Recent Computer Installations at the Hale Observatories

EDWIN W. DENNISON

Hale Observatories, Pasadena, California, U.S.A.

PROJECT GOALS

Approximately two and a half years ago we started to design a comprehensive computer controlled system to handle data and control telescopes at the Hale Observatories. Our previous experience with hard-wired digital data systems had adequately demonstrated that digital systems can increase the astronomical observer's efficiency by at least a factor of two, that is, we had found that our observers, when using these digital data systems were able to observe twice as many stars per night as they had previously. We became painfully aware of the fact that the hard-wired systems were extremely difficult to modify for new observing requirements. It therefore appeared logical to develop a data system using a small computer which had the facility of permitting the addition of a large number of new devices without modifying the hardware which had been previously constructed. This concept has the advantage that new observing instruments can be added by constructing new hardwire peripheral devices and developing new software. During the development time of a new device it is always possible to insure that the instrument can be returned to its previous configuration by loading the computer with its previous program. This permits an observer to use the same equipment configuration for a period of years even though the capability of the basic system has been greatly enlarged.

As with our previous systems, we established the general philosophy that the observer and night assistant controls must be simple and directly related to the observing operation. This is necessary because there are times at night when even the best observers lose their peak efficiency due to fatigue. The number of devices which confront an observer will undoubtedly increase with time and if each device is moderately complex, it could easily develop that no one person could handle all the control functions efficiently. In the case of these new systems, this philosophy suggests that the observer, seeing only the simple control buttons, need not be aware that his observing instrument contains a computer. Some observers in the future will wish to make full use of the flexibility and power which the computer can provide.

When designing the computer systems, we had to consider the type of peripheral devices which might ultimately be used with this system, the timing relationships of these devices, and the physical problems resulting from mounting various pieces of equipment on the telescopes.

In summary, our goal was to develop a computer data and telescope control system which was uniquely suited to astronomical observing problems.

SYSTEM DESCRIPTION

The system described here will be installed on the new photometric 60-inch telescope which is now being tested at Palomar Mountain. We are building a similar system for the 200-inch telescope and hope shortly to start one for the 60-inch telescope at Mount Wilson. In addition we are constructing a system for the 150-foot Solar Tower at Mount Wilson which will have sufficient memory to reduce and plot solar magnetograms in addition to collecting data.

We selected the Raytheon 703 computer for our system because it was a 16 bit machine which could perform one half word or byte operations, it could be supplied with a large number of standard peripheral devices, it had a convenient instruction set, and finally, the Raytheon software systems were well developed and complete. The system which we are using on the 60-inch has 8000 words on core memory and a standard Teletype printer and paper-tape punch. It also has power-fail protection. If the power fails during the operation, the programs are stored and can be resumed when the power returns.

The 703 computer is normally configured for a large number of standard input and output devices which are generally not needed for astronomical work. It was necessary for us to develop a generalized I/O expander circuit which would enable us to attach our own peripheral devices. The unit which we

https://doi.org/10.1017/S0252921100032139 Published online by Cambridge University Press

have designed and constructed communicates to all of the other devices by means of a single cable which runs serially through each device. This cable will run through each chassis in the computer room and then out to the telescope. Once the cable has been installed, little or no additional cabling on the telescope will be required in the future. We have the possibility of attaching over two hundred devices and we can issue up to 256 commands to each device. Each device can be addressed and sent data by the computer or each device can cause an interrupt to the computer and have its data read by the computer. The data is transferred eight bits or one byte at one time. Each device can be sensed for its status.

The primary data interface between the operators and the computer is a series of television monitors and a keyboard. A character generator which is controlled by the computer transmits a composite video signal to the TV monitors using a 20 by 40 matrix and alpha-numeric characters. All of the telescope information and observing data which is gathered by the computer is revised approximately 10 times per second and displayed to both the observer and the night assistant. Control information, *e.g.* data acquisition time, telescope tracking rates, etc., is entered with the keyboard by the night assistant and immediately displayed for verification. The use of this type of observer-computer interface eliminates the requirement that the observer must act as a skilled or semiskilled computer operator.

The entire system is controlled by the night assistant or the observer from several push-button control panels. One panel enables the operator to select the various program options which are available. A second panel, available to both the observer and the night assistant, contains buttons to start, stop and hold (suspend) the data collection process. It also enables the operator to suppress the recording cycle when the data is considered to be of no value. An additional button enables the observer to enter an identification record. Because the observer is working with little or no light, a sounder indicates a change in the data system's status.

Because accurate time is fundamental for most astronomical observations, the clock peripheral chassis was designed to operate as an independent unit. The computer can read the sidereal and civil time under program control, but it has an independent display and a separate power source which remains on when the rest of the system is turned off. The clock chassis can be run from stand-by batteries if power interruptions prove to be frequent. The basic crystal oscillator has a stability of nearly one part in 10^8 and operates at 5 MHz (civil time). The sidereal time is derived from the civil time with an error of 1.6×10^{-8}. This conversion from civil to sidereal time is done with a hardwired algorithm. An accuracy of 0.1 sec can be maintained for a period of several months.

The tenths of seconds or deciseconds are indicated on a cold-cathode, numerical-display tube which has the numerals located on the circumference of a circle. To the viewer the illuminated numerals appear to move in a circle. If the viewer listens to the 1 sec WWV time ticks as he watches the decisecond display he can very easily determine the clock setting with an uncertainty of 1 decisec. By pressing either the "advance" or the "retard" push-buttons he can adjust the decisecond clock counter with an uncertainty of no more than 1 decisec. The hours, minutes and seconds of civil time can be set by appropriate buttons and thumbwheel switches. Setting the sidereal time is accomplished by two lines of thumbwheel switches, one for sidereal time and one for civil time. The operator must compute the sidereal time which corresponds with some future civil time. He then sets the thumbwheel switches to these values and presses the "stop and set" button which stops the sidereal clock and sets it to the value which has been specified. When the preset civil time arrives the sidereal clock is started with an accuracy of 1 decisec. The operator can also manually start the sidereal time if no calculated time is available. The clock chassis also provides time pulses at decade intervals from 10 Hz to 1 MHz as a time base for any special external equipment.

The right ascension and declination tracking rate chassis also has front-panel operator controls. The right ascension signal is a 60 Hz line-frequency generator which can be varied in increments which correspond to a telescope drift rate of 0.6 sec of arc per hr with a total range of plus or minus 5000 sec of arc per hr. This 60 Hz signal is amplified with a suitable power amplifier and used to drive the telescope tracking motor. The declination tracking-rate chassis generates pulses for a stepping motor with a step size of 0.00375 sec of arc. This rate can be set over a range of plus to minus 5000 sec of arc per hr and has a resolution of less than 1 sec of arc per hr from plus 1500 to minus 1500 sec of arc per hr. Normally the computer sets the tracking rates, but in case of computer failure, the operator can manually set the tracking rate by means of a series of switches.

The data generated by the system are recorded on a strip printer as well as the Teletype punched paper tape. On the 200-inch system, the output will be recorded on magnetic tape. Ultimately we hope to have magnetic tape recorders on all the computer systems.

The pulse data from photomultiplier tubes is collected in digital counters. Inputs from voltage-to-frequency converters can also be connected to the data counters when infra-red analog detectors are used. The integration time is determined by an acquisition timer. A chopper timer is also available for systems which have mechanical chopper wheels.

Absolute position encoders are used to measure the hour angle and declination of the telescope as well as the telescope focus. A similar encoder is used to measure grating position angles for spectrum scanners. The dome and windscreen motions are controlled by the computer by comparing the actual positions read from encoders with the computed values generated from the telescope coordinates. Our existing instrument does not control the telescope slew motors, but we hope to accomplish this during the coming year. We believe that we will be able to set the telescope to within 10 sec of arc of the apparent position of any object in the sky.

SOFTWARE SYSTEM

The software system is being done in a modular form using the Raytheon assembly language. This software system does all of the necessary calculations, controls the cathode ray tube display and handles all of the data gathering and recording. It also provides for automatic dome and windscreen positioning and automatic telescope tracking rate selection. At this time our operational experience with the software system is limited and we feel that this is the area which will undergo the greatest change and development in the future.

SUMMARY

We feel that we have achieved the goals which we set initially, but can now see many powerful and exciting possibilities for the future. One such possibility is to provide a link between these small, dedicated, telescope computers and a large computer which is designed primarily for arithmetic calculation rather than control functions as is the case with our existing machines. With this larger computing power, it should be possible to provide the observer with the reduced data either during the night or during the next day. Complex reductions can be incorporated as part of the observing operation.

We feel that computers are not only practical but essential as an integral part of productive, modern telescope installations. The problems encountered in this new area of observational astronomy are formidable indeed, but the rewards will certainly be well worth the effort.

We wish to gratefully acknowledge the support of this work by the National Science Foundation and the National Aeronautics and Space Administration.

DISCUSSION

J. Tinbergen: What is the construction of the busbar cable that goes from the computer to all the instruments on the telescope?

E. W. Dennison: It's not as nice and simple as we should have liked! For the data there are 8 lines out and 8 back, and there are series of address lines, sense lines, and interrupt lines; the total cable has about 50 twisted cable pairs, some of these have to be shielded, and one has to be coaxial, for the timing pulses. But the data is sent parallel and the encoding and addressing schemes are also sent parallel. Part of the problem is that you have to generate a system which your software system can address easily and is also compatible with your hardware. Because it's a serial cable, when an interrupt line is connected, the computer has to find out which device has generated the interrupt; it doesn't simply go down and read each one, that takes too much time, but it's worked out as though the first one down the line has its unique device and generic address on the line, this address is read by the computer, that interrupt is reset, and the computer goes on to read the next one that has its interrupt on, and so on. So that you can rapidly read several devices, the interrupt addresses are put in a queue in the program and then are serviced in the order determined by the software.

R. B. Dunn: My wife tells me that computerese is absolutely the dullest language! Would Dr. Dennison tell us all what some of these words mean?

E. W. Dennison: A bit is the single information element, *i.e.* a single memory core is either on or off, or one element in a binary register. A byte is 8 bits at a time; in our computer, which is a 16-bit machine, the words are two bytes long. Other machines use different word-lengths, such as 24 or 32 bits; and with 16-bit words you can combine two for double precision and make 32-bit words out of it. A memory, in our case is 8K, this means 8000 16-bit words. Interrupts are electrical circuits that stop the machine, save whatever information it was processing, and go to this device and ask the device "what do you want?". Input-output devices are any kind of device that's used to transfer data in or out of the computer.

G. W. BOTHWELL: You have an 8000-word core store. In the light of the quite considerable computer requirement that might be involved in telescope control, instrument and data handling, and especially the visual display unit, do you find the core size sufficient, and do you anticipate expansion, involving, say, backing store? Do you write the executive system yourselves?

E. W. DENNISON: We write everything ourselves, except that we lift from the Raytheon system as much software as we can in the way of subroutines. There is a rule of thumb, our hardware engineer tells, that no matter how much core you provide for the programmer, he will use it all and will need a little more. It's a boundless requirement. So his advice is always to make it small and tell the software man that's it, then you have in your back pocket a little extra. Honestly, 8K is not large enough. We had originally hoped to write it in conversational Fortran. The Raytheon Fortran package fits in 3K words of core, it's very compact and well-written, but even with this advantage the remaining 5K is not sufficient to write our entire program in Fortran. So we had to go back and re-code everything into assembly language, and that's why we were delayed. With assembly language there's no question that we'll be able to make it in 8K words. Ideally, the only thing is to select machines that are expandable, because you can always think of new requirements which will require more memory.

https://doi.org/10.1017/S0252921100032139 Published online by Cambridge University Press