CAMAC CONTROL OF
DIVERSE DATA ACQUISITION INSTRUMENTATION

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ABSTRACT

The LLNL Nuclear Chemistry Counting Facility has been converted into a modern research facility. A distributed data-acquisition network has been designed and implemented for this conversion. A major task of the conversion was to provide support for diverse nuclear instrumentation using the CAMAC instrumentation standard. This paper addresses the design and implementation of a CAMAC subsystem incorporated into the data-acquisition network.

INTRODUCTION

The Nuclear Chemistry Division of Lawrence Livermore National Laboratory operates nuclear-radiation-counting and mass-spectrometry facilities to perform analytical analysis of isotopic species for programmatic studies. On-going support is also provided for geological research and basic research in nuclear science. The facilities are comprised of more than 100 counting stations with a variety of configurations that perform alpha, beta, gamma-ray, and x-ray counting and spectroscopy in addition to magnetic mass spectrometry. The Nuclear Chemistry Counting Facilities (NCCF) has completed an upgrade project to improve counting, data storage and retrieval, and data analysis capabilities. The NCCF Upgrade Project upgrades the facilities' control and operation into one integrated system [1]. There were two major goals of the NCCF Upgrade. One was to replace obsolescent nuclear instrumentation and procedures with an integrated data acquisition and analysis facility employing current state-of-the-art technology. The second was to provide a standard mechanism for centralized data access and control by Nuclear Chemistry's data-reduction codes.

The first goal, involving control of diverse nuclear instrumentation, was a major task of the NCCF Upgrade. Instrumentation includes scaler/timer systems, pulse height analyzer (PHA) systems, and sample changer systems. PHA systems are designed for multichannel analysis while scaler/timer systems are designed for integral counting on 1 to n channels. The pulse-height analyzer is controlled via an intelligent serial line card [2]. It will not be addressed in this paper. The remaining instrumentation is attached and controlled via a CAMAC subsystem. This paper will address the NCCF data acquisition network, counting-system workstations, the CAMAC subsystem, scaler/timer systems, sample changer systems, and NCCF workstation software.

The second goal involved designing a network through which data acquired from nuclear instrumentation could be forwarded to a central computer.

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DATA ACQUISITION NETWORK

We have implemented a network of distributed control workstations with a centralized storage computer to support the facilities. The workstations are responsible for the acquisition of data, while the central computer will archive and reduce the data. This system, the Nuclear Chemistry Counting Facilities Network (NCCF-NET), is the end product of the Counting Facilities Upgrade Project (see Figure 1).

Figure 1. The Nuclear Chemistry Counting Facility Network (NCCF-NET).

A VAX 11/750 computer from the Digital Equipment Corporation (DEC) is at the hub of the NCCF-NET and is used for gathering, storing, and analyzing scientific data. The network is implemented using hardware available from DEC and DECNET, a DEC networking software package. The VAX is dedicated to treating data and performing analysis requiring certain measures of control and security. This computer serves as the central host for the counting system workstations networked to it. Communication protocols have been developed that allow data acquired on workstations to be forwarded automatically via the network to the VAX, where they are stored in a data base by the INGRES data base management system (DBMS).

To provide data communications between the various systems associated with the Upgrade Project, a secure classified-only IEEE 802.3 ETHERNET Local Area Network is installed in the Nuclear Chemistry Building. Each workstation can transmit its data to the central host VAX directly through the ETHERNET link.

COUNTING-SYSTEM WORKSTATIONS

The workstation provides a standardized control point to which a number of experiment configurations can be attached. This allows

researchers the flexibility to alter an experimental configuration and still be able to use the standardized mechanisms for control and data transfer to a central data base. This includes standard interfaces to scientific users with customized menus. Also included is computer control of existing equipment with automatic data acquisition, transfer, and archiving to a central host processor.

Each workstation controls the instrumentation for one to eight nuclear counting systems. The workstations are based around the LSI-11/73 microcomputer running the RSX-11M multi-user multi-task operating system. The workstation is responsible for the user-machine interface, count scheduling, schedule maintenance, nuclear instrumentation control (setup, initiation, termination), sample changer control, data acquisition, local data storage, and transmission of data to the central VAX host computer. The workstation must be capable of performing these tasks on all instrumentation to which it is attached. The workstations attached to the NCCF-NET are distributed throughout the building, in the vicinity of the counting stations that they control (see Figure 2).

Users interface to workstations through a video terminal. The terminal displays a set of menus that provide for sample entry, acquisition parameter entry, count scheduling and status display. The set of menus is customized for the equipment that the scientist is using. The format, entry, and maintenance of the schedules are tailored to the counting station configuration.

In addition, data files are stored locally in the workstation. The disk storage units have sufficient storage to maintain the data collected

Figure 2. A typical setup showing the RSX workstation, local CAMAC crate system, pulse height analyzer, user interface, sample changer (SC), and Sample Changer Crate System (SCCS).

for at least a 72-h period. This allows the workstations to operate unattended when the host computer is unavailable. This loose coupling between the host and the workstation also increases the reliability of the network as a whole - no single unit, host or workstation, can drastically affect the remainder of the network in the event of a crash.

The majority of instrument control performed by the workstation is supported by the CAMAC subsystem.

CAMAC SUBSYSTEM

The major benefit of the use of CAMAC in the network is that most required functions are available commercially and are compatible with the CAMAC standard. This allowed not only more rapid initial development, but will also facilitate future expansion. The CAMAC subsystem is incorporated into the workstations to provide support for sample changers and scaler/timer systems.

Prior to providing support for CAMAC devices, our Electronics Engineering group modified the RSX CAMAC I/O driver to include support for recognizing, clearing, and buffering module LAMs. We incorporated a general-purpose interrupt handler into the driver [3]. This driver returns a buffer of data containing the crate LAM request and the module LAM request for each slot in the crate. Individual LAMs are disabled and the crate LAM buffer is returned to upper level codes for further processing.

A function code (IO.PLB) has been added to the CAMAC I/O driver to provide for reading of LAM information from the crate controller [4]. This function returns the crate LAM buffer which contains specific information for each slot in the crate. It contains the crate controller LAM Low/LAM High (LL/LH) combination along with the LL/LH of all slots in the crate. LL is the LAM Low register that contains the lower 16 bits of the 24-bit CAMAC LAM pattern. LH is the LAM High register that contains the upper 8 bits of the 24-bit CAMAC LAM pattern. The crate controller LL/LH pattern defines which slots within the crate have posted a LAM. The IO.PLB function allows the application task to post a buffer to the driver, go about doing other work and be notified, through AST routines, when the buffer has been filled. The crate LAM buffer contains the LL and LH of the crate controller (slots 24 and 25) as words 1 and 2 followed by the individual LL and LH of the modules in slots 1..23. When LAM buffers are processed the driver attempts to disable the LAM that caused the crate LAM request. Two methods of disabling module LAMs are used [4]. The first method attempts disabling module LAMs using the mask/status registers, and the second method tests appropriate module subaddresses and disables those causing LAMs. Crate interrupts are disabled during LAM processing and re-enabled upon exit, if the appropriate LAMs were disabled.

We have modified the CAMAC crate controller to provide a momentary power-up LAM. A hardware change was implemented on the CAMAC crate controller to pulse the crate LSUM line only on power-up of the crate.

This allows a power-up buffer to be passed back to the RSX system when a receive buffer is posted. Code has been added to test bit 24 of the

crate LAM High word which is the LSUM bit of the crate controller. This bit is active momentarily, just long enough to signal the LSUM and cause the system to recognize it.

The CAMAC subsystem is also supported by a functional software library. This library allows the application codes in the workstation to control all functions available from the modules currently attached to the CAMAC subsystem. The functional software supports not only the crate attached directly to the workstation, but also modules residing in remote crates such as those required by sample changer systems and scaler/timer systems. Support is included for all CAMAC functions such as: perform single CAMAC function, perform CAMAC function list, generate dataway initialize, generate crate clear, test crate demand enabled, enable or disable LAM, clear LAM, test LAM, and send command to remote crate.

Individual CAMAC functions are merged to perform various sets of functions required by both sample changers and scaler/timer systems.

THE SCALER/TIMER SYSTEM

The scaler/timer system performs gross counting and single channel analysis. It is attached to the workstation via the CAMAC subsystem and is packaged as two CAMAC modules. Design of the CAMAC and scaler/timer system allows the flexibility of setting up a scaler/timer set either in a crate local to the workstation or in a crate remotely controlled from the workstation (see Figures 3 and 4).

Figure 3. The LOBACCA counting system using CAMAC controlled Scaler/Timer Systems for data acquisition.

The scaler/timer system is configured from one Master Timer Module (MTM) and a general purpose scaler module with 6 scalars. The scalars support a maximum count rate of 10 MHz to allow for fast accurate dead time correction. Scalers are cascaded in pairs to provide a 48-bit register. This gives a maximum of $2.8E14$ counts per pair.

Figure 4. The 2PI-ALPHA counting system using CAMAC controlled Scaler/Timer Systems and the SCCS for sample positioning.

This allows count times to exceed several months at the maximum count rate. The MTM is designed to accumulate live time, real time, and dead time for long count periods. It has 3 input channels, 3 output channels, a GATE signal, a RESET signal, and an ENABLE signal. The Electronics Engineering group designed this module to meet the NCCF-NET requirements for a scaler/timer system since there were no commercially available CAMAC modules.

The display for the CAMAC scaler/timer system is provided by a NIM scaler/timer module, which is local to the counting station and run in parallel with the CAMAC scaler/timer system. Control of the scaler/timer system is from the workstation via the CAMAC subsystem. Software is written to terminate counts upon reaching either a preset live time, a preset real time, or a preset count in any of the data channels.

A library of functional software has been developed to allow the application code access to the scaler/timer system through standard subroutine calls. Functions supported by this library include: set scaler/timer, start scaler/timer, stop scaler/timer, and read scaler/timer.

SAMPLE CHANGERS

The Division uses eight different varieties of sample changers to support the counting stations in the facility. These sample changers range from

four positions to 200 positions, from a simple turntable to a carousel with eight stacks of 10 samples. Five of these are converted to workstation control. These are the Frisch-Grid 6-position, the Solid-State 6-position, the 2Pi-Alpha 4-position, the 16-position belt, and the 26-position wheels. All are capable of stand-alone operation. The remaining changers will either be retired or upgraded at a future date when their need to be linked into the NCCF-NET is required. The workstation must have the ability to manipulate all aspects of sample changer control, including positive position feedback and counting system status monitoring. This control capability requires three major parts: an interface to the workstation, an interface to the sample changer, and functional software to drive these interfaces.

To minimize the amount of customized software and hardware needed, the interface to the workstation and the major portion of the interface to the sample changer have been standardized. A small amount of customized software is necessary to adapt each of the five varieties of changers to the standard interface.

The interface to the workstation is a RS232 serial line packaged in a commercially available CAMAC module. Software is designed and used by both the workstation and CAMAC crate system to ensure the integrity of data passed between the workstation and CAMAC modules. With this reliable data path, a sample changer interface is designed and built specifically for the changer to be controlled (see Figures 5, 6, 7, and 8). The sample changer interface is controlled via a CAMAC microcrate. This microcrate, known as the Sample Changer Crate System (SCCS), contains a stand-alone crate controller with an LSI 11/23 processor, an input module, and an output module to provide feedback to/from the sample changer interface and to the expansion modules. These expansion modules house a 2-channel serial line card (workstation

Figure 5. The 2PI-ALPHA SCCS controlling a 4-position SC interface.

Figure 6. A GAMMA counting system using the SCCS to control a 26-position SC interface.

Figure 7. The Germanium counting system using SCCS's to control 16-position SC interfaces.

channel and debug channel), 96K words of RAM, and 32K words of PROMmed firmware to control and interpret workstation sample changer commands for the specific changer. All modules are commercially available.

The SCCS design was a major portion of this project. It also provides control to additional CAMAC modules located within the Sample changer CAMAC crate. With a standardized SCCS design,

Figure 8. The ALPHA counting system using the SCCS to control Frisch Grid and Solid State 6-position SC interfaces.

diverse sample changer systems and CAMAC modules can be controlled. The customized sample changer interface is designed according to the specific changer being controlled.

The sample changer operating system firmware is designed with the MicroPower/Pascal (MPP) development language available from DEC. MPP is a software development tool for creating ROMmable real-time applications that run in dedicated target systems (sample changers). MPP allows tailoring the application to contain only the specific MPP operation system services it needs to run in the target microcomputer (LSI-11/23). Applications are coded in a high-level Pascal language that includes extensions for real-time and multitasking support. Each application is constructed specifically for its target system, with the exact set of operation system services required to control a sample changer. This development tool allowed design of a stand-alone system for operation of sample changers.

The SCCS system software is designed to operate both in remote and local control. This feature allows the workstation to have complete remote control of the sample changer when required. The sample changer is released from workstation control only by workstation software or by a reboot of the SCCS system. SCCS software is designed to prevent sample changer manipulation while the workstation is actively collecting data. A Local Control Unit (LCU) is designed for each sample changer to allow users local manipulation of the changer only when in local control. Functions available to the user through the LCU include: move turntable, move to next position, move belt, and move RAM up/down. Depending on the sample changer, additional changer specific functions are available. The LCU design provides the user with all necessary control for manipulation of the sample changer during loading and unloading of samples.

The functional software supporting the sample changer subsystem for the workstation is in the form of a library of subroutines. Application codes in the workstation have complete control of all sample changer functions via standard subroutine calls. This library includes such functions as: move sample changer to specified position, search to a position with sufficient activity, and report current sample changer status.

WORKSTATION SOFTWARE

We have developed control software that operates in DEC's RSX-11M operating system environment of the NCCF workstations. All upper level software is written in FORTRAN while any low-level system codes are written in MACRO. The numbers and types of supported instruments and controllers vary from station to station, requiring each to have a unique set of software control. We have designed a layered software system that extends from modules that control individual hardware components to application codes that manage each counting system.

A set of menus, designed with the Forms Management System (FMS) produced by DEC, is customized for the equipment that is to be controlled. The NCCF Menu System provides convenient and consistent menu-driven communication between each user and each control system resident in a given workstation. This Menu System enables users to control and specify system selection, configuration data, status reports, and sample entry and control.

A menu is designed specifically for the functions required by each type of counting system. Functions include: display and modification of current scheduling and detector parameter information, pausing and resuming the current count, restarting the current count, starting the next sample after aborting or retrieving data for the current count, continuation of data acquisition for the current count after retrieving and transferring data, and a schedule status page for all systems currently controlled by the selected counting system. Scheduling forms are customized for each type of counting system whereby the user enters relevant information about each sample.

Subroutines within the Menu System communicate with Configuration, File Management, Data Management, and Executive Application (EXEC) codes to provide for the creation and maintenance of schedule files for each detector in the workstation configuration.

The Configuration code establishes and maintains files for the configuration status and equipment parameter specifications for each workstation. The File Management code is responsible for transmitting data files to the host computer, maintaining a file management system of resident data files, and making space available when requested by other tasks. The Data Management code merges spectral and header data from the nuclear instrumentation with schedule file information and other pertinent parameters to form a Nuclear Chemistry Standard data file. A separate EXEC for each counting system on a workstation has the responsibility for directing the flow of information controlling the system. It accesses the schedule files when prompted from either the Menu System or instrumentation handlers and initiates the appropriate process as required by

status state flags. The EXEC issues all setup commands, initiates counting, terminates counting, issues commands to collect and transfer data, and checks schedule files for the next sample to be counted.

The EXECs that operate the different nuclear measurement systems use local data bases to store parametric and counting data related to samples. Users may access the data bases through the Menu System to enter, alter, or examine information pertinent to the counting of the samples. The EXECs also interact with the network to transfer counting data and other relevant information to the control host processor.

Several quality assurance features have been implemented in the design of the workstation software that enables monitoring equipment status and configurations easily. Many potential problems can be detected automatically and either corrected or flagged for operator action. Fatal errors or damaging conditions result in an immediate shutdown of the faulty equipment with appropriate messages to operators. The system also protects stored data, control information, and system status against power failures or interruptions. Should such problems occur, an automatic restart allows workstations to pick up the final status of the samples being processed and resume the counting schedule.

All devices are ultimately driven by an EXEC which calls for functional tasks to initiate specific actions on a device. These functional tasks in turn process the command and pass control to a device communications handler. The communication handler issues appropriate buffers to the device and returns command acknowledgments back through functional software. The functional software then returns command status to the EXEC. All task interactions take place via task-to-task communication buffers. Any type of interrupt request is first processed by a device communications handler and then sent to the EXEC. A CAMAC device communication handler (CAMCH) code has been specifically designed to support all interaction between the workstation functional software and the CAMAC subsystem. The CAMCH is designed to process LAM buffers and return necessary information to the appropriate EXECs. LAM processing includes support for recognizing power-ups and individual module LAMs. It is the function of the CAMAC I/O driver to recognize, clear, and buffer the crate and module LAM requests to the CAMCH.

SUMMARY

We have accomplished the goals of the NCCF upgrade project. These goals include modernizing both the counting equipment and information gathering techniques used in the facilities by taking advantage of new state-of-the-art technology. This includes a distributed control network, a centralized data base for storage and analysis, and increased data integrity through automation and standardization of data acquisition instrumentation, data structures, and data flow. Along with providing audit trails for quality assurance, this design and incorporation of a CAMAC subsystem to control diverse nuclear instrumentation has also enhanced reliability, maintainability, and flexibility of the counting facilities.

We have installed and made operational eleven workstations integrating different counting systems into one unified data acquisition network. They control a total of 22 sample changers, 14 PHA systems, 2 scaler/timer systems, and 59 detectors. These data acquisition systems include support for PHA gamma and alpha systems with sample changer control, and scaler/timer systems for alpha and beta counting.

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