Monitoring activities of daily living based on wearable wireless body sensor network

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***Abstract*—With recent advances in microprocessor chip technology, wireless communication, and biomedical engineering it is possible to develop miniaturized ubiquitous health monitoring devices that are capable of recording physiological and movement signals during daily life activities. The aim of the research is to implement and test the prototype of health monitoring system. The system consists of the body central unit with Bluetooth module and wearable sensors: the custom-designed ECG sensor, the temperature sensor, the skin humidity sensor and accelerometers placed on the human body or integrated with clothes and a network gateway to forward data to a remote medical server. The system includes custom-designed transmission protocol and remote web-based graphical user interface for remote real time data analysis. Experimental results for a group of humans who performed various activities (eg. working, running, etc.) showed maximum 5% absolute error compared to certified medical devices. The results are promising and indicate that developed wireless wearable monitoring system faces challenges of multi-sensor human health monitoring during performing daily activities and opens new opportunities in developing novel healthcare services.**

I. INTRODUCTION

Recent progress in microprocessor chip technology, wireless communication, and biomedical engineering made it possible to develop miniaturized pervasive health monitoring devices designed for monitoring of physiological signals during activities of daily living (ADL).

Deep understanding of patterns and characteristics of physiological signals and their variation during daily activities is crucial for the development of advanced methods for diagnosis and treatment of patients suffering from chronic diseases including cardiac disorders, asthma or diabetes [1-3]. 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, body temperature, skin humidity) and physical activity (type and level of activity). These nodes are placed on the human body as tiny patches or attached to users' clothes [1-5]. One of the first academic research paper advocating the use of body sensor network for health monitoring application were published in 2001[2]. The authors presented a design of wireless personal area network with physiological sensors (such as EEG, GSR) for telemedical application. Since then, we witness tremendous advances in semiconductors technology enabling sensing of vital signs and accurate tracking of user's physical activity[1 - 5]. A small device named WalkECG, developed for non-hospital patient monitoring is presented in [7]. The device is based on a microcontroller and includes an ECG amplifier, a GSM modem and a battery. It transmits raw ECG strips to Telemedicine Central Station.

There are several examples of commercially available systems based on BANs. The most common application is monitoring of cardiac patients. The Corventis System consists of a wearable device that captures ECG data and a mobile transmitter. It offers continuous surveillance of symptomatic and asymptomatic cardiac abnormalities to help physicians in diagnosing and treatment of cardiac arrhythmias. When an arrhythmia is detected, the system automatically transmits the ECG via wireless data transmission device to the Monitoring Center. Another example of cardiac monitoring system is CardioNet which monitors the patient via small sensor during normal daily routine. As events occur, information on patient's activity is automatically transmitted to the Monitoring Center for analysis and response. CardioNet is focused on diagnostics of patients with arrhythmias. There are examples of different wearable sensors to acquire diagnostic data [8-14].

The aim of our research was to design, implement and verify a wearable health monitoring system based on selected wearable sensors for tracking and analyzing of human physiological signals. Custom-developed algorithms process and analyze signals in order to calculate physiological activity descriptors in real time. Main advantage of the system is optimization for wearable data processing.

II. SYSTEM ARCHITECTURE

The presented system incorporates body sensor unit consisting of Atmel®AVR 8-bit microcontroller, a Bluetooth module, dedicated ECG sensor (one lead, 12-bit resolution, up to 500Hz sampling frequency), a temperature and skin humidity sensor,an accelerometer, placed on the human body or integrated with clothes and a smartphone as a network gateway to forward the acquired data to a remote medical server. The system architecture is shown in Fig. 1 and the system hardware is shown in Fig. 2.

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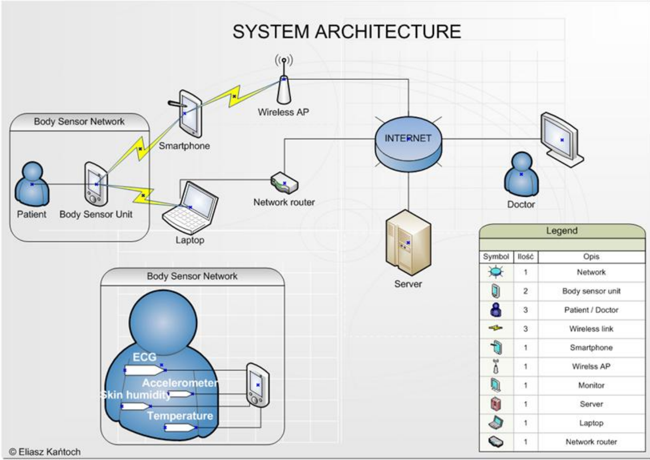

Figure 1. BSN-based system architecture.

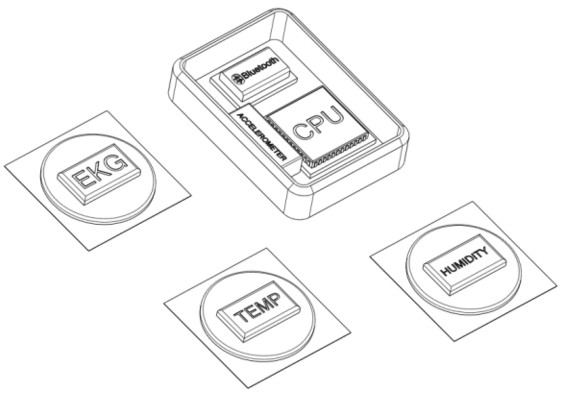

Figure 2. Body sensor unit with three body physio units.

The system works as a part of telemedical service which provide remote access to monitoring data via web-based graphical user interface for authorized users (family or physician). The web-based graphical user interface is shown in Fig. 3.

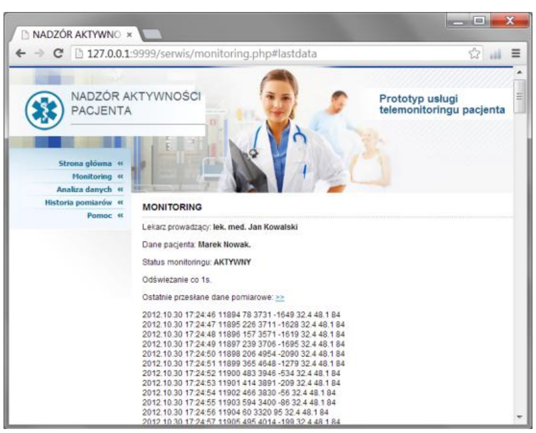

Figure 3. Web-based graphical user interface.

III. Materials and Methods

The system was tested on 15 healthy volunteers (3 females and 12 males, age 21-32). Each subject was examined according to a research scenario during common daily activities, such as: working, resting, walking in different directions, physical exercising, etc. Measurements of the heart electrical activity was limited to one bipolar lead. The motion signal was captured by means of the 3-axes accelerometer sensor integrated in the Body Sensor Unit placed on the chest with use of a fasten belt, which is shown in Fig. 4. Temperature and skin humidity signal was measured under the arm.

Figure 4. Sensors attached to the body and clothes.

For investigating of data from the experiments we propose to calculate a four-dimensional activity vector based on sensors signals (acceleration, temperature, skin humidity, heart rate) accordingly to equations 1-8.

The activity vector describes the level of patient activity in N-time period. Main idea is to extract specific signals features and use then to calculate d-vector and then γ-vector (activity vector) as it is shown in equations 1-8.

$$ACC_d = \sqrt{\frac{\sum_{i=0}^{N}(ACCX_i - \overline{ACCX})^2}{N}} + \sqrt{\frac{\sum_{i=0}^{N}(ACCY_i - \overline{ACCY})^2}{N}} + \sqrt{\frac{\sum_{i=0}^{N}(ACCZ_i - \overline{ACCZ})^2}{N}} \quad (1)$$

$$TMP_d = \frac{1}{N}\sum_{i=0}^{N} TMP_i + \Omega * (TMP_{max} - TMP_{min}) \quad (2)$$

$$HUM_d = \frac{1}{N}\sum_{i=0}^{N} HUM_i + (HUM_{max} - HUM_{min}) \quad (3)$$

$$HR_d = \frac{1}{N}\sum_{i=0}^{N} HR_i + \beta * (HR_{max} - HR_{min}) \quad (4)$$

$$ACC_\gamma = \frac{ACC_d}{2} \quad (5)$$

$$TMP_\gamma = \frac{TMP_d}{\alpha} \quad (6)$$

$$HUM_\gamma = \frac{HUM_d}{2 * \alpha} \quad (7)$$

$$HR_{\gamma} = \frac{HR_d}{2 * \alpha} \quad (8)$$

For optimal separation of activities the parameters were adjusted during the experiments:

Ω is 10,while β=2 and α = 100.

IV. Results and Discussion

We organized the experiments in three steps:

1.Subjects were asked to wear the developed prototype of health monitoring system for two hours.

2. During this experiment they were asked to perform various physical activities specified in a scenario.

3.The data were recorded and available remotely to the supervisor with a maximum delay of 30 s.

Experimental results for the group show maximum of 5% of absolute error in comparison with certified medical devices, which was shown in the table I. This experiment demonstrated that it is possible to remotely monitor patient activity via wearable wireless monitoring system during daily activities. Moreover, the system developed can be a starting point for developing novel healthcare telemedical services.

TABLE I. Absolute Error

Parameter	***Absolute error***
Temperature	<0.5 °C
Skin humidity	<11 (<2 after removing symmetric error) %
Heart rate	<=5BPM
Accelerometers	<3%

Experimental data in the following order: 3D accelerometer data [ACCX,ACCY,ACCZ], skin temperature [TEMP], skin humidity [HUM], heart rate [HR]) for a exercising subject in 95s time window are shown in Fig. 5. Statistical analysis (mean value, standard deviation, minimum value, maximum value) is shown in the table II while d-vector and γ – vector calculation was shown in table III.

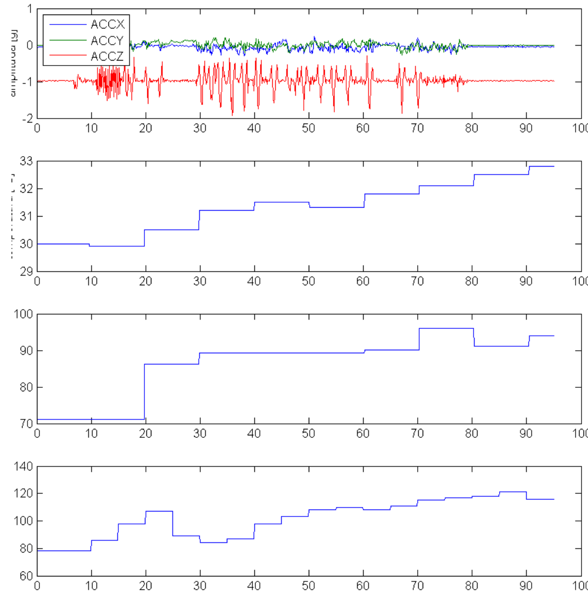

Figure 5. Experimental data aquired from sensors in 95s time window. Plot show from the top to the bottom the values of: 3D acceleration signal, temperature signal, skin humidity signal, heart rate signal)

TABLE II. Statistical Analysis

Parameter	**MEAN**	**STD**	**MIN**	**MAX**
ACCX	-0.05	0.07	-0.29	0.24
ACCY	-0.00	0.07	-0.28	0.20
ACCZ	-0.98	0.20	-1.94	-0.29
TMP	31.28	0.90	29.90	32.80
HUM	86.39	8.19	71.20	96.00
HR	101.70	13.78	78.00	121.00

TABLE III. D-vector and Γ-vector

d-vector	***value***	$\gamma - vector$	***value***
ACC_d	0.34	ACC_{γ}	0.17
HR_d	187.70	HR_{γ}	0.94
HUM_d	111.19	HUM_{γ}	0.56
TMP_d	60.28	TMP_{γ}	0.60

This graphical representation of the activity is the visual sign for a physician who can easily assess the level of patient activity and identify unhealthy habits. This visual (shape and color) activity description method is simple communication mechanism for chronic disease patients and older people who can get instant feedback about their health state. Sample signals from the experiment with graphical representation of the calculated four dimensional activity vector for selected physical activities are shown in Fig. 6. Three activities (resting, walking, exercising) were compared in the Fig. 7.

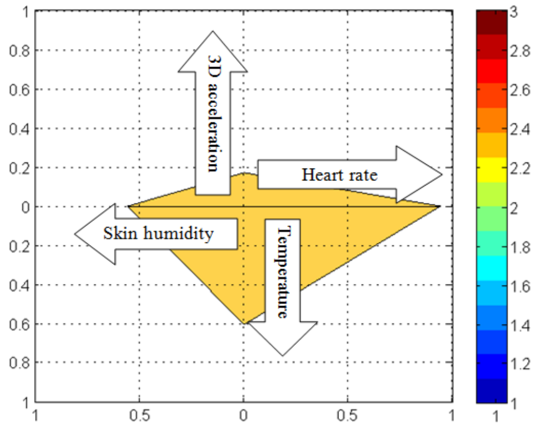

Figure 6. Four dimensional activity vector representation on the surface.

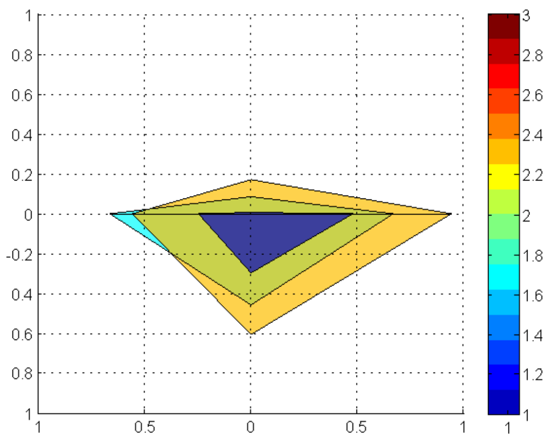

Figure 7. Comparison between calculated 4D activity vectors of three activities (resting, walking, exercising).

The major research achievement is selection of physiological and movement parameters that can be monitored during activities of daily living and optimization of BSN-based health monitoring system in term of wearability.

V. Conclusion

The experimental results are promising and indicate that custom-developed wireless wearable monitoring system faces challenges of multi-sensor human health monitoring during the performance of typical daily activities and open new opportunities in evaluating the treatment of numerous patients. The achieved results are satisfactory for the monitoring purposes. However, more tests are needed to develop a system that will focus on prevention and early detection of specific 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 an opportunity to search for personalized trends and group patterns, allowing insights into disease evolution, the rehabilitation process, and the effects of drug therapy. Future research includes developing of algorithms that will automatically detect unusual and potential dangerous events. The concept of sensor-based patient monitoring using body sensor network (BSN) can bring revolutionary changes in health care systems.

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