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THE TECHNICAL DESIGN CONCEPT OF THE NEW ACCELERATOR CONTROL SYSTEM FOR PETRA IV

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

Abstract

At DESY, a technical design report is currently being prepared for the upgrade of the PETRAIII synchrotron light source to PETRAIV, a fourth-generation low-emittance machine. Within the framework of this planned project, the accelerator control system is also to be renewed and adapted to the growing user requirements. This concerns on the one hand the core components of the control system itself, but also the hardware interfaces, the technical and beam physics control applications, the data acquisition and archiving systems, and the entire supporting IT infrastructure. The paper reports on the details of the proposed technical design concept.

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), latter a unique feature of PETRAIII. 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 an ultimate, 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 size 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 offers outstanding possibilities and optimal experimental conditions for industry. Special emphasis is also placed on the sustainable operation of the facility.

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. Recently, research has begun on the development and construction of a 6 GeV laser plasma injector.

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 2027, followed by a commissioning phase in 2029.

The following chapter will describe the technical design concept of the accelerator control system of the future PETRA IV facility.

TECHNICAL DESIGN CONCEPT

The development and implementation of the future PETRA IV accelerator control system will be embedded in a long-term process to consolidate and simplify the whole accelerator control system landscape at DESY and to take advantage of synergies between the accelerator facilities operated by DESY. Support and maintenance of the existing control system framework used at PETRA III will not be continued beyond its expected lifetime. Central control system services such as data acquisition and archiving or configuration management are to be renewed and prepared for future requirements.

The accelerator control system of PETRA IV will closely follow the control system concept implemented at the European XFEL which is pulsed linear accelerator and free-electron laser. Therefore, the control system concept of PETRAIV will be adapted where necessary to the special needs of a storage ring X-ray radiation source.

Control System Framework

The Distributed Object-Oriented Control System (DOOCS) [2] will form the basis of the future control system of PETRA IV (Fig. 1). 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. Design features of DOOCS include:

- DOOCS follows the object-oriented design paradigm. Devices and data are objects. The basic entity is a device server representing some control system hardware or logic.
- DOOCS is based on a distributed client-server architecture. Each control system parameter is made accessible via network calls. Its transportation layer is currently based on the standardized, industrial RPC protocol with XDR data representation. Integration of the 0MQ protocol is in progress.
- The DOOCS server core library and the server API are written in C++. A variety of fieldbus and hardware interfaces are supported via device classes. These are accessible through additional libraries which can be linked as needed individually to the server core library.
- A fine-grained mechanism for access authorization as well as monitoring and extensive logging functions are provided.
- Libraries for creating client applications in C++, Java, Python or MATLAB are available either as a separate implementation or as C-bindings.

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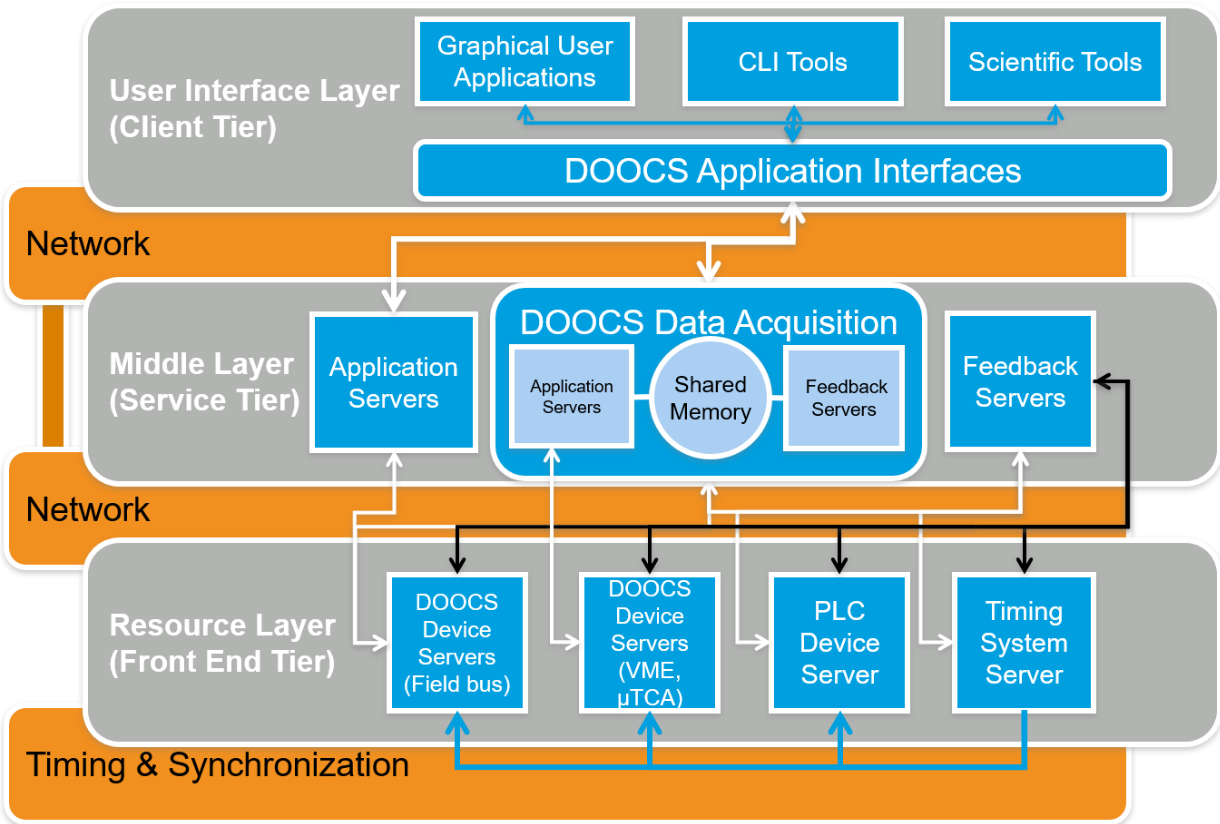

Figure 1: DOOCS control system layout.

- 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.

Graphical User Interfaces

The proven Java DOOCS Data Display (JDDD) [3] is chosen as standard user interface. JDDD is a Java application and follows a thin-client approach with a functional and rich set of widgets. Individual UI components can be easily created through a versatile editor IDE without the knowledge of any programming language

While JDDD is the tool of choice for the standard beam operation as well as operating technical accelerator devices and systems, Python is increasingly becoming the preferred programming language for rapid prototyping and visualization of scientific procedures and data.

Even if JDDD also provides a secure, HTML5-based Web interface, with the advent of modern Web standards such as Progressive Web Apps (PWA) other promising alternatives to design graphical user applications seem to be available. PWA are multi-platform, browser-based applications with a look-and-feel of versatile classical desktop applications. The potential of graphical user applications based on the React [4] JavaScript framework and the D3.js data visualization library [5] is currently investigated and first prototype applications are implemented and tested with respect to performance and user acceptance.

Hardware Interfaces

In general, the hardware interfaces for triggered, high-performance applications (e.g. beam diagnostics, injection/ejection system, feedback systems, timing/synchronization system, machine protection system, RF control) will be compliant with the high-end MTCA.4 technology [6]. MTCA.4 is the accepted long-term standard for the DESY accelerators and is enjoying growing popularity within the accelerator community and the related industry. The operating system for server hosts running within the MTCA.4 platform will be Linux.

The base configuration of a MTCA system includes a power-supply, a Management-Controller Hub (MCH), a CPU as an Advanced Mezzanine Card (AMC), a Timing System AMC, and optionally a Timing System Rear Transition Module (RTM) if required.

Based on the existing MTCA.4 timing module used at the European XFEL, a successor model is currently being developed at DESY. This module will function either as a transmitter or as a receiver. The module will distribute the

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RF reference signal, provide low-jitter clocks and trigger signals as well as beam-synchronous data such as a timestamp, revolution counters, beam modes, bunch pattern and bunch current via a dedicated optical fibre network. Storage ring, booster and linac will each be equipped with central timing system components, synchronized across the overall facility. Beamline experiments can make use of the same MTCA-based timing system hardware to exploit all accelerator-provided timing system information.

Dependent on the location in the accelerator, the MTCA systems will be equipped with additional AMC, FMC (FPGA Mezzanine Card) and RTM modules for specific read-out, measurement and control tasks, e.g. interface boards to the beam position monitor front-end electronics or feedback controllers as well as ADC boards to acquire measured bunch current pulses or HV-pulses generated by the injection and ejection elements.

All of these modules can be managed remotely via Intelligent Platform Management Interface (IPMI) interfaces and the MCH. Linux drivers with hot-swap support allow for PCIe access of the various AMC and RTM modules from applications running on the CPU AMC.

Likewise, the hardware interfaces for conventional slow-control applications (e.g. magnet power supplies, vacuum system, movable girders) will be compliant with industrial process control standards (e.g. OPC UA, Profibus, EtherCAT, CANopen, USB, RS232/485) preferably providing a well-established and widely-used industrial API.

Special emphasis will be put on the OPC UA interface technology [7]. All power converters for magnets as well as power supplies for getter pumps of the vacuum system will implement an OPC UA server. DOOCS provides a generic bridge server, which seamlessly integrates OPC UA devices into the accelerator control system.

Front-end hardware systems based on the Beckhoff controller technology (EtherCAT/OPC UA) [8] will also be used in many cases, e.g. to control the motors of the insertion devices or of the movable girders supporting all accelerator components. In addition, classical PLC system have to be interfaced. In both cases, generic bridge servers to the accelerator control system are available.

Data Acquisition and Data Archiving

The systems and tools for data acquisition and data archiving have to process time series data as well as snapshot data.

Time series data include data from fast as well as slow data streams. Examples of fast data are data synchronous to the beam orbital frequency (130 kHz), such as that used by low-level RF control algorithms, or magnetic current readback values (41 kHz) used to monitor and analyse power converter performance. Slow data includes data that is updated asynchronously at less than 100 Hz, such as multiturn orbit data or measured vacuum pressures.

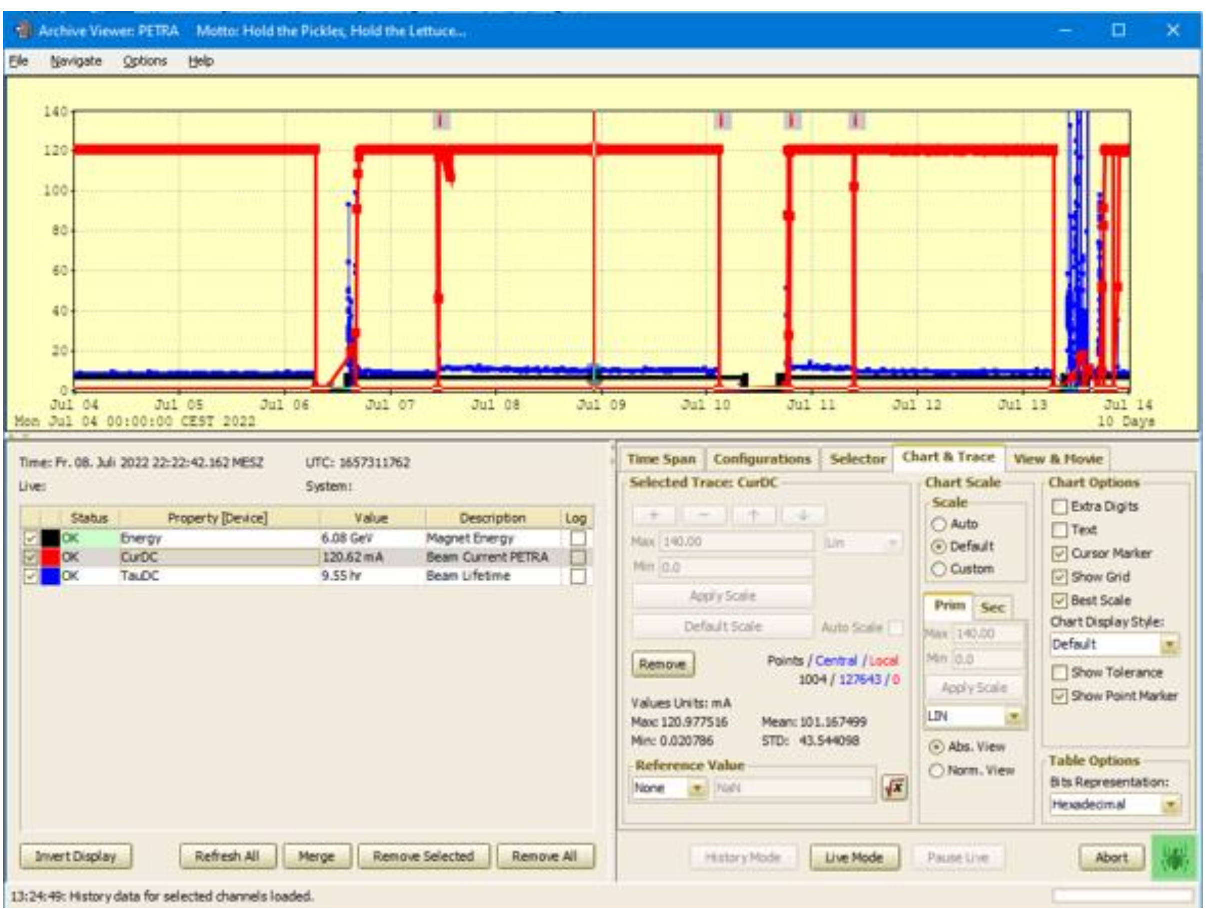

Figure 2: Archive data viewer (PETRAIII).

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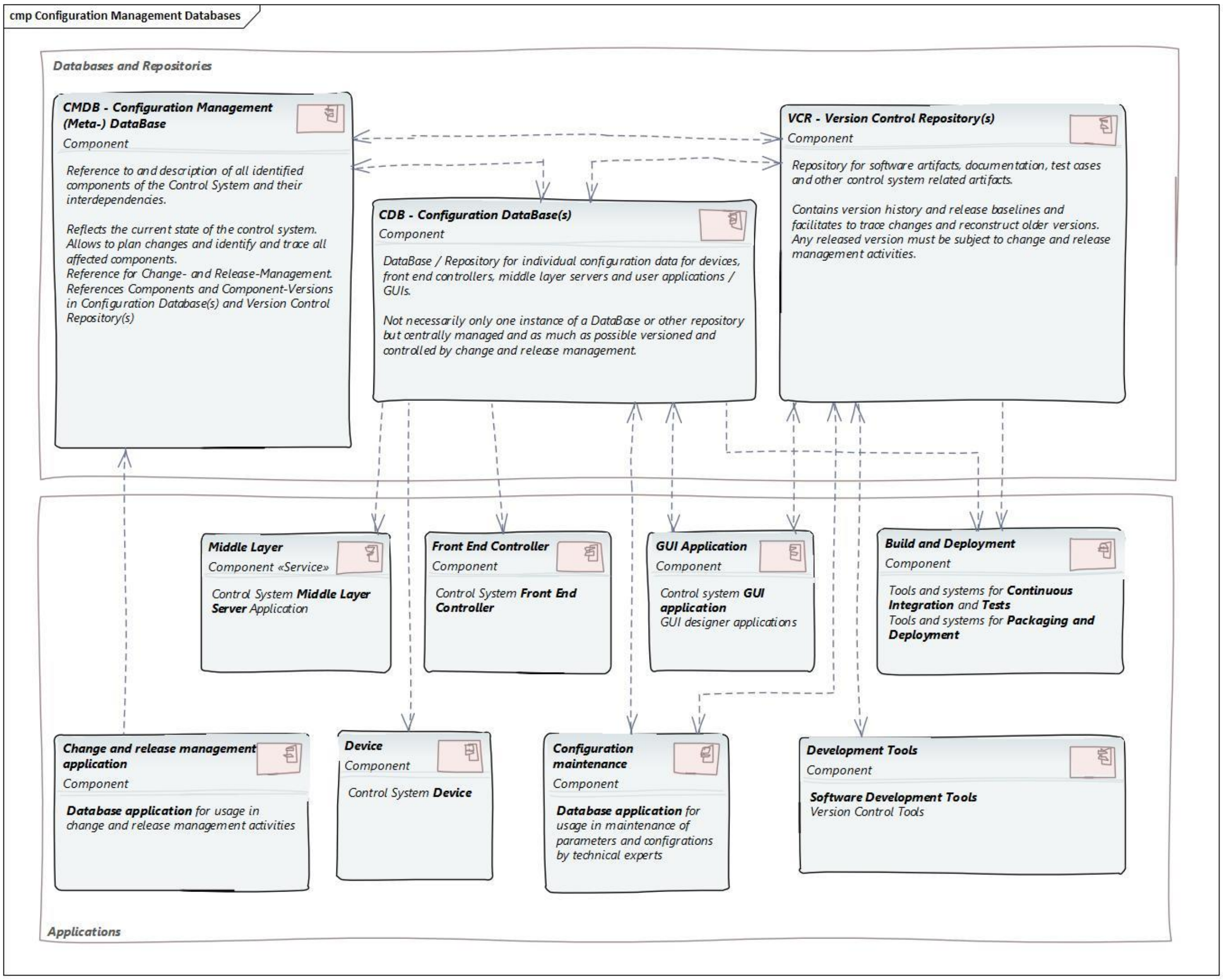

Figure 3: Configuration management system (design sketch).

Generally, the data from the fast data stream is processed by the front-end device electronics and must be aggregated (e.g., averaged) before being made available to other server processes via the control network. Both the aggregated data from the fast data stream and the data from the slow data stream can optionally be stored locally for a limited period of time and are received by a central archiving service, where multiple filtering algorithms can be applied to reduce the amount of data to be stored. Various databases that are particularly suitable for time series data such as TimescaleDB [9] or InfluxDB [10] are currently evaluated and benchmarked.

Only in special cases sequences of fast raw data of selected devices are transmitted via UDP multicast through the control system and will be processed and stored by the so-called DOOCS DAQ system. This system was especially developed for the acquisition and synchronization of pulsed data, such as those generated by the EuXFEL accelerator, and is currently being revised to handle higher data rates.

Snapshot data are stored in a multi-purpose relational database. They are triggered either by a value change (e.g. in case of a device error), by a specific event (e.g. at beam injection), or by an operator request (e.g. while performing a study).

For both cases, versatile visualization (Fig. 2) and analysis tools have to be provided. Particular emphasis will be placed on the capability to support data science applications operated in either online (e.g. learning feedbacks, learning tuning procedures) or offline (e.g. failure prediction, predictive maintenance forecast) mode.

Configuration Management System

The control system of PETRA IV will consist of a large number of software artefacts. In contrast to PETRA III, the number of hardware components is also considerably larger. A comprehensive system for managing software and hardware components (Fig. 3) in all phases of the PETRA IV lifecycle will be established, e.g., by providing repositories and configuration databases, dedicated management applications, and clearly defined workflows and processes for changes and releases.

High-Level Control Applications

A team of controls experts and accelerator physicists has been already established to interface specific needs of beam commissioning and operations and implement corresponding tools and applications.

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The well proven MATLAB Middle Layer library suite [11] supplemented by procedures developed for PETRA III operation will be adapted for further use at PETRA IV. In addition, novel control concepts based on advanced machine learning algorithms are being developed and tested at PETRA III.

Similar to the so-called Virtual European XFEL Accelerator [12] a Virtual PETRA Accelerator infrastructure is being set-up. It will be used to test new concepts, enhancements or just modified and improved applications before they will be put into the field which can potentially save significantly commissioning and machine studies time.

ACKNOWLEDGEMENTS

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