Technical Verification of applying Wearable Physiological Sensors in Ubiquitous Health Monitoring

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Abstract

The aim of the research is to design, implement and verify health monitoring system to monitor and analyze human physiological signals. System incorporates central processing unit with Bluetooth module, dedicated ECG sensor, temperature sensor and movement sensors placed on the human body or integrated with clothes and network gateway to forward acquired data to remote medical server. The main advantage of the system is the ability to acquire, process and wirelessly transmit physiological data during daily activities. Moreover, system includes dedicated transmission protocol and remote web-based graphical user interface for real time data analysis. Experimental results for a group of human who performed various activities (ex. working, running etc.) show 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 open new opportunities in treating and evaluating the treatment of number of patients who suffer from chronic diseases including cardiac disorders, asthma or diabetes.

1. Introduction

Eurostat's latest set of population projections (EUROPOP2010) were made covering the period from 2011 to 2060 – and show that population ageing is likely to affect all EU Member States over this period. Those aged 65 years or over will account for 29.5 % of the EU-27's population by 2060 (17.5 % in 2011) [1]. Growing number of older people will limit the access to healthcare services.

Recent advances in electronics, wireless communication, and mobile sensors provide with opportunities to develop miniature devices that are capable of tracking patient health. Small, low-power, low-cost devices can be integrated into body sensor network (BSN) [2-4, 7-11]. This technology has the potential to have enormous impact on many aspects of future healthcare services make some of them more accessible, efficient as well as cost-effective. Today, it is possible to obtain measurements of various physiological parameters like heart rate or oxygen saturation with small non-invasive sensors.

The objective of this research is to design, build and test the health monitoring system which integrates wearable sensors: ECG, temperature, skin humidity and accelerometer and smartphone into BSN-based network and provide telemedical services. System's algorithms process and analyze input signals in real time in order to calculate 4-dimentional vector that describe patient activity.

There are a lot of research papers in area of wireless sensors, human monitoring and telemedicine however the majority do not combine them together into one integrated health monitoring system[4,8]. Movement (acceleration) monitoring was described in [10]. Lenov in [6] described a T-shirt with ECG sensor and thermoelectric generator. Mercury system which consist of several wearable accelerometers was developed by Harvard Sensor Lab [5]. It is intended for long-term data collection for people affected by neuromotor disorder, such as Parkinson's Disease, and living at hospital or at home.

The rest of the paper is organized as follows. Section 2 overviews the system design. Section 3 presents material and methods. Section 4 describes results. Section 5 concludes the paper and describes plans for the future work.

2. System design

System incorporates central processing unit (body sensor unit) based on 8-bit 16MHz ATmega microcontroller unit with Cambridge Silicon Radio Bluetooth v.2.0 class 2 module, dedicated ECG sensor (built based on Analog Devices medical amplifiers), temperature sensor and micromechanical BMA180 accelerometer placed on the human body or integrated with clothes and network gateway to forward acquired data to remote medical server. Network gateway can be either PC computer or smartphone. The system architecture was shown in the figure 1. While the system hardware was shown in the figure 2.

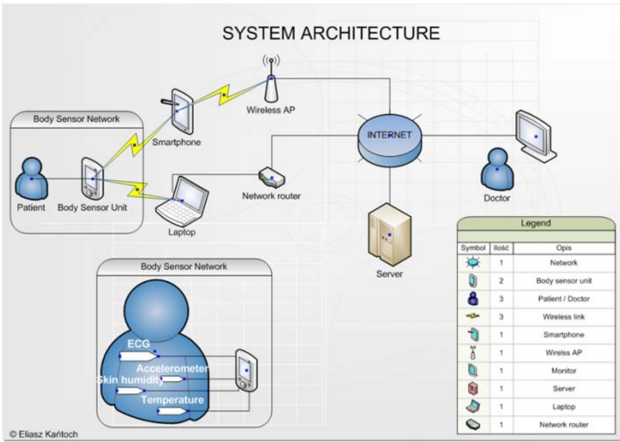

Figure 1. Wearable system architecture.

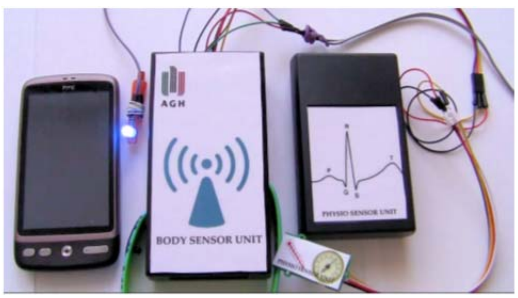

Figure 2. Body sensor unit with body physio units

The main advantage of the system is the ability to acquire, process and wirelessly transmit physiological data during daily activities. The system works as a part of a telemedical service which provide remote access to monitoring data via web-based graphical user interface for authorized users (family or physician).

Figure 3. System graphical user interface for PC. application, smartphone application and web application

3. Material and methods

Ten healthy subjects (4 females and 6 males, age 22-39) were asked to perform a set of activities of daily living (ADL) including: sitting, walking, physical exercising, running. Measurements of the heart electrical activity was limited to only 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 was shown in the figure 4. Temperature and skin humidity signal was measured under arm.

Figure 4. Sensors attached to the body and clothes

Proposed method of calculating the four dimension activity vector based on sensors signals (acceleration [ACC{X,Y,Z}], temperature[TEMP], skin humidity[HUM], heart rate[HR]) was shown in the equations 1-8. N refers to number of signal samples.

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

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

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

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

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

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

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

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

Parameters were optimized during experiments: $\beta = 2, \alpha = 100 \ and \ \Omega = 10$.

4. Results and discussion

Experimental results for a group of human who were performing various physical activities(e.g. sitting, standing, working, running) show maximum 5% absolute error in comparison with certified medical devices. This experiment demonstrated that it is possible to remotely monitor patient activity via wearable wireless monitoring system during daily activities. Data acquired from wearable sensors during walking in different direction was shown in the figure 5. Data statistical analysis was shown in table 1. D-vector and $\gamma - vector$ calculation was shown in the table 2.

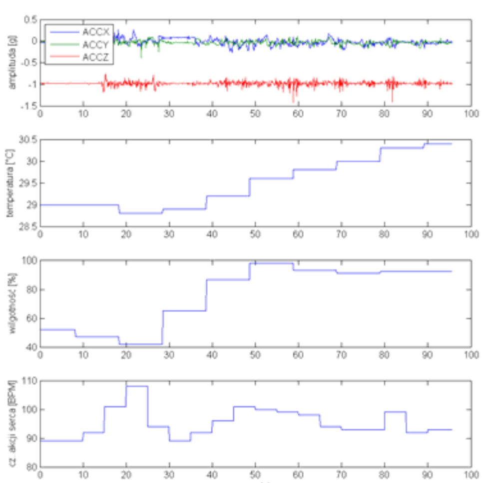

Figure 5. Data acquired from wearable sensors: 3D acceleration[g], temperature [°C], skin humidity [%], heart rate [BPM].

Table 1. Statistical analysis.

Sensor	MEAN	STD	MIN	MAX
ACCX	-0.02	0.07	-0.27	0.26
ACCY	-0.03	0.05	-0.39	0.20
ACCZ	-0.98	0.05	-1.43	-0.76
TMP	29.48	0.55	28.80	30.40
HUM	75.94	21.03	42.00	98.30
HR	95.35	4.88	89.00	108.00

Table 2. d-vector and $\gamma - vector$ calculation.

d-vector	Value	$\gamma - vector$	Value
ACC_d	0.17	ACC_γ	0.09
HR_d	133.35	HR_γ	0.67
HUM_d	132.24	HUM_γ	0.66
TMP_d	45.48	TMP_γ	0.45

Graphical representation of the calculated four dimension activity vector for walking subject was shown in the figure 6. While graphical representation of three different physical activities: sitting(blue), walking (light blue) and physical exercising (orange) was shown in the figure 7.

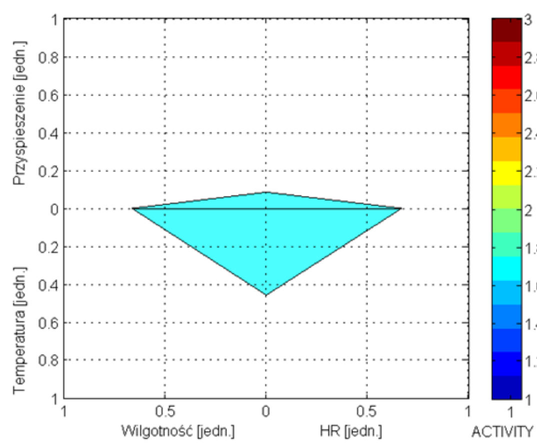

Figure 6. Graphical representation of the calculated four dimension activity vector for walking subject

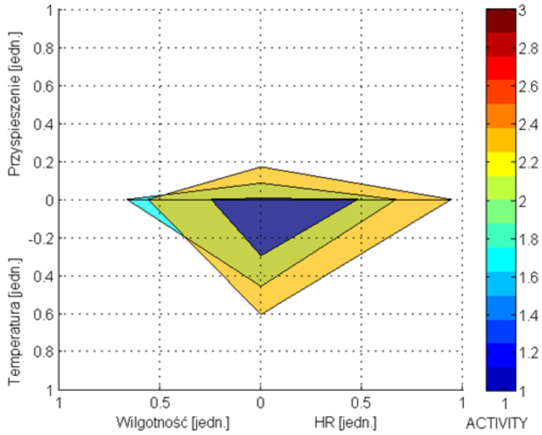

Figure 7. Graphical representation of three different physical activities: sitting(blue), walking (light blue) and physical exercising (orange).

5. Conclusion

The results are promising and indicate that it is possible to remotely monitor patient based on developed multi-sensor wearable health monitoring system during activities of daily living (ADL). Developed system openes new opportunities in developing novel healthcare services and may become one of the key components of the future e-health initiative that could make significant improvements in patient care and monitoring.

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