Minicomputer controller for a behavioral primate laboratory*

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To keep pace with the increased animal carrying load and research productivity of our facilities by perpetual modification of and additions to rigid hardwired equipment would have been a costly and time-consuming enterprise. Thus, a computer controller for the laboratory was an inevitable choice to replace our highly individualized analog and digital units. Our system is based on a minimally configured PDP-8/e, devoid of peripherals except for a Teletype, in which the first phase was guided by the intent to replace separate component instrumentation with a unified digital computer system. The interface design was confined to five different printed circuit boards which in combination could handle computer I/O, switch contact inputs, analog threshold inputs, and medium current output control. Our software package can be divided functionally into three parts: the program interrupt handler, the background control programs, and the resident subroutines.

The evolution of our behavioral primate laboratory from a 6- to a 20-monkey installation, coupled with a changing scientific emphasis from physiology to behavioral correlates of neurophysiology, requires sophisticated programming and flexibility of instrumentation. The laboratory provides two main experimental environments for studying the behavior of experimental epileptic monkeys: a semirestrained and semiroaming facility.

The restrained epileptic monkeys are monitored by means of a closed-circuit TV system with video tape recorders. Each primate chair is equipped with a strain-gauge transducer (Lockard & Barensten, 1967) for continuous activity recording. This activity is processed to operate the video tape recorders (Barensten & Lockard, 1969a) for clinical verification of the seizures. Each chair is also instrumented with a panel of stimulus lights, a joy-stick lever switch, and an automatic pellet dispenser. The data in this experimental situation consist of gross motor activity, video-tape-recorded seizure activity, lever pulls, and monkey reaction times while operating the lever.

The roaming monkeys are maintained on a 12-h day-night cycle and fed automatically by either a local wall feeder which is pulsed daily or two ceiling dispersal feeders which dispense pellets on a random schedule. These primates are viewed through one-way glass and

their social interactions systematically recorded via a keyboard. The data are stored for later card punching, collation, and sequential analyses.

To keep pace with the increased animal carrying load and research productivity of our facilities by perpetual modification of and additions to rigid hardwired equipment would have been a very costly and time-consuming enterprise. Thus, a computer controller for the laboratory was an inevitable choice to replace our highly individualized analog and digital units (Barensten & Lockard, 1969b). Recent articles by Sidowski (1972) and by Aaronson and Brauth (1972) have enumerated the advantages and disadvantages of computerized technology. For our purposes, we chose a system based on a minimally configured PDP-8/e, devoid of peripherals except for a Teletype, in which the first phase was guided by the intent to replace separate component instrumentation with a unified digital computer system. To accomplish this goal, fulfillment of two major tasks was required: (1) design and installation of a hardware interface and (2) design and development of a software package. Moreover, the budget could not exceed the sum required for discrete unit expansion.

HARDWARE INTERFACE

The comparatively small budget and the large number of 12-bit IOTs required led to the decision to design and construct the printed circuit boards required for the input/output interface. Interface design was confined to five different boards which, in combination, handle computer I/O, switch contact inputs, analog threshold inputs, and relay solenoid output control.

Figure 1 illustrates the typical combinations of circuit boards (each handling 12 signal bits) to effect signal transfers. Input/output transfer is handled by the multiple-purpose IOT board which plugs in to the omnibus of the PDP-8/e. In Fig. 1A, switch closures, after filtering, trigger the 35-msec one shots, which effectively eliminates switch contact bounce. Pulses longer than the execution time of an interrupt service routine (i.e., 50 microsec or longer) will be interpreted as a new signal. Thus, a 2-microsec one shot is inserted to insure only one acknowledgement per switch closure. A similar scheme is employed for analog input signals (Fig. 1B) where slow changing signals can hold the Schmitt trigger in its on state for long periods. The signal path in Fig. 1C establishes long-term bistable (on/off) output conditions in which each condition change is performed by software action. The scheme in Fig. 1D provides trigger starts for equipment which has suicide circuitry or other short-term actions where it is inconvenient to have the software follow up with a turn off.

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Fig. 1. Each circuit board block handles 12 signal bits. The signal channels in A and B process input signals; C and D typify output signal processing.

TYPICAL ANALOG INPUT SCHMITT TRIGGER

Fig. 2. Adaptation of the 72820 comparator for use in an electrically noisy environment. The 820K resistor provides positive feedback. Noise effects are further reduced by the two input filters.

TYPICAL DRIVER

Fig. 3. A compact and reliable medium power driver using integrated circuits is achieved by parallel connection of a hex driver. The LED provides a visual status monitor.

The IOT circuit was cookbooked from the scheme suggested in the manufacturer's handbook with error corrections and a modification allowing use of the buffer register for input or output. The one shots are 74121 monostables with an added input RC noise filter.

The Schmitt trigger, Fig. 2, employs a 72820

comparator buffered by a 7406 inverter. The basic comparator, a very fast high-gain unit, did not perform well initially in our electrical environment. Input filters were added to prevent false triggering from input line noise. Also, slow changing input signals will hold the comparator in its high-gain active state, which allows multiple output pulses from low-amplitude input noise. This was eliminated by the introduction of positive feedback (820K resistor) which speeds the transition and provides hysteresis. To aid adjustment of the threshold, a LED (light-emitting diode) is connected to the output.

The driver, Fig. 3, combines the 6 units of a 7406 open collector hex driver in parallel to create a medium power driver. An optional inverter can be connected for polarity inversion. The LED provides a visual monitor of the driver status.

SOFTWARE

The software was developed as a collaborative effort between the investigator and the electronics laboratory personnel. The type of programming was based on three significant factors: (1) available software development time of less than 6 months; (2) availability of a LINC-8 computer and the Wisconsin modification of LAP-6 (Bjerke et al, 1970) which allowed editing and assembling with oscilloscope display and magnetic tape; and (3) a comparatively naive base of programming skill initially.

A software development philosophy was first established to direct the programming effort in a manner which would allow for changing experimental situations in which the desirability for substantial involvement of the program interrupt system was a major factor. This led to a software package which can be functionally divided into three parts: The block diagram of the program is shown in Fig. 4. The right column blocks are the foreground or interrupt handler, including a section of the control/data acquisition routines; the left column blocks are the background programs, including the remaining control/data acquisition routines; and the bottom blocks are the resident subroutines which could be called up by one or more of the foreground/background programs.

Fig. 4. Block diagram of the operating program. The left column blocks are background programs. The right column blocks are the foreground or interrupt handler. The bottom blocks are resident subroutines, which are called by the other programs.

Considering the interrupt service first, top priority is given to the power fail program, which, if power is low, performs the housekeeping required for automatic start up when power is restored. The miscellaneous program handles clock interrupts, initiates the timing (PROGRAM TIMER) and execution (ACTION) of experimental treatments, and sets software flags for later action. The lower and upper threshold programs operate the video tape recorders (VTR) when integration of monkey-chair activity meets the seizure envelope criteria. The VTR also stores the integrated activity as data. The paddle program schedules stimulus lights, handles all lever pulls, stores their occurrences and latencies as data, and pulses the pellet dispensers during reinforcement periods. The keyboard (KRB) and teleprinter routines set software flags.

The background programs consist of a main listening loop (L1SN) and executer (DIRECTOR) which gives control to one of five programs either on Teletype keyboard command or automatically through software-flag sensing: TIME PRINT does just that, i.e., prints out time of day; MODIFY is our debugging and interactive program which allows any memory location to be inspected or changed through the Teletype keyboard; DATA PRINT selects and prints out in format the daily data; SHAPE is an interactive program for lever training, such that either the S or E can initiate a reinforcement; and CODE processes the behavioral observations on the social interactions of the roaming monkeys.

The resident subroutines provide a double-precision binary to decimal conversion of data for printout; a labeling routine (TEXTOUT); a paper tape routine (PUNCH) for punching out programs and data; a bit test subroutine (BITTST) which interacts extensively with the interrupt service programs to identify the bits in the input registers; and a four-dimensional storage and

retrieval address assembling DATA MATRIX. The subscripts of the latter array, based on (a) the experimental treatment, (b) the particular day, (c) the monkey, and (d) the behavioral measure, are used to specify the core location whenever data are stored or printed out.

With the basic system now in operation and running smoothly, an expansion phase has been undertaken in three areas. First, a magnetic tape unit and a card punch machine will be connected to the interface to increase data storage and facilitate transfer of data to a large number-crunching computer. Second, a more sophisticated variety of IOTs will be designed, such as a hardware clock, digital to analog converters for special readouts and experiment monitoring, and an analog to digital converter to further refine seizure detection. Third, improvements and additions to our software package will be made to cover expanding needs and objectives which were unattainable without a computer system.

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