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A MICROCOMPUTER-BASED DATA ACQUISITION SYSTEM FOR PHYSIOLOGIC STUDIES OF THE NEWBORN

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INTRODUCTION

The perinatal data base includes much information about the physiologic status of the newborn. Monitoring multiple parameters of the newborn has become routine. Whereas a decade ago, the infants' vital signs were determined by intermittently palpating the pulse, listening for breath sounds, and using a blood pressure cuff, the newborn receiving intensive care today is monitored with a continuous electrocardiograph transthoracic impedance respirometer and with a pressure transducer attached to an umbilical or radial artery catheter. Yesterday's research methods are now part of routine care; tomorrow's routine will be an extension of today's physiologic research.

Studies of the physiology of the newborn involve gathering large volumes of data and selecting those appropriate for calculations, some of which are tedious if performed by hand. The minicomputer has been successfully applied to studies of cardiopulmonary function, using time-sharing techniques.[1, 2] Recent developments in large-scale integration are now translatable into a more distributed, dedicated approach to computing, with the cost of the computer becoming less than that of the input instrumentation. We at the University of California at San Francisco (UCSF) have made this transition, moving the computer from the air-conditioned computer room to the patient's bedside. This chapter describes three applications of a personal computer for improving research methods in the study of newborn physiology.

DESCRIPTION OF THE SYSTEM

The USCF CVRI data acquisition system is based on the Apple II personal computer system. The hardware consists of two systems: (1) a stationary microprocessor development system, and (2) a mobile data acquisition system. Software and hardware are created primarily using the development system, consisting of an Apple II, dual mini floppy disk drives, a Teletype Model 43 terminal, and a Miplot X-Y plotter. The mobile system consists of an Apple II, dual mini floppy disk drives, a thermal printer, an analog-to-digital (A/D) converter, a Validyne transducer control system and pressure transducers, and an isolation transformer. The A/D converter has 16 multiplexed channels and a resolution of 12 bits. The entire mobile system measures 40 X 50 X 110 cm and is easily moved to the patient for gathering data. The two systems are completely compatible for ease of maintenance of the software.

The software used on the mobile system is diagrammed in Figure 20.1. All programs are written in BASIC, except for the A/D software and graphics (denoted by an asterisk in Fig. 20.1), which are written in machine code for speed. The acquisition program controls these two programs by setting up the channel numbers, sequence, and timing of the A/D conversions using BASIC commands. Analog data are digitized at rates of up to 7 kHz, displayed graphically in high-resolution color graphics, and stored in BASIC arrays in core memory. Up to 8000 data words can be collected at a time. The data are automatically transferred to a disk file with associated calibration data, gathered by automatic calibration programs run prior to the study. Applications programs reload arrays from the disk file exactly as the data are acquired, and interact with the standard high-resolution color graphics (196 X 280), keyboard, joystick, loudspeaker for prompting, and transistor-transistor logic (TTL) outputs for controlling external devices. The software is controlled by the disk operating executive system (DOX) for running multiple programs, using easily programmed command sequences.

APPLICATIONS AND RESULTS

Transcutaneous Blood Gas Measurements

We first applied the system to the task of automating a mass spectrometer device for estimating arterial blood gas tensions through the skin. This application uses the microcomputer both to make measurements and to control external devices. Figure 20.2 shows a diagram of the entire system. The skin surface chamber has two sampling

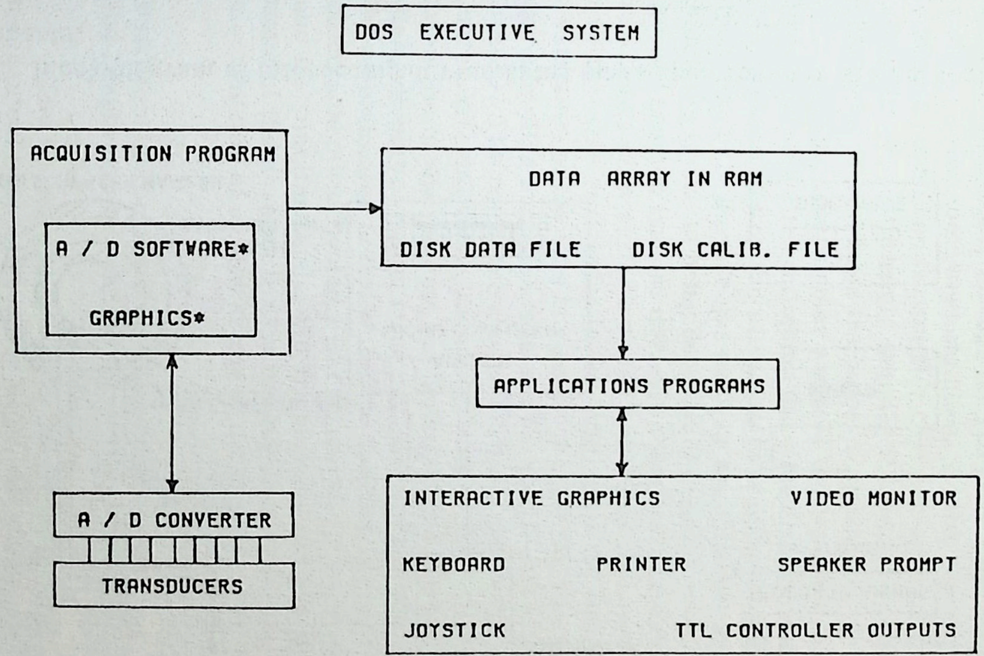

FIGURE 20.1. Diagram of software of microcomputer-based mobil data acquisition system. All programs are written in BASIC except as denoted with an asterisk. A/D software and graphics are written in machine code to facilitate speed of processing.

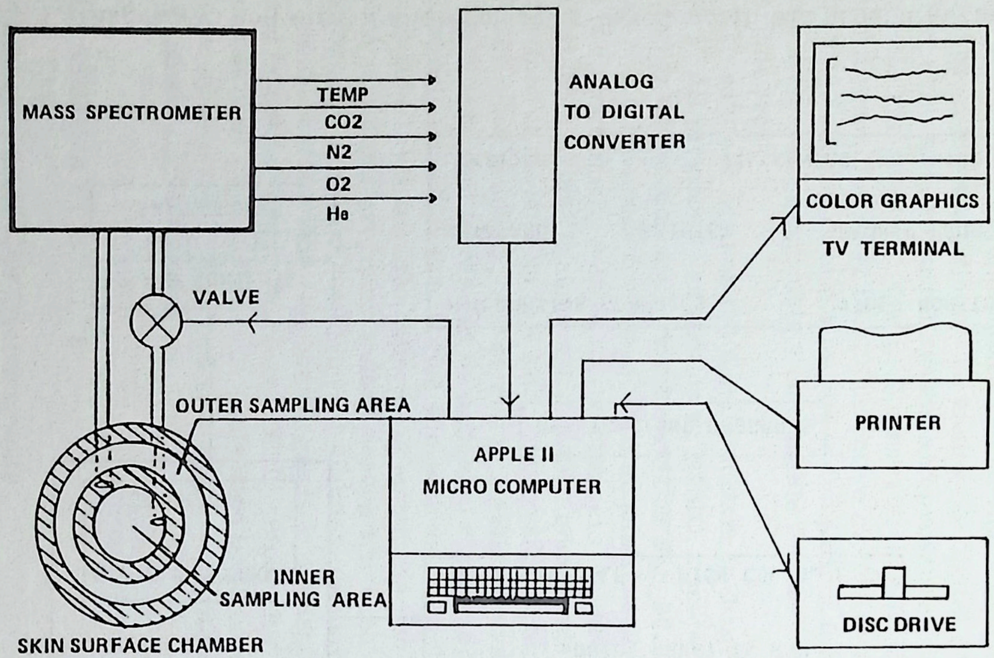

FIGURE 20.2. Block diagram of microcomputer-assisted mass spectrometer system for transcutaneous blood gas measurements.

areas, consisting of a sintered metal disk and ring, covered by permeable Teflon membranes. The chamber beneath the sampling areas is connected to the ionization chamber of a Perkin-Elmer mass spectrometer by two pieces of stainless steel tubing. The sampling surfaces of the chamber are attached to the skin with a ring of double-sided adhesive material, and the skin sensor is heated to 44°C, to produce maximal vasodilation. Gas diffuses through the skin from the dilated capillaries, through the sampling membranes, and into the vacuum of the ionization chamber. A valve controlled by the microcomputer switches the smaller chamber on and off, so that the mass spectrometer alternately samples the sum of the gas from the two chambers or that from the larger chamber.

The microcomputer samples the gas tensions from the mass spectrometer after switching the valve and then waits for equilibration. The membranes on the two areas have different permeabilities, and thus, the skin surface gas tensions are different for the two areas, since the tissue is being depleted of gas at different rates. The program assumes that the diffusion resistance through the skin under the two areas is in series with the resistance of the sampling membrane, and that this resistance is the same under the two areas. The diffusion resistance of the skin is calculated using the skin surface gas tensions, the sampling surface areas and the known permeabilities of the membranes. The computer also calculates a corrected value for the estimated arterial value, using the value of the diffusion resistance. Data from the measurements and the calculated values are stored on the disk, displayed on the video monitor, and printed. This system produces estimates of arterial blood gas tensions similar to those of electrochemical systems and measures the tensions of O_2, CO_2, N_2, and He simultaneously. We are beginning extensive clinical investigations of the changes in skin resistance as infants mature, and in the mechanisms of oxygen supply to the tissues.

Partitioning Contributions of the Chest Wall and Diaphragm to Ventilation

The second application is the separate measurement of the mechanical properties of the lungs, chest wall, and diaphragm. Ventilation is partitioned between that of the chest wall and diaphragm by measuring changes in the circumference of the chest and abdomen using mercury-in-rubber strain gauges. A multiple linear regression is used to find the best fit for the weighted sum of the circumference changes and lung volume changes, as measured with a face mask and pneumotachograph. Since the contributions to ventilation of the chest wall and disphragm are continuously changing, editing the data on a breath-by-breath basis is necessary. This is done at the bedside by redisplaying the data and editing it using a cursor and the joystick. A multiple linear regression is performed as a check of the fit of the data for the ventilation partition function, so that the positions of the strain gauges may be optimized before any lengthy session of data collection.

Using this system, we have studied seven premature infants recovering from hyaline membrane disease; we have been able to estimate lung volume changes to within 6 percent. We have also simultaneously measured the esophageal and gastric pressures, using a two-lumen feeding tube and esophageal balloon, and have separately calculated the work done on the lungs, work performed by the chest wall, and work performed by the diaphragm. Our preliminary results show that premature infants with chest wall distortion have to perform up to four times as much diaphragmatic work as is done on the lungs. We are beginning longitudinal studies of the development of the chest wall in premature newborn infants.

Analysis of Respiratory Muscle Electromyograms

A third application uses the Apple II to perform an analysis of respiratory muscle electromyograms (EMGs). When skeletal muscle fatigues, the strength of the high frequency components of its EMG decrease, and that of the low frequencies increase. This shift of the power spectrum occurs before loss of muscular force, hence this analysis of the EMG could prove useful in predicting respiratory failure. Conventionally, the EMG signals are recorded on tape and later played back for analysis by a minicomputer.[3]

We have applied the Apple II to this analysis using a fast-Fourier transform. The EMG signals are digitized at a rate of 1024 Hz and graphically edited to eliminate ECG artifact. The analysis is performed over a frequency range of 0-512 Hz, the results of which are displayed graphically, as shown in Figure 20.3. The spectral changes with fatigue are shown; literature values obtained using a minicomputer have been added for comparison. The computation time for this analysis was approximately 1 minute, taking longer than the conventional analysis. The results, however, are available at the bedside, so that these measurements could become useful in the clinical setting.

DISCUSSION

These applications illustrate that microcomputers can improve the perinatal data base by expanding the information about the physio-

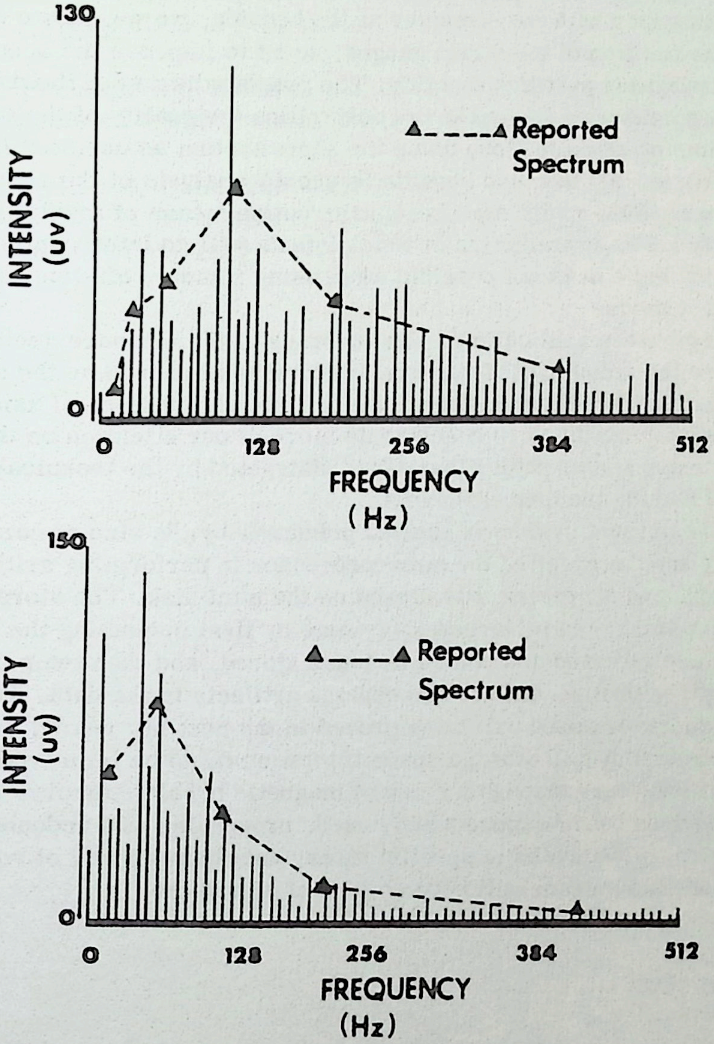

FIGURE 20.3. Results of frequency spectral analysis of non-fatigued (top) and fatigued (bottom) muscle. Literature values for the spectrum have been added for comparison.

logic status of the newborn. The automation of the mass spectrometry system makes the measurement system more flexible, improves the accuracy of the estimation of the arterial blood gas tensions, and will undoubtedly contribute to our understanding of the maturation of the skin. Likewise, with the computer at the bedside, we were able to check the position of the strain gauges, so as to improve the accuracy of the ventilation partition function. The graphic display of the data during its collection is a means of controlling the quality of the data at the time of its collection, using the same system as used for later computations. Finally, the bedside frequency analysis of the respiratory muscle EMG might even become a routine means of making a clinically relevant prediction of which infants will go into respiratory failure—a feat that is not possible when using remote, off-line processing methods.

In all these applications, the accuracy of the measurements and therefore the reliability of the data are further improved by the automated calibration of the instrumentation. The convenience of using this system permits us to concentrate more of our attention on the infants under study, rather than being distracted by the technical aspects of making the measurements.

The present system is limited primarily by the size of core memory and the speed of the microprocessor in performing arithmetic operations and accessing data stored on the mini disk. The storage space limitation can be largely overcome by first inspecting the data as they are gathered and before they are stored, and then temporarily interrupting storage if there are obvious artifacts in the data. The microprocessor speed will be improved in the next few years. The disk access time and storage space limitation could be improved in the next few years through the use of magnetic bubble memory. As these devices become more widely used, processing will undoubtedly become more dedicated to specific tasks, and the overhead of software and data storage will become less of a problem.

CONCLUSION

The time is quickly approaching when the cost of computing will be less than the cost of the instruments used for making the actual physiologic measurements. We expect that microcomputers will take on an expanded role in physiologic monitoring, making the research methods of today part of tomorrow's routine care.

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