Ewa KORZENIEWSKA[1], Agnieszka DURAJ[2], Andrzej KRAWCZYK[3,4]

Institute of Electrical Engineering Systems, Lodz University of Technology, Poland (1),
Institute of Information Technology and Applied Mathematics, Lodz University of Technology, Poland (2),
Electrical Faculty, Czestochowa University of Technology, Poland (3),
Military Institute of Medicine, Poland, Warszawa (4)

Detection of local changes in resistance by means of data mining algorithms

Streszczenie. *W artykule przedstawiono wyniki badań rezystancji specjalnych elektrod wykonanych z wykorzystaniem technologii próżniowej. Elektrody te mogą stanowić element odzieży wykorzystywanej do elektrostymulacji i monitorowania parametrów fizjologicznych. W artykule zaprezentowano sposób detekcji różnic w rezystancji e-włókien za pomocą algorytmów wykrywania wyjątków w bazach danych. (**Wykrywanie lokalnych zmian rezystancji z wykorzystaniem algorytmów data mining**).*

***Abstract**. The following article presents results of examination of the resistance of the special electrodes made with using vacuum technology. These electrodes can be a item of clothing and can be used for electrical stimulation and monitoring of physiological parameters. The discussion of the discrepancies of e-fiber resistances is carried out by means of the concept of data mining with exceptions.*

Słowa kluczowe: elektrostymulacja, próżniowe nanoszenie cienkich warstw, elektrody pomiarowe, wykrywanie wyjątków.
Keywords: electrostimulation, vacuum deposition of thin layer, electrodes, detect exceptions.

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Introduction

Wearable technology has attracted the interest of researchers, engineers and clinicians in the recent years. The main reason for such an interest is because the modern society is older and older and therefore requires long-term monitoring at home [1]. The process of wireless registering of physiological signals became possible thanks to telecommunications solutions and new technologies. E-fibers allow vital functions monitoring with using special electrodes placed in clothes. Preparing the intelligent threads and combining them into a consolidated matrix of electrodes leads to the sensors formation. It becomes possible not only the rehabilitation of disable people [2-6] but also the identification of a number of rare events. From the medical diagnostics viewpoint it is a very significant technological progress. Now it is possible not only to control heart rate but even the monitoring of tumor markers.

The transmission of physiological signals and their registration by medical devices, enabling monitoring of vital functions is a major issue with the use of sensors. Any deviation from the assumed value of resistance can lead to discrepancies between the read out information and the standard ones or during electrical stimulation to the local burns. From this point of view, it is advisable to develop a method to identify local problems and resistance increases by identifying exceptions during the transmission and data recording.

Materials and methods

The nonwoven fabric with polyurethane coating - Cordura was chosen for the surface modification and making the electrodes on it.

The obtaining of electrical conductivity on the surface of flexible textiles covered by polymers depends on technical parameters during process of applying conductive layers by thermal evaporation and the parameters of the surface.

The research involved the production of metallic layers on the samples of textile product covered with polyurethane in varying process conditions. Metal layers were applied on the surface using the Classic 250 Pfeiffer Vacuum system. During the research the tungsten boats as the resistance vapour source with evaporator current control were used. The deposition process was carried out after obtaining a vacuum of 0.01 Pa (1.0×10^{-4} mbar. The pressure in the chamber changed to a value of 0.1 Pa (1.0×10^{-3} mbar) during the deposition. The process was conducted in the generated initial vacuum of 10^{-7} bar and the application of the layer lasted 5 minutes. Silver with high purity 99.99% was used in the process of layer application.

One of the problems to be solved during process of making the pattern of electrode matrix is good electrical properties without interruption over the entire path length between the sensor and the interface of the data collector. In the preparation of electrodes on the surfaces of the textile the difficulty in adhesion to the substrate of the electrically conductive layer, as well as difficulties in obtaining continuous paths with good conductivity should be expected.

In the previous papers [2,7] the process of applying conductive layers by thermal evaporation was also discussed.

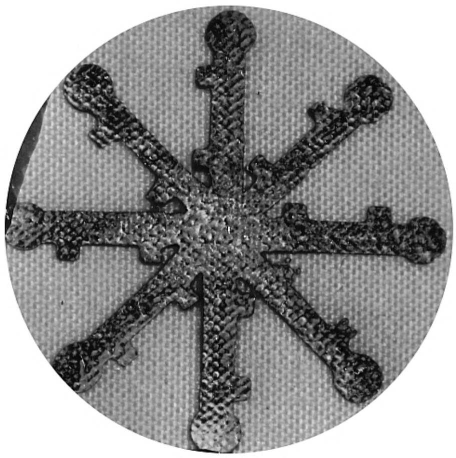


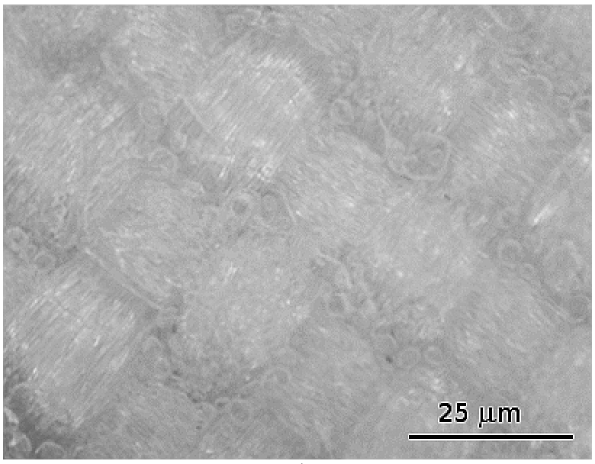
Fig.1. The image of created electrodes in the PVD process.

In the figure 1 there are presented the electrodes created in the PVD process.

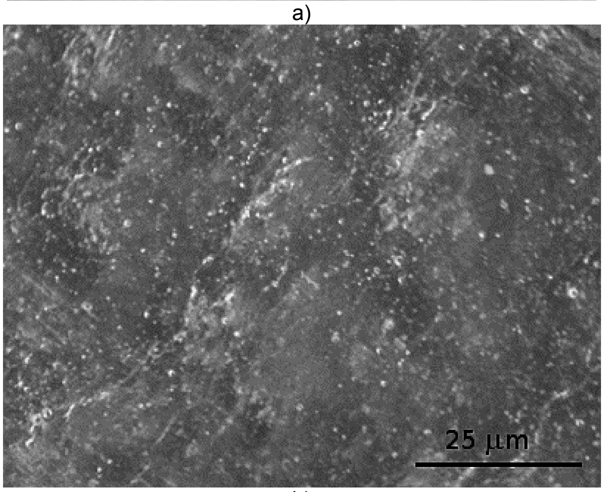
Preliminary microscope studies were carried out using the stereomicroscope Delta Optical SZ-630T with a magnification of 16× to 100×.

Some results of the microscope investigations of the created samples were presented in the figure 2.

As a result, the produced layers have resistance in the range of 0.5 Ω measured in the four-probe method and they are continuous in the 5 cm length. The obtained resistance per square was in the range of 25 mΩ/sq.



a)



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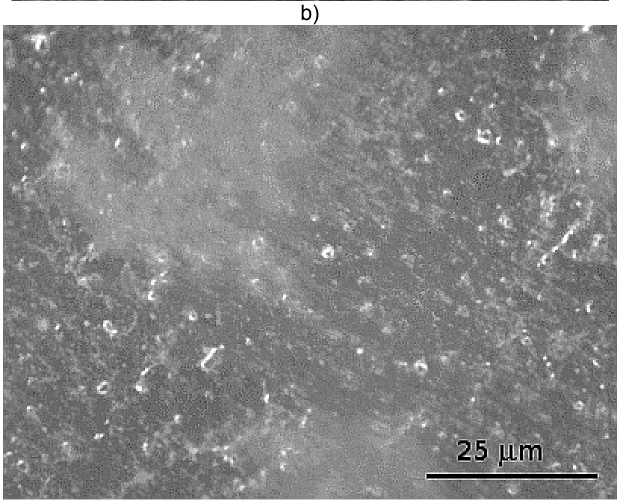


c)

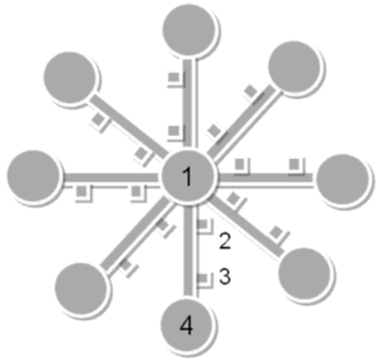
Fig.2. Microscopic images showing
a) the textile used as the surface for making the electro-conductive layer (magnification 40x)
b) the path of electro-conductive layer (Ag) on the fabric covered with polyurethane (magnification 40x)
c) the path of electro-conductive layer (Ag) on the fabric covered with polyurethane (magnification 100x)

The four-point method of resistance measurement is based on indirect measurement of the resistance of the samples using electrodes, which are placed on the sample as it is presented in the figure 3.

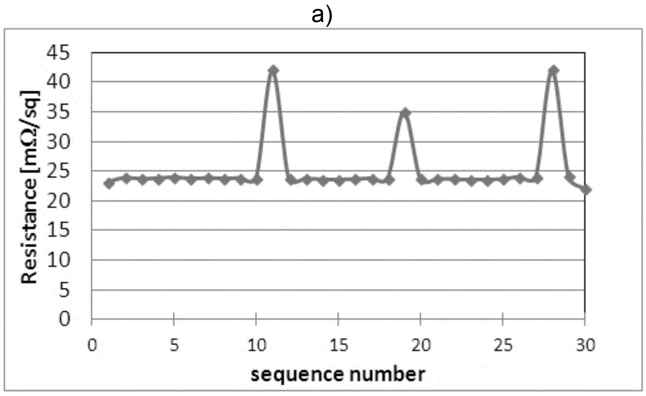
Next, the resistance was obtained from the rule:

$$R = \frac{1}{2}\left(\frac{U_{2-3}}{I_{1-4}} + \frac{U_{2-3}}{I_{4-1}}\right) \quad (1)$$

where R – measured resistance, U - measured voltage drop between the pair of 2 and 3 electrodes, I - forced current between measuring electrodes i.e. 1 and 4 or 4 and 1.



a)



b)

Fig.3. a) Scheme of the manufactured electrodes with measuring probes; b) The value of resistivity measured in the four-probe method of resistance measurement presented in figure 3a.

Because of the nature of the study authors did not take into account the adjustments associated with the edge effect recommended in the Polish standard for the method of surface resistance calculating. [8]

In the research local variations in resistance were observed. They result from the layout of the fibers in the fabric, the parameters of the evaporation process and the method of preparing the surface for PVD. Because the resistance of particular electrode is very important parameter in the process of gathering data the analysis of the distribution of resistance is a crucial in the designing of wearable sensors.

Another technological problem to be solved is the connection of the prepared electrodes with the signal supply lines to the data recording device. The thickness of resulting layers is about 20 nm and they have a low mechanical strength. Unfortunately, the attempts which have been made to connect the electrodes were failed. Further research will be carried out with the unique merger techniques using microwelding laser [9]. However, some another problems connected to the technological process can occur inter alia oxidation layers as well as the formation of intermetallic compounds [10].

The quality of the conductive layer and the constant resistance value over the entire surface of the formed electrode affects the amount of errors and distortions in the transmitted signals.

Identification of the exceptions in the collected data

The development of information technologies including image analysis [11,12], algorithms for the detection of exceptions [13] in pre-defined databases, contribute to the development of not only the procedures for the processing of sensitive data such as banking, but also, medical diagnosis [14-16] .

This article focuses on using data mining algorithms that detect exceptions in data sets. Data mining is a complex process that uses a very large range of algorithms for classification, clustering, detecting all kinds of exceptions and outliers, or detecting dependencies between data. It is obvious to search the new methods to support the detection of exceptions. Detecting outliers as a research problem encompasses a wide spectrum of applied techniques, primarily due to the variety of the denied tasks and purposes of the system. The outliers have many causes: because of natural human error, measurement device errors, natural error in population, changes in the functioning of systems or faults in the system, criminal activity of people, etc.

The tests are based on k-neighborn, DBSCAN and CLARANS algorithms to detect the local resistance changes.

One of the simplest classification methods is the k-nearest neighbor algorithm. It is based on a simple principle, namely: "data model belongs to this class, to which belong most of its k neighboring models". Therefore, the classification of a model means designating k samples from the training data set, located the closest in the context of the used metric (e.g. Euclidean distance, Manhattan or Hamming distance). Next, the class to which the analyzed sample of data belongs is determined. Here one of the two methods is used:

Majority Voting – method of voting on equal rights– the sample belongs to the class, to which belong most of k neighbors

Inverse Distance Voting – method of voting taking into consideration distance – for each of the classes among the found k neighbors the sum of inverse distances from the analyzed sample is calculated. This sample is classified to this given class, for which the calculated sum is the biggest.

The Density Based Spatial Clustering of Applications with Noise – DBSCAN algorithm is the most popular algorithm belonging to the group of algorithms based on density [2]. The disadvantage of partitioning algorithms, that is the difficulty in detecting spherical clusters, was solved by the introduction of algorithms based on density. In the developed methods clusters are the areas that are characterized by big density of objects.

This algorithm requires two input parameters:

- E - defines the maximum radius of neighborhood for a given object, all objects being in this area are called "neighbors";
- MinP is the minimum number of points required to form a cluster, a point is called the core point, if in the neighborhood of the given point there are at least MinPts objects.

Another type of algorithm is CLARANS (Clustering Large Applications Based on Randomized Search), which is a combination of PAM (Partitioning Around Medoids) and CLARA (Clustering for Large Applications). It searches the graph randomly to and points located centrally in the group. It requires the following initial parameters :

- Maxneighbor - the maximum number of neighbors of the node to be checked.
- numlocal - the maximum number of local minima information on which can be gathered
- numberofclasses - the number of classes which are considered as possible
- minimum the number of local minima for consideration before the end of the algorithm.

CLARANS (Clustering Large Applications Based on Randomized Search), belongs to the group of partitioning algorithms which use a limited search strategy. It is based on a random graph searching to find medoids representing the group.

In this conducted study it was assumed that there are three incorrect resistances which can be detected and treated as exceptions. One is the resistance of above 80 [mΩ / square], which can occur as the temperature increases. Another is the fact that for R [mΩ / square] > 100 mΩ / square means total destruction of the electrode. The third exception is the resistance above the value of R [mΩ / square] > 33 mΩ/square. In the analyzed set seven exceptions were introduced.

Three exceptions related to the first group of resistance of above 80 [mΩ / square] and two exception for the two other groups of exceptions. The density DBSCAN algorithm was the most effective, although the k-NN also classified correctly. CLARANS had trouble finding a real local minimum. Grouping is only possible if all the objects are in operational memory. This is the cause of a significant reduction of the size of the test file. DBSCAN algorithm and k-NN analyzed and detected exceptions quickly and with high accuracy. With proper selection of input parameters they detected other extreme values.

In order to reduce the cost of testing in a real environment, a part of it will be conducted using the COMSOL simulation environment software that allows simulation of even very complex processes [18, 19]. It is also possible to use neural networks [20] or the parallel algorithms [21] to optimize the calculating of the resistance value.

Summary:

The paper provides a brief description of the methods for detecting exceptions with particular emphasis on studied algorithms and most of all the preliminary results of experiments related to detecting exceptions defined as a resistance change in the electrodes produced by PVD method on flexible surfaces.

The study shows that there is a possibility of making electrodes with a surface resistance of single mΩ/square by PVD method on a flexible textile substrates. It should be remembered that the mechanical washing process may cause local deterioration of the electrical properties of the sensors. [17]

The fact that the resistance value is constant on the entire surface of the produced electrode is very important. This determines the levels of errors and interference minimizing during signal transmission. Proper quality of transmission lines and electrodes has a direct impact on the correct detection of exceptions analyzed by the diagnostic system. In the process of the application of the sensors it is very important to recognize the difference between resistance value recognized by the diagnostic system as the correct one and the resulting one from the on-line measurements. According to the authors a carried out comparative analysis using the DBSCAN algorithm is the most effective for this purpose.

Due to the very high complexity of the analysis of the received signals the possibility of using neural networks should be considered in future work. They are used in the optimization of complex processes e.g. [20,21].

Currently, studies on the identification of exceptions were conducted for three generated files. This was done in order to make a preliminary comparison of these algorithms and test the feasibility of the operation of each of them on the prepared sets. The next steps will address real samples.

The authors hope that these studies will help identify the regularities in obtained values but most of all disorders resulting from local changes in the resistance of parameters of deposition process and the way of preparation of the substrate. In the longer term, research will focus on the detection of sensory life functions using modern method of monitoring e-fibers described in this article.

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***Authors**: PhD Ewa Korzeniewska, Lodz University of Technology, Faculty of Electrical Engineering, Electronics, Informatics and Automatic Control, Institute of Electrical Engineering Systems, Stefanowskiego 18/22 Street, 90-924 Łódź, Poland e-mail: ewa.korzeniewska@p.lodz.pl; PhD Agnieszka Duraj, Lodz University of Technology, Faculty of Technical Physics, Information Technology and Applied Mathematics, Institute of Information Technology, Wólczańska 215 Street, 90-924 Łódź, Poland e-mail: agnieszka.duraj@p.lodz.pl; Professor Andrzej Krawczyk, Czestochowa University of Technology, Electrical Faculty, Armii Krajowej 17 Street, 42-200 Częstochowa Poland, Military Institute of Medicine, Szaserów 128, 04-141 Warszawa, Poland e-mail: ankra.new@gmail.com*