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A portable multi-sensor system for non-invasive measurement of biometrical data

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Abstract

In the last years, the availability of performing personal computing devices, like smartphones, opens new scenarios to the so called Body Area Network, i.e., sensor networks used to monitor physical conditions of the user. Generally speaking, the sensors adopted to monitor physical parameters, like heartbeat or exertion level, are not suitable for run-time measurements. However, the physical performance of athletes may be improved by a continuous monitoring of the body conditions. In this work, a simple, portable and low-cost system for non-invasive measurement of physical parameters is proposed and experimentally characterized. It is based on two different sensors combined in a unique structure to be applied in a clip-like fashion to the earlobe or analogue body part of a person. A photoplethysmographic sensor is used to optically measure the change in volume of blood in the arteries, thus to acquire information about heart beating, blood pressure, and arrhythmias. The second sensor is composed of two electrodes, thus an impedance measurement of the tissue is conducted. The impedance estimation can be used to monitor application-specific parameters, such as blood pH. The structure is compact in size and low-power, making it suitable for portable and battery-operated systems. The experimental characterization of the prototype demonstrates the feasibility of the proposed approach.

Keywords: Photoplethysmographic sensor; body impedance measurement, non-invasive measurement.

1. Introduction

The monitoring of physical data, specifically during sport activities, can help the sportsman by providing useful information about the response of the body to the fatigue. If the information is given in

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real-time, the sportsman can suitably adjust his activity to improve his performance or to avoid serious health risks. A system to acquire such data from the human body must be compact and portable, non-invasive and low-power, in order to be battery-operated during outdoor activities. Generally speaking, the devices available on the market, like heart rate belts, used to collect the information from sportsman body and to transmit it to smartphones or dedicated devices, are rather invasive and require a careful positioning of the sensitive elements in order to provide meaningful results. In [1], a new approach has been proposed to improve the comfort and the quality of the measures provided. The sensors are located on the earlobe and data are transmitted to an end device for data processing. In the following, a detailed description and an experimental characterization of the sensitive element have been provided. In the prototype, two different sensors are considered, to collect as more physical information as possible from athlete body: photoplethysmographic (PPG) and impedance sensors.

A PPG sensor is used to monitor changes in volume of blood in the arteries, measuring the variation of the light transmitted through the tissues [2]. The frequency of the signal provided by the sensor can be used to estimate the heart beating. Moreover, analysing the characteristics of the cardiac signal, additional information can be extracted. For example, by analysing the heart beat variability ([3], [4]), it is possible to evaluate the occurrence of arrhythmias or arterial occlusions, events that can seriously injure athletes. The use of an alternative sensor operating with two different wavelengths would allow also the estimation of the saturation of oxygen in blood as well [5], [6]. On the other hand, the bio-impedance measurement is a method well known in literature [7] to monitor the changes of biological tissue properties, like ions concentration, due, for example, to physical effort.

2. The proposed system

The proposed system consists of an optical PPG sensor and of two electrodes for impedance measurement. The two sensor components have been placed inside two copper rings, which act as the electrodes for the impedance measurement, as shown in Fig. 1. Each electrode has the form of a circular ring with 0.3 mm thickness. The diameter of the outer circumference is equal to 10 mm, whereas the inner one is equal to 0.7 mm. The PPG sensor (phototransistor or photodiode) is visible in the middle of the metallic ring. Connections of the phototransistor/photodiode as well as the electrode are visible. The whole structure has been fixed on a clip, in order to guarantee the alignment of the two parts and to allow easy application on the target (e.g., earlobe) and removal.

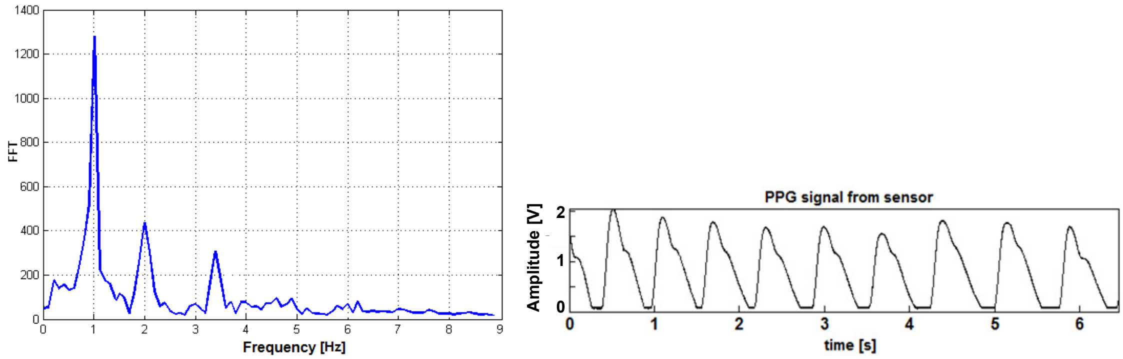
The PPG sensor is composed by a phototransistor and a photodiode, which need to be placed one in front of the other with the target tissue in the middle. In the prototype, the TCRT1000 PPG sensor [8] produced by Vishay semiconductor has been adopted. The operating wavelength is 950 nm. The infrared led has a nominal current of 50 mA with a forward voltage of 1.25 V. The current required by the phototransistor is about 200 μA.

(a) (b)

Fig. 1. CAD models of the sensor components: (a) front (towards the tissue); (b) rear.

3. Experimental characterization

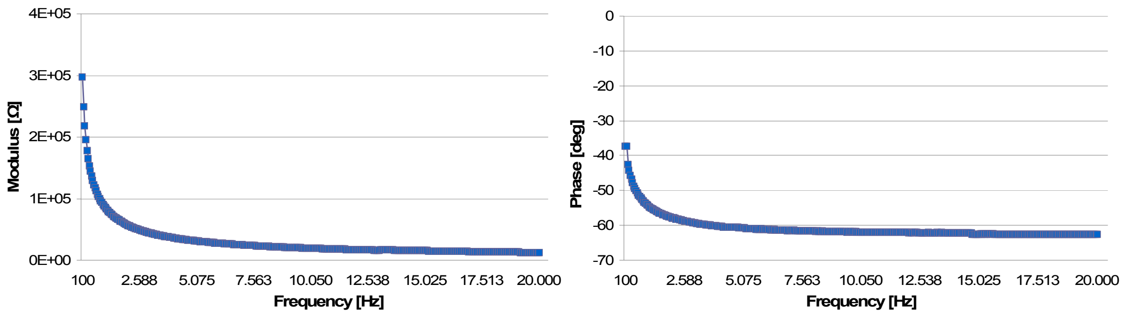
The frequency spectrum and the time domain behaviour of the PPG output signal applied to an earlobe is shown in Fig. 2(a) and Fig. 2(b) respectively. Data have been acquired with a data acquisition board (NI-USB-6009, equipped with a 14 bit ADC), placed after a suitable filtering and amplifying stage [1]. In Fig. 2(a), a peak is visible around 1 Hz, which is the heart beating frequency of a person in normal conditions. In Fig. 2(b), information about beat frequency, steepness of systole phase, its amplitude and period, localization of Dicrotic notch and the presence of the diastole phase can be easily obtained.



(a) (b)

Fig. 2. (a) Spectrum of the amplified signal of the PPG sensor; (b) PPG output versus time during the measurement of Fig. 2(a).

The measurement of the tissue impedance is performed by means of two aforementioned electrodes. From such kind of measurement, additional biometric parameters could be extracted, according to the specific application [7]. In Fig. 3, the module and the phase of the earlobe impedance during an acquisition with the sensor applied to a person in normal conditions are shown. The frequency sweep has been acquired with an HP 4194A impedance analyzer.



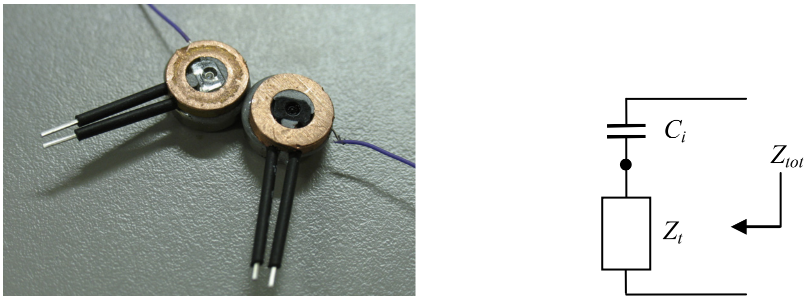
(a) (b)

Fig. 3. Impedance measurement of the earlobe of a person in normal conditions: (a) module; (b) phase.

At the stage of the project, the electrodes of the prototype (Fig. 4(a)), are in direct contact with the skin; covering the electrodes with an insulating film is advisable, but in this case, the estimated impedance Z_{tot} would be the combination of the target impedance Z_t and the capacitance effect C_i due to the insulator film, as shown in Fig. 4(b). The relationship between Z_{tot} and Z_t with the dependence on C_i and operative frequency f is shown in Eq. (1).

$$Z_{tot} = Z_t + Z_i = \mathrm{Re}(Z_t) + \left(j\,\mathrm{Im}(Z_t) + \mathrm{Im}(Z_i)\right) = \mathrm{Re}(Z_t) + \left(J\,\mathrm{Im}(Z_t) + \frac{1}{j2\pi f C_i}\right) \quad (1)$$

For this reason, it is important to accurately select the insulator film in order not to loose sensitivity in the measurement of the target impedance.



(a) (b)

Fig. 4. The prototype (a) used for the experimental characterization and (b) the equivalent model of the sensor.

4. Conclusions

The non-invasive measurement of physical parameters requires a simple, portable and low cost system able to collect the information without interfering with athletic training. A system composed of an earphone equipped with different sensors has been proposed. The multi-sensor prototype described and characterized in the paper has demonstrated the feasibility of the approach, collecting properly information about the cardiac signal and variation of human tissue due to physical effort.

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