standardized stack of industrial technologies (WinCCOA SCADA [1]), enhanced with in-house developed frameworks [2,3] allowed for rapid development and effective maintenance of hundreds of complex control system across the organisation. However, this wouldn't be possible without centrally supported IT services and infrastructure. In particular, provisioning of secure network connectivity, computing server hardware, installation of operating system and software, high capacity database service, shared file-systems, consoles in the control rooms or terminal servers for secure remote access have been essential for reliable day-to-day operation. Harmonized efforts of numerous expert teams, ensured the maintenance and upgrades of applications and infrastructure [4] throughout the life-time of control systems.

In general, production control systems are hosted on centrally maintained infrastructure, remain highly homogeneous in terms of technologies and assume the availability of services and also experts. Nevertheless, this may not be achievable for international research collaborations, where the development and precommissioning of the control system may be performed in collaborations, where the development collaborations, where the development and precommissioning of the control system may be performed in a different place than the final location of the equipment. The local infrastructure, available expertise and policies at the deployment site may differ, making the integration and maintenance of such control system seemingly impossible.

LUCASZ CO2 Cooling Stations

LUCASZ [5], *Light Use Cooling Appliance for Surface Zones*, is a medium size I-2PACL CO_2 cooling system developed at CERN with 1kW cooling power at −35°C. It was designed with the purpose of cooling down small and medium sized light tracking detector structures and supporting detector-assembly. A number of research institutes collaborating with CERN needs to build their own replicas of the LUCASZ system to proceed with their activities and commitments related to the phase-II upgrade of the LHC Experiments.

The control system for LUCASZ employs the standard CERN UNICOS [3] technology stack with a Schneider M580 PLC. To facilitate the local operation for non-expert users LUCASZ has a detachable *LocalBOX* featuring an industrial touch-panel. However, its functionalities are limited: for instance it is not suitable for long-term storage of historical data, hence it may not be considered a replacement for a complete, PC-based UNICOS SCADA.

Provisioning a stand-alone cooling system to be operated outside CERN is a technical challenge and requires expertise in several domains not always available in the institutes. Indeed, in addition to cooling, mechanical engineering also the expertise in deployment and configuration of control systems would be required.

PROBLEM AND PROPOSED SOLUTION

Difficulties in deployment and maintenance of control systems, requiring specialized skills, may hinder the effective collaboration and prevent possible re-use of existing instruments or technologies. A solution allowing for the control system to be deployed in form of a "black box" next to the equipment, with the purpose of acting as the *local control station* is demanded.

Unlike for the PLCs, deploying the full UNICOS SCADA application on top of undefined IT infrastructure remains a complex task requiring specific knowledge. In what follows we propose a solution allowing to package a complex SCADA application together with the necessary environment, and at the same time address the problem of the infrastructure compatibility.

Virtual Software Appliances

To address the class of practical problems of lack of local domain-specific technical expertise the IT industry applies a pattern of *software appliances* [6]: self-contained

† Piotr.Golonka@cern.ch

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-FRAL01

THE Laser MegaJoule FACILITY STATUS REPORT

H.Cortey, CEA/DAM CESTA, Le Barp, France

Abstract

The Laser MegaJoule (LMJ), the French 176-beam laser facility, is located at the CEA CESTA Laboratory near Bordeaux (France). It is designed to deliver about 1.4 MJ of energy on targets, for high energy density physics experiments, including fusion experiments. The first bundle of 8-beams was commissioned in October 2014 [1]. By the end of 2021, ten bundles of 8-beams are expected to be fully operational.

In this paper, we will present:

- The LMJ Bundles Status
- The main evolutions of the LMJ facility since ICALEPS2019
- The result of a major milestone for the project: ‘Fusion Milestone’

INTRODUCTION

The laser Megajoule (LMJ) facility, developed by the “Commissariat à l’Energie Atomique et aux Energies Alternatives” (CEA), is designed to provide the experimental capabilities to study High Energy Density Physics (HEDP). The LMJ is a keystone of the Simulation Program, which combines improvement of physics models, high performance numerical simulation, and experimental validation, in order to guarantee the safety and the reliability of French deterrent weapons. When completed, the LMJ will deliver a total energy of 1.4 MJ of 0.35 µm (3ω) light and a maximum power of 400 TW.

The LMJ is sized to accommodate 176 beams grouped into 22 bundles of 8 beams. These will be located in the four laser bays arranged on both sides of the central target bay of 60 meter diameter and 40 meter height. The target chamber and the associated equipment are located in the center of the target bay.

The first bundle of eight beams has been commissioned at the end of 2014. The second bundle has been commissioned at the end of 2016 following the same commissioning process. Seven additional bundles are now operational since the end of 2020, and the first physics experiments using the 56 operational beams took place in the second semester of 2019.

The PETAL project consists in the addition of one short-pulse (0.5 to 10 ps) ultra-high-power (1 up to 7 PW), high-energy beam (1 up to 3.5 kJ) to the LMJ facility. PETAL offers a combination of a very high intensity petawatt beam, synchronized with the nanosecond beams of the LMJ [2].

The first phase of nuclear commissioning of LMJ has been achieved to take into account high-energy particles created by PETAL, and neutron production from D-D fusion reaction. A subsequent phase will take into account tritium targets.

This paper describes the LMJ facility status and the new target diagnostics. A milestone physics experiments is presented to illustrate the facility capacity to realize the first thermonuclear fusion by implosion of a D_2 capsule in a cavity.

LMJ BASELINE

The 176 beams (37 × 35.6 cm² each) are grouped into 22 bundles of 8 beams. In the switch-yards, each individual bundle is divided into two quads of 4 beams, the basic independent unit for experiments, which are directed to the upper and lower hemispheres of the target chamber.

Basically, an LMJ laser beam line is composed of three parts: the front-end, the amplifying section, the switch-yard and the final optics assembly.

The front end delivers the initial laser pulse (up to 500 mJ). It provides the desired temporal pulse shape and spatial energy profile.

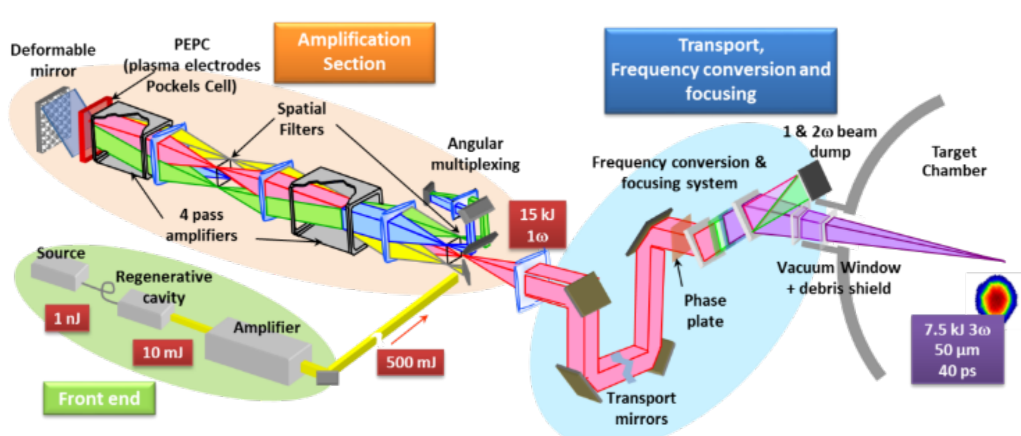


Figure 1: Laser beamline schematic diagram.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-FRAL02

DISCOS UPDATES

S. Poppi*, M. Buttu, G.Carboni, A.Fara, C. Migoni INAF - OA Cagliari, [09047] Selargius, Italy
M. De Biaggi, A. Orlati, S. Righini, F. R. Vitello, INAF - IRA, [40138] Bologna, Italy
M.Landoni[1], INAF - Osseravatorio Astronomico di Brera, Merate, Italy
[1]also at INAF - OA Cagliari

Abstract

DISCOS is the control software of the Italian Radio Telescopes and it is based on the Alma Control Software. The project core started during the construction of the Sardinia Radio Telescope (SRT) and it further developed to support also the other antennas managed by INAF (National Institute for Astrophysics), which are the Noto and the Medicina antennas. Not only DISCOS controls all the telescope subsystems - like servo systems, backends, receivers and active optic system - but it also allows users to exploit a variety of observing strategies. In addition, many tools and high-level applications for observers have been produced over time. The development of this software follows test-driven methodologies, which, together with real hardware simulation and automated deployment, speed up testing and maintenance. We here describe the status of the DISCOS project and of the related activities, also presenting its ongoing upgrades.

INTRODUCTION

The Italian National Institute for Astrophysics (INAF) manages three single-dish radio telescopes: The Sardinia Radio Telescope (SRT), the Noto and the Medicina radio telescopes. These are open sky facilities; the international scientific community is invited to submit observing projects through calls for proposal, published twice a year [1]. The telescopes cover radio bands from 305 MHz up to 26.5 GHz, allowing many research topics to be explored. Examples are pulsars, astrochemistry, extragalactic sources, space weather. SRT and Noto are already provided with an active surface, allowing for observations at much higher frequencies; Medicina is planned to have it installed within spring 2023.

The control software plays a key role in an observing facility, allowing the users to perform the needed observations by using proper strategies and modes, while ensuring the quality of the acquired data. Therefore, in 2004 we started developing NURAGHE, the SRT control software. In 2007 we parallely began the ESCS (Enhanced Single-dish Control Software) project, devoted to the Medicina and Noto radio telescopes. Eventually, in order to optimize the efforts, in 2015 the three development lines were unified in DISCOS, a common control software for all the three telescopes.

DISCOS is built on top of the Alma Common Software, which is based on CORBA [2]. This framework allowed us to realize a modular software mostly made of common codebase, reused and deployed at all sites, as much as possible. Considering this, only a small part of the codebase (23%) is telescope-specific, essentially in the low-level and no-logic control of the devices and of the telescope hardware [3]. In 2017 we refactored part of the code, in order to adapt it to the upgrade of the framework to a newer version of ACS [4]. Also, we chose Github [5] to track issues and manage version control.

Equally important is the development strategy. We followed guidelines in the adoption of an approach called Behavior Driven Development (BDD) [6] which aims to test the software behaviour and it is used together with Test Driven Development (TDD) and unit testing strategies [7].

In the following sections we show the ongoing and planned DISCOS upgrades. In particular we present the integration of new instrumentation, such as new receivers and backends, a new simulated environment of the SRT hardware devices, a middleware DISCOS wrapper called SURICATE and a simple web-based monitoring and alarm system.

TELESCOPES UPGRADE

In 2019 INAF was granted a PON (National Operational Program) funding to upgrade the Sardinia Radio Telescope and its infrastructure toward higher frequencies (up to 100 GHz). Within this scope, up to a 15% of the overall funding was aimed to also upgrade the Medicina and Noto radio telescopes. The funded project includes the acquisition and the installation of new receivers on the telescopes:

- Three coaxials receivers K/Q/W band (18–26 GHz, 34–50 GHz, 80–116 GHz). for Medicina, Noto and SRT.
- 16-Beam W Band receiver (70–116 GHz) for SRT
- 19-Beam Q Band receiver (33–50 GHz) for SRT
- A bolometric millimetre camera for SRT operating in the 77–103 GHz made of 408 detectors.

Furthermore, the PON project includes, as concerns the SRT, the procurement of three digital data acquisition systems (backends), a new state-of-the-art metrology system, an HPC system and laboratory instrumentation. Also, the telescope minor servo system, which is responsible for the proper positioning of the telescope optics, will undergo a refactoring and a major upgrade.

It is worth noting that new receivers and new backends will need a big effort in order to integrate them in the control software. To do this, we exploited the ACS architecture and the DISCOS modularity. Not only the new receivers have the same interfaces, but also the communication protocols are the same of the SRT first-light receivers.

* sergio.poppi@inaf.it

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-FRAL03

CRYOGENIC CONTROLS TODAY AND TOMORROW

M. Pezzetti, P. Gayet, CERN, Geneva, Switzerland

Abstract

The CERN cryogenic facilities demand a versatile, distributed, homogeneous and highly reliable control system. For this purpose, CERN conceived and developed several frameworks (JCOP, UNICOS, FESA, CMW), based on current industrial technologies and COTS equipment, such as PC, PLC and SCADA systems complying with the requested constraints. The cryogenic control system nowadays uses these frameworks and allows the joint development of supervision and control layers by defining a common structure for specifications and code documentation. Such a system is capable of sharing control variables from all accelerator apparatus. The first implementation of this control architecture started in 2000 for the Large Hadron Collider (LHC). Since then, CERN continued developing the hardware and software components of the cryogenic control system, based on the exploitation of the experience gained. These developments are always aimed to increase the safety while improving, at the same time, the performance. The final part will present the evolution of the cryogenic control toward an integrated control system SOA based, using the Reference Architectural Model Industrie 4.0 (RAMI 4.0).

INTRODUCTION

The CERN cryogenic infrastructures for accelerators, detectors and test systems include large and complex facilities able to cool the equipment down to 80 K with liquid nitrogen (LN_2), to 4.5 K with liquid Helium (*LHe*) and to 1.9 K with super fluid helium. These facilities are placed in dedicated test facilities, experimental areas and around the 27 km LHC. The complexity of the cryogenic facility requires an automated and homogeneous control system that must be flexible, reliable and distributed around the entire CERN LHC cryogenic line QRL [1]. Today, for the High luminosity (HL-LHC), era some adaptions will be applied to fully automate the control development and to prepare the integration of the control system with the existing Maintenance Management Software (MMS) and the operational support environment from the conception stage to the daily operation. Tomorrow, a new generation of large accelerators is forecasted, making the story far from finished. Hence this article will also present additional thoughts and potential developments proposals.

CRYOGENIC CONTROL SYSTEM TODAY

Currently, the cryogenic control system follows the standard automation pyramidal structure of the International Electrotechnical Commission (IEC-62264) and is based on industrial components deployed in all control layers (see Fig. 1):

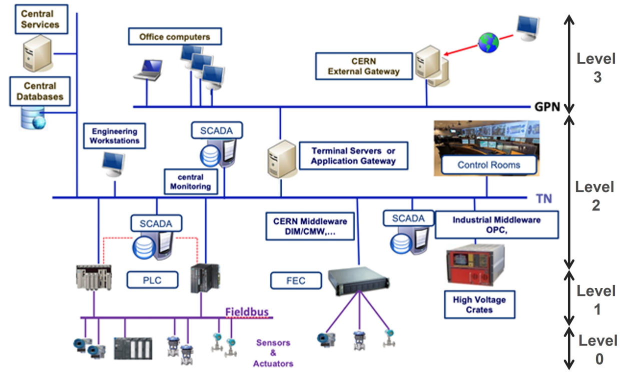


Figure 1: CERN Industrial Control Ecosystem.

- Instrumentation layer (IL): The cryogenic instrumentation needs a significant number of industrial sensors to collect data, electronic conditioning units and actuators to execute commands. To ensure the correct communication with the devices, both copper cable connections and a protected and dedicated Ethernet network or industrial field-buses are used. In the LHC, where the environment is hostile, radiation resistant instruments and fieldbuses were chosen.
- Control layer (CL): The control duties are executed within PLC, with safety interlocks either cabled in the electrical cabinets or programmed in local protection PLCs. In radiation exposed area radiation tolerant crates and field-bus are used, coupled with standard CERN Front End Computer (FEC). The long-distance integration site to site or toward the supervision layer, relies on the CERN Ethernet Technical Network (TN) whereas the local ones (internal to a cryogenic site) are implemented on field-buses using both fibres and copper cables or direct cabled to the cabinets.
- Supervision layer (SL): All cryogenics systems are supervised through Data Servers (DS) running the WinCC-OA® SCADA system within off-the-shelf's Linux machines. The Human-Machine Interface (HMI) clients allows operators to monitor and act on the cryogenics facilities using Linux PC deployed within the control rooms. In addition to the classical SCADA features, several functionalities have been added in the last decade: visualisation of the process hierarchy, access to the interlocks per devices, control loop auto tuning, direct access to device documentation, etc. This layer provides also interfaces to the Management Layer, and a dedicated connections toward the CERN central alarm system and the LHC experiments control systems.
- Maintenance & Operation Management System layer (ML): The central long-term logging database (NXCALS), the CERN CMMS (Infor-EAM) and the Accelerator Fault Track application (AFT) are parts of this

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-FRAL04

THE CONTROL SYSTEM OF THE NEW SMALL WHEEL ELECTRONICS FOR THE ATLAS EXPERIMENT

P. Tzanis*,[1,2], on behalf of the ATLAS Collaboration
[1] National Technical University of Athens, Athens, Greece
[2] Brookhaven National Laboratory, Upton, NY, USA

Abstract

The present ATLAS Small Wheel Muon detector will be replaced with a New Small Wheel (NSW) detector in order to cope up with the future LHC runs of high luminosity. One crucial part of the integration procedure concerns the validation of the electronics for a system with more than 2.1 M electronic channels. The readout chain is based on optical link technology connecting the back-end to the front-end electronics via the FELIX, which is a newly developed system that will serve as the next generation readout driver for ATLAS. For the configuration, calibration and monitoring path the various electronics boards are supplied with the GBT-SCA ASIC and its purpose is to distribute control and monitoring signals to the electronics. Due to its complexity, NSW electronics requires the development of a sophisticated Control System. The use of such a system is necessary to allow the electronics to function consistently, safely and as a seamless interface to all sub-detectors and the technical infrastructure of the experiment. The central system handles the transition between the probe's possible operating states while ensuring continuous monitoring and archiving of the system's operating parameters.

NEW SMALL WHEEL

In order to efficiently handle the increased luminosity that will be provided by the High-Luminosity LHC (HL-LHC), the first station of the ATLAS [1] muon end-cap system (Small Wheel, SW) will need to be replaced. The New Small Wheel (NSW) [2] will have to operate in a high background radiation region (up to 22 kHz/cm²) while reconstructing muon tracks with high precision as well as providing information for the Level-1 trigger. The detector technologies to be used come from the family of gaseous detectors, the first is called small-strip Thin Gap Chambers (sTGCs), and the second comes from the category of micro-pattern gas detectors and is named Micromesh Gaseous Structure (Micromegas (MM)) [3] . The new experimental layout will consist of 16 detection layers in total and 8 layers per detection technology (8 layers sTGC and 8 layers Micromegas), as shown in Fig. 1. The sTGC detectors are designed to provide fast trigger and high precision muon tracking under the HL-LHC conditions. On the other hand, Micromegas detectors have a small conversion region (5 mm) and fine strip pitch (0.45 mm) resulting in excellent spatial resolution and are primarily used for precise tracking.

* polyneikis.tzanis@cern.ch

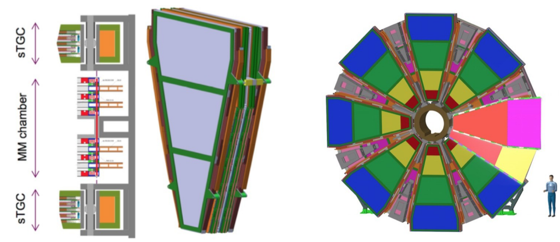


Figure 1: A graphic representation of the NSW sector (left) which consists of 8 layers of Micromegas in the inner part and sandwiched by 4+4 layers of sTGC detectors in the outer parts and view of the NSW (right) with 16 sectors in total. [4]

ELECTRONICS OVERVIEW

The NSW electronics for the trigger and Data Acquisition (TDAQ) path of both detectors is divided into two major categories, on-detector and off-detector electronics, as shown in Fig. 2. On the left-hand side, the front-end boards that

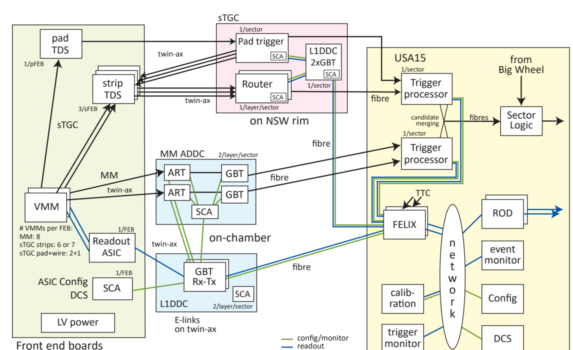


Figure 2: Overview of the NSW electronics scheme. The front-end detector boards are depicted on the left (for MM and sTGC), the data-driver cards (L1DDC, ADDC) in the middle while the back-end electronics can be seen on the right. [4]

are attached to the chambers bear VMMs, SCAs(Slow Control Adapter) and ROCs(Read Out Controller), while for the sTGCs they also host TDS chips. The ROC aggregates L1 data from many VMMs [5] and sends them to (Front End LInk eXchange (FELIX) [6] via the GBTx [7]. FELIX also sends trigger signals to the front-end electronics via the ATLAS TTC system. It also sends tracking data from the ROC to the swROD (here depicted to send the data fragments to the HLT), and communicates with the Detector Control System (DCS) [8] for slow control purposes. The Micromegas trigger data are collected from many VMMs by

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-FRAL05

MACE CAMERA ELECTRONICS: CONTROL, MONITORING & SAFETY MECHANISMS

Saurabh Kumar Neema, Shikha Srivastava, Hariharan J., Sandhya Mohanan,
Saju Joy, Padmini S., Anita Behere
Bhabha Atomic Research Centre, Mumbai, India

Abstract

MACE Telescope installed in Ladakh Region of India comprises of many functionally diverse subsystems, Camera being the most important one. Mounted at the focal plane of 21 m diameter parabolic reflector dish, event driven Camera system comprises of 1088 PMTs, with 16 PMTs constituting one Camera Integrated Module (CIM). Central Camera Controller (CCC), located in Camera housing, manages and coordinates all the actions of these 68 Modules and other camera subsystems as per the command sequence received from Operator Console. In addition to control and monitoring of subsystems, various mechanisms have been implemented in hardware as well as embedded firmware of CCC and CIM to provide safety of PMTs against exposure to ambient bright light, bright star masking and detection and recovery from loss of event synchronization at runtime. An adequate command response protocol with fault tolerant behaviour has also been designed to meet performance requirements. The paper presents the overall architecture and flow of camera control mechanisms with a focus on software and hardware challenges involved. Various experimental performance parameters and results will be presented.

INTRODUCTION

The MACE Telescope is a 21m diameter gamma ray telescope installed at Hanle in Ladakh, India at an altitude of 4270m above sea level, the highest for any Imaging Atmospheric Cherenkov Telescopes (IACT) based telescope. Primary objective of such IACT's is to detect High energy cosmic gamma rays emanating from various galactic and extragalactic sources. MACE Telescope detects very faint and narrow (5-10 nS) Cherenkov light generated by Extensive Air Shower when High Energy Gamma rays (20 GeV – 10 TeV) interact in the earth's atmosphere. The Imaging Camera is an essential subsystem of the Huge Telescope system and has been designed with state-of-the-art technologies for High Speed Data acquisition within the constraints of space, weight and power in such a way that the entire electronics for analog signal processing, digitization, triggering and event building is fully integrated into the camera body. Only Power supply and Network cables are connected between Ground station and Camera. Control and monitoring aspects of highly compact camera electronics is discussed in the current paper. Figure 1 presents the latest photograph of MACE Telescope during observation.

Figure 2 describes the block diagram of various subsystems of Camera Electronics. Second level trigger Generator (SLTG) detects time-space coincidence across nearby pixels in trigger regions based on the first level Trigger information from various CIMs and generates system-wide Trigger signal. After receiving the Trigger signal, CIMs start acquisition and send event data to the Data Concentrator (DC). Efficient data processing algorithms [1] have been implemented in CIM and accumulated charge data for each pixel along with profile of hit pixels is formed in the CIM data packets. DC collects these data packets from all the CIMs and prepares camera event packets. Event data from camera is sent via 1 Gbps Ethernet link to the Ground station. The co-ordination, control and monitoring of various subsystems in a reliably deterministic manner is a challenging task.

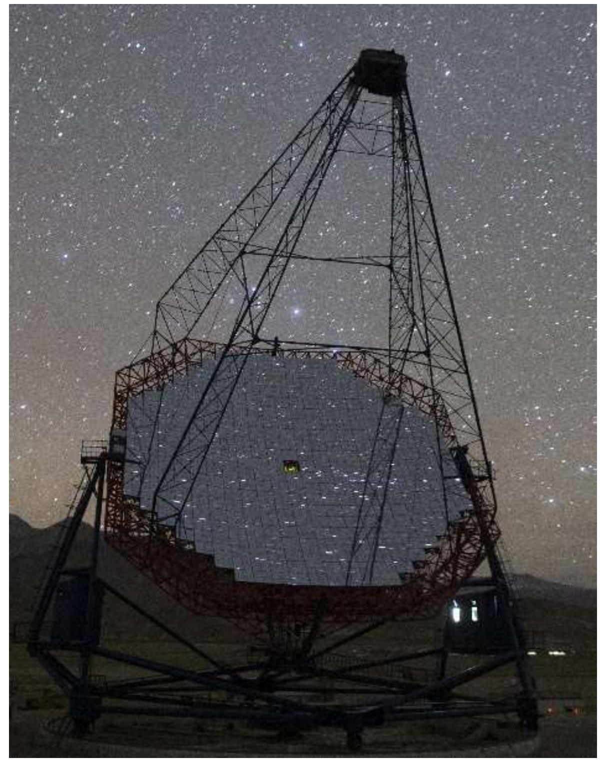


Figure 1: MACE Telescope during observation.

Other subsystems which are part of the camera electronics are Lid Controller, Temperature monitoring system and LED/Sky Calibration system.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-FRAR01

TARANTA, THE NO-CODE WEB DASHBOARD IN PRODUCTION

M. Eguiraun*, V. Hardion, Y. Li, M. Saad, A. Amjad, J. Rosenqvist, L. Nguyen, J. Forsberg
MAX IV Laboratory, Lund, Sweden
M. Canzari, V. Alberti INAF-OAAB, Teramo, Italy
H. Ribeiro, Atlar Innovation, Portugal
V. Alberti, INAF-OATs, Trieste, Italy
A. Dubey,Persistent Systems, Pune, India

Abstract

The remote control and monitoring of accelerators and experimental setup has become essential when remote work has become the norm for the last two years. Unlike the desktop user interfaces which have been developed for the use from physical workstations, web application are naturally accessible remotely via the ubiquitous web browsers. On the other hand, Web technology development requires a specific knowledge which has yet to be disseminated in the control system engineering and desktop frameworks still have the benefit of rapid, and easy development even for the non-specialist. Taranta Suite is a collection of web applications jointly developed by MAX IV Laboratory and the SKA Observatory, for the Tango Control System. In line with the "no-code" trend for the users, truly little knowledge of web technologies is needed. An operator can create a graphical user interface on-the-fly and can share it instantly. Authentication and authorization ensures that the right access level is given to the user. This paper will describe the system, the details of its implementation, and the first usage at the different facilities.

INTRODUCTION

There is no doubt about the usability and the optimised user experience of web interfaces and applications in everyday life situations. The last decade has seen an explosion of these kind of developments. New tools, new frameworks and new wide-spread applications have gained fame and number of users and slowly displaced traditional desktop applications. However, scientific environments are usually built on traditional and well known infrastructure, lagging behind software innovation and trends. MAX IV and SKA facilities were pushing and promoting the usage of web applications in their respective communities and in 2019 they joined efforts and gave birth to Taranta, a web application for building user interfaces in a Tango ecosystem [1]. The tango community renamed it from the previous Webjive name [2].

This new application is profiting from recent years of development in User Experience (UX) and User Interface (UI) web frameworks. It provides an out of the box, modern and stylish environment for accessing the most important functionality of a Tango device, from what is called the Device View [2]. Simple and powerful enough for fast access, however, the most remarkable functionality is the Dashboard View. This element is where the user can create its own user interface by drag and drop components (which are called Taranta Widgets) and easily configure and link them to Tango devices. This is where the idea of No-Code plays a fundamental role, Taranta leverages the UI development to the end user.

* mikel.eguiraun@maxiv.lu.se

NO-CODE PARADIGM

The lead time to get a new user interface is usually very long. The software development and UI design have to follow a number of established stages starting from the user requirement gathering to the usage of a final product. The no-code trend define a way for any end-user to develop their own software and then to make it available immediately to a larger audience of the same end-user group [3]. This way, user of a no-code system doesn't need to be knowledgeable in software development and how the software is deployed to be able to add value into the system. All the infrastructure is completely transparent and does not prevent fulfilling their will.

There is a lot of advantage for the users to bypass the traditional software development chain. First of all, as users themselves, they know exactly what the software should look like and which feature is expected. The users own the requirements like in any development method, although in a no-code system many filters are avoided since the users develop their own product. Writing down the requirements, understanding the specification and code development throughout different persons are some examples of filters which attenuate the original idea.

The concept of accelerating the software development has started years before the no-code trend arrived. Prototype generated by sketch of the Graphical User Interface (GUI) in the Rapid-Application Development (RAD) [4] made a step closer to the final product by developing only the functionalities. An extension of the same concept appears in the early 2000s for the creation of UI based on the definition of the domain i.e in the model development driven (MDD) all the structure of the software (Model) and part of its implementation is generated from the requirement. Visual programming language helps the power-users with enough software skills to design a system rapidly for their local applications i.e workbench like LabView can produce application with no manually written code code. The dissemination to a larger group of users can be delegated later to the software engineers.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-FRAR02

canone3: A NEW SERVICE AND DEVELOPMENT FRAMEWORK FOR THE WEB AND PLATFORM INDEPENDENT APPLICATIONS*

G. Strangolino, L. Zambon, Elettra, Trieste, Italy

Abstract

On the wake of former web interfaces developed at ELETTRA [1] as well as in other institutes, the service and development framework for the web and platform independent applications named PUMA (Platform for Universal Mobile application) has been substantially enhanced and rewritten, with the additional objectives of high availability, scalability, load balancing, responsiveness and customization. Thorough analysis of Websocket limits led to an SSE (Server-Sent Events) based server technology relying on channels (Nchan over NGINX) to deliver the events to the clients. The development of the latter is supported by JQuery, Bootstrap, D3js, SVG (Scalable Vector Graphics) and QT and helps build interfaces ranging from mobile to dashboard. Ultimate developments led to successful load balancing and failover actions, owing to the joint cooperation of a dedicated service supervisor and the NGINX upstream module.

DESIGN RATIONALE

The system consists of a cluster of servers, thereafter synonymously named services, and two client side development environments. One is based on web technologies on browsers. The second is a C++ client library to build native Qt applications. The main objectives of the service design are reliability, security, scalability and accessibility. To satisfy them, a set of state of the art technologies and software serve as the groundwork of the system.

RELIABILITY

The design rationale identifies the principles of a reliable service as follows. The system shall work:

- from any place and platform;
- at any time;
- regardless the number of clients
- included when part of the system is unavailable
- included when the network performance is suboptimal or even subject to charges.

The first requirement ruled out the *WebSocket* technology after an accurate analysis of its assets and liabilities.

WebSocket

WebSocket is a computer communications protocol, providing full-duplex communication channels over a single TCP connection. The WebSocket protocol was standardized by the IETF as RFC 6455 in 2011, and the WebSocket API in Web IDL is being standardized by the W3C. [2]

WebSockets are widespread and efficient when handling huge amount of messages from both ends, where duplex communication is continuously involved: Massive Multiplayer Online (MMO) and messaging applications.

The list of liabilities is nevertheless long in our situation:

- WebSockets can be potentially blocked by proxies;
- CORS (Cross-Origin Resource Sharing) [3] related concerns;
- no multiplexing over HTTP/2 (implementing it on both ends is complicated);
- no load balancing;
- susceptible to DoS;
- problems already taken care of in HTTP must be solved ad hoc;
- operational overhead in developing, testing and scaling is increased.

Some proxy servers are transparent and work fine with WebSockets; others will prevent them from working correctly, causing the connection to fail. In some cases, additional proxy server configuration is required.

Load balancing is very complicated. When servers are under pressure and new connections need to be created and old ones closed, the actions that must be taken can trigger a massive chain of refreshes and new data requests, additionally overloading the system. It's not possible to move socket connections to a different server to relieve one under high load. They must be closed and reopened. It turns out that WebSockets need to be maintained both on the server and on the client.

Multiplexing is usually handled by front end HTTP proxies that cannot be handled by TCP proxies which are needed for the WebSockets. Connecting to the sockets and flooding servers with data is a possible eventuality.

Concerning the last weakness in the list, we observe that mobile devices would maintain a WebSocket open by keeping the antenna and the connection to the cellular network active. Battery life would be reduced, heating increased, and, where applicable, extra costs for data usage applied.

SSE

Server-Sent Events (SSE) is a server push technology enabling a client to receive automatic updates from a server via an HTTP connection, and describes how servers can initiate data transmission towards clients once an initial connection has been established. They are commonly used to send message updates or continuous data streams to a browser client and designed to enhance native, cross-browser streaming through a JavaScript API called EventSource, through which a client requests a

* inspiration by Alessio Igor Bogani, Elettra, Trieste, Italy

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-FRAR03

A MAJOR UPDATE OF WEB BASED DEVELOPMENT TOOLKIT FOR CONTROL SYSTEM OF LARGESCALE PHYSICS EXPERIMENT DEVICE

X. Xie, W. Zheng, M. Zhang, B. Rao, Y. Yang, F. Wu, Y. Jiang, P. Zhang, W. Wang, S. Li, International Joint Research Laboratory of Magnetic Confinement Fusion and Plasma Physics, State Key Laboratory of Advanced Electromagnetic Engineering and Technology, School of Electrical and Electronic Engineering, Huazhong University of Science and Technology, Wuhan, China

Abstract

The deployment of the control system called CODAC (Control, Data Access and Communications) is necessary for the operation of large-scale experimental facilities. CFET (Control system framework for experimental devices toolkit) is a flexible SCADA (supervisory control and data acquisition) software tool, which is used for the construction of a CODAC. CFET is fully based on open web technologies, it is easy to integrate all kinds of systems and devices into CFET. This paper has undergone a major iteration of CFET. HMI has been redesigned and implemented. The control engineer can use a web based WYSIWYG HMI editor to compose the HMI. In CFET, InfluxDB has been integrated. It is used to store the engineering data, and also visualize the data on the website. Docker based microservices architecture has been designed, putting CFET and dependent packages into a lightweight container. At present, CFET has been used in the CODAC system of J-TEXT tokamak and HUST Field-Reversed Configuration facility.

INTRODUCTION

For a long time, Experimental physics and industrial control system (EPICS) have been used to build large-scale experimental equipment control systems in the accelerator field. So far, the community has been very mature, and EPICS has very strong support for hardware equipment in the accelerator field [1-2]. ITER (as the world's largest tokamak) chose EPICS as the core framework of their control system [3-6], and chose EPICS Channel Access protocol as the communication protocol for the control network. Therefore, many other equipment in fusion field have chosen EPICS to build their own control systems. However, due to the differences in equipment and control requirements, EPICS has not demonstrated its advantages in the fusion community, and EPICS Channel Access protocol also has the problem of opacity and operability. Control system Framework for Experimental Devices Toolkit (CFET) framework is implemented as .NET standard libraries. It bases on Web technologies and uses HTTP as the control system communication protocol [7-8]. Web technology almost supported by all the devices. Countless web APIs have been published and consumed by all kinds of devices. It's also easy to integrate various new devices via the network, and provides flexible control system solutions for users in different scenarios. CFET is an efficient development tools with transparent protocol, and provides stronger support for new devices, also has the characteristics of easy integration and strong interoperability between subsystems.

This paper first briefly talked about the basic concepts of CFET. The third section will introduce the support of new communication protocol. Section 4 will introduce the redesigned HMI. The engineering data storage and management system will be described in the fifth section. CFET also uses docker to realize the cross-platform deployment of the user side rapidly. In the end, the application of CFET on HFRC will be briefly demonstrated.

BASIC CONCEPTS OF CFET

As mentioned before, CFET is a Web-based SCADA. Web plays a big role from websites (online services), online games, to smart sensor and IoT application. So CFET has good adaptability to a variety of different large-scale equipment, and can also meet new development models and new operating environments. HTTP is the most common communication protocol in web applications. The main communication module of CFET (CFET HTTP CM) uses the HTTP protocol of the RESTful architecture as the basic transmission protocol. The format of the RESTful framework is to use URI to locate resources and add verbs (intended action) in front of the resources. For example, if you need to know the switch status of light bulb A in the laboratory, the corresponding resource request should be "get + /lab/lightA/status". In HTTP CM, the client actions are mapped to HTTP verbs. There are three resource access actions, namely Get, Set and Invoke, mapping to HTTP Verb GET, PUT and POST. To different types of resources, HTTP verbs are different, otherwise an error that does not conform to the design principles will be reported.

The basis of interoperability is that every client in this system can understand each other conceptually, so we have to encapsulate the equipment in control system into a common model with consistent interfaces. The model has 5 types of resources: Thing, Status, Configuration, Method and event. Status, Configuration and Method are the property of Thing. A Thing can be either physical or logical. Event is a property based on publish/subscribe pattern. The subscriber can subscribe a resource and get notified on a certain condition.

NEW CFET COMMUNICATION MODULE

A CFET application, in principle, is allowed mount multiple Communication Modules. Each Communication

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-FRBL01

MACHINE LEARNING FOR ANOMALY DETECTION IN CONTINUOUS SIGNALS

A. A. Saoulis*, K.R.L. Baker, R. A. Burridge, S. Lilley, M. Romanovschi
ISIS Neutron and Muon Source, Didcot, UK

Abstract

High availability at accelerators such as the ISIS Neutron and Muon Source is a key operational goal, requiring rapid detection and response to anomalies within the accelerator's subsystems. While monitoring systems are in place for this purpose, they often require human expertise and intervention to operate effectively or are limited to predefined classes of anomaly. Machine learning (ML) has emerged as a valuable tool for automated anomaly detection in time series signal data. An ML pipeline suitable for anomaly detection in continuous signals is described, from labelling data for supervised ML algorithms to model selection and evaluation. These techniques are applied to detecting periods of temperature instability in the liquid methane moderator on ISIS Target Station 1. We demonstrate how this ML pipeline can be used to improve the speed and accuracy of detection of these anomalies.

INTRODUCTION

The ISIS Neutron and Muon source, located at the Rutherford Appleton Laboratory site in Oxfordshire, UK, creates neutron and muon beams used to perform a range of high quality scientific experiments. The facility has developed a great deal over its 35 years of operation [1], both increasing the complexity of the facility and the production of machine data. Currently, anomaly detection and response are generally handled manually by operators, and require large amounts of domain knowledge and expertise. Outlined in this paper is a pipeline to take unlabelled, continuous time series data and train a model that can detect anomalies on live data during operations, improving the response-time and effectiveness of reacting to these anomalies.

ISIS TS1 Methane Moderator

The facility accelerates protons up to 800 MeV, which are used to generate neutrons through a spallation process at ISIS Target Station 1 (TS1) [1], the first of the two target stations at ISIS. These neutrons are moderated at TS1 through several different moderators, one of which is a liquid methane moderator, in order to perform neutron scattering experiments. For high quality experiment data, very stable temperature in the methane moderator is required.

Whilst methane has many properties that give it excellent performance as a moderator [2], it is well known that it is susceptible to radiation damage [3]. The irradiation of the methane produces long chain polymers and releases hydrogen [3,4], the former causing the moderator to fail and require replacement roughly every six months. The build-up of free hydrogen within the moderator system causes loss of flow and leads to unpredictable pressure variability and spiking. This causes the temperature in the methane moderator to become unstable, which increases the variance of neutron energy leaving the moderator; it is therefore of key operational importance that these losses of flow are dealt with quickly. One method through which the operations team have dealt with this issue is through daily, scheduled "recoveries" of the moderator that consist of flushing through one third of the liquid methane in the system into a dump tank. This has improved its stability, but occasional periods of flow, and thus pressure and temperature variability, still occur.

The operations team currently have systems in place for detecting these instabilities, such as monitoring differential pressure in the system for any reduction in pressure. If an anomaly is detected, the operations team inspect the recent behaviour of the moderator and decide whether to run an unscheduled recovery in order to return the system to normal operation. The current systems often fail to flag up ongoing anomalies, leading to long periods of temperature variability that can cause the data recorded in downstream instruments to be unusable.

This paper will investigate the automated detection of these periods of temperature variability, with the goal of aiding the operations team to track down and fix issues faster. The paper will make use of supervised Machine Learning (ML) algorithms, which require labelled data (i.e. each data instance has an associated class label, such as whether it is "normal operation" or an "anomaly") to train a model. Finally, a brief description of the process of deployment of such trained models to live operation will be given.

DATA PIPELINE

Here, a pipeline is given that takes raw time series data without labels and produces a dataset that is suitable for training ML models. In the case of the ISIS TS1 methane moderator, there was neither a logbook nor a convenient signal that could be used to automatically label temperature anomalies in the historic data. One key contribution of this paper is to define a general procedure for automatically labelling periods of anomalous behaviour in historic time series data so that models can be trained to detect these periods during live operation. Note that while this paper focuses on a single signal (i.e. a univariate time series), these methods are generalisable to multivariate time series.

* alex.saoulis@stfc.ac.uk

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-FRBL03

A LITERATURE REVIEW OF THE EFFORTS MADE FOR EMPLOYING MACHINE LEARNING IN SYNCHROTRONS*

A. Khaleghi†1, Z. Aghaei, K. Mahmoudi, H. Haedar, I. Imani, Computer Group, Imam Khomeini International University, Qazvin, Iran
M. Akbari, M. Jafarzadeh, F.A. Mehrabi, P. Navidpour, Iranian Light Source Facility Institute (ILSF) for Research in Fundamental Sciences (IPM), Tehran, Iran
[1]also at Iranian Light Source Facility Institute (ILSF) for Research in Fundamental Sciences (IPM), Tehran, Iran

Abstract

Using machine learning (ML) in various contexts is increasing due to advantages such as automation for everything, trends and pattern identification, highly error-prone, and continuous improvement. Even non-computer experts are trying to learn simple programming languages like Python to implement ML models on their data. Despite the growing trend towards ML, no study has reviewed the efforts made on using ML in synchrotrons to our knowledge. Therefore, we are examining the efforts made to use ML in synchrotrons to achieve benefits like stabilizing the photon beam without the need for manual calibrations of measures that can be achieved by reducing unwanted fluctuations in the widths of the electron beams that prevent experimental noises obscured measurements. Also, the challenges of using ML in synchrotrons and a short synthesis of the reviewed articles were provided. The paper can help related experts have a general familiarization regarding ML applications in synchrotrons and encourage the use of ML in various synchrotron practices. In future research, the aim will be to provide a more comprehensive synthesis with more details on how to use the ML in synchrotrons.

INTRODUCTION

Synchrotrons light sources are very large-scale experimental facilities. A synchrotron is a large machine whose size is about a football field (Fig. 1). In these facilities, electrons are accelerated to almost the speed of light. By deflecting electrons through magnetic fields, they create incredibly bright light. The electrons are deviated in the storage ring by different magnetic components such as bending magnets, undulators, wigglers, focusing magnets. This deviation results in a tangential emission of X-Rays by the electrons. The resulting X-rays are emitted as dozens of thin beams, each channeled down "beamlines" surrounding the storage ring in the experimental workstations where the light is used for research. Each beamline is designed for use with a specific technique or type of analysis [1]–[3]. The produced light is advancing research and development in fields as diverse as biosciences, medical research, environmental sciences, agriculture, minerals exploration, advanced materials, engineering, forensics [1]. The intense and highly focused light is used to study the dynamic and structure of materials down to atomic level using various techniques offered by different beamlines like diffraction, spectroscopy, tomography, and imaging [4]. Please see the references [1]–[3], [5] to see how a synchrotron works in more detail. Also, the list of light sources of the world can be found in [6].

Synchrotrons light sources worldwide are experiencing fast changes from traditional 3rd generation to multi-bend achromatic (MBA)-based 4th generation storage ring light sources to achieve high-brightness and low-emittance upgrades [7], [8]. The Advanced Photon Source (APS) and the Advanced Light Source (ALS) are both being upgraded

Figure 1: A 3D illustration of a synchrotron [2].

to MBA-based new rings. Diamond Light Source (DLS) designed a machine lattice based on double triple bend achromats [8]. The upgrades will substantially harness the light beam brightness from what is offered by the existing rings (the light brightness is much more greater than the sunlight) [7].

The rapid development of synchrotrons massively is accompanied by two significant challenges. First, the new rings drive for significantly lower emittances. Therefore, the beam dynamics in the rings become extremely nonlinear, causing smaller dynamic aperture and potentially smaller momentum aperture [7]. The extremely small emittance in a new ring needs much higher beam stability, which raises the need for a good understanding of the impact of environmental factors on the accelerator and

* Work supported by Iranian Light Source Facility (ILSF)
† khaleghiali@ipm.ir

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-FRBL05

RemoteVis: AN EFFICIENT LIBRARY FOR REMOTE VISUALIZATION OF LARGE VOLUMES USING NVIDIA INDEX

T. V. Spina*, D. A. D. Alnajjar, M. L. Bernardi, F. S. Furusato, E. X. Miqueles, A. Z. Peixinho
Brazilian Synchrotron Light Laboratory, CNPEM, Campinas, Brazil
A. Kuhn, M. Nienhaus, NVIDIA, Berlin, Germany

Abstract

Advancements in X-ray detector technology are increasing the amount of volumetric data available for material analysis in synchrotron light sources. Such developments are driving the creation of novel solutions to visualize large datasets both during and after image acquisition. Towards this end, we have devised a library called RemoteVis to allow the visualization of large volumes remotely in HPC nodes, using NVIDIA IndeX as the rendering backend. RemoteVis relies on RDMA-based data transfer to move large volumes from local HPC servers, possibly connected to X-ray detectors, to remote dedicated nodes containing multiple GPUs for distributed volume rendering. RemoteVis then injects the transferred data into IndeX for rendering. IndeX is a scalable software capable of using multiple nodes and GPUs to render large volumes in full resolution. As such, we have coupled RemoteVis with slurm to dynamically schedule one or multiple HPC nodes to render any given dataset. Remote-Vis was written in C/C++ and Python, providing an efficient API that requires only two functions to 1) start remote IndeX instances and 2) render regular volumes and point-cloud (diffraction)

INTRODUCTION

Improvements in synchrotron light source technology are pushing forward the boundaries of X-ray microscopy imaging. Recently, 4th generation synchrotron light sources are increasing the amount of available beam flux and coherence, opening the doors to novel imaging techniques while representing an improvement of orders of magnitude with respect to previous generations. Hence, the entire imaging pipeline is evolving to make those powerful improvements available to the beamlines and their users; starting with the creation of fast X-ray detectors capable of acquiring frames at multiple kHz and reaching the development of high performance data processing, visualization, and analysis workflows.

In this paper, we propose a volumetric data visualization workflow in the form of a library called RemoteVis, to address some of the challenges imposed by the large data volumes being generated. RemoteVis is designed as an efficient C/C++ API for sending image volumes for remote 3D rendering, using NVIDIA IndeX [1] as the rendering backend. In-memory data is transferred directly to dedicated servers over the network via *Remote Direct Memory Access* (RDMA), without involving temporary file transfers or centralized storage. NVIDIA IndeX is a scalable software for interactive visualization of large volumes in full resolution, written in CUDA and designed to render data leveraging multiple GPUs and/or multiple nodes of a distributed HPC environment. When the volume is received by an instance of IndeX, it is immediately injected for visualization by the user, who can interact with the volume in real time using a web viewer.

The combination of RemoteVis and NVIDIA IndeX aims to overcome several limitations of existing open source and commercial visualization softwares. For instance, Neuroglancer [2] is a community-supported tool for visualization of very large volumes originally created by Google. It is capable of displaying arbitrary (non axis-aligned) cross-sectional views of volumetric data, as well as 3D meshes and line-segment based models (skeletons). Neuroglancer uses a tiling mechanism to handle zooming with different resolutions of large volumes, which are displayed on the web browser. Napari [3] allows simplified visualization of n-D data via Python, while ImageJ/Fiji contains plugins for rendering volumes [4]. 3D Slicer [5] is a rich application devoted primarily to medical imaging, containing several visualization tools for these types of data.

Despite some of the advantages of the aforementioned softwares, they either make limited use of GPU capabilities for rendering 3D volumes, relying on a single device to do so, or only displaying cross-sections of data, while providing less than optimal techniques to handle larger volumes (i.e., data sets with more than 2048^3 voxels). Even commercial solutions, such as ORS DragonFly [6] and Thermo Fisher OpenInventor [7] (Avizo/Amira), tend focus on single GPU/single node rendering, with limited APIs that can be used to address the needs of modern synchrotron light sources. Finally, those softwares are usually implemented considering that data is essentially stored on disk.

We initially designed RemoteVis to tackle the issue of sending volumes generated on local servers connected to X-ray detectors to remote dedicated servers for visualization. The local servers are freed to receive data at high frame rates and to perform local processing on the data using custom multi-GPU code. Such processing may involve, for instance, frame correction operations and even high performance tomography reconstruction [8]. In parallel, the remote servers receive the resulting volumes and are responsible for rendering them at full resolution, with interactive responsiveness.

* This is a joint work between the following groups of the Brazilian Synchrotron Light Laboratory: Sirius Scientific Computing (SSC – TVS, AZP, MLB, and EXM), Throughput Enhanced Processing Unit (TEPUI – FSF), and Beamline Software (SOL – DADA); in collaboration with the NVIDIA IndeX team (MN and AK). Corresponding author: Eduardo Xavier Miqueles (eduardo.miqueles@lnls.br).

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-FRBR01

PROCESS AUTOMATION AT SOLEIL: TWO APPLICATIONS USING ROBOT MANIPULATORS

L.E. Munoz*, Y-M. Abiven, F. Briquez, J. Da Silva, E. Elkaim, A. Noureddine, V. Pinty, M. Valléau, Synchrotron SOLEIL, Saint-Aubin, France
S. Bouvel, EFOR, Levallois Perret, France

Abstract

Robot manipulators are an important component in most autonomous systems in the industry. Arc welding, machine tending, painting, picking, are only some examples where the robot manipulators are widely employed. In Synchrotrons some process can benefit from robotic approaches in order to improve automation. Automatic Sample Changer on beamlines is the most common example of automation. This paper describes two robotic applications developed at Synchrotron SOLEIL. Both applications use the SOLEIL robotic standard introduced some years ago [1]. The first application aims to automate the exchange of samples for powder diffraction experiment on the CRISTAL beamline. Hence, a pick-and-place robot is used to automate the process of picking up the sample holders and placing them on the goniometer. The second application, also of the pick-and-place type, is dedicated to the automation of the magnetic characterization of magnet modules of an U15 undulator. These modules, built with a permanent magnet and two poles, are measured using a pulsed wire method [2]. In this case, the robot picks the modules stored in boxes to then place them on the test bench of the U15 undulator.

INTRODUCTION

According to the International Federation of Robotics (IFR) an industrial robot is an automatically controlled, reprogrammable multipurpose manipulator programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications (ISO 8373:2012). At the beginning, since manipulators had no external sensing, they were used for simple tasks as pick and place, mainly doing monotonous, repetitive and dangerous tasks for humans. As a result of technological advances, robots could handle more complex motion and had external sensors and then, more complex applications followed like welding, painting, grinding and assembly. Nowadays, the use of an industrial robot, along with Computer-Aided Design (CAD) systems and Computer-Aided Manufacturing (CAM) systems, not only characterize the latest trends in process automation in the industry [3], but the robot manipulators are becoming essential components in various growing sectors such as medical.

In a synchrotron facility, the most common application of industrial robots is to use the manipulator as a sample changer. The principle of a robotic sample changer is to take samples from one place and put them in another place with accuracy and repeatability. Thus, these robotic exchangers are widely used in experimental stations for Macromolecular Crystallography (MX), like is the case of the beamlines AMX and FMX at the National Synchrotron Light Source II (NSLS-II) [4], the beamlines I03, I04, I04-1 and I24 at Diamond Light Source (DSL) [5], the beamlines ID23-1 and ID23-2 at the European Synchrotron Radiation Facility (ESRF), among other MX beamlines. Some other techniques like biological Small-Angle X-ray Scattering (bioSAXS) at NSLS-II [4] and the powder X-Ray diffraction at the ESRF [6] integrate the sample changers to sample automation.

Nevertheless, the use of industrial robots is not limited to the sample changer, they can also be used to detector positioning: for Bragg CDI and Bragg-ptychography [7], to study structural dynamics with X-ray techniques [8], to enable coherent diffraction and SAXS experiments [9]; or even, robot manipulators can execute similar tasks to those present in the industry, such high precision manufacturing [10].

At Synchrotron SOLEIL, two robotic sample changers were installed on the beamlines PROXIMA-1 [11], and PROXIMA-2 [12], long before SOLEIL developed the robot standardization in 2019. This standardization, see Fig. 1, designed as part of a larger strategy in process automation, defines a robotic standard on both hardware and software which is versatile enough to cover the synchrotron requirements, while being easy to implement, to employ and to maintain in operation [1].

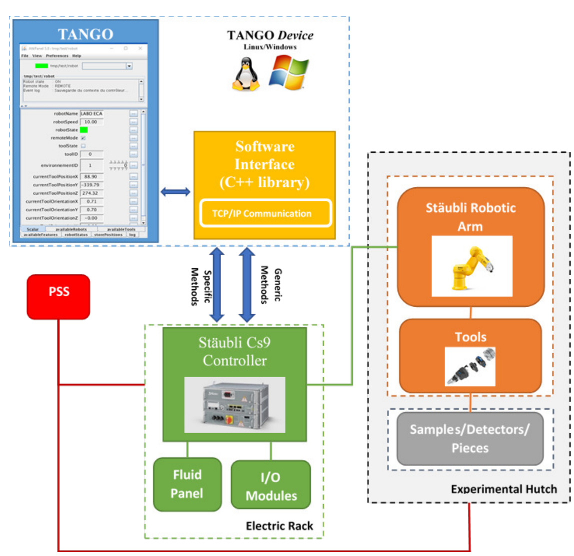


Figure 1: SOLEIL Robot Standardization Scheme.

* laura.munoz-hernandez@synchrotron-soleil.fr

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-FRBR02

AN INTEGRATED DATA PROCESSING AND MANAGEMENT PLATFORM FOR X-RAY LIGHT SOURCE OPERATIONS *

N.M. Cook†, E. Carlin, P. Moeller, R. Nagler, B. Nash, RadiaSoft LLC Boulder, CO 80301, USA
A. Barbour, M. Rakitin, L. Wiegart, National Synchrotron Light Source II,
Brookhaven National Laboratory, NY, 11973, USA

Abstract

The design, execution, and analysis of light source experiments requires the use of increasingly complex simulation, controls and data management tools. Existing workflows require significant specialization to account for beamline-specific operations and pre-processing steps in order to collect and prepare data for more sophisticated analysis. Recent efforts to address these needs at the National Synchrotron Light Source II (NSLS-II) have resulted in the creation of the Bluesky data collection framework, an open-source library providing for experimental control and scientific data collection via high level abstraction of experimental procedures, instrument readouts, and data analysis. We present a prototype data management interface that couples with Bluesky to support guided simulation, measurement, and rapid processing operations. Initial demonstrations illustrate application to coherent X-ray scattering beamlines at the NSLS-II. We then discuss extensions of this interface to permit analysis operations across distributed computing resources, including the use of the Sirepo scientific framework, as well as Jupyter notebooks running on remote computing clusters.

INTRODUCTION

X-ray light sources are prominent drivers of scientific discovery across a range of disciplines. These facilities serve a diverse user community, often providing concurrent beam time and user support to tens of domain scientists with unique backgrounds. Increasing demand for beam time, coupled with the increasing sophistication of experiments, places constraints on the infrastructure required to successfully carry out experiments within time and resource constraints. Recently, significant development efforts have been made towards improving experimental planning and execution; however, significant challenges remain to integrating real-time analysis tools within the experimental workflow. In this proceedings, we discuss a strategy for incorporating analysis pipelines within common experimental workflows, focusing on applications at the NSLS-II light source. We present a schematic workflow for orchestrating analysis in concert with experimental execution. We then demonstrate this workflow via an open source, browser-based interface furnishing beamline agnostic analysis pipelines.

* This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Advanced Scientific Computing Research under Award Number DE-SC00215553.
† ncook@radiasoft.net

AN INTEGRATED FRAMEWORK FOR EXPERIMENT AND ANALYSIS

Our proposed strategy is to integrate a flexible analysis platform with a mature controls framework, leveraging pre-existing workflows and data schemes wherever possible. To this end, we have adopted the Bluesky Data Collection Framework, which is in active use across many beamlines at the NSLS-II [1]. BlueSky aims to provide end-to-end experimental planning, execution, and data acquisition tools through a set of interoperable Python libraries. We highlight a few of the critical libraries for the application discussed below. First, the eponymous `bluesky` library implements a run engine and event model to permit experimental control and data collection through the execution of high level plans. The `ophyd` library provides hardware abstraction to communicate plans to devices along the beamline. The `databroker` library implements an API for structured access to experimental data and metadata generated during an experiment executed by Bluesky.

For the analysis component, we chose to use the Sirepo platform to orchestrate execution of analysis pipelines. Sirepo is an open-source scientific computing gateway that provides access to community codes through custom, browser-based interfaces and an embedded JupyterHub instance. Sirepo is designed to be hardware agnostic; simulation environments are deployed via Docker containers, and can be executed across a range of computing systems, ranging from a laptop to a GPU cluster an high performance computing facility. Sirepo provides support for numerous accelerator modeling and related tracking codes; existing applications have been employed to provide customized simulations of X-ray beamlines at the NSLS-II using the Synchrotron Radiation Workshop code [2]. Sirepo has also been integrated with Bluesky to enable the asynchronous execution of long-running SRW simulations to support multi-parametric optimizations of beamlines [3].

Our approach is to provide support for analysis pipelines that complements Bluesky's support for experimental execution. Figure 1 depicts a relational diagram between the different components of the envisioned platform. The Sirepo API and user interface will support the design, templating, and execution of analysis software, to be run in tandem with experimental execution. Sirepo templates simulations via JSON schemas, providing descriptive metadata, as well as mechanisms for sharing simulations or downloading and reproducing them elsewhere. This approach is akin to Bluesky's event model for describing documents generated by experimental plans. Sirepo enables hardware-independent descriptions

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-FRBR03

STATUS OF BLUESKY DEPLOYMENT AT BESSY II*

William Smith†, Sebastian Kazarski, Roland Müller, Luis Vera Ramirez, Pierre Schnizer, Simone Vadilonga
(HZB, Berlin)
Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Berlin, Germany

Abstract

The modernization plan for the experimental DAQ at the BESSY II [1] is underpinned by the capabilities provided by the Bluesky software ecosystem [2]. To interface with the hardware Bluesky relies on the Ophyd library, that provides a consistent high-level interface across a wide-range of devices. Many elements of the accelerator, some beamlines and endstations are adopting the Bluesky software. To meet FAIR data obligations, the capture of metadata with Bluesky and the export into a permanent and easily accessible storage called ICAT are investigated [3]. Finally, initial studies to investigate the integration of ML methods, like reinforcement learning [4] were performed.This paper reports on the work that has been done so far at BESSY II to adopt Bluesky, problems that have been overcome and lessons learned.

INTRODUCTION

The modernization strategy for experimental DAQ at BESSY II [1] uses EPICS as the unique integration layer for subsystems and software packages. There are many different solutions in use on the experimental floor for the layer above EPICS at BESSY II. This layer has to facilitate experimental flow control, data and metadata collection, storage and analysis.

While various home-grown solutions are in use at BESSY II, most beamlines use spec [5]. This popular and flexible tool has an easy to learn command line interface, has been deployed for decades in production at facilities around the world and is known and understood by many beamline staff. However it is not open source, has a tiny developer community, uses a language that is not well known outside the research community and has no error checking.

Open source alternatives including Sardana [6], PShell [7] and Bluesky [2] were all considered. The Bluesky software ecosystem was judged the most promising tool. Many other synchrotron facilities in Europe (Alba, PETRA III, ESRF, ELI NP, MAX IV, SOLARIS ...) use Sardana interfacing with TANGO. In principle it's possible to use EPICS with Sardana, but the underlying data models of the frameworks differ extremly. Due to the complex adaptation effort required, no facility is doing this in production. Bluesky and Ophyd interface natively with EPICS and there is a large user community in the US (NSLS II, APS, LCLS, SSRL, ALS) and a growing community in Europe (BESSY II, MPG/FHI, Diamond, PSI/SLS ...) and around the world (CLS, ANSTO, PLS II). Like Sardana, it's also based on Python. The data model of Ophyd devices is close to a corresponding TANGO device server instance. That might open opportunities to integrate complex TANGO units into Bluesky or take advantage of Sardana controlling Ophyd devices. Using a tool based on well known language with widely available training has made it easier to bring new people into the project.

This paper will report on progress in the deployment of Bluesky at the facility. First background on the infrastructure of BESSY II and a specific case study, the Energy Materials In situ Lab (EMIL) beamlines, is described. Then component integration, experimental flow control, data and metadata collection, user interfaces, and integration with machine learning (ML) tools are all explored.

SPECIFICS OF BESSY II

From the accelerator commissioning test bed, Bluesky made its way to the experimental floor via instrument integration at the EMIL beamlines. With the aim of being able to collect metadata about the state of the entire beamline when running Bluesky plans, each element of the beamline was given a Python device abstraction using the Ophyd Python package. These general devices classes were then easily transferred to create an interface for a novel beamline project (U49/2 PGM-2, "Aquarius") and to aid replacement efforts at a spec [5] automated beamline (μSpot). Work now continues to integrate other beamlines.

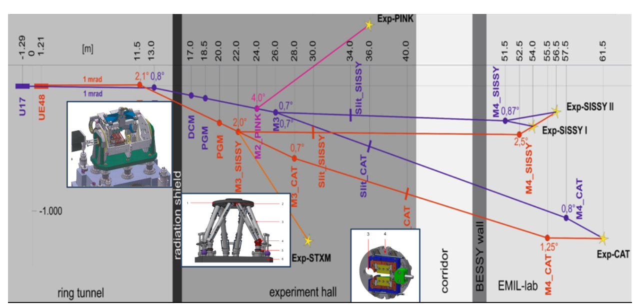


Figure 1: Complex beamline switch yard of the EMIL featuring multiple end stations, instruments and use cases.

CASE STUDY ON EMIL

The initial work to investigate deploying Bluesky at the beamlines was carried out at EMIL. EMIL comes with numerous additional challenges that are due to the complexity of the set-up and the variety of instruments to serve. Plain vanilla EPICS device control of the beamlines comes with EDM based engineering screens, the monochromator controls is based on an integrated VME application, obscur-

* Work funded by BMBF and Land Berlin
† william.smith@helmholtz-berlin.de

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-FRBR04

CONTINUOUS SCANS WITH POSITION BASED HARDWARE TRIGGERS

H. Enquist, A. Bartalesi, B. Bertrand, J. Forsberg, A. Freitas, V. Hardion, M. Lindberg, C. Takahashi, MAX IV Laboratory, Lund, Sweden

Abstract

In traditional step scanning, repeated starting and stopping of motors leads to inefficient usage of the x-ray source. In addition to increasing measurement times, this also increases the risk of sample radiation damage. We have developed a system where scans are performed while continuously moving the motors. To ensure stable repeatable measurements, the detector triggers are generated, in hardware, from the motor encoder positions. Before the scan starts, a list of positions is generated. That is then used to generate the triggers when these positions are reached.

The solution is implemented with Tango and Sardana. The encoder signals from the motors are connected both to the IcePAP motion controller for closed loop operation, and a PandABox which is used as the trigger source.

The scan is controlled by a TriggerGate controller, that calculates the motor positions and configures the PandABox. The scanned motor can be either a single motor, for example a sample translation stage, or a combined motion like a monochromator. When combined motions are used, these are using the parametric trajectory mode of the IcePAP. This enables continuous scans of coupled axes with non-linear paths.

INTRODUCTION

Many experiments require performing scans to measure some quantity as a function of another. The easiest approach is to use a step scan, and therefore this is very commonly used. In a step scan each step consists of moving the scanned axis to a certain position, then arming and triggering the detector, waiting for acquisition to finish, and finally reading out the data. This process is repeated for every step. Only the time spent acquiring the data is useful, while the rest can be considered deadtime. The starting and stopping of the scan axis (typically one or several motors), and the arming of the detector can take a considerable amount of time. Under typical conditions, scans can run no faster than a few points per second. If the acquisition time is then in the millisecond range, the deadtime tends to make up for the majority of the time required to perform the scan.

An alternative solution is to keep the scan axis moving continuously during the scan. This has previously been implemented using combinations of software and hardware solutions [1-3]. In this case, the scanned axis needs only to be started and stopped once. The aqusition loop then consists of only triggering the detector, waiting for acquisition to finish, and readout. Many detectors are able to read out the data in millieconds, meaning the scan can run at hundreds of points per second. This is the approach taken in this work. We have chosen to implement a system that handles the motions and trigger generation completely in hardware.

CONTINUOUS MOTION

Letting the motion to run continuously during the scan is straightforward when the axis corresponds to a single motor that needs to run at constant speed. This is the case when for example scanning along the surface of a flat sample using a single motor. But in many cases the motion involves several motors, that can't simply be moved at constant speed. To scan for example the energy of a plane grating monochromator, both the mirror and grating positions must move acording to some formulas. They also need to perform their motions synchronized, in order to keep the x-ray beam stable on the sample, with the right energy and properties. As illustrated in Fig. 1, a simple software pseudomotor will perform motions that start and end at the correct positions, but while moving, the path does not follow the ideal trajectory.

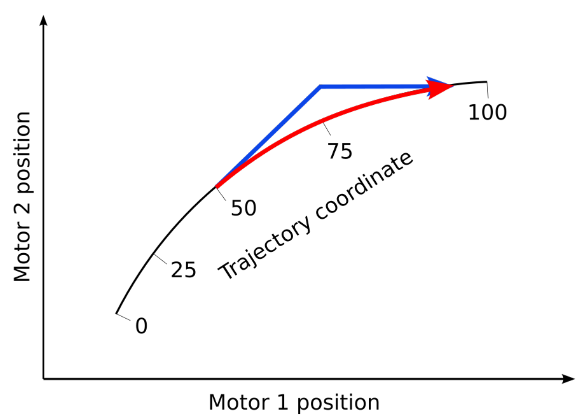


Figure 1: The difference between typical pseudomotions and parametric trajectories for a move along the parameter axis. The pseudomotor starts moving both motors at their nominal velocity. Once the first motor has reached it's position, the second continues moving towards the target. The parametric trajectory on the other hand follows the trajectory the whole way by continuously adjusting the motor velocities.