THE LLNL NUCLEAR CHEMISTRY AUTOMATED
PRODUCTION COUNTING FACILITIES: DESIGN AND IMPLEMENTATION*

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Abstract

Livermore's Nuclear Counting Facilities Upgrade Project was undertaken to replace outdated instrumentation and data and resource control mechanisms. The specification and design of a facilities system for data collection, data flow, and control, from instrumentation to the generation of reports, are discussed. The authors show how a collection of scientific experiments, responsible for production acquisition and handling of data from radiation detection and mass spectroscopy, may be automated.

Introduction

The Nuclear Chemistry Division of Lawrence Livermore National Laboratory has responsibility for the radiometric assay of samples in support of the Nuclear Test Program, Chemistry Research, Environmental, and Hazard Control Programs. Production radiation counting includes support of alpha, beta, gamma, x-ray and mass spectroscopy experiments using scaler/timers, single-channel analyzers, multichannel analyzers, and multichannel scalars. Over 100 individual experiments are configured in a variety of ways to satisfy the user community at Livermore.

A facility which supports many similar, but not identical experiments, can find itself with a collage of "systems" inflexible to changing needs, difficult to maintain, and, on occasion, unusable because of incompatibilities. Inexpensive computing, coupled with modern information and resource management techniques, it making it attractive to implement total facilities systems for nuclear counting, analysis and report generation.

Today we are faced with imposed regulations, risk analysis, quality assurance programs, and simply the demand to be more responsive in the production and handling of nuclear data. A facilities system of people and machines, specified in a top-down fashion, can provide these benefits without compromising the science of nuclear counting.

The Nuclear Chemistry Counting Facilities Upgrade Project was undertaken in July 1978 to meet changing needs and take advantage of new technologies. A six-month process of seminars, interviews and questionnaires culminated in a Requirements Definition document and a functional and performance specification for the design of a facilities system. The project involved three identifiable areas of development; engineering, analysis codes, and operations. An interdisciplinary team of professionals and support was mobilized to contribute their expertise as needs required.

The goals of the project were stated. We were to meet the needs of the counting facility both in the short-term and in the foreseeable future, providing migration paths for future growth or change. We were to implement a system which is reliable, maintainable and usable. Required benefits included a high level of automation, better tools to carry out

scientific counting needs, an active quality assurance program, and modularity of design to respond to changing facility usage and technologies.

Standards were adopted. Even with diverse experiments there are many commonalities which lend themselves to standardization. We have standardized on pulse electronic modules and their configurations. We chose a standard commercial product for all our multichannel analyzer uses, and a standard in-house designed scaler/timer product for integral counting and single-channel analyzer needs. The scheduling of samples in a sample changer, to be counted by an experiment, was generalized, and a standard approach designed. Computing hardware was standardized, as were the functions to be carried out. All engineering code is implemented in PASCAL, a "de facto" standard higher level language for engineering control and signal processing applications.

The design of the facilities system was driven by two considerations: allow data flow to determine the system architecture; allow work flow (the control of events) to determine operations. These considerations, with the project goals and facilities specifications, permitted the confident design of a facilities system which would, indeed, satisfy the user base and management.

System Architecture

The facilities requirements called for a central data base. This data base is to be accessed by data reduction codes, which, in generation programs in a hierarchical fashion (Fig. 1). Distributed instrumentation control and data collection, local to the user's instrumentation, were also required. Based on the ideas put forth in the previous discussion a network of instruments, controllers, small controlling computers, and a central, host computer was conceived.

Figure 1. Data from the various detectors and instruments are reduced and merged for use by analysis codes which yield reports.

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The Nuclear Chemistry Counting Facilities Network (NCCF-NET) is a collection of ten "workstations" distributed throughout the three floors of the building which makes up the counting facilities (Fig. 2).

Figure 2. A network of workstations on three floors forward collected data to a central data base on a host computer. Workstations (as shown on top floor) provide local control of instruments and sample changers via dedicated controllers.

Each workstation is responsible for the automated control and scheduling of the experiments resident in a room or adjacent rooms.

The workstation uses dedicated instrumentation controllers to carry out instrument and sample changer control. These slave controllers extend the reach of each workstation and perform all the low level communication and control of instrumentation.

The ten workstations are also loosely coupled to the host computer in a "star" configured communication network. It is the function of the workstation to collect data for use by the central computers data base, then store and forward collected data for reduction, analysis, and report generation on the host machine.

This is by no means a hierarchical architecture, however. The central, host computer performs a service for the workstation under a request. Loose coupling of responsibility allow the workstation to collect data for up to 72 hours unattended with the host computer unavailable, and indefinitely if operation is periodically suspended for disk change. And no control is presupposed from the central computer.

In this way, we can maintain the hierarchy in data processing, while preserving distributed control and operation of individual experiments. By adopting "data flow" and "work flow" criteria to the facilities system architecture we hope to achieve a modularity of hardware and software along the lines of the existing modularity of facilities usage. The result is a system capable of changing or adopting new modules as science and technologies changes.

Instrumentation

The integral radiation counting done at the Livermore facilities is supported by two products. The first is a commercial multichannel analyzer (MCA) product capable of performing multichannel scaling (MCS) and low performance "list" mode acquisition of individual events. The second is a scaler/timer designed to be used with an in-house designed three decade discriminator product for single-channel analyzer (SCA) applications.

The MCA chosen as the facilities standard is Nuclear Data's ND66. This instrument was built to our specification and chosen by competitive bid. The analyzer provides support of up to four analog-to-digital converters (ADCs), mixer/router multiplexing of up to four detectors per ADC, and a maximum of 32K channels of 24 bit memory configured as needed by the ADCs.

We paid a great deal of attention on the human engineering needs of an analyzer to support diverse counting needs. The ND66 has an excellent 12 inch diagonal display, good manual controls, and keyboard lockout of all but the display commands while under computer control.

Another concern was that the analyzer provide a robust communication environment in a master/slave relationship with a controlling computer. Digital Equipment Corporation's (DEC) link level communication protocol, DDCMP, was adopted for this purpose quite successfully. We can demonstrate the ability of the computer and analyzer to resynchronize and complete an interrupted data transfer.

The scaler/time for this system is an LLNL designed, LSI-11 Q-bus compatible printed circuit (PC) board. This PC board contains 55 integrated circuits (ICs) and is compatible with a standard double height DEC module. One board holds two complete scaler/timers. Each scaler/timer, implemented with National INS8253 scaler ICs, contains a 48 bit live time timer, a 32 bit dead time timer and two 36 bit data scalars. There is a single 1.25 MHz clock source for live time and dead time, which is gated between the two timers by a signal generated in the detector amplifiers. One of the data scalars, which accept input frequencies to 10 MHz, is used to gather counts falling within a selectable energy window. The proposed use of the other is to gather background counts.

This board is driven by a DEC LSI-11/2 microcomputer as a peripheral device, occupying sixty-four bytes in the reserved I/O portion of memory. A preset count can be set in either of the data scalars or a preset value may be set in the live time timer. Once the count has started, the scaler/timer needs no more service until the count is complete and an interrupt is generated to the controller. At that time, the LSI-11 reads the results and a new count can proceed. If the dead time timer should overflow, this is logged and the count continues.

Dedicated Instrumentation Controller

The DECDIC (Dedicated EPROMed Computer for Distributed Instrumentation Control) is a slave peripheral to the workstation. It provides the data and control channel between the workstation and the nuclear instrumentation which it controls. Control of these instruments is implemented through simple, relatively primitive functions performed by the DECDIC on command of the workstation. Control messages emanate from the workstation and data is gathered by the controller and forwarded to the workstation.

The controller provides the workstation with a standard interface and insulates it from the hardware specific details of controlling the attached instruments. The interface between DECDIC and the workstation is a standard, high speed (9600 baud), RS422 compatible, asynchronous serial line. The link level protocol used is SCULL (Serial Communication Utility for Long Links) an LLNL developed serial line proto-

col. The message level protocol was designed by the NCCF-NET design team and is specific to this job. This protocol is derived from the master slave relationship between the workstation and the controller. All actions are initiated by commands from the workstation, with messages from the DECDIC limited to responses to said commands. The one exception to this rule is a service request message that the controller will send the workstation on completion of previously requested tasks.

The instrumentation connected to the controller includes up to four sample changers, up to sixteen scaler/timers, one multichannel analyzer, up to 64 programmable DACs and a CRT terminal. There are eight types of sample changers involved in the network and the DECDIC drives all types through a standard interface.

A generalized model of a sample changer has been developed. The eight specific changer types have been mapped onto this model, and a hardware interface was developed to be driven by this sample change model. The interface then drives all sample changers.

The scaler/timers are the LLNL designed product previously discussed. The controller is responsible for setting up the scaler/timer, gathering the data and forwarding it to the workstation. An ND66 is the multichannel analyzer to the MCA via a 9600 baud serial line and communicates using a version of the DDCMP protocol. The controller provides protocol translation between the workstation and the MCA. The programmable DACs connected to the controller provide computer control of detector amplifiers/preamplifiers, high voltage power supplies and energy level discriminators. A terminal local to the DECDIC provides display of scaler/timer counts, messages to users, and interactive input during calibration.

The controller is based on a Digital Equipment Corp. LSI-11/2 microcomputer with 30K words of semiconductor memory. The microcomputer, scaler/timers, interfaces to sample changers, and DAC controls for automated pulse electronics are all housed in an LLNL standard 19 in. wide, 7 in. high, 22 in. deep chassis along with power supply and fans. In automatic power-up restart, the code running the DECDIC is firmware, burned in EPROMs. The 30K words of available memory are partitioned into approximately 22K words EPROM for the program storage, and 8K of RAM for variable and buffer storage.

The firmware package for the controller was designed in a top down, modular fashion, providing higher maintainability and facilitating additions to handle new hardware. Firmware modules drive each of the controller supported I/O devices and, although there may be several of any type of device, only one module drives all of them. Parameters passed to the module by the main line code describe which device is involved and where in memory it exists.

The main line of the code is a state machine, driven by commands from the workstation. Actions taken by this state machine perform the actual control of the instruments. Although the state machine can handle only one command at a time, there are multiple state tables in the controller, allowing for simultaneous processing of several commands by the DECDIC. Hang-up due to resource lockout is prevented by requiring the workstation to wait for a response to each command from the controller before issuing the next command. Before generating this response, the controller places a lock on all devices needed to satisfy the request. If a needed device is locked, the incoming command is rejected.

A local calibration move is provided to aid in the adjustment of high voltage power supplies, amplifiers, and discriminators. This mode protects the production counting environment from inadvertent interference by users with a software lockout. Users wishing to use calibration mode must get approval from the workstation before any adjustments are allowed. Calibration of one experiment attached to a controller can proceed while production data acquisition is carried out unimpeded on another portion of the same instrument.

The Workstation

The purpose of a workstation is to automate Nuclear Chemistry detector systems by controlling instrumentation (via dedicated controllers), to collect and forward data to a host computer, and to serve as liaison between user and local equipment. One workstation controls up to 20 detector systems.

Each workstation is DEC LSI-11/23 microcomputer based, and includes a CRT terminal, printer, and 10 Mbyte hard disk storage. A typical workstation is shown in Fig. 3. Sample identification must be entered at the workstation by either typing their unique identification codes at the terminal, or by using a bar code reader.

There is a wide variety of instrument configurations and usage within Nuclear Chemistry. It was important that code be generalized and modular in order to be shared, though customized, for each detector system. All code was well documented for maintainability. Good human engineering was crucial to produce an understandable and usable product for the chemists. All software was written in OMSI PASCAL.

The workstation's internal data base uses three main library files resident on the workstation's disk, one each for sample identifying information, scheduled runs, and control parameters for counting equipment (Fig. 4). Each sample record contains a unique identification word, position on the system, nuclide of interest, etc. This record also contains a pointer (ptr) which links it to a schedule directory entry.

The latter points to a unique schedule which consists of a linked list composed of run-time records. Each of these records notes the day, hour, and minute for the scheduled run. This time may be repeated (as is the case if the list becomes circular at any point) or several times may be joined with the last one pointing to "nil". With this information, a sample may be scheduled to run (i.e., be counted) at any desired time with variable or constant frequency.

In addition, each time record is linked to a control directory entry, which points to a file containing the proper machine settings for that run. There are four Nuclear Chemistry counter types: scaler-timers (SCTIMER); multichannel scalars (MCS); a sequential listing mode (LIST); and multichannel or pulse-height analysis (PHA). Discriminator level settings, energy levels, etc., are set through this file. Thus, the user may change machine settings from run to run.

Two or more samples may share the same schedule directory entry, in which case they will run at the same time with the same control parameters (any conflict due to equal run times are arbitrated automatically by a preset priority scheme). Semaphores are used to protect these task-shared files.

Figure 3. Standard hardware includes the ND66 multi channel analyzer, eight types of sample changers, the DECDIC controller, and the workstation with bar code reader.

Figure 4. The workstation's internal data base structure includes sample identification, schedule and instrument control parameters.

The user may create new schedules for the schedule library, new control tables for a control library, or enter a new sample along with any of the preceding. All control and schedule library entries retain a reference number, and thus may be shared among samples upon request, without the need to create new entries. A user may change a sample's schedule or control information at anytime, delete library entries, scan the libraries, or search for user-specified information. The status of the system or of a particular sample may be requested. The user may also request a halt of current operations for manual control. A "help" page define available operations.

Display and interactive operations are facilitated by the use of a "forms" package designed in-house. With this package, each type of record being manipulated or used by an operator is displayed as a standard form for the user to view or complete.

A user may customize an experiment by specifying counting schedule and machine control parameters. The created data base is easy to maintain and easily accessible. Man-machine interface has been carefully designed to provide the user with a true tool for data acquisition. The workstation also offers the capability of automated quality assurance and instrument "health" monitoring and logging.

The Host Computer

The functions and performance required of the central, or host computer was specified. If the intent was to simply collect data for reduction and analysis on the mainframe computers at the Livermore Computation Center (LCC), another workstation with communication hardware to LCC would have sufficed. However, it was desirable to perform in-house data base management, I/O, and, as resources permits, move data reduction codes in-house. The host computer was implemented using a DEC top-of-the-line minicomputer, a PDP-11/70.

The host computer provides a service in three distinct areas. The data acquisition network of workstations is supported with hardware and DECnet of software. The host offers an automated data path from the workstation to a central data base on the host. The host provides for automated batch processing of production data collected by the workstation, residing in the central data base. The host computer also permits up to 16 timesharing users to perform interactive data reduction, query the data base and access data, and develop software.

It is required that the host computer be upgradeable or replaceable as the need or technology arises. As data reduction codes move to the PDP-11/70, and system performance becomes less available, it is possible to split the functions between a higher performance computer to carry out data reduction and time-sharing, leaving the networking and data base management chores to the "backend" PDP-11/70. Or, as technologies progress, replacing the PDP-11/70 with another machine could be carried out painlessly.

This requires a concerted effort of strict standardization and modularization. All software tools (languages, data base management system, etc.) and all application codes must be transportable. Throw away software is a luxury we cannot afford.

Conclusion

It is possible to implement a total facilities system in support of diverse scientific needs. Inexpensive computing hardware makes it practical to allow

the facilities usage to drive the system's architecture, rather than making compromises to inadequate technologies and designing from the bottom up.

We have demonstrated the ability of an interdisciplinary project team to meet the needs of a well-specified facilities system, without presupposing architecture or hardware components. A strict adherence to standards, documentation, and design philosophy will allow the system to be maintainable, upgradable, and, above all, understandable over many generations of technical and scientific development.

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