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A LOW-COST ELECTROCARDIOGRAPH INTEGRATED WITH A MULTIMEDIA AND AUTOMATIC ANALYSIS SYSTEM

Elisabeth Costa Monteiro, Carlos Hall Barbosa, Raul Hernández Tabares, Cassio Scheffer, Raul Queiroz Feitosa

Pontifícia Universidade Católica do Rio de Janeiro, Rio de Janeiro, Brazil

Abstract – This paper presents a computerised low-cost electrocardiograph system for application in low-income communities. The system hardware is connected to the serial port of an IBM-PC microcomputer, and integrated with a multimedia software, which controls the acquisition process, manages patient data, provides information on heart disease prevention, and performs an automatic analysis of the electrocardiogram signals. The main objective is to provide a screening diagnosis of patients with heart diseases, forwarding them to a specialist to further analyses.

Keywords*:* instrumentation, ECG, multimedia

1. INTRODUCTION

An electrocardiogram (ECG) is a noninvasive diagnostic tool that records the electrical activity of the heart, presently being the most widely used biomedical instrument for the investigation of heart diseases [1]. Also, it is metrologically certified by several standards organisations world-wide. Virtually any physician is able to interpret an electrocardiogram and infer a large amount of information about the patient's health. Albeit its large application, its cost is not always affordable by some non-governmental, non-profit health care organisations, especially those localised in low-income communities of developing countries, where generally only a small, and poorly equipped, health station is available.

A low-cost system called SABIO (acronym in Portuguese for "Interactive System for Acquisition and Analysis of Biomedical Signals") has been developed, based on discrete analogue and digital components and circuits, aiming at enhancing the quality and availability of health services, specially in low-income localities where there is no cardiologist present.

The main focus of the entire project was to make the system as user-friendly as possible, making extensive use of multimedia and automation techniques. The hardware is based on conventional bioelectric signals acquisition methods, allowing the measurement of the twelve standard ECG leads. Another key concern was to provide information on heart diseases prevention, based on interactive multimedia presentations.

Next section presents an overview of the whole system, followed by sections describing the two main subsystems: hardware and software.

Fig. 1: "Interactive System for Acquisition and Analysis of Biomedical Signals" (SABIO).

2. SYSTEM OVERVIEW

Fig. 1 shows an illustration of the SABIO ECG system. Ten electrodes are connected to the patient (four electrodes connected to the limbs, and six precordial electrodes, attached to the chest), allowing all twelve standard ECG leads to be measured. The recorded signal (electrocardiogram) is divided into six limb leads called I, II, III, avL, avR, avF, and six precordial leads V1, V2, V3, V4, V5 and V6.

The SABIO system can be divided into 2 main subsystems:

– SAAC: Subsystem for acquisition, amplification and bioelectric signal conditioning.
– SPII: Subsystem for processing, interpretation and interactivity.

3. SAAC SUBSYSTEM

The SAAC subsystem is composed by two separate printed circuit boards, both fed by an isolated power supply with 8 kV isolation voltage. The first circuit, analogue (see Fig. 2) contains a multiplexed instrumentation amplifier to which a pair of bioelectric sensors is connected, depending on the desired lead, which is digitally selected and the proper signals routed through analogue switches. After amplification, the signal is high-pass filtered by a passive circuit at 0.5 Hz, and low-pass filtered by a 2nd order Bessel filter with 150 Hz cut-off frequency. A 60 Hz digital notch filter with –120 dB roll-off is later employed by the acquisition software.

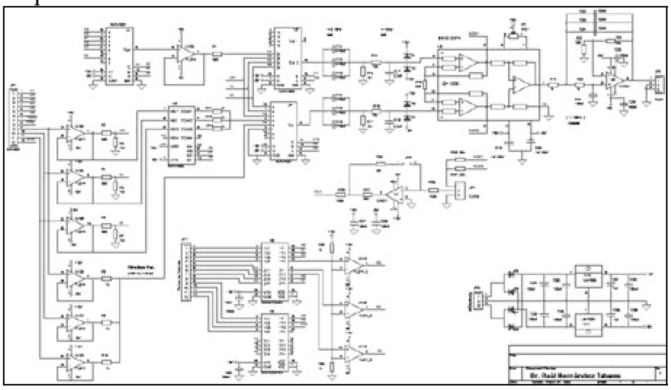

Fig. 2: ECG’s analogue electronic circuit, comprising the selection switches, filters and instrumentation amplifier.

The second circuit, shown in Fig. 3, contains a digital microcontroller coupled to a 16-bit A/D converter and to a isolated serial transceiver, being responsible by serial communication with the microcomputer and by A/D conversion of the ECG signals measured by the analogue hardware. This hardware is isolated from the microcomputer by optocouplers. The acquisition rate is 1,024 samples/sec.

4. SPII SUBSYSTEM

The SPII subsystem is composed by a set of independent programs, implemented in distinct platforms, and interconnected through Macromedia. These programs are responsible for the following tasks:

- LabVIEW: Acquisition of the bioelectric signals.
- C: Automatic analysis of the acquired waveforms.
- Macromedia: Interactive multimedia for training and heart diseases prevention.

Besides providing an intuitive graphic user interface (see Fig. 4) the signal acquisition and storage program also controls the interaction with the automatic interpretation and multimedia software. Multimedia applications control the acquisition process, manage patient data and promote the interactivity of the preventive tutorial and equipment training programs.

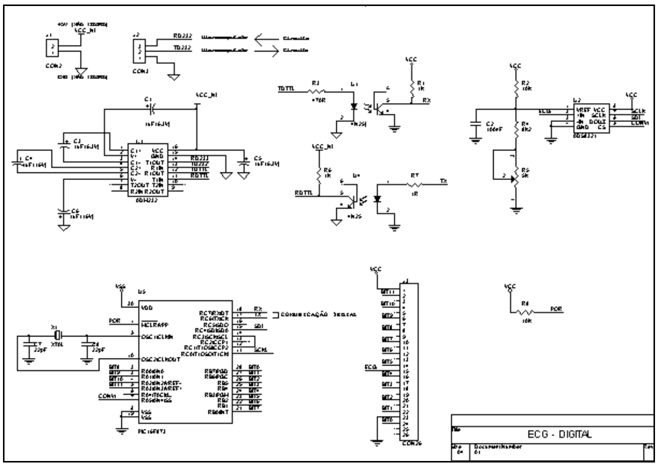

Fig. 3: ECG’s digital electronic circuit, comprising microcontroller, A/D converter, optocouplers and serial transceiver.

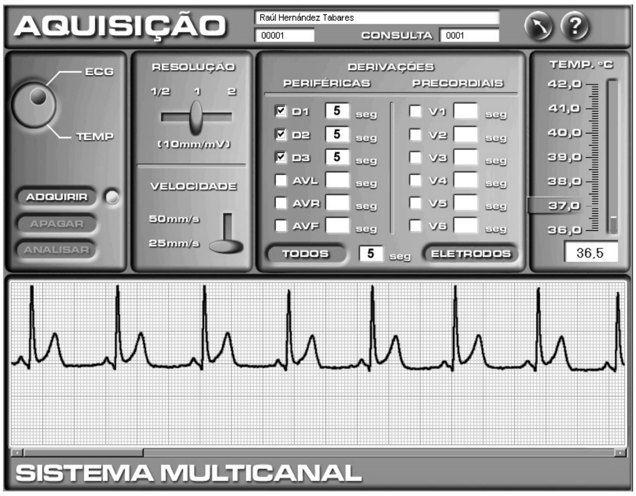

Fig. 4: Main window of the program for acquisition and storage of bioelectric signals for the SABIO electro-cardiogram system.

The educational program comprises not only the preventive tutorial, but also provides information about the functioning of the heart. This section is performed on non specialized language in order to be well understood by non professional users (see Fig. 5). The lifestyle goals for coronary heart diseases are didactically presented including themes like smoking cessation, healthy food choices, physical activity, and other risk factors control as body mass, blood pressure, plasma total cholesterol, plasma lipid levels and diabetes mellitus.

5. AUTOMATIC ANALYSIS

The limb leads of the electrocardiogram can be considered as projections of an equivalent current dipole (that encompasses the electrical propagation in the heart) on various directions in the frontal plane, whilst the precordial leads are projections on the transverse plane.

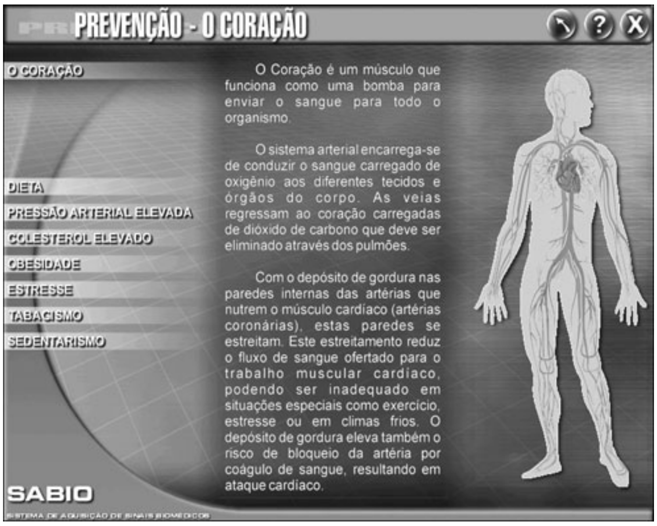

Fig. 5: Example of the preventive tutorial windows of the SABIO electrocardiograph system.

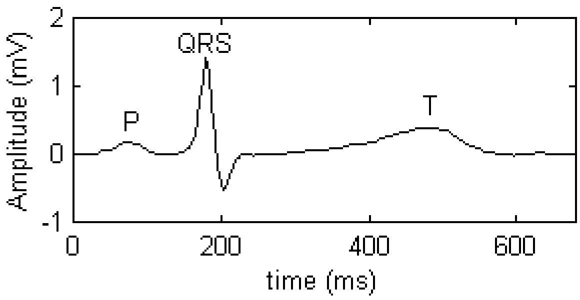

Fig. 6: ECG signal measured by lead II, depicting the three distinct wave components: P, QRS and T.

Fig. 6 shows a typical lead II measurement, where it can be clearly seen that the signal is composed by various separate waves, each one corresponding to a specific electrical event on the cardiac cycle.

The P-wave corresponds to atrial electrical activation, the QRS complex corresponds to ventricular electrical activation, and the T wave to ventricular electrical recovery.

The analysis of an ECG record is performed in three sequential steps. In the first step the signal is pre-processed, in order to produce a single noise-free wave sample, as illustrated in Fig. 6. In the second step the constituents of the ECG wave (P,Q,R,S,T) are located by identifying the instants corresponding to the following events:

- P-wave onset, peak and offset
- QRS-complex onset and offset
- R-wave peak
- T-wave peak and offset

Still in the second step, the amplitude and/or duration of the waveforms are measured, which are the so-called ECG parameters:

- Heart rate (bpm)
- P-wave duration (ms) and amplitude (mV)
- QRS-complex duration (ms)
- R-wave amplitude (mV)
- T-wave amplitude (mV)
- PR interval duration (ms)
- QT interval duration (ms)

The procedure applied in this second step relies on a structural description of a typical ECG wave in terms of the singular points (local minima and maxima) of the wave itself as well as of its first to forth derivatives. This description consists of a set of heuristics derived from a careful observation of many noise-free wave samples.

As an example consider Fig. 7 which shows a wave sample. In Fig. 8 the region containing the T-wave is enlarged. A heuristic applied by SABIO states that the T-wave onset (A) corresponds to the highest peak of the second derivative (B) within the interval defined by the deepest valley of the signal after the QRS complex (C) and the T-wave peak (D). Another heuristic locates the T-wave offset (E) as the point where the second derivative reaches the maximum value (F) after T-wave peak (D). All relevant events are located by applying similar heuristic rules on the signal and its derivatives.

Fig. 9 shows the results of the heuristic analysis algorithm, and Table 1 shows the parameter values extracted from the ECG signal, once the onsets and offsets have been determined.

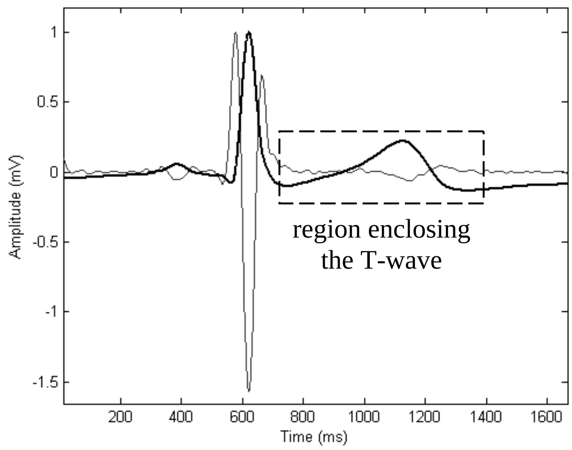

Fig. 7: ECG wave sample (thick line) and its second derivative (thin line).

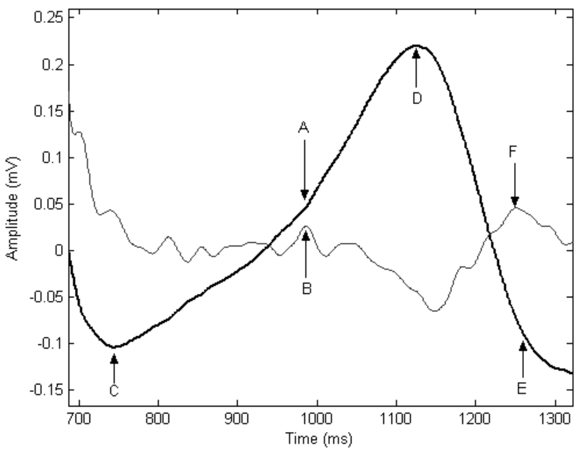

Fig. 8: Zoom of the T-wave (thick line) and its corresponding second derivative (thin line).

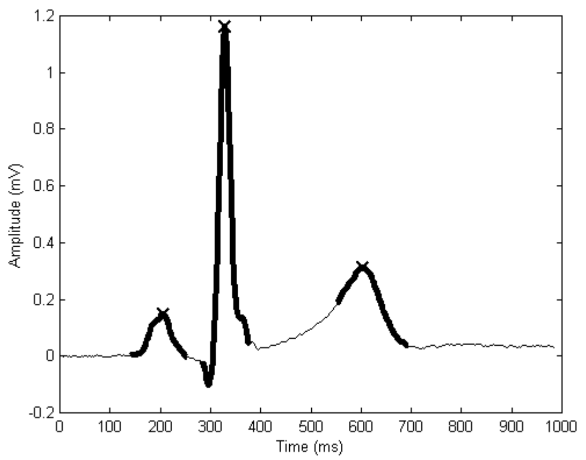

Fig. 9: Wave segments (thick lines) corresponding to P-wave, QRS-complex and T-wave, as determined by the heuristic analysis algorithm.

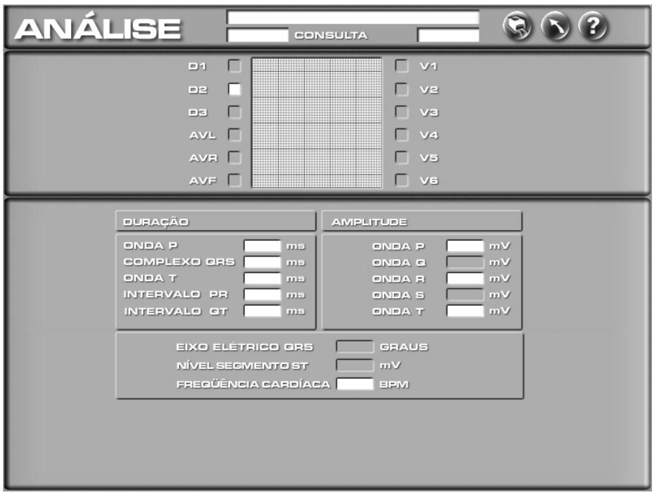

Fig. 10: Main window of the program for presentation of the electrocardiographic waveform parameters informed by the automatic analysis.

Table 1: Parameters measured for the signal in Fig. 9.

ECG Parameter	Value
Heart rate	61.1 bpm
P length	113 ms
P amplitude	0.150 mV
QRS length	96 ms
R amplitude	1.16 mV
T amplitude	0.290 mV
PR interval	142 ms
QT interval	411 ms

The parameter values obtained through the automatic analysis, like the ones shown in Table I, are then presented to the user through an interactive analysis window, as shown in Fig. 10, where one can choose which electrocardiographic lead to get information of the waveform parameters.

The recognition of abnormalities concerning the cardiac rhythm and electrocardiographic waveform parameters is performed by means of automatic pattern recognition techniques in the third and last step.

6. DISCUSSION AND CONCLUSIONS

An interactive system for acquisition and analysis of biomedical signals, called SABIO, has been developed at PUC-Rio University. The present system presents a total cost about three times lower than conventional commercial electrocardiograph instruments.

The low cost of the developed instrument, associated with the automatic analysis algorithm, contributes for the enhancement of the quality and availability of health services, especially in low-income localities where in general no cardiologist is present. In this case, according to the necessity verified by the automatic pre-analysis the system can perform in the community, the patients can then be forwarded to more specialised medical centres.

Even for the specialised physician, the automatic information of electrocardiographic waveform parameters in comparison to the qualitative analysis of this time signal data can provide a faster and more accurate diagnostic. In addition, the developed low-cost system presents the advantage of allowing the possibility of been used by persons without any extensive medical training, since an interactive multimedia for training is available.

All over the world, cardiovascular disease is a heavy burden. An adequate preventive program can reduce risk in patients with coronary heart disease because so many do not achieve the recommended lifestyle and risk factor goals [4]. Since the SABIO electrocardiograph system provides an interactive educational program comprising a preventive tutorial and informations about heart functioning, this system has a considerable potential to contribute to a better quality of a preventive educational strategy not only for the non specialised team in the health services but also for the domestic and familiar use of this equipment [5].

The automatic analysis module is still being improved. In a next version of this module, it is intended to incorporate more sophisticated approaches of signal analysis in order to obtain a higher accuracy and precision in the determination of wave morphology parameters. Such approaches include artificial neural networks [2] and wavelet transforms [3], aiming at automatic detection and classification of heart diseases.

7. REFERENCES

[1] J. G. Webster, "Medical Instrumentation: Application and Design ", *John Wiley & Sons*, New York, NY, 1998.

[2] S. Haykin, "Neural Networks: A Comprehensive Foundation", *Prentice Hall*, Upper Saddle River, NJ, 1999.

[3] K. Sternickel, "Automatic pattern recognition in ECG time series", *Computer Methods and Programs in Biomedicine*, vol. 68, no. 2, pp. 109–115, May 2002.

[4] David Wood, "The treatment potential in preventive cardiology", *Atherosclerosis Supplements*, Volume 2, Issue 1, pp. 3-8, 1 February 2001.

[5] David Wood and on behalf of the Joint European Societies Task Force, “Established and emerging cardiovascular risk factors”, *American Heart Journal*, Volume 141, Issue 2, Part 2, pp. 49-57, February 2001.

Authors: Elisabeth Costa Monteiro, Carlos Hall Barbosa, Raul Hernández Tabares, Cassio Scheffer, Raul Queiroz Feitosa, Department of Metrology and Department of Electrical Engineering, Pontifícia Universidade Católica do Rio de Janeiro, Rua Marquês de São Vicente, 225, RJ 22453-900, Rio de Janeiro, Brazil, (5521) 3114-1258 (241), fax: 3114-1271, beth@fis.puc-rio.br.