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APPLICATIONS OF SMALL COMPUTERS IN NUCLEAR SPECTROSCOPY

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October 15, 1965

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Abstract

Two data-acquisition systems are described; both are built around small digital computers and are designed for use in nuclear spectroscopy experiments. The computers are used for storage of data, graph plotting, control of hardware devices and CRT displays, and for routine arithmetical operations required in the preliminary analysis of experimental data.

Both computer systems can be easily operated by relatively inexperienced personnel. Most routine operations can be controlled with simple multiposition selector switches, although more specialized operations are carried out with a question-and-answer routine on the typewriter. Operations involving CRT display can be initiated with the light pen. With this procedure, routine operation of the computer requires little more training than is needed to operate a pulse-height analyzer.

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1. Introduction

This paper describes two small digital data-acquisition installations, designed to aid in nuclear spectroscopy experiments. One system, designed around a PDP-5 computer (Digital Equipment Corporation) has been in use at the LRL 88-inch cyclotron for almost a year. The second system, still under development, is based on a PDP-7 computer and will be used in beta-gamma spectroscopy and in low-temperature nuclear alignment experiments. This paper describes our experiences with the PDP-5 and our plans for the PDP-7.

Nuclear spectroscopy experiments produce large amounts of data in digital form. Reduction of the data often requires manipulation of large arrays of numbers--by hand and desk calculator or by a digital computer. For example, consider the typical spectrum plotted by the PDP-5 computer and shown in Fig. 1. Alpha particles at 50 MeV have been scattered by a vanadium target and the scattered-particle energy spectrum recorded by a 1000-channel pulse-height analyzer.¹ The noticeable peaks in the spectrum correspond to energy levels excited by the incoming particles.

The data-reduction procedure must provide the exact location and amplitude of these peaks, to enable calculation of energy and cross section of the nuclear reactions. A graphical record is also needed to allow rapid data evaluation and also to allow recognition of any unexpected peaks, which can indicate target contamination, instrument malfunction, or possibly an unexpected nuclear reaction.

An additional requirement is that much of this information must be available within minutes after a run is completed to allow planning for succeeding runs.

2. System Planning

Several alternative data systems designed to meet these requirements were considered. Before the PDP-5 system was acquired, nuclear spectroscopy experiments were carried out with a 4096-channel pulse-height analyzer, whose digital output was recorded photographically and also on punched paper tape. Initial data processing was done by an "on-line" graduate student with a desk calculator. The facilities of the LRL Computer Center were used later to provide

graphical records and detailed analysis. These records were really needed to allow optimum selection of parameters for the experiment, but unfortunately, the results from the Computer Center could not be obtained for several hours, often not until after the experiment was over.

At first we felt that the existing procedure should be continued, but should be improved by adding a few extra pieces of equipment. We considered an all-hardware system, including items such as magnetic tape, X-Y plotter, and some arithmetic circuits to allow simple addition under peaks and subtraction of background. The difficulty with such a system would have been its lack of versatility; new and unforeseen needs would probably have made the machine inadequate almost before the design was complete. Although the component costs for this system would have been fairly low, the engineering effort required would have resulted in total costs approaching that of a small computer. Thus, for economic reasons, consideration was given to the purchase of a small digital computer.

A number of computer-based systems for nuclear-data acquisition have been described.² Most of the arguments in favor of such systems are based on the versatility and flexibility of the computer.

Versatility is of special importance for instrumentation around an accelerator, since it is desirable that the various users of the accelerator should be able to share instrumentation just as they share the accelerator. The consideration of flexibility, coupled with recent sharp drops in the costs of small computers, led to the decision to avoid a special-purpose hardware system and to base our digital-data acquisition and handling on an on-line computer.

3. System Description

A system was designed and built, based on a PDP-5 computer. The system as it now exists is shown schematically in Fig. 2. The basic PDP-5 has a 4096-word, 12-bit-per-word memory. This was increased by an additional 4096 words and the following optional features were purchased:

- Fast multiply-divide hardware
- "DEC-TAPE" (dual micro-tape)
- CRT display
- Light pen
- 60-cps paper-tape punch
- Calcomp digital plotter

In addition, several other devices were interfaced after the machine was installed:

- IBM compatible magnetic tape
- 60-cps paper-tape reader
- 4096-Channel two-dimensional pulse-height analyzer
- 4096-Channel analogue-to-digital converter

- Automatic program loader
- X-axis control for CRT display
- Switch panel for special information

4. Special Features

When a stored-program system is installed, a major source of apprehension is the amount of training needed by the people who will use the machine. It was feared that the mechanics of learning to operate the computer might be troublesome enough to prevent its use or to require a full-time operator. In fact, during the first few weeks of operation, serious problems did arise. Operator errors occurred that would modify a stored program, so that users began to lose confidence in the reliability of their output information. It appeared that a very rigid operating procedure might be necessary.

The problem was overcome by the addition of hardware that allowed automatic loading of programs from the magnetic-tape library. A "call-program" push button (see Fig. 3) is now used to initiate transfer of a "bootstrap-loader" from a diode matrix into the computer memory, via the direct data channel. The bootstrap program loads a longer routine from the library tape. This in turn loads the program selected by a 12-position "program-selector" switch, all in a few seconds. Users now often reload their program before each operation to ensure that initial conditions are always the same.

The use of a rotary switch and push button for control of the computer allows an inexperienced user to make good use of the machine after a few minutes of practice. More sophisticated operators can take advantage of the potentialities of the machine by using the main control console, but the user who merely wants to do a few specific operations can operate the computer just as he would operate a special-purpose hardware system.

Figure 3 is a photograph of the "program selector" unit. In addition to providing for the switch selection of programs, this unit contains the following features:

- (a) Circuits that can generate the X-axis sweep for the CRT display and initiate a program interrupt after a preset number of points have been displayed. These circuits are needed to allow a flicker-free display of a 1024-channel analyzer spectrum.
- (b) Circuits that provide X-axis expansion of the CRT display without computer intervention.
- (c) Switches whose setting can be read by the computer program. These can be used at the discretion of the programmer. Normally, they are used to determine full scale for the

CRT display and graphical plotter. (Data is renormalized by an arithmetic program for display and graph plotting.)

A "light pen" is used to control many of the operations involving the CRT data display. (The light pen is a photosensitive device that sends a pulse to the computer when it detects a brightening on the CRT.) This technique is very convenient, since one can, for example, bracket a peak in a spectrum for special manipulation without knowing any artificial information such as channel number or core-storage location. When the light pen is pointed at the display to mark an area of interest, a marker appears on the display. The location of the marker, stored by the computer, is used as a reference for operations such as summing under peaks and printing out data.

5. System Operation

The computer system is used for most nuclear spectroscopy experiments at the cyclotron for periods ranging from 3 to 5 days a week. The remaining time is used for maintenance, program development, and analysis of data taken in past runs. The system has been quite reliable and has been operational for each scheduled experiment.

In a typical experiment, the experimenter is provided with two magnetic tapes on the dual microtape transport. One tape contains his program library, and the other is used for data storage. Data is collected by the 4096-channel pulse-height analyzer (PHA) in runs lasting from a few minutes to over an hour. Just before a run ends, the experimenter loads a "data-transfer" program into the computer memory, using the automatic loader unit. The data-transfer program obtains the run description by means of a typewriter dialogue with the experimenter. When the run ends, the data is transferred to the computer and stored on the magnetic data tape together with the run description. The data is immediately read back as a check that storage was done correctly; then the PHA is cleared and a new run is started.

While new data is being taken during the next run, the experimenter loads a "data-analyzer" program into the computer memory. This program recalls data from the data tape and displays it on the CRT, where a suitable scale factor is selected for both display and graph plotting (either log or linear ranges can be selected). While the data is being plotted, the experimenter uses the light pen to select areas of interest in the CRT display. The sums of counts under peaks are typed out, together with channel-by-channel information where needed.

When plotting and typeout are complete (5 to 10 minutes later), one of several Fortran programs can be loaded into the computer memory to allow more detailed analysis of the data.

At the end of the experiment, the data tape is kept by the experimenter as the permanent record of the experiment. This tape is brought back to the computer if a second look at any of the data is required. If more complex calculations are required, the data is copied onto an IBM compatible magnetic tape for analysis at the main computer center.

6. Programming

The programs used in this system came from several sources:

- (a) Software provided by the manufacturer.
- (b) Programs written at the LRL Computer Center and assembled with an off-line program written for the IBM 7094.
- (c) Programs written during hardware development and assembled with a magnetic-tape-oriented program for the PDP-5.
- (d) Machine language and Fortran programs written by experimenters and compiled on the PDP-5.

Much of the effort that went into this equipment was devoted to the development of a convenient programming system. The system provided by the manufacturer was paper-tape oriented; in order to be used effectively, it was modified to use magnetic tape. In addition, a program was developed³ that assembles PDP-5 programs off-line with an IBM 7094 computer.

Unfortunately, most of the programs used for the PDP-5 must be written in symbolic machine language. A great need exists for a method of generating short, self-contained machine-language programs by means of Fortran or other high-order language statements. Such a program would add immensely to the versatility of any small computer, but as yet has not been developed.

7. The PDP-7 Pulse-Height Analyzer System

A more ambitious spectroscopy system is now under development for use in beta-gamma spectroscopy and in nuclear-alignment experiments. The 8192-word memory of a PDP-7 computer will be used as the magnetic-core store for as many as 8 analogue-to-digital converters (ADC). Modifications have been made that divide the computer memory into ten fields, each of which is protected from all other fields. If an illegal memory-access instruction, an input-output command, or a halt occurs in a program, the offending program will be interrupted and a monitor or "executive" program will resume control. This executive program, responsible for all input-output operations, will be capable of loading and starting

special machine-language programs in any selected field to manipulate incoming data for purposes such as storage on magnetic tape, CRT display, plotting, and background subtraction. The executive program will also allow time-shared operation of two or more programs in separate memory fields.

In one mode of operation, the system will act as eight independent pulse-height analyzers, the count in any channel being incremented in one 1.75- μ sec memory cycle by the direct-access or "data-break" link. The amount of memory assigned to each ADC will be determined by the setting of "boundary switches" so that the available memory can be allocated to meet changing needs. Multiparameter experiments will also be possible. Since most runs on this system will be quite long, experimenters should be able to share the input-output equipment of the computer. The speed of the machine is such that several input-output devices can easily run concurrently even while ADC data is entering the computer via the data-break.

8. Conclusions

Although the systems described here have not yet utilized fully the capabilities of the small computer, even the present unglamorous work more than justifies the initial costs. The greater sophistication that will come as better programs are written can be regarded as pure profit.

Our experience indicates that the choice between a computer or an all-hardware system should be based on the range of problems likely to be encountered and the manpower available. If the work to be done is fully predictable, a hardware system is probably competitive with a computer-based system. But in a field such as nuclear physics, where progress is continuous and future requirements are unpredictable, the versatility of the computer more than repays the additional expense and planning required for the initial installation. With the addition of a small amount of special-purpose hardware, the computer can do everything that a hardware system will do, as well as many of the tasks that are discovered only after the machine has been purchased.

However, several months of engineering and programming effort will be required before good results are obtained from a computer-based system. If manpower required for this effort is not available, an on-line computer installation may be a disappointing investment.

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FIGURE CAPTIONS

- Fig. 1. A typical 1024-channel pulse-height-analyzer spectrum from the LRL 88-inch cyclotron. (Descriptive information, entered via the typewriter when the data is stored, is drawn on the graph by the digital plotter.) Horizontal axis is channel number. Vertical axis is number of counts.
- Fig. 2. Schematic of the digital-data system at the 88-inch cyclotron.
- Fig. 3. Program selector unit on the data-handling system. (To load a program into the computer memory, the program selector switch is set and the call-program button is pushed. The selected program is automatically loaded from the magnetic-tape library.)

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Fig. 1

DATA PROCESSING SYSTEM AT THE LRL 88" CYCLOTRON

MUB-8425

Fig. 2

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