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ABSTRACT

Hardware and software developments which permit simultaneous use of a PDP-7 computer for both data-taking and preliminary data analysis are described. The hardware includes a set of remote-control consoles, and a memory-protection system. System programming is not yet complete, but currently operating programs allow concurrent data-taking from as many as four remote stations, with versatile CRT display, graph plotting, storage on both IBM-compatible and micromagnetic tape, and printout on an electric typewriter. A third-order polynomial background-fitting routine has also been written, mainly as a demonstration of the capabilities of the system, since most data analysis should be carried out with the CDC-6600 facility at the main computer center. Work has also been done to simplify the preparation of future machine-language programs for the PDP-7.

INTRODUCTION

This report describes an on-line computer system designed for use in pulse-height-analysis experiments. A number of hardware features and program procedures have been implemented so that the rather expensive machine and its powerful peripheral equipment (total cost ≈ $100 000) can be conveniently shared by several experimenters at locations remote from the computer. The initial hardware-development program has been completed, and preliminary data-taking programs are in use, but it is already clear that development work of both hardware and software is likely to continue indefinitely as new applications are found for the machine.

Two identical systems, each using a PDP-7 computer with 8192 words of memory, have been built. These systems were designed mainly for data taking in nuclear-spectroscopy experiments. We expect that most data reduction will be done with the nearby CDC-6600 computers. The hardware has been designed to allow simultaneous data-taking by as many as eight independent experimenters using eight separate pulse-height encoders that share the computer's memory. Hardware-memory protection has been provided so that a user's program and data can affect only the part of the memory assigned to him. The limitation of an 8192-word memory makes it probable, however, that no more than three or four experimenters will use the machine at any one time.

A preliminary programming system has been developed to facilitate hardware check-out. (A more comprehensive programming system is being prepared by the LRL Math and Computing Group--that system will not be described here.) The preliminary system contains basic routines for data handling, CRT (Cathode-ray tube) display, graph plotting, and printout, plus facilities to allow remote control of the computer from several experimental areas. Remote CRT displays are provided at these areas. This program system allows a rudimentary form of time-sharing among four users, so that each user can start and stop data-taking into his assigned area of computer memory, preset his counting time, store and recall data from magnetic tape, and control the CRT display from his remote station. Additional operations such as data printout, graph plotting, on-line gain stabilization of a pulse amplifier, and fitting of third-order polynomial background curves can be done by this program for any user's data without affecting data acquisition of other users who are concurrently taking data. This program has several versions, and uses between 1000_{10} and 2500_{10} words of memory, with the actual number depending on which features are included.

HARDWARE

Both PDP-7 computers when purchased had 8192 words of memory, hardware multiply-divide, micromagnetic tape (DEC-Tape), CRT control, and a real-time clock. Figure 1 shows the data-taking system. A toggle switch, which starts the computer and then causes a short (16-word) bootstrap program to be read into core via data-break, has been added to the machines since purchase. The bootstrap program dumps a longer program into core from micro-tape, and this program in turn loads the library system.

Normal operation, therefore, is completely divorced from paper tape.

For low initial costs, CalComp plotters and magnetic tape transports (Ampex TM-7 IBM-compatible) were purchased and interfaced to each PDP-7. In addition, a high-speed analog-to-digital converter (30 microseconds to encode with 12 bit or 4096 channel precision) suitable for pulse-height analysis[1] was designed and built at Berkeley. To match experimental resolution, flexible hardware associated with each ADC (analog-to-digital converter) allows the number of channels to be reduced by the experimenter. Several of these ADC units are interfaced to the computer via a multiplexer, which is in turn muliplexed to the computer's direct memory or "data-break" input channel. This ADC interface allows a word in the computer memory, corresponding to the code from any of the connected ADC's, to be incremented in one memory cycle when the computer is used for pulse-height analysis. This input mode operates completely outside of program control, except for the ADC count-on, count-off controls. The ADC has also been interfaced to an extension of the PDP-7 information collector, to allow acquisition of pulse-height data under full program control, for multiparameter analysis.

Great care has been taken to ensure that no standard PDP-7 program or diagnostic test is affected by the modifications and additions to the computer's hardware; thus continued use of the basic machine debugging routines supplied by the manufacturer is permitted.

REMOTE CONSOLES

The experimenter doing pulse-height analysis with the computer must be able to control his data-taking from the site of his experimental equipment, because most experiments are situated beyond sight or hearing from the computer. Control could be done with a remote typewriter, but for the CRT display needed in pulse-height analysis, typewriter control is very inadequate.

Special switch-panel remote consoles have been interfaced to the computer program and are labeled on the panel and decoded by the program in such a way that the user can get the same response on his computer display as he would with a conventional pulse-height analyzer display. (Of course, a much greater variety of operations can be selected when the computer system is used.)

Figure 2 is a photograph of one of the remote consoles. They require very little hardware, operating entirely under program control. The console to be interrogated is selected by loading a bit (1-8 for consoles 1-8) in the accumulator; a status test then loads the switch codes from the selected console into bits 9-17 of the accumulator. Bit ϕ of the accumulator can be used to select a second 9-bit bank of switches in the same console. This scheme uses only a few gates and line drivers, plus a single 9-bit information collector input to the computer, to interrogate eight remote consoles.

TIME-SHARING AND MEMORY PROTECTION

The time-sharing and memory-protection system was developed for shared use by several experimenters. Some experiments will, of course, require the whole system. In such cases, sharing means simply that the machine will be allocated to different users at different hours or on different days. However, many lengthy counting experiments need only a small amount of supervision from the computer, and will use only a fraction of the computer's memory. It seems reasonable that several such experiments will use the computer simultaneously. In order to give security to each of the users in this "time-shared" mode, special memory-protection circuitry was added to the computer.

The memory-protection circuits guard against two types of interference between users. Program instructions that go outside a defined area of memory are trapped by the program-interrupt system. Pulse-height codes entering the computer from the ADC's via the "data-break" facility are tested by the protection circuitry and can cause words in memory to be incremented only if the computer address produced in the ADC code falls within the area assigned to the ADC that originated the pulse-height code.

The memory-protection box holds 10 groups of toggle switches that determine the boundary addresses of 9 memory fields. These fields are selected in 256-word segments. The boundary switches determine the areas into which pulse-height data can be loaded and the areas in which programs can run with memory protection.

The memory protection for programmed operation makes use of the "trap" facility of the PDP-7. Instructions that try to access illegal addresses are trapped in the same way that illegal halts and illegal input-output instructions are trapped in all PDP-7 computers. An instruction trapped by memory protection is executed as a PDP-7 "CAL" instruction before the trap operates, so that it leaves a unique "signature," differing from normal input-output trap operation.

PROGRAMMING

It has been a sizeable task to develop programs for complete hardware checkout and for data taking in the interval between completion of the hardware and completion of the time-sharing program being written by the Math and Computing group. Efficiency in use of memory is of the utmost importance, since each ADC is capable of using as many as 4096 words of memory just for data, and only 8192 words of memory are available. (Clearly, it is impossible for even two ADC's to operate simultaneously with full 4096-channel resolution, since even a minimum program needs a few hundred words of memory.) The memory limitation forces the use of machine language programming for most experiments, certainly for all time-shared experiments. The use of Fortran programming has to be restricted to times when a single experimenter has command of the machine and when a very limited data-storage area is needed.

The programs described here have been prepared as small, virtually independent subroutines. We have developed a method to allow convenient assembly of a number of these subroutines for special-purpose programs. The subroutines fall into two categories: First, there are a number of basic routines for control, CRT display, interrupt service, and clock, needed for even the simplest data-taking operations. These routines can easily be reduced to fewer than 1000 words even with some elementary time-sharing facilities included. Second, a much larger number of optional routines are needed for operations such as graph plotting, storage on and retrieval from magnetic tape, data typeout, control of special experimental hardware, and arithmetic calculations necessary for on-line data analysis.

The memory space needed for these options is large, since many special routines will be needed by different experimenters. In order to efficiently use the available memory space, only the routines actually in use should be in computer memory at any one time. We can use memory space more efficiently by designing procedures that allow the necessary subroutines to be loaded into the main magnetic-core memory of the computer from micro-tape only when actually needed. Thus, an experimenter could use his assigned area of memory either for data or for a data-reduction program, storing his data on magnetic tape before replacing it in the memory with his data-reduction program. A program system to allow this mode of operation is being developed by the Math and Computing Group at Berkeley. That system will allow relocatable loading of subroutines into core memory from DEC-Tape, and will allow assembly of programs for the PDP-7 by means of an assembler written for the CDC-6600 computer.[1]

An interim program between the paper tape system and the 6600 system has been developed and is now in use on both PDP-7 systems. This system allows rapid assembly of a large program from a list of standard subroutines written in symbolic machine language and stored on DEC-Tape. A very important advantage of this system is that a program of about 2500 words can be assembled in less than 10 minutes on the PDP-7 in a form that can be debugged at the symbolic language level by means of the standard Digital DDT program supplied by the manufacturer. Debugging requires much of the total programming time, and must be done with the computer. The ability to use symbolic language for debugging is extremely helpful, especially to the technician or engineer who wishes to use the machine.

This interim programming system uses modified versions of the standard DEC paper-tape editor and extended symbolic assembler for the PDP-7. Changes were made so that the storage medium for the editor could be DEC-Tape, and also so that the assembler could accept symbolic language input from DEC-Tape and still produce paper-tape output. A hundred or more 150-line symbolic language subroutines can be stored on one DEC-Tape and recalled by name either with the editor or assembler. The modified versions of both the assembler and editor use exactly the same format as the original paper-tape versions, and the modified assembler has a paper-tape output format that facilitates use of the DEC DDT degugging program.

AUTOMATIC PROGRAM ASSEMBLY

A special feature of the DEC-Tape version of the assembler is its ability to automatically assemble a list of subroutines. Thus, to prepare a new program from the symbolic language subroutines on the magnetic tape, it is necessary to store only a master list of the required subroutines on the tape. Given the name of such a master list, the assembler will find each required subroutine in turn and punch out a single binary paper tape of the whole program.

With the automatic-program assembler, it has been relatively easy to prepare a number of special combinations of the currently available data-handling routines. Special combinations of these subroutines currently in use include programs for multiparameter data-taking, multiparameter data-sorting off-line, time-shared single parameter data-taking, and a program for data-taking with third-order polynomial background fitting.

AN OPERATING SYSTEM

As an illustration of the operation of the equipment, we briefly describe one currently operating experiment. (It is important to realize that many of the sequencing and control operations of the program for this experiment can be changed in a few minutes at the symbolic language level by means of DDT without reassembly.) The program uses about 2400 words of memory. In the experiment, low-temperature nuclear alignment is studied in a magnetic field, where the degree of alignment is determined by the change in the ratio of counts under a selected peak in the energy spectrum by two detectors set at right angles to each other. The program and computer hardware would allow additional pulse-height analysis experiments to be run simultaneously, but until now only one experimenter has used the equipment at any one time.

The experimenter starts and stops counting, erases memory, or starts a graphical plot by turning his console FUNCTION switch to the appropriate position and pressing the "COMMAND" button (see Fig. 2). He has chosen to use a console near the computer, since some of his special analysis routines currently require inputs from the computer typewriter. (The remote console could readily supply these inputs if the program were modified.)

First, an amplifier gain-stabilization routine is initialized. A marker is caused to appear on the oscilloscope by depressing the toggle switch marked CREATE. This marker is moved along the display, under toggle switch control, to one edge of a peak in the spectrum whose position is to be held stable. Then a second marker is generated by pressing CREATE again. This marker is placed at the other edge of the peak. (Alternatively, the markers could have been inserted from the teletype.) Now the experimenter types G, then strikes the "ALT MODE" key on the teletype. Henceforward, the program will test for any change in the balance of counts around the center of the peak defined by the two markers. If the balance changes, a pulse is generated to servo an amplifier gain at the site of the experiment in a direction to rebalance the counting rate around the peak center.

Next, the experimenter may remove the CRT markers by pressing REMOVE on the console. (The gain stabilizer program has already stored the positions.)

The preset counting time is now entered by turning the FUNCTION switch to A, and pressing COMMAND. The counting time selected is determined by the position of the SCALE switches. (Special labels on the control console switches can be used to avoid confusion.) Alternatively, the preset counting time can be entered on the typewriter in tenths of a second, followed by typing T, then the ALT MODE key.

Data taking is started by turning the FUNCTION switch to START COUNT, and pressing COMMAND. The ADC ON light on that remote console remains on while counting continues. At the end of the preset counting time, the teletype bell rings and counting stops. Both start and stop are synchronized to the 60-cycle clock. The data can now be ordered to be saved on DEC-tape, or IBM-compatible tape, by typing either Z or S, along with a run number and identifying information. (The bell ringing at the end of data-taking could be replaced by a call to a subroutine providing automatic storage, memory erase, and restart of data taking, but the experimenter prefers manual operation at present.)

This experiment required immediate data analysis, which can be done at the end of each run or after several runs are stored on DEC-Tape. It is feasible to recall a run from magnetic tape into an unused area of memory and proceed with the analysis while the next run is going on. The analysis program fits a background curve by means of a third-order polynomial approximation and types out the total counts under a peak, the background counts, and the difference. This can be done for a number of peaks in each run.

Since memory space is limited, the third-order polynomial program has been written to use only about 200 words of memory at the cost of several seconds of computing time.

The analysis is carried out by setting six CRT markers on the data spectrum, two on each side of the peak to determine the background and one on each side to define the peak limits. As many as eight sets of six markers can be saved by typing nM and ALT MODE followed by six numbers from 0 to 31, which indicate how many channels should be averaged in calculating the background; n is a number 0 to 7, which indicates which set of markers is to be stored. (This procedure can readily be adapted for control from a remote console for time-shared use.).

To analyze peak number n, one types nL ALT MODE. The CRT display is discontinued during the background calculating, but data taking and timing are unaffected. After a few seconds, the display reappears, along with a display of the computed background, and the peak area is typed out. Several such calculations can be started automatically by typing nA ALT MODE, where n is 8 or less and indicates how many peaks are to be analyzed.

The pulse-height data can, of course, either be typed out or plotted graphically while data taking goes on, and can be recalled from DEC-tape at any later time for more analysis, or data can be transferred to IBM-compatible tape for analysis at the main computer center.

CONCLUSIONS AND PROSPECTS

The computer systems described in this report are currently operational, and are being used regularly in single-and multi-parameter pulse-height analysis experiments. The hardware has been proven reliable, except for some bad solder connections in the central processor. Although interim programs are in operation considerable system programming is still needed to provide best use of the equipment.

The most severe hardware problem is the extremely limited memory size. Current plans call for the addition of another 8192-word peripheral random-access memory to each computer to help alleviate this problem.

No single solution to the programming problem is yet in sight. The expected time-sharing monitor program is one essential step, but it is still not clear that graduate students and experimenters will ever want to program the PDP-7 computer. Machine language programming requires special skills that most experimenters are unwilling to acquire, so a higher order programming language is needed. This higher order language could be some sort of translator, similar to Fortran, but with experimental hardwarde control functions, in addition to the arithmetic features of Fortran. The Fortran system now available for the PDP-7 uses more memory space than we can spare. A satisfactory system to translate or compile efficient machine-language programs for data-taking experiments would be an enormous step forward in the use of systems such as this.

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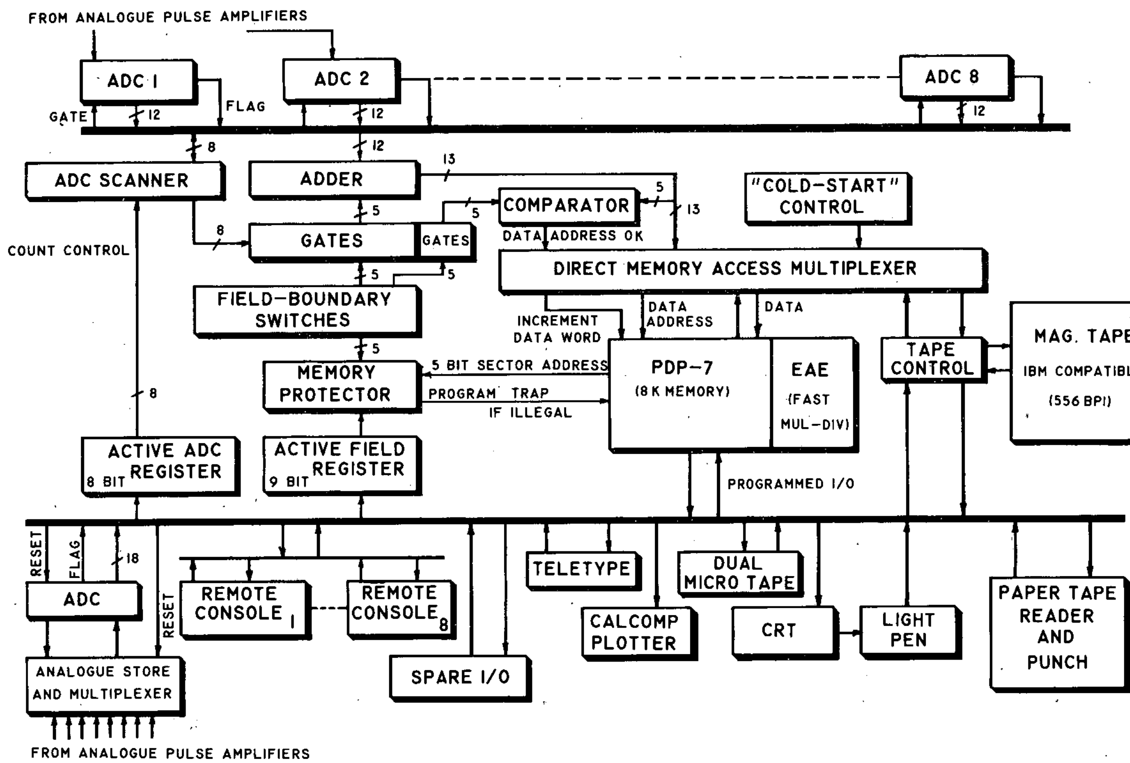

Fig. 1. Block diagram of the PDP-7 data acquisition system.

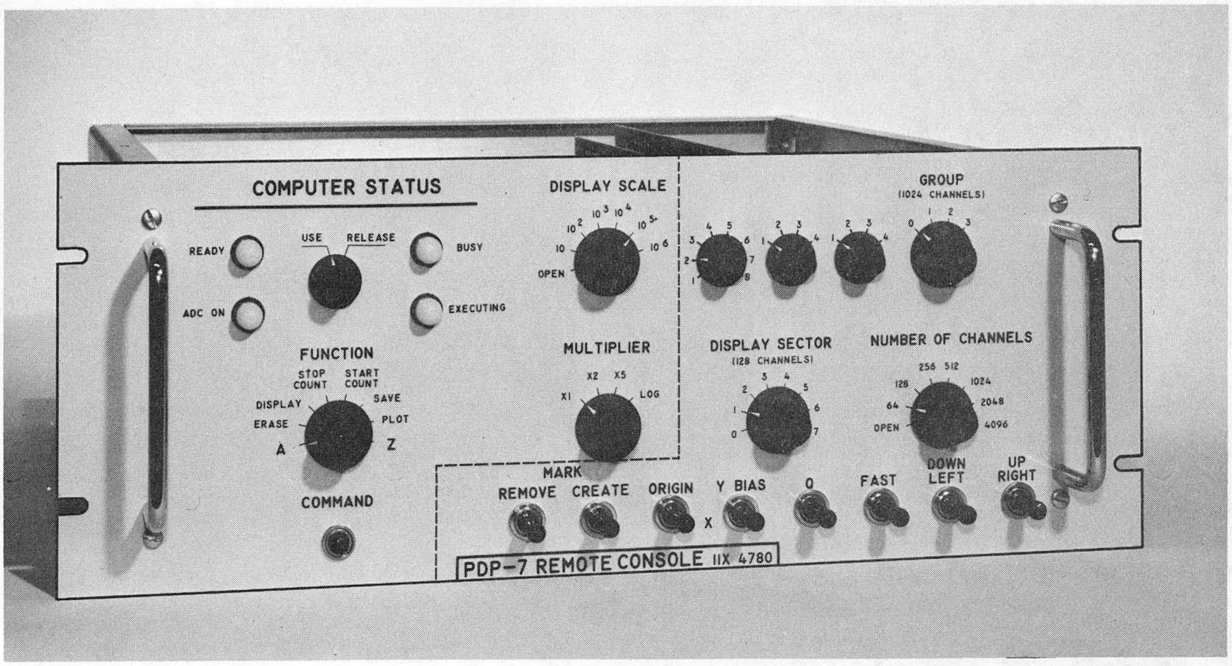

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Fig. 2. A switch panel used for data-taking and control of CRT display in conjuction with the PDP-7 computer. The switch-setting codes can be read into the PDP-7 accumulator under program control, and are used to select branch points in the program. As many as eight of these units can be connected to the system. The lights are used to indicate program status.