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Temperature Measurements in a Textronic Fireman Suit and Visualisation of the Results

Abstract
This article presents a system designed for monitoring the temperature in a textronic fireman suit. The system consists of a set of sensors placed in the suit, a wireless connection sending the data to the main computer and a visualisation system. The article also focuses on software which enables to monitor the parameters of 30 firemen. The material presented illustrates contemporary problems occurring at the meeting point of three areas of knowledge: textile engineering, electronics and informatics.

Key words: *textronic, protective clothing, fireman suit, temperature measurement.*

Introduction

In the 80s of the last century, intelligent materials were defined as materials which are able to react to external stimuli by significantly changing their properties to properly respond to these stimuli. Such a definition combines the characteristic features of a sensor, a processor and an actuator. Some special alloys such as ceramics, magnetostrictive materials and rheological liquids were then classed as intelligent materials. Apart from the term 'intelligent', another term-'smart' soon appeared, and according to Tagaki [1] it stands for materials which possess only some properties of intelligent materials- for instance sensory materials.

These terms were adopted in European terminology, and in the 6 Framework Programme of the European Union a priority topic (1.3) called 'Nanotechnologies, intelligent materials and new production processes' appeared. These facts contributed tothea dynamic development of intelligent materials, among which 'smart textiles' appeared, around the year 2000 [2]. Their Polish counterpart are intelligent textiles: multifunctional or interactive. The most important interactive textiles are fibres, electroconductive threads and fabrics, piezoelectric, magnetic, optical and electroluminescent fibres (also with Bragg effect), Shape Memory Materials-SMMs, electroactive polymers, processed textiles, textiles with metallic covers and surface modifications (plasma and UV), and Phase Change Materials-PCMs.

Smart textiles were developed simultaneously with wearable electronics, the aim of which was to place electronic devices within clothes, such as mp3s, headphones, microphones, telephones, batteries, "poma" computers and electronic systems for measuring heartbeat with an indicator placed on the wrist. The development of these constructions together with the development of interactive textiles inspired a new area of knowledge which is called textronics [3].

Textronic measuring systems is the area of textronics which is developing the fastest [4].

They are based upon one of three systems for combining electronics with textile products:
- using freely available electronics (FAE), placing them in a fibrous structure as closed devices,
- using special miniaturised constructions, for instance in ASIC technology (Application-Specific Integrated Circuits), which gives the opportunity to realise the VLSI scale and installing them inside a structure, for example between the layers of the product,
- direct installing of p-n connections on fibres (FE- Fibre Electronics) or using elastic labels (PE- Plastic Electronics).

The last method is undoubtedly the most interesting and promising one; however, the present state of technological development in Europe limits any practical applications in this area.

Despite the quick development of textronics, there are a number of limitations connected with emerging technical problems, which accompany any innovation. [5 - 8]. In the material presented, the cheapest and best known FAE solutions were used, as the project had to finish with the practical implementation of its effects.

The development of textronics in Europe is now taking place, mainly thanks to a number of projects which are realised within the scope of the 6 Framework Programme (and other projects). A few of them focus on special garments, including new generation fireman suits [9 - 11]. The project realised by the Advanced Technologies Centre - Pro Humano Tex (Łódź, Poland) aims at increasing firemen's safety, which can be achieved in two ways. One of them is to quickly inform the fireman about the external thermal hazard. Currently used suits separate the fireman from this hazard for some time, but simultaneously they make it impossible for the fireman to identify the hazard early enough. That is why the project focuses on measuring the external temperature, and when it exceeds a given value it is immediately signalled to the fireman. The second method is measuring selected physiological parameters of the fireman and sending the results to a monitoring centre situated, for example, in the fire-engine. Having analysed the physical condition of the organism, the system generates an alarm signal which is sent back to the fireman and forces him to escape. Apart from the temperature, the heart rate and immobility of the fireman are also measured in the project.

Figure 1 presents a general schematic diagram of the system. Measuring converters are placed at the selected points of the

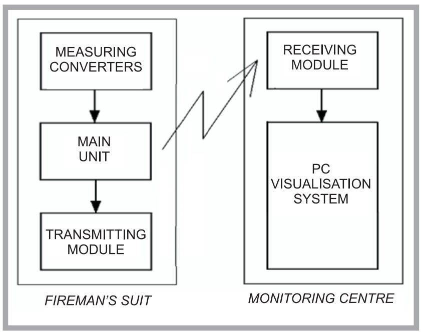

Figure 1. General diagram of the system.

suit. The main unit and transmitting module are situated in a special pocket placed in the jacket. Other elements are in the monitoring centre, where the receiving module and the visualisation system constitute one miniaturised device connected to a personal computer. The whole system works as an integrated computer system using a highly advanced language.

Temperature measurements

The system uses a number of converters-of the external temperature, internal temperature (between the clothing layers) and skin temperature (under the clothing). The converters are equipped with digital outputs of the measuring signal in the 1-wire standard. This standard is a type of an electronic interface equipped with its own communication report. The measuring data in the 1-wire standard is sent by means of one wire which is at the same time one of the feeding cables. The characteristic feature of the standard is that all the measuring converters are connected in parallel to one feeding-signal line. It considerably reduces the number of necessary connections, which is especially important in the case of devices placed inside clothing. A block diagram of the temperature monitoring system is presented in ***Figure 2***.

To make it possible to distinguish the converters which are connected in one line, each of them has its own unique 64-bit address recorded during the production process in the internal ROM memory. When the microcontroller sends the address of a given converter together with a command initiating the measuring process to the 1-wire bus, the converter starts measuring. The measuring data from the temperature converters are fed to the converter, which changes them into RS232 standard data (***Figure 2***). After the conversion the data are delivered to the input of the microcontroller, which forms them into packets, counts the control total - CRC for each packet and sends them by a ZigBee radio connection to the Monitoring Centre.

For measuring the external temperature, a special converter was designed, the block diagram of which is presented in ***Figure 3***. Due to the required range of measurements of this converter, which is -15 °C ÷ 150 °C, measurements were made on the basis of a T type thermo element (made of copper and constantan). The ends of the thermo-element are connected directly to the input of the analog - to - digital converter, which is equipped with an integrated circuit of the DS2760 type.

If we denote by:

S - the measuring span of the thermo-element, understood as the difference between the highest and lowest boundary of the measuring range,

ΔU_t - the range of changes in the voltage generated by the thermo-element within the measuring scope,

ΔU - the acceptable range of changes in the input voltage of the AC converter,

n - the number of bits of the converter.

Resolution r of the temperature measurement in the system outlined will be described by the following equation (1):

$$r = \frac{S}{Ent\,(2^n \frac{\Delta U_t}{\Delta U})} \qquad (1)$$

in which *Ent* stands for the entire operator. The denominator of the formula denotes the largest whole number of quanta used in processing the voltage from the thermo-element.

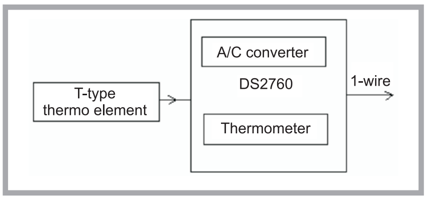

Figure 3. *Block diagram of the external temperature converter.*

As in the case considered, S = 165 °C, ΔU_t = 7.3 mV, n = 12 bits and ΔU = = 64.0 mV then r = 0.36 °C. The value is small enough to fulfil the project assumptions, which define the acceptable inaccuracy range as ± 1 °C.

Apart from the AC converter, the DS2760 system is equipped with an internal digital thermometer for measuring the temperature of the system. This temperature is treated as the temperature of the cold junctions of the thermo-element. The results of measurements of the thermo-element tension and temperature of the cold junctions are recorded in the inner memory of the DS2760 system and are automatically sent to the 1-wire bus whenever the microcontroller requires them (***Figure 3***). The microcontroller calculates the measured temperature on the basis of the voltage value and the temperature of the cold junctions of the thermocouple

The underclothing temperature converter was also made on the basis of the DS2760 system. A block diagram of the converter is presented in ***Figure 4***.

A resistance semi-conductive sensor - KTY82-150 was used to measure this

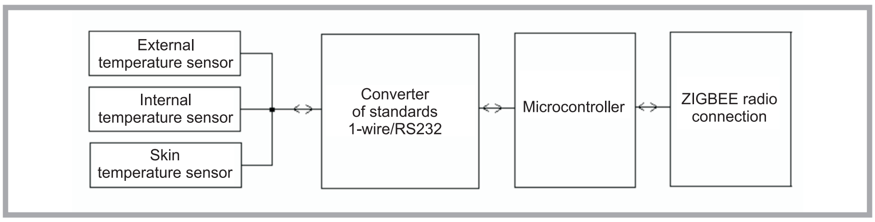

Figure 2. *A block diagram of the systems placed in the fireman's suit.*

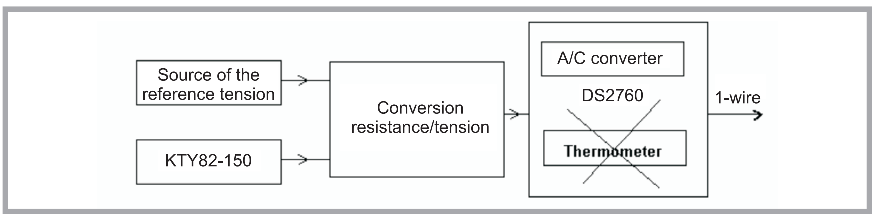

Figure 4. *Block diagram of the underclothing temperature.*

temperature. A change in the temperature causes a change in the input resistance of the sensor. The resistance changes are converted into proportional voltage changes, measured by the converter A/C of the DS2760 system, which records the results in its inner memory, just like the external temperature sensor, and sends them to the 1-wire bus when the micro-controller requires them. In this case the inner thermometer of the DS2760 system is not used.

As regards the internal temperature (between the clothing layers), type DS18B20 integrated circuits, which are digital thermometers equipped with an output of the 1-wire standard produced by Dallas company, were used. They enable temperature measurements within the range from -55 °C to 125 °C which fully covers the assumed measuring scope of the converter(-10 °C ÷ 70 °C). The maximum measuring inaccuracy declared by the producer for the temperature range of -10 °C ÷ 85 °C does not exceed ± 0.5 °C, which fulfils the project assumptions. Such a solution makes it possible to reduce the total cost of the measuring system.

The ZigBee standard

In the monitoring centre the data are collected by means of a ZigBee radio connection and then they are sent to a PC computer via a USB interface, where they are further processed. The ZigBee standard [12] governs data transmission via wireless technology, used for constructing cheap networks of wireless data transmission from measuring sensors. The standard uses the specification IEEE 802. 15.4 and operates in non-licensed frequency bands 2.400 - 2.484 GHz, 902 - 928 MHz and 868.0 - 868.6 MHz. The main advantages of the standard are low power consumption, which ensures a long running time in the case of devices fed by batteries, the possibility of having 65,000 devices working in one network, and possibility of encoding the transmitted data, which makes the information confidential.

Visualisation of the results and software

The measuring application was established in a LabVIEW environment [13, 14]. The software responsible for the visualisation of the measurements and the controlling process consists of the following panels:

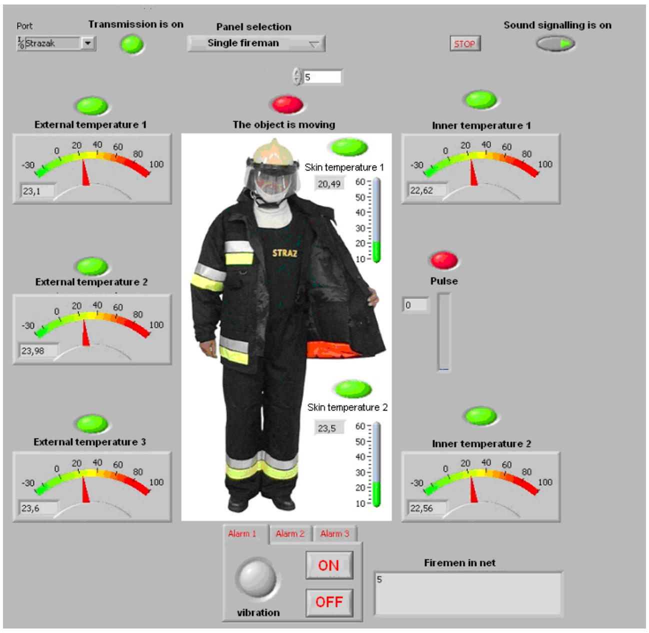

Figure 5. Panel of a single fireman-monitoring detailed data for a single fireman; external temperature measured at three points of the suit, (right-hand indicators) the internal temperature (temperature between clothing layers) measured at two points, (left-hand indicators) the underclothing temperature (skin temperature) at two points (central indicators).

1) a panel representing a single fireman (***Figure 5***); where it is possible to carefully observe all the parameters measured,
2) a panel enabling simultaneous observation of 30 objects (firemen) (***Figure 6***), which makes it possible to find out which objects are active at any given moment (transmitters switched on) and if any of the alarm scopes have been exceeded,
3) a panel for introducing values of the coefficients of approximation by the multinomials of individual sensors (in order to correct their characteristics, as sensors in different modules may have different parameters) and ranges of the alarm states (the centre program) [15].

Exceeding the acceptable range of parameters (alarm state) is signalled by a red lamp corresponding to the given parameter and by sound signalling (additional sound signalling can be switched on manually). When the measured parameter is contained within a safe range, the colour of the lamp is green. A grey lamp means that the value is inaccessible (no command has been sent)

In the panel window for a single fireman module (***Figure 5***), the following parameters are shown: the external temperature measured at three points of the suit, (right-hand indicators) the internal temperature (temperature between clothing layers) measured at two points, (left-hand indicators) the underclothing temperature (skin temperature) at two points (central indicators) and other physiological parameters. In addition to this there are also alarm buttons on the panel, thanks to which it is possible to send information to the fireman module that some param-

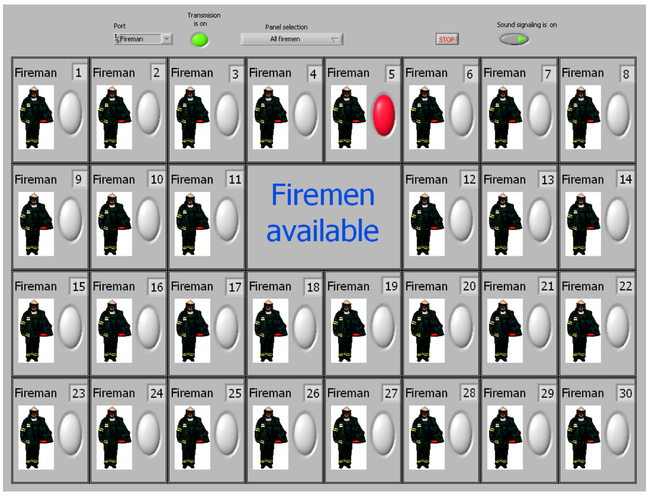

Figure 6. Panel of the centre program - all the firemen are monitored simultaneously; the pane included signal lamps for 30 firemen

eters have been exceeded (alarm state) by means of a light, sound or vibration signal.

In the panel window with 30 firemen (***Figure 6***) there is only one lamp corresponding to one person, signalling one of the possible conditions. A grey lamp means that the given module is not logged on to the network. A green lamp means that the fireman is logged on and all the parameters are OK. A red lamp means that one of the parameters has been exceeded.

The programme presented was worked out on the basis of an algorithm [16] which realizes the following operations:
- registering the incoming data,
- dividing the data into commands and checking their correctness (control total - CRC),
- recording the parameters in the form of matrices,
- processing the measurement data into real values, taking into consideration the characteristic properties of the sensors,
- correcting the processing characteristics,
- checking whether the parameters are contained within the assumed ranges,
- generating alarm signals when the assumed range is exceeded,
- presenting the results.

The algorithm also makes it possible to control the executive elements which signal the alarm states (sound and light signals).

Because of the 12 bit measurement result of the A/C converter in the DS2760 system [17], a 2-bit register was used to record it (***Figure 7***). ***Figure 7*** presents the information recorded in the form of 2 bytes, and for the address OE the oldest bit refers to the sign of the number (plus $S = 0$, minus $S = 1$); value 2^5 refers to the newest bit. In the case of the second byte, MSb refers to the value 2^4, and the newest bit is recorded under the address OF.

In the system measuring the external temperature, the voltage generated by thermo element T was measured. In order to determine the external temperature first, one has to count the difference in temperature (in degrees centigrade) between the measuring weld and the cold junction of the thermo-element according to the formula:

MSB—Address 0E							
S	2^{11}	2^{10}	2^9	2^8	2^7	2^6	2^5
MSb							LSb

LSb—Address 0F							
2^4	2^3	2^2	2^1	2^0	X	X	X
MSb							LSb

Figure 7. *Register with the recorded result of the tension measurement (S = 0 - plus value, S = 1 - minus value).*

MSB—Address 18							
S	2^9	2^8	2^7	2^6	2^5	2^4	2^3
MSb							LSb

LSB—Address 19							
2^2	2^1	2^0	X	X	X	X	X
MSb							LSb

Figure 8. *Register with recorded measurements of the reference temperature.*

$$\Delta T = 3{\cdot}10^{-20}\,x^5 - 2{\cdot}10^{-15}\,x^4 + 4{\cdot}10^{-11}\,x^3 - 8{\cdot}10^{-7}\,x^2 + 0.0259\,x - 0.0248 \quad (2)$$

Where x is the value of the voltage measured in μV. The dependence (2) was determined by the approximation method on the basis of tables [18], containing the values of the voltage generated by the thermo-element depending on the temperature. Then one has to make compensation for the cold junctions by adding a voltage value proportional to the value of the temperature (the value is recorded in the register) measured by the temperature sensor inside the DS2760 system. The sensor can measure temperature within the range of ± 127 °C; the result is a 10-bit number, and the resolution of the measurement is 0.125 °C. Two bytes are used to record the data in this case (***Figure 8***); the only difference in reference to the previous measurement is a smaller number of bits - (10) instead of 12.

On the basis of dependence (1) and the data registration method, an algorithm for processing the external temperature was worked out (***Figure 9***). All the data are gathered within a matrix, the size of which is 31X15 [19]. The number of the column in the matrix refers to the number of the object. Number 0 is reserved for the central module, other numbers, from 1 to 30, refer to the firemen. The rows of the matrix contain non-processed values of parameters for the individual commands, and they inform of the following:

Row 0 - the communication between the modules is switched on,
Row 1- the fireman's module has been logged on to the network,
Row 2- there is no connection with the fireman,
Row 3 - informs about the inner temperature for sensor 1
Row 4 - inner temperature for sensor 2
Row 5 - underclothing temperature for sensor 1
Row 6 - underclothing temperature for sensor 2
Row 7 - external temperature for sensor 1
Row 8 - reference temperature for sensor 1
Row 9 - external temperature for sensor 2
Row 10- reference temperature for sensor 2
Row 11- external temperature for sensor 3
Row 12- reference temperature for sensor 3
Rows 13, 14 - other physiological parameters.

For a given fireman module (the numbers of the matrix columns being from 1 to 30), one has to choose the proper row. For row k = 7 (sensor 1) and, respectively, k = 9, 11 for sensors 2, 3, one has to remember to successively delete the oldest bit (number sign) and then move the number by three places to the right (record in the register - ***Figure 7***). The value received should be multiplied by the coefficient 15.625, which reflects the resolution of the smallest bit. The result of the operation corresponds to variable x in formula (1). On this basis one has to count the value of multinomial (2). A detailed block diagram of the processing algorithm, including determining the temperature of the cold junctions of the thermo element in Celsius degrees, is at the authors' disposal.

Figure 9 presents a view of the panel which enables to introduce changes in the characteristic parameters of the sensors (approximation coefficients - formula 1) and their alarm ranges; thanks to which it is possible to correct the characteristics

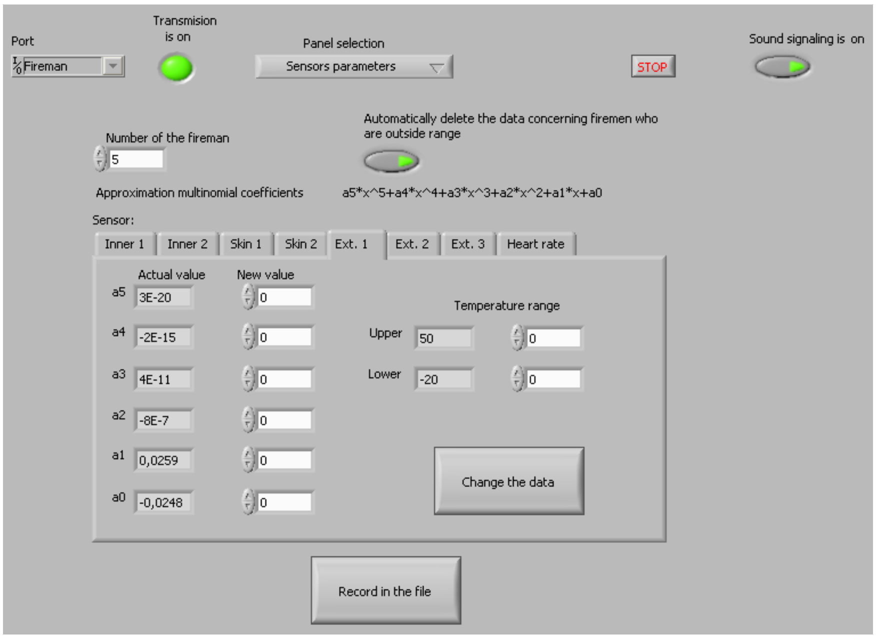

Figure 9. *Panel of the centre program- introducing coefficients of approximation by multinomial and alarm ranges for the individual sensors.*

when the sensors are changed, without interfering with the software.

Summary

The article describes a textronic measuring system constructed using FAE technology (Freely Available Electronics). The application presented can be used for controlling a multi-object system for monitoring the physiological parameters of firemen. The software created makes it possible to:

- measure the signals from several sensors for 30 fireman modules,
- process the data received into real measured values,
- choose one of the possible options of result presentation (panels for 1, 6 or 30 firemen) to put on the screen,
- introduce corrections to the sensors' characteristics and change their alarm ranges,
- receive information that the fireman is outside the network,
- send alarm signals to the fireman.

The advantage of the application presented is the possibility of measuring many parameters for many objects. The possibility of introducing correction of approximation characteristics makes it possible to use different types of sensors. Global data transmission between different fragments of the software makes it possible to minimise the size of the application and the amount of memory it requires.

The work presented documents a state of the art development in textronic measuring systems, in which textile and clothing problems appear next to electronic and software ones. The article describes an attempt to use the most advanced achievements in multifunctional textiles for protecting and monitoring the state of health of people working in extremely difficult and dangerous conditions. It seems that electronic and computer problems will appear more and more often in articles concerning textiles, as it is the latest trend in the development of advanced technologies in the textile and clothing industry.

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