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Thin film electrodes as elements of telemedicine systems

Streszczenie. *W artykule opisano współczesne trendy w zakresie wytwarzania elektrod cienkowarstwowych wykorzystywanych w telemedycynie. Elektrody takie stanowią elementy składowe systemów informatycznych i stanowią integralną część odzieży. Przedstawiono również standardy przesyłu informacji używane w systemach medycznych.*

Abstract*. current trends in the production of thin film electrodes used in telemedicine are described in the following article. Such electrodes are main components of information systems and are an integral part of the clothes. Some information about transmission standards used in medical systems is also presented in the paper. (**Elektrody cienkowarstwowe jako elementy układów systemów telemedycznych**).*

Słowa kluczowe: telemedycyna, próżniowe nanoszenie cienkich warstw, elektrody medyczne, standard przesyłu informacji.
Keywords: telemedicine, vacuum deposition of thin layer, electrodes, standard information transmission.

Introduction

The constantly growing number of mobile phone users, progress in technology and the development of mobile LTE broadband encourage reflections on the use of mobile phone as a tool in telemedicine. At the moment the phone is used not only to talk, but also to the broadly understood exchange of information and its pre-processing as well. Video calls make it possible to determine the physical condition of the caller. In addition, there are applications that allow the assessment of the vital signs of people using mobile phones. For this purpose built-in sensors such as accelerometer, video camera with flash and a microphone are used. With the apply of these sensors the most basic functions of life, which indicate the physical condition and well-being, can be monitored. These include temperature, pulse, blood pressure and respiratory rate.

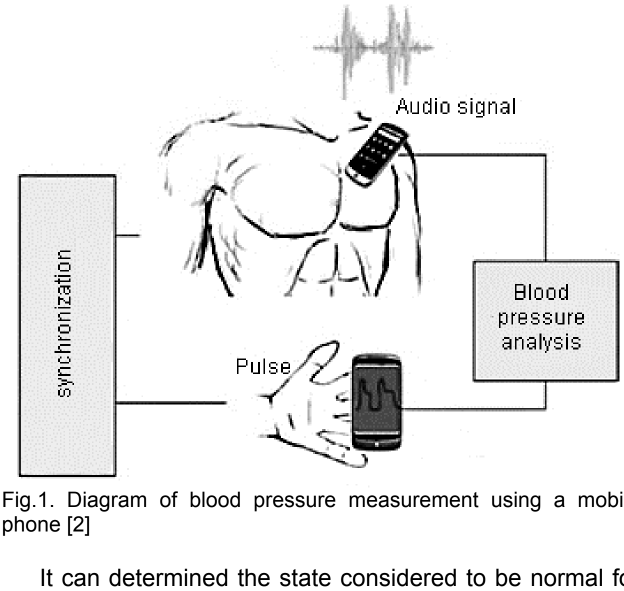

Fig.1. Diagram of blood pressure measurement using a mobile phone [2]

It can determined the state considered to be normal for each monitored person and, if any irregularities are detected, it is possible to connect to the previously entered phone number. Assessment of the physical condition should not be made on the basis of only one parameter, because for example, a higher heart rate, in addition to the symptoms of the disease, can also be caused by emotions such as fear, anger or a heavy meal. In addition, it is expected that some biological reactions also affect the measurement signals by changing the properties of the electrodes (eg. resistance change of contact or electrode).

There is no need to equip people with additional specialized equipment due to the possibility of using the device used by people every day to monitor their vital functions. However, detection systems should be connected to a mobile phone via wireless systems in order to ensure correct initial diagnosis [1,2]. It is advisable to develop clothing equipped with electrodes during the implementation and development of telemedicine solutions. Possession of additional equipment will not be necessary thanks to the integration of sensors with clothing [3]. It can be monitored, recorded and transmitted data on the patient's health status by creating sensors using thin conductive layers embedded in textiles. Example of e-fabric used in upper-limb rehabilitation is shown in Fig. 2.

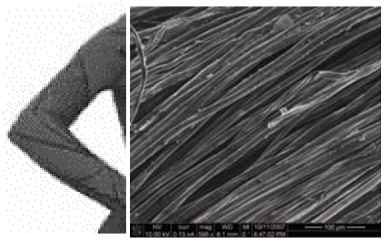

Fig. 2 E-fabric used in upper-limb rehabilitation [3].

Medical electrodes

The existing main types of applied electrodes are shown in figure 3.

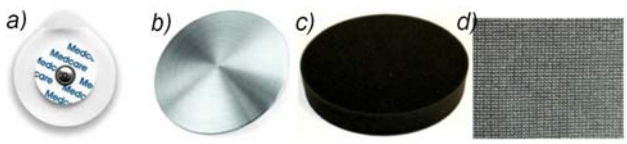

Fig. 3 Categories of electrodes: a) conventional Ag / AgCl; b) metal electrode c) conductive foam; d) conductive fabric

Because of the irritation occurring on the skin in case of application of conventional electrodes which require the use of gel as an intermediate medium between the skin and the proper electrode, so it is appropriate to develop dry electrodes.

Equivalent circuit of electrode-skin connection in case of application of dry electrode and the electrode with gel is shown in figure 4.

Model proposed by Webster [4] showing an electrical connection between the electrode and the skin contains data of used gel. The resistance Rs is the effective resistance associated with interface effects of the gel between the electrode and the skin. The potential difference E_{se} is given by the Nernst equation. The epidermal layer behaves as a parallel RC circuit. The dermis and the subcutaneous layer under it behave as pure resistances. They generate negligible dc potentials. However, the electrical connection between a dry electrode and the skin is different due to the absence of the electrolyte gel.

The electrical equivalent circuit of a dry electrode is simplified due to the lack of an intermediate medium.

Comparison of dry electrodes, which have been researched in the recent period, is presented in table 1.

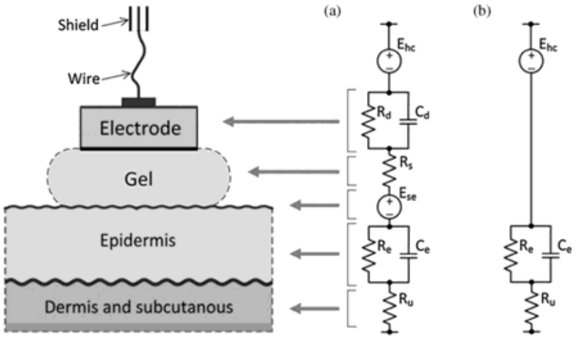

Fig.4. Electrical model for electrode-to–skin interface for: a) gel electrode; b) dry electrode [4]

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Table 1. Some fabric electrode comparision [9]

	electrode constitution	geometric form	findings	comments
1.	Two stainless steel wires twisted around a viscose textile yarn Ag/AgCl [5]		Signal comparisions to reference electrodes, quality signal preserved if washed	Using hydrogel membrane (dynamic conditions) 5-8 h of membrane wearing
2	Polyester yarns covered with silver [6]	7,10,15,20, 30 diametres	Higher noise for dry textile, most reliable behavior (hydrogel)	10-15 min stabilizing time tests taken 5 min after electrode placement
3	Bakintex Bare elastane silver-coated yarns [7]	x 2 cm squares	Significant deterioration when electrode stretched	Use in swimsuit, water as electrolyte gel
4	Thin silver-nylon 117/17 2-ply conductive thread [8]	Rectangular 16cm^2 25 cm apart	0-0,67 Hz noise	Mounted on chest belt, moistening of textile electrode 5 min settling time

Electrodes made in 2011 by a team of Marozas [8] require moistening with water in order to reduce the time of determining of the value of the output signal. Studies have shown that the produced textile electrodes were less susceptible to broadband noise, but they caused additional noise in the signal band 0.05-0.67 Hz.

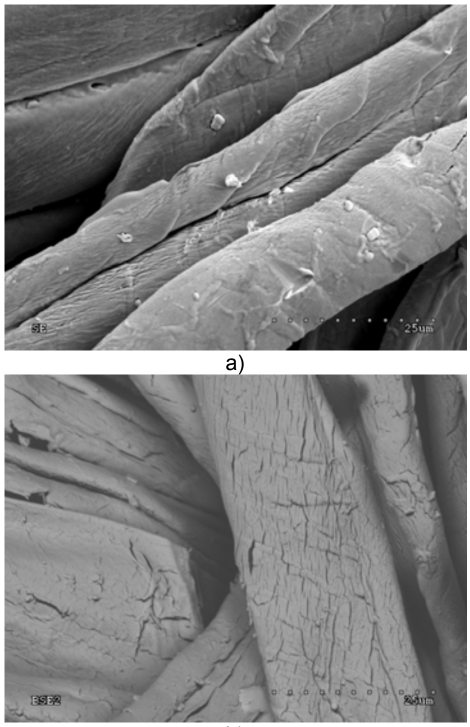
Marquez et al used textile electrodes to analyze the composition of the human body. The inner surface of the electrode was made on basis of synthetic textile knitted additionally with slivers fibers. They used the differences in resistance of the electrodes in their studies.

Silva [7] studied the monitoring of vital signs in the aquatic environment. He designed textile electrodes integrated with bathing suit. During the stretching of the electrode a significant deterioration of the received signals was observed.

As a result of research provided by Yoo and his team [10] a system with thin-film electrodes integrated with a shirt has produced. That can collect data from the body continuously for 14 days without replacing the power supply. The amplitude distortion of the received signal was observed due to the higher impedance of the dry electrodes. Attempt was also made to produce wireless inductive sensors as part of an integrated system using thin film electrodes. But there is no economic justification for the use of such sensors.

The general trend in the production of a dry electrode is to apply them in a vacuum deposition process [11,12] or digital printing [13-16]. It is also important to eliminate wires and skin irritation and provide low energy consumption (a few mW). In the case of a vacuum deposit PVD, obtaining the continuous layer required additional technological treatment of the textile substrate or the using the flexible composite substrates.

Figure 5 shows examples of microscopic pictures of electroconductive layers with continuity path (Fig. 5a) and the metal layer which does not exhibit good electrical properties (Fig. 5b). They were taken with using a scanning electron microscope Hitachi S-4200.



a)

b)

Fig.5. Microscope image of thin films deposited on the textile substrate in PVD process (magnification 1800x), a) with the continuity of the metallic layer b) without the continuity of the metal layer

In view of the fact that the processed data are the low-amplitude electrical magnitude, the constant value of resistance of electrode matrix is very important. Electrodes formed as matrix of electrodes are used to collect information which is generated by the electric potential of the heart or a change in body temperature. The attention should be paid to do the correct sensor resistance measurement. It will be considered as the default value in devices processing the transferred data [17]. A low mechanical strength as another technological problem needs to be solved. Any connection of the prepared electrodes with the signal lines is difficult and inconstant. Some research of connection electrodes with any wires were taken. It is worth to carry out some research with the unique merger techniques using microwelding laser [18]. However, some another problems connected to the technological process can occur inter alia oxidation layers as well as the formation of intermetallic compounds [19].

In future research authors would like to use COMSOL simulation environment software to model specific complex processes during the modeling of electrode-skin connection. In that kind of software it is possible to simulate even very complex processes [20, 21]. Using neural networks [22] or the parallel algorithms [23] to describe the behavior of the skin in connection to electrode is also possible.

Standards for the transmission of information

In the open market conditions and growing competition in the market of Internet services, the introduction of standards for the transmission and exchange of information between medical institutions and systems integration has become intentional. HT7 (Health Level 7) is known a the standard for the exchange of information. DICOM (Digital Imaging and Communications in Medicine) is known as the standard in the field of medical images transmission [24,25].

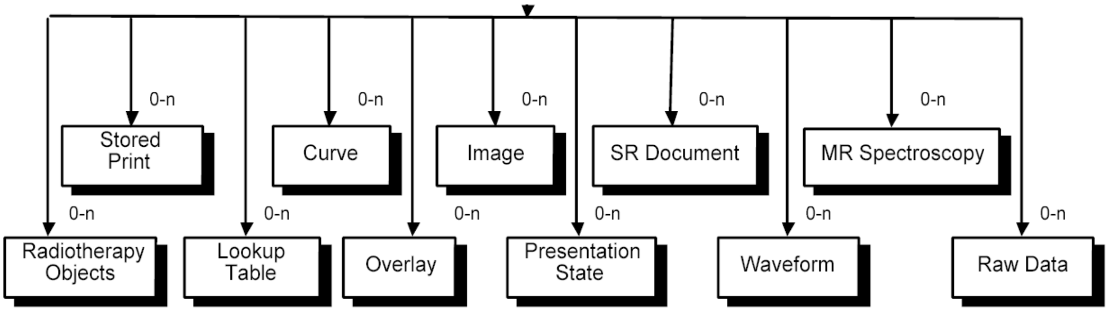


Fig.6. Fragment model of real medical data In DICOM. [27]

Obtaining the reliable data from monitoring, requires its detailed analysis to detect the unusual events and also incompatible ones with the standards. It also requires data protection at the time of their production, transmission and processing. In this aspect, the identification of exceptions occurring in the transmitted signal is important [26].

Description of medical data and its collection and sharing between departments or hospitals is significant and important. Currently, there are standards for telemedicine systems in the form of norms and standards for data exchange. These are primarily HL7 and DICOM.

DICOM (ang. Digital Imaging and Communications in Medicine) was created for exchanging graphical data and their description as the complement of the HL7 standard. Combining between different medical information and dependencies between them was shown in Figure 6.

According to fig.6. it can easily be noted that all the necessary data about the patient (personal data), all the data about visits and the examination, the procedures and the results of research in the form of reports are recorded. Also data series as images, raw data are stored For example, the resolution, the distance between the sections, the reconstruction filter or window parameters are stored as a series of data even after the CT examination.

Information model, which is Introduced in DICOM (figure 7) groups data modules and thematic collections and specifies the format (images, waveforms, graphical objects, reports, printouts) in the same time. Information model defines the data format for different types of information, such as images, waveforms, graphics, reports, printouts etc. Data are grouped in thematic collections (called Entities) and subsets (called Modules). Each module is formed by a set of attributes as the basic unit of data (Data Element) and the flow of information (Data Set).

Data Element contains the following elements: identification data item which consists of two numbers specifying: group and element groups (called Element), written in hexadecimal form, the data type specified in the form of a pair of letters in ASCII, and enables the correct interpretation of the data, the size of the element in bytes. Data Set is an ordered stream of data elements.

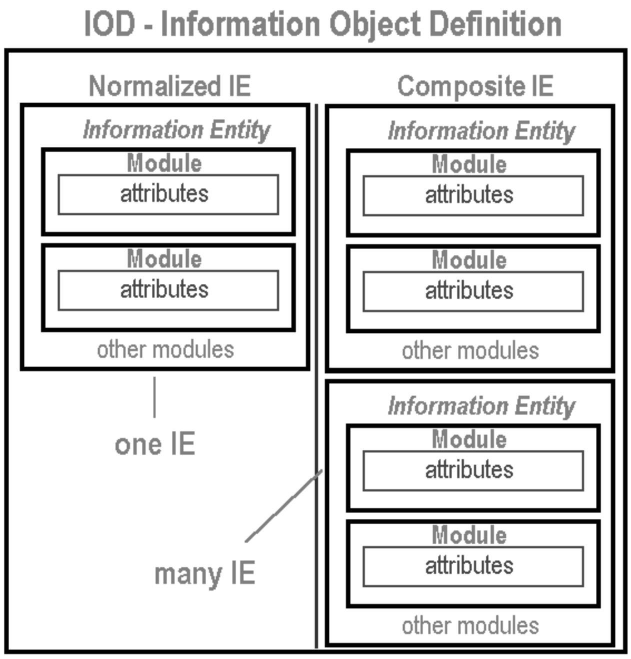


Fig.7. Structure of information model IOD - Information Object Definition, [27]

Today, most modern diagnostic equipment supports DICOM. It is the leading standard for medical images in computed tomography (CT / CT), magnetic resonance imaging (MRI), positron emission tomography (PET), digital subtraction angiography (DSA), digital radiography conventional (CR) and all research digital high-resolution image used, among others, in radiodiagnostics, ultrasound examinations, karyology, radiotherapy.

Summary

Possession of a number of tools implemented in the device used in everyday life is now natural thanks to the development of microelectronics. Standard in modern smartphones is equipping them with the functionality of an alarm clock, stopwatch, dictionary, calculator, camera, camcorder, notebook, calendar and thousands of other applications. At the same time universal medical diagnostics becomes a pressing need. So the natural consequence is to create a diagnostic system using the existing capabilities of smart telephones, systems processing and transmitting data.

To generate an optimum system allowing to identify health risks as early as possible should be the aim of research.

Thin film electrodes formed on flexible substrates in the process of vacuum application may be a component of telemedicine systems. The formation of electroconductive layers in PVD is a complex process. It is desirable to conduct further tests to select for appropriate textile substrates, on which it will be possible to produce a thin layer of low resistivity and high resistance to mechanical factors.

For the proper functioning of the entire telemedicine system it is also important to monitor the electrical properties of thin film electrodes by computer algorithms continuously.

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