A Low-Cost Solution to follow the Evolution of Arrhythmic Patients

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Abstract

The aim of this paper is to discuss the main features of a system designed to study the evolution of arrhythmic patients doing their daily activities. The proposed system is composed by three parts: a small battery-powered device designed to acquire and transmit, via Bluetooth, an ECG channel; a mobile application based on Android operating system to process the ECG and a web application. The ECG device is able to acquire and transmit the ECG continuously since it is turn on. The Android application receives the ECG data; QRS complexes are detected and classified and RR intervals are measured to compute heart rate. All these information is uploading to a web application using GSM/GPRS network and HTTP protocol. The web application stores each ECG file in a SQL database; cardiologists can check ECG strips and analyze trend charts associated to each patient. Also, cardiologist can call any patient in order to adjust his drug treatment. The ECG device is easy to use, patient only have to attach three electrodes to his skin and press the ON/OFF button. Two ECG device´s prototypes have been tested according to the IEC 60601-2-47 standard and all the tests were passed successfully. The Android application has been tested with three hundred three-minute ECG strips; Bluetooth communication was without errors. QRS complex detection algorithm was tested with MIT-BIH database and the sensitivity was 99,03%. Web application provides graphical tools to analyse the ECG and its measurements. The SQL database has been tested without any problem to store or recover information.

1. Introduction

Heart disease is one of the three leading cause of death worldwide; scientists from around the world perform numerous efforts focused on developing increasingly effective methods for prevention and treatment of these diseases [1]. The health systems of all countries face a serious problem: the continuous increase in the cost of the procedures for prevention and treatment of these diseases [1]. The continued growth and improvement of data transmission networks has been the technological basis for the continued development of Telemedicine [2]. The mobile networks have added flexibility to this kind of systems.

People with chronic heart disease should visit their cardiologist regularly to check the evolution of their disease and to correct medical treatment. This follow-up procedure can cause agglomerations in hospitals and discomfort for patients and medical staff. A solution to the described situation could be the development of systems to study these patients wherever they are. Multiple systems, based on mobile networks, have been developed to capture or to measure different signals and parameters (ECG, blood pressure, blood glucose, etc.). However, there has been no definitive resolution for this kind of systems or their interoperability.

The aim of this paper is to discuss the main features of a system designed to study the evolution of arrhythmic patients doing their daily activities. The system is composed by a small battery-powered device designed to acquire and transmit, via Bluetooth, an ECG channel; a mobile application based on Android operating system to process the ECG and a web application. Preliminary results will be presented.

2. Materials and methods

The proposed system was designed to:

- Document the evolution of heart disease.
- Correct medical treatment dynamically by frequent review of ECG.
- Avoid inconvenience to patients and medical staff.

The system operation was designed as simple as possible for its main actors: the patient and the cardiologist. The operation can be summarized as follow:

- The cardiologist enrols the patient in the system.
- The patient receives the User Guide, the ECG device (including patient cable and electrodes) and the application is installed on his phone.
- The cardiologist explains the patient's role in the system.

- The patient places the electrodes on his skin and turn on the ECG device. A bipolar ECG lead is amplified and digitized. This digital signal is transmitted to the mobile phone.
- The incoming digital ECG is filtered; the QRS complexes are detected and classified; heart rate is computed. All these data is stored in a database and is uploaded to a HTTP server.
- The web application inserts all the upload information in a database.
- The cardiologists log in the web application in order to study a patient. Arrhythmic evolution is analysed and the treatment is corrected if necessary.

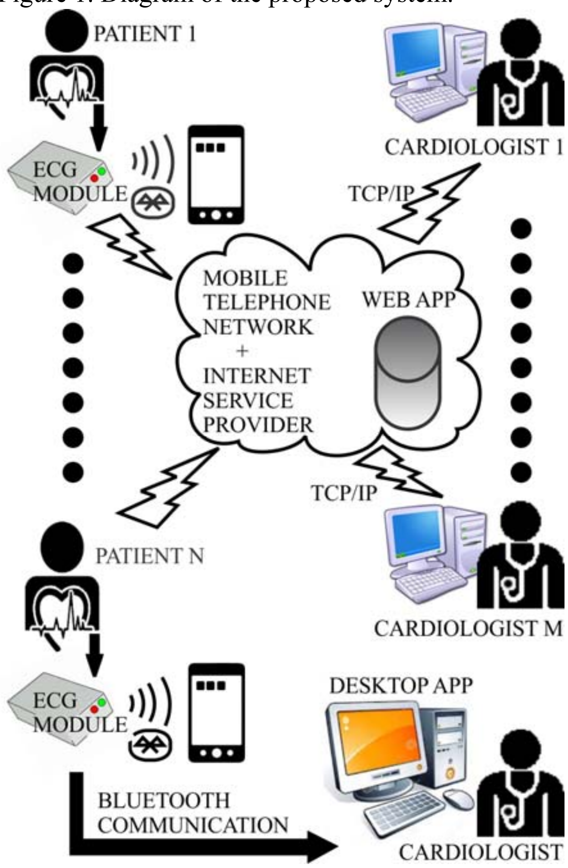

Figure 1. Diagram of the proposed system.

2.1. The ECG device

A small battery powered device was designed to amplify and to digitize a bipolar ECG lead. The electronic design was oriented to be a low-cost solution, reliable and easy to use. The surface montage technology (SMT) was used in conjunction with multilayer print circuit. The proposed device can be divided in the following blocks:

- The ECG amplifier: It is one-channel ECG amplifier characterized by its low power consumption (below 10 µA). The amplifier design is based on the OPA4236 operational amplifier and the mcropower single-supply INA826 instrumentation amplifier. The bandwidth is limited between 0,5 Hz and 40 Hz in order to improve the signal quality and to keep the main ECG frequency components.
- The MSP430F5529 microcontroller: It is an ultralow-power microcontroller with a 16-bit RISC architecture. The microcontroller includes, in a single chip, several peripherals such as serial ports, timers, program memory, data memory, A/D converter, etc.
- The Bluetooth block: It is based on the LMX9838 Bluetooth Serial port module. All hardware and firmware is included to provide a complete solution for this kind of wireless communication. This module was optimized to handle the data and link management processing requirements of a Bluetooth node.
- The battery: The isolated power is supplied by two AAA NiMH batteries. The proposed device does not include a battery-charging circuit, so batteries should be charged in any commercial charging station.

When the device is turned on, automatically the ECG is sampled at a frequency of 250 Hz. This data is transmitted to a mobile phone using the Bluetooth standard. The ECG amplifier includes a circuit for pacemaker spike identification and another circuit to detect poor contact between the electrodes and the patient´s skin.

ECG samples are sent in packages that include a sync byte; so the receiver (an application running on an Android mobile phone) can identify the start of each packet and recognize the dedicated bits to indicate the presence of pacemaker spikes and the poor electrode contact with the patient´s skin. ECG duration is set at the Android application in dependence of the study to be performed; a typical duration could be three minutes. When ECG transmission is over, the device is shut down.

2.2. The Android application

The Android application was programmed in Java language. The Eclipse platform was used as a programming framework. This application was divided into two programs, one for the pairing process between Bluetooth devices (ECG device and mobile phone) and other for Bluetooth ECG reception, processing and data upload.

The incoming digital signal is filtered to remove or attenuate spurious signals. A FIR filter (Finite Impulse Response) that has been used in previous researches is applied in this case [3]. It was proposed by Ligtenberg and Murat [4] and its mathematical expression is as follow:

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

where:
x(n): input signal
y(k): output filtered signal
K, L: filter constant

The QRS complex detection is based on an energy collector and two thresholds updated periodically. The energy function is easy to implement because it is based on integer arithmetic; this auxiliary function is computed as the sum of the squared derivate of the samples corresponding to a time's window of 150 milliseconds previous to the study sample. The window width was defined taking into account the typical duration of the ectopic QRS complexes. A threshold is used to detect high-energy peaks; a second threshold is applied to identify the onset and offset of each QRS complex. RR intervals are computed after the identification of all R wave's peaks. Each cardiac beat is classified as premature or not premature according to their previous RR interval duration. An ECG strip is classified as ¨arrhythmic¨ if more than 10% of QRS detected get this classification. This percentage can be configured at the Android application setup.

All information associated to the studied ECG is stored in a database and uploaded to a HTTP server. The mobile phone database can be very useful in combination with a desktop application, developed as part of the proposed system, to display ECG data when mobile connectivity is not available and the patient has to visit his cardiologist with the ECG data collected.

2.3. The Web application

The web application was developed using Codeigniter framework; this open source tool is very useful to build dynamic web sites with PHP (a server-side scripting language). This application is composed by a SQL database, a graphic interface to display ECGs and trend graphics and other complementary tools. ECG files are read and insert into a SQL database. The proposed application provides the following features:

- User login/logout: By controlling user name and password, the application organizes the data access. Each cardiologist can only review ECG associated to his patients. A cardiologist is associated with N patients (registered in the system for him), but a patient is only associated with a cardiologist.
- Patient registration: The patient is registered in the system by any cardiologist; this process set a relationship in the database between the patient and the cardiologist. All patient data are introduced by the cardiologist using an electronic form implemented into the proposed system.
- Database management (querying, sorting, updating, etc.): A SQL database engine provides all the mechanism to management electrocardiographic information associated to each patient.
- ECG display in several formats: Several graphic tools are provided to facilitate the ECG study.
- Trend graphs of different electrocardiographic parameters: This kind of graphics make so easy to study the progression of parameters like heart rate and premature beat per ECG strip.
- Printed reports: This feature is implemented to allow data interchange between specialists and to create traditional patient paper-files.
- Export results: This feature is implemented to allow the integration with other medical systems.

This web application allows cardiologists to study the evolution of patients and correct their drug treatments. For example, a cardiologist instructs a patient to make himself three ECGs daily. After ten days, the cardiologist has thirty ECGs of the specific patient and he can analyse in detail how it is influencing medical treatment in the disease studied.

2.4. The Desktop application

Optionally, a desktop application can be used to check the ECG data recorder by the patients. It is recommended when Internet connectivity is not available.

The desktop includes the same features of the web application. The same database design was implemented and identical graphic tools are available on this application. It was programming in C language using QT framework for Linux and Windows operation systems. A version for each operating system is available.

3. Results

Two ECG device´s prototypes have been tested according to the IEC 60601-2-47 standard and all the tests were passed successfully. The proposed device is not classified as an ambulatory medical device, but it has many technical characteristics similar to this kind of devices, so the IEC 60601-2-47 standard can be applied. The most significant results are shown in Table 1.

Table 1. Some results of technical tests.

Test	Result
Dynamic input range	± 5 mV
Input impedance	Greater than 2,5 MΩ
Maximum DC input level	320 mV
Internal noise	Less than 25 µV
Patient auxiliary current	Less than 0,01 mA
Setting time	Less than 3 s
Common Mode Reject Ratio	Greater than 90 dB
IEC 60601-1 classification	Class I, BF type

All technical results meet the IEC 60601-2-47 standard requirements. The use of the proposed device can be considered safe for patients because all electrical safety parameters comply with the existing international standards for this kind of medical device.

All the blocks of the Android application were tested. The Bluetooth communication was checked as follow: an ECG simulator was used to generate two hundred three-minute ECG strips; heart rate was 60, 80, 120 and 150 beats per minute. These strips were transmitted from the ECG device to a mobile phone running the proposed Android application. This test passed without errors, the signals received by the Android application were identical to the original simulated ECG. Also, the communication process was never aborted by errors.

The digital filter performance was not tested because this filtering scheme has been used and tested in previous researches with good results [3, 5].

The QRS detection process was based on previous experiences of the authors [3, 5]. This detection scheme was tested previously with twelve ECG strips from MIT-BIH database; results are shown in Table 2.

Table 2. Results with twelve ECG strips from MIT-BIH database.

ECG	QRS/strip	QRS detected	%
100	2273	2273	100.00
101	1865	1865	100.00
103	2084	2063	98.99
105	2572	2560	99.53
106	2027	2019	99.61
108	1774	1761	99.27
112	2539	2512	98.94
123	1518	1493	98.35
208	2955	2920	98.82
209	3005	2970	98.84
210	2650	2604	98.26
230	2256	2211	98.01
Total	27518	27073	99,03

The performance of the algorithm seems satisfactory, but should be evaluated for all the ECG strips of the MIT-BIH database.

All the features of the proposed Android application have been tested with a significant amount of ECG strips. The implemented Bluetooth link has been stable; no errors have been detected at the user level. QRS complex detection algorithm was tested with MIT-BIH database and the sensitivity was 99,03%; this result is enough for this kind of application.

The proposed Web application provides several graphical tools to analyse the electrocardiographic information captured. A desktop application with the same The SQL database has been tested without any problem to store or recover information; its operation has been consistent.

4. Conclusions

A first version of the proposed system was completed and tested preliminary. The goal of the research project described in this paper has been accomplished.

The proposed system looks like a useful tool to study the arrhythmic patient progression using existing data networks, mainly the mobile telephone networks. Other chronic diseases can be studied following the same philosophy.

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