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Wearable sensor for biopotential measurements of patients' health monitoring

***Abstract**. The article presents the concept and prototype of a sensor network for biopotential measurements for long-term and remote tracking of vital signs of patients or athletes. Portable monitoring solutions consist of two basic elements: sensors and a data collection device. In this work, we propose a new type of dry textile electrodes to detect physiological signals that can be an alternative to gelled electrodes. Preliminary ECG measurement results show that after further improvements they can be good candidates for use in intelligent clothing for real applications.*

***Streszczenie.** Artykuł przedstawia koncepcję i prototyp sieci czujników do pomiarów biopotencjałów do długoterminowego i zdalnego śledzenie parametrów życiowych pacjentów lub sportowców. Przenośne rozwiązania monitorujące składają się z dwóch podstawowych elementów: czujników i urządzenia do gromadzenia danych. W tej pracy proponujemy nowy rodzaj suchych elektrod tekstylnych do wykrywania sygnałów fizjologicznych, które mogą stanowić alternatywę dla elektrod żelowanych. Wstępne wyniki pomiarów EKG pokazują, że po dalszych ulepszeniach mogą być dobrymi kandydatami do zastosowania w inteligentnej odzieży do rzeczywistych zastosowań. (**Mobilny czujnik do biopotencjalnych pomiarów monitorowania zdrowia pacjentów**).*

Keywords: wearables, biopotentials, sensors.
Słowa kluczowe: urządzenia ubieralne, biopotencjały, czujniki.

Introduction

According to the assumption, the designed measuring device fits into the trend of wearable technology. It has the form of a well-tailored piece of clothing, in this case a t-shirt or vest, equipped with a number of sensors located on its front and back, and an integrated electronic module responsible for the measurement process and data acquisition. The system is assumed to be used for long-term monitoring of cardiological and pulmonary functions, hence it is to provide the user with a high level of comfort while ensuring high quality and usability of the collected measurement data [1]. These requirements impose on the whole structure a number of restrictions both in the field of textile materials used for its implementation as well as the broadly understood ergonomics of the entire device. When designing such a device, a number of factors related to the anatomy of a potential user should be taken into account. Considering the various types of human figure structure, sizes etc., it is very difficult to create a universal device. In our opinion, the right concept is to create a device that is best suited to a specific user. Similarly to the textile industry, the sizes and appropriately scalable arrangement of the electrodes will be developed to maximize the group of potential users.

Factors such as the material, shape or dimensions of the electrodes have a significant impact on the quality of the skin-electrode connection [2]. So far, different types of dry electrodes have been studied: CNT-PDMS [3], PEDOT ink-printed: PSS electrodes [4], graphene electrodes [5-7], matrix electrodes with microneedles [8] and many others.

Recently, textile electrodes attract more attention because they can be easily integrated into non-standard clothing parts, making them much more user-friendly. Due to different production methods, textiles have different yarn and fiber structure, fabric density, etc. Based on this classification, woven fabrics [9], nonwovens [10], knitted fabrics [11] or embroidered [12] were tested for suitability as the electrode material. However, textile electrodes have to deal with obstacles typical of dry electrodes in general: high skin electrode interface impedance due to lack of electrolytic fluid; motor artifacts caused by user's movement, muscle spasm or breathing, and more. There are many algorithms for solving optimization problems [13-30] and being elements of complex systems [31–36]. The presented solution is part of such an application [37-40].

Textiles electrodes

It’s known that human skin consists of several layers: hypodermis, dermis, epidermis.

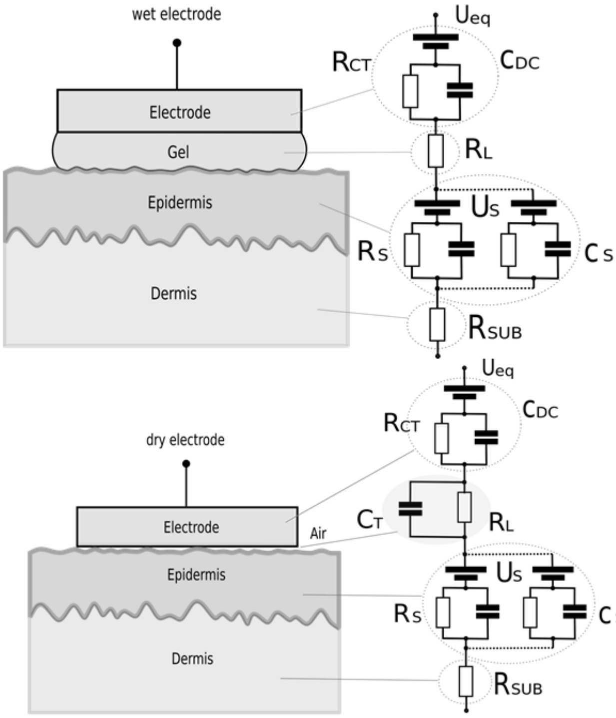

Fig. 1. Equivalent circuit of a standard wet electrode-skin interface (a), (b) equivalent circuit of a dry electrode interface.

Within these layers we can find: blood vessels, sweat glands, connective tissue, fat, hair follicle. All them together can be characterize by capacitance Cs and resistance Rs + Rsub (see Fig. 1). Us represents the potential that arises from different ion concetration in consecutive layers of the skin [9]. In the case of standard wet electrode (with gel layer) (Fig. 1a) impedance of ecquivalent circuit can be expressed by the formula:

$$Z_{wet} = \frac{R_{CT}}{1 + j\omega R_{CT}C_{DC}} + R_L + \frac{R_S}{1 + j\omega R_S C_S} + R_{SUB} \tag{1}$$

where: RCT is the charge transfer resistance, CDC- double layer capacitance.

In case of textile electrode equivalent circuit (Fig. 1b) is modified by additional capacitance CT which is caused by the lack of the gel layer, and another resistance RL in parallel, that comes from sweat and skin humidity [29]. In this case impedance is given by the formula [9]:

$$Z_{dry} = \frac{R_{CT}}{1 + j\omega R_{CT} C_{DC}} + \frac{R_L}{1 + j\omega R_L C_T} + \frac{R_S}{1 + j\omega R_S C_S} + R_{SUB} \tag{2}$$

Support system

Commercially available patient monitoring systems using EIT are based on the concept of a measuring belt equipped with evenly spaced electrodes. In our first prototype, we based the same approach. The mobile measuring device consisted of a measuring belt equipped with 32 electrodes arranged in a specific way around the chest with two rows of 16 electrodes and a main module controlling the measuring process. The proposed solution had a dedicated connector, thanks to which a recording and measuring device could be connected to it.

To date, several prototypes of the support system have been developed, ranging from a single chest strap, through a belt with suspenders to a short vest. The belt is fastened in a strictly defined position.

Fig. 2. Vest with wiring and visible rivets.

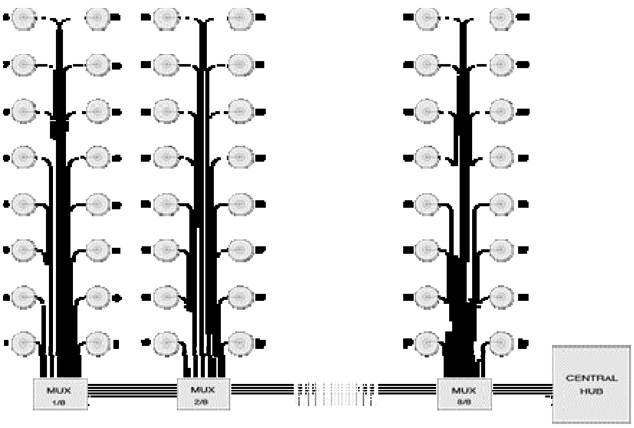

Fig. 3. Wiring diagram inside the material busbars.

Currently, the most advanced solution is a vest. This project was prepared with a view to collecting measurements for the BSPM (Body Surface Potential Mapping) research method. The solution proposed by our team consists of 101 electrodes attached to the mounts located in appropriately selected places of the vest. Naps were used to apply new silicone-textile electrodes. The measuring device is designed for one person who has a chest circumference of 110 cm with a belly circumference of 105 cm. Wiring was carried out in special stitched material rails to minimize the risk of mechanical damage. Female snaps to which wires have been installed are designed to connect with the electrode's male plug. On the back there is a zipper for easy putting on the vest.

Electrodes

An electrode was designed that consisted of three layers.

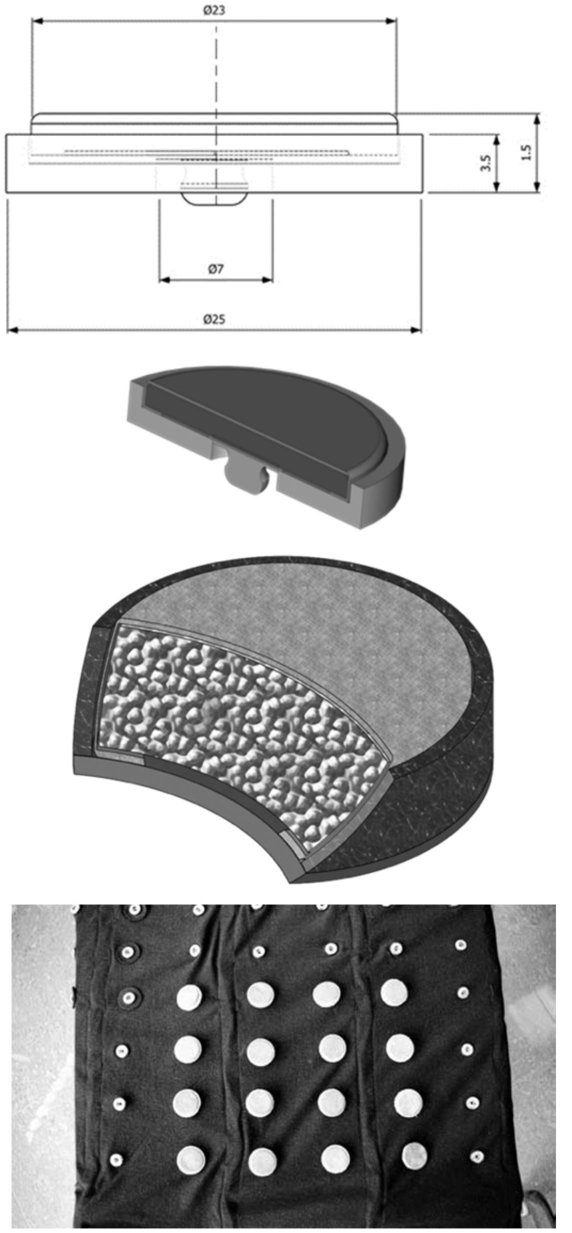

Fig. 4. Diagrams of building silicone electrodes with their placement on the vest.

The bottom of the electrode consisted of a laser-cut plexiglass to which a sponge and a conductive material were attached. The conductive material is stretched through a plexiglass ring and glued together with the conductive material. We decided to route the wires in a connector on a circle that is embedded in conductive material. The construction scheme is shown in the figure below. The electrodes have a diameter of 25 mm.

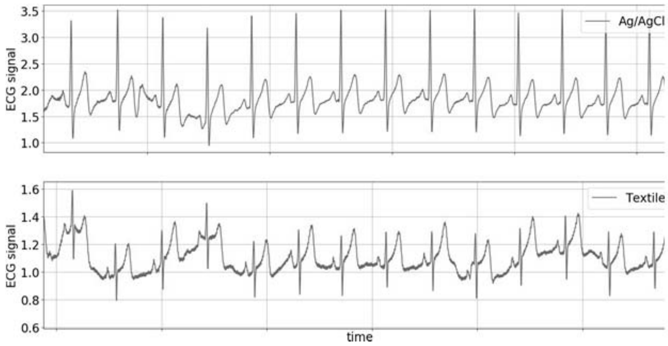

Fig. 5. a) Two ECG signals of normal subject recorded in resting condition by standard 3-lead system with disposable Ag/AgCl electrodes (top graph), with textile electrodes (bottom graph).

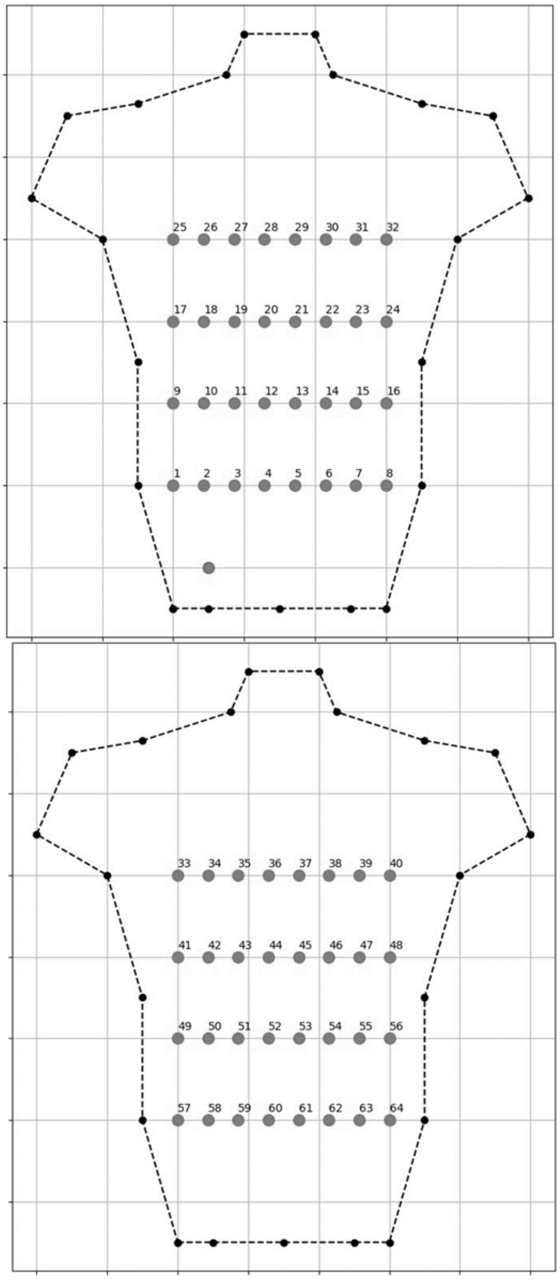

Fig. 6. Posterior and anterior model of human thorax with example of 64 electrodes arrangement.

Results

To check the function of the textile electrodes, we performed standard 3-lead ECGs in a 30-year-old volunteer in a sitting position. Figure 5 shows the results of a single measurement taken with disposable Ag / AgCl electrodes (Farum, model: FES-5541C) and our textile electrodes. Due to the fact that the textile electrodes do not have any glue layer, they were attached to the skin with medical adhesive tape to ensure stable recording conditions. The same ECG device was used to acquire data. There is not much difference in the waveform of both signals. In the case of wet Ag electrodes, the signal has very good quality. The QRS complex and the P and T waves are clearly visible. On the other hand, the data obtained by the textile electrodes have a significant baseline drift and are generally much louder, which may be associated with motor artifacts due to possible poor attachment to the skin. However, QRS, P and T waves are also visible with some differences in amplitude. Comparison of both results shows that our textile electrodes are quite promising candidates for detecting physiological signals, but further work is needed.

Conclusion

The article presents a solution based on a sensor network for biopotential measurements to diagnose and monitor human parameters. The system uses two complementary diagnostic techniques: electrical impedance tomography and ode surface potential mapping. The wearable solution consists of sensors, an electronic device and an IT application. The presented sensor matrix model collects measurement data and processes it accordingly. The reliability of measurements requires that all the sensors involved have the same properties due to several factors: the varied landscape of the human chest, different fat content and skin properties at different locations of the chest. The proposed new type of dry textile electrodes for detecting physiological signals is an alternative to gelled electrodes. The measurement results show that after further improvements, the properties of the sensors are suitable for use in intelligent clothing for real applications.

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