IMAGING SYSTEM INTEGRATION AT THE SNS *

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Abstract

Over the past several years, a variety imaging systems have been deployed at Oak Ridge National Laboratory's (ORNL) Spallation Neutron Source (SNS). The systems have supported accelerator instrumentation, neutron beam measurement, target commissioning, and laser diagnostics. For each application, performance requirements drove the choice of camera technology and this naturally led to a variety of interfaces. This paper will describe the experience gained during the integration and operation of these systems. Several challenges will be highlighted including: deployment in harsh environments, correlation with other accelerator data, and real-time video distribution. Although heterogeneous systems must continue to be deployed to meet imaging needs, some common tools and technologies have been identified and are expected to enhance system integration efforts.

INTRODUCTION

Table 1 presents the SNS imaging systems in roughly chronological order of deployment. In the next two section of the paper, selected systems are described in more detail, with a focus on the requirements that led to particular technology choices, and the techniques used to integrate each system. Most systems are deployed as PC-based network attached devices [1].

Table 1: Summary of Imaging System Types

System	Interface	Comments
Laser	RS-170	radiation, in feedback system
Foil Video	RS-170	high radiation
Ion Source	RS-170	low radiation, intensity trigger
Target	Firewire	remote camera via fiber, future low light option
Neutron	Firewire/USB	Cooled for low light, future options: MCP, EMCCD
Linac Dump	GigE	remote camera via fiber
Electron scanner	GigE	future system

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DEPLOYED SYSTEMS

Laser Drift Compensation

In the superconducting linac, the H- beam profile is measured by scanning a laser across the H- beam and detecting the liberated electrons. A plot of the collected electron current versus the laser position yields the transverse projection of the H- beam density. The laser beam is transported for about 200 meters along the linac and pickoff mirrors route the beam to measurement stations. To allow accurate profile measurements, the laser beam must remain stable during the scan. This is accomplished by imaging the laser beam, calculating its centroid in real time, and feeding back a correction signal to a moveable upstream mirror [2].

For this application, cameras must be located in the linac tunnel, exposing them to X-rays from the superconducting cavities and the usual radiation dose from H- beam loss. For this reason, CID cameras were selected and the RS-170 video signal was run on coax up to National Instruments NI-1409 frame grabbers installed in the acquisition PCs. Image processing is performed at 6 frames per second in LabVIEW and scalar data is shared with the EPICS based control system via a shared memory interface to IOC software [3]. In the control room, LabVIEW is again employed to provide an interactive display that allows the user to visualize the measurement results and conveniently set targets for laser beam position. In this system, the raw images are not available via EPICS process variables, but are instead carried to the user interface over National Instruments' DataSocket protocol.

Foil Video Monitor

H- beam is injected into the ring by stripping it to protons with a carbon foil. At full beam intensity, this foil will become hot enough to present a thermal image of the beam. A second foil strips the residual H0 and H- that made it past the first foil. During studies, a chromium doped alumina screen can be inserted to view a single pass of the beam at either foil location. Due to the high radiation in this area, survivability of the cameras is an overriding concern. For this reason, 2 all-tube cameras (Dage model 70R-2V) were installed in enclosures recessed into the tunnel wall. The remaining camera control chassis are located upstairs in the equipment building and produce RS-170 video signals that are then digitized with a system similar to that of the Laser Drift Compensation System. Since the pulsed linac is synchronized to the AC line, beam synchronization is accomplished by locking the analog camera to its AC power input. Individual video fields are selected for processing by triggering the frame grabber with an output from an embedded timing card. This trigger typically occurs at 6 Hz.

In this system, all data is available as EPICS process variables, including an array PV that contains the raw, uncompressed image. As shown Figure 1, the addition of a picture widget in the Extensible Display Manager (EDM) allows presentation of images within a screen. This screenshot depicts a typical layout for video system screens, with the camera system controls and raw image on the right, and the calculated data on the left. In this case, the image is not actual beam, but is an illuminated foil shown during the final alignment process.

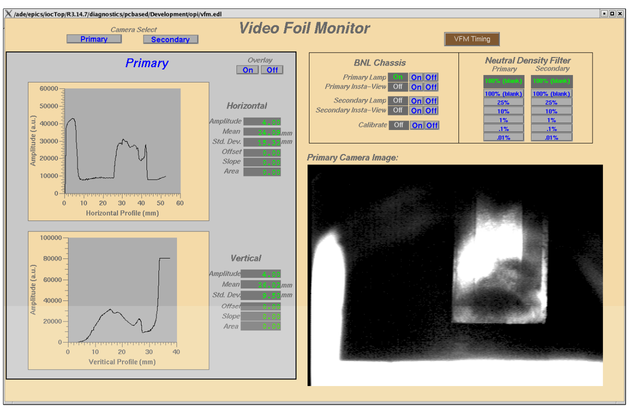

Figure 1: Video Foil Monitor console display.

Temporary Target Viewscreen

To assist in delivering the first beam to the SNS target, a temporary viewingscreen system was deployed prior to the final commissioning run [4]. Like the foil video system, the phosphor screen was chromium-doped alumina. Unlike that system, the 2 cameras servicing the target viewscreen were located in an area of negligible radiation. This was accomplished by using radiation hard imaging fibers and optics to transmit the image from the target nose to an area behind the target shielding. The benign radiation environment allowed use of more modern cameras. CMOS sensors with an IEEE-1394 interface were selected for their ease of integration and flexible triggering options. The camera location was still inaccessible during operations, so long-distance fiber transceivers from Arvoo were used to connect the cameras to the acquisition computers. Triggers were provided by timing receiver cards installed in the acquisition computers and the trigger signals were transmitted to the cameras over fiber.

The selected cameras (Model LW-WVGA-G-1394-M manufactured by Imaging Solutions Group) were compliant with the DCAM standard and therefore directly supported by commercial image processing software. Since the diagnostics team had previous experience with LabVIEW and the Vision Development Module, these commercial tools were again used to allow rapid deployment and upgrades.

In its initial form, this system simply delivered raw images for live viewing in the control room and for integration into a summary web page that was updated once per second. The web page allowed anyone in the world to observe SNS commissioning progress in real time. Each acquired image was also timestamped and saved locally on RAID arrays. After successful commissioning, the target viewscreen system was upgraded to provide more quantitative data during early operations. Additional functionality was deployed on an analysis tier and included the following features:

- Non-linear geometric mapping to correct for optical distortion, screen angle, screen offset
- Normalization using a real-time data stream from an upstream Beam Current Monitor
- Calculation and strip chart display of horizontal and vertical centroid and RMS width of beam distribution

Acquisition was supported up to a 20 Hz frame rate and full analysis typically was performed at a downsampled rate of 2 Hz or less. The acquisition and analysis computers communicated via the DataSocket protocol and console displays were implemented in LabVIEW. No EPICS integration was provided for this temporary system. Before it was decommissioned in late 2006, tip of the imaging fiber had received about a one GigaRad dose and the system had archived nearly one Terabyte of data. Based on the temporary system's success, a more permanent system is under development.

FUTURE SYSTEMS

Injection Dump Monitor

Beam that is not fully stripped for injection into the ring must be transported cleanly to the Injection Dump. A new imaging system currently under development will allow monitoring of this waste beam just upstream of the dump. Its design incorporates some technologies from previously deployed systems. For example, an imaging fiber will be used to allow placement of the camera in a low radiation area. As in the Target Viewscreen system, the selected camera (a Prosilica GE640) is compliant with standards for industrial imaging, so the same commercial software can be used. However, it also supports the more recent GigE Vision interface that allows long distance communication without the additional IEEE-1394 to fiber converters. Full integration with EPICS is envisioned and the control room screen will be modeled after the one depicted in Figure 1.

Neutron Beam Imaging

Several neutron beam imaging systems are under development at SNS and some share characteristics with the systems deployed in the accelerator. A typical viewscreen for neutron applications is a ^{6}LiF/ZnS:Cu,Al,Au scintillator which yields about 160,000 green photons per incident neutron. Neutron flux typically ranges from 10^{5} to 10^{8} n/cm^{2} s. Therefore, low light cameras are required. In a recent test at ORNL's

High Flux Beam Reactor, a cost effective cooled astronomical camera was employed to acquire a rough neutron beam image in a few seconds and a high quality image in about one minute. The camera incorporated a USB interface with a proprietary protocol that was supported by vendor-supplied software. Although standardization on one interface such as GigE Vision is desirable, the reality is that high performance cameras required for these applications will probably come with proprietary interfaces and will require additional integration effort.

STREAMING VIDEO

Currently, all imaging instruments provide video on the network as uncompressed arrays over Channel Access or DataSockets. In the case of systems like the target viewcreen, we would like to not only reduce network utilization but also support commonly available viewers. Therefore, we have begun work to provide standard video over the real time streaming protocol (RTSP).

Proposal

The proposal is to use a separate server to transform images into the live streaming video. A custom QuickTime video digitizer component (the only custom software needed) will monitor the waveforms using the EPICS channel access client libraries and convert each image into a video frame. For each waveform we wish to broadcast, we will have one such video digitizer component on one server running QuickTime Broadcaster® which polls the component for video frames and generates a live broadcast in MPEG-4. A single server running QuickTime Streaming Server® will be dedicated to streaming all the videos from the broadcasters to multiple external clients. As shown in Figure 2, the images are still available to channel access clients that require the uncompressed data.

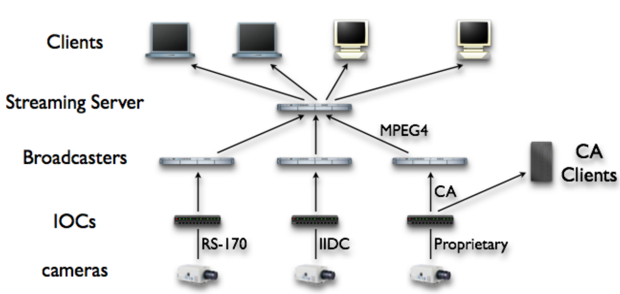

Figure 2: Image Acquisition and Streaming Video

Prototype

A prototype system has been created to demonstrate the feasibility of the proposal. The foil video system described above was triggered at 10 Hz and provided 256 bit grayscale images as usual over channel access. We developed a software video digitizer component that monitors the video foil waveforms and converts them into video frames. QuickTime Broadcaster loaded our custom component and created a live unicast video stream that was fed to QuickTime Streaming Server. Both the broadcaster (containing the video digitizer component) and the streaming server were run concurrently on the same 2.4 GHz Core 2 Duo laptop computer. QuickTime clients on remote machines were able to observe the live video in real time. Video was provided at 10 frames per second, matching the waveform monitor rate. At this rate, no significant buffering delay was observed. The CPU load was 20% for the Broadcaster process and 1% for the Server process. Due to multicasting, the 100 kbit/s network utilization was nearly independent of the number of clients. The MPEG-4 image was virtually indistinguishable from the uncompressed bitmap display.

Table 2 summarizes the two communication techniques that we plan to use. A significant disadvantage of our current MPEG-4 stream is that is does not allow correlation with other accelerator data. Software for the target viewscreen system supported export of AVI video files that embedded the SNS global timestamp as text data in each frame. We plan to investigate a similar technique for the streaming MPEG-4 video.

Table 2: Summary of Communication Techniques

Technique	Advantages	Disadvantages
EPICS Channel Access over TCP with frame as array PV	Integration with: archiver, EDM, etc; easy correlation via EPICS timestamp; lossless	high network utilization; does not scale to many clients; no industry standard tools/clients
MPEG-4 over RTSP	Low network utilization; scaleable; industry standard; many standard clients	time correlation still not implemented; challenging integration with EPICS tools; lossy

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