Human Activity Surveillance based on Wearable Body Sensor Network

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Abstract

With the rapid advancements of biomedical engineering and wireless communication it is possible to develop body sensor networks (BSN) which support a range of applications including medical and healthcare systems. The aim of the research is to propose a prototype of BSN-based wearable wireless monitoring system optimized to monitor patient's activity and physiological signals. The system consists of a number of miniature sensors (ECG, accelerometer, GPS sensor, temperature sensor), wireless modules (Bluetooth) and a gateway node to connect to the external database server. Developed algorithms process and analyze biomedical signals in real time in order to calculate proposed motion activity factor based on movement sensors and selected physiological parameters including heart rate and body temperature. The main advantage of the system is the algorithm optimization for real time computing and web-based remote interface to the patient location and data. The system was tested on 10 healthy volunteers. Each of them was monitored during common daily activities.

1. Introduction

Recent advances in electronics, integrated circuits, system-on-a-chip, wireless networks and biosensors have allowed the construction of novel health monitoring systems based on Body Sensor Networks.

A body sensor network (or BAN - body area network) consists of one or more wearable network nodes, each of them capable of sensing, and processing one or more physiological signals (e.g., heart rate, blood oxygen saturation, physical activity (e.g., body orientation, type and level of activity), and environmental parameters (location, light, atmospheric pressure). These nodes are placed on the human body as tiny patches or attached to users' clothes [1].

The first academic research paper advocating the use of body sensor network for health monitoring application were published in 2001[2]. It presented a design of wireless personal area network with physiological sensors (such as EEG, GSR) for medical application in a telemedical environment. We have witnessed tremendous advances in semiconductors technology since then enabling sensing of vital signs and accurate tracking of user's physical activity[3 - 6]. A small device named WalkECG, developed for out of hospital patient monitoring is presented in [10]. The device is based on microcontroller and includes ECG amplifier, GSM modem and battery. It transmits ECG strip to Telemedicine Central Station.

There are several examples of commercial systems based on BAN. The most common application is monitoring of cardiac patients. Corventis System[7] consist of wearable device that captures ECG data and a mobile transmitter. It offers continuous surveillance of symptomatic and asymptomatic cardiac abnormalities to help physicians diagnose and treat cardiac arrhythmias. When an arrhythmia is detected, system automatically transmits the ECG via a wireless data transmitter device to the Monitoring Center. Another example of cardiac monitoring system is CardioNet [8] which monitors the patient via the small sensor during normal daily routine. As events occur, patient activity is automatically transmitted to the Monitoring Center for analysis and response. CardioNet is focused on helping physicians diagnose and treat patients with arrhythmias.

This paper presents a health monitoring system which integrates wearable and battery-operated ECG, movement (accelerometer), temperature and GPS sensors which send data to monitoring gateway via wireless Bluetooth network. Algorithms were developed that process and analyze signals in real time in order to calculate heart rate, activity, temperature and locate the patient. The main advantage of the system is algorithms optimization for real time data processing.

The rest of the paper is organized as follows. Section 2 overviews the system design and presents hardware used to build a prototype. Section 3 describes material and methods. Section 4 presents results. Section 5 discusses the paper and describes ideas for the future work.

2. System design

The architecture of the proposed health monitoring system consists of a mobile wireless ECG, acceleration activity(ACC), temperature and GPS sensors that is placed on the user body and a monitoring gateway. Sensors sample, process and send the information about user cardiac activity, movement, temperature and location to the monitoring gateway (notebook or smartphone). Received data is analyzed by custom built algorithms and forwarded to private medical database, where data is accessible to a doctor. Figure 1 presents the system design.

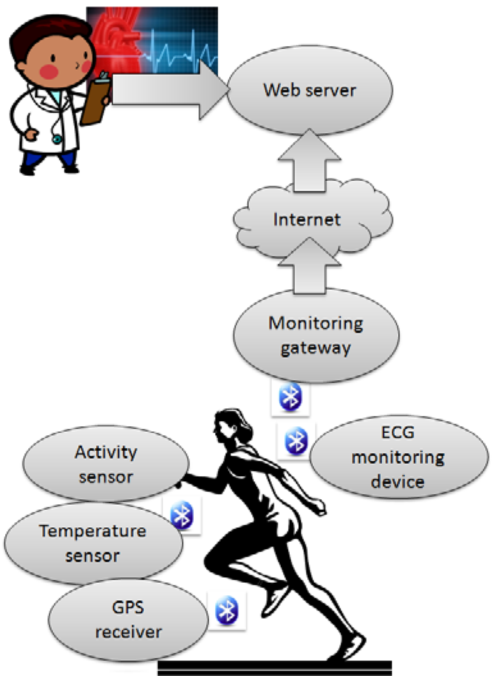

Figure 1. The system architecture.

2.1. Hardware

Monitoring system integrates Aspel Aspekt 500 ECG signal transmitter, MMA7341L accelerometer, temperature sensor MCP9700 and Pentagram Pathfinder GPS sensor.

Aspekt 500 (Fig. 2) is a digital unit designated for wireless ECG signal transmission. It is equipped with a ten electrodes cable. ECG signal is sampled at the frequency of 500 Hz. The transmitter allows a free patients movement up to 10 m from monitoring unit. Aspekt 500 is a portable sensor (dimensions 130×96×30 mm). ECG monitoring device sends the data into separate structured packets. Each packet is 126 bytes long and stores seven 16 bytes samples of ECG signal. The rest 14 bytes are responsible for marking the beginning of packet (x8081), packet number, battery state and control sum.

Figure 2. Aspel Aspekt 500 ECG signal transmitter.

The MMA7341L is a low power, miniature (3mm x 5mm x 1mm) capacitive, 3-axes accelerometer featuring signal conditioning, low current consumption(400uA), temperature compensation and self test.

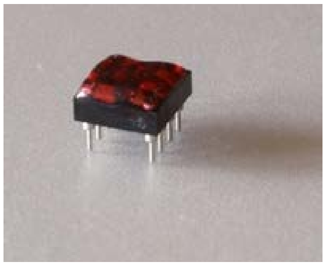

Figure 3. Accelerometer MMA7341L.

Accelerometer is used for motion sensing and fall detection. Connection diagram was shown in the fig. 4.

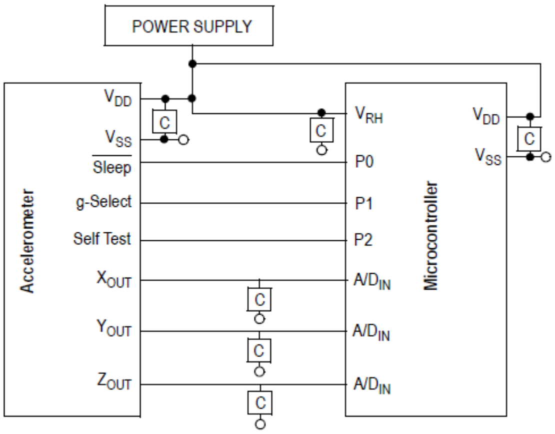

Figure 4. Accelerometer connection to microcontroller.

The MCP9700 is an analog temperature sensor that converts temperature to analog voltage. It is a low-cost and low-power sensor (consuming 6 µA of operating current). Connection diagram was shown in the figure 5.

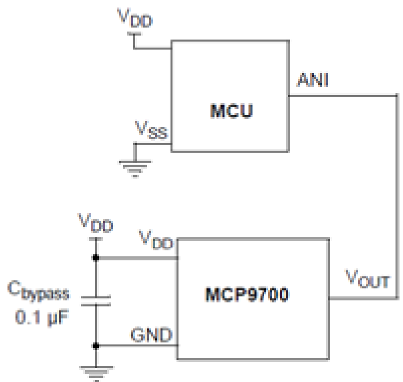

Figure 5. MCP9700 connection diagram.

MCP9700 and MMA7341L are controlled by ATmega328 microcontroller board with integrated Bluegiga WT11 bluetooth module.

GSP PENTAGRAM PathFinder P 3101(fig. 6) is a 32-Channel Bluetooth GPS Receiver with -158dBm high sensitivity and has up to 25 hours of battery operated time.

Figure 6. Pentagram PathFinder P 3101.

2.2. Software

The most demanding task was to design and implement the software that will cope which huge data flow from the monitoring device and real time signal analysis at the same time. Key functionalities of the software include calculating and displaying the values of heart rate, body temperature, GPS coordinates and the measure of patient motion based on accelerometer data. All this data are forwarded using the Internet to a purposely-designed medical web server where it is accessible to a doctor or selected people through easy to use web-based graphical interface. All data can be saved for further statistical analysis in the friendly CSV format.

Algorithms were implemented in Java language. Therefore, they can be used by a wide range of smartphone devices and operating systems.

2.3. Remote surveillance

Part of the system is the mechanism that enables to send sensor data to the remote web server. Every 60s heart rate, ACTIVITY factor, body temperature and GPS coordinates are uploaded to medical web server for the storage and display as a web page for authorized doctors or patient's family. In case of emergency it is possible to access the patient location on the map through web based interface.

3. Material and methods

3.1. Material

The system was tested on 10 healthy volunteers (10 males). Each subject was examined during common daily activities, such as: working, resting, walking. The motion signal was captured by means of the 3-axes accelerometer sensor integrated in the placed on the chest with use of a fasten belt.

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.

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:

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

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.

Fall detection is perform by algorithm is responsible for analyzing data from accelerometer. The absolute sum of tree axis accelerometer data is calculated. If obtained value is higher than experimentally set trigger point, the alarm module is switched on.

3.4. Body temperature and location

To calculate subject body temperature the BTEMP factor was introduced. It is calculated according to following equation:

$$BTEMP = \frac{\sum_i^n (TEMP_i)}{n}$$

where TEMP is a body temperature measured on the left arm in Celcius and is sampled at 1 Hz; n is the number of samples in 10s window. Positioning data (longitude, latitude) is calculated based on GPS data from the sensor.

4. Results

In order to test the proposed system we planned and carried out experiments of HR, ACTIVITY and BTEMP variability measurements during selected daily activities. The results from three of 10 investigated volunteers are presented in Table 1.

Table 1. Variability measurements during selected daily activities – average values.

Activity		Subject 1	Subject 2	Subject 3
Resting	HR	52	64	62
	ACTIVITY	971	1094	1203
	BTEMP	31	31	33
Working	HR	78	82	82
	ACTIVITY	1138	1286	1350
	BTEMP	34	34	35

5. Discussion and conclusion

This paper presents an example of wearable BSN-based patient monitoring system which was tested by volunteers who were performing activities most common for their daily living and involving diversified level of heart activity and amount of motion (from resting to working). The achieved results are satisfactory for the monitoring purposes. However, more tests are needed to develop system that will focus on prevention and early detection of health conditions. Potential applications include early detection of abnormal conditions and supervised cardiac rehabilitation. Automatic integration of collected information and user's inputs into research databases can provide medical community with opportunity to search for personalized trends and group patterns, allowing insights into disease evolution, the rehabilitation process, and the effects of drug therapy.

The concept of sensor-based patient monitoring using wireless body area network (WBAN) will bring revolutionary changes in health care systems. WBAN allows flexibility in providing location independent and seamless patient monitoring without affecting the lifestyle of patients.

Acknowledgements

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References

[1] Jovanov E, Milenkovic A, Otto C, de Groen P. A wireless body area network of intelligent motion sensors for computer assisted physical rehabilitation; J NeuroEng Rehabilitation 2005;2:6.
[2] Jovanov E, et al. Wireless personal area networks in telemedical environment, IEEE EMBS Information Technology Application in Biomedicine 2000.
[3] Bonato, P., Wearable Sensors and Systems. IEEE Eng. Med. Biol. Mag 2010; 29(3):25–36.
[4] Chen X, Ho CT, Lim ET, Kyaw TZ. Cellular Phone based online ECG Processing for Ambulatory and Continuous Detection. Computers in Cardiology 2007;34: 653-656.
[5] Sun H, De Florio V, Gui N, Blondia C. Promises and Challenges of Ambient Assisted Living Systems. In: Sixth International Conference on Information Technology: New Generations, ITNG 2009: 1201-1207.
[6] IEEE 802.15 WPAN Task Group 6 Body Area Networks (BAN), http://ieee802.org/15/pub/TG6.html.
[7] Corventis, http://www.corventis.com/ (June 2012).
[8] CardioNet, http://www.cardionet.com/ (June 2012).
[9] Otto C, Milenkovic A, Sanders C, Jovanov E. System Architecture of a Wireless Body Area Sensor Network for Ubiquitous Health Monitoring. Journal of Mobile Multimedia 2006;1: 307-326.
[10] Gonzlez R, Jimnez D, Vargas O. WalkECG, A Mobile Cardiac Care Device. Computers in Cardiology 2005;32, 371-374.

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