

# Fundamental Aspects on Conductive Textiles Implemented in Intelligent System

**L R Manea<sup>1\*</sup>, L Hristian<sup>1</sup>, D Ene<sup>1</sup>, N Amariei<sup>1</sup> and A Popa<sup>2</sup>**

<sup>1</sup>"Gheorghe Asachi" Technical University of Iasi, Faculty of Textile, Leather & Industrial Management, Department of Engineering and Design of Textile Products, Blvd. Mangeron, No.28, Iasi, Romania

<sup>2</sup>"Aurel Vlaicu" University of Arad, Romania, Engineering Faculty, Textile Department, Romania

E-mail: lili191065@yahoo.com

**Abstract.** Conductive fibers, which are electrically conductive elements having the structure of a fiber, have a fairly long history and have been used for applications in electronic textiles as well as for aesthetics, anti-static and shielding purposes. Electrically conducting textile fibers, such as gold-coated threads, were produced in antiquity for aesthetic purposes, before the discovery of electricity, using various manufacturing methods. The textile intelligent systems, which comprise conducting textile structures (electroconducting wires or structures), present a dynamic behavior which favors the self regulation of the thermal insulation and vapor permeability with the purpose to maintain the thermo-physiological balance; the clothing assembly aims at monitoring the biologic potential, used only in critical situation (ex. accidents, falling down in a precipice etc.).

## 1. Introduction

In the eighteenth century, after the discovery of electricity, copper, iron, steel, brass, platinum, silver electrically conducting wires have been used in non-textile applications [1,2]. Fibers explicitly designed for electrical conductivity appeared in the late nineteenth century, and they were even used in textile structures, such as the electric corset which enabled the ladies to recover from different illnesses [3]. In the early twentieth century, more useful blends of electrical functionality and textiles appeared, such as the electrically heated glove for drivers, and, after the discovery and development of conducting polymers in 1977, illuminated clothing and heated clothing [4]. Modern methods to produce electrically conducting filaments comprise conductive substrates, metal wires, metallized yarns and inherently conductive polymers [1].

## 2. Main sorts of conductive fibers

In There are many types of conductive fibers:

- Substrates and conductive elements – mainly used in anti-static applications. Textile materials that conduct electricity can be produced by the polymerization of pyrrole on an appropriate substrate that provides the required characteristics of flexibility, strength and processability. Besides applications in anti-static fabrics, such materials are used in radar-absorbing products for camouflage [5]. Other approaches are to embed conducting elements strait within a fabric or yarn, or to apply conductive inks to a fabric [6] using screen printing [7].



➤ Metal fibers – which have very low electrical resistance, but also low elasticity and bending resistance. Such metal conductive fibers were woven into a fabric, producing a bus to link conventional rigid printed circuit board (PCB) electronics [8] or used in sports bra to form pulse-sensing electrodes [9].

➤ Metallized fibers – obtained from silk wound with thin gold strips [10], or adding a metallized coating directly to a core yarn. Many metallized fibers were obtained from silver-coated polyamide yarns or from polyester fibers with copper sulphide suffused to their surface [11].

Electrically conducting strips – strips of 2mm wide, containing the metal bond pads, are connected to link components and are woven in the weft direction into the textile in the place of standard yarns [12], or conducting lines are printed onto insulating plastic strips [13]. Inherently conductive polymers - conductive polymers such as polyaniline (PANI) and polypyrrole (Ppy) are used in smart clothing as sensors and actuators [14]. The electrically conducting yarns are obtained by melt spinning or a coating process [15]. PANI is one of the most promising conductive polymers for several reasons: its conductive form has excellent chemical stability combined with a relatively high degree of electrical conductivity; it can be processed in melt or solution; the monomer (aniline) is relatively cheap and the chain polymerization reaction is highly efficient.

The conductive states of polyaniline appears upon protonic doping of the emeraldine form of polyaniline. Emeraldine, which is one of three idealized oxidation states of PANi, consists of equal numbers of reduced and oxidized repeat units. One of the methods for processing PANI, without affecting the polymer structure, consists in mixing it with conventional polymers.

These blends combine the desirable properties of the two components, such as high electrical conductivity of the PANI with the physical and mechanical properties of the matrix polymer. The morphology of such mixtures has a dominant effect on their properties. The level of interaction between the PANi and matrix controls the morphology of the polymer mixture and thus, its electric conductivity.

Mixtures of PANI-based electrically conductive polymer can be obtained using conventional solution or melt processing techniques. Common polymers used for producing electrically conductive polymer nanocomposites are: polyethylene, polypropylene, polystyrene, polyvinyl chloride, polymethylmethacrylate resins, melaminformaldehyde phenol resins, epoxy and thermoplastic elastomers (polyethylene terephthalate). There are different methods for obtaining the conductive yarns:

- the SOL–GEL method, which consists in the chemical coating of different yarns (for example, polyethylene terephthalate (PET) or polypropylene (PP)) with the conductive polyaniline polymer (PANI) [16 -21];
- the melt-spinning of the polymeric composites obtained by mixing the polymers (PET or PP) with the conductive PANi polymer [22-32].
- fibers with conducting elements introduced during extrusion - metal particles and tiny particles of carbon have been used, but the method has the drawback that the physical properties of the fiber can be compromised [16].
- conductive carbon nanofibers - manufactured using a wet spinning technique based on short carbon nanotubes [33].

Less conductive fibers and textiles are mainly used in static dissipation, electromagnetic shielding [34], signal and power transfer, while higher resistance conductive fibers are used as a heating element. Their flexibility and ability to be used in existing textile represent significant advantages over the solid or stranded metal.

Conductive fibers have been used in aeronautics for shielding aircraft and light-weight, high strength specialty cables, and in medical equipment industry, for electroencephalogram electrodes. Another medical application is the strain measurement. PPy-coated Lycra can be used as strain gauge material [35]. In electronic textiles, the conducting fibers can deliver power, transport input and output signals or perform as a transducer [1].

### 3. Implementation of electroconductive textile structures in obtaining communicating clothes

#### 3.1. Smart materials

The term "smart" textiles covers a very broad range. Thus, one can talk about smart materials and smart systems, respectively. The *smart materials* are the unconventional structures capable of taking over and processing the information, then reacting specifically to external stimuli. These materials include specific characteristics of multi-functionality and adaptability, having the capacity to data processing by exclusively using the intrinsic characteristics of that respective material. The assembly of smart materials integrated at a nanomeric scale is called a *smart structure*, a structure which can unitary respond to the action of some external stimuli [36-38]. The explosion of micro/nano/biotechnologies, electronic devices, computers, communications under the form of sensors and incorporable systems has supplied the natural need of man living in permanent interaction with the environment, to increase its claims to clothes adaptable and synchronized with the individual. The new information processing systems for the choosy persons need not only to deliver information about certain conditions or interactions with environment conditions, but also to be able to feel, think and act. In the textile area, the concept of artificial intelligence can be attached to the new generation of textile fibers, of non-conventional materials (knitting, woven and unwoven fabrics) within a unitary product structure that can change some of its properties under the influence of an external stimulus, generating optimal answers adapted to each situation. A smart system is the result of assembling some active elements (attachment or integration of active particles) within a unitary product structure, to facilitate the mobile and personalized information processing, in order to offer comfort, safety or individual protection. At the same time, textiles offer large surfaces that can "host" artificial intelligence. Therefore textiles are another dimension of the artificial intelligence that can serve as a real information-processing superstructure, with the capability to feel, think and act, based on the wearer and/or environment stimuli. In other words, one considers the intelligent textile systems as products that have in their structure intelligent materials assembled within a complex structure, in order to obtain some special effects concerning their functionality under the action of stimuli. Their structure is different, depending on the intelligence degree of the considered textile system (passive or active intelligence, very intelligent) [39].

Referring to the articles of clothing, their aesthetic function was considered as the most important until recently, but its place has been taken by the functions of comfort (thermo-physiologic, psycho-sensorial), protection and availability. In a few words, the functionality got the front rank. Therefore, the user's requirements have directed specialists' concerns toward the elaboration and utilization of intelligent materials. These confer the human body good heat insulation, but the basic requirement is to ensure a body constant temperature, which is one of the conditions of preserving the wearer's disposition and moving capability [40]. Besides temperature, the characteristics of the materials and of the clothing products have also been chosen according to the weather conditions (air currents, wind, moisture etc.).

For accomplishing the integrated apparel, there have been taken into account the requirements imposed by the usage environment. The thermo-physiological comfort is provided when the inner temperature of the body is maintained at a constant value (37°C), under various environment conditions and different intensities of the effort made by the wearer. The human body is subjected, below 36°C and above 39°C, to the hypo- or hyper-thermic risk which can lead to death when the variations exceed 5° up to 12°C. The providing of the thermo-physiological comfort mainly depends on the balance between the heat produced and lost by the body and, respectively, on the equilibrium between the thermogenesis (the heat production) and the thermolysis (the heat loss). The heat exchange between the human body and the environment is accomplished through different ways, namely, conduction, convection, irradiation (thermal radiation), evaporation. The heat lost from the skin surface implies a heat transfer from the inner part of the body towards the surface, a heat transfer accomplished by the *circulatory system* in two ways, out of four, namely, convection and conduction [41]. The loss is done by evaporation (the saturation of the expired air with vapours) and by

convection (the heating of the inspired air) through the agency of the *circulatory system*. About 85% of the heat quantity is eliminated by skin through evaporation, thermal radiation, convection.

### 3.2. *Technical and constructive characteristics of communicant products*

The achieved communicating clothing is addressed to sportsmen eager to perform sports at extreme temperatures, and to alpinists. In order that the equipment should finally accomplish the conditions of maximum efficiency with respect to the wearer's protection, it is necessary that all the materials and technologies implied in equipment realization correspond to the final goal. Generally, the humidity is mostly due to the organism's reaction meant to loose the additional heat produced through physical effort, as well as to the warm and wet environment created within the under-cloth microclimate, through the utilization of ensembles that "do not breath", as they are not sufficiently permeable to vapors.

The electronic systems for monitoring the user, accompanying the conductive structure, can include the following parts:

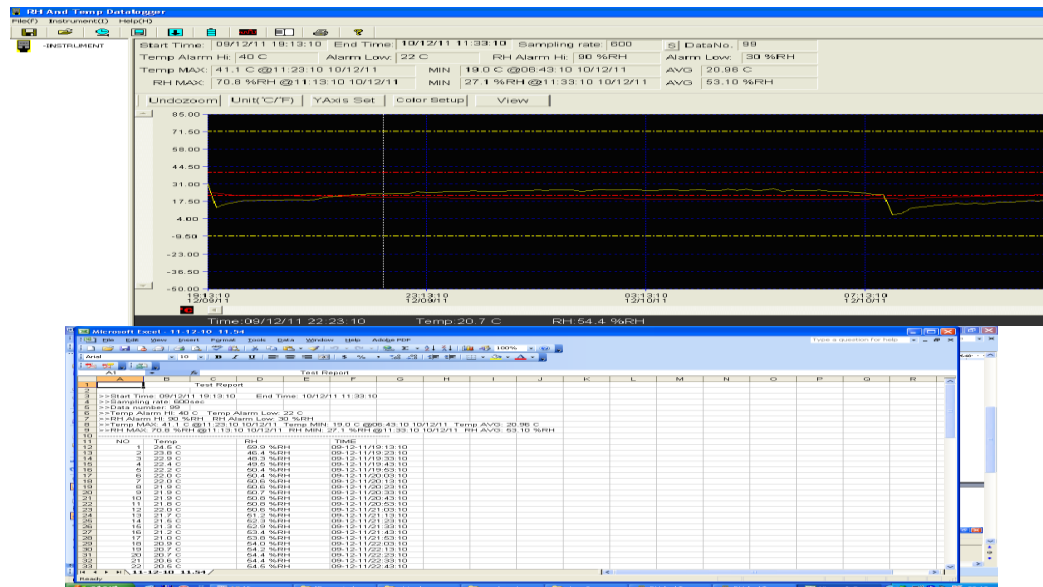
1. sensors (temperature, humidity, conductivity, acceleration) of reduced dimensions (nanometrical) on various types of carriers (flexible, ceramics/polymer-type) with the purpose to ensure the adjustment of temperature and humidity of the body;
2. stabilized source board (with adjustable specific parameters, namely, voltage); power generator – specialized circuits for the electrical supply of the conductive structures to the sensors network;
3. control board of the intensity of the supplied power, with a role in the reduction of the power consumption and the prevention of overheating the integrated structure, which will be able to control separately each electroconductive structure, with the possibility to being individually supplied;
4. mixed interface electronical unit (for the user) with the following roles: 1. on/off heating (hand-driven); 2. on/off temperature and humidity measurements, with the possibility to change the values set for in order to be adjusted according to the environment parameters; 3. the ensuring of the information transmission towards the hardware unit, which processes the received information with the purpose to adjust/monitor the state parameters of the users.

The operation of the *resistive temperature factors* is based on the variation of the electric resistance  $R$  of the resistive element, which constitutes the sensor according to temperature. The *resistive temperature factors* convert a physical value (heat quantity / temperature) in another physical value of an electric nature (electric resistance / electric voltage), which can be measured or used for connecting some electrotechnical components (the electric supply system) onto certain functions (e. g. heating by means of conductive textile structures). The resistive temperature factors can be accomplished by thermoresistive materials (in which the electric resistance varies at the same time with the temperature) under the form of yarns, bands, foils and thin layers. For monitoring the temperature of the environment respectively, of the user, between the smart garment and the body, the most suitable form of material for the resistive temperature sensor is the thin layer obtained by the deposition on a carrier. The thermoresistive materials under the form of thin layers have a series of advantages, as compared with the thermoresistive materials of other geometrical shapes (e.g. yarns); these advantages are the following:

- high resistivity, this being the reason why the resistive route for obtaining high values of the electric resistance (e.g. of  $1\text{k}\Omega$  order) is much shorter;
- the high contact surface, a fact which leads to the improvement of the heat transfer from the inner environment to the sensor, and therefore, to the increase of the estimation precision of the environment / human body temperature;
- the material can be geometrically structured as a resistive route, under the form of a meander to increase the value of the sensor electric resistance;
- reduced material consumption;
- low thermal inertia.

The software of the system for electric monitoring, temperature control and humidity detection permits memory intervals from 1 second to 24 hours, data transfer compatible with Windows

98/2000/XPE, USB interface to connect with the computer. Figure 1 presents examples of temperature and humidity records, taken from performed experiments [37-41].



**Figure 1.** Records of the parameters temperature and humidity.

### 3.3. Embedded wireless networked device for internet/GSM network control

A communicating clothing article provides the following functions: a. communication and navigation functions performed through functional architectures implemented by GPS utilization; b. positioning (location and posture); c. user's monitoring (temperature, humidity, pulse); d. environment parameters monitoring. Intelligent clothing also has a computerized module (embedded wireless networked device – EWND) for control through the internet/GMS networks. This module can includes: a. local PC provided with software for the management of the physiological monitoring process and for ensuring an user interface to set the specific working conditions; b. embedded-type computer for controlling the physiological monitoring process; c. sensors of position and motion, humidity, temperature, electric conductivity and impact detection; d. GSM modems and proper software for M2M-type remote control. Monitoring the environment parameters (temperature, humidity) provides the user with concrete data necessary in difficult surviving situations. The researches on the development of smart clothing require novelty elements from the following domains: textile materials (composition, structure, technology, manufacturing process, non-textile insertion; clothing comfort (ergonomics, modular design, integration of the data processing modules and communication modules); microelectronics (electronic devices miniaturization, sensors integration, textile aerals integration, aerals flexibility); computation technique (specific processing systems, communication proceedings); service (maintenance, reconfiguration).

The integrated apparel ensemble has been structured as follows: a. conductive structures accomplished by electroconductive yarns; b. physiological monitoring electronic device. c. basic apparel. The realized communicating clothing has in its composition the following elements: a. the accomplishment of conductive textile structures by nanometric processing (superficially/in the mass) through the insertion of organic materials with high levels of conductivity; b. the integration of electronic systems (for physiological monitoring) through which the interface with the external environment is achieved on the basis of the conductive properties of materials; c. the putting together of the effects (a and b) for accomplishing a perfectly compatible and functional product structure, which constitutes a technical solution at hand for any user; d. the accomplished apparel ensemble ensures the temperature of the human body under low conditions to provide the wearer's



comfort; e. the maintaining of the temperature is provided by some textile structures with conductive yarns, which operate on the basis of the Joule effect, having a reduced mass which does not inconvenience the wearer; f. the garment can be used under the climatic conditions during winter. Smart clothing allows monitoring on a permanent base, without affecting the comfort of the person wearing them.

The textile intelligent systems, which comprises conducting textile structures (wires and electroconducting structures) present a dynamic behavior which favors the self regulation of the thermal insulation and vapor permeability with the purpose to maintain the thermo-physiological balance; the integrated clothing assembly has as an option the module for monitoring the biologic potential, used only in critical situation (ex. accidents, falling down in a precipice etc.).

#### 4. Conclusions

Smart clothing is a reality of our times. Even if they are still the prerogative of some special social categories such as sportsmen, informatics specialists, businessmen or researchers, the explosive expansion of the mobile communications and of the computation technique, will bring them into everybody's wardrobe. The textile smart systems represent a challenge that one has to be able to cope with everyday.

#### References

- [1] Cork C R 2015 *Woodhead Publishing* Elsevier Ltd. Cambridge UK
- [2] Csiszar G, Ungar T and Jaro M 2013 *Appl. Phys. A* **111** 897
- [3] Fishlock D, Doctor volts. 2001 *IEE Rev.* **47** 23
- [4] Ghosh T K, Dhawan A and Muth J F 2006 *Intelligent Textiles and Clothing*. Woodhead Publishing 239
- [5] Kuhn H H, Child A D and Kimbrell W C 1995 *Synth. Met.* **71** 2139
- [6] Parashkov R, Becker E, Riedl T, Johannes H and Kowalsky 2005 *W Proc. IEEE* **93** 1321
- [7] Paul G, Torah R, Beeby S and Tudor J 2014 *Sens. Actuators A: Phys.* **206** 35
- [8] Park S, Mackenzie K and Jayaraman S 2002 *PMIP, Proceedings of the Thirty-Ninth Annual Design Automation Conference* 170
- [9] Adidas 2015 <http://www.numetrex.com/wearable-technology/>
- [10] Post E R 1996 E-broidery: An Infrastructure for Washable Computing. MSc Thesis MIT <http://cba.mit.edu/docs/theses/99.02.post.pdf>.
- [11] R-STAT 2016 <http://www.r-stat.fr/>
- [12] Zysset C, Kinkeldei T W, Munzenrieder N, Cherenack K and Troster G 2012 *IEEE Trans* **2** 1107
- [13] Beeby S, Cork C, Dias T, Grabham N, Torah R, Tudor J and Yang K 2014 *Advanced manufacturing of Smart and Intelligent Textiles* SMIT
- [14] Cho G 2010 *Crc Press* Boca Raton
- [15] Kim B, Koncar V, Devaux E, Dufour C and Viallier P 2004 *Synth. Met.* **146** 167
- [16] Gibbs P and Asada H H 2004 *IEEE International Conference on Robotics and Automation. Proceedings ICRA'04* **5** p 4753
- [17] Manea L, Buhu L, Buhu A and Aniculaesei G 2007 *Intelligent Textiles and Mass Customisation* (Casablanca, Morocco) **1** p 439
- [18] Manea L R and Pieptanariu M 2006 *Proceedings of the International Scientific Conference, Unitech Technical University Gabrovo* (Gabrovo, Bulgaria) **3** p 330
- [19] Buhu A, Buhu L, Manea L and Amariei N 2007 *Intelligent Textiles and Mass Customisation* (Casablanca, Morocco) **1** p 350
- [20] Amariei N, Pieptanariu M and Manea L R 2006 *International Scientific Conference Unitech Technical University Gabrovo* (Gabrovo, Bulgaria) **3** p 265
- [21] Pieptanariu M, Amariei N, Manea L R 2006 *International Scientific Conference Unitech Technical University Gabrovo* (Gabrovo, Bulgaria) **2** p 313

- [22] Manea L R, Amariei N and Buhu A 2007 *Intelligent Textiles and Mass Customisation* (Casablanca, Morocco) **1** p 356
- [23] Buhu L, Manea L, Avram D and Aniculaesei G 2007 *1st International Conference – Intelligent Textiles and Mass Customisation* (Casablanca, Morocco) **1** p 565
- [24] Buhu A, Manea L and Buhu L 2007, *Cortep, Buletinul Institutului Politehnic Iași, Section Textile and Leather, Tomul LIII (LVII) Fasc. 5* **1** p 121
- [25] Manea L and Buhu L 2007 *Cortep, Buletinul Institutului Politehnic Iași, Section Textile and Leather Tomul LIII (LVII) Fasc. 5* **1** p 103
- [26] Manea L, Aniculaesei G, Leon A L, Hanganu L C and Potop G 2008 *Buletinul Institutului Politehnic Iași, Section Textile and Leather Tomul LIV (LVIII) Fasc.3* p. 427
- [27] Manea L R, Berteau A, Nechita E, Popescu C V and Sandu I 2016 *Rev. Chim. (Bucharest)* **67** (7) 1284
- [28] Manea L and Buhu A 2007 *Buletinul Institutului Politehnic din Iași, Section Textile and Leather Tomul LIII (LVII) Fasc. 5* **1** 109
- [29] Pieptanariu M, Amariei N and Manea L 2006 *International Scientific Conference Unitech Technical University Gabrovo* (Gabrovo, Bulgaria) **2** p 316
- [30] Manea L, Aniculaesei G, Leon A L and Hanganu L C 2008 *Buletinul Institutului Politehnic din Iași, Section Mechatronics and Precision Engineering Tomul LIV (LVIII) Fasc.4* **1** p 59
- [31] Stanescu I, Manea L R, Berteau A, Berteau A P and Sandu I C A 2016 *Rev. Chim. (Bucharest)* **67** (10) 2082
- [32] Manea L R, Hristian L, Ostafe M M, Apostol L L and Sandu I 2016 *Rev. Chim. (Bucharest)* **67** (9) 1758
- [33] Devaux E, Koncar V, Kim B, Campagne C, Roux C, Rochery M and Saihi D 2007 *Trans. Inst. Meas. Control* **29** 355
- [34] Aniołczyk H, Koprowska J, Mamrot P and Lichawska 2004 *J Fibres & Textiles in Eastern Europe* **12** 47
- [35] Cho G, Jeong K, Paik M J, Kwun Y and Sung M 2011 *IEEE Sens. J.* **11** 3183
- [36] Popa A, Bucevschi A, Pustianu M, Manea L R and Sandu I 2016 *Mat. Plast.* **53**(2) 316
- [37] Hristian L, Sandu A V, Manea L R, Tulbure E A and Earar K 2015 *Rev. Chim. (Bucharest)* **66** (3) 342
- [38] Hristian L, Ostafe M M, Manea L R and Leon A L 2016 *IOP Conf. Series: Mater. Sci. Eng.* **145** 022014
- [39] Hristian L, Ostafe M M, Manea L R and Leon A L 2016 *IOP Conf. Series: Mater. Sci. Eng.* **145** 032004
- [40] Manea L R, Hristian L, Leon A L and Popa A 2016 *IOP Conf. Series: Mater. Sci.Eng.* **145** 032007
- [41] Manea L R, Hristian L, Leon A L and Popa A 2016 *IOP Conf. Series: Mater. Sci. Eng.* **145** 032006

### Acknowledgments

This work was supported by a grant of the Romanian national Authority for Scientific Research and innovation, UEFISCDI, project number PN III 46 BG 2016 within PNCDI III