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Noninvasive, Wireless Textronic System to Breath Frequency Measurement

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***Abstract*—**In this paper authors presented the research of textile electroconductive materials, which can be used to construction sensory textronic shirt to breath frequency measurement.

The full paper also will present results of measurements carried out on unique measurement stands.

***Keywords*—**Electroconductive fibres, textile sensor, textronic, respiratory rhythm measurement.

I. Introduction

BREATHING is a term commonly used with reference to the following two stages: external respiration - the transport of oxygen from the environmental air and the transport of carbon dioxide outside of the body; and internal respiration - the exchange of oxygen and carbon dioxide between blood or lymph and cells.

The first of the processes mentioned above includes the following stages: pulmonary ventilation, gas exchange between the alveoli and blood, gas transport through blood from the lungs to the tissues and from the tissues back to the lungs.

The ventilation of lungs provides gas exchange, where the air is exchanged between the pulmonary alveoli and the environment. The process occurs as a result of the respiratory movements of the rib cage, known as inspiration and expiration.

The first one is an active process, in which the contraction of the diaphragm muscle and the external intercostal muscles occur. The diaphragm contraction is responsible for increasing the superior-inferior thoracic volume, whereas contraction of the external intercostal muscles (with their insertion on ribs I-IV) for increasing the anterior-posterior thoracic volume (moving sternum away from the spine) and contraction of external intercostal muscles (with their insertion on ribs V-X) for increasing the transverse thoracic volume.

The volume of the rib cage increases the most in the superior-inferior dimension due to contraction of the diaphragm muscle. The movements of the diaphragm are responsible for 75% of thoracic volume changes during quiet inspiration. The range of the diaphragm movements vary between 1.5 cm and 7 cm during deep inspiration. The movements of the rib cage as well as the increase of its volume provide the lungs volume increase and the insertion of a certain amount of the air from about 500 ml during low breathing rate to about 4000 ml during maximum breathing rate. The respiratory movements of the rib cage as well as the pulmonary volume depend on many factors, such as age, gender, height, weight, mobility and elasticity of the rib cage walls, elasticity of the pulmonary tissue and achieved training intensity of the body. During inspiration, the pressure in the respiratory tract is about 2 mm Hg lower than the air-pressure, whereas during expiration, it is about 2 mm Hg higher than the air-pressure, what induces the movements in the respiratory tract. The simplest way to measure the respiratory mobility of the rib cage is a circumference measurement technique, where the mobility depends on the factors previously mentioned. Rib cage expansion for healthy adults equals from 5 to 8 cm. Lower values of rib cage expansion, with the thoracic circumference increased, are common for pulmonary emphysema, bronchial asthma and chronic pulmono-cardiac syndrome. For adults, the average chest circumference is about from 1 to 3 cm bigger than half of the body. The measurements of the thoracic volume are conducted with the use of tape-measure with centimeters scale, on the level of a patient's nipples and interior angles of the scapula. The normal rate of breathing is about from 16 to 18 inspirations per minute, the respiratory movements are regular and rhythmic. In the physiological conditions, the inspiration lasts from 2 to 3 times longer than the expiration. During sleep, due to the decreased excitability of the respiratory centre, a state of abnormal pauses of breathing, known as apnoea may be achieved. This state can last minimum 10 s, and may occur no more than 10 times a day. Abdominal breathing (diaphragmatic) is common for men, while chest breathing (thoracic) for women. During sleep, chest breathing is dominant for both, women and men. For different functional states of human body, breathing as well as mobility of rib cage depends on many factors. In both, normal physiological state, for example increased physical activity and pathological state, such as metabolic acidosis, breathing can be modified.

Basically, respiration is controlled unconsciously by the respiratory centre in the medulla oblongata. Conscious control of breathing is also possible. It takes place when nerve impulses are sent through the corticospinal tract to the respiratory muscles, directly from the cerebral cortex, omitting the respiratory centre. There is a wide range of research methods to study respiratory system, to begin with spirometric methods, gasometric or those based on biomechanics of respiration. Also, the study based on monitoring the thoracic mobility and recording respiration seems to be of great importance. As yet, there are not any devices available to record the mobility of rib cage in a continuous and non-invasive way. However, the attempts of elaborating such

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sensors and measuring instruments are a very interesting problem. The use of sensors measuring thoracic mobility, in textronics seems to be even more interesting. Its insertion into textronic clothing will allow to continuously register respiratory functions (rib cage movements, its amplitude) in different conditions of human body, such as physiological (e.g. exercise) as well as pathological (e.g. monitoring the sleep apnoea). The right connection of the sensors with the monitoring devices can be used in recording life conditions of human body [1, 2].

II. Textronic Sensors to Breath Frequency Measurement

The rhythm of breathing can be measured using T-shirts, where textile sensors are placed. The textronic shirt is fitted to the human body and deforms under the influence of breath. The authors have developed several versions of textronic sensors for the measurement of respiratory rhythm [3, 4]. Photoelectric sensors have been developed for the clothing construction, which uses optic fibers, piezoelectric fibers and resistance fibers.

A. Optical Fibers Sensors

Two types of optical fiber sensors are elaborated. The flux modulation is transported inside the optical fiber sensors. The first variant of sensor consists of two optical fibers, which are optically coupled diode LED and illuminating photodiode FD. In the first sensor light modulation is caused by changes radiation intensity which is resulting of change the distance between the ends of the optical fibers in the sensorial head during the movement of the chest, Fig. 1. Sensors are placed on the chest [5, 6].

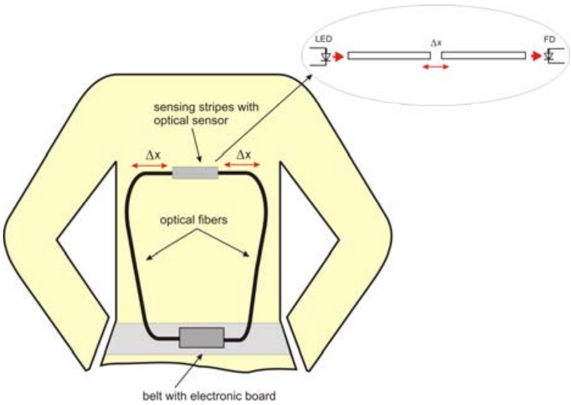

Fig. 1 Optical fibers sensors to breath frequency measurement [3]

The Fig. 2 presents recorded breath signals using textronic shirt.

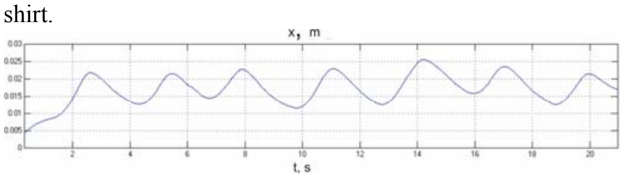

Fig. 2 Example of a breathing rhythm waveform: quick breathing

Optoelectronic sensor elements are: light emitting diode LED and photodiode FD and optical fiber. The LED lights on the beginning of optical fiber and the end of it illuminates by the photodiode. In second variant fiber is spirally arranged in clothing structure. Deformation of fiber causes a modulation of the transmitted light Fig. 3.

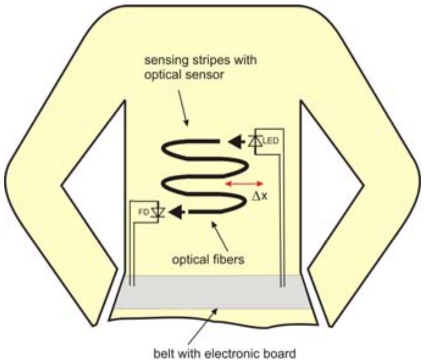

Fig. 3 Optical fibers sensors

Fig. 4 Knitted shirt with optical fiber sensor

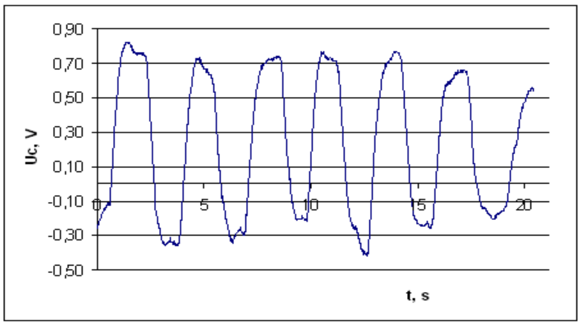

Fig. 5 Example of a breathing rhythm waveform, quick breathing [6]

B. Piezoelectric Sensor

Piezoelectric polymeric material was used to construction of breath rhythm sensor [8]. The sensor was connected to the amplifer, filter circuit, made by Department of Clothing Technology and Textronics. The first layer (1) of the inner electrode is made of semiconductor polymer; the second layer (2) was created from polyvinylidene fluoride (PVDF).

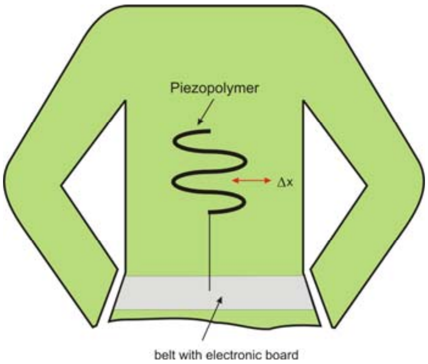

Fig. 6 Piezopolymer sensor in textronic shirt structure

The shirt with piezopolymer sensor is presented in Fig. 7.


Fig. 7 Real photo of knitted shirt with piezofibers sensor in sensory shirt

The Fig. 8 presents waveform recorded from piezoelectric breath rhythm sensor.

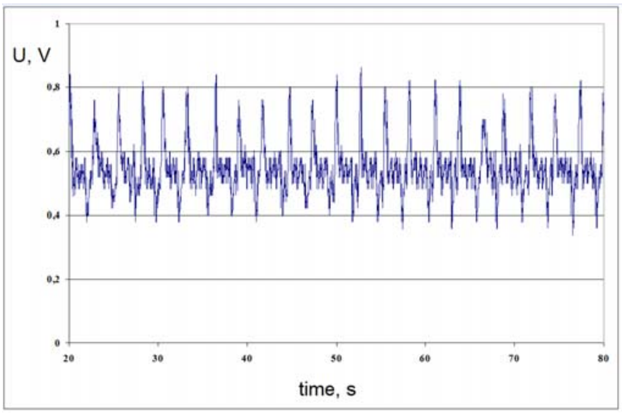

Fig. 8 Example of a breathing rhythm run: quick breathing [7]

C. Resistance Sensor

The resistance sensor [9, 10] is another type of sensor used to breathe rhythm monitoring.

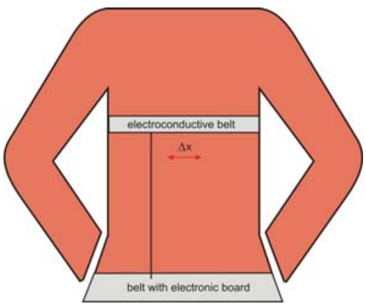

Fig. 9 Resistance sensor

III. Technological Approach to Design of Textronic System For Breath Monitoring

The aim of this research was to extend the functionality of traditional clothing with new functions that have not seen in conventional clothing solutions yet. Taking into consideration the fact that clothing is directly connected with the human body, attempts have been made to construct a textile clothing interface which adds a new function – interactive adaptation for external impulses.

Prototype of a textile breath rhythm sensor has already been elaborated [5] using the concept of mass-customization. This conception is suited to individual user preferences and follows the existing trend of manufacturing textronic clothing.

Particular stages of the design process, presented in fig. 10, are the following: identification of functions of newly created clothing, adjustment of the clothing and user by scanning the figure, and the design of clothing with the use of specialised software. The production process was performed on numerical knitting machines, obtaining a knit and wear clothing product. The whole process ends with verification tests of the textronic system [10].

T-shirt made using clothing technology. All dimensions necessary for construction obtained from 3D body scaner.

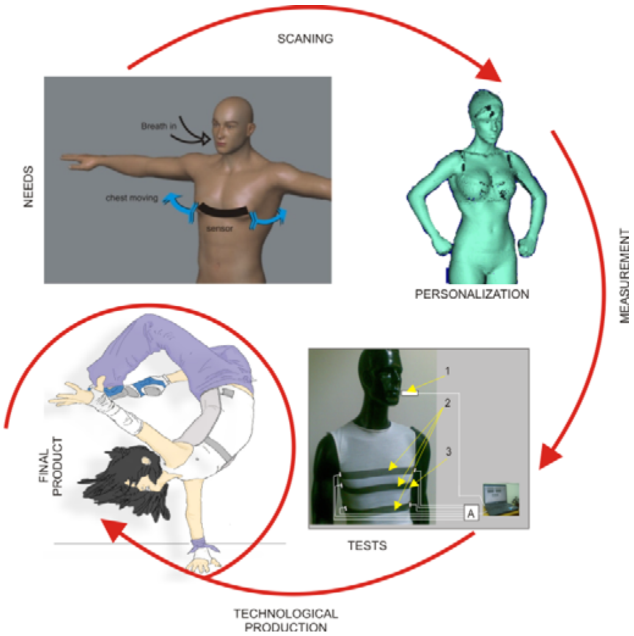

Fig. 10 Simplified scheme of the technological process of producing textronic clothing products to monitor the frequency of respiratory rhythm.

IV. Structures of Textronic Clothing

The volume of the chest changes during a respiratory cycle due to an increase in the three main dimensions: anteroposterior, transverse and vertical. The purpose of research was to determine the exact dimensions of human silhouette in order to design a T- shirt with implemented electroconductive sensors. The close fit shirt construction is necessary condition to proper work of textronic system.

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The 3D body scans of postures were performed in TUL. Measurements were taken in two different body positions and at two different respiration phases (inhalation and exhalation). Specialized software recorded over 140 dimensions. The chosen received result for one of volunteer presents Table I [12].

TABLE I
THE DIMENSIONS OF MAIN BODY ARTS FROM THE SCA

	P_{max}, Inhalation, cm	P_{min}, Exhalation, cm
Upper Chest Perimeter, cm	94,1	92,0
Band Size, cm	77,1	74,0
Waist Perimeter, cm	72,8	71,8
Stomach Perimeter, cm	86,2	84,7

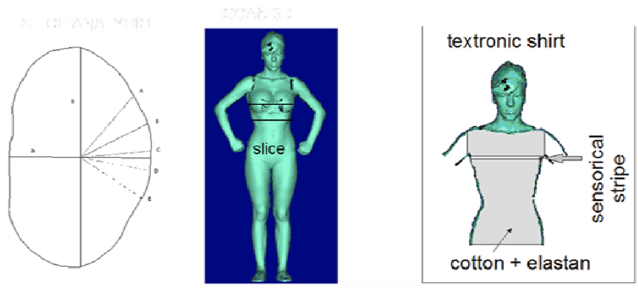

Fig. 11 The example of body scanning and the project of textronic shirt, slices analysis

The determination of exact dimensions (especially P_{max} and P_{min}) of the body is necessary to the precise locations of textile sensor. An Electroconductive yarn was used to sensors production. The properties of these kind materials can be determined by resistance or conductivity. The substitute scheme of multifunctional yarns presents Fig. 12 A.

A

B C

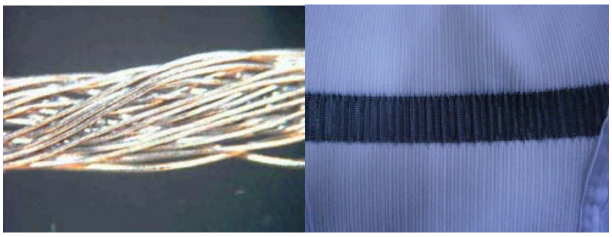

Fig. 12 Substitute scheme of multifunctional yarns, sensor's base material (A); The sensor construction in clothing structures (B); the microscopic photo of electroconductive yarns (C)

An example of real photo of textronic sensor and base material, electroconductive yarns presents Fig. 12 B and C. Stoll flat knitting machines was used to the production of this sensor.

The block scheme of electronic system connected to textile sensor is presented in Fig. 13.

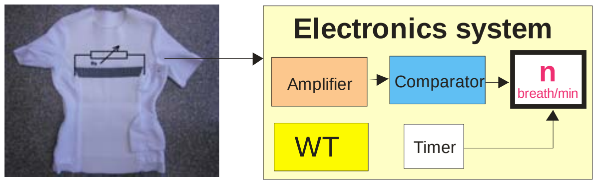

Fig. 13 Block diagram of a system for measuring respiratory rate

Wireless technology is necessary to send data from breath rhythm sensor to outside shirt.

Furthermore, the use of wireless technology allows the efficient and fast performing measurements on a large population of people.

There are many possibilities of using wireless technologies such as radio connection [14, 15, 16], inductive coupling [18], ultrasonic link [17] and infrared [22].

There are many wireless technologies that could be used to transmit information from the textronic system [13] which is a knit shirt with a belt made of electroconductive fibers. On the basis of earlier comparative studies between different techniques [20, 21, 22] found that the most suitable for the described application is radio technology.

Put some assumptions is needed in order to select the appropriate technology. First of all, determine the distance between the transmitter placed in a shirt and a signal receiver connected to the computer. Distance from 1m to 1 km is sufficient in the laboratory or open space where physiological parameters can be tested during physical activity. Then you take into account the visibility of the transmitter and the receiver. The next step is to determine the maximum rate of transmission of signals from the textile belt to your computer. It is assumed that the measurement takes place every 1 second.

There is a lot of radio techniques available in the market that differ frequency band, maximum radiated power, maximum radio baud rate etc. The most popular wireless technologies are GSM, TETRA, WiFi, Zigbee and ISM 868MHZ. Criteria of selection appropriate wireless technique are following:

- regulations of country affected of frequency bands without license,
- appropriate frequency,
- maximum power of signal for given frequency band,
- maximum radio baud rate transmission that it is used by devices of wireless technique,
- security of transmitted data,
- possibility of battery supply,
- availability of devices in modular form,
- kind of transmitted data, for example video, audio or text files,
- maximum number of devices working in area of one system,
- possibility of work of system when base station is damaged,
- cost of system [16].

The radio modules for 868 MHz frequency was chosen using above mentioned criteria because they work in unlicensed band, maximum radiated power of transmitted signal is 500 mW and therefore maximum range is 4 km in line of sight of transmitter and receiver. These radio modules enable easy enlargement of system, communicate with computer using RS-232 interface, can be supplied from battery, don't require communication with base station and have maximum radio baud rate up to 38,4 kb/s [15]. The block diagram of system for testing radio link using 868 MHz modules is presented in Fig. 14. The breath rhythm sensor is connected to amplifier. Voltage signal is fed to microcontroller. The microcontroller prepares data to transmission via radio transmitter. The transmission between microcontroller and radio transmitter is realized by UART interface. Measurement data is transmitted from smart clothing to radio receiver placed in monitoring station.

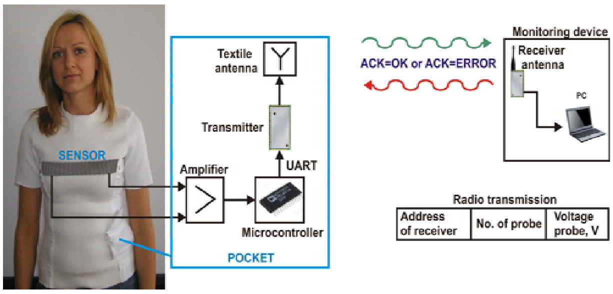

Fig. 14 Wireless system to breathe rhythm monitoring

This data is displayed in software created in Delphi environment. Format data of transmitted signal is following: address of receiver, no. of measurement and voltage probe. Research was carried out in different direction in respect of monitoring station, in neighborhood of buildings, trees and tramway lines. When transmitted frame was correctly received, receiver transmitted back ACK=OK and transmission was continued. If ACK was equal ERROR, the transmission was broken and transmitter resumes the signal. Permanent breaking of transmission specified point of maximum distance in appropriate direction. Gain of used antennas was 1dbi. Results of distance tests were following:

- North – 446 m,
- South – 918m,
- West – 418 m,
- East – 272 m [21].

Neighborhood of high buildings and small gain antennas influence on values of maximum distance.

The prototype of textronic shirt with one sensorial stripe (textile knitted sensor) present in Fig. 15.

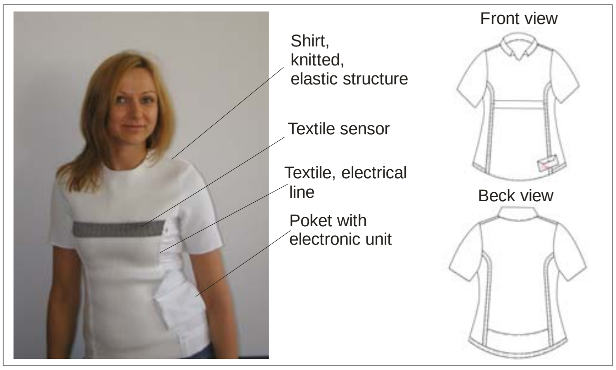

Fig. 15 The real photo of textronic shirt to breath frequency measurement

The last part of technological process of producing textronic shirt for monitoring the frequency of respiratory rhythm ware real tests. The example course presents Fig. 16. The chosen characteristic corresponds to 18 breaths per minute.

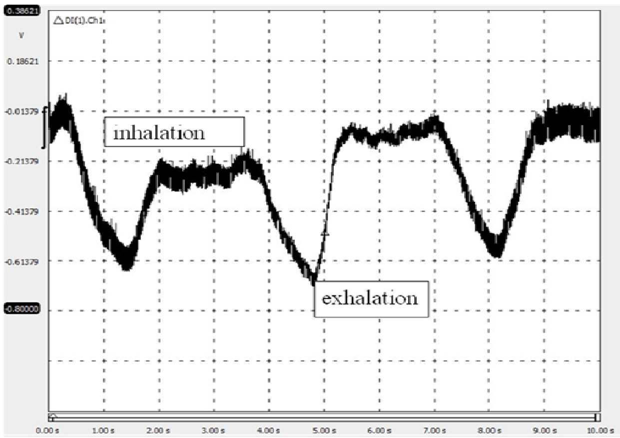

Fig. 16 Example of results obtained in the measurement of Sensor Resistance in the T- Shirt in relation to breathing rhythm

V. Discussion and Conclusion

The construction of textronic products requires changing the prevailing mentality of manufacturers of specialised clothing. First of all, the production of this kind of product requires the cooperation of a few branches of industry (textile industry, electronics, medicine), which means an increase in the expenditure of companies in order to change their production systems and develop technological lines. However, it seems as if continuous technological progress will force this kind of course of the development of the modern textile industry. Modern clothing with sensory characteristics is a new specialisation being developed at the Department of Clothing Technology and Textronics.

The textronic sensor described integrated with clothing allows to monitor the breathing rhythm frequency and can be inserted in different types of apparel (shirt or blouse).

The advantage of the sensors discussed is that they do not interfere directly with the human body and their textile form does not cause discomfort of use.

The textronic sensor for measuring the respiratory rate described can be applied in many different products due to its fibrous structure and elasticity. The sensor has a linear static characteristic. The tests performed showed that the sensor works correctly, as the output voltage of the sensor followed changes in its deformation. Moreover the real measurements of the respiratory rhythm using the test shirt confirmed that it works correctly.

Scanning of human postures is the modern method of designed the textronic clothing with textile sensors. The knowledge obtained in this experiment would be helpful in further analysis of the investigated material with textile sensor.

Authors also concluded that it is possible to manufacture a textronic sensor in clothing structures (shirt) to control of human breathing.

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