Design and Evaluation of an ECG Holter Analysis System

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Abstract

The aim of this paper is to discuss the design and evaluation process of software for the analysis of ECG signal in a Holter system. The software was developed with RAD Studio 2009 using the Object Pascal language. The complete design and programming process was oriented to obtain different classes that encapsulate the needed functionality and combine them to obtain the final application.

The analysis process was organized in different steps: acquisition of the 3 channels of ECG and other recording information from the record device, filtration of ECG signal to remove movement and electrodes noises, detection and classification of QRS, detection of rhythm events and pacemaker malfunction, search of ST deviation episodes, HRV and spatial QT dispersion studies. All the processes were executed in this order and finalize with the compression and storage of the results.

1. Introduction

Holter monitoring, also known as ambulatory or 24-hour electrocardiography, is continuous monitoring of the electrical activity of a patient's heart muscle for at least 24 hours, using a special portable device called a Holter monitor. Patients wear the monitor while carrying out their usual daily activities.

This is an extremely safe procedure used to help determine whether someone has an otherwise undetected heart disease, such as abnormal heart rhythm (cardiac arrhythmia), or inadequate blood flow through the heart. Specifically, it can detect abnormal electrical activity in the heart that may occur randomly or only under certain circumstances, such as during sleep or periods of physical activity or stress, which may or may not be picked up by standard, short-term electrocardiography performed in a doctor's office. Therefore, it can also help to recognize any activities that may be causing the heart problems. And it can define and correlate symptoms that may be caused by irregularities of the heart.

This paper presents the design and evaluation of the software for acquiring and processing data from a Holter monitor.

2. Description

This kind of systems consists of a recorder, which function is to acquire and store ECG and other related data from the patient, and an application dedicated to read data from the recorder analyze them and show the results. Communication between these two parts is throughout a SD flash memory.

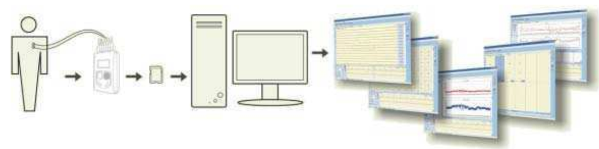

Figure 1. Holter system

The main characteristics of the recorder are:

- 3 channels amplifier
- Power consumption: < 12 mA.
- Power source: 1 rechargeable AA battery.
- Dimensions: 93x64x20 mm
- Weight 80g with battery
- Maximum 72 hours of ECG recording
- Sampling frequency: 500 Hz during the first hour and 250 Hz thereafter

The analysis process was organized in different steps which are explained later on this paper. Due to the large amount of data to be analyzed, all the algorithms were optimized to run fast. It was implemented a transparent buffering mechanism to manage the large ECG data files, performing reading and writing operations from disk as if they were in memory. The average times to analyze recording of 24, 48 and 72 hours were 10, 30 and 70 seconds respectively.

2.1. Acquisition

Data from the recorder are acquired through the SD flash memory. It acquires 3 channels of up to 72 hours of ECG. Other recording information is read too from the record device: patient events, pacemaker spikes and leadoff data.

This process is very fast with times of 2, 6 and 15 seconds for recordings of 24, 48 and 72 hours respectively.

2.2. Filtering

Digital filters are applied to remove movement and electrodes noises. Specifically a moving average filter is applied to stabilize base line and remove some noises. It is also applied a Notch filter of 50 or 60 Hz [1, 2].

$$F(j) = \frac{1}{K^2} \sum_{m=j-K+1}^{j} \sum_{n=m-K+1}^{m} ECG(n) - \frac{1}{L^2} \sum_{m=j-L+1}^{j} \sum_{n=m-K+1}^{m} ECG(n)$$

After filtering, it is evaluated the signal quality to identify non useful ECG intervals and exclude them from the rest of the analysis.

2.3. Detection and classification of QRS

An energy function is used for detection of QRSs complexes. Multiple thresholds are used to detect QRS zone, QRS onset and offset and to measure others segment and waves, and they are updated every 10 minutes of ECG. All the significant points are obtained with high accuracy: fiducial point, QRS onset and offset, T wave peak, T wave offset, P wave and RR interval [1,2,3,4].

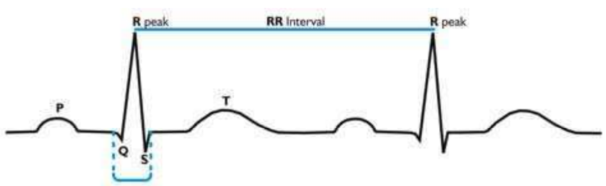

Figure 2. Significant points obtained after analysis

Classification is based on a specific implementation of a sequential pattern comparison algorithm calculating the correlation between every beat detected [5]. Beats are classified as: Normal, Ventricular, Supraventricular, Paced and Artifact

2.4. Detection of rhythm events and pacemaker malfunction

Rhythm events are detected using an algorithm based on string pattern identification that combines accuracy and faster processing [5]. This algorithm allows identifying the following events:

- Isolated Ventricular and SupraVentricular Beats
- Ventricular and SupraVentricular Couplet
- Ventricular and SupraVentricular aRun
- Ventricular and SupraVentricular Tachycardia
- Bigeminy and Trigeminy
- Pause, Bradycardia andTachycardia
- Paced Rhythm

It is also performed detection of pacemaker malfunction. This is implemented on a basis of a sequential revision and comparison algorithm [6, 7, 8]. At the end of this analysis the following pacemaker functioning errors are obtained: Failure to Output, Failure to Capture and Failure to Sense

2.5. Search of ST deviation episodes

Algorithm used to search for ST deviation episodes begins with the selection of the ST measuring point. Two alternatives are available, 80 ms after the QRS offset and the other 1/16 * RR Average after the QRS offset. Having selected the measuring point, ST level and slope are obtained, estimating base line and calculating ST level as the difference between the previous selected point and the base line. I t is also calculated the slope in 40 ms around the ST measuring point [9].

2.6. HRV study in time domain

For each QRS complex previously detected, the normal-to-normal (NN) intervals (all intervals between adjacent QRS complexes resulting from sinus node depolarization) are selected. Then, simple time–domain variables are calculated include the mean NN interval, the mean heart rate, the difference between the longest and shortest NN interval, the difference between night and day heart rate. Statistical variables are also calculated like standard deviation of the NN interval (SDNN), standard deviation of the average NN interval from segments (SDANN) and others as specified in Task Force [10].

2.7. Spatial QT dispersion study

This study is performed on a selected 10 seconds ECG segment with sampling rate of 500 Hz. It should be synthesized the standard twelve ECG lead from the three channels acquired. For that purpose is used the Dower matrix.

In every lead are detected the heart cycles and building of the average cycle. Every obtained mean cycle is then processed, filtering it, and then calculating the onset and offset of the QRS, T wave offset and QT interval. Finally, it was calculated the QT Dispersion value and other important statistic related parameters like Mean and Standard Deviation [1, 3, 4, 9].

2.8. Compression and storage of the results

The results obtained from the entire analyzing process are stored for later review. A zip algorithm is used to packing and compressing all the results files.

2.9. Visualization and user edition of beat detection and classification results

All the information acquired and resulting from the analysis is shown by means of attractive and comprehensive user interface. This information is represented in summary tables and on graphics, always relating ECG signal drawing with all the significant detected events.

Many comprehensive and easy to use edition tools were included. They make possible reclassification of beats, exclusion of noisy zones and wrong detected beats, all of this with the consequent reanalysis.

Figure 3.Visualization and user edition

3. Evaluation

The beat detection and classification algorithms were evaluated against MIT-BIH, NST and AHA databases according to AAMI standard. It was selected a total of 126 recordings, excluding patients with implanted pacemakers and others registers containing segments associated to either tachycardia or ventricular flutter, as proposed by AAMI document [11,12].

It was obtained values of sensitivity and positive predictivity higher than 90% for detection and classification as outlined in regulatory documents applicable to this kind of medical device.

Table 1. Evaluation of results.

Database	Records	QRS Detection (%)		QRS Classification (%)	
		Sensit.	Posit. Predict.	Sensit.	Posit. Predict.
MIT-BIH	39	99.77	99.90	95.27	96.70
NST	12	94.90	91.6	90.36	90.12
AHA	75	99.35	98.39	93.91	91.62

The user interface of the software, entire system operation, and analysis results were also tested and validated by specialists from the National Institute of Cardiology of Cuba during a period of 4 months during which 160 patients were studied. Nowadays there are 50 systems, working with good results in many hospitals around the world for more than 3 years.

It was obtained a library, grouping all the classes involved in the analysis process. The resulting design of this class hierarchy is robust and very reusable, helping future upgrades and the maintenance process.

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