Evaluation of wearable system for measuring vital parameters in clinical environment

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Abstract. A continuous monitoring of physiological data is especially important for individuals whose chronic condition includes the risk of sudden acute events. Physiological measurements fluctuate over the course of the day, so a once-daily reading might not provide the whole picture. Standard ambulatory systems for monitoring, are not suitable for monitoring over long period of time. The new systems and techniques suitable for hospital environment are investigated over the past years. In this study, we present a wearable system which includes a Zephyr biomodule for measuring patient's vital parameters. Data is collected wirelessly and displayed on mobile device via software. In order to be used in hospitals, the developed system was clinically tested. The data for heart rate (HR) and respiratory rate (RR), obtained with the developed system were compared to the same parameters obtained by the standard medical device, in order to compare their accuracy. Preliminary results from these tests are shown in this paper.

Keywords: wearable sensor, vital signs monitoring, medical mobile application.

1 Introduction

Recent advances in telecommunications, microelectronics, sensor manufacturing and data analysis techniques have opened up new possibilities for using wearable technology. Wearable smart sensors can be used for measuring physiological and behavioral data in our day-to-day lives. The interest of using these devices originates from the need for monitoring patients over extensive periods of time. This is especially important for individuals whose chronic condition includes risk of sudden acute events. Vital parameters data of these patients can vary greatly over the course of the day, so a one-time reading may not be representative or give enough information to make a personalized assessment. A continuous monitoring of physiological data is important for these individuals. Standard ambulatory systems for monitoring, like ECG monitoring systems, are not suitable for monitoring over long period of time (several weeks or months).

They are very robust, demanding a large space for operating. They also limit the patients' movement, because they use wires that need to be attached to a human body for measuring the vital parameters data.
To overcome these limitations of ambulatory technology, a wearable systems can be used. These systems can measure various parameters like: heart rate, respiration rate, ECG, blood pressure, oxygen saturation, posture etc. Furthermore, the widespread use of mobile devices and wireless connectivity make real-time monitoring in ambulatory conditions possible.
This paper present the design and evaluation of a monitoring system that uses Zephyr biomodule for measuring ECG, heart rate, respiratory rate, posture and acceleration. The sensor transmits these data to the developed mobile application, that can store the data locally and on the cloud server. The system is set up for a clinical trial in General hospital in Celje, Slovenija. The preliminary clinical tests included continuous measurement of HR and RR on healthy and hospitalized patients. The results of these testing are presented and discussed in this paper.

2 Related work

Many studies explored the clinical applications of wearable sensors in cardiovascular, neurological, asthma, and hypertension diseases [1, 2]. Asada et al. [3] developed a ring sensor for measuring blood oxygen saturation (SpO2) and heart rate. Sensor can be worn on a finger (like a ring), for long period of time without any discomfort to the patient. The ring sensor is equipped with a low-power transceiver for bidirectional communication with a base station, thus allowing uploading or retrieving data at any point in time. Another device that was subsequently developed by the same research group was a wearable cuff-less photoplethysmographic (PPG) based blood pressure monitor [4]. Similar system was developed by Corbishley et al. [5]. They used a miniaturized wearable acoustic sensor (i.e. microphone) for measuring respiratory rate. The sensor can be placed on patients' neck and record the acoustic signals associated with breathing. Using a band-pass filter to reduce noise and other artifacts in signals, the authors managed to achieve approximately 90% of measurement accuracy. The research work was then extended for detecting apneas using a specially developed algorithms. Patterson et al. [6] developed an ear-worn, flexible, low-power PPG sensor for heart rate monitoring. The sensor is suited for long-term monitoring due to its unobtrusive design and a usage location. A wrist-worn integrated sensor for measuring electrodermal activity, was developed by Swenson [7]. The novelty of the system consists of the dorsal forearms as recording sites.
Other possibilities for wearable sensor placement include gloves, shirts [8], vest [9], shoes etc. But these are not suitable for clinical environment. Monitoring systems for hospital use, should be small, non-intrusive, and non-invasive external systems that can continuously measure, store and visualize physiological data in real time.

3 Physiological signals

Vital signs are used to measure the body's basic functions, and they are critical component of a patient care. The main vital signs routinely monitored by medical professionals and health care providers include the following:

- Body temperature
- Hart rate
- Respiration rate (rate of breathing)
- Blood pressure (blood pressure is not considered a vital sign, but is often measured along with the vital signs).

Zephyr Bioharness 3 biomodule provides monitoring of several vital parameters: ECG (electrical activity of the heart), heart rate (number of times heart beats per minute), respiratory rate (number of breaths per minute), posture (body position) and acceleration (activity level). For the purpose of this research we are particularly interested in heart rate and respiratory rate.

The heart rate is a measurement of the number of times the heart beats per minute. As the heart pushes blood through the arteries, the arteries expand and contract with the flow of the blood, resulting in the formation of pulse The normal pulse for healthy adults ranges from 50 to 80 beats per minute [10]. The pulse rate may fluctuate and increase with exercise, illness, injury, and emotions.

The respiration rate is the number of breaths a person takes per minute. The rate is usually measured when a person is at rest and simply involves counting the number of breaths for one minute by counting how many times the chest rises. Respiration rates may increase with fever, illness, and with other medical conditions. When checking respiration, it is important to also note whether a person has any difficulty breathing. Normal respiration rates for an adult person, at rest, range from 16 to 20 breaths per minute [10].

HR and RR are parameters that contain valuable information about patients' general health, give clues about possible diseases, and show progress toward recovery. For example, heart beat rate is a key indicator for the risk of heart attack [11]. Abnormalities of heart rate can indicate some serious heart disease or heart failure [12]. On the other hand an abnormal respiratory rate has been shown to be an important predictor of serious events such as cardiac arrest [13, 14].

Given the fact that any changes in these parameters can indicate serious changes in patients' condition, continuous monitoring of HR and RR is extremely important [15]. It can provide valuable information to the clinician for identifying the problem and to make life-saving decisions in critical moments.

4 System architecture

The developed healthcare monitoring system is composed of three tiers as shown in Fig.1. The system is composed of:

1. Zephyr biomodule
2. Mobile device
3. Remote server

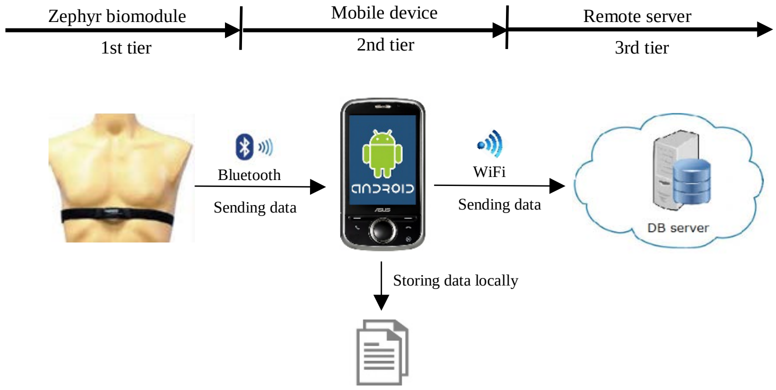


Fig. 1. Architecture of developed healthcare monitoring system

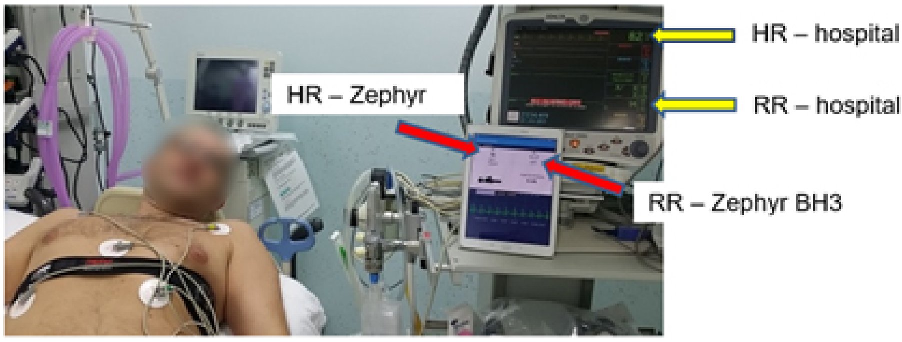
Zephyr Bioharness 3 biomodule [16] is a wearable device used for monitoring physiological parameters of the patients. The device consists of a chest strap and an electronics module, that attaches to the strap. The module contains several sensors which enables simultaneous monitoring of HR, RR, ECG, posture and acceleration. The facility of using one physical device with multiple sensors, increases applicability of the developed system. Zephyr biomodule sends physiological data wirelessly using Bluetooth low energy to the developed mobile application with graphical interface. Using Bluetooth low energy technology makes this device feasible to use for longer time, which helps in increasing the system's durability.

A mobile application was developed to capture and visualize the data sent from Zephyr biomodule. The application runs on mobile devices with Android Operating System 4.4 or above. Received data are stored locally in internal memory device as .csv files, and on a remote SQL database.

The third tier is a remote server that receives data from mobile device. We have used MS SQL server installed on a Windows server machine. If Internet connection exists, data sent from a mobile device is stored on this server. These data can be used later for personalized analysis.

5 Evaluation

For evaluating the accuracy of the developed system, a preliminary clinical testing, was performed at the intensive care unit, in General hospital in Celje, Slovenia. Two subjects, one healthy individual and one comatose, mechanically ventilated patient participated in the test (Fig. 2). Both subjects wore Zephyr biomodule to measure their heart rate, respiratory rate, posture, peak acceleration and ECG. They were also attached to standard medical device (General Electric vital signs monitor Dash 5000) to allow comparison of measurements. For conventional ECG measuring we have used 5-electrodes: four electrodes were placed on the torso corresponding to the limbs, and the fifth electrode was used on the standard chest lead positions (V1).



a)

b)

Fig. 2. Experimental setup for a) healthy individual b) comatose patient

For each patient a tablet with Android 6.0 Operating System (OS) was provided. The developed application was installed on the tablet and was used for real-time visualization of the parameters measured by Zephyr biomodule, with data streaming at frequency of 250 Hz. The mobile application received the data and stored it locally on the device as .csv files for later processing. The data was also transferred to the remote server for further analyses.

For the purpose of this testing we have used only HR and RR obtained from both systems at the same time.

6 Results and discussion

The Bland-Altman plots is used for visual representation of the distribution of the differences between the two measurement techniques for both HR and RR. The resulting graph is a scatter plot XY, where the Y axis represents the difference between the two paired measurements and the X axis - the average of these measures. In other words, the difference of the two paired measurements is plotted against the mean of the two measurements. The graph also shows the upper and lower control limits of plus and minus 1.96*sigma, respectively, where sigma is the standard deviation of the measurement differences. The graphs for both parameters show the values of the upper and lower lines, inside of which 95% of the observed values fall, and also the value of the central line, which corresponds to the mean value of these observations.
The first test was done on healthy individual in resting, calm position, with a normal heart rate and breathing. The second test was done on comatose (deeply sedated), mechanically ventilated patient.
Results from both tests, for HR and RR, are shown in Fig.3 and Fig. 4 respectively.

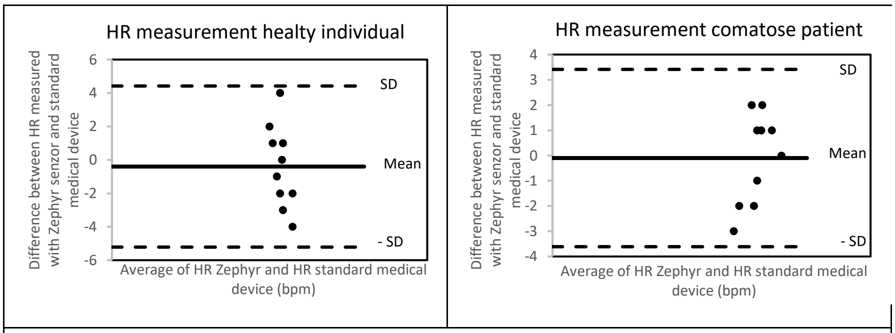


Fig.3 Bland-Altman plots difference between developed system and standard medical devise for HR measurement

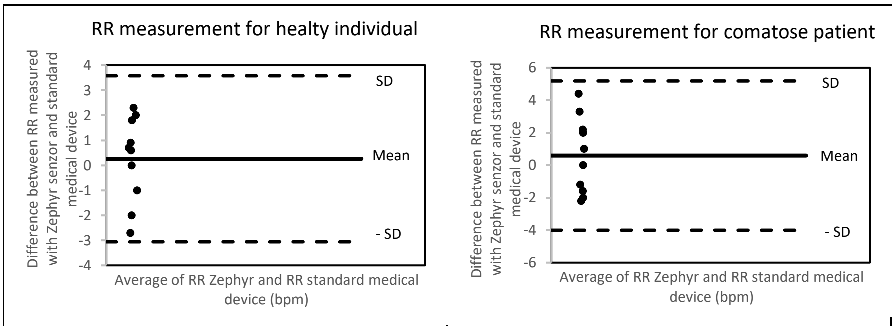


Fig. 4 Bland-Altman plots difference between developed system and standard medical devise for RR measurement

If we summarize the results we can see that: the percentage error of HR measurement for heathy subject is -0.4 ± 2.46; for comatose patient is -0.1 ± 1.79; and the percentage error of RR measurement for heathy subject is 0.26 ± 1.69; for comatose patient is 0.59 ± 2.34.

An overview of the results is shown in Table 1.

Table 1. Percentage error of HR and RR measurements

	HR – healthy subject	HR – comatose patient	RR – healthy subject	RR – comatose patient
Error %	-0.4 ± 2.46	-0.1 ± 1.79	0.26 ± 1.69	0.59 ± 2.34

7 Conclusion

The purpose of this study was to compare the accuracy of the developed system with Zephyr biomodule, for monitoring the main vital parameters (HR and RR) to the same parameters obtained by the standard medical device, and to verify its accuracy. Preliminary clinical testing was done on both healthy and hospitalized patients. The results indicated that the developed system is suitable for clinical environment, and can be used as a continuously monitoring system. The proposed system for wireless monitoring of vital parameters will ease the monitoring of patient's stability during their stay in the hospital environment. The use of this system will also improve hospital staff compliance. Future work will undertake research about another vital parameter using the same setting of Zephyr biomodule with the designed application for capturing the signals - the ECG. Also, blood preasure and oxygen saturation can be monitored with additional wireless devices, but their correlation with the standard hospital equipment must be confirmed.

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References

1. S. Patel, H. Park, P. Bonato, L. Chan, and M. Rodgers, "A review of wearable sensors and systems with application in rehabilitation".Journal of NeuroEngineering and Rehabilitation, vol. 9, no.1, article 21, 2012.
2. F. Palumbo, J. Ullberg, A. Stimec, F. Furfari, L. Karlsson, and S. Coradeschi, "Sensor network infrastructure for a home care monitoring system," Sensors, vol. 14, no. 3, pp. 3833–3860, 2014.
3. Asada HH, Shaltis P, Reisner A, Rhee S, Hutchinson RC: Mobile monitoring with wearable photoplethysmographic biosensors. IEEE Eng Med Biol Mag 2003, 22:28-40.
4. Shaltis PA, Reisner A, Asada HH: Wearable, cuff-less PPG-based blood pressure monitor with novel height sensor. Conf Proc IEEE Eng Med Biol Soc 2006, 1:908-911.

5. P. Corbishley and E. Rodr´ıguez-Villegas, “Breathing detection: towards a miniaturized, wearable, battery-operated monitoring system,” IEEE Transactions on Biomedical Engineering, vol. 55, no. 1, pp. 196–204, 2008.
6. Patterson JAC, McIlwraith DG, Guang-Zhong Y:A Flexible, Low Noise Reflective PPG Sensor Platform for Ear-Worn Heart Rate Monitoring. Wearable and Implantable Body Sensor Networks, 2009 BSN 2009 Sixth International Workshop on; 3-5 June 2009 2009, 286-291.
7. Sardini, Emilio, Mauro Serpelloni, and Marco Ometto. "Multi-parameters wireless shirt for physiological monitoring." Medical Measurements and Applications Proceedings (MeMeA), 2011 IEEE International Workshop on. IEEE, 2011.
8. Pandian PS, Mohanavelu K, Safeer KP, Kotresh TM, Shakunthala DT, Gopal P, Padaki VC: Smart vest: wearable multi-parameter remote physiological monitoring system. Med Eng Phys. 2008, 30: 466-477. 10.1016/j.medengphy.2007.05.014.
9. Swenson, N.C., and R.W. Picard, with Ming-Zher Poh. “A Wearable Sensor for Unobtrusive, Long-Term Assessment of Electrodermal Activity.” Biomedical Engineering, IEEE Transactions On 57.5 (2010) : 1243-1252. Copyright © 2010, IEEE.
10. Charbek Edward. “Normal Vital Signs”. Medscape [Online]. Available: http://emedicine.medscape.com/article/2172054-overview.
11. Cooney, Marie Therese; Vartiainen, Erkki; Laatikainen, Tiina; Laakitainen, Tinna; Juolevi, Anne; Dudina, Alexandra; Graham, Ian M. (2010-04-01). "Elevated resting heart rate is an independent risk factor for cardiovascular disease in healthy men and women". American Heart Journal. 159 (4): 612–619.e3.
12. Woodward, Mark; Webster, Ruth; Murakami, Yoshitaka; Barzi, Federica; Lam, Tai-Hing; Fang, Xianghua; Suh, Il; Batty, G. David; Huxley, Rachel (2014-06-01). "The association between resting heart rate, cardiovascular disease and mortality: evidence from 112,680 men and women in 12 cohorts". European Journal of Preventive Cardiology. 21 (6): 719–726.
13. McBride J, Knight D, Piper J, et al. Long-term effect of introducing an early warning score on respiratory rate charting on general wards. Resuscitation 2005; 65: 41-44.
14. Hodgetts TJ, Kenward G, Vlachonikalis IG, et al. The identification of risk factors for cardiac arrest and formulation of activation criteria to alert a medical emergency team. Resuscitation 2002; 54: 125-131.
15. Zimlichman, Eyal, Martine Szyper-Kravitz, Avraham Unterman, Anny Goldman, Shiraz Levkovich, and Yehuda Shoenfeld. "How is my patient doing? Evaluating hospitalized patients using continuous vital signs monitoring." IMAJ 11, no. 6 (2009): 382-384.
16. Zephyr Technology Corporation. [Online] Available at: https://www.zephyranywhere.com/media/download/bioharness3-user-manual.pdf