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NEW DIRECTIONS OF INTEGRATION OF DIFFERENT DISCIPLINES OF SCIENCE AS ILLUSTRATED BY THE EXAMPLE OF TEXTRONICS

Abstract
Textronics is a new field of knowledge, created by the intensive development of the textile technology and fabric construction, as well as by the ever-expanding scope of electronic system applications. The article presents the completed textile industry projects, as well as proposals for new solutions that can enrich the range of intelligent clothing, in order to improve functionality of attire and its comfort of use. The focus was on the use of flexible temperature sensors and the use of flexible photovoltaic cells.

Key words
textronics, electronics, textile industry, automation, metrology, informatics, textile industry technology, fabric construction, electronic systems, textronic products, smart formulated products, smart protective products

Introduction
Textronics is a new field of knowledge that has emerged from such fields of science as electronics, textile industry, automatics, metrology and informatics. [60] It was created by the intensive development of the textile technology and fabric construction, as well as by the ever-expanding scope of electronic system applications.

Textronic products
Textronic products integrate miniaturized electronics and specialized electronic systems with fabric into one functional unit. Its typical applications include smart formulated products and protective products, which do not differ much from usual outfits at first glance. However, after careful observation, everyone can notice the integrated sensor networks, linked to electronic control systems for internal and external parameters of the attire, which can significantly improve functionality and improve its protective parameters[61]. An exemplary textronic product is presented in Figure 1.

Figure 1. Intelligent fireman's outfit Four areas of innovation.
Source: http://www.slipperybrick.com/2008/01/firefighters-sensor-jacket/

The textronic product shown above is equipped with a set of sensors that monitor the physiological parameters of the user and the environment in which the rescue action is conducted. The most commonly used sensors detect internal and external temperature, pulse, and the presence of harmful gases. For proper operation of such a system, it is necessary to use appropriate power supplies for certain sensors and microprocessors. The simplest

[60] K. Gniotek, Z. Stempień, J. Zięba, Tekstronika – nowy obszar wiedzy, „Przegląd Włókienniczy" 2003/2.
[61] W. Bendkowska, Tekstylia inteligentne – przegląd zastosowań, „Przegląd Włókienniczy" 2002/8.

and cheapest option is to use reusable, rechargeable batteries. The operation of such a battery can be divided into two cycles:

- charging, during which electricity is transferred to the interior of the battery in which it is transformed into chemical energy;
- work, during which chemical reactions take place inside of the battery, resulting in the gradual discharge of electrical energy. [62]

Traditional storage cells and batteries, however, are quite large in size, which greatly aggravates the comfort of use of the attire. Another disadvantage is the ability to discharge during the action conducted, which interrupts monitoring and control of the currently measured parameters. The shortcomings of batteries have initiated a number of Fibrous Power Supply (FPS) research projects, which is the technology of producing fiber-based textronic power sources. FPS products should be lightweight, flexible and bear a large electric charge, in addition to being able to store electricity.

In most cases, photovoltaic elements and piezo- and thermoelectric generators are used as the power source.

In the context of the above statements, it is important to consider what might be an alternative to a typical battery capable of powering the textronic systems built into a fabric. One of the optimum choices is a flexible, thin-layer solar cell. The advantages of photovoltaic cells are:

- low-cost operation, resulting from the inexhaustible and environmentally friendly energy source of the sun
- no need for specialized system maintenance.

An exemplary flexible solar cell is presented in Figure 2.

Figure 2. Flexible solar cells.
Source: http://www.konarka.com/

The cells used in textronics must be flexible, and therefore can be produced as thin-layer structures made of amorphous silicon or polymers. One of the most important parameters of a cell is its efficiency, otherwise called conversion efficiency. It is defined as the ratio of the maximum power of a cell and the power of light projected onto a given cell, following the formula below:

$$\eta = \frac{P_{max}}{P_{in}} = FF\frac{U_{OC} \cdot I_{SC}}{L}$$

Where FF is fill factor, UOC is open circuit voltage, ISC is short-circuit current, and L is the intensity of the light projected onto the cell (radiation power).

[62] http://pl.wikipedia.org/

Silicon cells have the highest efficiency, reaching around several tens of percent. Unfortunately, their rigidity and impossibility to integrate with the fabric prevent their use in textronics. On the other hand, flexible solar cells, made of amorphous silicon or polymeric compounds, while in fact characterized by lower efficiency, have considerable advantages such as their flexibility, lightness and low cost of production, which predisposes them to textronics applications.

Applications of textronics in the design of smart attires

Modern intelligent systems designed for rescue workers and other users allow you to measure parameters such as internal and external temperature, heart rate, breath rate, blood pressure, skin moisture, and the presence of harmful gases and liquids. Knowledge of these data can significantly improve and automate the work of rescue units and doctors who, by means of continuous monitoring of patients, will be able to observe and analyze the values and amounts of selected parameters over a long period of time. Such additional information can optimize the accuracy of the diagnosis and the effectiveness of treatment of patients. Many research centers are working on the use of flexible electronics for medical safety provision purposes.

Within the framework of ten-odd Polish and international projects, constructions of intelligent clothing were developed, which were designed to increase the safety of rescue workers as well as victims of accidents. One of the projects was ProeTEX. Its main purpose was to create a safe firefighting suit equipped with a network of functional sensors that monitor the physiological condition of the firefighter. The data obtained from sensors of temperature, pressure, and harmful gases were transmitted by radio to the rescue command center. Knowledge of the health parameters of rescuers and the environment in which they work enables the supervision of correct and positive completion of the course of actions.

Another project was Healthwear, which aimed to provide continuous monitoring of the patient's health during rehabilitation, demonstrating that intelligent fabrics can be used in clothing, biomedical and technical apparel used by uniformed and civilian services[63] .

The projects cited show that the field of applications of textronics extends into other areas such as security, sports, military applications, entertainment, leisure, and civil engineering[64].

The aim of the next international project, Wealthy (Wearable Health Care System), launched in 2002, was to create a user-friendly health monitoring system using a set of smart sensors and an interface that would utilize cutting-edge data processing and transmission methods.[65] According to the assumptions of the project, the basic sensors were to be manufactured in the form of fibers, characterized by appropriate electrical properties. This project was completed with the preparation of several prototypes of clothing, one of which is presented in figure 3. It denotes the electrodes used to measure pneumography, that is, to record the breath by measuring the chest movement.

[63] P. Leitch, T.H. Tassinari, Interactive textiles: new materials in the new millenium, "Journal of Industrial Textiles", vol.29, 2000/3, p. 173-189.

[64] I. Krucińska, Diagnoza potencjału jednostek badawczo-rozwojowych i procesu komercjalizacji badań, Społeczna Wyższa Szkoła Przedsiębiorczości i Zarządzania, Łódź 2007.

[65] http://www.wealthy-ist.com

Figure 3. One of the prototypes created under the Wealthy project.
Source: R. Paradiso, G. Loriga, N. Taccini, A. Gemigani, B. Ghelarducci, WEALTHY – a wearable healthcare system: new frontier on e-textile, "Journal of Telecommunications and Information Technology" 2005/4.

Due to the growing number of cardiovascular diseases in Europe, the My Heart project was launched. Its main purpose was to design and manufacture an intelligent, biomedical outfit equipped with a sensor system, the indications of which were used for monitoring, diagnosis and treatment of cardiovascular diseases[66]. As a result of the project, underwear was created to allow precise monitoring of the cardiac and respiratory functions of its user.

In addition to the aforementioned projects, many companies also work on flexible, smart electronics. One of the most famous is Smartex, which opened its business in the late 1990s. This was the beginning of the development of the so-called smart textiles, which, in addition to their functionality, were supposed to provide security, monitor health parameters, and share the scientific achievements with a broader audience. The application of these additional electronic devices has greatly enhanced the development and competitiveness of the Italian company. As part of its R&D activities, Smartex is developing technologies for the creation of new materials that are sensitive to specific external factors to bring the finished and fully functional product to the market at the final stage. This company also deals with the coordination of scientific meetings, during which representatives of units from around the world have the opportunity to exchange their views on smart clothing[67]. Based on the above review, one can notice the very rapid development of textronics, which started thanks to international projects, motivating scientific units from all over the world to cooperate and popularize knowledge and increase the commercialization of the so-called smart textiles.

Measurement of temperature in intelligent rescue clothing

One of the most important physical parameters while fighting a fire is the temperature at which the rescue services are forced to work. Staying in rooms that are too hot may be dangerous to a human, so a very important function that a rescue service suit should have, in addition to protection from excessive temperature rise, is its continuous control, both inside and outside of the suit. Indications of sensors placed in different layers and locations of firefighters uniforms should be forwarded to the control center. Knowledge of these parameters can greatly improve the work of rescue units. In this case, the action commander is able to keep up with the work of his subordinates and keep an eye on how fast the heat penetrates the structure of the fabric while approaching the firefighter's body. This is necessary because as a result of increased temperature, a human being is not able to function normally. In addition to the general weakness of the body, dizziness, visual disturbances, and nausea may also occur, reducing the possibility of successful completion of the rescue operation. Contemporary firefighting clothing consists of three layers of materials, each of which is characterized by strictly defined parameters. The outer layer is made of the NOMEX® material, resistant to flames, piercing and tearing. The next layer is AIRTEX®, responsible for waterproofing, protection against wind and chemicals. In turn, the inner layer is made of PARALINEX®, NOMEX® and KEVLAR® materials to prevent excessive heat from penetrating the firefighter's body. The use of temperature sensors, hidden in the above layers, has not yet been implemented in commercially available suits. However, this seems necessary to improve the functionality of the fireman's suit. The task of the research group executing the Protex project was to develop flexible sensor structures designed to measure internal temperatures. Temperature sensors have been propose that are suitable for embedding into various places in firefighter suits. During the rescue operation, the measured values are sent via wireless data transmission to the control unit, which watches over the safety of firefighters at work. [68]

Textronic electronic elements as illustrated by the example of temperature sensors

The electronic components used in clothing are subjected to high demands, not only regarding the accuracy and dynamics of the measurement, but also the strength, elasticity and compatibility of the fabric. In order to develop a complete temperature sensor design, commercially available integrated circuits and experimental analog sensors were used. Innovative research was also carried out, leading to the identification and optimization of the utility parameters of the sensors, as well as the circuits made on flexible bases and covers for garment applications. The circuits produced for the needs of textronics should also be as small in size and weight as possible so that their integration with the fabric minimizes the impact on the structure of the material and the

[66] http://www.hitech-projects.com/euprojects/myheart/en/objectives.html
[67] http://smartex.it/
[68] S. Bielska, M. Sibinski, A. Lukasik, Polymer temperature sensor for textronic applications, Material Science & Engineering B, vol. 165, 2009/1-2, p. 50-52.

user's comfort. [69] Because of their area of application, their important standout feature should be the increased resistance to various types of occupational and atmospheric exposure, such as humidity, bending, chemicals, and sweat.

One of the main problems concerning textronics are:
- the method of supplying textronic systems,
- the selection of data transmission,
- ensuring good contact for fiber and electrically conductive connections with a commercial or test electronic circuit. [70]

Another important matter is the proper implementation of a commercial sensor into a textile product and finding the appropriate base, compatible with the active layer, characterized by specific parameters. It is also important to provide a suitable encapsulation coating for the finished component that will protect it from the various operational exposures that result from the implementation within a textile product, such as moisture and chemical agents. From the point of view of mobile textronic applications, the less important parameters of digital sensors are their size and housing type, as well as the signal output system and their average and instantaneous power consumption during operation. Due to their comfort and functionality, such systems should, in addition to high static accuracy and good dynamics, be characterized by the smallest possible size and flexibility. [71] An exemplary digital textronic sensor is presented in Figure 4.

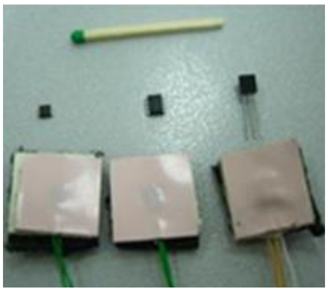

Figure 4. DS18B20 digital temperature sensors in flexible thermal conductive covers.
Source: own materials.

The sensor design shown in Figure 4 includes a digital sensor in a rigid housing (µSOP8, SOP8 and TO92), placed on a flexible printed circuit board, enclosed by a thermally conductive flexible material and insulated thermally from the outside. The parameters of the tested thermally conductive foams were selected experimentally by comparing thermal conductivity, thermal resistance, Shore hardness, and temperature resistance. As a result of these considerations, foams 86/200 and 86/255 were chosen. It is also possible to make a flexible textronic element on one's own by using screen printing technology. In this case, the base material and the composition of the active layer of the sensor should be selected accordingly. KAPTON® polyamide film with the HN higher temperature resistance version parameters has been selected as the base material for the designed sensor.

Using the described technology, functional analog sensors of the PTC type with high linearity of thermal characteristics were obtained, as presented in Figure 5.

[69] L. Michalski, K. Eckersdorf, J. Kucharski, Termometria, przyrządy i metody, Politechnika Łódzka, Łódź 1998, s. 119-121.
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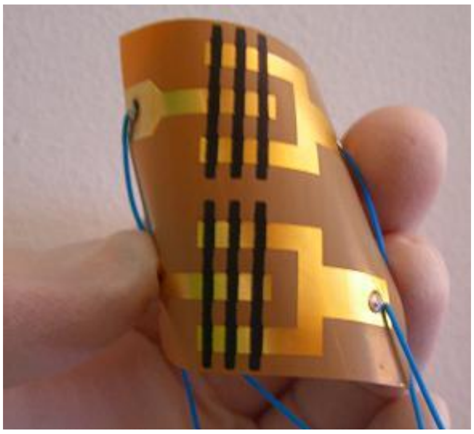

Figure 5. Flexible temperature sensor.
Source: own materials.

Conclusion
This paper presents the completed projects from the textronics industry, as well as proposals for new solutions that can enrich the offer of intelligent clothing. Replacing traditional electronic components with elastic equivalents greatly improves the functionality of the garment and its comfort of use. The use of flexible temperature sensors as elements of an exemplary smart rescue attire was presented. Commercial sensors as well as innovative flexible sensors made using the screen printing method were used. The presented sensors were practically tested and were confirmed for use in mass manufactured products. An alternative to the existing power supply systems was also proposed. It was suggested to use flexible photovoltaic cells capable of supplying the electronics embedded in the fabric, thus providing the necessary energy, as well as improving the functionality and comfort of use of the garment.

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NOWE KIERUNKI INTEGRACJI RÓŻNYCH DYSCYPLIN NAUKI NA PRZYKŁADZIE TEKSTRONIKI

Abstrakt

Tekstronika jest nową dziedziną wiedzy, powstałą dzięki intensywnemu rozwojowi technologii włókiennictwa oraz konstrukcji tkanin, a także dzięki stałemu poszerzaniu się zakresu zastosowań układów elektronicznych. W artykule zaprezentowano zrealizowane projekty z branży tekstronicznej, a także propozycje nowych rozwiązań, mogących wzbogacić ofertę inteligentnej odzieży, w celu poprawy funkcjonalność ubioru oraz komfortu użytkowania. Skupiono się na zastosowaniu elastycznych czujników temperatury oraz zastosowaniu elastycznych ogniw fotowoltaicznych.

Słowa kluczowe

tekstronika, elektronika, włókiennictwo, automatyka, metrologia, informatyka, technologia włókiennictwa, konstrukcja tkanin, układy elektroniczne, wyroby tekstroniczne, inteligentne wyroby użytkowe, inteligentne wyroby ochronne