Wireless Body Area Network System based on ECG and Accelerometer Pattern

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Abstract

Health monitoring and body area network (BAN) applications require wireless intelligent monitoring devices and information systems. The aim of our research is to propose a prototype of wearable wireless monitoring device optimized to supervising the patient and examine the influence of movement on the heart rate during normal daily activities. Main purpose of the proposed system consists in simultaneous acquisition and automatic analysis of two bipolar ECG and three-axes acceleration (ACC) signals measured by means of wireless, battery-operated prototype of Revitus ECG module. The processing of the ECG and ACC data is performed by the custom-developed software installed on PC. All recorded information is uploaded to a purposely-designed medical web server for the storage and display as a web page for authorized doctors or patient's family. The system was tested on 10 healthy volunteers. Each of them was monitored during common daily activities.

1. Introduction

Advances in communication technologies and construction of wearable biosensors are enabling the design of body area networks. Wireless body area networks are one of the most developed technologies for wearable health monitoring systems.

Wireless body area networks is widely investigated subject. One of the approaches is MIThril project, a system developed in the MIT Media Lab. It includes ECG, skin temperature and galvanic skin response (GSR) sensors. This wearable computing platform is compatible with both custom and off-the-shelf sensors. MIThril is being used to research on human behaviour recognition and to create context-aware computing interfaces [1]. Another example is CodeBlue project described by Malan and co-authors [2]. They propose a hardware and software platform for medical sensor networks. CodeBlue provides protocols for device discovery and multi-hop routing. It includes pulse oximeter, ECG and motion-activity as a set of sensors.

The aim of our research is to propose a wireless monitoring system optimized to remotely supervise the patient. In this paper we present a WBAN-based health monitoring system which integrates wearable and battery-operated ECG and ACC sensors which send data to the PC or laptop via wireless Bluetooth link. We developed algorithms that process and analyze signals in real time in order to calculate the heart rate and a quantitative estimate of human motion activity. The main advantage of the system is the use of algorithms optimized real time data processing. System is not only a valuable monitoring tool but also is an experimental base. Ten people were tested in order to find ECG and accelerometer signal during carefully prepared experiments. Results are included in this paper.

The rest of the paper is organized as follows. Section 2 overviews the hardware and software of the proposed system for home use health monitoring. Section 3 describes material and methods. Section 4 provides results of the system evaluation on healthy adults during normal daily activities. Section 5 describes discussion and section 6 concludes the paper.

2. System implementation

Wireless Body Area Network System includes wireless prototype monitoring device described in section 2.1 and custom designed and implemented software for the experimental purpose described in section 2.2. Data flow in wireless monitoring system is shown in fig. 1.

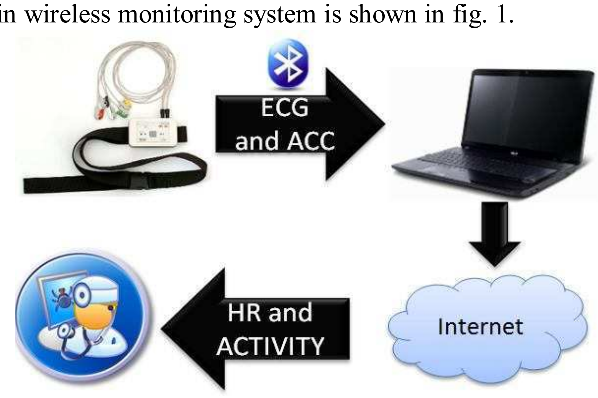


Figure 1. Data flow in wireless monitoring system.

2.1. Hardware

The heart of the system is wireless, battery-operated prototype of Revitus ECG and ACC sensor that is placed on the user body and connected to a notebook computer. The device records both the two channel ECG (1000 sps) and the three-axes acceleration (100 sps) signal. The patient's data buffered in the internal memory module are transmitted to the PC via Bluetooth connection online – allowing for real time processing or offline – when onboard data storage is completed. Received data are processed and analyzed by designed algorithms.

Monitoring device sends the data into separate structured packets. Each packet is 485 bytes long and stores 100 two-byte samples of ECG signal from each channel which equals 400 bytes for ECG data and 10 two-byte samples from each acceleration axis which equals 60 bytes for ACC data. The remaining 25 bytes are responsible for marking the beginning of packet, packet number, battery state and control sum. More details concerning packet data structure are shown in table 1.

Table 1. Data packet structure

Data	Number of bytes
ECG	400
ACC	60
Start packet sequence	4
Packet number	3
Battery state	1
Packet control sum	1
Other data	17

2.2. Software

The most demanding task was to design and implement the software that will cope with huge data flow from the monitoring device and real time signal analysis at the same time. Wireless Monitoring System Application (WMSA) was implemented and tested.

Key functionalities of the software include calculating and displaying the values of heart rate and the measure of patient motion based on ACC data. The software was designed to provide with easy access to monitoring data by drawing graphical charts of incoming data in the real-time. The user can easily access the ECG signal, heart rate value, HRV graph, ACC signals, and function of ACTIVITY factor in time. Screenshot from the working application was shown in fig. 2.

All data can be saved for further statistical analysis after pressing 'save data' button. Application exports data in the friendly CSV format.

2.3. Remote access

Part of the system is the mechanism that enables to send heart rate and motion factor to the remote web server. Every 10s heart rate and ACTIVITY factor is uploaded to medical web server for the storage and display as a web page for authorized doctors or patient's family. Web remote access interface is shown in fig. 3.

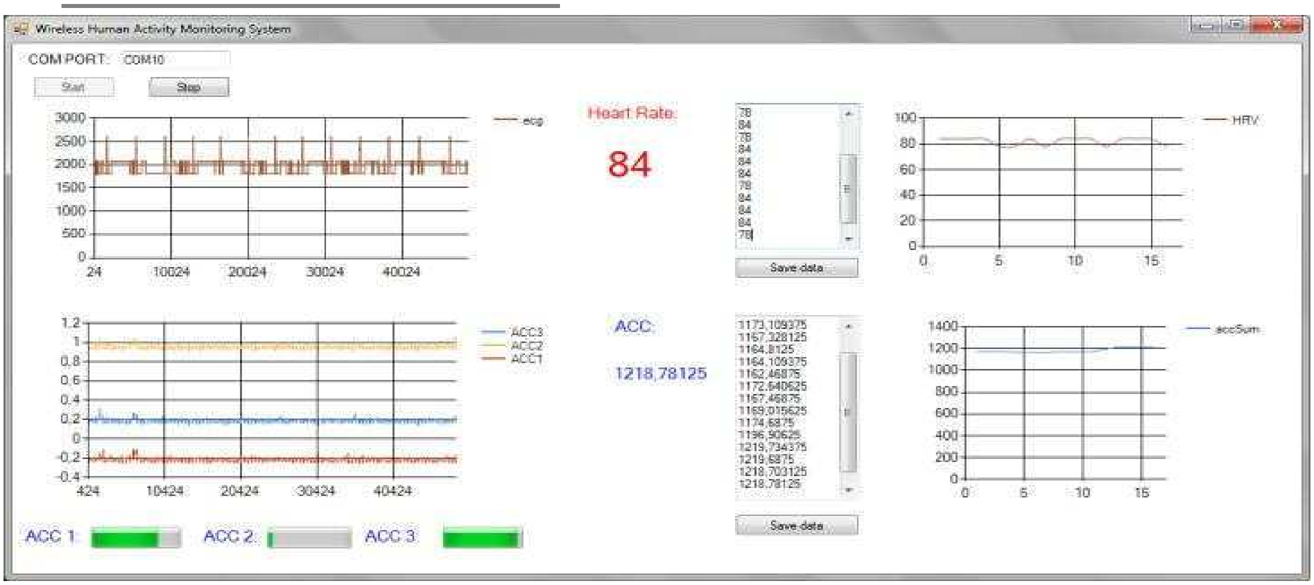
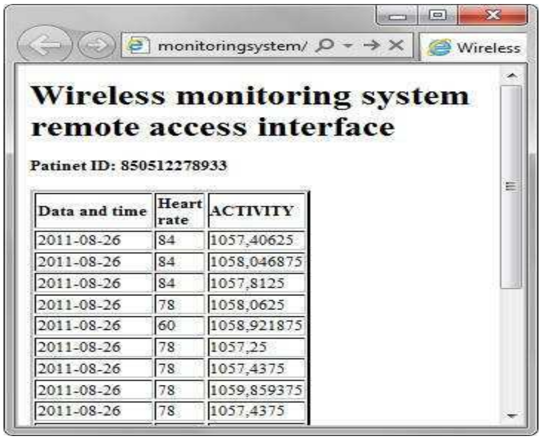


Figure 2. Screenshot of the wireless monitoring application.



Data and time	Heart rate	ACTIVITY
2011-08-26	84	1057,40625
2011-08-26	84	1058,046875
2011-08-26	84	1057,8125
2011-08-26	78	1058,0625
2011-08-26	60	1058,921875
2011-08-26	78	1057,25
2011-08-26	78	1057,4375
2011-08-26	78	1059,859375
2011-08-26	78	1057,4375

Figure 3. Web remote access interface.

3. Material and methods

3.1. Material

The system was tested on 10 healthy volunteers (5 females and 5 males, age 25-59, mean age: 35 years). Each subject was examined during common daily activities, such as: working, resting, walking in different directions, physical exercising, etc.

Measurements of the heart electrical activity was limited to only one bipolar lead. Corresponding surface electrodes were located in the following areas (Fig. 4) [5]:

- Channel 1 (+) – in the fifth intercostal in anterior axillary line.
- Channel 1 (–) – manubrium of sternum on the right side.
- Ground – in the fifth intercostal in midaxillary line

The motion signal was captured by means of the 3-axes accelerometer sensor integrated in the Revitus box placed on the chest with use of a fasten belt.

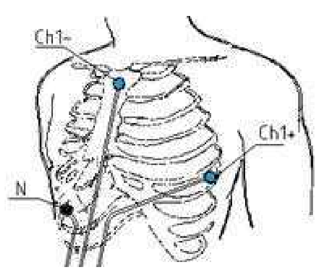


Figure 4. One bipolar lead used in the study [5].

3.2. ECG processing and analysis

Heart rate was determined from the ECG with use of the peak searching algorithm, which calculates the number of ECG peaks in 10s moving window. For higher accuracy a filtering-thresholding algorithm was used to eliminate peaks that were not representing the cardiac activity. All this led to monitor heart rate variability in the colour graph.

3.3. Acceleration processing and analysis

To calculate subject relative movement the ACTIVITY factor was introduced. It is calculated in a simplified way as a sum of absolute values of ACC signals from all directions in 10s moving window:

$$ACTIVITY = \sum_{i}^{n} \left(|ACC_x^i| + |ACC_y^i| + |ACC_z^i| \right)$$

where ACC_x, ACC_y, ACC_z is a *x*-, *y*- and *z*-axis acceleration component respectively; *n* is the number of samples in 10s window.

4. Results

In order to test the proposed system we planned and carried out experiments of HR and ACC variability measurements during selected daily activities. The results from one of 10 investigated volunteers are presented in fig. 5. In the graph red dash lines divide ranges with different type of activities: resting, house working, natural gait with direction change and physical exercising successively.

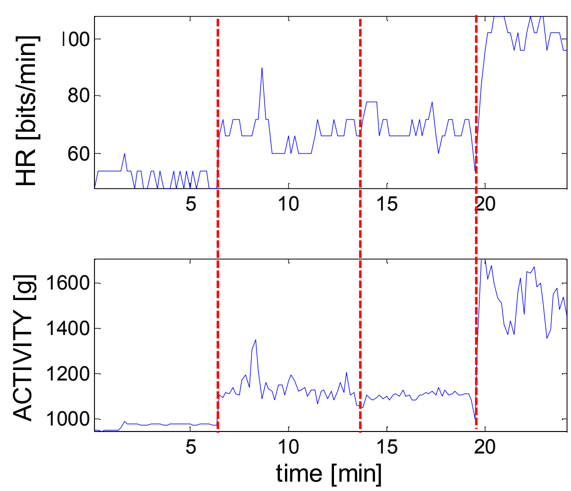


Figure 5. HR and ACC variability during resting, working, walking and physical activity.

Average values of heart rate and motion activity factor for 3 chosen subjects were collected in table 2.

Table 2. HR and ACC variability – average values.

Activity		Subject 1	Subject 2	Subject 3
Resting	HR	52	67	64
	ACC	971	1094	1203
Working	HR	67	75	68
	ACC	1138	1286	1300
Walking	HR	69	72	71
	ACC	1103	1097	1682
Exercising	HR	98	119	90
	ACC	1515	1371	1950

5. Discussion

All participating volunteers were performing activities most common for their daily living and involving diversified level of heart activity and amount of motion (from resting to physical exercising). During testing Revitus ECG module, Wireless Monitoring System Application and remote access in real environment conditions no significant disturbing problems were observed.

6. Conclusions

The proposed architecture and algorithms proved to be suitable for home-care patient surveillance. Our results indicate that it is possible to monitor patient's heart rate and motion activity remotely. Moreover, the system collects health signals without interfering with user's normal daily activities. Applied algorithms were found to be suitable for real time processing. Presented system can also be used for computer-assisted physical rehabilitation and ambulatory monitoring.

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