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CONTROL SYSTEM FOR THE NEUTRON THERAPY FACILITY AT FERMILAB

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Abstract

A new real time control and calibration system has been installed at the Fermilab Neutron Therapy Facility. An IBM-PC/AT user console is networked to the VMEbus-based front-end computers using a Token Ring local area network. Two 68000-based single board computers are used in the front end station to isolate the time-critical dose measurement and accumulation tasks from the network functions. The system is fabricated from commercially available computer, memory and data acquisition cards.

Software in the front end processors is written in assembly language, but application programs for the IBM-PC/AT are written in Turbo Pascal. Chamber calibration, beam calibration and patient dose delivery functions are all controlled through the IBM-PC/AT by the radiation therapists. Records of each treatment are printed automatically after the prescribed dose is delivered.

Introduction

The Fermilab Neutron Therapy Facility (NTF) has been in operation since 1976. The original computer control system used an 8-bit MC6800-based processor[1]. This paper describes the recently installed control system based on VMEbus-68000 front end computers connected by a Token Ring local area network to an IBM-PC/AT console. The IBM computer provides all the console and operator interface functions needed for the treatment facility. For ease of maintenance, the majority of the system is assembled from commercially available equipment and the IBM software is written in Turbo Pascal. Safety considerations for such a system and operating experience are discussed.

System Architecture

The overall design of this system, shown in Figure 1, is the same as the architecture found in modern accelerator control systems: a workstation-based console connected by a proven and reliable commercial local area network standard to VMEbus-based front-end processors that interface to the accelerator hardware. In this design, the workstation is an IBM-PC/AT, the network is the IEEE-802.5 Token Ring standard, and because it is small system, only one VMEbus front-end chassis is needed. For safety reasons, there are only two nodes on the network during treatment. The VMEbus node contains two 68000 processors: a Local Control Station and a Beamline Coprocessor. Functions performed by the three computers are given below.

Therapist's Console

The console provides the operator interface to the NTF control system. All application programs reside on and are executed in the IBM-PC/AT. These programs include the facility calibration, patient treatment, and dose distribution measurement programs. Before starting a treatment, the therapist uses the console to input patient data and parameters for the treatment. Some of these parameters, such as dose limits, are sent to the 68000 systems. During patient treatment the console provides the therapist with information about the progress of the treatment, though actual control of the beam resides with the Beamline Coprocessor.

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VMEbus Systems

The Beamline Coprocessor reads analog and digital status from the facility hardware for its own use and also for use by the Local Station. When conditions are appropriate for beam, the Coprocessor outputs a 'Computer Enable' signal to the hard-wired interlock chassis. During a treatment, the Beamline system monitors the delivered dose and removes its Computer Enable signal when the prescribed dose is reached. Several other conditions monitored by this station will also terminate the radiation in a way that requires operator intervention to proceed.

The Local Station processor provides the communication path between the IBM Console and the Beamline Coprocessor. Its hardware and software are the same as the local control stations used for distributed accelerator control at Fermilab.[2] It has the ability to monitor and control a local group of hardware, provide alarm scanning and reporting, and support a local control console. Communication between this system and the Beamline Coprocessor is by way of shared memory message queues.

The Local Station—Coprocessor arrangement allows the dedicated Coprocessor to monitor the progress of the treatment without needing to service network communication. All software for this processor is contained in PROM. The Local Station, in addition to handling communication, controls experimental equipment such as positioning tables used for measuring dose distribution in a phantom. Note that parameters controlled by the Coprocessor are not directly accessible to the Local Station because they are not global VMEbus memory or I/O. RAM variables, such as maximum dose of this treatment, are kept in private RAM on the Coprocessor CPU board. External I/O makes use of Motorola's I/O Channel that is driven by the Coprocessor CPU card itself. Because of this organization, an external computer cannot inadvertently change sensitive parameters controlled by the Coprocessor. Requests to change Coprocessor settings must pass through the shared RAM queue and be processed by the Coprocessor.

Hardware

All processors in this system operate synchronously with the 15 Hz repetition rate of the Fermilab Linac. Most of the tasks performed by the three computers in this system are executed at 15 Hz. Figure 2 shows the VMEbus crate and the complement of cards used to implement this system. The Beamline Coprocessor and the Local Station each use a Motorola MVME-110 CPU card and a Fermilab-designed Crate Utility Card. This card accepts external interrupts, supports a small local console, and contains diagnostic LEDs, system timers, a watchdog timer, and two 8-bit digital I/O ports.

Beamline Coprocessor

The Coprocessor system includes a CPU card, a Crate Utility card and several Motorola MVME-410 digital I/O modules that are controlled by a Motorola I/O Channel, an 8-bit master-slave bus driven by the MVME-110 CPU card using the VMEbus P2 connector. The use of this bus makes the Coprocessor's I/O inaccessible to the Local Station processor. Signals read by the Coprocessor allow it to monitor the operation of the facility and the progress of the treatment. Data acquired or developed by the Coprocessor are stored in the shared non-volatile RAM for use by the Local Station CPU. The FIFO card shown in Figure 2 is a connection to the control system of the Fermilab Linac.

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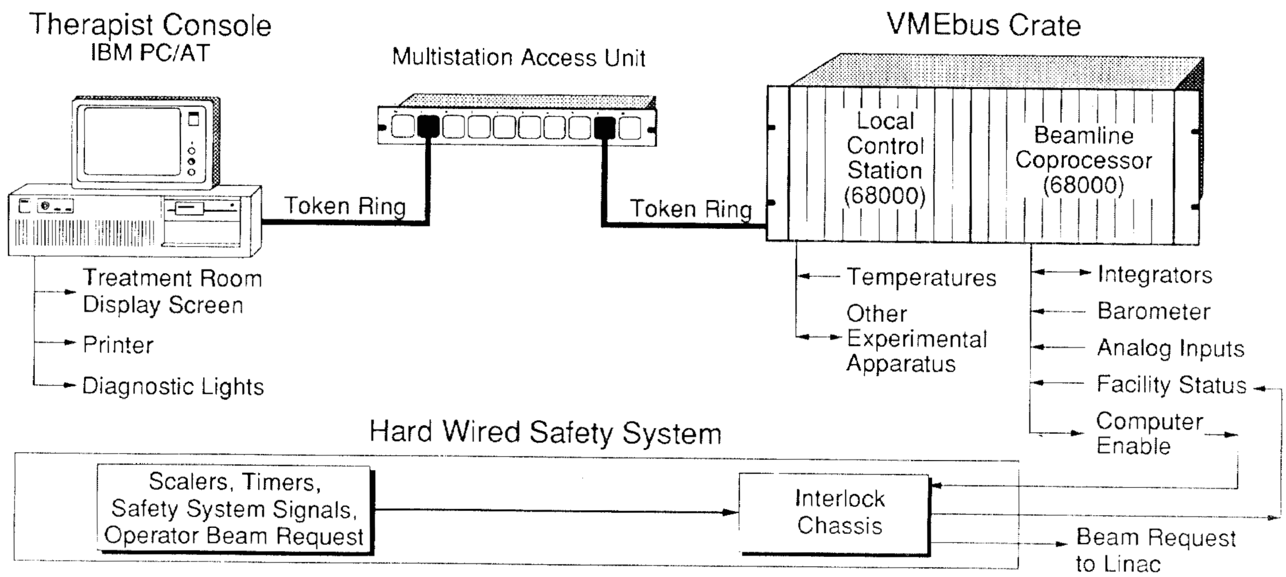

Figure 1: Overall system architecture for Neutron Therapy Facility control system.

The Coprocessor functions as an embedded controller that performs a well-defined group of tasks and its PROM-based software is seldom changed.

Local Station

A more complete description of the Local Station is given in Reference [2]. For the Neutron Therapy Facility, the Local Station provides the support for the Token Ring Network and handles the communication with the Coprocessor. This system reads facility temperatures, needed by the console computer, and controls stepping motors used for dose distribution studies. The flexibility of the Local Station makes it possible to incorporate other experimental equipment into the facility without affecting the more critical Coprocessor.

Therapist's Console

The therapist's console is a standard IBM-PC/AT computer that only connects to the rest of the system by the Token Ring. This makes replacement easy in case of a computer failure. All the software necessary for treatment will fit on a single 1.2 MB floppy disk. The parallel port is used to automatically print out a hard copy record of each treatment and a serial port drives an oversized alphanumeric display in the treatment room that shows the patient data, chair angles, and collimator position. This information is used by the radiation therapist during patient setup.

Software

Console software

Console software consists of application programs that allow the therapist to control and monitor the treatment and system routines that are called by all application programs. System routines include keyboard and screen handling software and the Token Ring driver.

System Software: The system software is in precompiled Turbo Pascal units. The network unit handles the interface between the IBM-supplied Token Ring device drivers and the Pascal environment. It contains procedures to get onto the network, set parameters, receive alarms, and request data from the Local Control Station. This unit contains software applicable to any IBM-PC using Pascal and a Token Ring communication system. It has, in fact, been incorporated into other data acquisition systems at Fermilab.

Procedures for keyboard input and a screen oriented user interface are organized in a second unit. The user interface has fields on the screen that are used for entering or displaying text, numerical values, and binary status data.

Application Programs: The application programs use the general system software to perform tasks that are specific to neutron therapy treatment. Each of the application programs has a similar structure. They are all data-driven, real-time programs that display pertinent information to the operator at 15 Hz. They also send the therapist's requests to the Local Control Station. Each application initiates requests for data from the Local Station. The Local Station continues to send the requested data back to the console every 15 Hz cycle until the console cancels the request.

Two of the application programs are used to control the calibration procedures that are performed each day before the beam is used to treat patients. In the first procedure the chamber factor is measured by determining the amount of charge collected by a spherical ionization chamber when it is exposed to a cesium source of known activity. Nine measurements are made under computer control and the temperature-pressure corrected chamber factor is calculated and written to a file. In the second procedure the spherical chamber is exposed to the neutron beam at the treatment isocenter. Under computer control the charge collected in this chamber is related to the charge collected by a parallel-plate ionization chamber permanently mounted in the neutron beam just downstream of the production target. The average of several runs is used to calculate a multiplicative factor relating signal in the parallel-plate chamber to absorbed dose at 10 cm depth in a tissue-equivalent phantom.

The third application program calculates the parallel-plate chamber signal corresponding to the requested dose for a specific clinical setup. The magnitude of this temperature-pressure corrected signal is sent to the Beamline Coprocessor via the Local Control Station. As treatment proceeds under control of the Beamline Coprocessor this application program displays status information with respect to the delivered dose, critical magnet currents, and other safety-related ratios.

A fourth application program is used for beam studies and allows the operator to remotely position an ionization chamber in a liquid phantom for the systematic measurement of central axis depth doses and off-axis ratios. The ability to perform these measurements easily allows for good quality control and makes it possible to look for long-term changes in the beam.

Local Station Software

The Local Station software supports a general purpose distributed control system station. The original implementation of this system was installed in 1982 for the upgrade of the Linac control system.

The system has evolved since that time and has been used to support standalone test stations and as a component in a network of control stations. It supports a suite of local console application program displays useful for diagnostics and system configuration. It also fulfills data requests from the network and emits alarm messages about its local devices. The local database defines the detailed nature of the station's devices and interfaces.

The system software provides a path to other CPU coprocessor cards in the same VMEbus crate. A device-setting message received from the network can result in a message passed via a shared memory queue to a coprocessor. The host that sent the message need not be aware that the device is supported by the coprocessor. The local station's database contains the necessary parameters for composing the message to the coprocessor.

In the NTF system, data sent to the Beamline Coprocessor are passed through the message queue. Data received from the Coprocessor are made available to the Local Station via shared memory, from which they are copied into the Local Station's datapool. Requests for Coprocessor-based device data can therefore be handled in the same way as data requests for device data read directly by the Local Station.

Beamline Coprocessor Software

The dedicated Beamline Coprocessor is designed to support the particular needs of the NTF beam delivery hardware. It monitors the currents of the bending magnets that steer the beam around a 90° bend into the neutron-production target as well as supply voltages of the A/D that is used to read the ion chambers. It accumulates the proton beam charge delivered to the target and the ion chamber readings for the neutron flux. It calculates the ratio of neutrons produced to the protons impinging on the target, as well as the neutron detection efficiency. It monitors beam quality to ensure reasonable transmission through the bending magnets. When anomalous conditions are detected or the prescribed dose limit is reached, the Beamline Coprocessor system inhibits further delivery of Linac beam.

The Beamline Coprocessor also supplies copies of its data to the Linac control system, which resides on a separate network, so that NTF operation can be monitored by the Main Control Room. A separate diagnostic display is also provided so the programmer can diagnose the internal health of the system. It is seldom used.

Safety Considerations

The Fermilab Neutron Therapy Facility has never considered computers to be part of the safety system. One cannot guarantee that an operating processor will never fail, and if a failure occurs, it could occur at any point in the execution of a program, leaving the system in an unknown state. Even the action of a 'heartbeat' style watchdog timer reset cannot make a system completely fail-safe, because, for example, the failure of a simple bus transceiver chip can keep the system from clearing a Beam Enable signal previously set by the system.

Safety is handled by hardwired systems designed so that unsafe conditions will disallow sending beam to the facility. An interlock chassis receives status from facility equipment to determine when the facility is ready for beam. Door interlock, power supply status, and operator beam requests are all included as inputs along with beam permits and watchdog timer inputs from the Coprocessor. The output from this chassis is a Beam Request signal that is sent to the Linac. Any input signal can negate this signal, and some conditions latch so that manual operator intervention is required to continue treatment.

A second group of hardware is designed to terminate a treatment if the Coprocessor fails to do so. The prescribed dose of each treatment is converted to 'scaler units' to be entered in hardware preset scalers by the therapist before treatment begins. The outputs of ionization chambers are converted to serial pulse trains that are counted by the scalers. If the preset dose is exceeded, the treatment will terminate. In a similar fashion, the expected treatment time is calculated and set into a timer by the therapist. If this time is exceeded, the treatment terminates.

The hardware system described above is used as a backup. For normal operation the delivered dose is measured and accumulated by the Coprocessor, and the Coprocessor terminates the treatment when the required dose is reached. Anomalous conditions detected by the Coprocessor will also terminate treatment.

In defense of microprocessor-based system reliability, it should be pointed out that in the 12 years of operation, the radiation therapists have not observed a single instance in which a computer failure resulted in having treatment terminated by the backup systems. The use of Coprocessors makes it possible to easily include many more checks of the equipment and beam quality without additional hardware. The entire facility, its operation, and maintenance are simpler and more reliable.

The flexibility of a Local Area Network brings with it the possibility of other nodes on the network inadvertently changing critical parameters. As shown in Figure 1, the Neutron Therapy network has only two nodes - the IBM/AT and the VMEbus Local Station. The Token Ring multistation access unit is located in a visible place in the operator's control room to insure that no other access to the network is possible.

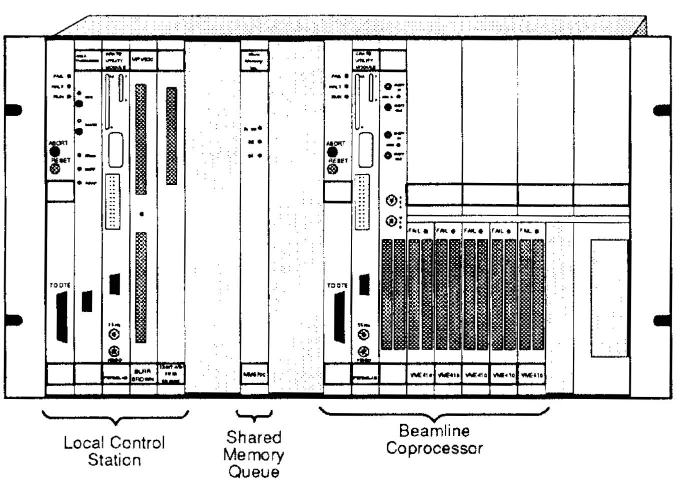

Figure 2: Beamline Coprocessor hardware.

Status and Operating Experience

The VMEbus part of the system described here was installed in 1985, and the IBM console has been in operation since August, 1988. During development of the IBM system, the facility was operated alternately with the old 6800 console and with the IBM console. This allowed a thorough checkout of the new system before it was installed permanently. The entire system has been very reliable and the architecture allows a quick replacement of any component in the case of a failure.

Because of the modularity of the architecture, individual parts of the system can be upgraded independently as needed. For maintenance reasons, the 68000 processor board in the Local Station will soon be replaced with a 68020-based board in order to keep the NTF hardware and software the same as other Local Stations at Fermilab.

References

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[2] M. F. Shea, R. W. Goodwin, M. E. Johnson, R. J. Florian, and A. A. Jones, 'The Dzero Downloading and Control System,' Proceedings of the Europhysics Conference on Control Systems for Experimental Physics, Villars-sur-Ollon, Switzerland, 1987.