A DATA COMMUNICATIONS AND PROCESSING SYSTEM FOR CARDIAC ANALYSIS

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Many aspects of medical diagnoses involve extensive, tedious procedures in which the capabilities of a digital computer can provide the physician an invaluable aid.† Because of the complexity and cost of modern computers, systems to aid in diagnostic procedures must generally be centrally located and be capable of serving many physicians. Thus, data communication links between the physicians and the computer location are required. Such a data communication and processing system for cardiac analysis is now in operation and is described in this paper.‡

The cardiac data processing system discussed in this paper is comprised of data acquisition units located throughout the country, data communication links which can be established as required, a data processing unit, and print-out devices.

The data acquisition unit, as shown in Figure 1, provides the capability of recording an electrocardiographic signal simultaneously on a graphical recorder and on a magnetic tape recorder. Prior to recording the electrocardiogram, an 8-digit, serial, binary-coded signal...
decimal number is generated and recorded on magnetic tape. This 8-digit number is used to identify the particular data that is recorded. Two digits indicate the place where a recording is taken; four digits indicate the patient's number, and the last two digits indicate the particular electrocardiographic lead that is recorded. The electrocardiographic signal is modulated using pulse repetition frequency modulation prior to recording on magnetic tape in order to achieve a frequency response down to 0.1 cycles per second. The upper frequency response extends to 200 cycles per second.

Figure 2 is a block diagram of the data acquisition unit. The input electrocardiogram is amplified prior to recording. A decoder generates the 8-digit number corresponding to the location, patient and lead.

The code number followed by the amplified electrocardiogram is fed to pulse repetition frequency modulator whose center frequency is 3600 cycles per second. The output of the modulator is recorded on magnetic tape. The output of a second head on a tape recorder is demodulated and the demodulated signal is fed to a graphical recorder and/or a DATA-PHONE data set for transmission to the data processing unit. The magnetic tape records generated by the data acquisition unit contain completely identified electrocardiographic signals. These magnetic tape records can be sent via DATA-PHONE service to the data processing unit for subsequent analysis and processing.

Communication between the data acquisition units and the data processing unit is achieved over DATA-PHONE service on switched telephone facilities. Specially designed and constructed analog transmitting data sets are located at the data acquisition units while receiving data sets are located at the data processing unit. These analog data sets incorporate integrated telephone sets which allow, when in the voice mode of operation, the dialing of calls and normal voice communication over the regular switched telephone network. When in the data mode of operation, the data set provides modulation and demodulation circuitry to allow the transmission of analog signals with frequencies from 0 to 200 cps over dialed-up voice telephone facilities. An input to output linearity from transmitting to receiving data sets is maintained to better than 1%.

Figure 3 shows a block diagram of the electrocardiogram data set transmitter. The input circuitry provides a load impedance of 1000 ohms and accepts analog signals which can range from -3 volts to +3 volts and can contain frequency components between 0 and 200 cps. The input circuitry acts to adjust the DC level and gain of the input signal such that it provides proper bias range for the astable multivibrator which follows the input circuit. This astable multivibrator accomplishes the actual frequency modulation. A
given voltage delivered to the input of the data set represents a particular bias on the multivibrator and determines the multivibrator's frequency of oscillation. For the indicated input voltage range, the astable multivibrator will oscillate at frequencies ranging from 1000 cps to 1500 cps when the input circuit level and gain controls are properly adjusted. The square wave output of the multivibrator is filtered and attenuated by the transmitter output circuitry. The output circuitry provides a 900 ohm source impedance to the telephone line. The signal transmitted to the telephone line is essentially a sine wave with a fundamental frequency between 1000 cps and 1500 cps at a level of -6 dbm. A bandpass filter removes harmonics above 2500 cps.

Figure 4 shows a block diagram of the electrocardiogram data set receiver. The input bandpass filter terminates the telephone line in 900 ohms at all transmitting frequencies. It has a slope of 12 db/octave to either side of the 1250 cps center frequency of the telephone line signal. Following the bandpass filter is a combined amplifier and limiter, the gain of which determines the sensitivity of the receiver, -38 dbm. The output of this stage is a 1.5 volt square wave with a fundamental frequency that of the received signal. The square wave is differentiated and full-wave rectified to give a sequence of pulses which correspond to the zero crossings of the received signal. These pulses are used to trigger a mono-pulser which delivers a pulse of fixed width each time it is triggered. Thus, the mono-pulser delivers an output pulse for every zero crossing of the input signal from the telephone line and provides an average output voltage which is proportional to the received signal frequency. By passing the output of the mono-pulser through a low pass filter, the original baseband signal is reconstructed.

The output circuitry serves to amplify the signal and restore the correct DC signal level. This output circuitry is designed to drive a 1000 ohm load impedance.

The telephone line signal spectrum (1000 cps to 1500 cps) is chosen to avoid falling within the same band used by various kinds of single-frequency signalling equipment employed in Bell System switching facilities. If this were not true, automatic circuit disconnect could occur when certain signal patterns are transmitted. The input sensitivity of the data set receiver is chosen to be appropriate for the range of typical dialed-up telephone connections.

Figure 5 is a block diagram of the equipment in the data processing unit. This consists of three basic units; an input console, a digital computer, and an output unit. The input console can accept data that is transmitted over the telephone line or data obtained from playing back magnetic tape records made in the field. The data transmitted over the telephone line is recorded on one of the two magnetic tape recorders. If it is desired, the data transmitted over the telephone line can be recorded on magnetic tape and fed into the computer simultaneously.

The input console is capable of automatically searching the magnetic tape for any pre-selected set of identification numbers. Once finding the proper set of identification numbers, these numbers are decoded and fed into the computer and serve to identify the result of the data processing. Alternately, the system can accept any electrocardiogram and set of identification numbers, whether transmitted over the telephone line or played back from a magnetic tape recording, decode the identification and feed the identification number into the digital computer.

An oscilloscope and photographic recorder are incorporated into the system to monitor the electrocardiogram while recording and playing back. The electrocardiogram is filtered with a bandpass filter to eliminate high frequency noise. The derivative of the filtered electrocardiogram is then obtained using conventional analog techniques. The filtered electrocardiogram and the derivative of the electrocardiogram are converted to digital form at a rate of 500 samples per
second using a successive approximation analog to digital converter. The digital representation of these two signals, along with the decoded identification numbers, are then fed directly to the digital computer for subsequent processing. Figure 6 is a photograph of the system. The input console is at the left and the computer is at the right.

The digital computer is a Control Data Corporation 160A computer (CDC 160A) and is programmed to automatically recognize and measure the wave forms of the electrocardiogram. The cardiologist uses these measurements to interpret the electrocardiogram. The measurements are of amplitudes and duration of the waves, and the interval between certain of them. The program recognizes whether some waves are diphasic, bi-fed or tri-fed. The measurements made by the computer were programmed based on conventional EKG criteria for wave onset, termination and slope.†

The computer processes an electrocardiographic lead and arrives at the desired measurements in 12 seconds. The entire input, process, and write-out time is 52 seconds. The output of the computer is printed on an automatic typewriter or punched on paper tape that can be used for telephone transmission of the results back to the sender. Although at present verbal telephone communication is used for return of results, a completely electronic system has been tried.‡

*Reference #3.
†Reference #4.
‡Reference #5.
The data communication link used for output data from the data processing unit has consisted of DATA-PHONE service over switched telephone facilities. Bell System Data Sets 402A and 402B have been used in conjunction with Tally Register Corporation Model 51 tape-to-tape equipment. This communication link is capable of transmitting 8-level parallel digital data at a rate of 75 characters per second.

The approach taken in the system described in this paper can be extended to other medical diagnostic processes such as the analysis of phono-cardiograms, electroencephalograms, etc. There is great potential here for electronics to assist the medical profession.

REFERENCES