

A New Tool for Heart Disease Prognosis in the Community

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Abstract

The aim of this paper is to discuss the main characteristics of a system created to study, in a community, the evolution of people suffering cardiac disease or people prone to suffer it. The system has two main components: a portable device for ECG acquisition, henceforth Recorder, and Windows-compatible software, named Analyzer, to storage and study the signals acquired by the recorders. The Register acquires the twelve leads of the standard electrocardiogram (ECG) simultaneously. These signals and the mean heart rate are displayed on the device screen. When the operator requests, the Recorder measures the amplitude and duration of all ECG waves and other relevant electrocardiographic event. All the information is stored on the Recorder; this data is then transmitted, via USB, to a personal computer running the Analyzer. The received information is stored in a SQL database and the trend of the following ECG parameters is computed for each patient: spatial dispersion of QT interval is studied to predict dangerous arrhythmias; the Sokolow Index is analyzed due to its relationship with ventricular dilatation and hypertrophy. Also, the progression of R wave amplitude in chest leads is studied in patients who have suffered a heart attack. The Recorders are able to connect to a Telecardiology system, developed by the authors, in order to ask for advice in a sudden urgency. Five prototype Recorders have been manufactured and evaluated successfully according to the IEC 60601-2-51 standard. The CSE database was used to test the ECG processing algorithms. The average error in the measurements of the QT interval length was 7,62 milliseconds; all the mean errors in measurements of the ECG waves met the tolerances described in the IEC 60601-2-51 standard.

1. Introduction

Heart disease is one of the three leading causes of death worldwide [1]. It is established that all health system should focus on prevention and prognosis of diseases such as task priority. In the case of heart disease,

there are some electrocardiographic parameters which are indicators of the presence of certain disease. If these parameters are studied periodically during prolonged periods, they can characterize the behavior of the patient studied.

The detection of heart disease in its early allows more effective medical treatment and a better quality of life for the patient. That is why physicians and researchers are currently working intensively on the primary and secondary prevention of heart disease. Primary prevention means the care of people who are prone to heart disease; they should learn to improve their lifestyle (elimination of smoking, adequate nutrition, physical training, etc.). When a person has already suffered a heart attack, the medical procedure is to include that person in a cardiac rehabilitation program. The secondary prevention is focused to induce healthy lifestyles and to make regular reviews to detect any early signs of another attack. The rest ECG is a low-cost cardiac test that provides valuable information to reach this kind of cardiac prevention.

The aim of this paper is to present and discuss the main features of a system, called CardiHogar, which has been designed to study people in a community, especially those prone to heart attack or who already have suffered with the to study the evolution of different ECG parameters. This kind of study is focused on the prediction of cardiac complications.

2. Materials and methods

The proposed system is composed by two main elements: a portable device for rest ECG acquisition, henceforth Recorder, and Windows-compatible software, called Analyzer.

The CardiHogar recorder design was focused on the following goals: to get a low-cost device able to get a high quality rest ECG; this device must be easy to use at any place. These recorders are based on an ARM9 microprocessor operating at a frequency of 400 MHz; they have the following features:

- Graphic LCD with touch screen interface.
- Soft keypad.

- USB interface.
- Embedded modem with TCP/IP stack.
- Eight-channel ECG amplifier.
- SD memory.
- NiMH battery-pack.
- Medical grade's power supply.

The multichannel ECG amplifier is dedicated to acquire and adequate the electrocardiographic signals generated by the patient. These analogue signals are converted to digital values at a sampling rate of 500 Hz [2].



Figure 1. View of CardiHogar recorder.

The ECG amplifier includes an analog band pass filter in order to limit the frequency spectrum of the signal between 0.05 and 100 Hz, according to the IEC 60601-2-51 standard [2]. Circuits connected directly to the patient are protected against defibrillator discharge through 10 kΩ resistors and includes the classic right-leg circuit to improve the common mode rejection ratio [3]. The detection of pacemaker spikes is made from lead II. For this, the signal at the output of the instrumentation amplifier is passed through a filter that isolates the ear and fired a single shot each time identifies one of these events. A circuit named “trace recover” trace is implemented to recover the baseline level when an electrode is disconnected and connected again.

$$y(k) = \frac{1}{K^2} \sum_{m=k-K+1}^k \sum_{n=m-K+1}^m x(n) - \frac{1}{L^2} \sum_{m=k-L+1}^k \sum_{n=m-K+1}^m x(n) \quad (1)$$

where:

x(n): input signal

y(k): filtered signal

K, L: constants according to the cutoff frequency

The eight independent leads (I, II, V1, V2, V3, V4, V5 and V6) are digitized simultaneously at a frequency of 500 Hz with a twelve-bit A / D converter; the LSB value is 3.15 microvolts. Classic expressions can be used to

compute the other four leads (III, aVR, aVL and aVF) because of the simultaneity in the acquisition of leads I and II [4]. When the signal is digitized, a digital filtering scheme consists of a FIR filter of the moving average type and a 60 Hz notch filter is applied in real time to improve the signal quality.

The QRS complexes are detected in real time to calculate the heart rate when ECG is acquired. A function called Function of Spatial Velocity (FSV) is used as an auxiliary function in this process. This function allows to easily differentiating the areas associated with the QRS complexes [4].

$$y(k) = \sum_{i=1}^C [x(i, k) - x(i, k + 1)]^2$$

where:

y(k): the FSV value

x(i,k): ECG for lead I at k time.

C: number of simultaneous leads

When a QRS complex is detected, its RR interval is computed and the average of this interval is updated. The heart rate value is computed every ten seconds and its value is based on the RR interval average.

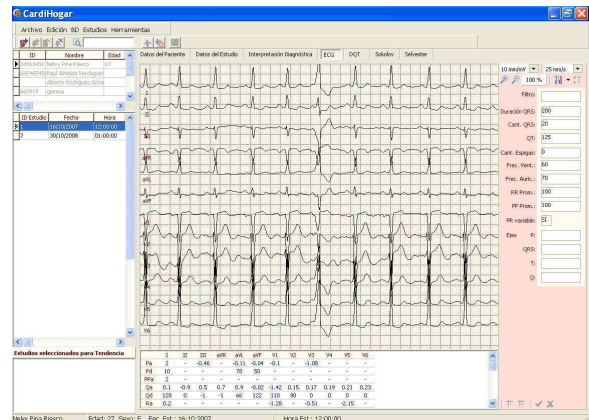


Figure 2. A Rest ECG on Analyzer screen.

If the operator selects the option to store the signal, the ECG acquisition is stopped and the last ECG ten seconds are analyzed automatically. More than 200 electrocardiographic measures are made in three seconds. The main events for each of the leads can be summarized as follows:

- Amplitudes and lengths of P, P', Q, R, S, R' and T waves.
- ST segment deviation.
- PR, QT and QRS widths.
- QT spatial dispersion.
- Time of ventricular activation

For each patient studied, the CardiHogar recorder stores the patient's general data, ECG and measurements on an internal SD memory. The information is written in a proprietary format that ensures its confidentiality. Also, the device is able to transmit the information via a USB interface.

For viewing information, the recorder has a liquid crystal display (LCD) of 800x600 pixels. The touch screen interface makes easy the man-machine communication. The keypad complements the operator interface and its technology facilitates the use and cleaning.

In an emergency, the recorders are able to connect to the TeleECG system (a Telecardiology system developed by the Central Institute for Digital Research). The recorder can send the ECG and receive guidance about the actions to take on the patient studied. The embedded modem is used to set the connection using the traditional telephonic network or using a TCP / IP stack.

The Analyzer stores all information associated with each patient. The physicians use a graphical interface to evaluate patient ECGs; they can see the ECG one by one or they can study the trend of different parameters and thus detect the first signs of a heart disorder. The parameters studied are:

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- Sokolow Index: Associated with the ventricular hypertrophy. It is calculated as the sum of absolute values of the maximum amplitudes of the QRS waves in the chest leads.
- QT interval spatial dispersion: Reported as an indicator to predict the onset of malignant arrhythmias [5]. It is calculated as the difference between the maximum and minimum QT interval duration for a single cardiac cycle of a group of leads acquired simultaneously.
- Selvester Score: A score is assigned based on the fulfillment of certain rules based on the duration and amplitude of the waves that make up the QRS complex. This score is used to estimate the myocardium area affected by a heart attack [6].

The proposed system studies the trend of the parameters mentioned above. Isolated values can be affected by different factors, while the tendency of a collection of values will indicate its behavior over time.

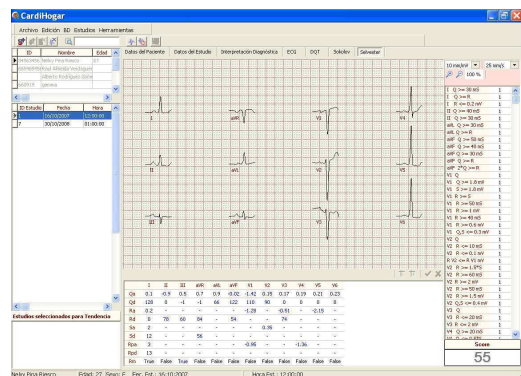


Figure 3. Screen of Selvester Score.

The study of QT interval dispersion for a patient is carrying out a series of ECGs, the calculation of the spatial dispersion of the QT interval for each ECG and the construction of a graph of the dispersion values against time, so a specialist can observe the trend of this parameter and infer whether the person studied is evolving into a dangerous state from the cardiac point of view or not.

The aim of the study of Sokolow Index over time is the early detection of ventricular dilation process because this process appears at the beginning of the ventricular hypertrophy. This type of study makes medical treatment more effective because they are applied on the onset of the disease.

3. Results

Five prototypes have been manufactured and tested; they have successfully passed parametric tests and electrical safety tests established in IEC 60601-2-51 and apply to devices for resting ECG. Some of the main results of these tests are summarized in Table 1; it is impossible to show all of them because of the available space for the present document.

Table 1. Main results of parametric tests.

Parameter	Result
Frequency response	0,05 to 100 Hz
Accuracy and stability of the sensitivity	Less than $\pm 5\%$
Intrinsic channel noise	Less than 30 μV
Common Mode Rejection Ratio	Greater than 90 dB
Patient auxiliary current	Less than 50 μA
Permanent leakage current	Less than 300 μA
Classification according to IEC	Class 1, type CF

The results correspond to those specified in IEC

60601-1-52, so the electronic design solutions used in this device have been effective. The software used for processing the ECG has been evaluated with CSE and CTS databases according to the same IEC standard [2]. In all studied variables, the maximum permissible error in measuring an ECG event has not been exceeded. Some of the results are shown in table 2.

Table 2. Mean differences and standard deviations for global intervals on analytical ECGs.

Interval	Mean error (ms)	Standard Deviation (ms)
P wave	7,02	6,73
PQ interval	6,88	6,91
QRS complex	4,02	5,48
QT interval	8,17	9,12

All the QRS complexes of the ECGs used to test the algorithms were detected; these ECGs are included on the CTS and CSE databases. This result is very good and demonstrates the effectiveness of the methods used.

When the accuracy of amplitude measurements within the QRS complex was analyzed, it was found that the measurements never deviated from the reference more than 25 microvolts for amplitudes little than 500 microvolts or more than 5% for amplitudes greater than 500 microvolts. This behavior is established by the IEC standard as appropriate.

The whole system has also been preliminarily tested with simulated signals and volunteers. The performance has been stable and there were not recorders out of order or software malfunctions.

4. Conclusions

The proposed system has been completed with satisfactory results. All the IEC tests have been passed successfully.

The Analyzer works without problems. This software is easy to use and offers all the feature necessities for this kind of system. The graphical tools make easy the study of cases processed by the system.

The proposed system seems a useful tool for the study of heart disease at the community level.

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