A Mobile Application for Cardiac Rhythm Study

Rene Gonzalez-Fernandez, Margarita Mulet-Cartaya, Juan Dayron Lopez-Cardona, Rolando Lopez-Rodriguez

[1]Central Institute of Digital Research, Havana, Cuba

Abstract

The aim of this paper is the discussion of the main features implemented in an Android application for ECG processing. It was designed to use a mobile phone, connected by Bluetooth to a battery-powered ECG device, as a signal acquisition layer in a Telemedicine platform. The Android application receives the ECG data according to a simple protocol. The Bluetooth pairing process is made by the proposed software following the traditional procedure. ECG data is filtered using a FIR filter. QRS complexes are detected and classified, as premature or not based on the duration of RR intervals. An energy collector, combined with heuristic rules, was implemented to detect QRS complexes. All these information is uploading to a web site using GSM/GPRS network and HTTP protocol. Also, all the data is store in a database implemented in the phone; this feature allows downloading that information into a personal computer to make other studies. The software was programming in Java language using Eclipse SDK and SQLite database engine. The proposed solution has been tested with ten models of Android mobile phones, working without problems. Errors have not been reported in communications. QRS complex detection algorithm was tested with MIT-BIH database and the QRS detection sensitivity was 99,03%.

1. Introduction

Cardiovascular disease kills almost seventeen million people around the world each year [1]. Persons who are at cardiac risk require that their electrocardiogram be registered frequently to get information about their cardiovascular system. Telemedicine is considered a powerful tool to solve this kind of situation; it is defined as the combination of advanced telecommunication technologies and informatics tools to improve the traditional health services and to create new ones [2].

Scientists from around the world perform numerous efforts focused on developing new Telemedicine solution to improve the quality and effectiveness of health systems.

Mobile phones have been recognized as an important tool for Telemedicine services because of the continued growth and improvement of mobile networks [2]. Several biosignal acquisition modules have been developed to be connected to mobile phones by Bluetooth, USB or another communication standard, but and unique standard solution is not available. This kind of solution could be considered as a data collection layer within a Telemedicine system.

The aim of this paper is the discussion of the main features implemented in a mobile application for ECG processing. The proposed solution was developed for Android operation system.

2. Materials and methods

The proposed solution was designed to be the host of an ECG module designed to digitize up to three minutes strip signals. QRS complexes are detected and classified as the first step of any arrhythmia study. These features are basics to implement a Telecardiology system.

Android operating system support, Eclipse SDK and Java language were used to develop the proposed mobile application. Also, a SQL database engine was used for data management.

2.1. Data reception

The first step for Bluetooth communication is the pairing process between the ECG module and the Android phone. This process is made only the first time that the proposed application is running to set the communication between the Android phone and the ECG device; they must recognize each other. The pairing process is based on the Android Bluetooth API, being necessary to declare the following manifest:

- BLUETOOTH: It allows Bluetooth connections and data transfers.
- BLUETOOTH_ADMIN: It allows, in addition to Bluetooth connection and data transfers, to manipulate system options, device's searching and link setting.

The proposed application searches for a Bluetooth device with a specific name. If that Bluetooth device is not detected in a three-minute window, the pairing process is aborted and it should be repeated later. When the Bluetooth device is detected, setup data is interchanged and the Bluetooth link is set. All the process was based on the Android operating system support

Data incoming is read according to a simple protocol defined by the authors. Figure 1 represents the protocol.

…<55H><ECG><status><55H>><ECG><status><…

Figure 1. Data transmission protocol.

The goal of this protocol is an easy synchronization between the transmitter (the ECG device) and the receiver (the proposed software). ECG samples and status bits are the useful information, while the 55 hexadecimal values are used as a synchronization byte. The receiver can check the incoming data to detect a sequence of useful information enclosed between two synchronization bytes.

ECG sample length is twelve bits and status bits are four bits associated to the electrode status and the pacemaker spike presence.

2.2. ECG processing

A bipolar ECG lead signal is sampled at a rate of 200 Hz by the data acquisition module connected to the Android phone running the proposed software. Each sample is filtered to improve the signal noise ratio. A moving average filter proposed by Ligtenberg [3] is applied to each ECG sample; its expression is the following:

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

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

The structure of the filter expression seems very complex because it contains four sums, but it can be implemented as partial sums easily. This filter has been used in previous researches with good results [4]. The constants K and L should be set according to the cut-off frequencies.

An energy collector is used as auxiliary function to detect QRS complexes. The energy for each sample is computed using the Teager operator [5]; its expression is the following:

$$y(k) = x^2(n) - x(n-1) * x(n+1)$$

where:
x(n): input signal.
y(k): Teager operator output.

The Teager operator is easy to compute because it is based on integer arithmetic. At the same time, this operator is very useful because is able to emphasize the ECG high frequency components which are associated to the QRS complexes.

The energy collector it computed as the sum of the Teager operator values corresponding to a time’s window of 150 ms previous to the studied sample. The window width is set to 150 ms in order to detect QRS complexes with duration between 30 and 150 ms.

Two thresholds are calculated from the maximum value of the energy collector. The first is computed as the 20% of the maximum energy and the other one as 0,5% of the maximum energy.

The first threshold is used to define the border between the high-energy peaks, associated to the QRS complexes, and the rest of the ECG. A second threshold was used to identify the onset and offset of each QRS complex; a candidate to be an identified complex must reach a minimum duration (30 ms), so this value must be computed for each candidate.

When a QRS complex is detected, the duration of its previous RR interval is computed and a RR interval average is updated for each 15-second ECG strip. Also, heart rate is computed.

The QRS complexes are classified as normal (N), premature (P) or unclassified (U). The classification rules are as follow:

- The duration of a RR interval previous to a normal QRS complex must be between 80% and 110% of the mean duration of this interval.
- The duration of a normal QRS complex must be between 85% and 110% of the mean QRS complex duration for the ECG strip.
- The premature QRS complex duration must be greater than 120% of the average value.
- The RR interval previous to a premature QRS complex must be less than 80% of the average for this interval in the studied ECG strip.

A Premature Contraction Rate (PCR) is computed to classify each ECG as arrhythmic or not. This value could be used to define if an ECG strip is considered as “arrhythmic” or not. All these information, digital ECG and measurements, is identified by the date and time when the ECG was acquired and is available for subsequent more specific studies.

2.3. Data store and uploading

Each ECG strip is store on a SQL database together with measurements. The key to look for each ECG data is composed by an index generated by the database engine each time a new data set is inserted and the date/time when the ECG strip was acquired. Standard database operations (insert, delete, ordering and search) were implemented.

3. Results

The proposed software has been tested with ten models of Android phones, running Android operation system version 2.3 or higher. The application performance has been independent of the version of the operating system, but some changes were necessary in Bluetooth communication for older versions.

The Bluetooth communication was tested with five hundred three-minute ECG strips; these signals were generated by an ECG simulator for heart rate of 40, 60, 80, 120 and 160 beats per minute. The strips were transmitted to a mobile phone running the proposed application. This test pass without errors, the signals received by the proposed application were identical to the original simulated ECGs. Also, the communication process never was aborted by errors. Information about electrodes failures and pacemaker presence was received in the same way.

The QRS detection process was preliminary tested with twelve ECG strips from MIT-BIH database. The results can be seen in table 1. The performance of the QRS complex detection process can be considered satisfactory because 99.03% of the real QRS complexes were detected and False Positives were not identified. It is very important for this kind of applications because False Positive can generate bad automatic ECG interpretation.

Table 1. Tests of QRS complex detection.

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	27251	99.03

QRS complex classification was not tested with the MIT-BIH because it includes a more detailed classification than needed for the proposed Android application. Three experienced cardiologists, with more than 10 years reviewing ECG strips, tested all the signals. They never found than a premature QRS complex were classified as normal. This fact is very important because the experts agreed with the proposed application in the whole premature beat classification process.

All the features of the proposed Android application have been tested with a significant amount of ECG srips. The implemented Bluetooth link has been stable; no errors have been detected at the user level.

4. Conclusions

A first version of the proposed Android application was completed and tested with good results. Bluetooth communication was reliable; this process never was aborted due to errors o data loss.

The performance of the algorithms developed for ECG processing is enough for this kind of application. However, the authors will work to improve these results.

The developed software seems a powerful to convert a mobile phone, combined with the appropriated ECG device, in a medical device for several Telecardiology services. The same approach could be used for rest ECG if the ECG device is the appropriated.

References

[1] World Health Organization. The World Health Report 2013 at http://www.who.int/research/en/..

[2] Choi Y B, Krause J J, Seo H, Capitan K E and Chung K. Telemedicine in the USA: standardization through information management and technical applications. IEEE Communications Magazine, 2006:44:41-48.

[3] Ligtenberg A and Murat K. A Robust Digital QRS-Detection Algorithm for Arrhythmia Monitoring. Computing and Biomedical Research, 1983:16:273-286.

[4] Gonzalez R I, Guardarrama R, Leon F, Rodriguez A, Jimenez D. Two Low-Cost Solutions for Cardiac Mobile Monitoring. In: O. Dossel and W. C. Schlegel. IFMBE proceedings. Springer, 2009:25:188-191.

[5] Sharmila V, Ashoka Reddy K. Modeling of ECG signal with Nonlinear Teager Energy Operator. IJCSNS International Journal of Computer Science and Network Security 2014;14:34-41.

Address for correspondence.

Rene Gonzalez Fernandez.
Calle 202 #1704 entre 17 y 19, reparto Siboney, municipio Playa. La Habana, Cuba.
rigonzalez@icid.cu
rigf58@yahoo.com