

# Telemedical Human Activity Monitoring System based on Wearable Sensors Network

Eliasz Kańtoch

AGH University of Science and Technology, Kraków, Poland

## Abstract

*The aim of the research is to implement and test a telemedical system to monitor and analyze physiological and movements signals from human. The system incorporates the body central unit (Bluetooth radio, CPU and accelerometer), wearable sensors (ECG, temperature sensor, skin humidity sensor) which are located on the human body, and a mobile computing device to forward data to the remote medical server. The system includes specially designed transmission protocol and remote web-based graphical user interface for real time data analysis. The system was tested on 20 healthy volunteers (15 male, 5 female) during activities of daily living (ADL). Experimental results showed maximum 4% error compared to medical devices and demonstrated the possibility of delivering the telemedical service using data from a remote wearable sensor network.*

## 1. Introduction

Telemedicine is the use of telecommunication technologies to provide medical services. The key aspect of telemedicine is the use of electronic signal to transfer medical information from one place to another [1]. Various medical sensors are valuable source of information about the patient health. Unfortunately, they are only accessible to patients who stay in specialised hospitals and clinics.

Recent advances in electronic, materials and biomedical engineering accelerate development of sophisticated sensors, which can be used for monitoring outside of clinical settings (e.g. in the home or work).

In this paper, the method of telemonitoring based on wearable sensor network is proposed. In this system, health information collected by developed prototype of monitoring device can be transmitted wirelessly to a remote medical server for storage and analysis.

Past studies on wearable sensor networks were focused on single sensors especially accelerometers and electrocardiographs. In [2] wearable sensor badge and wearable sensor jacket is described that measure body movement. The authors of [3] showed the feasibility of using waist-mounted, wireless triaxial accelerometers to identify the performance of activities of daily living

(ADL) by older adults monitored in home environment. In [4] a distributed recognition framework to classify continuous human actions using a low-bandwidth wearable motion sensor network is proposed. In [5] authors described and evaluated a miniature ultra low noise capacitive ECG sensor called Eco. It does not require direct contact to the skin and has comparable performance to standard ECG.

In recent years there can be found systems, which use multiple sensors [6-8]. The research presented in [9] proposed an armband-based wearable monitoring device for ECG and PPG measurements and evaluated it in an out-of laboratory setting. ECG was measured by three electrodes and PPG was measured by near-infrared LED emitter and a phototransistor in reflective mode. The acquired signals were amplified and filtered by band-pass filters. The filtered analog signals were digitalized by the ATmega8 at the sample rate 500 Hz and resolution of 8 bit, and then stored in a flash memory module mounted on the arm-band. In [10] authors proposed the in-shoe pressure and acceleration system that was used to automatically recognize postures and activities of patients with stroke.

## 2. Material and methods

The telemedical human activity monitoring system was divided into three autonomous modules: prototype of the monitoring hardware, the system software and server scripts. The main task of the system is to remotely monitor and analyse selected human physiological and movements signals.

The system was modelled using IDEF0 (Integration Definition for Function Modeling). IDEF0 top level diagram was shown in the Figure 1.

The system behavior was described by the state diagram (Figure 2). User's interaction with the system was shown using the use case diagram (Figure 3).

The system hardware incorporates the Body Sensor Unit (BSU) and sensor boards. The BSU consists of ATMEL AVR 8-bit microcontroller, a Bluetooth module and accelerometer (Figure 4). Three different sensor boards were developed in order to combine multiple sensor data (ECG, skin temperature and humidity) into one record.

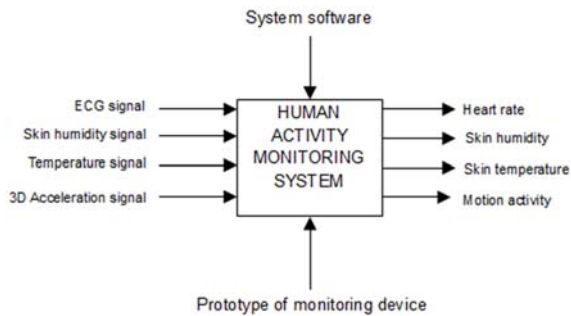


Figure 1. IDEF0 top level diagram of the system

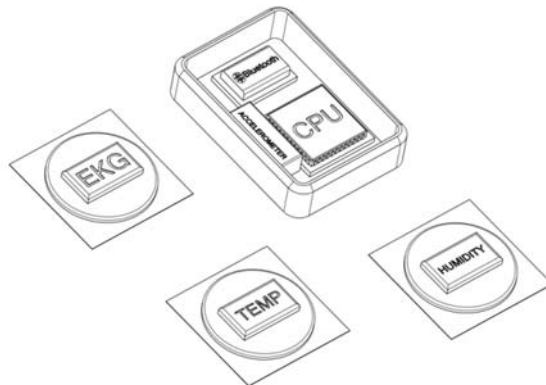


Figure 4. Body sensor unit and three sensor units

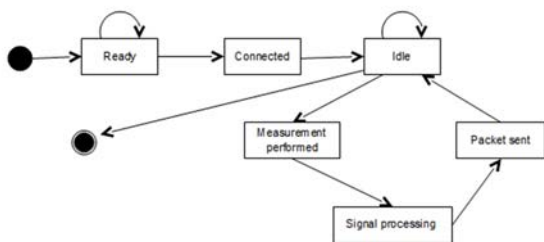


Figure 2. State diagram.

Acquired data are processed and transmitted to the mobile computing device, where they are analyzed and forward to a remote medical server. Authorized users (family or physician) can access monitoring data via web-based graphical user interface. The system architecture was shown in the Figure 5.

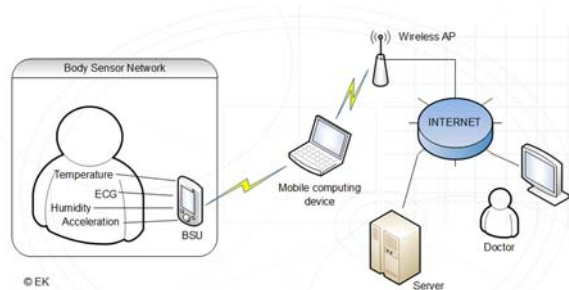


Figure 5. System architecture.

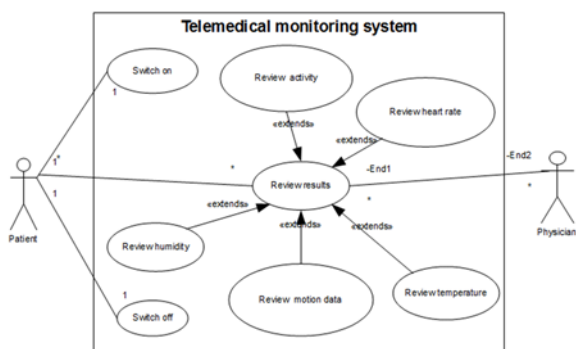


Figure 3. Use case diagram.

The system was tested on 20 healthy volunteers (15 male, 5 female). Each subject was examined according to a research scenario during activities of daily living (ADL), such as: sitting, picking objects, working in the garden etc. Measurements of the ECG was limited to one bipolar lead. The motion signal was acquired by means of the 3D accelerometer sensor integrated in the Body Sensor Unit (BSU) placed on the chest with use of a fasten belt, which is shown in Figure 6. Temperature and skin humidity signal was measured under the arm.

Software dedicated for monitoring device was implemented in C language. Server scripts were implemented in PHP.

The most challenging task was to ensure reliable data transfer. It was achieved by developing specially designed transmission protocol optimized for real time data processing. Nodes communicate using specific packet structure that was shown in the Table 1. Sampling frequency can be modified according to the monitoring requirements.

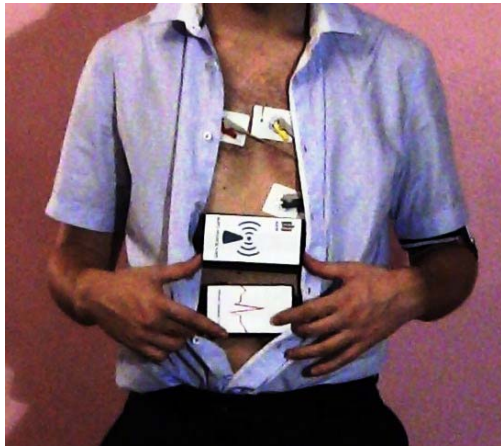


Figure 6. BSU and sensor boards location

Table 1. Packet structure with example data

Frame no.	Acc. (X)	Acc. (Y)	Acc. (Z)	Tem p.	Skin hum.	Heart rate	M
4B	4B	4B	4B	4B	4B	4B	4B
5212	-225	-656	-4522	32.2	66	78	0

The graphical user interface is shown in Figure 7.

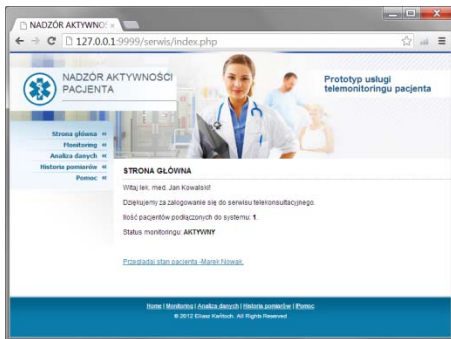


Figure 7. Graphical user interface

### 3. Results and discussion

In the experiments subjects were asked to put on the developed prototype of health monitoring device for 30 minutes. They were instructed to perform various physical activities specified in a scenario. The data were recorded and available remotely to the supervisor with a maximum delay of 28 s.

Example of the acquired experimental data consisted of 3D accelerometer signal, temperature, skin humidity and heart rate for a subject picking different object from above in 60s time window are shown in Figure 8. System automatically performed statistical analysis of data (mean value, standard deviation, minimum value, maximum value), which was shown in the Table 2.

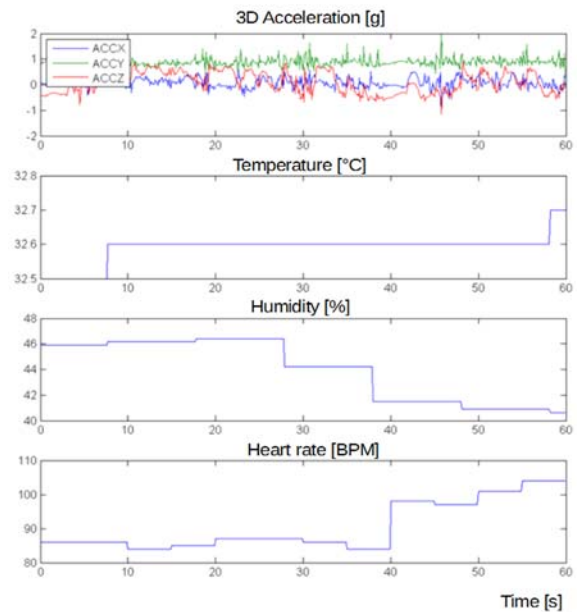


Figure 8. Signals acquired from the experiment during the picking up objects activity

Table 2. Statistical analysis of experimental data for the picking up object activity

Parameter	Mean	SD	Min. value	Max. value
Acc. (X)	0.09	0.20	-0.95	0.59
Acc. (Y)	0.88	0.17	0.27	1.99
Acc. (Z)	0.11	0.43	-1.13	1.02
Temp.	32.59	0.04	32.50	32.70
Skin hum.	44.01	2.30	40.60	46.40
Heart rate	90.42	7.02	84.00	104.00

Experimental results for the group show maximum of 4% of error in comparison with certified medical devices.

### 4. Conclusion

The results of the experiments show that the proposed system architecture and the signal acquisition method is suitable for monitoring selected physiological and movement signals remotely. In addition, developed infrastructure can be used to provide with telemedical health monitoring service for older adults and patients undergoing clinical intervention in the home setting.

The application of wearable physiological sensors promises to reduce the cost and improve the quality of healthcare services. Moreover, the system developed can become the framework for novel healthcare telemedical services.

## Acknowledgements

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Address for correspondence.

Eliasz Kańtoch  
AGH University of Science and Technology  
30 Mickiewicza Av.  
30-059 Kraków, Poland