NEW PRODUCTS

Textronics – Electrical and Electronic Textiles. Sensors for Breathing Frequency Measurement

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Abstract
The aim of this paper is to present research work into designing prototype textile sensors devoted to measuring a human physiological signal, the frequency of breathing. These sensors may be used in medical applications or for firemen's protective clothing. The aim of our work was to design a textile sensor which could be easily included in clothing structures. The preliminary research into the sensorial materials is described in this paper.

Key words: *textronic, interactive textiles, textile sensors, frequency of breathing.*

Introduction

The term 'textronics' refers to interdisciplinary approaches in the processes of producing and designing textile materials, which began about the year 2000. It is a synergic connection (Figure 1) of textile industry, electronics and computer science with elements of automatics and metrology knowledge [1, 2].

A new quality is achieved as result of using component elements, which thanks to mutual feedback increase their affect. This can be obtained by the physical integration of microelectronics with textile and clothing constructions. The main task of textronics is to produce multifunctional, intelligent products with complex inner structures, but which have uniform functional proprieties. Textronic products are characterised by the following features:

- flexibility – meaning facility in modifying the construction at the stage of design, production and exploitation; for example, modular construction;
- intelligence of the textiles – referring to the possibility of an automatic change in properties influenced by external factors (parameters) and even taking decisions, which means learning or communication with the environment.
- multifunctionality, – or the ease of realising different functions by one product.

It can be stated that textronics means the design and production of intelligent and interactive textile materials which are characterised by variable structures or electrical resistance, which include microchip elements and is characterised by self-adaptive features [1].

It must be noted that sensors and actuators should have a fibre shape and an electrical output. Their usage makes it necessary to ensure flexibility, and resistance to washing processes and cyclic mechanical deformations. Fibrous actuators should react to changes in their electrical value, to temperature or chemical features with changes of their geometrical dimensions, and at the same time they should be able to direct interactive with textile and biological objects. From the textronic point of view, the electrical input is the basic problem. Modern actuators such as shape memory fibres must be supplemented by current or voltage inputs. Clothing which is in contact with the human body is called a clothing interface. If it executes only one basic function, namely protecting the human body from environmental influences, it is called one-dimensional a clothing interface. Moreover, clothing must satisfy the individual's requirements concerning his physique, trends in fashion, financial possibilities, aesthetic sense, etc. When adding a new function to clothing (besides functionality and aesthetics), the interactive adaptation to external stimuli causes the creation of a three-dimensional clothing interface [3, 15, 17].

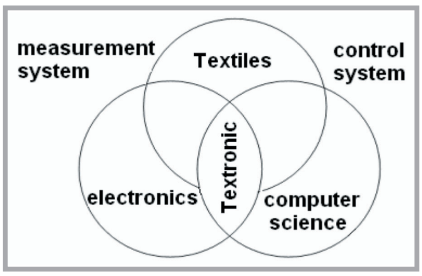

Figure 1. Textronic as the synergic connection of three disciplines.

Considering that clothes have a direct connection with the human body, the most important function of textronic clothes is to increase human safety [3]. The best way to achieve this is to detect hazards easily and counteract them effectively. In this category we can distinguish the situations connected with professional activity, for example that of soldiers, policemen, firemen, and lifeguards, as well as those connected with patients' medical conditions. Monitoring working conditions and the state of health are necessary elements to realise this function. It must be supplemented by control systems, including automatic regulation systems, storage and data transmission [3, 15, 17].

This kind of activity, focused on protecting human health, is called e-medicine or telemedicine. It has been developed dynamically over recent years. Nowadays they include not only internet medical services, access to specialist databases or internet co-operation between hospitals, but also virtual clinics which allow quick remote contact between doctors and patients, as well as remote diagnostics, EKG or even monitoring biophysical parameters all the time (24 hours a day) [4, 18]. Thanks to these new technologies, it may be possible to create special links between the patient and the doctor. Thus modern scientific discoveries allow ordinary people a normal life together with their illnesses.

The next question with textronics is that of transmission measurement and control signals. This transmission must be performed inside and outside the fibres' structure, for example between intelligent clothing and a monitoring centre. It can be conducted with or without the use of wires. As at present electro-conductive fibres and yarns have low conductivity, it seems that the best present-day solution is wireless transmission. The existing Bluetooth technology only requires adaptation to specific needs [11, 12, 14, 16].

It should be stressed that the power supply to electric systems is the most difficult problem to deal with in textronics. Traditional batteries and rechargeable alls are still too large and heavy, and it seems impossible to use them in future textronic applications. On the other hand, modern sources of energy used in textile constructions such us thermo-generators, piezo-generators or photovoltaic elements have too small a capacity and maximum current value, especially in wireless communication. Therefore it is necessary to find new solutions for the question of textile power sources [1, 2].

Optoelectronic sensors are a very important group of sensors used in textronic application [5, 6, 13]. Optoelectronic sensors first found usage in the marine field, among other areas; Aston University and the British Aerospace Unit have constructed a system which could monitor tensions in carbon masts of yachts. Optical fibres found usage not only as optoelectronic sensors but also as communication elements between particular systems, or as luminescent elements. In cooperation with

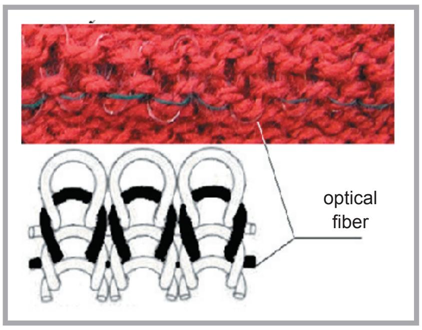

Figure 3. Optical fibres in a knitted fabric.

***Figure 2.** a) knitted sample of sensorial material; b) woven sample of sensorial material with conductive yarns.*

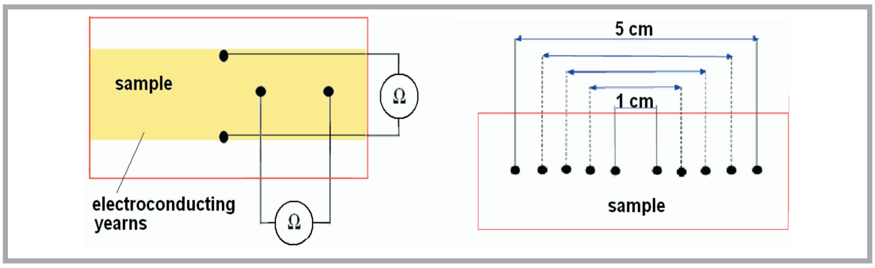

***Figure 4.** Simplified measuring scheme of the samples resistance.*

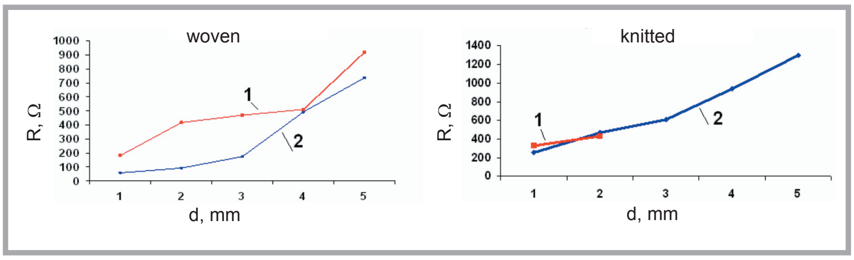

***Figure 5.** The results of resistance measurement for the first group of sensitive materials; (1) horizontal measurements, (2) vertical measurements; d - distance between measuring points, R - resistance.*

France Telecom's R&D some fibrous, static and dynamic prototype screens have been manufactured from 1999 to 2000, which have been applied in clothing applications (the so-called communicating garments). This kind of clothing appears in such fields of life as:

- public safety, active uniforms for policemen, firemen and airport services,
- internal decoration of living apartments, and
- the car industry (such as internal warning screens).

There are two basic kinds of screens, static and active. The first are made using elementary weaving methods. Their display image is static, and they are made from optical fibres which are composed according to templates. The image created by them is not of high quality, and usually has bad resolution. Only the change of the light source's colours is possible. The second kind of screens are created by special weaves on jacquard machines. The matrix created allows us to display texts and logos in a static or dynamic way [6, 7].

The Georgia Institute of Technology was the first company which used fibres and optical sensors in applications monitoring human health. The final product was called Sensata Linear, and took the form of a uniform which could monitor the soldier's vital signs in a battle. It can determine and locate the places of injury and their extent, and send the collected data to a medical centre [8].

This clothing, also called life shirts, was popularised by the American Sensatex company [9], and is used as an undershirt. Optical fibres are spirally plaited into its structure. The whole undershirt has been made with a special weaving technique, in one piece, without any cuttings or seams. The main task of this intelligent shirt is to monitor human physiological parameters such as temperature and heartbeat.

It can be used with different textile sensors, not only optical sensors. It is also possible to include sensors into the textile structure to measure the presence of poisonous gases in the air. The sensors collect data into a central unit, and send it to the information centre. Data transmission is wireless.

The modern tendency in developing textronic clothing is related to protecting human health. This problem has arisen in many European and national projects in various science centres around the world. Furthermore, the Department for Automation of Textile Processes of the Technical University of Łódź is participating in a human health protection project, where the main stress is laid on measuring human bio-physical parameters. One of the tasks realised within this subject is monitoring human breathing by using textile sensors. Similar solutions are currently being realised by the following companies:

- Textronics™ Inc has presented the Textro-monitoring™ system, used to monitor human biophysical parameters, such as respiration and heart rhythm [10].
- The Braebon company introduced the Ultima Respiratory Effort Sensor, based on piezoelectric crystals, which generate electric charges by deformation during breathing. The signal is sent to an amplifier without an external current source [9].

Although several such items of textronic technology have been developed, textronic science still confronts the great challenge of making further attempts to obtain new differentiated constructions which could find application as reliable sensors for monitoring heartbeat or breathing rhythm. The aim of the work presented is to make such an attempt.

Sensors for measuring breathing frequency

Sensor materials

Textile sensors to measure the breathing frequency and rhythm were createdon the basis of textronic principles. This paper contains a description of two kinds of textile sensors which we have manufactured; the first is based on electro-conductive yarns, and the second on optical fibres. In the first case, we tested knitted and woven fabrics which contained electro-conductive yarns. The sensitive material samples are presented in Figure 2; Figure 2.a shows a knitted textile sample with an electro-conductive yarn stripe (green colour) made from a single thread manufactured from polyacrylonitrile staple fibres, where the conductive materials are copper sulphides with the Euro–static brand name. The remaining part of the sensorial fabric is white cotton yarns. The welt stitch 2/2 was used to make the sample in the knitting technique which enabled us to obtain good elastic properties. The woven sample is shown in Figure 2.b. It was manufactured by Pomtór of Katowice. It consists of 48% cotton, 50% polyester and 2% electro-conductive yarns. This company produces fabrics with electro-conductive yarns, which can be applied for protective clothing with antistatic properties. We took the opportunity to use the presented materials as sensors for breathing frequency measurement.

Another group of textile sensors are fabrics with optical fibre implementations. Figure 3 shows part of a knitted sample with an optical fibre in the knitted loop.

Measurement of the sensor fabric's resistance

During the first stage of the presented research, the sample's resistance were measured in static conditions at specific sections of 1 to 5 cm (1 cm each). A simplified measuring scheme is presented in Figure 4.

The measurements were carried out under the following conditions: temperature of 23 °C, and humidity of 47%. The results are presented in graphic visualisatio for horisontal (a) and vertical (b) measurement in Figure 5:

The resistance measurements were also carried out under static elongation change, with the use of a laboratory stand, as shown in Figure 6.

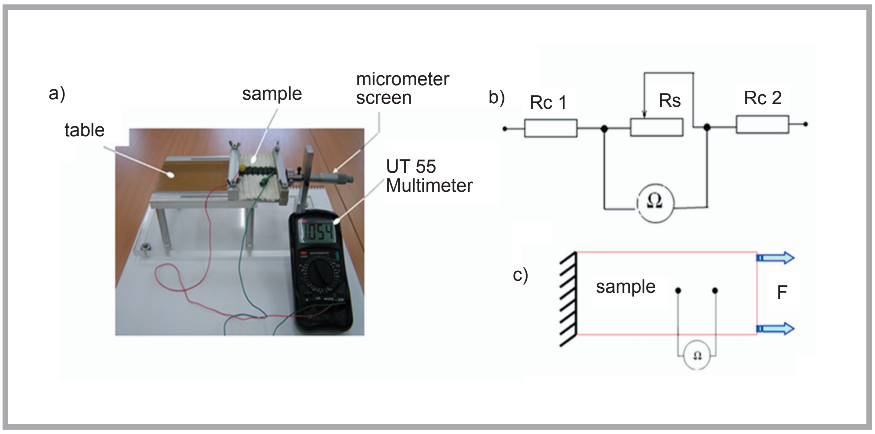

***Figure. 6.** a) Laboratory stand for resistance measurement; b) Equivalent electric circuit diagram; c) measurement diagram, where R_{c1}, R_{c2} are connection points resistances, R_s is the sensor's resistance.*

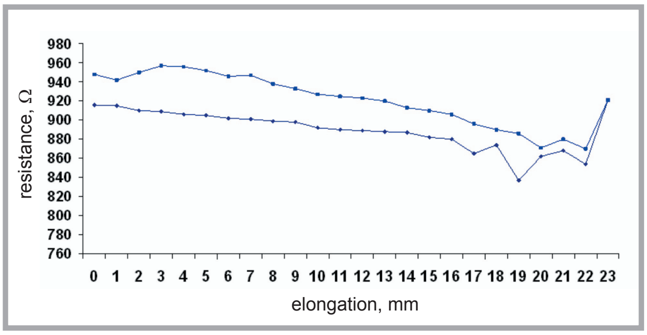

***Figure 7.** Changes of resistance in the knitted sample with electroconductive yarn stripes dependent on elongation, obtained with the laboratory stand shown in Figure 6.*

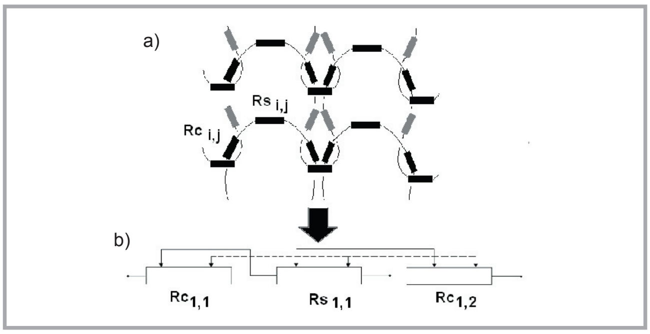

***Figure 8.** a) Spatial net of resistances between contact points of the knitted loop; b) Equivalent circuit diagram of the changing connection resistances.*

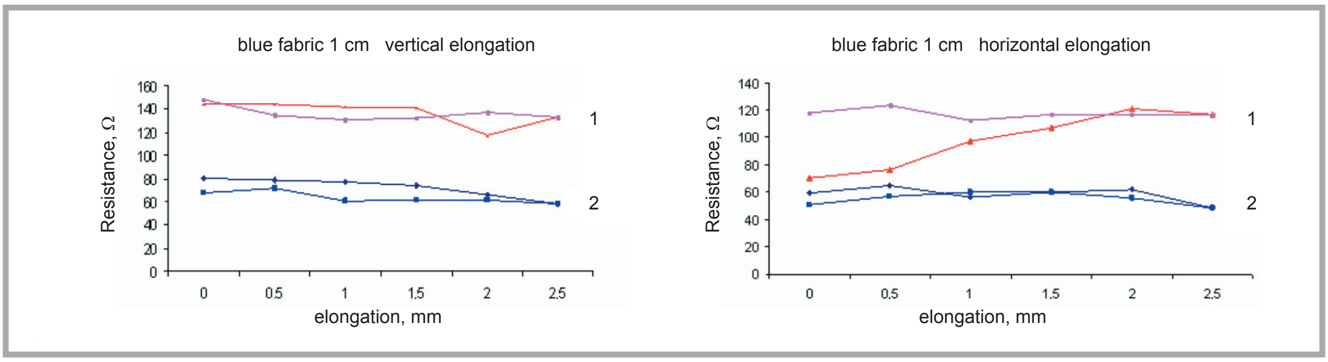

Figure 9. *Changes in resistances in warp and weft directions for sensor fabrics with leads of 1 cm; (1) resistance change in warp direction, and (2) resistance change in weft direction.*

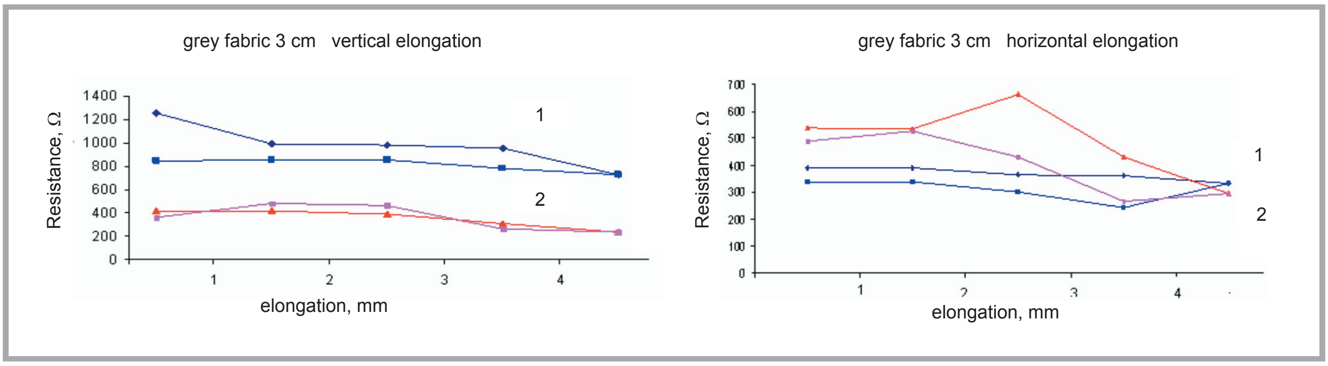

Figure 10. *Changes in resistances in warp and weft directions for sensor fabrics with leads of 3 cm; (1) resistance change in warp direction, and (2) resistance change in weft direction.*

The results received for the knitted sample with conductive yarn stripes are presented in Figure 7.

A very important problem is the method of connection between conductive yarns and the measurement device of the electrodes, because the resistance of connection points between the yarns and connecting wires are of essential importance. In the work presented, the authors used electro-conductive glue (based on silver) to join the copper surfaces with yarns, as it has high conductivity.

Figure 8.a presents a spatial net of elementary resistances between the points of contact in the structure of the knitted loop. An equivalent scheme of this phenomenon presents Figure 8.b, where the resistances of connection points $Rc_{i,j}$ are variables (i, j are the values of wale and course for each particular point of contact), $Rs_{i,j}$ is the resistance of the top of the arc. We assume that the alternative resistance of the sensor will be a combination of each yarn's points which build the knitted loop.

The dependence of the change of the warp and weft resistance for the sensorial fabric with lead at the length of 1 cm and 3 cm, for elongation in weft and warp direction is presented in Figures 9 and 10.

The knitted sample, with the inclusion of optical fibres, was subjected to static elongation. The results are presented in Figure 11. The changes of voltage on the amplifier were recorded, where upon input a photodiode lit by an optical fibre was connected. The static deformations of the sample tested were characterised by a linear dependence, which is certainly an advantage for the knitted sensor fabric.

The sensor fabrics were stretched with an Instron tensile tester. The resistance change of the sample at a 2 cm distance was also recorded. An equivalent electrical scheme of the sensorial material with

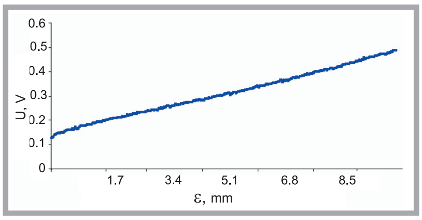

Figure 11. *Changes of the photodiode voltage, for an electronic system with optical fibre; U - voltage, ε - elongation.*

a measurement scheme is presented in Figure 12, where: U_s - voltage on R_s, resistance R_{c1}, R_{c2} - connection resistance, R_s - sample resistance, R_a - additional resistance.

The following dependences are valid:

$$R_s = \frac{U_s}{I}, \quad I = \frac{U_a}{R_a}, \quad R_s = \frac{U_s \cdot R_a}{U_a}$$

The results of resistance change for warp and weft directions under vertical (warp) elongation for the woven sample are shown in Figure 13.

Recording breathing frequency

The last and main part of our research was, on the basis of the tests carried out, to select the fabric most suitable for biomonitoring from all the fabrics studied. The sensor fabric selected was used for breathing frequency measurements. We decided to use the knitwear sample with electro-conductive yarn because of its good elastic properties and relative facility in connections between the fibrous structure and the electronic elements. Although these materials are characterised by large changes in resistance under the influence of small deformations, we hope for an intensive development of sensor materials with the use of optical fibres.

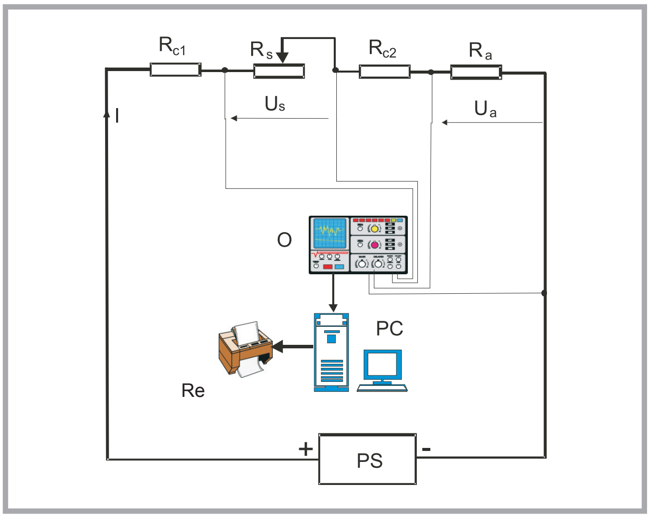

Figure 12. Scheme of a laboratory stand to measure the resistance changes during continuously elongation of the sample; PS – power supply, PC – computer, O – oscilloscope, R_{c1}, R_{c2} - connection resistance, R_s - sample resistance, R_d - additional resistance, Re - recorder.

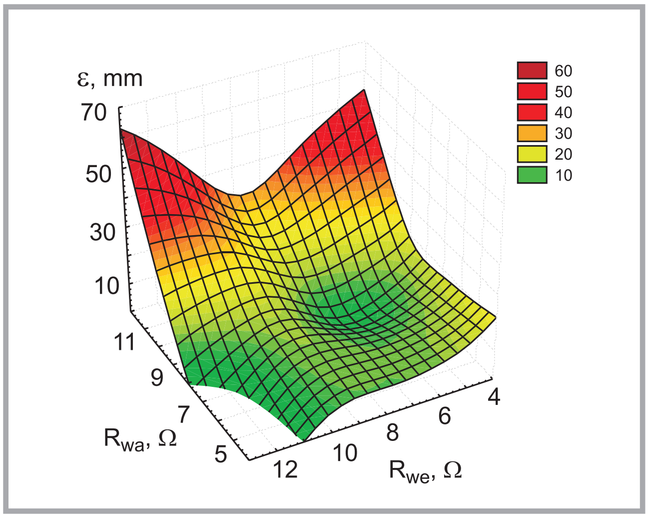

Figure13. Changes of the resistance in warp and weft direction; R_{we} - resistance in weft direction, R_{wa} - Resistance in warp direction, e - elongation; the shodes at the right side of the drawing mark the elongation values .

Detailed investigations must also be continued in the light of the possibility of damage during technological processes.

The prototype of the textile sensor we created has the form of a belt with elcro-fastenings, and girds arround the patient's chest. The sensor is shown in Figure 14a. The results received of breathing rhythm in a rest state and at medium effort for different persons of different ages are shown in Figures 14.b and 15.

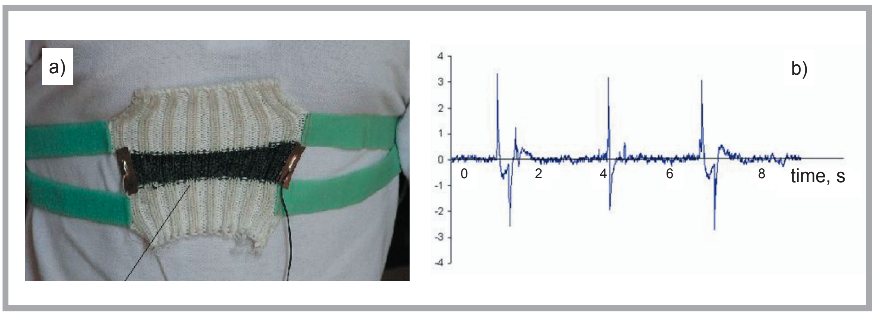

Figure 14. Recording of human breathing; a) textile sensor in the form of a belt fostened arround the patients chest, b) a record of the breating rythm.

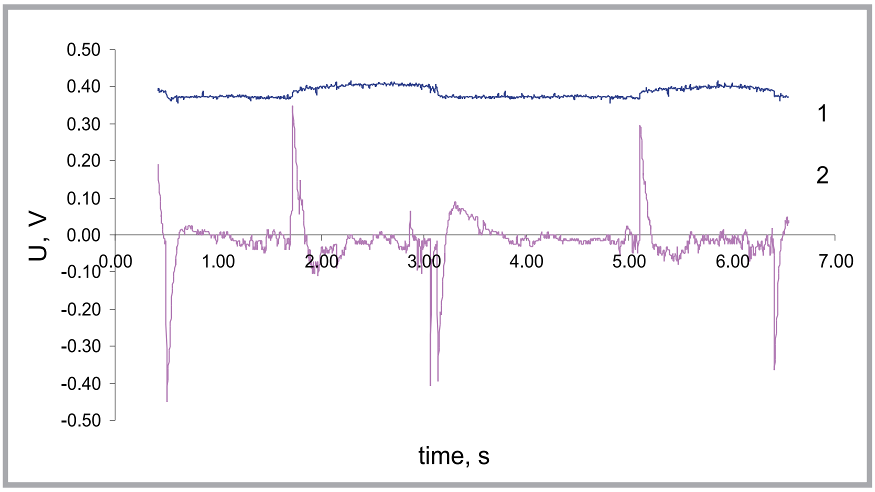

Figure 15. Characteristic of the breathing rhythm on the output of the sensor (output of a direct current amplifier) and input of the alternating current amplifier (1) and on the output of the alternating current amplifier (2).

Conclusions

1. The problem described plays a significant part in research into monitoring of human physical parameters.
2. The problems are of current importance and are being examined by different research centres all over the world.
3. The authors focused on the use of specified fabrics as textile sensors. Initial research into sensory materials were carried out, which gave us the opportunity to present the results obtained from sensors devoted to measuring breathing frequency.
4. Modern electro-conductive textiles were used to construct textile sensors characterised by the changes of resistance under deformations. A very important problem, which needs special attention, is the influence of resistances of the connection points on transmitting signals from textile sensors.
5. The authors have stated that electro-conductive polymer yarns and metallic yarns may be useful in designing textile sensors for breathing frequency measurements.
6. An effort was undertaken to use optical fibres as textile sensors for the measuring breathing rhythm.

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