THE PROTON STORAGE RING CONTROL SYSTEM*

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Summary

When designing a control system for a new facility, one is faced with a bewildering array of electronic devices to use in the solution. There is, of course, no single correct solution because the constraints are Laboratory and project dependent. The major constraint applicable to the hardware choice for the Proton Storage Ring (PSR) control system was the limited manpower available for the design, development, and documentation of custom hardware. As a result, wherever possible, commercial components have been used that are based on recognized standards.

The array of choice on the hardware side contrasts markedly with the absence of suitable commercial software products, and it is unfortunate that here there seems to be little prospect of change.

The analysis of the overall system that follows will lead to a suitable hardware choice and a description of the software's structure. This paper is an overview, but more information is available.[1-4]

The PSR Control System

The PSR is a new addition to one of the beamlines at LAMPF. The beamline, Line D, provides a short, high-intensity burst of protons to a spallation neutron source. The nature of many of the experiments at the neutron source is such that the length of the neutron pulse determines the energy resolution. As beam is taken directly from LAMPF, this length also determines the total, time-averaged neutron flux and hence the signal-to-noise ratio of the experiments. Thus the setting of the existing facility is a compromise between resolution and signal strength. The PSR will remove this compromise by accumulating LAMPF beam for up to 750 μs, a complete LAMPF cycle, and then delivering the accumulated charge with a time structure suitable for the experiment. The overall gain is dependent on the particular experiment, but it will usually be over two orders of magnitude.

The existing controls for Line D consist of a single computer and ∿950 channels connected to it. The new PSR control system will take over these channels and will add ∿1500 new channels. However, the controls problem does not scale with channels; the PSR adds a new dimension of complexity to the facility because it is a state-of-the-art machine. Thus the machine physicists and the operators need much more help than the existing controls system on Line D can give. Line D has been operational for some years, and the PSR is due to take first beam in March 1985.

Requirements

The PSR control system overall requirements are

- the system must provide the operator with full and responsive facilities for bringing on-line all the equipment that makes up the PSR;
- the system must automatically monitor equipment for normal operation and report exceptions to the operator;
- the system must present information to the operator about the current state of the PSR, or any selected section, in an easily understood form;
- the system must maintain a log of significant events; and
- the system must be flexible enough to add new equipment and channels easily, as well as to add new programs for operator interaction.

These requirements specify two kinds of processing required of the computers in the system. The first kind is single-word input/output (I/O) processing associated with reading values from and writing them to the interfaces connecting the PSR's equipment to the controls computers. This task also will include simple routine conversions and range checks, and the magnitude of the task scales with the amount of equipment and number of channels. The second kind of processing relates to the provision for operator interaction, and the magnitude of this task scales with the number of operators and their activity.

The choice of microprocessors for the first task and a computer system for the second task is a natural one. To simplify the software development, the microprocessors and the computer were chosen from a compatible range and are Digital Equipment Corporation (DEC) LSI 11/23's running RSX 11S and a VAX 11/750 running VAX/VMS. Thus the LSI 11/23's are memory-only systems down-line loaded from the VAX 11/750.

For many reasons, CAMAC was chosen as the interface system between the computers and microprocessors of the control system and the equipment of the PSR. More recently an analysis of the software overhead, hardware costs, and performance showed that, given the communications needs of the system, a serial CAMAC system was by far the best choice for the communications between the VAX 11/750 and the LSI 11/23's.

Detailed Hardware Description

Figure 1 shows schematically the hardware of the system, which is located in several buildings. The computer-related items on the two operator consoles are six color-graphics displays with touch screens, twelve computer-assignable knobs, and a conventional computer terminal. The remainder of the console is taken up with oscilloscopes, TV monitors, and other dedicated instrumentation. Although the touch screens and color graphics systems are commercial products interfaced to the VAX 11/750 Unibus, the programmable knob units are being constructed in-house and are interfaced through CAMAC modules. These devices make up the main hardware of the operator interface with the control system. The console is made up of ten bays arranged to form two operator consoles and one single-bay alarm console.

The CAMAC driver on the VAX is a powerful interface with extensive direct-memory access (DMA) facilities, and it has a software driver under VMS, the VAX operating system. As will be seen in Fig. 1, the serial highway from the VAX 11/750 controls the CAMAC crates in which are mounted the LSI 11/23 microprocessors. One component of the LSI 11/23 system is a module that gives CAMAC access to the Q-bus of the LSI 11/23. It is this module and the DMA facilities of the CAMAC driver that allow the VAX 11/750 to keep data bases up to date with minimum VAX software overhead and almost no LSI 11/23 software overhead. Both processors also are able to interrupt the other by CAMAC Look-at-Me (LAM) interrupts.

There are five such LSI 11/23's planned, including one for development, and each will have a serial

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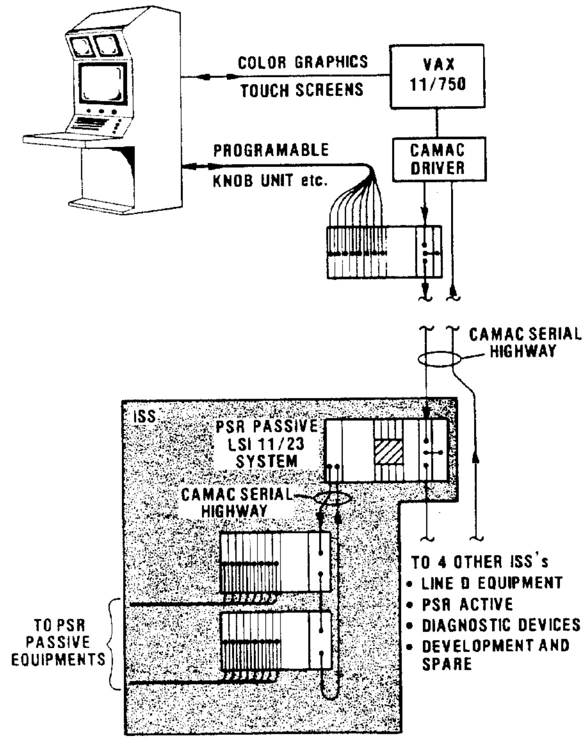

Fig. 1. Hardware of the PSR control system.

highway of its own to connect its CAMAC crates. These crates hold the CAMAC plug ins that connect to the equipment of the designated area for the LSI 11/23. A watch-dog system in each LSI 11/23 crate will ensure that if any fault occurs in the LSI 11/23, the run permit for the PSR will be dropped within 1 s. The LSI 11/23 and its associated CAMAC system is termed an Instrumentation Sub-system (ISS); the PSR Passive ISS is the shaded area in Fig. 1.

Data in the System

In the control system, data exist in one of four forms. Binary data are used to represent two valued inputs and outputs, such as on or off. Analogue integer data represent I/O values that are covered by an integer in the range -32 000 to +32 000. Analogue real data are used for all other single-valued channels. Finally, analogue vector channels are used where an array of integers is required, for example to specify a waveform. Each of these forms can be in a number of different types:

- Interface units--the value in primary SI units at the front panel of the CAMAC or IEEE 488 unit.
- Hardware units--the bit pattern read or written across the I/O bus.
- I/O units--hardware units modified to a legal PDP/11 and VAX/11 data type (the form in which data are stored in the run-time data base).
- Engineering units--value in meaningful units to an operator; for example, pounds per square inch, amperes, degrees Celsius.
- Physics units--value in meaningful units to a physicist; for example, tesla.
- Process units--high-level units that cannot directly translate to a single I/O channel; for example, tune.

Not shown, on the diagram of the software that follows, is that the conversion between I/O units and engineering or physics units is carried out by a conversion module. This module has coded into it the various required algorithms and has access to the run-time data base to obtain the parameters needed for each conversion.

Detailed Software Description

The overall software has been broken down into a number of modules, each of which has a well-defined function and a clear interface to the rest of the system. In fact, the modularity of the software reflects that of the hardware, allowing ease and flexibility in making changes. The modules are defined so that:

- one or more modules make up a program or task;
- ideally, each module should be less than one month's work to code and test; and
- the intermodule interface is chosen to isolate future changes.

The first step was to isolate in a single data base all information that relates to the individual equipment and its associated channels. The information in this data base is held in an ASCII file established and maintained using a DEC product, DATATRIEVE. DATATRIEVE allows easy maintenance of a data base and easy-to-use sorting of the data and report writing.

From this data base is generated a machine efficient run-time Control (COOL) data base. It is this data base that exists in main memory of the VAX 11/750 and the LSI 11/23's, and which the programs reference. As an example, the address of a CAMAC plug in will take several ASCII characters in separate fields in the ASCII data base from which the run-time data-base generation program will produce packed binary addresses. The format of the packed address will be defined by the CAMAC coupler, so that it can be directly used at run-time. The run-time data base generation also will produce any data tables required by individual programs or tasks. Thus the generation of a new data base will at least mean relinking much of the system.

Figure 2 shows schematically the system's software layers. Generally, the LSI 11/23's act as intelligent I/O controllers to the VAX 11/750, enabling the VAX 11/750 to carry out operator-requested functions.

At the center of the VAX 11/750 software is the COOL data base that is referenced through access routines to isolate the detailed structure of the data base. On top of the access routines come all the other modules of the system.

The Command Module is responsible for the interaction with the operator to assign knobs or start specific operator-interaction programs. It is also responsible for keeping track of console resources. This is the module that comes up first at the console when the system is started.

The Knob Module is responsible for accepting knob assignments, taking knob input, and making the corresponding changes in the COOL data base. It also maintains the one-line display on the knob unit.

The Alarm Module is responsible for maintaining the alarm screen and the log of significant events. Each channel, soft or hard, will have three sets of limits associated with it. Warning and alarm limits are self-explanatory, but the log-by-exception limits are less clear. These define a delta so that when an input channel is more than this delta from its last logged value, the new value is logged with the time and date. For control channels, these data are maximum range, normal range, and maximum rate of change.

The Data Migrator ensures that the varying data and the flags that indicate changes are kept current between the VAX 11/750 and the individual LSI 11/23's. For this the CAMAC system is used as described above.

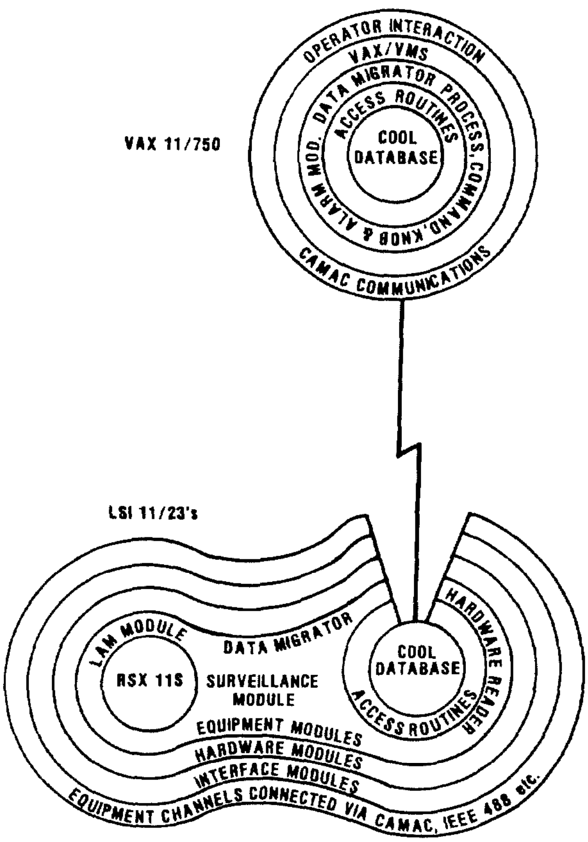

Fig. 2. Software layers of the PSR control system.

Although all these modules are single modules, the Process Modules are many and varied. It is here that the expansion takes place, and the system is tailored to the particular needs of the tuning of the PSR. Selected Process Modules are started by the Command Module on the request of the operator. The running Process Modules have full access to the graphics devices on the console and the COOL data base, which includes the last inputs from the touch screens. Thus they have full information on the state of the PSR and full control of the PSR equipment. It is in the Process Modules that the flexibility of the system exists.

The next layer of the software is the operating system, VAX/VMS, through which goes all communication with the real world. For this purpose, VAX/VMS includes the I/O drivers added for CAMAC and the Lexidata color-graphics system.

Finally comes the Operator Interaction and CAMAC communications layer, which represents the main functions of the VAX 11/750.

There are two fundamental differences between the VAX 11/750 software layout and the LSI 11/23 software layout. The first is that the RSX 11S operating system is used only for task management and not for I/O management. This gives rise to the double-centered representation of the software. The second difference is that, as shown, the VAX 11/750 has direct access to the LSI 11/23 COOL data base. This is a simplification in some respects, because the VAX 11/750 Data Migrator has control access to the Data Migrator in the LSI 11/23 to ensure that the LSI 11/23 takes action on the changed data.

Input channels are handled differently from output channels by the ISS. Two software modules, the LAM Module and the Hardware Reader, are responsible for ensuring that the COOL data base input-channel data in the ISS are up to date. The LAM Module does this for I/O plug ins that are interrupt or LAM based, whereas the Hardware Reader does the updates on a timed basis. All the other software modules access input data from the COOL data base.

The Surveillance Module is responsible for checking input data against specified limits and reporting exceptions to the Alarm Module in the VAX 11/750 through the COOL data base.

All changes to be made to equipment must be made through an Equipment Module, which is a separate program for each set of equipment. This module can check input channels in the COOL data base and apply the change in a manner specific to that equipment. This allows checks to be programmed into the system to ensure safe and correct operation. The Equipment Module also implements soft channels. These channels do not directly relate to a single hardware channel, but to two or more channels in a specific way. A simple example might be the on-off control of an equipment where a single soft on-off channel might be translated by the equipment module into a pulse output on one of two binary output channels.

All access to the I/O plug ins by the LSI 11/23's is through the Hardware Modules and the Interface Modules. These modules are designed to hide the differences between, for example, I/O plug ins of similar function but different detailed design. Thus the code in an Equipment Module need only reflect the type of I/O not the details of the actual I/O plug in used. The Hardware Module also has no need to know the details of how the I/O bus is connected to the computer, but rather it issues calls in terms of the I/O bus (CAMAC, IEEE 488 etc.) to the Interface Module that localizes the code reflecting the actual connection of these buses. To illustrate: if a pair of wires bringing a 0- to 10-V signal to a CAMAC plug in were to be moved to a similar IEEE 488 unit, all that need be changed is the run-time data base.

Conclusion

We have presented the basic design philosopy of the new PSR control system, which is now being coded and tested. We claim to have developed a sound, economic design and implementation for the PSR control system using commercial products wherever possible.

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