Multi-functional Wireless Body Sensor

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***Abstract*—A wireless multi-functional body sensor for monitoring vital bio-signals is proposed. The sensor uses modern, moderately priced, user-friendly and robust technology solutions. It supports advanced algorithms for local analysis of data and communication infrastructure to widely available personal terminals for visualization of measurements, and further transfer of critical data, either to medical experts or to a personal database. We pay a special attention to the fusion of different sensing functions in a single multi-functional sensor. To improve the reliability and robustness of the system, the measured signals, e.g., ECG, light, voice, acceleration, etc., can be combined in order to prevent the rising of false alarms. The proposed multi-functional body sensor contributes in significantly elevated quality, unobtrusiveness and robustness of the health care and patient safety.**

Keywords - multi-functional body sensor; wireless; mobile; healthcare; monitoring

I. Introduction

The introduction of modern information and communication technologies (ICT), as support to medical activities, is one of the possibilities to increase the efficacy of the health care system and to decrease its costs. This basic premise is included in all strategic plans of the EU and the rest of the world. Numerous studies have confirmed the benefit of the development of Telemedicine/Telecare systems [1, 2]. We are proposing a multi-functional wireless body sensor (MWBS) that uses modern, moderately priced and user-friendly technology solutions. It is appropriate as a building block in systems for continuous monitoring of hospitalized patients, post-hospital care, or diagnostic long-term monitoring. It measures vital functions, e.g., heart beat rate, blood pressure, body temperature, etc. Classically, these measurements are performed by nurses several times a day and then manually entered in the patient’s charts. In addition to the issue of intermittent monitoring of vital functions in non-intensive wards, there are other weaknesses in the current health care system. The interpretation of the patient’s condition and the consequent measures taken depend on the personnel, who could be, in certain conditions, overwhelmed with work or busy with other patients. The measured indicators can also be inaccurate - sometimes being biased by the presence or the inexperience of the medical personnel and therefore unreliable.

In proposed systems for remote monitoring of vital functions [3, 4], patients or monitored subjects are fitted with several body sensors for vital functions, which communicate with personal terminals (size of a mobile phone) via wireless connections. The measurements are stored in the personal terminal for monitoring and processing with automated procedures based on comparison with threshold values, predetermined rules and automatic learning. The data are sent, either periodically or because of unusual events, to a computer server that maintains a database and is responsible for presentation, alerts and necessary actions.

Taking into account that unobtrusiveness and robustness might be decisive factors for the success of the future bio-monitoring systems, we concentrate on these two issues. We investigate options for the development of the MWBS and integrations in final monitoring systems that can fulfill both requirements.

The rest of the paper is organized as follows. First, the architecture of the proposed system for remote monitoring of vital functions is presented. Next, the implementation of the system is described, elaborating the role of the wireless multi-functional body sensor, the concept for improved alarms using environmental sensors, and the platforms for transmission, representation and collection of data from the sensors. The paper concludes with a summary of our findings and potential future extensions of the proposed multi-purpose body-sensor approach.

II. System Architecture

The architecture of the proposed system for remote monitoring of vital functions is shown in Fig. 1. The design of the system takes into account the existing technical standards, allowing easy connection of various body sensors and their immediate replacement, if an improved version becomes available. The system allows connection of new sensors, which could help in the improvement of the monitoring of the patient's condition, for example, sensors for remote monitoring of respiratory acoustic phenomena (cough, obstruction), simple video sensors, etc. Some of the measurements are feasible with our custom sensors [5]; for others, like blood pressure measurements, new unobtrusive and non-invasive body sensors are to be developed.

The transmission of the measurements to remote places is done by existing infrastructure (Ethernet, Bluetooth, Wi-Fi, etc.) and the Internet, which offers an inexpensive implementation, as well as wide availability. The information is available on site and controlled/monitored by

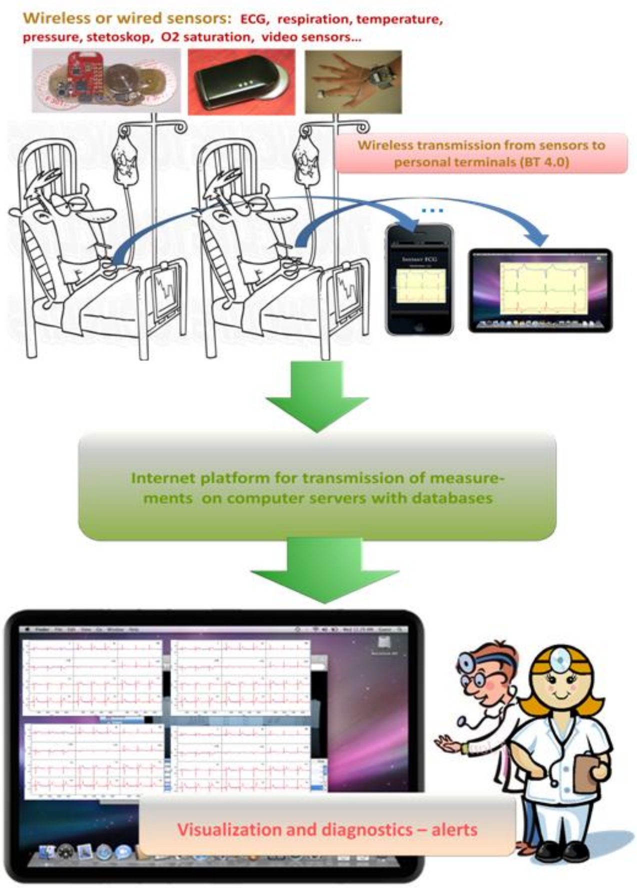


Figure 1. Architecture of the system for remote monitoring of vital functions. All sensors should be merged into a single multi-functional unit.

the staff on call, which enables immediate detection of deterioration in the patient's state and prompt actions.

Based on the simultaneous evaluation of multiple variables, the system will provide the threat level and its trend [6]. The analysis of vital functions in a longer time period allows for the implementation of cognitive methods; for example, analysis of a cardiogram over longer time period contributes to personalized patient's threat level [7, 8].

III. Implementation Concepts

The implementation of the proposed system significantly increases the research potential of medical institutions. The system provides documented measurements and events obtained in an objective manner during different stages of the well being of patients or other users (elderly, athletes, etc.). The system could be upgraded with new medical research methods. Following are related research activities and findings that contribute in the system implementation.

A. Development of multi-functional body sensors

Body sensors should be non-disruptive to users; therefore, we consider small and multi-functional wireless sensors. We have already prototyped a differential wireless bio-electrode (WBE) for measuring ECG [5] and EEG. Within the WBE, other sensors can be incorporated towards the final version of the MWBS. We have currently identified the following options:

bio-sensors

- heart beat rate,
- blood pressure,
- respiration,
- temperature,
- oxygen saturation,

environmental sensors

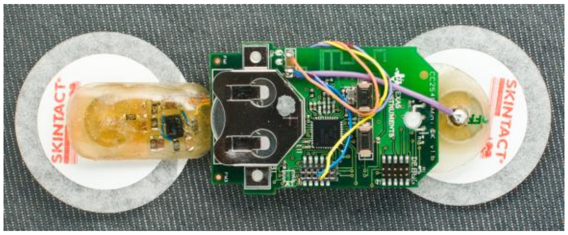
- acceleration,
- position,
- audio recording,
- video detection.

The wireless technology considered for transmission of measured data from the sensors to personal terminals is the newest version of Bluetooth technology – low energy Bluetooth 4.0 (BT4). It enables direct communication between the MWBS and newest Smart phones and devices with incorporated Bluetooth Smart technology.

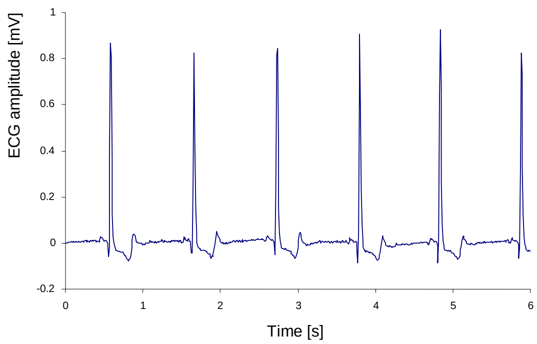
Bluetooth low energy protocol is low-cost wireless solution designed to meet special requirements for long-term operation in devices with limited energy capacity (e.g. coin-cell battery). Its ultra-low peak, average and idle mode power consumption and enhanced working range enables the MWBS to operate on a single coin-cell battery for several days while transmitting live stream of raw ECG data. Based on our preliminary measurements, we conclude that the BT4 enables 4 days of external power supply independency for a MWBS with a small coin battery. The maximal bit-rate of the data payload is 1 Mb/s, which is sufficient also for high-resolution short-term measurements.

Other features can be also added to the MWBS: vascular pressure, oxygen saturation, skin resistance and respiratory rate measurements. Furthermore, microphones, accelerometers and video sensors could offer additional environmental data that contribute to a better estimate of the status of the monitored patient. An example of the prototype multisensory electrode is shown in Fig. 2a. It is equipped with a BT4 radio and sensors for ECG, respiration acceleration and light. On the measured raw ECG signal (Fig. 2b), a respiration signal as an envelope of the R-peaks is clearly visible.

The ECG-Derived Respiration (EDR) techniques relevant to our work are based on the observation that the positions of the ECG electrodes on the chest surface move relative to the heart. We confirm, with the analysis of clinical multichannel ECG measurements, which include also reference thermistor based respiration signals, that the proposed approach is a viable option for the monitoring of the respiration frequency and for the rough classification of the breathing types [9]. The obtained results are evaluated on a wireless prototype of respiration body sensor from Fig. 2. We indicate the best positions for the respiration body sensor and prove that a single sensor of body surface potentials

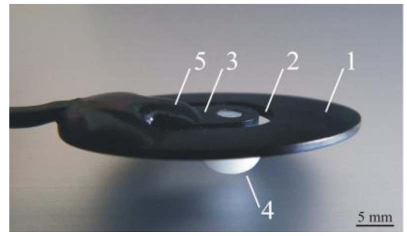


(a)



(b)

Figure 2. (a) A prototype of the MWBS with two self-adhesive disposable electrodes, a lithium coin battery, micro-processor, BT4 radio, and printed circuit board antenna. (b) An example of an ECG recorded wirelessly – raw signal.



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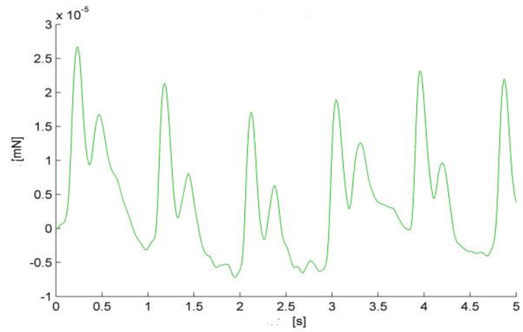

(b)

Figure 3. (a) A prototype of the muscle contraction (MC) sensor: (1) laminate, (2) incision, (3) tonguelet, (4) sensor tip, (5) strain gauge. (b) An example of measured tactile pulse.

difference on proximal skin electrodes can be used for combined measurements of respiratory and cardiac activities.

A new prototyped muscle contraction (MC) sensor [10] is considered for integration into the system. The sensor is relatively small and light. It is based on a novel principle for measuring muscle tension during muscle contractions and provides important data about patient's muscular activities. Additionally, we consider the option to use the MC sensor for detection of the tactile pulse. The sensor could be also adopted for measurement of changes in the blood pressure. An example of the prototype MC sensor and a preliminary measurement of the tactile pulse are shown in Fig. 3a and Fig. 3b, respectively.

In clinical medicine, the gold standard for diagnosis of pneumonia is the X-ray imaging; nevertheless, in a clinical examination, pneumonia is diagnosed only in a small proportion of ill children. Computer analysis of the sounds in adult patients with pneumonia has been proved to confirm the diagnosis [11]; however, the method uses sixteen microphones, which is not suitable for clinical use. The proposed system enables development of convenient and computerized systems, designed by a smaller number of microphones, which spare the patients from the X-ray radiation.

One of the advantages of the proposed system is the ability for continuous monitoring of ECG. In a recently published study on children with RSV bronchitis, the presence of abnormal heart rhythm was also found [8]. Long-term monitoring of ECG is an important source of data for confirming the correlation of the two diseases, which is not known so far. We can aggregate different sensor data and, using rule-based algorithms, devise higher-level diagnostic conclusions on medical or rehabilitation status of users.

In some rare cases, more body sensors are still needed. An example is the synthesized 12-lead electrocardiogram (ECG) [12], which is the gold standard in cardiology.

B. *Improved alarms with environmental sensors*

One of the most critical problems that influence a sustainable use of monitoring systems is issuing false alarms. The personnel that assists and manages a monitoring system cannot tolerate false alarms above some minimal limit. We pay special attention to overcome this problem with multilevel alarms based on data from more than a single sensor. To improve the quality of patients' status interpretation, we introduce visual sensors consisting of simple and low cost video detectors [13]. Visual sensors will not allow interference with personal intimacy. The video detectors cover just a near area of the patient's bed and, after a simple local video processing, detect and store patients' motion, movement and position. Based on these additional data, an improved reliability of raised alarms can be obtained.

C. *Platforms for transmission, representation and collection of data*

The transmission of data from the sensors, and later its representation, are planned on two levels: to the patient itself and to the medical personal.

First, we have wireless transmission of the measured data from the sensors to personal terminals, like Smartphones or other portable smart devices. Custom made applications provide the opportunity for suitable representation of the transmitted data and the possibility for the patient to monitor its vital functions. We have already developed an application that provides a comfortable option for telemonitoring of the heart activity. We use the prototyped wireless bipolar body electrode to record ECG wirelessly, coupled with the advantages of existing portable smart devices to display the real-time data from the electrode [14]. Local processing of the measured data and alarm triggering can be done already on the sensor or on the portable device. For example, the respiration rate can be calculated on the sensor, while the reconstruction of the standard 12-lead ECG can be performed on the Smartphone for the visualization of the reconstructed signal.

Second, a SOAP (Simple Object Access Protocol) client on the portable platform transfers relevant data (for example, ECG data when an alarm has been triggered) to a computer server. The transferred data on the server [15] is appropriately visualized to the medical personal for diagnostic purposes, and also is collected in a database for further analysis.

IV. Conclusion

We have designed a system for continuous remote monitoring of patients at risk, which is based on multi-functional wireless body sensors. We thus contribute to significantly elevated quality, unobtrusiveness and robustness of the health care and patient safety. Widespread, accessible, and tested ICT solutions from the field of measuring sensor systems, mobile communications and network services, are incorporated into the system. Medical expertise are also included through the software for analysis of multi measurements, as well as the triggering of alerts and alarms for urgent action. The responses of medical personnel to clinical deterioration in patients will be faster; therefore, the patients will experience fewer complications in case of sudden deterioration of their health. The work of medical personnel will be less stressful and more efficient.

The applicability of the proposed system is not limited only to hospitals and health care centers, where the added benefit of the system will enable “doctor-to-doctor” and “patient-to-doctor” communication. The system can be also installed in nursing and patients’ homes, e.g. for early postoperative care. The patient-friendly approach will contribute to easier diagnostics and reduction of healthcare costs.

We developed and evaluated a prototype of multi-functional sensor that can record main features of ECG, respiration, and acceleration. Further sensing options, e.g., temperature and MC, are under development and laboratory testing. It is clear that the proposed approach is ideal for users from the comfort point-of-view; however, the main focus of our future work is in the evaluation study of long-term functional performances, including data security and privacy, and added diagnostic value of the proposed system.

Acknowledgment

The authors acknowledge the financial support from the state budget by the Slovenian Research Agency under Grant P2-0095.

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