Multisensory Wristwatch System for Unobtrusive Physiological and Kinematical Signals Recording

D. Stankevičius*, V. Marozas

Biomedical Engineering Institute, Kaunas University of Technology, Lithuania

E-mail: dainius.stankevicius@ktu.lt

Introduction. It has been known for a couple of years now that the wearable technologies in healthcare are highly relevant. However, it can be seen today that only a small amount of the systems from the research tend to end up in clinical practice. As [1] indicates, one of the main reasons of this situation is that most of the systems are overly complex and counter-intuitive. Therefore, neither the patients nor the clinicians want to work with them and these sensor systems become needless. It should be mentioned that such issues are very important in long term monitoring, for example in chronic diseases or physical activity assessment where the data collection is crucial but not necessarily lifesaving [1]. The same research [1] pointed out some key recommendations from both the patients and the clinicians. The system should be compact, simple to operate and maintain, should not affect daily behavior nor seek to replace a healthcare professional but is expected to reduce the number of visits to clinic and hospital [1].

The aim of this work was to develop an unobtrusive physiological and kinematical signals recorder which would be suitable for long term monitoring.

The monitoring system based on such recorder would allow healthcare specialists to follow vital signs and the progress of the disease more accurately. It could also be beneficial for scientific research in order to find new relationships between different symptoms, new risks and treatment methods. As already revealed, one of the most important criteria for such system are comfort and unobtrusiveness.

The device presented in this paper is a wristwatch type recorder. It is able to acquire the following signals: photoplethysmogram (PPG), galvanic skin resistance (GSR), skin temperature, skin humidity, acceleration, angular velocity and atmospheric pressure. The key idea presented here is to obtain as much information as possible while occupying only one relatively small part of the body. Even though the first iteration of the prototype is still large and bulky, it has a lot of potential in becoming user-friendly data logger for healthcare. This paper is based on our previous work on the bachelor thesis [2].

Implementation. From the outside the device looks like a large wristwatch (see Figure 1). The case was manufactured out of ABS plastic using a 3D printing technology. Recorder is attached to the wrist via elastic textile strap. The device combines a graphical LCD and 4 pushbuttons for user interface. The recorded data can be transmitted via Bluetooth Low Energy for real-time monitoring or stored in the micro SD card for long term monitoring.

Fig. 1. The device placed on the wrist

Detailed structure of the device itself can be seen in Figure 2. Power is managed using smart battery charger and two 3.3 V LDO regulators – one exclusively for micro SD card and one for the whole system. Main microcontroller is Nordic Semiconductor nRF51822 with ARM Cortex-M0 core and embedded Bluetooth Low Energy radio. All sensors and LCD are enabled via the same SPI interface. Inertial measurement sensors consist of two-in-one accelerometer and gyroscope LSM330DLC and additional very high resolution (up to 10 cm) altimeter MS5611-01BA03. Temperature and humidity are measured using also two-in-one digital sensor HIH6131. Photoplethysmography signals are obtained using analog front-end AFE4490. GSR sensing was accomplished using external analog to digital converter AD7192 with specific analog signal conditioning circuit, which was presented in [3].

Experimental results. In order to evaluate functionality, the device was tested on one healthy volunteer. Several quantitative parameters were carried out. At first, good functionality of PPG, GSR and accelerometer sensors were tested by recording and visually analyzing corresponding signals. PPG signals

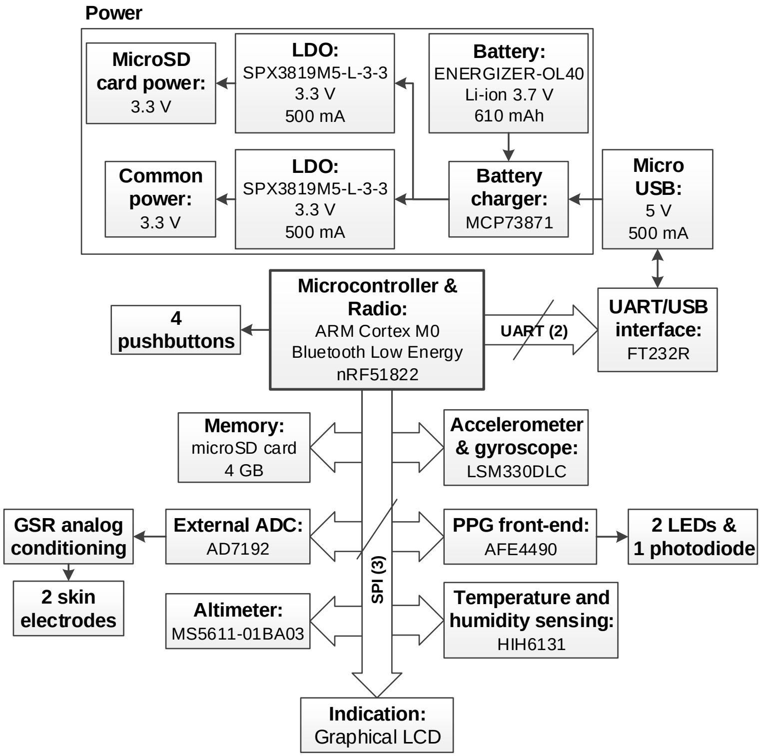

Fig. 2. The detailed structure of the device

were recorded at 500 samples per second, placing sensor on the upper side of the wrist (see Figure 3a). Acceleration signals were recorded at 50 samples per second, while trying to place the accelerometer statically in the way that one of the axis was parallel to Earth gravity vector. This should result in approximately 1 g acceleration in the parallel axis and 0 g acceleration in two other axes (see Figure 3d). GSR signals were recorded at 100 samples per second, with electrodes placed on the wrist of the volunteer (see Figure 3b).

GSR subsystem accuracy was tested by measuring the resistance of the fixed value resistors. Intermittent measurement was accomplished 30 times for each resistance value and averaged. The reference value was measured using FLUKE 199C LCR meter (0.6 % accuracy). The results are presented in Table 1. As it can be seen, relative error does not exceed 1 % in the range of typical resistance of human skin (66 kΩ – 10 MΩ) [3], but outside this range error tends to increase.

Altimeter accuracy was tested by moving the device upwards in pre-set distance (50 cm) at the starting position of 65.497 m above sea level (according to Google Maps based altitude estimation [4]). Pressure signal was sampled at 20 Hz, the experiment lasted for 60 seconds. Due to high frequency fluctuations, the recorded signal had to be filtered with 8th order low-pass Butterworth filter (0.2 Hz cutoff frequency) in order to extract the baseline. These signals are presented in Figure 3c.

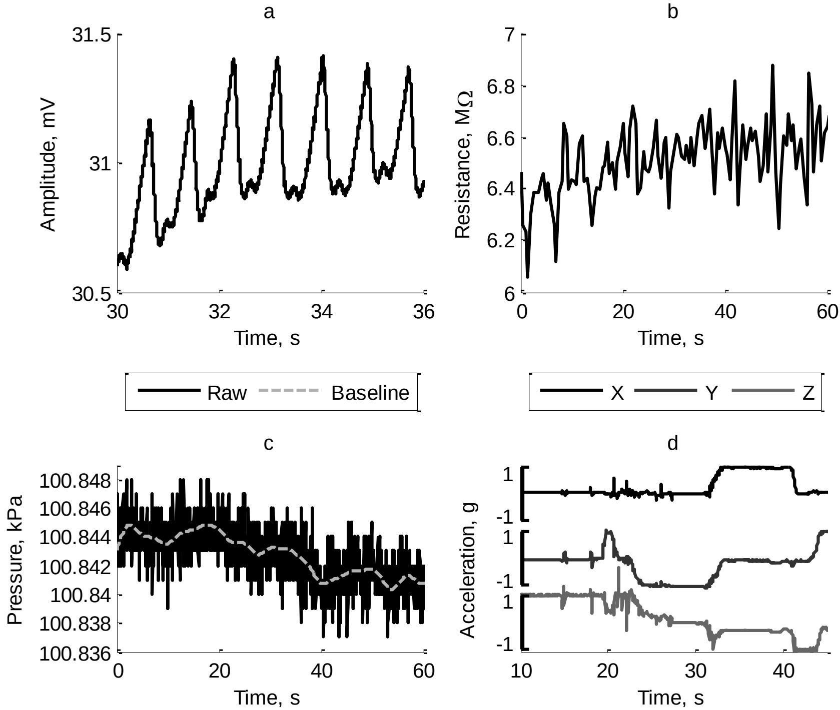

Fig. 3. Examples of some of the recorded signals: a – photoplethysmogram, b – GSR, c – atmospheric pressure, d - acceleration

The pressure values at the bottom and at the top were calculated as an average of 20 seconds long episode. The values were 100844.25±0.47 Pa and 100841.13±0.49 Pa respectively. Hence, the difference in the average pressure was 3.12 Pa. According to the theoretical calculations [5], the atmospheric pressure difference under these conditions should be approximately 6 Pa. The error of this measurement is quite large. However, it may still be useful for the detection of the change in the altitude instead of measuring the exact change in the absolute values.

While evaluating the accuracy of HIH6131 sensor temperature measurement, the reference temperature was measured with BIOPAC TSD202B – thermistor probe, dedicated for skin surface temperature measurements with 0.2 °C accuracy. Both sensors were attached to the skin as near to each other as possible. Temperature signals were sampled at 2 Hz. Later, 5 seconds length episodes were extracted from those recordings, the average temperature and error were calculated in the episode. Results can be seen in Table 1. Relative error does not exceed 2 %, systematic error (0.5 °C) can be eliminated during calibration.

Table 1. Measurement errors of the GSR and temperature subsystems

Type of measurement	Reference measurement	Measured value	Absolute error	Relative error
Resistance	47900 Ω	47413±31 Ω	487 Ω	1.02 %
	149900 Ω	149453±37 Ω	447 Ω	0.30 %
	1400000 Ω	1399205±216 Ω	795 Ω	0.06 %
Temperature	33.85 °C	34.34±0,005 °C	0.49 °C	1.43 %
	33.89 °C	34.34±0,016 °C	0.50 °C	1.47 %
	33.92 °C	34.46±0,010 °C	0.54 °C	1.59 %
	33.96 °C	34.48±0,005 °C	0.52 °C	1.53 %
	34,04 °C	34.57±0,009 °C	0.54 °C	1.58 %

The average operating current was measured using 6.3 Ω shunt resistor connected in series with the battery. The voltage across the shunt resistor was measured using Tektronix MDO4140B oscilloscope, which showed that the RMS voltage value was 0.1545 V. It is equal to 24.2 mA operating current. With given 610 mAh capacity battery, this equals to the approximate operating time of 25 hours. The measurement was accomplished at a worst case scenario – when the microcontroller never goes idle and is continuously transmitting data over the radio. Therefore, even better performance can be expected during offline monitoring.

Summary and future work. Unobtrusive multimodal signals recorder, suitable for long term monitoring has been developed. The device is able to acquire signals of 7 different types from one specific place of the human body – the wrist. The recorder is able to communicate with PC via Bluetooth Low Energy. The recorded data is stored in micro SD memory card.

Primary experimental evaluation showed that signals are being obtained and recorded successfully. Quantitative analysis showed that:

- skin resistance measurement error is within 1 %;
- the measurement of small changes in altitude results in high relative error of 48 %;
- skin temperature measurement error is within 2 %, however a high portion of this comes due to systematic error, which could be eliminated;
- the average operating current of the device at worst case scenario is 24.2 mA, which results in approximate of 25 hours of operation.

In the future, we are planning to optimize the energy consumption including hardware and software optimization. Embedded signal processing algorithms should be developed and implemented in the near future, as well. According to the signal processing, the device could have more specific application than just the biosignals recorder. In order to do so, there is a need to reduce the size and clumsiness of the device and to test it from the ergonomic point of view.

Acknowledgement. This research is supported by European Social Fund within the project "Intelligent wearable sensor system for human health monitoring" (Agreement No. VP1-3.1-SMM-10-V-02-004).

References

1. Bergmann J. H. M., McGregor A. H. Body-Worn Sensor Design: What Do Patients and Clinicians Want? // Annals of Biomedical Engineering, Volume 39, Issue 9, 2011 – P. 2299.
2. Stankevičius D. Design and investigation of multimodal signal recorder for long term chronic disease monitoring: Bachelor's work in electronics engineering / supervisor dr. assoc. prof. V. Marozas; Department of Electronics Engineering, Faculty of Electrical and Electronics Engineering, Kaunas University of Technology. – Kaunas, 2014.
3. Poh M. Z., Swenson N. C., Picard R. W. A Wearable Sensor for Unobtrusive, Long-Term Assessment of Electrodermal Activity // IEEE Transactions on Biomedical Engineering, Volume 57, Issue 5, 2010 – P. 1243.
4. Google Maps Find Altitude (online interactive tool) http://www.daftlogic.com/sandbox-google-maps-find-altitude.htm
5. Air Pressure and Altitude above Sea Level (online) http://www.engineeringtoolbox.com/air-altitude-pressure-d_462.html

Multisensory Wristwatch System for Unobtrusive Physiological and Kinematical Signals Recording

D. Stankevičius, V. Marozas
Biomedical Engineering Institute, Kaunas University of Technology, Lithuania

A wearable system for physiological and kinematical signals recording is presented. The device is able to record photoplethysmogram, acceleration, angular velocity, atmospheric pressure, galvanic skin resistance, skin surface temperature and skin humidity. One of the main problems with such data loggers is that they are overly complex and therefore becomes needless. This device is supposed to be worn on the wrist as a simple wrist watch, therefore it is unobtrusive and suitable for long term monitoring. Good functionality and several quantitative parameters of the system was attested by measurements on a healthy volunteer.