SNS INSTRUMENT DATA ACQUISITION AND CONTROLS*

S. M. Hartman†, Oak Ridge National Laboratory, Oak Ridge, TN, 37831, USA

Abstract

The data acquisition (DAQ) and control systems for the neutron beam line instruments at the Spallation Neutron Source (SNS) are undergoing upgrades addressing three critical areas: data throughput and data handling from DAQ to data analysis, instrument controls including user interface and experiment automation, and the low-level electronics for DAQ and timing. This paper will outline the status of the upgrades and will address some of the challenges in implementing fundamental upgrades to an operating facility concurrent with commissioning of existing beam lines and construction of new beam lines.

ORIGINAL SNS INSTRUMENT DATA ACQUISITION SYSTEM

The SNS accelerator completed construction in April 2006. The first three neutron instruments—liquids reflectometer, magnetism reflectometer, and backscattering spectrometer—began commissioning in 2006 and began supporting user experiments in 2007. The years 2008 and 2009 saw a rapid build-up of the suite of SNS instruments. There are currently sixteen instruments supporting users at the SNS, with another in commissioning and two more under construction.

While the SNS accelerator control system was developed in partnership with contributing laboratories using the Experimental Physics and Industrial Control System (EPICS) toolkit [1], the beam line control and data acquisition system took a separate path.

The SNS data acquisition system (known as DAS), was built in-house using mostly custom code for instrument control and data acquisition. The system was built on a Windows XP platform with custom hardware to provide an interface to the neutron detectors. Applications, written in C++, provide detector interface, timing system interface, basic live viewing of the neutron data, and local data storage. UDP broadcasts are used for signaling between applications for experiment start/stop/save and passing some data. An additional service runs at the end of an experiment to copy the data files from the local data acquisition system to the data analysis system which then translates the data files to produce NeXus files for analysis. Instrument device control applications are written in Lab-VIEW (sample environment equipment, neutron choppers) or C++ (motion control) and use National Instrument's DataSocket library for network communications. A shared memory interface is used for interprocess communication

to the control application. A custom python application provides a scripting environment and a basic graphical user interface for experiment control. The python environment uses another shared memory interface to the control application.

Separate computers are used for each application resulting in typically twelve to fifteen computers per beam line for data acquisition and control. Each beam line system resides in a private network with some routing to outside networks. Remote access is via Remote Desktop connections. Some status and fault condition information can be pushed out by the python scripting environment.

Lessons Learned

After six years of operations, the reliability, maintainability and level of support required for this system have led to the decision to replace the DAS. Some of the more problematic areas include:

- The custom network protocol used for signaling between application continues to be problematic. The implementation of the multipart handshaking mechanism contains a number of race conditions which impact the reliability of the system.
- Device communication using DataSockets has also proven to be problematic. Device dropouts generally require manual intervention and application restart impacting in-process experiments.
- Maintenance—including patching and virus scanning—of the large number of Windows computers requires a significant amount of effort during scheduled maintenance periods. Central management of the computers is also difficult.
- Lack of centralized services for remote monitoring, archiving and alarming restricts the data which can be seen by offsite users, and makes troubleshooting and maintenance more difficult for the technical support teams. Limitations with access control for Windows combined with the network design also complicates the support effort for operational beam lines.
- Obsolescence is a problem for some of the custom hardware, particularly for the PCI card which provides computer interface to the DAQ hardware. End-of-life for Windows XP also requires significant changes to the system.

The tight coupling between the user interface, scripting environment and device control (via a shared memory interface) makes a staged migration difficult.

UPGRADE PATH

Three basic approaches can be taken when beginning a major upgrade to an existing control system: rework the exiting software, begin a new software project from scratch, or identify and leverage an existing control system or control system toolkit upon which to build the new system. Given the limitations of the existing system and difficulty in maintaining the system, a rework of the original software was inappropriate. Likewise, starting a project would entail significant risk and require more time and resources than could be devoted to such a project. Therefore, identifying an existing control system or control system toolkit to use was the logical choice.

The neutron scattering community has not standardized on a consistent software framework for building instrument controls and data acquisition systems. Each facility has generally built its own system. A number of existing software packages were reviewed for potential use at SNS including SPiCE from Oak Ridge National Laboratory's High Flux Isotope Reactor, NOMAD from Institut Laue-Langevin, SICS and Gumtree SE from Swiss Spallation Neutron Source, and others. Each application offered a number of benefits, but none provided a general purpose solution which could be used to build a system to meet the needs of all of the SNS instruments. A toolkit approach would offer a more general collection of building blocks from which to build a system which could be extended to meet individual instrument needs.

The two most common toolkits for building experimental physics control systems are TANGO and EPICS. Both are widely used for building beam line control systems at synchrotron user facilities. EPICS has also been used for several neutron scattering beam lines at the Lujan Center at Los Alamos National Laboratory. Both EPICS and TANGO have a large developer and user base and have demonstrated their ability to meet the needs of beam line control systems. Given that SNS was already using EPICS for accelerator controls and had in-house expertise with EPICS, the selection of EPICS over TANGO was the practical choice for SNS.

EPICS MIGRATION

The first beam to migrate to EPICS as part of the SNS upgrade was actually not an SNS beam line. The initial implementation was an imaging instrument [2] at the High Flux Isotope Reactor (HFIR), a reactor-based neutron source at Oak Ridge National Laboratory. HFIR's CG-1D Imaging instrument was running a variant on the SNS DAS but this system was not meeting the operational needs of the instrument.

The instrument is relatively simple from a controls point of view. A typical experiment consists of a tomography scan with the sample rotated via one of two rotation stages. Additional motion stages are used for positioning and alignment. The neutron beam is used to image the sample with a scintillation plate to convert the neutrons to photons for capture by a charge coupled device (CCD) camera used as a detector.

The EPICS toolkit provided most of the needed building blocks for building the control and data acquisition system for this beam line. The EPICS motor record provided a driver compatible with the existing motor controller. A combination of Asyn and Streams device support provided tools for interfacing with additional components at the beam line. The EPICS AreaDetector software package provided support for the CCD detector.

The decision was made to move from Windows as used on the original implementation to Linux for ease of maintenance, reliability and improved access control and remote access. Control System Studio (CSS) was chosen as the user interface. A CSS-based Scan System tool [3] was developed to provide a mechanism for submitting, queuing, running and monitoring the long tomography scans which can run for twelve or more hours for a sample.

The implementation began in late 2012, utilizing reactor maintenance periods for integration testing at the beam line. The EPICS-based system was fully operational in January 2013. It has proven to be robust, reliable and easy to use. The Imaging beam line instrument scientist has reported more efficient use of beam time as a result of this system.

Current Status

To begin work on the SNS instruments, the first step needed was the setup of a network infrastructure. The original DAS used private address space for each beam line, but duplicated the IP addresses across each beam line. While this simplified computer and software deployment, it resulted in barriers to remote access and remote management of the computers. For the new implementation, a class B-size network using private address space has been allocated for all of the instruments, with a class C-size subnet for each instrument. Linux-based firewalls/routers are used to isolate each beam line from the other beam lines, and to create a demilitarized zone (DMZ) which can aggregate data across instruments for remote monitoring. EPICS channel access gateways at each beam line provide a read-only view of the instrument while a gateway-of-gateways on the DMZ aggregates the beam lines to allow read-only monitoring from the ORNL enterprise and visitor networks.

The initial deployment focused on beam line subsystems which were not tightly coupled with day-to-day operations. This allowed for an initial rollout of the infrastructure without impacting beam line use.

The first area for EPICS deployment at SNS was beam line vacuum monitoring. These systems had not been instrumented for remote monitoring, archiving or alarms. A prior effort was already well underway to standardize beam line vacuum components, interlocks and controls to be consistent with the existing accelerator vacuum systems. Integrating these systems with EPICS could utilize existing device drivers and methods already in use for accelerator

vacuum systems. The deployment to the beam line required development of the server infrastructure, networking, access control firewalls, software repository (using git), and system documentation and issue tracking tools (using Trac).

The T0 Chopper system was chosen as the next SNS subsystem to migrate to EPICS. The T0 Chopper is used to filter out the high-energy head of the neutron beam. This system is not tightly coupled with day-to-day operations since this chopper (unlike bandwidth, Fermi, or disk choppers) is typically set and not adjusted during operation. However, the system does need to be monitored with data archiving and alarming for system troubleshooting and service. The existing chopper controller utilizes an OPC server which necessitated that the IOC for this system be deployed using Windows rather then Linux. CSS running on a local computer provides a control interface for the technical staff while the network architecture allows for remote monitoring and archiving.

The initial SNS beam line chosen for migration to EPICS is the engineering materials diffractometer instrument known as VULCAN. During the regularly scheduled SNS summer maintenance period in 2013, access to the beam line was provided to allow for initial integration of beam line components using EPICS. Systems including detector high voltage power supplies, low voltage power supplies, motor controllers, and some sample environment equipment (such as temperature controllers) were implemented in EPICS. With the start of the autumn run cycle, beam line control was restored to the legacy system to support operation while offline development continued. An EPICS interface to the network broadcast from the existing DAQ software system was developed to provide a simple live view of the detector system in both physical space and converted to D-space. CSS/BOY provides a user interface to the data while allowing for selection of region of interest for calculating statistics which are available as EPICS process variables and can be used for scanning parameters within the CSS Scan Server. Standard scans for adjusting slits and aligning samples were also developed for the CSS Scan Server. Web-based tools have been developed to simplify starting and stopping EPICS Input/Output Controllers (IOC) to accommodate temporary sample environment equipment.

The effort is ongoing to provide sufficient functionality within the EPICS framework to allow for a full transition for the beam line control system. The largest area currently remaining is the integration of the control system with legacy data acquisition system components until those systems can be redesigned. Additional work remains to provide integration the beam monitor system, the legacy data file transfer and translation system for capturing sample environment and other metadata from EPICS, integration with the legacy start/stop/save handshake, and integration with the experiment proposal system database.

FUTURE WORK

Another development project began in 2012 to streamline data processing and data transfer from the instrument data acquisition system to data storage and data analysis systems. This project's initial deployments are running on beam lines using the legacy control system. The two projects will need to be merged, which will simplify EPICS integration with data collection for both neutron event data and slow control metadata.

A project to replace the current data acquisition software is also beginning. The system architecture for this new approach consists a core runtime component consisting of three layers: a device interface layer to communicate with the custom hardware, an application layer providing some data processing while offering an application programming interface (API) for additional processing, and a network layer for data transfer. The device interface layer will need to be modular to allow for planned replacements of the current custom hardware which has obsolescence issues. The API will allow the core runtime component to remain small and robust. Diagnostics, detector status monitoring, detector configuration (e.g., high voltage and discriminator control, and detector calibration) will be implemented in EPICS to allow for integration into the overall beam line control system. Data output will use a custom SNS-developed protocol, but investigation of options utilizing EPICS V4 will also be considered. The existing EPICS AreaDetector may provide a basis for the development of this software.

For the DAQ custom hardware providing the interface to the neutron detectors, another project is also underway. A new timing receiver compatible with the SNS accelerator timing system is being deployed to several beam lines. Efforts will take place over a number of years to address reliability and performance issues and resolve obsolescence issues with some of the key components of the hardware. A review of the overall hardware architecture to provide for more robust board interconnects, communication links and power distribution is underway.

As these new hardware and software systems are deployed and able to provide a more reliable and maintainable beam line data acquisition and control system, additional effort will focus on building on this foundation for expanded functionality. Better integration between the data acquisition and data analysis systems will allow for increased capabilities. Integration of planning tools, such as single crystal orientation, can provide better utilization of beam time. A high level, science-oriented user interface can provide a better abstraction for the visiting researcher who may have limited experience utilizing neutron scattering instruments. A plug-in approach, offering technique-specific interfaces, would offer a user-friendly experiment interface to these beam line users.

OPPORTUNITIES FOR COLLABORATION

A great benefit of re-implementing the data acquisition and instrument control system using the EPICS toolkit is the opportunity for collaboration and for leveraging existing software and development. The SNS accelerator controls group has provided in-house expertise which has been critical to moving this project forward. We are also able to leverage prior developments for beam line controls for light sources. Much of the sample environment equipment and some beam line equipment is similar between a neutron beam line and a light source beam line. By using software already developed and tested in a light source operational environment, we can focus our development efforts on areas that are more unique to neutron sources (e.g., detectors, neutron choppers, etc.).

Even in these areas, though, we have opportunities for collaboration within the EPICS community. The ISIS Neutron Source has also embarked on a project to migrate instrument controls to EPICS this year [4]. The European Spallation Source (ESS), an international project to build a spallation neutron source in Sweden, has also chosen EPICS as their toolkit for accelerator and instrument controls [5]. With SNS, ISIS and ESS all standardizing on EPICS, opportunities for ongoing collaboration within the neutron community are strong.

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