THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI
FASCICLE III, 1996 YEAR, ISSN 1221-454X
ELECTROTECHNICS, ELECTRONICS, AUTOMATIC CONTROL, INFORMATICS

A METHOD FOR ACQUISITION AND PROCESSING OF ELECTROPHYSIOLOGICAL SIGNALS ON COMPUTER. THE CASE OF ECG SIGNAL.

Rustem POPA, Iuliana CORNEI *

"Dunărea de Jos" Galați University, Electrical Engineering Department, Domnească Street - 111, Galați - 6200, România, Tel : 036.460182
** "Sfântul Andrei" County Hospital, Technical Department, Brăilei Street - 177, Galați - 6200, România, Tel : 036.444444*

Abstract: The acquisition of electrophysiological signals, including ECG signal, is performed with a hardware equipment, according to the medical rules of electrosecurity. The conditioned analog signal is converted into digital form on 12 bits and sent to any computer through serial V24 interface. The samples of signal are stored in a file for future off-line processing. The processing program implements the digital filtering of ECG signals to reduce the influence of internal (muscles, breath) and external (50 Hz) disturbances, detects the specific points of the ECG signal (P, Q, R, S, U, T) and computes the main parameters of the probe, including FFT. The program may be improved in the future research with blocks of parameters recognition using neural networks.

Keywords: ECG signal, isolation amplifier, signal acquisition, serial V24 interface, digital signal processing, neural networks.

1. INTRODUCTION

The registration of ECG signals, known as electrocardiograms, represents the recording of the electrical potential of the heart. Physicians record ECG signals easily and noninvasively by attaching small electrodes to the human body. Electrocardiograms are a standard tool used to diagnose heart disease. The equipment used usually to this purpose has a dedicated construction called electrocardiograph. This paper presents a low-cost hardware coupled with any computer through serial V24 interface. We considered this way more flexible than other IBM-PC interfaces for ECG processing coupled with PC on ISA bus (Iacob, 1993; Gheorghe and Sabău, 1994). The ECG signals have a low amplitude (less than 1-2 mV, but another electrophysiological signals, like EEG signals, have even a much lower amplitude) and they are mixed with other disturbing signals produced by the muscles or by external sources. The patient has to be electrically isolated from the main part of the equipment, for protection reasons. The continuous component in ECG signals must be rejected, because it can disturb the input amplifiers. For all these reasons presented above we designed the equipment in two blocks: one of them for conditioning the ECG signal (amplification, filtering, galvanic isolation, adaptation of output voltage level) and another one for analog-digital conversion with 12 bits resolution and comunication with computer.

A real recorded ECG signal with the most important patterns from the physicians' point of view is shown in figure 1. Physicians first locate such specific

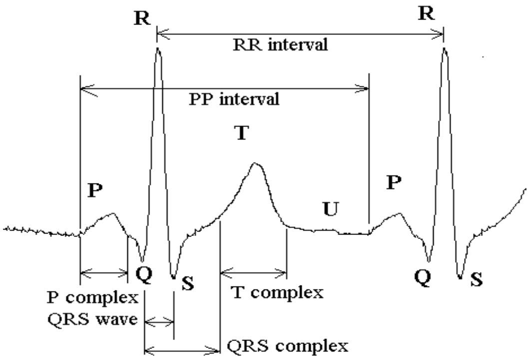

Fig. 1. The patterns of real ECG signal are waves, complexes and intervals defined in this figure.

points as Q, R and S points in the ECG, called by (Suzuki, 1995) as fiducial points, from which they locate P and T complexes and QRS waves. They calculate then parameters (the height and the interval of each wave in fig. 1) to determine whether the ECG shows signs of cardiac disease or not. In recent years some automatic ECG interpreting systems have been developed. Those systems recognize first the fiducial points, then calculate the parameters and finally determine the presence of cardiac disease using the calculated parameters. An ECG interpreting system that is good enough to satisfy physicians' needs has not been developed yet (Suzuki, 1995), because it is dificult to locate the fiducial points with a computer. Also, the shape of the ECG varies with each patient and the signal from the same patient changes as time passes. Statistical methods are not useful for this kind of problem, because a criterion for one patient may not be applicable to another patient.

Our processing program is composed of a set of functional blocks: the acquisition block, which initializes the hardware and handles the ECG signal acquisition, block for off-line waveform visualisation on the screen, the processing block, which implements a digital filtering of acquired signal, detects the fiducial points of an ECG signal, calculates with a good precision the main parameters of the probe necessary for recognition of the signal and finally allows to calculate FFT.

The frequency domain approach, including the advantages of discrete cosine transform spectral patterns for diagnostic, is very interesting and offers new means for ECG processing (Ahmed and Rao, 1975; Iacob, 1993; Neagoe, 1992). Future development of the program will take into account the possibility of parameter recognition in ECG using neural networks (Suzuki, 1995). Neural networks have the ability to learn patterns in response to newly input patterns. Those learning

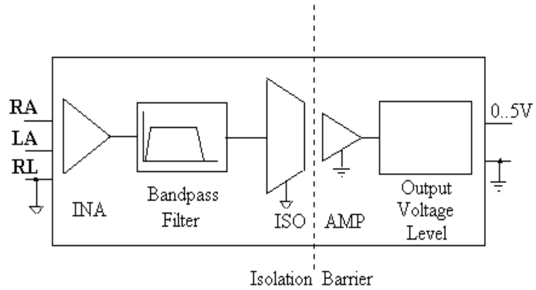

Fig. 2. Block of ECG signal conditioning.

and self-organizing abilities are appropriate for recognition of changing parameters with patient's physical condition.

2. HARDWARE

A channel of ECG signal is acquired with three electrodes: RA (right arm), LA (left arm) and a reference one RL (right leg) for minimization of external disturbances (see figure 2). The input signal is amplified with an instrumentation amplifier (INA) implemented with three super beta operational amplifiers βM108 and precision resistances ($<$ 1%). After being amplified by 500, for another electrophysiological signals this amplification can be greater, the signal passes through a bandpass filter with cut-off frequencies at 0,05 Hz and about 150 Hz, to remove the DC artifact and noise. Amplified and filtered ECG signal is transmitted across a Burr Brown ISO 100 isolation amplifier, with a new amplification of 10. On the other side of isolation amplifier, the signal is added with a positive low voltage to obtain an output of 0 to 5 Volts, necessary for the next block of conversion. At the beginning we introduced a rejection analog filter on 50 Hz, but the experiments pointed that the presence of this filter is not absolutely necessary, so we removed it.

Another hardware component is the block of analog-digital conversion presented in figure 3. The signals of serial V24 interface used for acquisition of samples are: DSR (Data Set Ready) and CTS (Clear To Send) as input digital signals for computer interface, and RTS (Request To Send) and DTR (Data Terminal Ready) as output digital signals.

The analog-digital converter is a CMOS IC, MMC757. The resulting 12 bits appears at SEROUT output of converter and are moved in a serial register on 12 bits implemented with 3 IC's SN7495, by the own clock signal of A/D converter, the output CLK. The output signal $\overline{EOC}$ is HIGH during conversion and LOW at the end of conversion. When $\overline{EOC}$ is LOW, computer takes the control of serial register and reads the bits of data, one by one,

Table 1. The registers of a serial port: 3FE is the input address and 3FC is the output address

	B7	B6	B5	B4	B3	B2	B1	B0
3FE	x	x	DSR	CTS	x	x	x	x
3FC	x	x	x	0	x	x	RTS	DTR

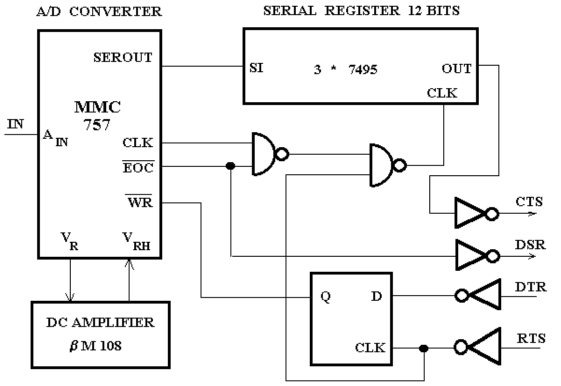

Fig.3. Block of analog-digital conversion.

through CTS output. The shifting of register is controlled by RTS input signal. The DTR signal starts the conversion, but the presence of D flip-flop is optional. Table 1 shows the registers of a serial port for generation and reading the interface signals mentioned above.

Practical experiments pointed that this simple circuit is good for signals acquisition up to 500 Hz. For ECG signals we chose a sampling frequency of 1 KHz, that is about 600-900 samples/cardiac cycle.

This block of conversion needs no sample / hold circuit, because of the low frequency of acquired signal. The error introduced is less than 0,1%, while the nonlinearity error of converter is about 0,2%, according with the IC's specifications from the databook.

3. SOFTWARE

The acquisition block of the program is in connection with the above described hardware. The samples of signal are stored in a file on hard-disk and the block for off-line waveform visualisation shows on the screen the shape of the signal. Such a screen for an ECG signal, before and after filtering, is shown in figure 4.

For digital filtering of noise, it was chosen a method used in 2D images filtering. The principle consists in averaging of each point of image with his neighbours, which have different weights, depending on their position. A window with $n \times n$ dimension was chosen (n - odd number). If $n = 3$,

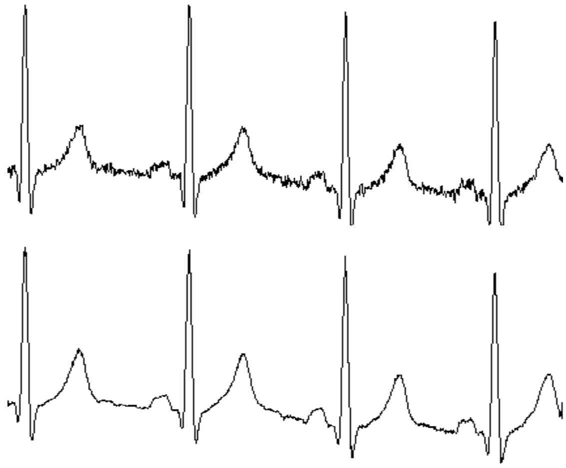

Fig. 4. An ECG signal before and after filtering.

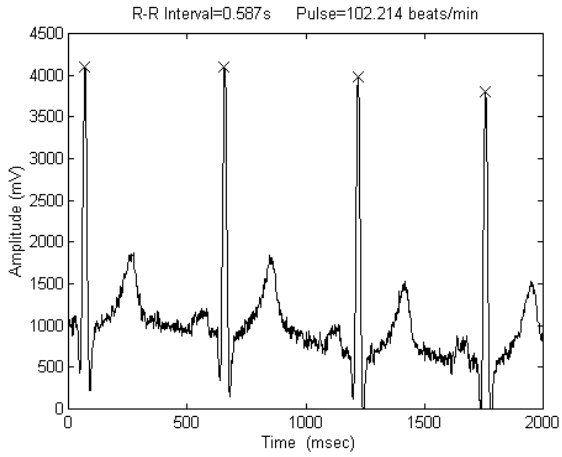

Fig. 5. The detection of R points and calculus of the cardiac frequency.

the window is done in the left. In the right side is the filtering matrix for this window:

$$\begin{array}{ccc} & a & \\ a & 1 & a \\ & a & \end{array} \qquad \begin{array}{ccc} 0 & a & 0 \\ a & 1 & a \\ 0 & a & 0 \end{array}$$

The weight a is a number between 0 and 1. The central element of weight 1 takes a new value according with the weighted average of his neighbours. For signals with a single dimension, the window is a vector with n components. If the signal is stored in the vector $\left[v_1\ v_2\ v_3\ v_4\ v_5\ v_6\ v_7\ \ldots\right]$ and the filtering vector with 5 components is $\left[a^2\ \ a\ \ 1\ \ a\ \ a^2\right]$, then the filtering begins with the v_3 component and its new value will be:

$$v_3 = \frac{a^2(v_5 + v_1) + a(v_2 + v_4) + 1}{2a^2 + 2a + 1} \qquad (1)$$

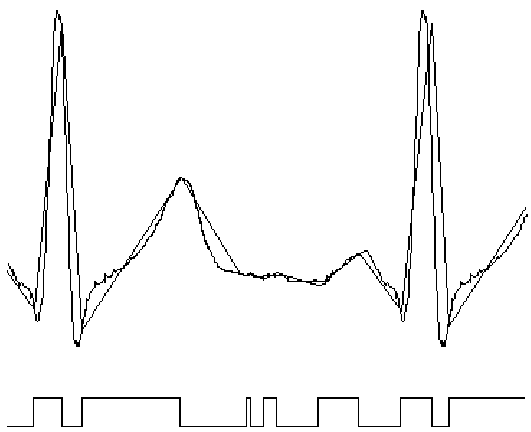

Fig. 6. The detection of fiducial points.

An efficient filtering is obtained when a has a value near to 1. The signal represented in figure 4 was filtered with the parameters: $n = 11$ and $a = 0{,}8$.

The processing program detects the R points as the maximum values of acquired samples, calculates the RR interval and cardiac frequency in beats/min (pulse), as the average value of 3 consecutive RR intervals. The next value of amplitude, usually less then 3/4 of a R point, is a T point. The calculus of the waves and complexes of ECG signal is made by finding the fiducial points, through "derivation" on a window of dimension $2f+1$, f being a parameter of the program. The decision about affiliation of $v[i]$ point to the crowd of fiducial points is taken if $|S_1 - S_2|$ is less than a threshold value r, another parameter of the program. The expressions of S_1 and S_2 are:

$$S_1 = \sum_{k=1}^{f} v[i-k] \quad , \quad S_2 = \sum_{k=1}^{f} v[i+k] \qquad (2)$$

The modification of the slope on less then 10 consecutive samples is ignored, because of the noise in the signal. After the identification of fiducial points, they are joined with straight lines, like in figure 6, and the calculus of the ECG signal parameters is not a difficult problem. The fiducial point U is most difficult to detect on account of his little amplitude. Our program detects this point with a good precision on more than 95% of ECG signals registered in our database.

Figures 7 and 8 offer precisely representations of the parameters of the same ECG signal, before and after filtering. Although the digital filtering cut the

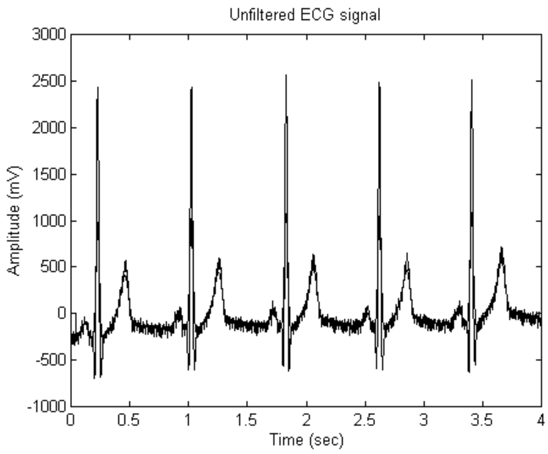

Fig. 7. A MATLAB representation of an ECG signal before filtering.

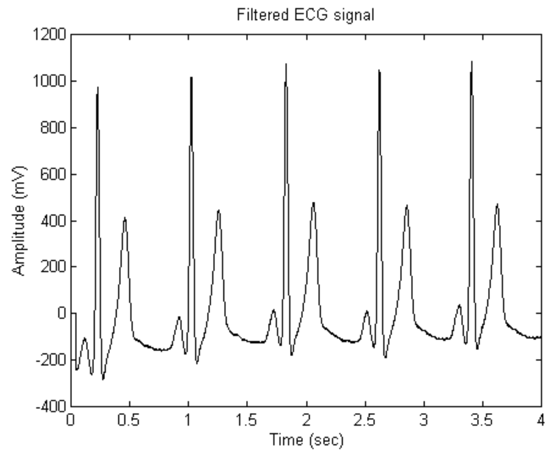

Fig. 8. A MATLAB representation of an ECG signal after filtering.

amplitude of R wave, the shape of the signal is preserved.

For the representation of the Fourier spectrum, the signal is cut-up with a Hanning window. Almost all components of interest in the spectrum are below the frequency of 40 Hz. The graphical MATLAB representations of the Fourier spectrum for the signals given in the figures 7 and 8 are done in the figures 9 and 10. A better filtering of the external disturbances in the signal, without affecting of spectral components like in figures 9 and 10, is possible by eliminating the 50 Hz component in the spectrum and calculating then an inverse FFT.

The programs have been written in C, ASSEMBLER and MATLAB. The whole equipment was tested and the measurements were provided on a 386 SX computer, with a clock frequency of 40 Mhz.

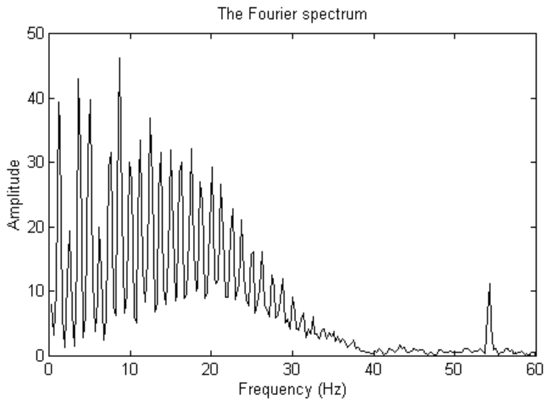

Fig. 9. A graphical representation of the Fourier spectrum for an ECG unfiltered signal.

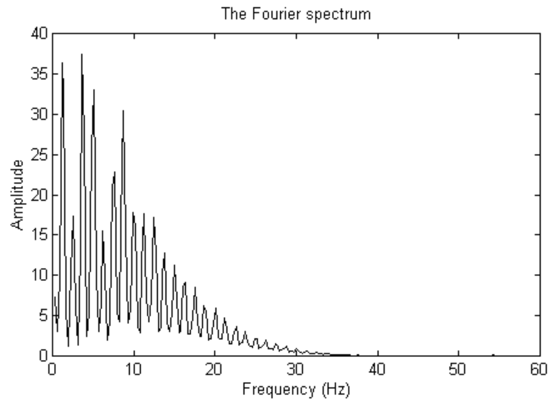

Fig. 10. A graphical representation of the Fourier spectrum for an ECG filtered signal.

4. CONCLUSIONS

This paper presents a methodology of acquisition and processing of ECG signal, on a single channel, using an original hardware and software conception. Another electrophysiological signals, like EEG, EMG and many others, can be acquired and processed in the same way. There are presented the hardware components and the principles of software implementation. The approach offers some advantages like a quite simple hardware, precision in data acquisition, automatic detection and computation of ECG signal's parameters and the possibility to generate a database on computer with the ECG probes.

For a multichannel acquisition the circuit must be modified by introducing a multiplexer. Some other improvements may be done in an eventualy second prototype, like the replacement of ISO 100 isolation amplifier with a cheaper one, as ISO 122 for example. Another hardware alternative solution is to convert the analog ECG signal before galvanic isolation and to transmit the digital data to computer through optocouplers. In this case, the problem of energy transmission from the power supply through the isolation barier is more difficult than in our practical implementation.

Software detects the fiducial points of the signal and calculates with a good precision the parameters necessary for recognition. But recent results (Suzuki, 1995; Neagoe, 1992) indicate methods of better recognition. Suzuki (1995) proposed the use of neural networks for self-organizing QRS-wave recognition in ECG and the average recognition error of his system is less than 1 ms for the Q and S points. Other authors (Neagoe, 1992; Ahmed, 1975) pointed the advantages of discrete cosine transform spectral patterns for diagnostic. Future improvement of the program will take into account all this considerations.

REFERENCES

Ahmed, N. and K. R. Rao (1975). *Orthogonal Transforms for Digital Signal Processing,* Springer - Verlag, Berlin, Heidelberg, New York

Armaşu, I. (1996). *Sistem de achiziție şi prelucrare a semnalului ECG pe PC,* Diploma Work, Galați, Guide: R. Popa

Gheorghe, S. and M. Sabău (1994). ECG signals processing on a personal computer. In: *Proceedings of Symposium on Electronics, november 1994,* Cluj - Napoca, 173 - 179.

Iacob, F. (1993). IBM interface for ECG processing. In: *Proceedings of the 9-th World Conference "Control Systems and Computer Science",* Bucharest, 310 - 315.

Neagoe, V. E. (1992). Ischemic heart disease diagnosis using classification of ECG spectral patterns. In: *Semnalul biologic,* (coord. E. Nicolau and R. Strungaru), Academy Ed., Bucharest, 177 - 182.

Suzuki, Y. (1995). Self - Organizing QRS - Wave Recognition in ECG Using Neural Networks. In: *IEEE Transactions on Neural Networks,* **6,** *1469 - 1477.*