Some Applications of Small Computers to Optical Spectroscopy

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At Lick Observatory we have begun to use small computers as a basic element of some electronic instrumentation systems. It is felt that computer technology has advanced to the point where the results are likely to repay the investment. In our approach and choice of machine, we have tried to benefit by the experience gained over the past several years by nuclear physicists in nuclear spectroscopy applications.[1]

The major factor involved in choosing a small computer is probably one of economics. The initial cost is important, but, equally important, the costs of maintenance, programming, and the connection of peripheral equipment must be considered. A computer is sufficiently complex to require at least one person in an organization to spend considerable time familiarizing himself with the details of the machine. These extra costs, required to realize the potential of any computer system, are likely to exceed the initial purchase price of the system! It is important to take such factors into account when choosing a machine.

The most important feature of a computer is that it is programmable. This provides enormous power and flexibility, with one limitation: the computer *must* be programmed before it is useful. The problem of programming a computer in machine language can be awesome. A programming system for a typical small computer application will consist of several thousand individual machine instructions, each of which must conform to special rules of format, addressing, etc. and also be coded into binary numbers. Estimates of the productivity of professional programmers range from 10 to 50 program instructions per day, including coding, debugging and documentation. An amateur programmer is unlikely to do as well.

The foregoing is not cause for gloom, merely for caution. Although some small computers will require extensive programming before use, others come complete with a large initial package of programs. Some have advanced "languages", so that by typing a single instruction, a complex operation, involving perhaps 1000 separate machine-language instructions, can be performed. Even a small computer, if backed up by such a programming system, can quickly and easily be programmed to carry out complicated operations. For many applications one should in fact regard the small computer as a programmable black box. The availability of programs is likely to prove much more important than details of architecture inside the machine.

Lack of adequate software is one pitfall for the purchaser of a small computer; lack of adequate peripherals can be equally bad. It is possible to buy a machine having a 10 character-per-sec teletype and paper-tape as the only method of entering programs or data into the machine. It may take 5 min or more to enter even a modest program into such a machine. If many different programs are used, or if occasional errors require reloading of programs, the need for faster program loading equipment will soon become evident. Magnetic tapes and discs for small computers are not exorbitantly expensive, and can increase the utility of a system many fold.

At Lick Observatory, we have chosen to use a very small computer, the PDP-8/I, for our electronic instrumentation. This machine has the advantage of relative simplicity, easy electronic interfacing, and reliable inexpensive peripherals. Computers of this family have been in existence for seven or eight years, and are now supported by a large program library. In particular, well designed and tested monitors, assemblers, and powerful programming languages are available. The machine language instruction set, word-length, and machine structure is possibly inferior to other small computers, but these disadvantages are felt to be outweighed by the availability of sophisticated software, and the fact that both hardware and software have been tested over a period of several years, long enough for most problems to have been eliminated.

Two identical computers have been purchased; one is presently used as the controller for a digitized microphotometer, and the second one is used for the memory, display, and control of a multichannel spectrum scanner using an image intensifier, image dissector combination. Both of the instruments mentioned above are undergoing additional development, but preliminary results have been obtained with the multichannel scanner, and the digitized microphotometer is used routinely by several people.

One machine is located on the university campus; the other will be placed at the Mt Hamilton observing station, some 60 miles distant. Since both computers are the same, preparation and initial testing of programs for the mountain machine can be done on campus.

DIGITIZED MICROPHOTOMETER

Figure 1 shows the electronic details of the digitized microphotometer. It also indicates most of the important peripheral devices included with the computer.

The digitized microphotometer was developed using an existing Gaertner microphotometer with

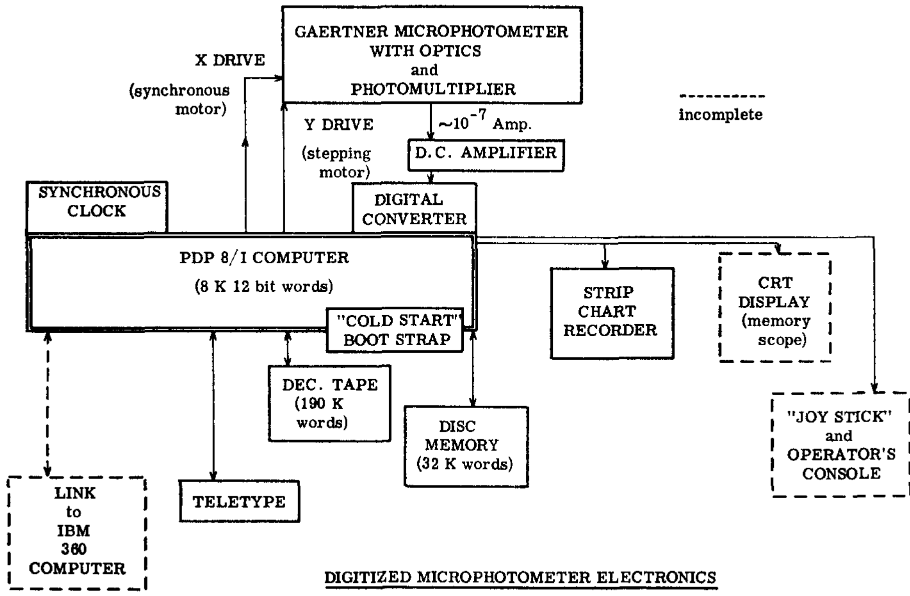

Fig. 1
Schematic diagram of the digitized microphotometer.

associated optics, drive screw, photomultiplier and strip chart recorder. Only minor modifications were necessary to allow the computer to control the drive screw and the strip chart recorder. A stepping-motor was added so that motion in the y direction could also be obtained. A single switch allows conversion of the equipment back to its old non-digitized operating mode, so that it can still be used in the traditional way if desired.

The transmitted light intensity as detected by the photomultiplier is digitized using an analog to digital converter supplied by the computer manufacturer. The digitized readings are stored under program control in successive positions on the magnetic disc, with the microphotometer drive screw running at the slewing speed. Readings are taken at rates up to 360 per sec; at the slewing speed, 360 readings per sec corresponds to a reading every 2.8 microns along the plate.

Several methods were considered for tracking the motion of the microphotometer table. The method chosen is essentially equivalent to that used in the traditional undigitized mode of operation, that is, both the drive for the microphotometer screw and the interval between readings are synchronized to the a.c. line. Thus, the high quality drive screw ensures that the timing of readings is proportional to the motion of the microphotometer stage, even if small variations in the a.c. line frequency should occur. This does not preclude the addition of a linear encoder in the future if more precise position information should prove desirable.

The exposure vs. transmission characteristics of the photographic plate are measured by scanning calibrated intensity strips recorded on the plate. A characteristic curve is calculated for the plate (or for each segment of the plate) and stored on the disc.

The transmission data are also stored on the disc and then can be plotted directly on the chart recorder, or the characteristic curve can be used to calculate the equivalent intensity for plotting. Currently the slow response of the chart recorder limits the overall speed of the system. It requires

https://doi.org/10.1017/S0252921100032516 Published online by Cambridge University Press

about 2 min to read a plate, about 5 min to obtain the characteristic curve, but about 30 min to plot the results.

A CRT display now being added may speed up some operations by allowing immediate reduction of the data, with the operator using a simple switch panel to indicate continuum levels etc., so that the computer can immediately print out the required information about the spectrum. A direct link to a larger computer will also be available for cases where very complex data reduction techniques are to be used.

In Figure 2, an application of the digitized microphotometer is illustrated. Five separate photo-

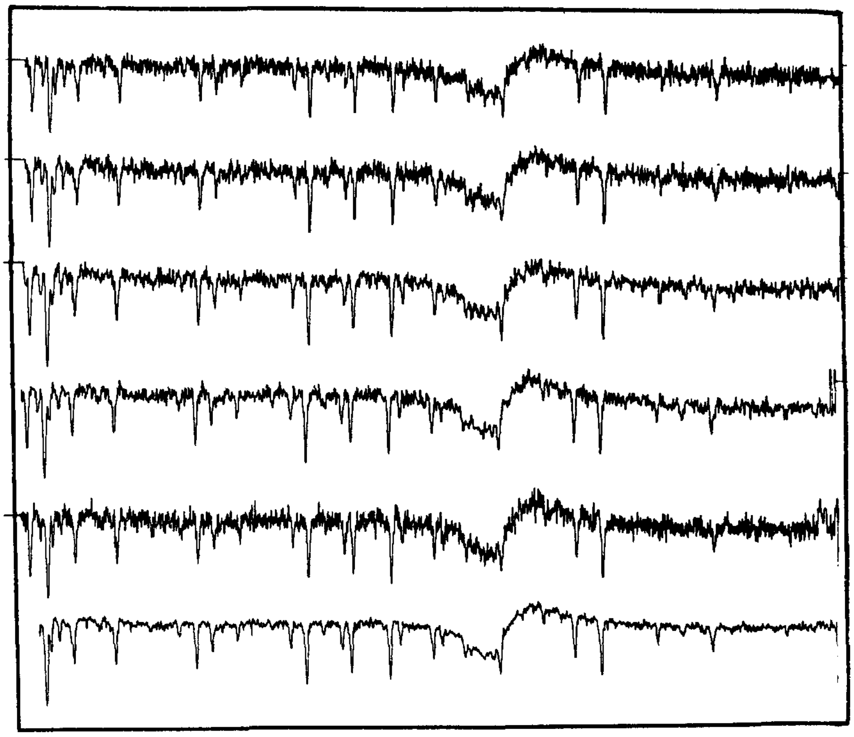

Fig. 2

Tracings made by the digitized microphotometer. Five separate photographic recordings of the spectra of ζ Orionis have been added to produce the tracing shown at bottom, with a view to improving the signal to noise ratio. (Wavelengths 6510–6600Å).

graphic spectra of ζ Orionis were digitized, aligned, converted to relative intensity and added together in an attempt to obtain an improved signal to noise ratio.

The processing required for this demonstration was quite simple. After storing the digitized transmission data for each spectrum on the disc, (along with measured transmission to intensity conversion curves) a tracing of the relative intensities for each plate was made. A peak finding program used the absorption lines to determine the relative misalignment of the 5 spectra, and the records were shifted on the disc so that the relative position of each spectrum in its segment of the disc was the same. The relative intensities for the 5 spectra were then added together to give the average intensity curve shown at the bottom of the figure.

A MULTICHANNEL SCANNER

Using an image dissector to scan the phosphor of an image intensifier, one can record optical spectra (or other optical information) directly in digitized form with no intervening photographic operations.[2] The phosphor of the image intensifier provides short term storage that is read out by the image dissector. Measurements[3] indicate that a simultaneous 512 channel spectrum can be acquired with statistical precision close to the limit imposed by the limited number of input photons and the quantum efficiency of the image intensifier's photocathode.

Figure 3 is a schematic diagram of a multichannel scanner, using the memory of the computer for

https://doi.org/10.1017/S0252921100032516 Published online by Cambridge University Press

storage of incoming data. The input to the computer memory address is made to correspond at all times to the location of the image dissector scan. Any photon detected by the image dissector results in a count being added to a word in memory corresponding to the spot on the phosphor that emitted the photon.

This computer application could be filled by any magnetic core memory. However, there are a number of problems with the scanner where the programmability and arithmetic capability of the computer will be very valuable. For example, corrections can be applied for the image tube response, which may vary by perhaps 50 per cent over the face of the tube, with additional small deviations due to phosphor and fiber-optic imperfections. In addition, a computer-generated CRT display during data acquisition will be very helpful. The image intensifier tubes generate occasional pinpoint bursts of

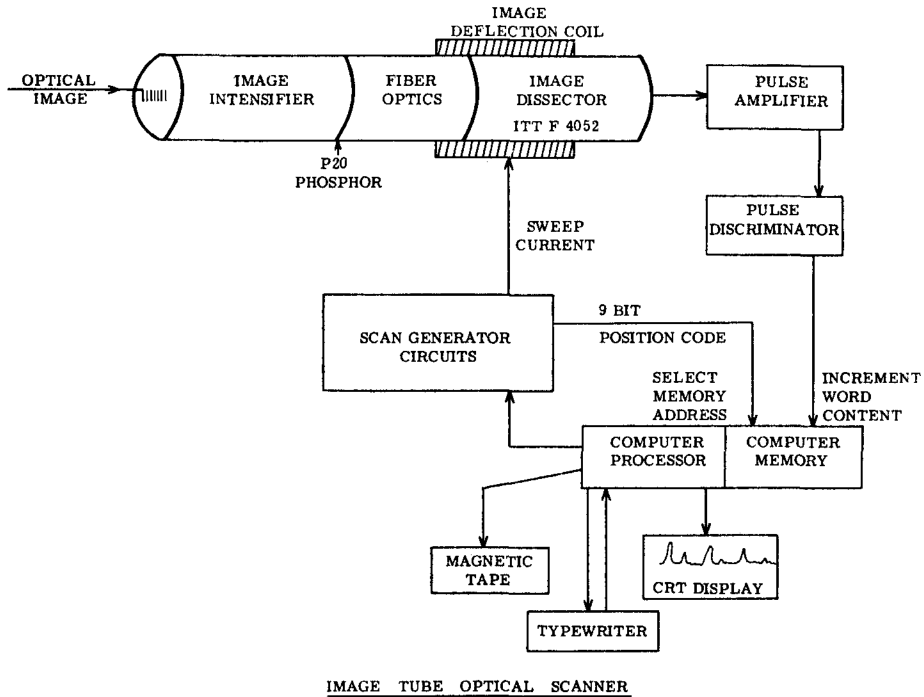

Fig. 3
Schematic diagram of a multichannel optical scanner.

light, many times brighter than the ordinary background. It may be useful to break each recording time into intervals of a few sec, and compare each successive run with the average, eliminating data points whose statistics show the presence of one of these flashes. All of these operations, which would ordinarily be very difficult, are relatively easy using a programmed computer.

It would of course be possible to simply store data on magnetic tape for later reduction at a large computer center. This would probably be somewhat less expensive than the on-line computer, but would preclude the possibility of preprogrammed data taking, and be much less flexible in operation.

The decisive advantage of a small computer in applications of this kind is the convenience to the observer of immediate access to his data. The ability to do relatively complex data reduction during an observation or experiment often allows a scientist to analyse his data in time to make additional crucial measurements. It is also probable that by continuous statistical analysis of incoming data, observing time can be optimized and incipient hardware faults or operating errors detected quickly.

Note that in the system shown in Figure 3, preparation and operation of programs can be carried out while data are being accepted by the computer memory, since data can go directly to part of the memory without program intervention, while a different part of memory is used for program operation. One memory cycle is "stolen" each time a count is added.

Figure 4 shows two test spectra obtained with the 512 channel scanner. These spectra were taken using a grating spectrometer with F 14 optics under a nearly full moon. Since we were merely recording average sky background, no telescope was necessary. The spectrometer slit area and light collecting efficiency was equivalent to what would be obtained over a sky area of about (2 arcsec)^2 at the 120-inch

https://doi.org/10.1017/S0252921100032516 Published online by Cambridge University Press

telescope. The sum of two 10 min runs with the shutter open is shown, with the sum of two 10 min dark runs plotted for comparison. (The dark signal can be significantly reduced by cooling the image intensifier tubes). The difference of the two curves is also shown. A neon comparison spectrum recorded at the same time is plotted below each set of curves. The upper set of curves was obtained using the first order grating spectrum, while second order reflections were used for the lower set. It should be noted that some response was obtained through the whole visible spectrum and up to about 9000 Ångstroms.

The resolution of the scanner was limited in this run by the wide slit of the image dissector (about

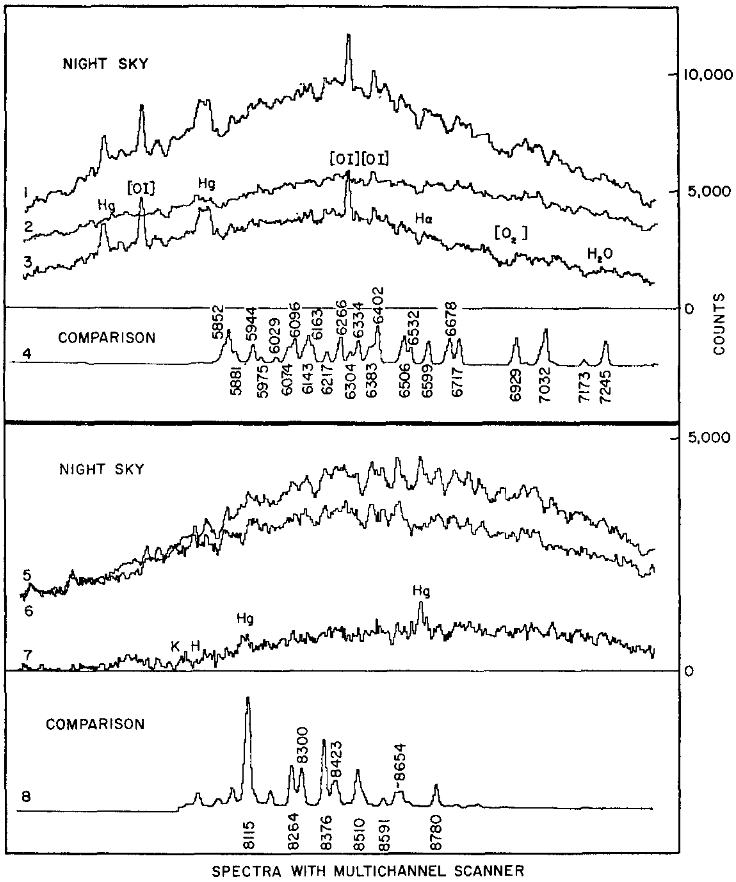

Fig. 4

Test spectra obtained with the multichannel scanner.

1. Night sky from a 20 min run. (Full Moon).
2. Tube background during a 20 min run.
3. Difference of 1 and 2.
4. Neon comparison spectrum.
5, 6 and 7: repeat of the preceding but were obtained using the second order diffraction-grating reflection. The reduced tube background in curve 6 is believed due to a drop in ambient temperature.
8. Neon comparison spectrum.

0.1 mm), which is almost 1 per cent of the total length of the 1.5 cm scan. A dissector with a 25 micron slit width is now on order and should improve the resolution considerably.

The spectrograph and scanner should be mounted at the Cassegrain focus of the 120-inch telescope during the month of August 1970, and the first use of the scanner for actual astronomical spectroscopy should occur shortly afterward.

COMPUTER OPERATION

It is of considerable importance that a small computer be easy to use and to program. Although standard programs should be available, it should also be easy for the average user to prepare his own programs. As mentioned earlier, our choice of computer was greatly influenced by the desire for a machine that would allow this flexibility.

Operating simplicity has been achieved by the use of magnetic tapes to load programs, together with added "cold-start" hardware which makes the initialization and start-up of the computer almost automatic. Ease in programming has been achieved through heavy reliance on software delivered by the computer manufacturer.

A powerful and easily used program language is available for the PDP-8. This language is named FOCAL and has many of the features of BASIC. It is an interpretive, conversational language, able to carry out floating point arithmetic to 10 significant figures. Mathematical functions include sin, cos, log, exp and square root. The language is easier to use than FORTRAN and because of the conversational features, an elementary command of the language can be gained in an hour or so by a novice. The main input-output device is a teletype.

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01.01 COMMENT: AN ELEMENTARY DATA TAKING PROGRAM
01.02
01.04 SET N=-1;               C-INITIALIZE RUN NO.
01.10 X CLER(0);              C-CLEAR DATA BUFFER
01.12 FOR J=1,100;X GRA(20);  C-DISPLAY ON CRT DURING DATA TAKING
01.14 SET N=N+1
01.15 X SAV(N,0);             C-SAVE DATA BUFFER 0,AS RUN #N ON DISC.
01.18 X PULL(N,1);            C-RECALL RUN #N TO BUFFER 1
01.20 SET SM=0
01.22 FOR J=0,511; DO 2;      C-ADD UP ALL CHANNELS
01.30 TYPE !"TOTAL COUNT=",SM
01.40 IF (N-30) 1.10,1.50,1.50
01.50 TYPE !"DISC IS FULL";   C-DISC HOLDS 31 RUNS
01.60 QUIT

02.10 SET SM=SM+FCHAN(J,1)
*
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Fig. 5

A simple PDP-8 computer program written in the expanded FOCAL language. The conversational features of the language allow new programs of this level of complexity to be written, debugged and used within the space of a few minutes.

We have expanded the FOCAL language so that hardware devices such as the chart recorder, the CRT display, microphotometer drives and multichannel scanner can all be controlled by simple programmable symbolic commands. Additional instructions also allow convenient access to both the magnetic tape and disc memories. A chaining command allows FOCAL language subroutines to be loaded automatically from magnetic tape so that the length of a program is not limited by the small size of the computer's memory. Even with this small computer, one can have programs of several thousand statements in length, and over eight thousand floating point variables with ten decimal digit precision. Best of all, the language and rules for operating and programming the computer are simple enough that graduate students and astronomers are willing to prepare their own programs.

In Figure 5 an example is given of a very simple program written in the expanded FOCAL language. This program would take data for a predetermined time, store it on the disc, add up the sum of all counts in a 512 channel spectrum and print out the result. The program repeats until the disc is full, and then stops. Programs of this kind can readily be prepared by an observer just before or even during an observation.

NOTES AND ACKNOWLEDGEMENTS

The development of the multichannel scanner was supported, in part, by NASA Grants NGL 05-061-008 and NGL 05-061-006 and by NSF Grant GP-6310.

The spectra shown in Figure 2 are from plates loaned by G. H. Herbig.

The multichannel scanner is being developed in cooperation with E. J. Wampler.

The assistance of T. Ricketts, R. Greeby, W. Stine and N. Jern is gratefully acknowledged.

REFERENCES

1. Fulbright, H. W., *et al.*, 1969.* On-Line Data-Acquisition Systems in Nuclear Physics, *National Academy of Sciences.*

* Available from: Committee on Nuclear Science, 2101 Constitution Avenue, Washington, D.C. 20418.

2. The Smoothing Dissector. *ITT Technical Note* 115.†
3. McNall, J. F., Robinson, L. B. and Wampler, E. J., 1970. The Response of Phosphor Output Image Intensifiers to Single-Photon Inputs, *PASP*, **83** 837.

DISCUSSION

D. W. LATHAM: What is the approximate cost of these PDP-8/I systems?

L. B. ROBINSON: The system I described cost about $35 000; a more recent version, not yet available, will run all that software for about half the price. These computers have been established several years and most of the problems have been ironed out.

G. B. WELLGATE: What is the word-length?

L. B. ROBINSON: The PDP-8 has 12-bit words, so to get 10 decimal digit precision you use several words per number.

M. J. SMYTH: How much store does the compiler occupy?

L. B. ROBINSON: There is no compiler as such; this is an interpretive language and the actual symbolic text is in the computer at all times. The interpreter and arithmetic package occupy about half of the store.

I. G. VAN BREDA: Can assembly-language subroutines be accessed by FOCAL on the PDP-8?

L. B. ROBINSON: The machine comes with some rudimentary ability to add machine-code instructions to it, and I've expanded that somewhat, and it's now very easy to add a set of machine instructions, for instance to control the microphotometer. You invent some sort of mnemonic symbol that you hope will remind you what the instruction means.

† ITT Tube and Sensor Laboratories, 3700 East Pontiac Street, Fort Wayne, Indiana 46803.