A Cardiac Telerehabilitation Application for Mobile Devices

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Abstract

This paper presents a personal system and software architecture dedicated for cardiac telerehabilitation. The key idea of the hardware configuration and the software implementation is the integration of a mobile device and an ECG recorder with the application of wireless technologies: Bluetooth, GPS and GPRS.

The main goal of the system is the reliable detection of the QRS complex providing a cardiovascular activity information to a cardiac telerehabilitation program. The prototype of the system allows the physician to construct a multistage training program, which can be divided into few levels. At each stage the supervising physician can customize parameters as: duration, speed, maximal and minimal heart rate. Additionally, a simple threshold-based alarm system has been implemented.

The application of such monitors can reduce the costs and make the rehabilitation efficient, easier and allow an ubiquitous access.

1. Introduction

The electronic and communication technologies with their rapidly developing potentials allowed to develop a new branch of remote medical rehabilitation, the cardiac telerehabilitation. Recent technological advances such as the increased data transfer efficiency and the reduced costs of computer-based products have contributed to the growing popularity of the use of electronic and communication technologies in cardiac telerehabilitation [1].

Patients recovering from acute coronary events and cardiac surgery need to undertake regular physical rehabilitation and check-ups to reduce the risk of further cardiovascular diseases.

The main period of cardiac rehabilitation is divided into two phases: the inpatient phase and the outpatient phase. During the first phase, which is most crucial, the patient is hospitalized for about 12 weeks. The second phase is much longer and takes place in the rehabilitation center or at home. The most important goal of the cardiac telerehabilitation is to monitor the out-hospital patient follow-ups and increase the number of participants in the rehabilitation which oscillates now between only 19% and 29% [2]. The participants drop off is mostly caused by the geographical location (under-developed, countryside), high costs of travelling to the rehabilitation center or hiring private physicians.

The cardiac telerehabilitation is an opportunity for people to improve the efficiency of the home rehabilitation, increase the quality of life and on the other hand to reduce the costs of the healthcare sector.

The purpose of this study was to develop a simple but effective cardiac monitoring system dedicated for the telerehabilitation. This paper presents the: architecture design, system implementation and testing of correct QRS detection and data flow.

2. Materials and methods

The telerehabilitation system integrates a mobile communication device (e.g. a smartphone) with a wireless ECG signal recorder in a Bluetooth-based body surface network (BSN). For the location and speed information we use the built-in GPS module. The data exchange between the mobile device and the supervising server is performed via Internet. The alarm system sends short SMS messages to inform about the patient state. The software detects the QRS complex and in real time calculates the heart rate as the main ECG exercise-dependent parameter. The monitoring system integrates the current heart rate of the patient with the GPS data. This gives us the opportunity to observe the dependence of heart rate variability and the physical load. We'll revisit all of these topics in the next sections.

2.1. Architecture design

The system architecture can be divided into 5 main modules. First module is managing the data exchange between the ECG recorder and the mobile device. Second module is the QRS detection algorithm. For this project we applied the most popular Pan and Tompkins algorithm [4] which is easy to implement, effective and optimal for our purpose. Third module is the GPS algorithm which calculates the motion speed and inclination based on location and altitude readout. The most important module for the rehabilitation is the Personal Training Program that allows to build personal training course. The last, fifth module is the Alarm Module that makes the rehabilitation safe and comfortable. Figure 1 presents the data processing diagram, the initiation of the processes and the interactions between the modules.

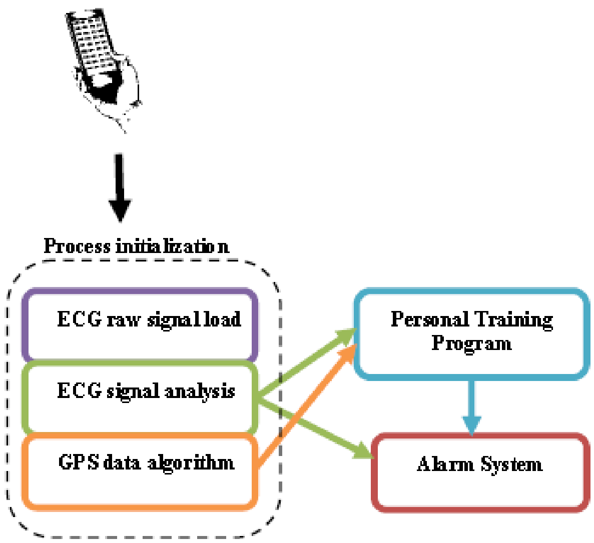

Figure 1. Block diagram of the implemented software in which the most important modules and functions are presented. Particular lines show the relationships and the dataflow between the blocks.

2.2. QRS detection algorithm

The most popular real-time algorithm for detection of the QRS complex of ECG signal was developed by Tomkins and Pan in the early 80-ties [3]. The algorithm is based on digital analyses of slope, amplitude, and width.

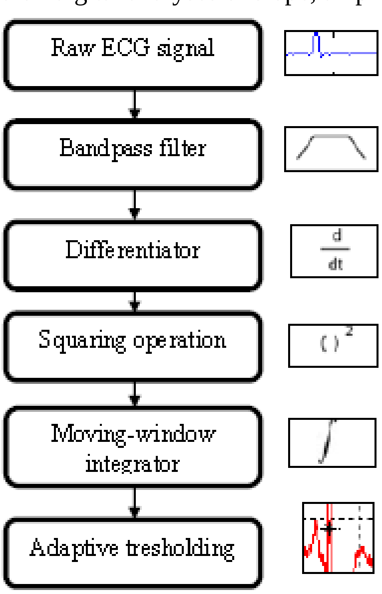

Figure 2. Flow chart of the implemented QRS algorithm.

In the first step we use a bandpass filter which is a combination of the lowpass and highpass filters and enhances components within a frequency range of 5 – 17 Hz. The bandpass filter also reduces noise in the signal such as 60 Hz interference, muscle noise and baseline drift.

In the second step we use a derivative operator to distinguish the QRS from P and T waves by its steep slope.

In the next step the squaring operation is applied. This operation emphasizes large differences characteristic for the QRS complexes and makes the results positive.

The next operation is the moving-window integrator which assures to recognize as QRS complex a unique point in each ECG cycle.

The signal from the moving-window integrator is passed to the last operation, which is the adaptive thresholding. If a given threshold value is exceeded, the QRS complex is validated and the RR interval is calculated as a time difference from precedent detection point. Figure 3 shows the results of the particular steps of the QRS detection algorithm.

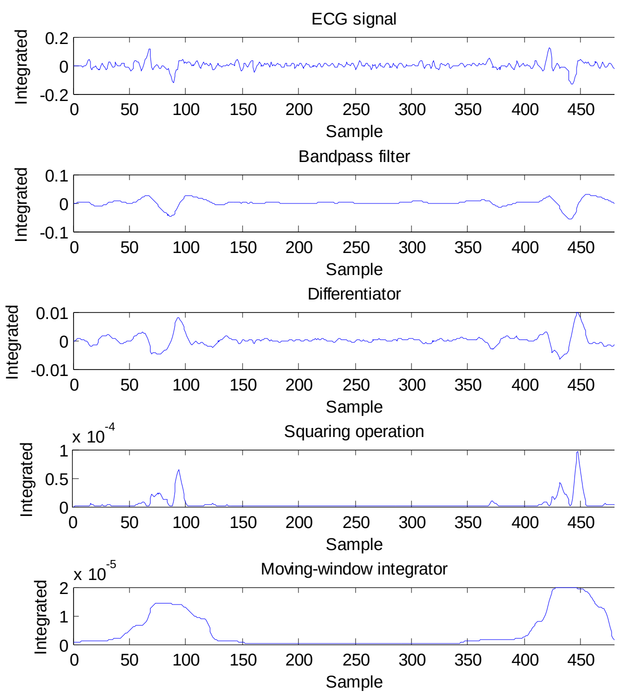

Figure 3. Output of the Pan – Tompkins algorithm to detect QRS complexes. Plots and descriptions after each stage of the algorithm.

2.3. Personal training program

The most important part of the application is the Personal Training Program which allows the physician to build a customize training program at any time without meeting the patient. The physician has access to a simple PHP (Hypertext Preprocessor) form. PHP is a general-purpose server-side scripting language originally designed for web development to produce dynamic web pages [6]. This created form allows the physician to select the patient from the list and change his training program. Every training program is divided into several levels where the distance/time, altitude, speed, minimal and maximal heart rate can be set. After confirmation the data are stored on the server. They are uploaded to the mobile device when the patient pushes the button START (fig. 4.). In the future we plan to extend the amount and types of exercises (crouch, press-ups, sit-ups).

2.4. Alarm system

The Alarm System plays an important role during the training. There are two different services for patient's safety.

The main task of the system is to react when an abnormal situation takes place. An SMS massage to the family member and to the physician is sent with the information about the heart rate and position. It allows to eliminate dangers like very high or low heart rate or even collapsing without any help from anyone (fig. 4.).

The second part of the alarm system is closely connected with the training program and informs the patient about the speed, distance, and heart rate and altitude. When the patient exceeds the limited values, the verbal messages are displayed (fig. 4.). This allows the training to be carried out efficiently and safely.

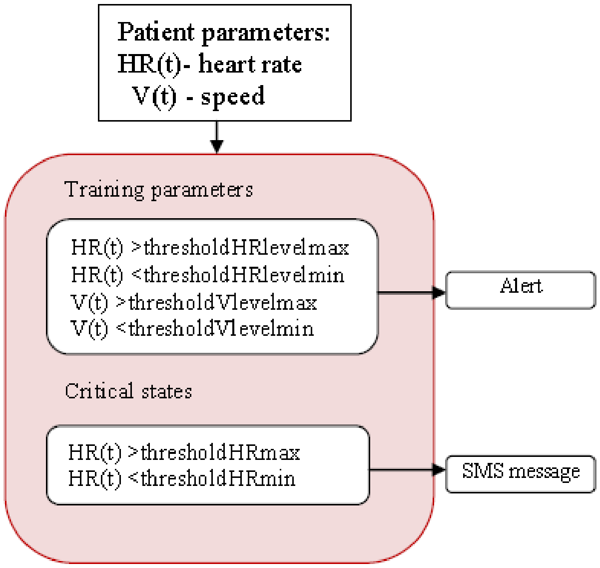

Figure 4. Architecture of the control system.

2.5 Application

The application is dedicated for patient in all ages so it is very easy and intuitive to use (fig. 5.). Most operations are performed behind the user. The proposed system has been developed for .NET 3.5 in the C# programming language.

Figure 5. Mobile ECG application.

3. Tests

At present, we have focused on the tests of correct implementation of the QRS detection algorithm on a mobile platform and the management of data flow between the modules. The QRS detection algorithm was tested on the records from the MIT-BIH Arrhythmia Database that was studied by the BIH Arrhythmia Laboratory [5].

The effectiveness of each file was compared by calculating the number of detected true positive (TP), false positive (FP), false negative (FN) QRS complexes. The detection error rate ER (equation 1) and the sensitivity SE (equation 2) were calculated for each file.

$$ER = \frac{FP+FN}{QRSall} \quad (1)$$

$$SE = \frac{TP}{TP+FN} \quad (2)$$

Table 1 presents the results of the QRS detection algorithm for selected files from the MIT-BIH database.

Table 1 Test results for MIT-BIH database files.

File name	Total QRS complex	FP	FN	TP	ER[%]	SE
100	2273	0	0	2273	0	1,00
101	1865	9	3	1862	0,64	0,99
103	2084	0	4	2080	0,2	0,99
105	2572	58	22	2550	2,4	0,98
Total	8794	67	29	8765	0,77	0,99

The records number 100 and 101 contain ECG signal of good quality. Record number 103 contains a signal with little noise, and the record 105 contains sections with very noisy signal. Using the MIT-BIH arrhythmia database (48 records) the algorithm failed to properly detect less than 2% of the beats.

At present we carry out tests with volunteers to check out the access to the GSM network, assess the influence of the motion on the devices and the quality of the signal during the exercises. We also modify the QRS detection algorithm to be more resistant to the artifacts.

After finishing the first part of the testing we plan to carry out tests during a real cardiac telerehabilitation.

4. Conclusion

The proposed system provides opportunity of distant participation in cardiac rehabilitation for people living in remote and rural areas outside the regional centre. The results of first tests that were carried out are satisfactory. The mobile application for QRS detection was reliable enough for HR-based assessment of physical load, and the implementation of data management over a wireless network is free of errors.

A well promising goal is to test the application during a cardiac telerehabilitation. This testing will be carried out in two stages: first in the standard supervised rehabilitation, during which information about the load of the body will be retrieved from the treadmill and not from the GPS. First stage will help us to test the correct interpretation of the data flow of the ECG signal. After this part of testing when the results from the first part are positive we will do the tests during a real cardiac telerehabilitation. This will help us to select the right functionality that will be added to the system.

We hope that the system allows physicians to monitor patients more effectively and this makes the follow-up rehabilitation easier and cheaper.

Acknowledgements

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