Proceedings of the Federated Conference on
Computer Science and Information Systems pp. 401–403
ISBN 978-83-60810-22-4

Design of a wearable sensor network for home monitoring system

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***Abstract*— In this paper we describe a wearable ubiquitous healthcare monitoring system that integrates electrocardiogram (ECG device) and an accelerometer sensor with a mobile device in a Bluetooth-based body surface network (BSN). Our research focused on the right connection of the hardware units, combination of the detection of QRS complexes, calculation of heart rate (HR) and the detection of human falls. The main aim of this research was the early detection of abnormal situations (high/low HR, a fall) and the heart rate variability analysis. The human falls are very risky events that occur not only in the elderly people's daily living but also by epileptics and asthmatics. For these people independent living is strictly forbidden. A wearable sensor based monitoring system can inhibit serious injuries and allow those people live an independent life. Additionally, an SMS messaging module was integrated with the monitoring system. After detecting a non-standard situation a short notice is sent. The implementation of the QRS complex detection algorithm, that was based on the Tompkins formula, was tested on the records from the MIT-BIH database.**

I. Introduction

RECENT advances in biomedical engineering, wireless network and computer technologies have enabled the possibility of remote patient monitoring. Based on these technologies, it is possible to improve patient care, chronic disease management, and promote lifelong health and well-being for the ageing population.

The aim of this paper is to provide an overview of the authors experience in constructing and implementing wearable sensor network for home monitoring. Our project and research are based on a wearable ubiquitous healthcare monitoring system that integrates 12-leads ECG signal transmitter (ASPEKT 500), an accelerometer sensor and a mobile device in a Bluetooth-based body surface network (BSN).

II. Hardware Units

ASPEKT 500 is a digital unit designated for wireless ECG signal transmission to PC or mobile device (fig. 1). It is manufactured by Aspel [8]. The transmitter allows a free patients movement up to 10 m from receiver. Small dimensions and weight make the examination more comfortable for a patient.

Fig. 1 ASPEKT 500 - Wireless ECG signal transmitter [8]

ASPEKT 500 - Wireless ECG signal transmitter is equipped with ten electrode cable. In order to receive 12-leads (Einthoven, Goldberger, Wilson) we need to connect electrodes as shown in the fig. 2.

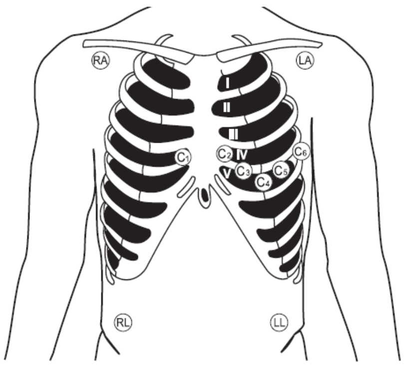

Fig. 2 Electrodes location on the patient [8]

ECG data is sampled at 500 Hz frequency. Battery operated time is about 12 hours.

III. Methods

The most important aim in the monitoring system is the detection of the QRS complexes in real-time. This gives us the opportunity to calculate the heart rate and observe the heart rate variability. The data processing is crucial to extract the correct part of the signal, the QRS complex. The ECG waveform contains also P, T, sometimes U waves and a lot of noise (60 Hz power line noise, EMG, motion artifacts) [3].

One of the most popular and often cited QRS detection algorithms that works in the time domain is the Pan and Tomkins algorithm that was proposed in 1985 [1, 2, 3]. The QRS detection algorithm is based on analysis of the slope, amplitude and width of the QRS complex which refers to the depolarization of the right and left ventricles. Figure 3 shows a block diagram of the Pan-Tompkins algorithm which will be hereafter described.

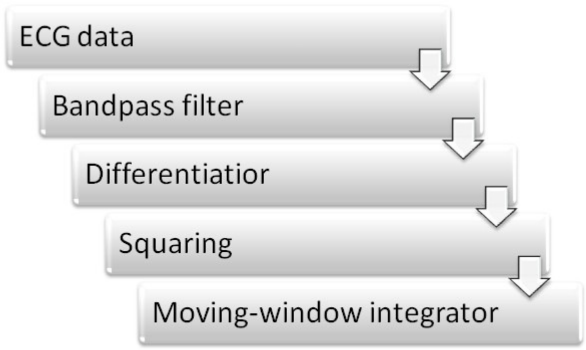

Fig. 3 Diagram of the Pan-Tompkins algorithm [1, 2].

The bandpass filter contains of a lowpass filter and a highpass filter. The lowpass filter has a cutoff frequency of 17 Hz and the highpass filter has a cutoff frequency of 5 Hz. After filtering the signal is differentiated. The derivative operator suppresses the low-frequency elements (P and T waves) and picks the high frequencies out (QRS complex). This operation gives us information about the QRS complex slope. The next step is squaring operation which makes all values positive. This enables us to analyze each channel. The squaring operation also emphasis the higher frequencies and makes the QRS complex interpretation easier. After the squaring operation multiple peaks are observed within the QRS complex. To eliminate this the moving-window integration filter is being performed. To detect QRS complexes an adaptive thresholding is applied. New peak is marked when a local maximum is find during before defined period. After the QRS detection algorithm the heart rate is calculated.

One of the project goals is to detect a fall. Fall detection could be achieved by analyzing the accelerometer data. The most common method of detecting a fall is calculating the absolute sum of ACC signal in different direction as shown in fig. 4.

$$FALL = \sqrt{ACC_X^2 + ACC_Y^2 + ACC_Z^2}$$

Fig. 4 FALL parameter

Thresholding FALL value is used to alert a fall.

IV. System Architecture

The monitoring system prototype has been build and analyzing software has been implemented in order to check if it is possible to monitor human activity remotely. The wireless ECG recorder transmits data to mobile device via wireless network based on Bluetooth technology. Data is analyzed by implemented software and forwarded using general packet radio service to Internet database, where medical data is accessible to a doctor. Fig. 5 presents the system design.

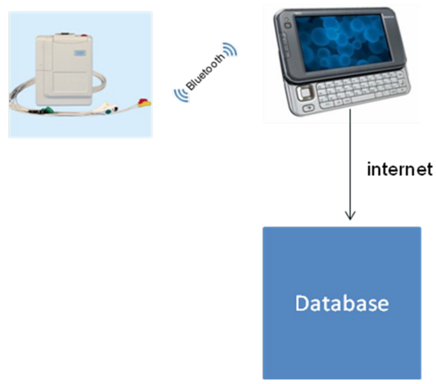

Fig. 5 Monitoring system design.

Implemented software is organized into 4 modules: ECG signal analysis, Fall detection, Heart Rate Variability and Database (fig. 6).

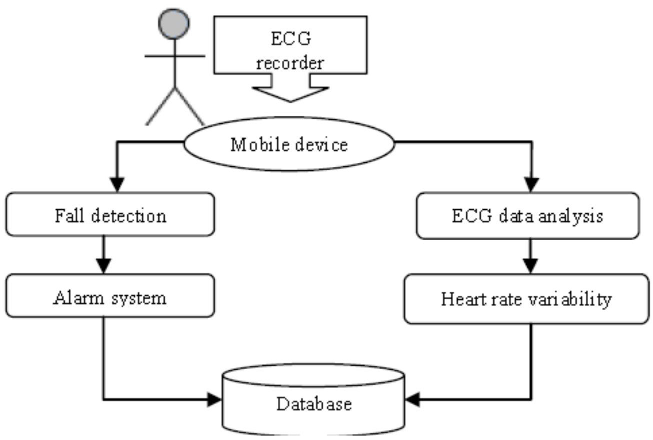

Fig. 6 Monitoring system architecture.

The most important module of the monitoring system is the ECG data analysis module which analysis the incoming signal data from the ECG recorder. The ECG data analysis module executes the Pan and Tompkins algorithm that was described in section III. The output of this module is transmitted to the Heart rate variability module. This part of the system calculates the HRV and sends the results to the Database via GPRS.

Fall detection module is responsible for analyzing data from accelerometer and calculating FALL factor described in section III. If the fall is detected the alarm module is switched on. The alarm module is a combination of two methods. The first one is a signal bell which can be switched off during 10 seconds. If it isn't accomplished a text message is send to a trusted friend.

V. Tests and Results

One of the most important stages in the implementation of the monitoring system is its verification. Tested has been the

QRS detection algorithm using ECG signals from the MIT-BIH arrhythmia database [5] and fall detection algorithm. Fig. 7 presents four cases of QRS detection possibilities.

QRS detection	Absence of QRS complex	QRS complex occures
Detected	FP (false positive)	TP(true positive)
Undetected	TN (true negtive)	FN (false negative)

Fig. 7 QRS complex detection possibilities.

The effectiveness of the application was performed by calculating the four cases mentioned in fig. 7 for every file from the database. The MIT-BIH database contains signals with different abnormalities (very noisy signal, high P wave, high T wave, arrhythmias and noise that is similar to QRS complex).

The most common used equation to demonstrate the effectiveness of the QRS detection algorithm is the sensitivity which equals TP times all QRS complexes (FN+TP). Fig. 8 presents results for selected files.

Signal nr.	Total QRS complex	TP	Sensitivity
100	2273	2273	100 [%]
101	1865	1863	99,8 [%]
105	2572	2541	98,6 [%]
113	1795	1711	95,2 [%]
117	1535	1498	97,4 [%]

Fig.8 Results for the MIT-BIH database files.

The proposed method of detecting falls did not give satisfactory results in performed tests. It often provided with false positive detections especially during making rapid movements or stops. Further research is needed in order to elaborate more accurate algorithm.

VI. Conclusion and Future Works

The achieved results are satisfactory for our monitoring purposes. However, more tests are needed on a representative group to access system performance. In the future works we plan to develop more advanced algorithms of detecting non-standard situations and improve fall detection algorithm.

The proposed healthcare monitoring system can help to monitor health conditions (heart rate, heart rate variability) and support elderly, sick and disabled people in their independent living.

Acknowledgment

This work was supported by AGH University of Science and Technology in Cracow as a research project no. 11.11.120.612.

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