Design and implementation of an electrocardiographical signal acquisition and digital processing system orientated to the detection of paroxysmal arrhythmias.

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Abstract. This article describes the design, technical aspects and implementation of a device capable of acquiring electrocardiograph signals; visualize them in real time over a graphic liquid crystal display (GLCD), and the storage of these ECG registers on a SD memory card. It also details a noise suppression algorithm using the Wavelet Transform. This system was specially developed to cover some bankruptcy that presents actual Holters or ECG regarding the detection of paroxysmal arrhythmias. The contribution of this work is settled on its portability and low production cost. The filtering method used provides an ECG signal without any significant noise and appropriate to the diagnosis of cardiac pathologies.

1. Introduction
Arrhythmia is any irregularity on the natural rhythm of the heart beat. The presence or absence of symptoms depends on the heart condition, type, seriousness, frequency and length of the arrhythmic event. Paroxysmal arrhythmias appear and revert spontaneously. This characteristic makes its detection and registration very difficult. The most appropriate study in this case is a Holter; but, at the same time, it is very inefficient if the arrhythmia does not appear while the Holter is connected to the patient. This work presents the design and implementation of a device, of reduce dimension, that allows to be used even by the patient oneself, simply connecting three electrodes to the chest and activating the device any time the arrhythmia appears. It makes possible to register the paroxysmal event and store a file with the ECG signal on a memory card for further analysis from qualified personal. This characteristic makes the device more efficient than the Holter for this kind of arrhythmias. Furthermore it is very comfortable to the patient because there is no need to be always connected, just the times there is an arrhythmic event.

2. System Overview
This project consists of two well delimited parts (Figure 1). In first place the device makes possible the acquisition, visualization and storage of the ECG signals. Subsequently there are digital processing algorithms and the conditioning process of the signal.

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2.1. ECG acquisition
The designed device is equipped with a 110 dB CMRR instrumentation amplifier [1] [2]. The analog filter bank leaves a band-pass signal that goes from 0.05 Hz to 105 Hz [1][2][3]. Besides, there is a Notch filter at 50 Hz that reduces the currents induced over the patient body and the device by the electrical distribution line [4] [5]. Two mid-range PIC microcontrollers (16F87X) carry out the storage and visualization processes in an independent way. The sampling frequency is 400 Hz and the resolution is 10 bits [7] in order to satisfy the conditions establish by the American Heart Association (AHA) and the SCP-ECG (Standard Communication Protocol for Computerized ECG). These protocols set up the minimum requirements for the digitalization of ECG signals in a sampling frequency of 250 Hz and a resolution of 8 bits.

The graphic display is a transmissive type and has a blue backlight that allows working in places dimly lit. The speed of the ECG signal over the display is 25 mm/sec which is one of the standards speeds of actual electrocardiographs.

The second microcontroller implements a FAT16 [8][9] file system over the SD memory card[10][11]. It generates text files that contain the samples of the ECG signal. The sizes of these files are 96 KB and contain 30 seconds registers. The name contains information of the date the signal was acquired. While in the files properties, the exact time and date of acquisition can be found. This information is taken from a real time/calendar clock (RTCC) that is read just before each file is generated.

2.2. Noise suppression using the Wavelet Transform
The ECG signal presents different kinds of noise-problems. The most frequent ones are the distribution line interference and the baseline wander. The last one is due to the movement of the electrodes over the patient body, physico-chemical alteration on the electrode-skin interface and the noise produced by the muscles involved in the respiration during the study.

2.2.1 Fourier Transform vs. Wavelet Transform
The Fourier Transform presents certain limitation such as temporal information of the processed signal. It means that FT fails to determine the exact moment at which certain frequency component appears. On the other side, the Wavelet Transform gives specific information in both, time and frequency [12], which makes it a very handy tool in the study of non stationary signals like ECG.
According to some properties of the Wavelet Transform, it could be seen like a band-pass filter [12] [13]. Considering this, the Wavelet Transformation of a signal could be represented as a signal passing through a filter bank, making possible to use it in the noise suppression process.

2.2.2. Wavelet de-noising
The de-noising [13] [14] procedure aims to suppress any noise, including the line frequency interference (50 Hz) added to the acquired ECG signal. There are three processes to be considered:

1. Decomposition. Choose a wavelet, and choose a level N. Compute the wavelet decomposition of the signal s at level N.
2. Detail coefficients thresholding. For each level from 1 to N, select a threshold and apply soft thresholding to the detail coefficients.
3. Reconstruction. Compute wavelet reconstruction based on the original approximation coefficients of level N and the modified detail coefficients of levels from 1 to N.

In order to filter the signal, the MATLAB “wden” function was used. The algorithm that provides the best results consists of a decomposition process of the signal up to the level 4, a soft threshold and a Daubechies 6 wavelet.

2.2.3. Baseline wander reduction
The baseline wander is due to low frequency interference. To reduce this interference the “wavedec” and “waverec” [13][14] MATLAB functions were used. The procedure consists on decomposing the signal up to level 9. Considering that the signal sampling frequency in the digitalization process was 400 Hz, this level represents a frequency of 0,78 Hz. The next step is to eliminate the coefficient that contains the frequency that goes from 0 to 0,78 Hz (Figure 4), and then reconstruct the signal using the details coefficients (Figure 5 and 6).
**Figure 4.** Decomposition Wavelet tree at level 9. Approximation Coefficient suppression and reconstruction using the Detail Coefficients.

**Figure 5.** Baseline Wander
3. Results

The device dimensions are 13 x 9 x 4 cm and it is powered by two 9 Volt batteries and a 3V coin battery that keeps actualized the time and date registers. Two LEDs indicate the beginning and ending of the storage process. The user is able to adjust the gain, baseline level, and GLCD brightness and contrast using potenciometers.

A successful implementation of a FAT16 file system over the SD card was achieved. The file extensions, characteristics and the contained information were as expected; as well as the used of the real time/calendar clock (RTCC).

Once the device was built, several studies were made using silver/chloride-silver electrodes. Leads I, II and III were successfully measured. Figure 7 shows the ECG registers displayed on the GLCD screen.

![Figure 7. ECG signal on the GLCD](image)

The results on the de-nosing algorithm and the baseline restoration process were a complete success. In the first case, the algorithms show to be extremely effective removing noise of nearly a 1% of the signal amplitude. Regarding to the baseline wander, constant baseline ECG registers were obtained after the process.
This work have already been showed to cardiologists, which were satisfied by the ECG visualization. Also, the device was tested in some patients. In one case, a patient was able to record himself his own ECG signal during an arrhythmic event (Figure 8).

![Figura 8. Arrhythmic ECG](image)

The good results obtained in this work encourage continuing the research and developing of this device and the studies of new filtering algorithms using the Wavelet Transform.

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