COMPUTER TECHNOLOGY

Graphic bar display of on-line physiological data using a minicomputer, DAC, and conventional servo recorder*

D. T. KRAUSMAN, R. W. BAER, and D. E. ANDERSON

*Department of Psychiatry and Behavioral Sciences, The Johns Hopkins University School of Medicine
720 Rutland Avenue, Baltimore, Maryland 21205*

A method is described for providing an on-line bar graph display of physiological data. A conventional servo recorder is coupled with an 8-bit digital-to-analog converter, and provides a low-cost, hard-copy graphic display peripheral that can be added to any laboratory type minicomputer system with buffered output data lines. The graphic display technique requires minimal memory allocations and a simple software algorithm to provide a flexible graphic system that can accommodate various types of biological data.

Many laboratories presently engaged in biological research employ on-line minicomputers for both experimental control and data analysis of real-time physiological functions. An efficiently programmed minicomputer system can provide the investigator with enormous amounts of on-line/real-time physiological data in either a raw or a condensed format. This on-line data, usually numerically listed via a teleprinter, line printer, or cathode ray tube (CRT) display, is often difficult to evaluate since the repetitious number lists of inordinate lengths tend to obscure pertinent physiological changes of the system under study. Visual detection of certain critical changes is often required to provide information necessary for dynamic experimental manipulations basic to the regulation of the ongoing behavior of the system under analysis. On-line graphic representation of the physiological values has provided an increasingly common approach to satisfy this requirement for real-time visual detection.

Another, and in many experimental applications, more advantageous use of a graphic display is to facilitate the automatic generation of either on-line or off-line data plots. This plotted data can relieve the investigator of laborious and time-consuming graph construction and scaling by hand. Commercially available soft- and hard-copy graphic displays (i.e., point plotters, X-Y plotters, CRT terminals, etc.) are now provided as standard peripherals on large computer systems which can produce graphic displays in the form of bar graphs, line graphs, plots, or even isometric views. The cost of these graphic display peripherals with accompanying controllers, however, is frequently

prohibitively high for owners of smaller systems.

This paper describes a technique which has been successfully implemented in the laboratory to integrate an inexpensive servo strip chart recorder with an 8-bit binary digital-to-analog converter (DAC) to provide a low cost, hard-copy peripheral for on-line graphical display of peripheral resistance (PR) in unanesthetized laboratory dogs. While cardiovascular functions are being monitored continuously from indwelling catheters and implanted flow transducers, the Ss are trained, using biofeedback procedures, to increase and maintain peripheral resistance above prespecified criterion values in order to avoid the contingent onset of an aversive electric shock (Krausman, 1970). The graphic plot of the animal's PR enables the investigator to rapidly assess baseline and dynamic resistance changes so that on-line changes of the criterion level can be effected.

METHOD

Although the minicomputer system provides extensive control and response functions for many on-line behavioral and physiological contingencies, only the graphical plotting of the computed peripheral resistance (PR) variable of the experiment will be described in the present report. The computed peripheral resistance is defined in this study as mean arterial blood pressure divided by aortic blood flow.

The basic flow and pressure signals are derived by chronic implantation of an electromagnetic flow probe around, and a polyvinyl pressure catheter into the ascending aorta. These signals are interfaced to a conventional polygraph recorder using standard signal conditioning instrumentation. These signals are illustrated in the polygraph tracing in Fig. 1. The electrically preconditioned signals from the polygraph are preprocessed (Krausman, Ehrlich, & Brady, 1972) and then digitized by the A/D converter input of the minicomputer. The resulting computed PR values are summated, scaled, and transferred to

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Fig. 1. A 3-min polygraph tracing of physiological functions in an unanesthetized behaving dog. On-line, 10-sec evaluations of peripheral resistance (blood pressure/blood flow) was determined from this data with a PDP-8/E minicomputer. These on-line evaluations, which provide biofeedback contingencies to the dog, are also graphically displayed in the bar graph in Fig. 2.

the graphic recorder in a bar graph format at 10-sec epochs (Fig. 2). The designated 3-min bar segment in Fig. 2 represents the actual computed peripheral resistance unit (PRU) values derived from the pressure and flow functions of Fig. 1.

INSTRUMENTATION

The servo recorder used is a Heathkit Model EUW-20 modified to accept an external relay closure for start-stop control of the chart motor. This modification was accomplished by placing the contacts of the external relay control circuit in series with the ac power lines of the chart motor. The chart width is 10 in., and the speed is fixed at 2 in./min. The digital-to-analog converter (DAC) is an inexpensive Zeltex Model ZD430-E11 (1000 Chalomar Boulevard, Concord, California 94520) with a straight unipolar 8-bit (255 parts full scale) TTL binary input and a 0- to +10.0-V, 5-mA analog output. The minicomputer system is a Digital Equipment Corporation (DEC) PDP 8/E central processing unit with 4K of core and standard DEC accessories which include a real-time clock, an 8-channel A/D converter, a 12-bit buffered I/O interface, and an ASR 33 Teletype. Power requirements of ± 15 V and +5 V for the Zeltex DAC were supplied by the internal power buss of the PDP 8/E minicomputer.

SYSTEM OPERATION

Figure 3 is a block diagram of the graphic system for producing a bar-graph display. A sequential description of the system's operation is as follows: A scaled binary

data value from the minicomputer is transferred and stored in the buffered output data lines. These lines are connected to the input of the 8-bit binary DAC. The DAC converts the input binary value into a linearly proportioned monophasic output analog voltage. The analog output voltage from the DAC is connected to the signal input of the servo recorder. This input signal, which is attenuated for a calibrated scaling of the servo chart, vertically deflects the servo pen to a level that corresponds to the original binary value. After a specified delay (depending on the response speed of the servo pen), the chart motor start-stop bit is transferred from the minicomputer to a buffered output line. This buffered bit starts the chart motor via a relay control

Fig. 2. A computer generated bar-graph display provided by a Heathkit servo recorder and an 8-bit DAC. The designated 3-min bar segment, where each bar represents a 10-sec epoch, is the actual computed PRU (peripheral resistance unit) values derived from the pressure and flow functions of Fig. 1.

Fig. 3. Block diagram of the graphic display system.

circuit. The chart continues to run to provide the horizontal top line of the bar graph. After a specified time period, which determines the width of a single bar plot, the start-stop bit stops the chart motor and a zero value data transfer resets the servo pen to baseline. Repeated cycling of the preceding events will produce a graphic bar display similar to the one illustrated in Fig. 2.

RECORDER CONSIDERATIONS

Three important electromechanical considerations in selecting or adopting a servo recorder to the graphic display system are: (1) the start-stop reaction time of the chart drive motor; (2) the chart speed; and (3) the full-scale response time of the servo pen.

On-line/real-time bar-graphing applications require that the response characteristics of all of these recorder control functions be compatible with the rate of data transfer. For example, beat-by-beat heart rate data of 200 bpm (1 beat/0.3 sec) could not be graphically plotted by the described Heathkit recorder. Since the balancing time of the servo pen is 1 sec full scale, and the chart speed is 2 in./min, the relatively slow Heathkit can not respond to this high-rate data. However, a slower data rate or condensed on-line data, such as the 10-sec epochs of average PR values, is easily handled by the Heathkit recorder.

An advantageous and efficient method of using the inexpensive and slow servo recorder for graphic display is an off-line or postexperimental approach. Data which has been converted, tabled, and stored during the real-time experiment can later be graphically displayed.

This postexperimental method can accommodate the serial graphing of multiple variables, whereas the on-line method can only provide for a single on-line variable. Off-line graphing also provides for software dependent control and data rate transfers that can conform to the operational specifications of most any recorder.

DISCUSSION

The software used to drive the graphic plot system is an assembly language subroutine that scales, times, and transfers data between the minicomputer and the servo recorder. The use of assembly language maximized the efficiency of the 4K PDP-8/E minicomputer by providing the most efficient code for detailed control of all recorder functions.

The Heath Company, which no longer manufactures the described Model EUW-20 servo recorder, currently produces a higher performance 12-speed servo chart recorder (Model IR-18M) at a cost of \$150. The Zeltex DAC, which is listed at \$39, combined with the servo recorder, provides a versatile graphic display for less than \$200.

The general approach represented by this bar-graph technique provides a flexible graphic plotting system that can accommodate many types of physiological, behavioral, and statistical data. Although the inherent limitation of this low-cost system is its slow response characteristics, it can easily be programmed to perform a variety of vital and comprehensive experimental data plots in both on- and off-line applications.

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