Multi-functionality of Wireless Body Sensors

Trobec, Roman; Avbelj, Viktor; and Rashkovska, Aleksandra

Abstract — *Body sensor networks for monitoring of bio-signals are technically feasible and economically relevant; however, their acceptance by patients and by medical experts is still not adequate. For patients, sensors are too obstructive, require technical skills, and introduce a perception of diminished safety and privacy. For medical experts, sensors and accompanied equipment introduce changes in the established treatment, and a new and still unapproved diagnostic approach. We propose a multi-functionality concept on a small number of wireless body sensors that can replace a complex network and is therefore a step towards better acceptance of the body sensor technology. The multi-functionality is related to the fusion of different sensors, the development of advanced algorithms for extraction of hidden information from a basic bio-signal, and improved information about the medical status obtained from a few sensors placed on strategic positions on the body. We confirmed with demo applications that the proposed multi-functionality of body sensors contributes in elevated quality, unobtrusiveness and robustness of the health care monitoring.*

Index Terms — body sensor, health care, mobile, monitoring, multi-functional, wireless

1. *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. Numerous studies have confirmed the benefit of the development of telemedicine/telecare systems [1, 2]. The proposed mobile approaches of telecare systems rely on body sensor networks that collect and manage recorded vital data.

Wireless body sensors are already moderately priced and use user-friendly technology solutions. They are appropriate as building blocks in systems for continuous monitoring of hospitalized patients, post-hospital care, or diagnostic long-term monitoring of 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 actions 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 biased by the presence of medical personnel or similar subjective factors.

Body sensor networks for monitoring of bio-signals are technically feasible and economically relevant; however, their acceptance by patients and by medical experts is still not adequate. For patients, sensors are often too obstructive, require technical skills and introduce a perception of diminished safety and privacy. For medical experts, sensors and accompanied equipment introduce changes in the established treatment, and a new and still unapproved diagnostic approach.

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 future bio-monitoring systems, we concentrate on these two issues. We investigate options for the development of a multi-functional wireless body sensor and its integration in a final monitoring system that can fulfill both requirements. We propose a multi-functionality concept with a small number of wireless body sensors, ideally a single wireless body sensor that can replace a complex network and is therefore a step towards better acceptance of the body sensor technology.

We analyze three main aspects of multi-functionality. First is a fusion of different sensors, e.g., ECG, light, voice, acceleration, etc., on a single wireless device placed on a strategic place on the body. Further step in the multi-functionality is the development of advanced algorithms for

Manuscript received May 31, 2013. This work was supported in part by the European Union, ProSense project and by the Slovenian Research Agency under grant P2-0095.

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extraction of hidden information from a basic bio-signal. For example, the ECG signal holds information about the respiration rate, nervous system, etc. Finally, reduced number of combined sensors, placed on different positions on the body, can provide improved information about the medical status.

We confirmed with demo applications that the proposed multi-functionality of body sensors contributes in significantly elevated quality, unobtrusiveness and robustness of the health care and patient safety.

The rest of the paper is organized as follows. First, all three multi-functionality aspects are described and supported by already published results. Next, the implementation of a demonstration mobile telecare system is described, elaborating the platforms for transmission, representation and collection of data. Finally, the performances of the wireless multi-functional body sensor based on first experimental measurements are presented. The paper concludes with a summary of our findings and potential future extensions of the proposed multi-functionality of body sensors.

2. Multi-functionality Concepts

2.1 Description of multi-functional body sensor

The multi-functional wireless body sensor is designed of two self-adhesive ECG electrodes positioned 5 cm apart, analog front-end, ultra-low-power (ULP) microcontroller and ULP Bluetooth V4.0 radio, ceramic chip antenna, and lithium coin battery, is shown in Fig.1 [5].

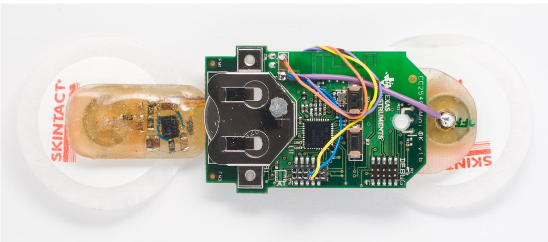

Fig. 1: A prototype of multi-functional wireless body sensor.

The analog front end is designed to suppress radio frequency interference. Signal amplification and filtering is made with a band-pass filter (0.15 Hz to 250 Hz, -3dB) before entering the microcontroller's 10-bit A/D converter. The 16-bit microcontroller (Texas Instruments, MSP430F2274) has 32kB of FLASH, 1kB of RAM and on chip temperature sensor, all with an average power in active mode of 270uA at 1MHz. The microcontroller has enough peripheral lines to support other on board sensors, like 3-axis accelerometer, skin temperature sensor and others. The Nordic Semiconductor's chip nRF8001 was used to support Bluetooth radio connectivity as peripheral (slave) role. We have chosen lithium coin battery CR2032 as power source for our multi-functional body sensor. The nominal cell capacity is 220mAh at discharge current of 200uA, but due to pulse operation, a lower capacity (approximately 180mAh) is expected.

The body sensor of skin potential, termed also differential lead (DL), with ECG as the main functionality and with other sensors (temperature, 3-axis acceleration and others), can support the decision for the conditions in which the signals are measured (running, walking, lying, etc.), and also the decision about dangerous situations and alarming.

2.2 Extraction of hidden information from a body surface potential

It is known that body surface potentials include a lot of information that can be used for the estimation of personal medical status. As a successful case, we refer to the respiration rate extraction directly from body surface potential sensors [6]. We confirmed that several DLs on positions near the center of the chest provide adequate signals for ECG-derived respiration (EDR) algorithms that can reliably extract respiration rates from variations in the R-peak amplitudes (see Fig 2). The proposed methodology is accurate enough for most practical cases and therefore useful for mobile health applications based on body sensors.

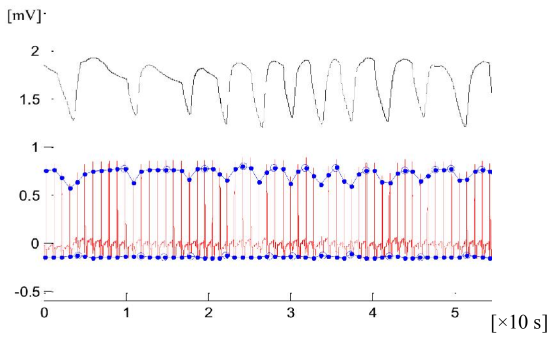

Fig. 2: 53 seconds interval of an ECG (red) measured with a DL positioned in the chest center and 11 respiration intervals (black) measured by a thermistor near the front of the nose. 58 R-peaks (blue filled points) are detected and all 12 respiration interval are identified (blue circles).

The measurement of ECG with sufficiently high amplitude and time resolution can support heart rate variability analysis [7], repolarization variability in the ST-segment of ECG (ST-denivelation) [8], characterization of arrhythmias, syncopes, sleep apneas and other.

2.3 Few synchronized sensors on strategic positions

We have shown [9] that a small number of DLs can reliably reproduce a standard 12-lead ECG and are, therefore, suitable for real wireless applications. An algorithm that finds the best combination of electrodes and evaluates all other combinations in terms of correlation coefficients with a measured standard 12 lead ECG is

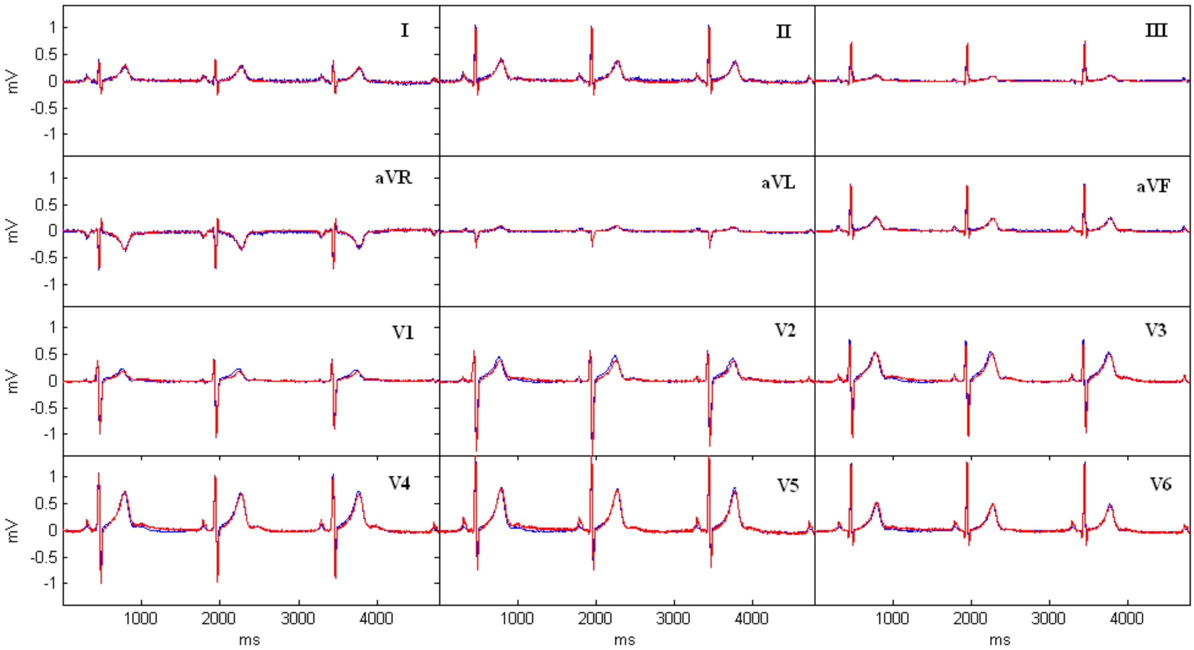

Fig. 3: Standard 12-lead ECG (blue) and synthesized 12-lead ECG (red).

proposed. This enables other combinations of DLs to be selected if, for some anatomic or ergonomic reasons, the best combination is inconvenient for placement.

While many standard ECG systems with reduced number of electrodes exploits fixed and easy to locate anatomic landmarks, we elaborate that the body sensor can be placed at arbitrary positions on a body surface, improving patient mobility and comfort.

We have demonstrated that just three sensors suffice for reliable synthesis of the 12-lead ECG. This result confirms the assumption that a single fixed-location dipole provides an adequate representation of the heart's electrical activity. An example of a measured and synthesized ECG is shown in Fig. 3.

The proposed approach is personalized in the sense that optimal positions of sensors and transformation matrices can be calculated for each individual. We compare in [10] the personalized approach with two alternatives: combined approach with universal (equal for all subjects) positions of sensors and personalized transformation matrix; and universal approach with universal positions and transformation matrix. The results indicate that the best methodology is personalized; however, the combined or even the universal approach can also be applied in some urgent cases.

We know that a single electrode is enough for the extraction of the respiration rate. However, if ECG electrodes are available they can be applied for improving the reliability. Three independent measurements of the respiration rate can be done concurrently and analyzed in parallel to obtain more reliable and accurate results.

3. *Demonstration Mobile Application*

We have also demonstrated a telemedicine application for mobile and comfortable telemonitoring of the heart activity on a Smartphone using ECG data from wireless body sensors [11]. The proposed wireless ECG system (Fig. 4) consists of three units: Wireless Bipolar Body Electrode/s (WBBE) as described in [12]; a communication gateway that receives the packets sent by the WBBEs and, at the same time, serves as a SimpiciTi-to-Bluetooth converter; and lastly, the Smartphone which receives the ECG data through Bluetooth.

The goal was to develop an application for graphical representation and interpretation of the received ECG data on the Smartphone. This wireless ECG system can have an important role for the goals of telemedicine and homecare. Its application is greatly endorsed with the increasing availability and performances of smart phones on today's market.

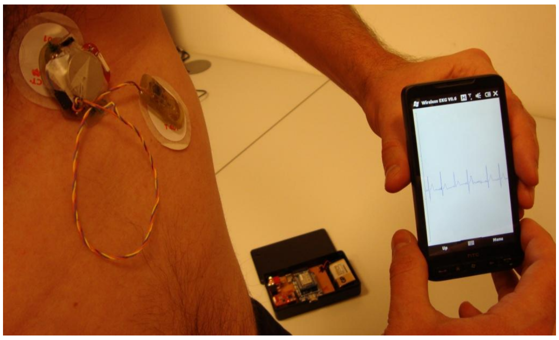

Fig. 4: Mobile application demonstrator.

Moreover, the previously described system can be considered as a part of a more encompassing system for remote monitoring of vital functions [13]. The proof-of-concept system takes into account: existing technical standards for easy connection of various body sensors; transmission of the measurements using standard technologies (Ethernet, Bluetooth, Wi-Fi, the Internet); and later, representation of the data from the sensors. The transmission and representation of data are planned on two levels: to the patient using personal terminals, like Smartphones or other portable smart devices; and to the medical personal for diagnostic purposes or alarm situations, using appropriate visualization of the data transferred on a server. On the server side, the data is also collected in a database for further analysis. The proposed system for remote monitoring of vital functions could act as a test ground for medical staff and a basis for the future Telemedicine/Telecare services.

4. Performance Results

4.1 Signal quality

ECG signals from proximal electrodes have different appearance than the signals from standard ECG. An example is shown in Fig. 5, where ECG is measured from a pair of electrodes, with positions optimized for good presentation of all ECG waves.

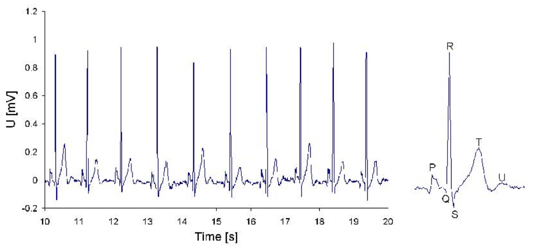

Fig. 5: Raw ECG signal from electrodes at a distance around 15 cm. The person is seating. All ECG waves are clearly visible (right: P, Q, R, S, T and U waves of the first heart beat). R and especially T waves are amplitude modulated due to breathing that modifies the geometry of the thorax.

Another example of ECG from the same person recorded with proximal electrodes is shown in Fig. 6.

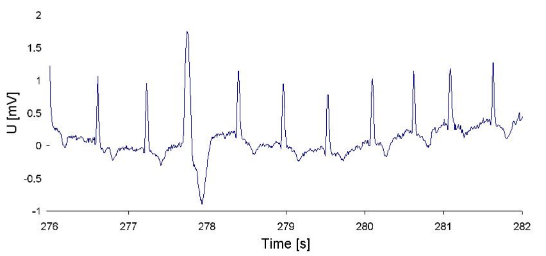

Fig. 6: Raw ECG signal from electrodes at a distance of 5 cm. The same person as in Fig. 5 is walking around. The third heart beat has ventricular extra systole with large amplitude and prolonged timing of the QRST complex.

The baseline is wandering and complete disappearance of the P, S and U waves can be observed. Note that the R and T waves have opposite polarity, which is rarely seen in standard ECG leads. From the above two cases it is clear that the position of the electrodes should be selected according to the goal we want to achieve, either information about the heart rate is needed only, or detailed analysis of the ECG signal is made for arrhythmia identification and characterization, measurement of amplitudes and time intervals of ECG waves, tracking the variability of repolarization (ST segment denivelation), etc.

4.2 Power consumption and autonomy

In our previous study [5], we measured the supply current of a wireless sensor in raw data transmission mode. The main part of the current is caused by transmission of data packets, which is evident from Fig. 7. Radio circuit uses much more energy for transmission than microcontroller for sampling and data processing. This means that we have to hold the frequency of transmissions as low as possible.

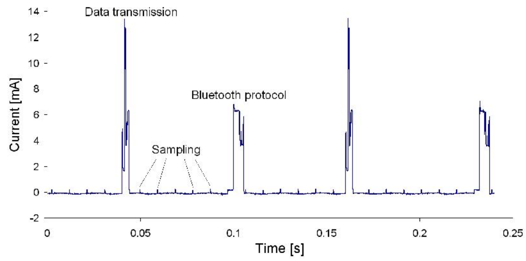

Fig. 7: Supply current due to sampling (125 Hz) and processing of ECG signal, and transmission of data blocks from wireless electrode. Huge current spikes are present during transmissions (over 12 mA) and Bluetooth protocol overhead, while sampling and signal processing produce low amplitude, but dense current spikes.

Raw ECG data transmission with sampling rate of 125Hz and 8.33 transmissions per second, shown in Fig. 7, demands an average current of 480μA. At this load, a battery with 160mAh capacity (CR2032) will run for 13 days. With sampling rate of 1000 Hz, the battery will still run 56 hours in raw data transmission mode.

5. Conclusion

We believe that multi-functionality is a key concept in the further developments of body sensor technologies. First, it was confirmed that with a single body sensor a lot of medical information can be obtained. In some more demanding cases, a few sensors may cover the professional requirements, e.g., three sensors placed on strategic places may suffice for the synthesis of a standard 12 channel ECG. Next, the necessity for wireless sensors is an important driving force for merging several functions into a single or a small number of sensors. Finally, low cost and simplicity of operations, e.g., only a single battery must be managed, contribute additionally to the value of the multi-functional body sensors. The published research work has confirmed that multi-functionality of wireless body sensors is applicable and relevant, while several emerging innovative companies confirmed with their products that body sensors will play a major role in the future penetration of ICT in the medical field.

ACKNOWLEDGMENT

The authors are grateful to the staff of the Clinic of Cardiovascular Surgery and the Clinic of Neurology at the Clinical Centre Ljubljana, Slovenia, where Multichannel ECG measurements were taken in the period from 2002 to 2012, which inspired the design of multi-functional wireless body sensor.

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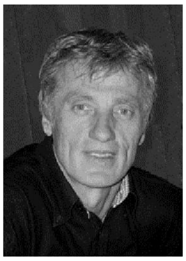

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