DEVELOPMENT OF THE HARDWARE CONTROLS SYSTEM FOR THE STAR EXPERIMENT

D. Reichhold[2], F. Bieser[4], M. Bordua[4], M. Cherney[2], J. Chrin[2], I. Ferguson[1], J. Fiedler[2], V. Ghazikhanian[1], J. Gross[2], G. Harper[6], M.Howe[6], S. Jacobson[4], P. Kravtsov[5], S. Lewis[4], J. Lin[2], C. Lionberger[4], C. McParland[4], T. McShane[2], J. Meier[2], I. Sakrejda[4], E. Yamamoto[1], and W. Zhang[3]

[1]Department of Physics, University of California, Los Angeles, California 90095, USA

[2]Department of Physics, Creighton University, Omaha, Nebraska 68178, USA

[3]Department of Physics, Kent State University, Kent, Ohio 64242, USA

[4]Lawrence Berkeley National Laboratory, University of California, Berkeley, California 94720, USA

[5] Moscow Engineering Physics Institute, Moscow, 115409, Russia

[6]Department of Physics, University of Washington, Seattle, Washington 98195, USA

Abstract

The STAR experiment completed its first commissioning run in August, 1999. Hardware was controlled by an EPICS-based system. Of special note is the use of a single field bus (High-level Data Link Control - HDLC) by all STAR subsystems for monitoring and control of front-end electronics and access to front-end buffers. STAR Controls was implemented by a consortium of institutions. A large portion of system development has been and continues to be carried out by undergraduate students. Effort has been minimized by the adoption of experiment-wide standards and the use of pre-packaged software tools.

1. THE STAR EXPERIMENT

The Solenoidal Tracker At RHIC (STAR) experiment will study relativistic heavy ion collisions of gold nuclei at 100 GeV per nucleon. STAR is also capable of studies using the less massive species at varying energies that will be delivered by the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory. STAR can measure single-event variables representing entropy, temperature, baryochemical potential, strangeness chemical potential, intermittency, and particle and energy flow. High transverse momentum processes in the form of jets, mini-jets and single particles [1] and peripheral collisions [2] can also be studied.

The baseline subsystems of the STAR experiment are the time projection chamber, data acquisition (DAQ), trigger, online computing and magnet. The main tracking device in STAR is a cylindrical TPC, 4.18 meters in length with inner and outer radii of 0.5 m and 2 m respectively [3]. Additional subsystems (a ring imaging Cerenkov detector, an electromagnetic calorimeter, a radial time projection chamber a silicon vertex detector, and a silicon strip detector) will be added in the next year. A second commissioning run will take place in December, 1999. The first collisions at RHIC for physics studies are scheduled for January, 2000.

2. STAR HARDWARE CONTROLS DEVELOPMENT

The STAR controls system was developed at a number of remote sites with the initial system integration taking place at Lawrence Berkeley Laboratory for cosmic ray testing of a single TPC sector [4]. Final integration is taking place at Brookhaven National Laboratory. To expedite the integration process, a number of design rules were instituted at the start of the process [5]. The development tools were standardized. Software toolkits that would be available to all collaborating institutions were selected. EPICS [6] was selected as well-suited to this project and the number of EPICS tools to be used was limited. It was perceived that graphical databases would be easier to maintain over the lifetime of the experiment. Similar efforts were made to limit the number of kinds of interfaces to the system. The experiment also adopted a common field bus. A mezzanine board was developed which could be used for all subsystems.

STAR hardware is designed to be failsafe. All required personnel and property protection is mandated to be independent of STAR Hardware Controls.

Controls systems were developed as hardware construction progressed for most of the baseline. This eliminated the need for the development of controls systems for test setups, and gave the users and developers early experience with the system. Databases are constructed on the subsystem level, such that they can be used for subsystem testing and remain easily included in a larger detector configuration.

The baseline system has required approximately 20 man-years to construct. Roughly two man-years were paid out of project funds. The remainder was contributed by collaborating institutions. Completing the hardware controls will require an estimated 6-8 man-years of effort. Project goals called not only for a reliable hardware controls system, but also for the training of young physicists. To this end, expert support was enlisted only for early special record development and system maintenance as well as hardware design and fabrication. Roughly 2/3 of the manpower consists of students and postdoctoral assistants. Undergraduate students played a significant role in the project. Their efforts were enabled by the use of standardized toolkits. These introductory students were able to take on projects, which, although routine to senior staff, were nevertheless interesting and capable of producing rapid and significant results from their standpoint. The use of undergraduates increased the manpower requirements, since students are only available part time, and face a significant learning curve. The structure of the project required that a postdoctoral researcher was present full-time at the integration site.

3. STAR HARDWARE CONTROLS SYSTEM

The STAR Hardware Controls system sets, monitors and controls all subsystems. In addition, Hardware Controls can generate and display alarms and warnings for each subsystem. A real-time VxWorks environment is utilized for this purpose and a controls software package, EPICS, is used to provide a common interface to all subsystems.

The baseline STAR detector consists of time projection chamber subsystems (anode high voltage, cathode field cage, gating grid, front-end electronics power supply, HDLC link, gas, laser, interlocks, and VME-crate control), mechanisms for the exchange of information with the STAR trigger and online, as well as external magnet and accelerator systems. Approximately 10,000 parameters governing experiment operation are currently controlled and monitored. The communication of the STAR Hardware Controls with the other systems is shown in Figure 1.

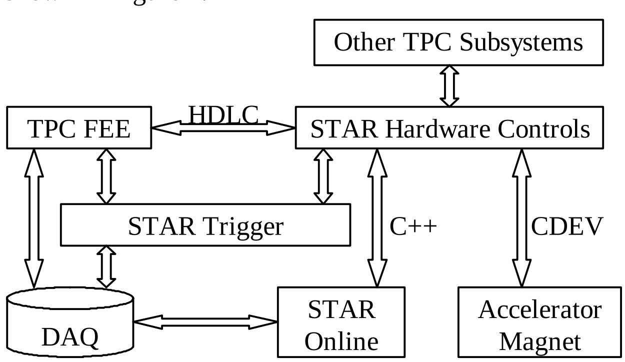

Figure 1. Communication between STAR real-time systems.

Magnet status and accelerator information is obtained from the accelerator controls database using a Control DEVice (CDEV) client/server interface [7]. Beam scalar information, STAR experiment status and STAR measurements of the magnetic field can also be provided to the RHIC control group using CDEV.

The set of databases for a particular run configuration is maintained by Hardware Controls. The set of all possible run-time databases are stored as part of Online Computing. The appropriate set is transferred to Hardware Controls as Run Control transitions between various operating states. At present, this connection consists only of an interface between EPICS and Objectivity. This connection will be completed by the December run.

4. STAR CONTROLS FIELD BUS

The majority of the experiment's electronics is located on the detector. In the case of the TPC alone there are over 4000 front-end electronics (FEE) boards in the endcap regions of the TPC for amplifying, shaping and digitizing signals from the TPC pad plane. FEE cards are connected to 144 readout boards also located on the TPC endcaps. Readout boards were designed with an internal memory and alternate readout path for diagnostic purposes and installation testing. The readout board memory can be written to and read from the Hardware Controls link as well as the normal data stream.

In order to have reliable links to the readout boards, easily identify any malfunctioning readout boards, communicate with a large bandwidth over a distance of about 30 meters under a strong magnetic field and minimize cabling using a multi-drop topology, an HDLC protocol (running at 1 Mbit/s) was selected as the field bus for the experiment. The link is based on a 68302 processor serial port. This link is mounted on a separate PC daughter board [8].

The VME interface, a Radstone SBCC-1 board, supports up to four HDLC channels. Each HDLC channel configures the readout of a single extended region of the TPC by communicating with six readout boards over an RS-485 link. In addition, the controls link can monitor and adjust voltages on the TPC readout boards and control the power on FEE cards (in groups of four). When testing, a bit pattern can be sent using the HDLC link to a readout board to initiate the creation of an analog pulse. The FEE cards that are connected to the readout board will receive the pulse signal, then amplify and digitize it. A comparison of the output data with the input data facilitates an examination of the operation of the event memory buffer and the electronics. To detect cabling errors each of the FEE boards and readout boards is tagged with a geographical address. The HDLC link controls the routing of the digitized data to the buffer on the readout boards or directly to DAQ via a fiber optics link. If the data is sent to the buffer, it can be read back by Hardware Controls via the HDLC link. Data can also be sent from the buffer to DAQ. A comparison of the data between Hardware Controls and DAQ allows the integrity of the data acquisition and HDLC paths to be verified. HDLC will also be used for four upgrade detector subsystems.

5. EPICS AT STAR

EPICS was selected as the foundation for the STAR control software environment because it incorporates a standard means of sharing information and services, graphical display and control interfaces, and a robust, real-time operating system. At STAR, EPICS is run on Sun workstations connected to VME processors running the VxWorks operating system. The components of EPICS used at STAR are the Motif Editor and Display

Manager (MEDM), the Graphics Database Configuration Tool (GDCT), the sequencer, the alarm handler, and the data archiver.

A number of I/O devices are included in the system [9]. The anode high-voltage system controls an Arcnet connection to the LeCroy 1458 power supplies. The Arcnet driver is adopted from the one developed by TJLAB-Hall-B. The communication between control-panels and the Arcnet is accomplished using subroutine records. A Glassman high-voltage power supply is controlled using four VMIC modules: a 64-bit differential digital input board (1111), a 32-channel relay output board (2232), an analog to digital converter (3122) and a digital to analog converter (4116). Precision measurements of the voltage drops and current are monitored using a new EPICS driver providing a GPIB connection to a Keithley electrometer. FEE power is controlled by six Acromag digital I/O boards that are connected to solid state relays. A new EPICS driver has been written for this purpose. The HDLC link has been interfaced with the EPICS software from which a number of control and monitoring tasks can be performed. An EPICS record and related EPICS driver support have been written for this purpose. Specialized control electronics were developed for the TPC gating grid. EPICS drivers have been written to control the potentials on the gating grid and to monitor its status. The gas control program runs on a PC using the Windows NT operating system. (Data is saved every 20 seconds onto a cross-mounted disk, which is accessed by Hardware Controls. The values are displayed in EPICS.) This is the only TPC subsystem with a front-end not under the direct control of an EPICS interface. The implementation of an EPICS front-end was not cost effective as the gas system was developed in Russia using interfaces developed specifically for the STAR experiment. Laser calibration is monitored and controlled through a VMIC 32-channel relay output board. A LeCroy 1440 high-voltage power supply monitors and sets the phototube voltages via an RS232 serial connection. Communication is accomplished using the subroutine records. New subroutine functions were written for this purpose. Additional support for VME access to STAR-specific trigger boards has been written. The safety interlock system is controlled using an Allen-Bradley PLC system. This stand-alone system passes status information via TTL signals to a STAR front-end, an Acromag 948X digital I/O board. Additional PLC systems monitor temperatures, humidity and cooling water flow.

At STAR, EPICS front-end readout (input-output controller) programs are distributed among twelve VME processors (of the types MVME 147, 162, 167). STAR electronics controls are housed in eleven 6-u and three 9-u Wiener VME crates. Since there is no access to the platform where these crates are physically located during run time, remote control of the VME crates is required. This is achieved through a built-in VME-CANbus interface. The crate housing the CANbus interface, platform ethernet hub, terminal server and platform based workstation are provided with uninterruptible power to minimize the impact of a brief loss of power. A second system oversees the 14 VME crates used for data acquisition.

The integrated system operated effectively during the first commissioning run. The single item of concern resulted from system developers being located at remote sites during run time, delaying the process of upgrading code. This difficulty should be reduced as more system experts are trained.

6. SUMMARY

An EPICS-based control system has been developed for the STAR experiment at RHIC. STAR Hardware Controls maintains the system-wide control of the STAR detector with its EPICS databases at the subsystem level. The system developed contains a number of new EPICS implementations. An HDLC link provides the field bus used by the experiment for controls and as an alternate data path. The system began operation as part of an engineering run during the summer of 1999.

7. ACKNOWLEDGMENTS

This work was supported in part by the United States Department of Energy under contract numbers DE-FG03-96ER40991 and DE-AC03-76SF00098, the Creighton College of Arts and Sciences and the Dean of the Graduate School, Creighton University.

8. REFERENCES

[1] J. W. Harris *et al.*, “The STAR Experiment at Relativistic Heavy Ion Collider,” Nucl. Phys. **A566**, 277c (1994); STAR Conceptual Design Report, Lawrence Berkeley Laboratory Report, PUB-5347 (1992).

[2] S. R. Klein and J. Nystrand, “Exclusive Vector Meson Production in Relativistic Heavy Ion Collisions,” Phys. Rev. **C60**, 014903 (1999).

[3] H. Wieman *et al.*, “STAR TPC at RHIC,” IEEE Trans. Nucl. Sci. **44**, 671 (1997).

[4] J. Chrin *et al.*, “Results from the STAR TPC System Test”, IEEE Trans. Nucl. Sci. **44,** 592 (1997).

[5] J. Gross *et al.*, “A Unified Control System for the STAR Experiment”, IEEE Trans. Nucl. Sci., **41** 184 (1994).

[6] A.J. Kozubal *et al.*, “Experimental Physics and Industrial Control System,” ICALEPCS89 Proceedings, 288 (Vancouver, 1989).

[7] J. Chen *et al.*, “CDEV: An Object-Oriented Class Library for Developing Device Control Applications,” ICALEPCS95 Proceedings, 97 (Chicago, 1995).

[8] S. R. Klein *et al.*, “Front End Electronics for the STAR TPC,” IEEE Trans. Nucl. Sci. **43**, 1768 (1996).

[9] J. Lin *et al.*, “Hardware Controls for the STAR Experiment at RHIC,” Real Time Proceedings (Santa Fe, 1999) to be published.