CARDIOLOGICAL MASS EXAMINATION WITH MICROCOMPUTERIZED DATA COLLECTION AND CENTRAL PROCESSING

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Today it is already obvious that a demand on social scale manifests itself for the creation of a national cardiological screening system, similar to the network of pulmonary screening. Evidently, the solution of this large-scale task rises several complicated medical, sanitary-organizational, technical and mathematical problems.

The present brief report will only deal with the latter two spheres of problems. As far as medical questions are concerned only remarks indispensable for understanding the applications will be made. As a starting point, it is sufficient to point out that the planned screening system is based on a single-lead ECG-system (Eidhoven I) and the first experimental installation has functioned successfully since January 1979, at the Pulmonary Screening Station of Gödöllő. For the sake of rapid recording, electrocardiograms are recorded on patients standing upright.

As a technical apparatus suitable for mass screening has to be developed, the primary concern is the highest possible automation of the examinations and of the medical decision tasks. Obviously, a high-speed digital computer is needed for this purpose. This, however, immediately raises the question of economy. Evidently, a general-purpose computer cannot be installed at each screening station, not even a small computer. Moreover, neither is the connection of the single screening stations as terminals to a central large computer a generally practicable solution, because this would *a priori* involve data transmission lines and a carefully organized collaboration.

The solution is represented by microprocessors, becoming today ever cheaper and steadily gaining new fields of application. Microprocessors permit to supply the planned cardiological screening stations at a relatively low cost

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with special purpose computers, suitable for automating the special functions of preprocessing and decision of the said screening examinations.

Essentially, the task can be divided into two main parts. On the one hand, an electronic special-purpose equipment has to be designed for recording and transitory storage of ECG registrates and accompanying data, while on the other hand the data processing and decision algorithm to be realized with this special purpose equipment has to be formulated.

As a starting point, those ECG parameters had to be selected, which can be readily measured also on the electronically stored records. This task was performed by Dr. Attila NASZLADY, Head of Department at Korányi National T. B. and Pulmonological Institute, Cand. of Medical Sciences, further by Dr. József NÉMETH, senior assistant. (The parameters selected will be given in the following.) The next step was the formulation of the decision rule, which, based on the aforementioned parameter set, realizes the essence of the screening task, the separation of ill and healthy patients, indicating, naturally, in the case of ill patients, the diagnosis the most likely on the basis of computer processing. Actually, it was attempted to reproduce some well-known and proved medical decision rules on the basis of the parameters measured. In a later phase of our investigations, when adequate archives material of several ten thousand electrocardiograms will be available, we intend to develop decision rules by mathematical-statistical methods.

In the following, we describe in detail, needed for understanding the basic functions, the actual microprocessor-based special-purpose equipment working at the Pulmonary Screening Station of Gödöllő, under the surveillance of Head Physician Dr. Tamás VÁRADY, which has already recorded and preprocessed on a digital tape recorder several thousand electrocardiograms in 1979. The further processing and evaluation of these data was made on a general-purpose computer Model IBM 370/115, operated at BME-HEI.

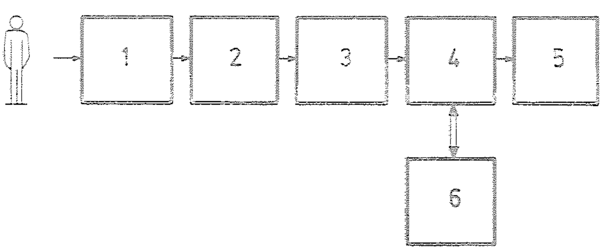

Fig. 1. Flow chart of the special-purpose equipment. 1. ECG apparatus; 2. Analogue filter; 3. A/D Sampler; 4. Microcomputer INTEL 8080; 5. Digital tape recorder; 6. Display (control)

Fig. 1 shows the flow chart of the special-purpose equipment for the digital recording of the electrocardiograms.

At present, an electrocardiograph Model EMG-4561 is used. Its output signal is sampled at a frequency of 300 Hz. However, to apply the sampling theorem, the bandwidth of the analog signal must be limited, in the present case to 150 Hz. An eighth-degree analog active filter, built up from RC-elements, is used for this purpose. (According to our experiences, this band-limitation causes no sensible loss of information in the ECG signal itself.) Analog-digital conversion is performed by a Videoton 12-bit Model VAD 260 – 12 converter, operating by successive approximations.

The system is based on an INTEL 8080 microprocessor, in which a 2 kilobyte ROM memory is available for the system-control programs. In the present form of the system, a 1 kilobyte RAM memory serves for storing the sampled ECG data, the quantities derived from these by preprocessing, and the accompanying information needed for identification. The main unit of the digital tape recorder is a "3M" Model DCD-1 data cartridge drive. The storage medium is a "Scotch" Model DC100-A cassette of an average capacity of 100 kilobyte. According to our experiences, this is sufficient for recording about 120 electrocardiograms in the form to be discussed later. The transmission speed of the digital tape recorder is 2400 byte/sec. For the control of the recording process, for typing in the identifiers of the electrocardiogram, etc., an alphanumerical display Model VT-340 is connected to the system.

Since a microprocessor of byte-organization, and a 12-bit A/D converter are used, for the sake of economic storage and rapid processing, the 12-bit data elements will be expediently transformed into 8-bit data elements. Naturally, the method resulting in the smallest possible loss of information will be selected. Therefore, not simply the lowest 4 bit are omitted, but differential coding, complemented by a simple variant of the adaptive round-off, is applied.

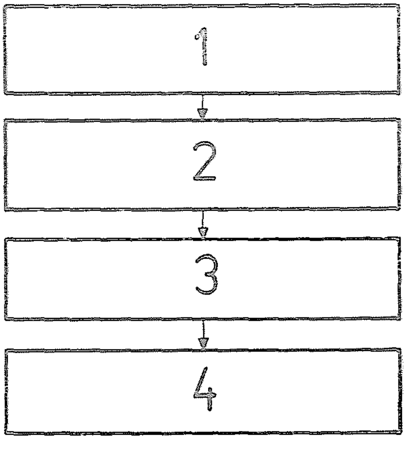

Fig. 2. Main phases of ECG signal recording.
1. Observation of a 2 sec signal section, calibration; 2. Differential coding, filtering, search for R-peaks; 3. Storage in RAM the last 3 sec period; 4. Typing in the identifier, output to magnetic tape

With this solution, the assistant handling the apparatus has not to adjust from recording to recording the amplification and the D. C. level to have the ECG signal filling out completely the whole range of the A/D converter, but one can work continuously with a relatively low amplification, at which the ECG signals of virtually all the patients remain in the appropriate range.

On inspecting the series of differences of adjacent 12-bit samples, it is observed that while in characteristic cases the original signal fluctuates between -5 mV and $+5$ mV, the series of differences remains between -1 mV and $+1$ mV, and even the typical maximum of the difference-series (at the 300 Hz sampling applied) is $0.3-0.4$ mV.

Recording the electrocardiograms follows the simplified flow chart in Fig. 2. Actual recording is preceded by the observation of a signal section of 2 sec. During this time, there occurs in every electrocardiogram practically met at least one R-peak. During this period, the maximum of the 12-bit difference series is searched and multiplied by a safety factor of 1.25. If the first (i.e. highest digit) "1" occurs in the n_0^{th} position in the 12-bit number obtained in this way, then the 8-bit transformed data series

$$i_{n0-1}, i_{n0}, i_{n0+1}, \ldots, i_{n0+6}$$

is truncated during recording from the 12-bit difference signal series

$$i_1, i_2, i_3, \ldots, i_{12},$$

where i_{n_0-1} is the sign bit. Thus, round-off essentially consists in selecting for each recording those 8 bits out of the total 12, which are especially "of interest for us", and these 8 bits are stored.

The 2 sec observation or calibration section is followed by the rhythm control (arrhythmia analysis) of a 10 sec signal section. The sampled values of the last 3 sec part of this 10 sec recording section are stored, to be available for further processing. In addition to this data mass of 3 sec duration, the positions of the R-peaks, calculated by the rhythm control program, are recorded on the digital tape recorder.

The diagnosis of certain types of heart diseases is known to be possible already if only the position of the R-peaks is known along a relatively long (at least $6-8$ sec) recorded section. One of the aims of the present screening is to study the effect of exhalation-inhalation on the behaviour of the $R-R$ distances, that is to say, on the length of the heart periods. We hope to derive in this way parameters of important diagnostic force.

Also the algorithm detecting R-peaks operates on the basis of the difference signal. Essentially it is based on the simple fact that where the difference signal exceeds a certain level, the algorithm presumes an R-peak.

This level is also determined as a function of the maximum, found along the above-mentioned observation section of 2 sec. For the elimination of the 50 Hz noise, (the noise component of largest amplitude) the search for R-peaks is not undertaken on the original difference curve, but on the curve derived from it by 6-point moving average method: in this way the interference effect of 50 Hz can be neutralized. Naturally, however, not this signal, filtered by this primitive digital filter and thus strongly distorted, will be stored, but the noisy, unfiltered difference signal, which is smoothed during later processing by a precise digital filter.

The further processing is made on the IBM 370/115 computer by algorithms written in FORTRAN program language. First an R-peak with the heart period belonging to it, completely sited in the last 3 sec section, is selected. The parameters shown in Fig. 3 of this heart period have been measured. (Subscript A stands for the amplitude of the waves, subscript D denotes their length of time.) The most important values measured are the amplitudes and lengths of time of the Q, R, S waves, the location of the ST-transition, the peak of the T-wave, and the end of the T-wave. The latter is defined as the point where the tangent drawn in the figure is farthest from the T-wave.

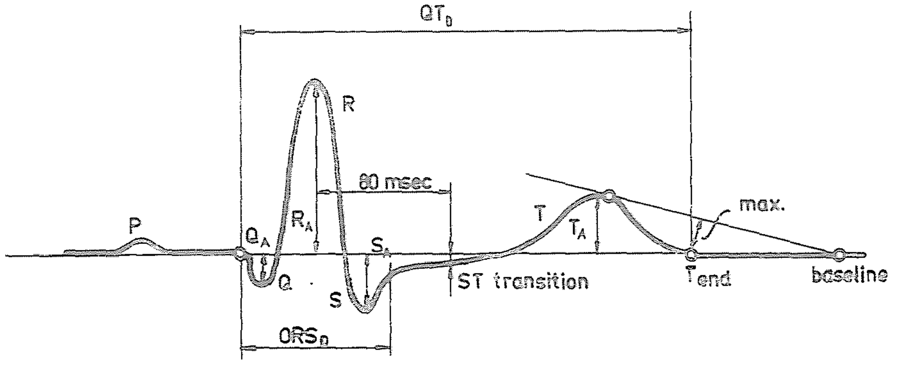

Fig. 3. Measured parameters of the ECG-wave

On the basis of values measured, the program in its present state prints out one or several of the following diagnoses, or none at all, if the algorithm does not find pathological changes:

a) Pathological Q wave, if $Q_A > 0.3$ mV or $Q_D > 40$ msec.

b) Indication of right bundle branch-block, if $QRS_D > 0.1$ s and $|R_A/S_A| > 1$.

c) Indication of left bundle branch-block, if $QRS_D > 0.1$ s and $R_A > 0$.

d) Flat T wave, if $|T_A| \leqq 1/6\,|R_A|$.

e) Isoelectric T wave, if $|T_A| < 0.1$ mV.

f) Abnormal QT distance, if $QT_D \lesseqgtr 0.39\sqrt{(R-R)_{av.}} \pm 0.04$ s (The distance $R-R$ has to be given here in sec units.)

g) Depressed *ST*-section, if the value of amplitude measured 80 msec after the *R*-peak is less than -0.1 mV.

h) Elevated *ST*-section, if the value of amplitude measured 80 msec after the *R*-peak is higher than $+0.1$ mV.

For $QRS_D > 120$ msec, no examinations under *g*) and *h*) are to carry out. In the next period of program development, parameter measuring will be extended also to the *P*-wave.

Another program performs detailed arrhythmia analysis. This comprises among others the determination of pulse frequency and also the percentage variance of the $R-R$ distances. $R-R$ distances are plotted as a function of time. Moreover, it depicts a diagram of the $R-R_{(i)}$ values as a function of $R-R_{(i-1)}$ values. Thus, in this diagram the points are by 1 less than the number of heart periods found in the 10 sec section investigated. In the normal case (i.e. when the lengths of period are influenced only by the respiratory arrhythmia), this curve has the shape shown in Fig. 4, that is to say, a shape approximating an ellipse, located around the average values. Deviations from this shape carry important diagnostic information, the detailed analysis of which is also included in our future program.

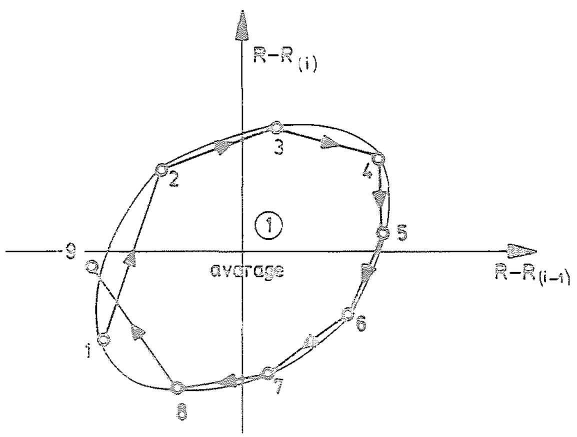

Fig. 4. Diagram of the lengths of periods
$R-R_{(i)}$ is the length of time between the *i*-th and the $(i+1)$-th *R*-peak

In the near future we plan to complement our present experimental equipment with further *IC* units of type INTEL and with commercial multiplying circuits. Thus, our equipment will be suitable also to perform the following tasks:

(*a*) Storage of cardiological signals of "arbitrary" length, limited only by the capacity of the magnetic tape cassette;

(*b*) digital filtering of the sampled signals, satisfying high quality demands;

(*c*) condensing of the sampled signal sequence improving utilization of the storage capacity of the cassette;

(*d*) on-line measuring of the characteristic ECG parameters within the microprocessor, which means considerable further reduction of useful information; and finally

(*e*) on-the-site-diagnosis.

In addition to solving the screening tasks listed, the described equipment (or one of similar structure) may become an important aid in the intensive-care units, too.

Summary

The development of health services tending to the creation of an integer screening network, foundation of a cardiologic screening network became timely. A technical and economical possibility resides in the generalization of relatively unexpensive microprocessors. A description will be given of the microprocessor data collection system type INTEL-8080 developed by the Research Group on Informatics and Electronics, Hungarian Academy of Sciences, at the Institute of Communication Electronics, Technical University, Budapest, according to instructions by experts in cardiology at the Korányi National Pulmonological Institute, and successfully applied at the Pulmonary Screening Station in Gödöllő since January 1979. Single-lead ECG records are processed in an IBM 370/115 digital computer at the Institute of Communication Electronics. Construction and operation of the equipment as well as signal-processing algorithms are presented, and possibilities of development outlined.

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