THE CANADIAN LIGHT SOURCE CONTROL SYSTEM: LESSONS LEARNED FROM BUILDING A SYNCHRATORON AND BEAMLINES CONTROL SYSTEM

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ABSTRACT

The Canadian Light Source (CLS) is a 2.9 GeV synchrotron that recently went into service. This paper presents some of the choices made in the design of this facility control system, and lessons learned from the CLS project. Some of the more novel technology choices in the design of the CLS include: (1) fully open source based operating system (RTEMS and Linux); (2) extensive use of fibre-optics bridges to connect Industrial PC hardware to VME IO crates; (3) a design/drawing set based on the use of industrial process and instrumentation drawings applied to accelerator systems; (4) extensive use of Ethernet based PLC and other intelligent network devices; and (5) common control system infrastructure across the accelerator and beamline systems.

INTRODUCTION

The Saskatchewan Accelerator Laboratory (SAL) was established in 1964 and operated until the late 1990s. In 1999 the pulse stretcher ring was decommissioned and the accelerator was refurbished to become part of the injection system for the new Canadian Light Source (CLS) facility [1].

The CLS facility consists of a linear accelerator, which operates between 200 and 250 MeV, Booster Ring 1 (BR1) - a 2.9 GeV electron synchrotron, Storage Ring 1 (SR1) - a high-current 2.9 GeV electron storage ring, two diagnostic beamlines and seven synchrotron radiation beamlines used for experiments. The phase II expansion is now underway adding an addition seven beamlines while the phase III expansion is in the proposal stages.

The scope of the CLS control system covers the accelerator, storage ring, building mechanical and beamline control functions and consists of over 50 000 data points. This paper discusses some of the principles that were used in the design of the control system and lessons learned by the design team.

DESIGN PRINCIPLES

Component Standardisation

A strong emphasis was placed on commonality of components across the accelerator system and all of the beamlines. This not only applied to the control system but also the mechanical, vacuum and electrical systems. There are obvious benefits such as the reduction in spares required on hand. Less obvious are the significant cost savings resulting from reduced design costs as well as improved familiarity with the equipment. On the software side this translates into the need for fewer drivers and the ability to allocate additional resources to the drivers that are written.

Software Engineering Process

For mechanical design, Process Flow Drawings (PFD) are used to describe the desired machine optics and mechanical services. Process and Instrumentation Drawings (PID) are the created from the PFD in the early control system design stage. These serve as the main design input to the control system hardware design. The PID coupled with the requirements specification documentation serve as the main requirements for the software. PID are heavily used in the design of industrial control systems and are starting to gain acceptance in the accelerator community. These become fundamental to the system specification.

For non-control software the Unified Process and Unified Modeling Language (UML) are starting to be adopted for newer projects. This includes the use of use cases to specify software behavior.

The use of Computer Aided Software Engineering (CASE) tools within CLS are still in their early stages. MKS Source Integrity and Integrity Manager are used for version control and configuration management. PID drawings and wiring diagrams are done in AutoCAD while UML drawings are done in MS-Visio. CLS is beginning to adopt some IBM Rational CASE tools.

Industrial PLC Systems

A strong emphasis has been placed on the use of industrial programmable logic controllers (PLC) equipment. Telemecanique Momentum PLC are used extensively for equipment protection, mechanical services and building automation. Siemens S7/400 and S7/300 PLC equipment are used extensively in the booster ring RF, storage ring RF and cryogenics plant.

EPICS

EPICS is in use or planned for use in accelerator facilities in North America, Europe, Asia, the Middle East and Australia. This widespread adoption and acceptance of EPICS was a key motivation in selecting EPICS at the CLS. By selecting EPICS, CLS has benefited from being able to reuse a significant number of libraries, drivers, and application programs.

EPICS core builds on contributions from various organizations, most notably Los Alamos and the Advanced Photon Source at Argonne. In addition CLS has reused the following EPICS extensions: (1) Extensible Display Manager (EDM) and the Channel Archiver from the Spallation Neutron Source (SNS); (2) a modified version of the Knob Manager from Los Alamos and (3) LabCA from Stanford.

The Experimental Physics and Industrial Control System (EPICS) was initially adopted for the accelerator and beamline control systems. The use of EPICS was later expanded to include the building automation and mechanical services. A strong emphasis has been placed on using only one control system environment for all in-house developed and maintained systems. CLS has also limited the number of drivers and EPICS extensions in use. This strategy has allowed the relatively small controls team to be more responsive in their support role due to the familiarity with a common platform. The experience at CLS is that this strategy has been effective in managing the development and maintenance of the control system and controlling labour costs. Where this strategy has been problematic has been in developing acceptance by staff not involved in developing the control system, especially when using systems for which they are not familiar.

One of the challenges faced in the use of EPICS has been compatibility of applications originating from other laboratories and configuration control. In several cases applications are written for a specific version or series of versions of EPICS. Care is required when integrating, testing and deploying these applications. These difficulties will hopefully be mitigated by the recent publication of the Channel Access (CA) Protocol and ongoing work by the developers of EPICS core to control changing and maintain backwards compatibility.

CONTROL SYSTEM SERVERS

Dell PowerEdge servers running RedHat Linux 7.2 or Scientific Linux are used to provide control network services. The main server is equipped with RAID disks, redundant power supplies and backed up by a hot-standby server. The dedicated servers provide network services, EPICS services, such as Process Variable gateways and channel archiving. Some file server functions are also provided by a Storage Area Network (SAN). The main server for the control network has been in continuous operation for nearly five hundred days; a hot standby server is also maintained. Operational experience suggests this to be a robust and reliable strategy.

DATA NETWORK

Several Virtual Local Area Networks (VLANs) are in use at the CLS running on a common hardware layer. The network is based on CISCO technology with redundant core switches. The network infrastructure is shared between the accelerator control system, beamline control, voice over Internet Protocol telephones, video and office networking needs.

OPERATOR INTERFACES AND WORKSTATIONS

Accelerator Operator Workstations

A common control room is used for the accelerator and common mechanical services. Some of the old hardwired Linac control were initially retained and are now slowing being replaced. The control room was design to meet modern human factors engineering standards. In addition to also housing operator workstations, the control room houses a facility library containing system manuals, PID drawings and wiring diagrams for major accelerator and beamline systems.

Operator Interface computers are provided in the control room with quad-screen displays. A limited number of lights, workstations and server equipment has backup emergency generator power.

Beamline Operator Workstations

Each beamline has a dedicated control area near the end-stations. These are equipment with Scientific Linux based workstations running similar OPI software as in the main control room.

The EPICS Gateway and security software is used to limit beamline control of accelerator equipment and control of other beamlines while still providing remote monitoring capability.

Display Manager and OPI Software

After experimenting with alternatives, CLS selected the EDM display manager. By importing background graphics from the AutoCAD general arrangement drawings, CLS is able to produce realistic looking screens. Initially being window based, the design has been evolving towards screen based displays.

Other OPI applications have been developed using Glade or Borland C++ Builder.

Matlab Accelerator Toolkit

Matlab is used as a platform to interact with the machine using several tool sets, these toolsets were the result of a collaborative effort between ALS and Spear over the past several years. Accelerator Toolbox (AT) [2] is used to model the storage ring lattice and perform simulations. LOCO [3] is an algorithm for debugging linear optics in the storage ring. The Middle Layer [4] is a set of scripts and functions that allow the accelerator tools above it to become machine and control system independent. Matlab Channel Access (MCA) [5] is used to connect the other tools to the EPICS control system. Matlab served as an indispensable platform during commissioning of the CLS. Many key measurements such as transverse orbit response and quadrupole centering were performed using this package.

The accelerator tool box, LOCO, Middle Layer and MCA are open source. Matlab is of course a commercial product. Matlab was selected primarily to take advantage of the rich toolset for accelerator control that has been developed at ALS and SPEAR III. Matlab has since been applied as a scripting tool to aid in the commissioning of beamlines.

Some of the beamlines have started to adopt Matlab as a general purpose scripting environment for beamline setup and scripting of experiments.

CERN Root

Still in the early stages, CLS has started to integrate CERN Root into the operator workstation software for beamlines. This provides for more advanced data plotting capabilities that commonly available in other EPICS user software as well as the potential for on-line real-time data analysis.

INPUT-OUTPUT CONTROLLERS (IOC)

Embedded Real-Time Output Controllers (EROC)

Single board computers (SBC's) based on the Motorola 68360 (originally developed for use at SAL) were chosen for use at the CLS [2]. Used extensively for control of RS-232 based devices, the EROC has four RS-232 lines. The RTEMS operating system is exclusively used on this hardware.

RTEMS support existed early for these Input/Output Controllers (IOC), and is now used for IOC applications running on these SBCs. The earliest RTEMS based IOC was installed in 2000. Today there are in excess of 150 IOCs within the facility based on RTEMS. RTEMS has proven to be a very

stable and mature platform. A version of RTEMS was selected for the Motorola 68360 based IOCs in 2000. However, the latest upgrades to EPICS (3.14 alpha1 to 3.14 beta1, and 3.14.7 is anticipated in the near future) have necessitated an upgrade to a newer version RTEMS.

As it becomes more difficult to source comports for the original EROC hardware, CLS has started to prototype a PC104 based replacement using commercially available boards. The next generation of EROC contains 8 RS-232 lines.

VME – Industrial PC Based IOC

Connection to VME hardware at the CLS is not accomplished with a CPU board located inside each crate, rather a pair of fiber optic transceivers (1 PCI and 1 VME) [8] are used to connect a single PC computer to 1 or more VME crates. The fiber optic link is achieved by using a pair of cards SIS3100(VME) and SIS1100(PCI) installed into their respective back planes and connected with a fiber optic cable. Once connected, a Linux application is able to map the memory locations of any VME board installed in the VME crate into the application memory space of the Linux application. This allows the Linux application to access the registers or FIFO's of a particular board installed in a VME crate simply by reading a pointer to a memory location. The actual transmission and reception of data across the fiber optic link is transparently taken care of by the SIS1100 PCI driver. Figure 1 shows how a single EPICS application running on a Linux IOC is able to read and write data to 3 different boards located in 3 different VME crates.
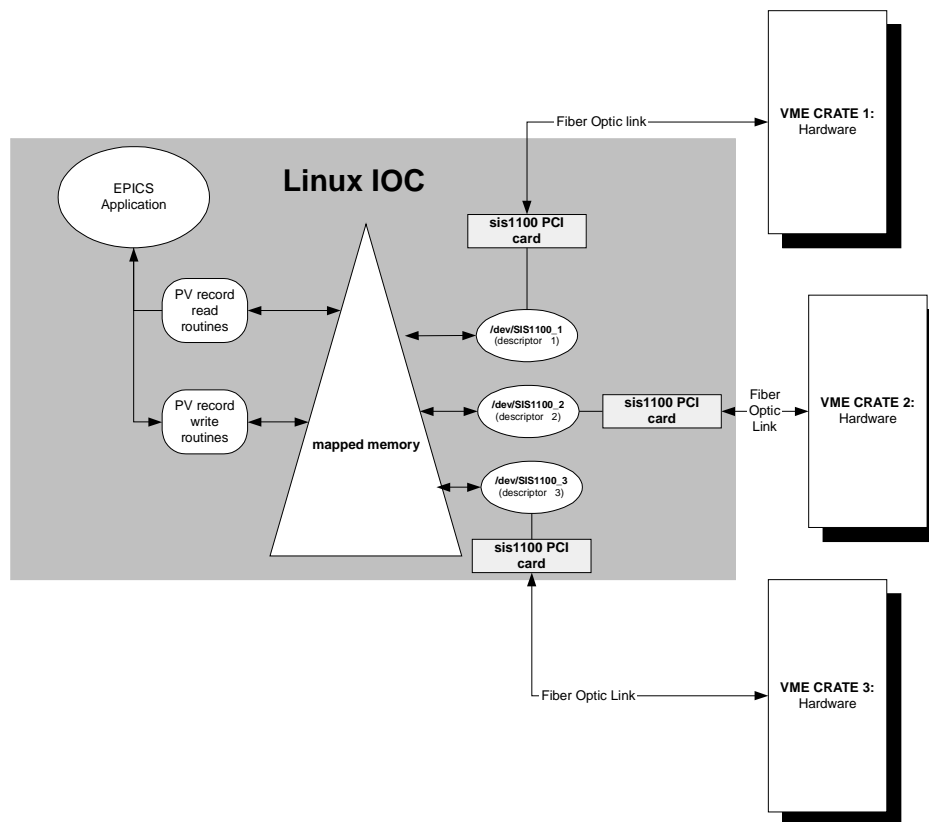

Figure 1: CLS Control System Architecture

Work is ongoing on converting some of these IOCs to RTEMS where real-time requirements cannot be met by the standard Linux kernel.

PLC

Telemecanique Momentum, Siemens S7/300 and S7/400 PLC hardware for used for machine protection, mechanical services and RF systems. The IOC interface to the Modicon Momentum PLCs is accomplished using Modbus over Ethernet. The IOC interface to the S7/300 and S7/400 PLC hardware is accomplished using Profibus networking and a Profibus interface board [7]. The CLS control system makes use of nearly thirty PLCs within the facility.

OTHER DEVICES

GPIB devices are integrated into the control system using a GPIB to Ethernet adaptor. The IOC then communicates with the G2E device via Ethernet.

Serial devices are connected either directly to EROC hardware or to RS-232 to Ethernet adaptors that are then mapped into EPICS by an EROC or Industrial PC.

FUNCTIONAL BREAKDOWN

Machine Protection

Machine protection on the accelerator and beamline systems is implemented using Telemecanique MODICON Momentum PLC equipment programmed in IEC 61131-3 function block language using Concept. Critical machine protection functionality is redundant using both the PLC and a separate relay chain for interlocking. These PLC communicate with EPICS using Modbus over Ethernet.

CLS experience with this design has been very positive. The PLC equipment has proven to be robust and reliable, and the Ethernet communication has provided a fairly straightforward way of interfacing the PLC with EPICS. The least reliable and most difficult to maintain part of the system has been the hardwired relay chains. Given system complexity it can be time-consuming to locate a failed relay or lose connection.

RF Control PLCs

MODICON Momentum PLC equipment is used for the LINAC RF controls. Siemens S7/300 and S7/400 PLC equipment is used in both the BR1 and SR1 RF systems as well as the helium refrigeration plant for the super conducting RF cavity. The Siemens PLC equipment are interconnected using a Profibus network. On the SR1 ring the Profibus deterministic network provides for reliability predictable communication between the low level RF, cavity cryogenics and RF amplifier.

Safety Critical PLCs

Safety critical software development is based on IEC 61508 using Siemens PLC hardware.

LESSONS LEARNED

Reliability and Availability

The control system has demonstrated a high degree of reliability and availability. A very limited number of problems were found with RTEMS and EPICS during the early commissioning stages. The IOC computers have proven to be very reliable, and problems with OPI computers have proven to be minor. The main control system server has been in operating continuously for over 1 ½ years.

Configuration Management

One of the challenges in the use of open source is that there is an increased burden on the configuration management system. This is primarily a result of a significant increase in the number of source code files under management.

MKS Source Integrity Enterprise was adopted for configuration management. This package was primarily selected because of the integrated work-flow management capabilities and change-package tracking.

Layered and Interdependent Software

One of the difficulties encountered with the CLS control system has been managing the interdependency of different layers of software that make up the control system. It is not unusual for an application program to be dependent on a specific version of EPICS, for a specific version of EPICS to be dependent on a specific version of an operating system, and a specific version of an operating system to be dependent a specific hardware configuration. This layering and interdependency problem would be encountered with either an open source based system or a

commercial system. What must be stressed is the importance of release management and regression testing in dealing with issue.

Managing Diversity

In comparison to many other facilities CLS has a small development team. In order to limit the resources needed to deploy and maintain the control system, discipline is required in the selection and adoption of new hardware and software components or packages. When new components were being considered for inclusion into either the accelerator or beamline system an assessment would be made to determine that it truly added new necessary functionality. A strong emphasis was placed on commonality of design across the entire facility.

Management of Evolution

One of the difficulties faced in maintaining a control system based on commercial software is the degree of dependence that one develops on the vendors product life cycle. This can sometimes drive upgrades and even complete redesigns when the product is discontinued or phased out. CLS has already experience some difficulties in this respect with commercial control software that has been used at the periphery of the control system. One of the strong points in the use of open source is that the lab has far more control over the time line for evolution and upgrade of software components. This becomes increasing important when these system become more interdependent.

FUTURE ENHANCEMENTS

CLS is beginning to explore the use of web services and IBM Websphere to provide remote user access to the CLS facility, as well as the introduction of more advanced configuration management software.

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