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The Basic Problems of Textronics

Abstract
This article describes the problems of a new branch of science designated as 'textronics'. This notion means a new interdisciplinary, common scientific branch created by the synergic connection of the three following disciplines: textile science, electronics, and computer science. Examples of fibrous sensors are presented against the background of problems connected with processing measurement signals. The weight of construction and the application of fibrous actuators is emphasised in the perspective of designing textile automatic control systems. Three basic means used for connecting electronic elements with textiles are characterised.

Key words: *textronics, textiles, electronics, informatics, smart textiles, wearable electronic, COMETMAN, fibrous sensors, fibrous actuators.*

Introduction

Recently, wearable electronics has become one of the forms of smart textiles, by which we understand any fibres, threads, and flat & 3D textile products which change their properties with the change of the value of various physical quantities, and in this way allow us to achieve an active realisation of the two basic textile functions: protection and decoration of humans. On the one hand smart textiles are characterised by sensorial features, and on the other they allow us to construct fibrous actuators. Such a duality of feature allows us to design a special class of automatic control systems. This opportunity, in turn, permits us to achieve active protection and monitoring of human health, as well as the user's feeling of comfort and satisfaction with the aesthetic features of the clothing. Wearable electronics aid the above mentioned possibilities by means of inserting micro- and nano-electronic circuits into the fibrous structure. The accomplishment of these functions has become possible because a new interdisciplinary, common scientific branch was created by the synergic connection of the three following disciplines: textile science, electronics, and computer science (Figure 1). This scientific branch is known specifically as textronics [1], a new field of knowledge which also include problems of automatics, automation, and metrology.

The designation 'textronics' is similar to the notion of 'mechatronics', which is a procedure of designing and manufacturing based on the synergic link of basic sciences and techniques, such as mechanics, electronics, informatics, and control science & practice. The range of activity concerned with textronics includes the design of multifunctional textile products, beginning with simple electronic devices placed in clothing, through microelectronic circuits connecting technological products with flat textiles, to fibrous electronics which used the fibres as carriers of semiconductor structures, while nevertheless not changing the fibres' spinnability.

The synergy of links between the three above-mentioned disciplines, with the new aspect of the connection of textiles with electronics and informatics, is demonstrated by the coming into existence of a new quality which action is mutually amplified by the component elements. This effect is achieved by the physical integration of micro-electronics with textile and garment constructions, which at the same time can act in accordance with a previously introduced program.

The Task of Textronics

The task of textronics is to obtain multifunctional, smart textile products of complex inert structure but uniform functional features.

Clothing of such a type takes on significant importance when the user's life is in peril. This is relevant in such situations as, for example, people with diseases of the cardiovascular systems, when continuous heart monitoring is demanded [2,3]. A system of monitoring, recording and transmitting ECG signals over radiotelephony has recently been developed in Poland. This system can be successfully modernised by the application of textile electrodes, which would contribute to the user's increased comfort , and would be willingly borne by patients. The Textrodes and Respibelt gauges developed by researchers from the University of Ghent are examples of solutions from the field of textile sensor designing [4]. The above-mentioned solution is based on the construction of an electrode in the shape of a knitted structure manufactured from metal fibres. The advantage of such a type of electrode is the possibility of connecting the electrode with the garment product thanks to the compatibility of both structures' mechanical features. The garment instrument which is thus obtained enables us to continue monitoring the user's cardiac functions without disturbing other daily activities, thanks to the electrode's direct contact with the skin. The Respibelt gauge has also been manufactured from a knitted fabric con-

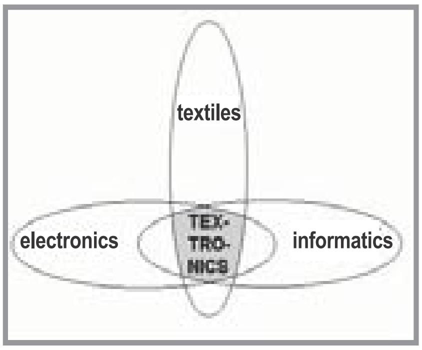

Figure 1. *Textronics as the synergy connection of three scientific disciplines.*

structed from classical synthetic fibres and thin metallic fibres which change its resistivity as a function of the field of tension. The structure manufactured is characterised by low bending rigidity, which significantly increases the user's comfort. The above-mentioned gauge prototypes fulfil a dual function. On the one hand they are a garment element, and on the other they are a part of the measuring system monitoring the patient's health. Both these gauges have been applied in baby-suits with the goal of detecting the danger of the so-called 'cot death' or Sudden Infant Death Syndrome.

Another example of an application of special sensors is the need to develop clothing for service staff and workers who are exposed during their work to the effect of elements such as fire flame, heat streams, hazardous gaseous and liquid chemical substances, electromagnetic radiation, and different biological factors. Besides its protective functions, modern clothing should also enable the identification of the hazard level at the place of action. This is especially important in all places where recording the different hazardous quantities has hitherto been impossible partly because of the diversified and changing environment conditions. One of the best examples of such a situation is the question of protective clothing for the fire service [5]. An attempt to integrate temperature gauges with clothing was commenced at the Faculty of Textile Engineering and Marketing of the Technical University of Łódź. The aim of the new design was the wireless transmission of data from the fireman to the central command point regarding the potential threat caused by too strong an impact of the heat streams. At the same time, these gauges should allow for switching on the automatic system of temperature control placed in the firemen's overalls, which should decrease the temperature in the garment layers near the skin, and prevent the formation of scaldings [6]. Professional and weekend sport is a quite different field of application for garments equipped with electronic elements, but an example of such use may be a sports shirt which is equipped with a gauge detecting the work of the heart, and a readout module placed on the sleeve. The components are integrated in the form of a wireless computer-aided measuring system [7].

The next application range of wearable electronics is a garment for mobile workers who must do their tasks during a journey. Clothing for such a person should enable office organisation by using various parts of the user's garment. An example for such an application could be a jacket [8] equipped with an MP3 player, a long-life battery, stereophonic ear- or headphones, a central processing unit, and a flexible textile keyboard (manufactured in the soft-switch technology). The future may also bring forth a textile monitor. Investigations with the aim of designing and manufacturing such a monitor have been started in France [10].

The Problems of Textronics

A new branch of science creates new possibilities, but also new difficulties. In Table 1 various quantities which should be measured are listed together with the corresponding textile sensors which are at present known and available on the world market. The term 'sensors' should here be understood to refer to devices which transform measured quantities into an electrical signal. The quantities are arranged according to the convenient COMETMAN acronym [11], which exemplifies the traditional range of quantities transmitted as measurement signals. The fibrous gauges known at present have been arranged according to the acronym denotations in Table 1. As can be seen, contemporary textile sensors such as optical fibres, devices based on the tunnel effect, and conductive fibres do not cover the whole range of the quantities to be measured.

On one hand, this gives rise to the need to use traditional gauges, such as thermistors or thermoelements, in textronics systems; on the other hand, it requires new fibrous devices to be developed which would be able to generate electric signals as a function of these quantities which hitherto cannot be transformed into electric quantities. Another solution is to furnish existing textile structures with electric outputs. This concerns devices such as certain kinds of optical waveguides, conductive threads, or gauges based on the Bragg effect. A need also arises to develop completely new gauges which could (for example) respond to changes in bio-potential, the amount of bacteria, and of viruses. All these sensors should have a fibrous form and an electrical output. It seems that polymer science is able to give the majority of answers to the questions which arise. Nevertheless additional questions arise, considering that appropriate flexibility, washing fastness, and resistance against cyclic mechanical deformations must be secured for the devices under discussion.

Similar problems are found with fibrous actuators, which should respond to the action of electrical quantities by change to their geometrical dimensions, temperature, or chemical features, while at the same time being able to directly affect textile and biological objects. From the point of view of textronics, the electrical input is the basic problem here. The actuators currently in use, for example fibres with form memory, and electric conductive fibres which can be used as heaters, must be completed by an electric current or voltage inputs. Practical realisations do not as yet exist on the world market. But at present, the Faculty of Textile Engineering and Marketing of the Technical University of Łódź has begun a research project connected with the use in textronics of fibres and membranes with shape memory. The application of fibrous structures with shape memory has special importance in the thermo- and hygro-controllability of textile products.

The availability of a full range of fibrous sensors and actuators would allow the design and construction of fibrous automatic control systems which would permit active protection of humans, and control of their life conditions in many special situations and different environ-

Table 1. *Examples of contemporary fibrous sensors listed together with the set of quantities traditional transformed in measuring systems.*

Abbreviation	C	O	M	E	T	M	A	N
quantities	chemical	optical	mechanical	electrical	thermal	magnetic	acoustic	nuclear
gauges (sensors)	chameleon fibres	optical fibres	Soft Switch	conductive fibres	Gorix	lack	lack	lack

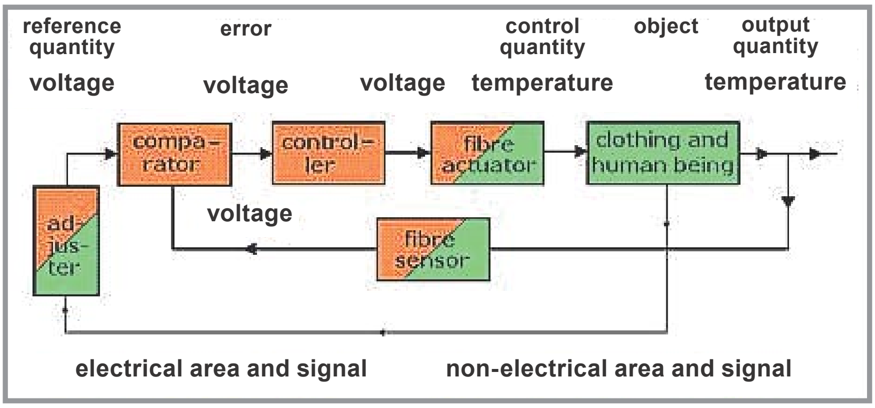

***Figure 2.** Fibrous system of automatic temperature control.*

ments. These matters are especially important when human life or health is threatened. Such a system, dedicated to temperature control in the interior of a garment, e.g. a firemen's coverall, is presented in Figure 2.

The partition between electric and non-electric signals is easily visible. The boundary goes through the adjuster, the actuator, and the sensor. At the present state of the development of textronics, the comparator and the controller must be autonomous electronic circuits. It could be expected that, thanks to the fibrous electronics further described in this paper, the above-mentioned devices will also take a fibrous form. An interesting question is the existence of two control circuits and a doubled feedback loop in the automatic temperature control system described. This results from the fact that, on the one hand, human beings have their own system of temperature stabilisation, but on the other hand they are submitted to the action of the external control system.

Independently, a given human being must be accepted as a multi-dimensional object, as he has the possibility to change the value set by the adjuster-unit. It should be emphasised that the realisation on an industrial scale of systems such as that described above, requires the development of new textile technologies; at present it would be best to base them on traditional technologies of spinning, weaving, and knitting. However, it seems that in fact the best perspectives are created by nonwoven technologies.

The solution of questions related to the transmission of measuring and control signals is a new group of tasks. Signal transmission must be carried out both inside and outside of the fibrous structure, e.g. between the smart clothing and the monitoring centre. The transmission can be performed with or without wires. As of now fibres and threads have rather a high resistance, so wireless transmission seems to be the better solution. On the other hand, wireless transmission requires aerials to be inserted into the textile structure. This would be the next task which textile technologists have to deal with. The existing transmission system with Bluetooth technology, which is ready to use, demands only an adaptation to the desired needs. Infrared links, and radiotelephony & Internet connections for transmission at longer distances can also be used. A difficult problem is the electric connection of textile elements, for example conductive fibres with electric wires. It is possible that in the future this very important question may stimulate the development of new, non-conventional manufacturing methods for textile products.

The construction of advanced monitoring and automatic control systems requires the development of new conversion methods for the transformation of measuring and control signals. This is related especially to low-frequency filtration, as the majority of processes in the textile structure are characterised by flow and creep tendencies; the frequency band is often below 10^{-4} Hz. It is very probable that filtration in the frequency domain will be impossible, and that it will be necessary to limit the quantity domain, which means the necessity of applying a result-elimination procedure (the elimination of gross errors). The existing interference signals also have another character, as in traditional control systems; the existence of signals resulting from the change of human psychophysical features should be taken into account. It should be emphasised that a human being is placed inside all clothing used, and when considering the textronics questions we should remember that the human being will be both the object and the subject of any measurement and control.

The most difficult problem with which textronics has to deal is the electric supply to the systems used. At this point in time, traditional batteries and accumulators are too large and too heavy, and they probably cannot be used in future textronics applications. On the other hand, contemporary energy sources, such as thermogenerators, piezogenerators and photovoltaic elements which are used in textile constructions, have too small values of capacity and maximum current, especially for the realisation of wireless connections. Thus, the necessity arises to develop new solutions for textile electric energy sources.

Three following methods of connecting electronic elements with textiles can be listed:

- the use of freely available electronics (FAE), which are connected by inserting such elements as closed devices in the fibrous structure;
- the application of special miniaturised constructions, for example manufactured with ASIC technology (Application-Specific Integrated Circuits), which allows the VLSI scale (Very Large Integration Scale), and their composite-like installation in the textile structure, for example between the product's layers;
- direct installation of p-n junctions on fibres (FE - Fibre Electronic).

This latter way, which is unquestionably the most interesting and promising for the future, can be realised by two methods. In the first, the fibre is treated as a carrier for the semiconductor structures (SOI: Silicon-On-Insulator), and in the second, the polymer matrices can be used for the direct realisation of p-n junctions. Contemporary literature includes information on attempts to obtain singular junctions [12]. The basic problem concerned with such junctions is their fastness against washing, ironing, mechanical stress, and other threats connected with everyday use.

Two new measuring devices, designed and constructed at the Department for Automation of Textile Processes in the Faculty of Textile Engineering and Marketing of Textiles, are examples of the application of FAE technology. One

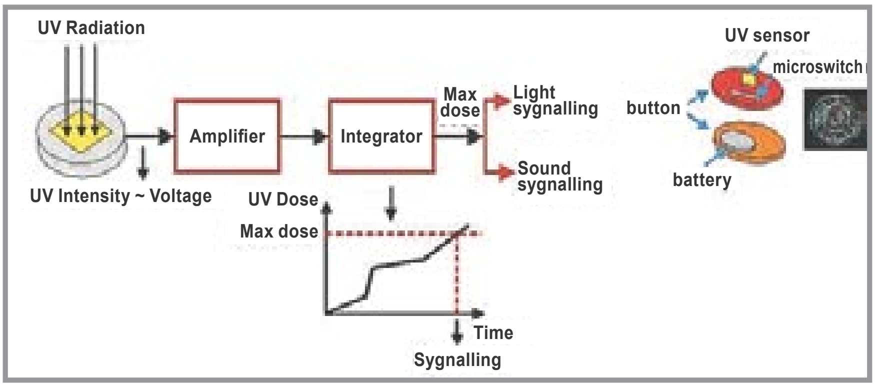

Figure 3. Scheme of the Tilmet 77 Dosimeter, instrument for estimation of the UV radiation dose.

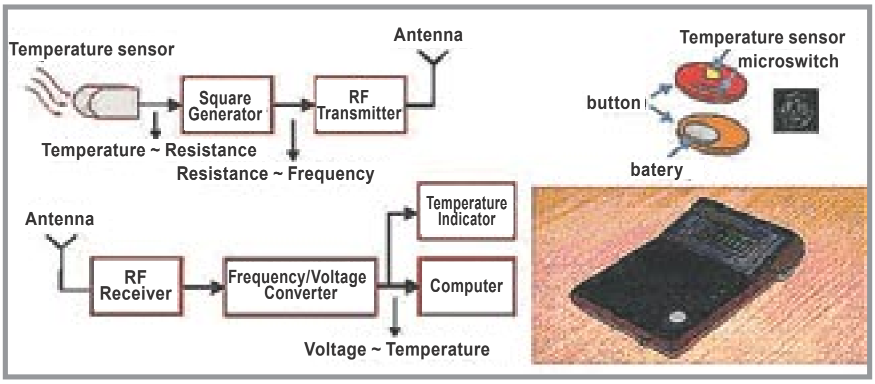

Figure 4. Scheme of the Tilmet 78 Telemetric Thermometer, instrument for remote temperature measurement of garments.

of these devices is the Tilmet 77 Dosimeter (Figure 3), a miniaturised device for estimating UV radiation doses, the other, the Tilmet 78 Telemetric Thermometer (Figure 4) for remote temperature measurement of garments. Both devices are equipped with micro-gauges of the quantity measured, which are adjusted to fit into a garment element, for example a fragment of a cap peak, a button or a zip fastener grip. Each of these elements takes over a new signalling or measuring function, and at the same fulfils the condition of multifunctionality.

Summary

The progressive evolution of textronics will unquestionably foster the development of new solutions, designs and products, and forecasting their features is very difficult at present. Thus, we should expect a need to develop new methods for estimating the functional and metrological properties of new gauges, actuators, complete automatic control systems and complete devices which together would compose sets designated as smart (intelligent) textiles. Investigations in the above-mentioned branches should lead to the elaboration of new standards and other standardisation procedures which would allow us to compare the different products within the international community. A special field of research should be devoted to estimating the resistance, fastness, or strength against threats and hazards connected with the use of textronics products. The estimation of the influence of the following influencing factors on textronics elements and systems should be considered: sweat, moisture, washing processes, temperature, mechanical impacts, repeated bending and compression, light (especially sunlight), selected chemical substances, dimension changes, creasing etc.

The most important function of textronics is to give aid to the development of smart textiles, which is proceeding in the direction of increasing human safety. The best way to achieve this safety is by early determining of threats and hazards, and effective counteraction. As typical examples should be mentioned situations connected with the professional activity of soldiers, police, fire brigades and lifeguards, as well as with the care of patients and protection of convalescents. A particular example of textronics application could be remote monitoring of a patient who is staying at home after a surgical operation, with the possibility of automatic ministration of medicine until the doctor's arrival. A broad, diversified monitoring range of working conditions and human health forms the basis for realising these functions. In addition, the importance of diversified control systems, especially automatic control systems, should be emphasised.

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Received 23.06.2003 Reviewed 10.10.2003