DESIGN AND COMMISSIONING OF THE ISAC CONTROL SYSTEM AT TRIUMF

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Abstract

The control system for the initial stage of the ISAC radioactive beam facility at TRIUMF was recently commissioned and the facility delivered the first radioactive beam to users in December of 1998. The control system is based on the EPICS toolkit. VME based Motorola MVME162 CPUs serve as input/output Controllers, SUN workstations as application servers, and PCs are used with X-terminal software as operator interface stations. Modicon PLCs control the vacuum system and ion sources. A network of CAN-bus based controllers is used for the beam guidance system. Custom VME modules were developed for beam diagnostics.

1 ISAC

ISAC, an Online Isotope Separator and ACcelerator, is being built at TRIUMF and provided the first beams of short-lived radioactive isotopes to experiments in December of 1998. At present, ISAC is the world's most *intense* source of low energy radioactive beams. By the end of next year it will also deliver the world's most *energetic* radioactive beams (1.5 MeV/u).

A 500 MeV proton beam of up to 10 µA from the TRIUMF cyclotron produces short-lived radioactive species in a hot (2000 °C) production target. They are extracted and accelerated to 60 keV in a target-ion-source and pass through a magnetic pre-separator before being isotopically separated in a high-resolution mass separator. This radioactive beam can either feed the low-energy experimental area or be further accelerated in a 19-ring radio-frequency quadrupole (RFQ) followed by a five-tank drift tube linac (DTL). For tuning purposes, an off-line ion source provides non-radioactive beams.

2 CONTROL SYSTEM DESIGN

2.1 Scope and Schedule

The ISAC control system is charged with all aspects of control of the radioactive beam including the vacuum systems, but excluding building services. RF systems have local control systems, which are supervised by the ISAC control system. Proton beam control is the task of the existing TRIUMF central control system. A summary of scheduled milestones is given in Table 1.

At the outset of the project, the EPICS collaboration was joined in order to evaluate the EPICS control system toolkit. After successful implementation of a prototype on an ion-source test stand [1], EPICS was adopted for implementation of the ISAC control system.

Table 1: ISAC Control System Schedule

Date	**Mile-Stone**	
Nov. 1996	Prototype ion-source test stand	X
June 1997	Off-line ion source	X
Dec 1997	Stable beam to RFQ injection	X
May 1998	Stable beam through 7-ring RFQ	X
Nov 1998	1st radioactive beam	X
June 1999	Beam to low energy experiments	X
Aug. 1999	Beam through 19 ring RFQ	X
Feb. 2000	Beam through DTL tank 1	
Dec. 2000	1.5 MeV/u beam to experiments	

At present, approximately 700 devices are controlled with a total of 2700 digital and 1300 analogue hardware channels. By the end of next year, a further increase by 50 % is expected.

2.2 System Architecture

The ISAC control system follows the EPICS model of a flat topology of Operator Interface (OPI) stations, application servers, and input/output controllers (IOCs), which are all nodes on the controls Ethernet. Other peer nodes are several PLCs and RF control systems. The controls Ethernet is tightly coupled with the data acquisition Ethernet and then bridged onto the general site Ethernet, which accommodates the development computers. Fig. 1 summarizes the hardware layout.

The operator console consists of two OPI stations - PCs with three monitors each, exploiting the multi-monitor capabilities of Windows98. The PCs are running the Exceed[1] X-server and connect with EPICS X-client applications on two application servers (SUN workstations).

EPICS IOCs are implemented in VME with Motorola MV162 CPUs running the VxWorks real-time operating system[2]. Ethernet based terminal servers are used to monitor the console output for the geographically distributed IOCs. A VME crate monitor module was designed [2] for monitoring crate parameters (voltages, temperatures, fans). It also provides watchdog registers (for monitoring software activity), remote reset and

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[1] Hummingbird Inc., Kanata, Ontario
[2] Wind River Systems, Alameda, CA, USA

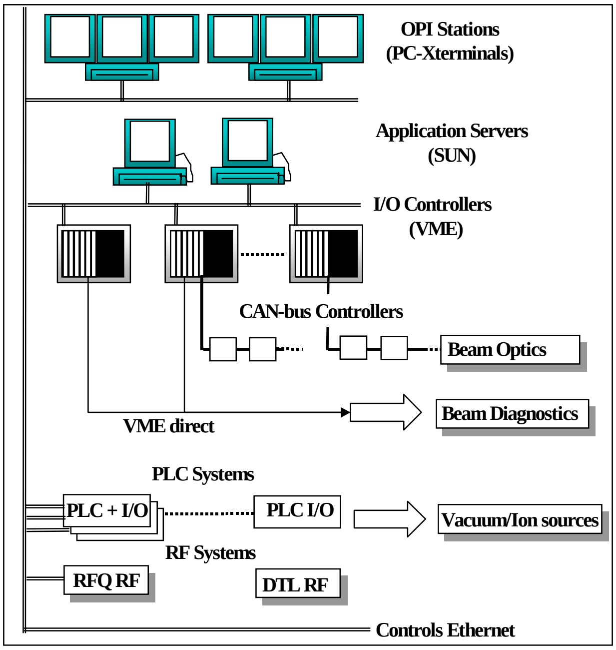

Fig. 1: Hardware Layout

power cycling of the VME crate. These crate monitors are connected by a separate fibre-optics CAN-bus loop. Each IOC can monitor the health of all other IOCs on the system.

Device control was organized into three different sub-systems:

- VME I/O modules are used for control and readout of beam diagnostics devices. This results in tight coupling of the I/O with the MV162 CPU for fast beam measurements. Several VME modules have been designed: an 8-channel variable gain beam current amplifier / ADC / transient digitizer, a high sensitivity read-out module for 96-wire harp monitors, a 32-channel binary I/O module, and an 8-channel 350V programmable bias supply [3].
- Microprocessor based power supply controllers have been designed [4] for control and readout of beam optics elements. These controllers are distributed on CAN-bus networks and interfaced to the MV162 with an industry pack[3].
- Modicon PLC[4] systems are used to control vacuum systems and ion sources. This ensures high up-time and easy implementation of interlocks. It also reduces constraints on software development for the IOCs, because IOC reboot does not affect PLC operation. The PLC systems are peer nodes on the controls Ethernet and are supervised by the IOCs via TCP/IP.

2.3 PLC Software

The PLC systems are programmed in ladder logic using the Modsoft package from Modicon. The program is structured as a series of individually scheduled, linear ladder segments. No use is being made of subroutines. This facilitates on-line inspection of the program state at the expense of memory usage. Critical operation sequences, e.g. emergency target cool-down, are implemented at the PLC level.

The PLC can be switched into simulation mode under program control by de-coupling the ladder program from the I/O registers and scheduling a simulation program segment. This allows testing of the PLC code together with the EPICs OPI code before any devices are installed.

2.4 EPICS IOC Software

Standard software development for the EPICS IOCs consists of:

- constructing a function block “data base” by configuring instances of EPICS “records”. From the tools and approaches, which are used in the collaboration, the Capfast[5] schematic editor was selected because of the graphical representation and its hierarchical capabilities.

  Based on the experience with the prototype system, an effort was made to develop a hierarchy of re-usable device components in order to implement devices in an object-“like” fashion.
- adding functionality which cannot be constructed out of existing records. No new EPICS records were developed, but subroutines for EPICS subroutine records were written to
  - provide fast read-out of wire scanners
  - collect emittance scan data at high speed
  - calibrate and index stepper motor devices
- writing device and driver support for hardware, which is not yet supported by the EPICS collaboration:
  - VME drivers were written for all TRIUMF designed VME modules [3]
  - TCP/IP drivers were written to integrate the MODICON PLCs
  - TCP/IP drivers were written to interface to several RF control systems for bunchers, RFQ, and DTL.
  - During implementation of the Capfast device schematics it was realized that cumbersome and error-prone parameterization was needed to implement a device which involved several different VME modules. Therefore an abstraction layer of module-independent VME device/driver support was developed.

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[3] TIP810, Tews Datentechnik, Hamburg, Germany

[4] Schneider Automation, North Andover, MA, USA

[5] Phase Three Logic, Beaverton, OR, USA

2.5 CAN-bus Software

Fortunately, a CAN-bus driver for EPICS was already available in the collaboration [5]. It was used to implement a simple protocol for the TRIUMF designed power supply controllers, using the multi-master capabilities of the CAN-bus. At boot, the IOC assigns each controller a device number from which the controller constructs a set of CAN-bus identifiers for its use. The controller then reports to the IOC the power supply status and read-back values on change only, but with upper and lower frequency limits. An IOC broadcast beacon at 0.5 Hz is required by the controller to keep a supply switched on.

2.6 EPICS OPI Software

The EPICS display editor / display manager combination *edd / dm* was chosen for its speed and resource friendliness. Some operational functionality was added to *dm*. Other routinely used tools are the alarm handler, channel archiver and retriever, and *stripTool*.

A simplified version of the *burt* save/restore tools was developed with increased functionality for beam line scaling.

An existing TRIUMF designed command procedure tool was adapted to work as an EPICS channel access client. It runs as a host-side sequencer on the SUN application server and allows operators and beam physicists to rapidly prototype simple control algorithms.

Increasingly, PERL scripts are used to automate generation of displays, command procedures, and Capfast schematics.

3 COMMISSIONING

For all ISAC sections, deadline pressures effectively reduced the scheduled commissioning period to one or two days after device installation. Pre-testing of the EPICS OPI with PLCs in simulation mode and using the simulation capabilities of the IOC database helped immensely to cope with this situation. Web-based support for operations includes fault-reports and a shift-log which was adapted from a Fermilab version.

4 MUSINGS

4.1 Manpower Effort

The EPICS software effort for this project, i.e. OPI and IOC software development, EPICS release management as well as UNIX and VxWorks support was initially carried out by two full-time equivalent (FTE) persons and has increased to four FTE during the past couple of years. One additional FTE takes care of the PLC systems including software development and hardware layout and installation. Installation of beam optics and beam diagnostics control hardware consumes another 0.5 FTE. These figures include ongoing maintenance, which rests with the same group.

4.2 Off-the-shelf vs. in-house design

It is often argued that custom hardware design is too uneconomical and should be replaced by a complete “off-the-shelf” approach. In our case, the large overlap between the electronics development group and the ISAC controls group made it possible to pick and choose from both worlds.

On one side, fully commercial PLC systems were used with a complete communication solution. In this case relatively high capital costs are offset by robustness and high system up-time due to on-line programmability. The adoption of standard network protocols by most PLC manufacturers over the last decade has made it much easier to integrate these systems into an accelerator control system.

On the other side, in-house design combined with small-series production in local industry achieved substantial cost reductions in addition to feature enhancements over off-the-shelf solutions. On the CAN-bus beam optics system a conservative estimate shows at least 30% of cost savings over any off-the-shelf solution. In the case of the VME beam current amplifiers, the development costs were amortized after installation of 10 modules.

4.3 EPICS

There is no question, that the software and effort sharing of the EPICS collaboration pays a big dividend. One of the great features of EPICS is its openness and extensibility, which does not impose a straightjacket on local solutions to local problems.

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