

Recent researches concerning the obtaining of functional textiles based on conductive yarns

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Abstract. Modern textile industry is influenced both by consumers' lifestyle and by novel materials. Functional textiles can be included into the group of technical textiles. The functional activity can be shortly interpreted as "sense - react - adapt" to the environment while traditional materials meet only passive protective role, a barrier between body and environment. Functional materials cross the conventional limits because they are designed for specific performances, being part of domains as: telemedicine, medicine, aeronautics, biotechnology, nanotechnology, protective clothes, sportswear, etc. This paper highlights the most recent developments in the field of using conductive yarns for obtaining functional textiles. Conductive fabrics can be done by incorporating into the textile structure the conductive fibers / yarns. The technologies differ from embroidering, sewing, weaving, knitting to braiding and obtaining nonwovens. The conductive fabrics production has a quickly growth because it is a high demand for these textiles used for data transfer in clothing, monitoring vital signs, germ-free garments, brain-computer interface, etc. Nowadays it is of high interest surface treatments of fibers/yarns which can be considered as a novel kind of textile finishing. There are presented some researches related to obtaining conductive yarns by coating PET and PP yarns with PANi conductive polymer.

1. Introduction

An overview of the textile industry shows that during the past decades the interest in producing innovative high-quality products has constantly growing. Specialists say *a new revolution began* with the apparition of new technologies and new materials which add new functions to the textile structures [2, 12].

Functional textiles are considered to be part of the technical textiles. For them, visual aspect has less importance than functionality, performance and added value [1]. The definition states that functional textiles are different from traditional materials because they offer additional functionalities as: water and wind proof, breathability, thermo regulating, stain resistant, antimicrobial, UV protection, electrical conductive, electrical shielding, antistatic protection, flame retardant, etc.

A short analysis of uses highlights that functional textiles are found in telemedicine and medicine (life saving, injury protective, therapeutic and rehabilitative clothing), aeronautics, biotechnology, nanotechnology, protective clothes for the army (surviving in hostile environment, protection against bacteria, radiation, and chemical agents), sportswear...



The term "*smart*" or "*intelligent*" means that functional textiles have the ability to react to different stimuli as mechanical, electrical, thermal and chemical [2]. The interaction with environment is the difference; for example, if the outside temperature is low, textile material responds immediately by heating the body. These smart textiles can be used for health monitoring, military domain, electroluminescent fabrics (fashion), etc. "They can be a chance for the future, for significant innovations in textiles and new business opportunities for the European industry" [18]. In conclusion, depending on the degree of functionality, the following three groups of technical textiles can be found: wearable electronics, smart textiles and functional textiles [3, 6, 18].

2. Role and design of the conductive textiles

Electronic textiles (e-textiles or wearable textiles) have both electronic functionality and textile properties. Their appearance on market was determined by the need of manufacture smaller portable devices, more flexible, easier to be used in emergency situations, health care as old people monitoring during their daily living (safety long term monitoring).

The role of conductive textiles is related to their ability to allow the passage of charged particles through their structures. Depending of the application, electronic functionality can be fully or partially integrated to monitor the person who wears the clothes or the environment and to interpret the obtained data [6].

Electrically conductive fibers are placed at the interface between the world of electric wires and the world of textiles, having attributes of each. For designing conductive fibers/yarns it must be taken in consideration the idea that they have a non-conductive or less conductive substrate (polyester, nylon, lycra, cotton), which is either coated or embedded with electrically conductive elements (copper, steel, silver).

Wireless communication between clothing and computers or other devices is a new challenge for specialists. For example, monitoring in real-time the parameters as heart rate, respiratory rate, blood pressure, blood oxygen saturation, glucose level, and muscles activity can be accurate done and sent by bluetooth to electronic devices. Different research groups try to fulfill clients needs for interactivity, connectivity, easy to use interfaces for information processing by integrating electrically conductive textiles into smart apparel that give a new meaning to the concept "human-machine symbiosis" [6].

There are produced several types of conductive yarns:

(1) substrates and conductive elements - they are used especially for antistatic applications and radar-absorbing products for camouflage [10];

(2) metal yarns - they can be inserted by weaving processes into fabrics for obtaining a link with conventional rigid printed circuit boards (PCB). Also they can be used in sports bra to create pulse-sensing electrodes [7]. For example, the Swiss company *Elektrisola Feindraht AG* produces metal monofilaments that can be blended with other fibers or directly fed to the weaving or knitting machines;

(3) metallized yarns - they are produced by adding a metal coating to a core yarn. For example, there are manufactured silver-coated polyamide yarns and copper-coated polyester yarns [13]. Core-spun yarns can be obtained on DREF spinning system. These yarns are a base for manufacturing high-performance textiles and sewing threads because of their exceptional strength, very good abrasion resistance, excellent resistance to perspiration, good elasticity, permanent press and wash-and-wear performances [6];

(4) electrically conducting strips - they are metallic strips with a width of 2mm that are inserted as weft in woven structures or they are conducting lines printed on plastic strips;

(5) fibers containing conductive elements - metal particles or carbon particles were introduced during extrusion in the polymeric matrix;

(6) carbon nanotube (CNT) yarns - the first generation of CNT yarns was manufactured by wet spinning process using polymer binder and CNT fillers [9]. In the second stage it was used dry method

to create CNT fibers and now the process consists of both CNT synthesis and yarns making. Figure 1 shows three types of conductive yarn structures.



Source: www.textileworld.com

a. Metal-wrapped yarn b. Metal-filled yarn c. Metal yarn

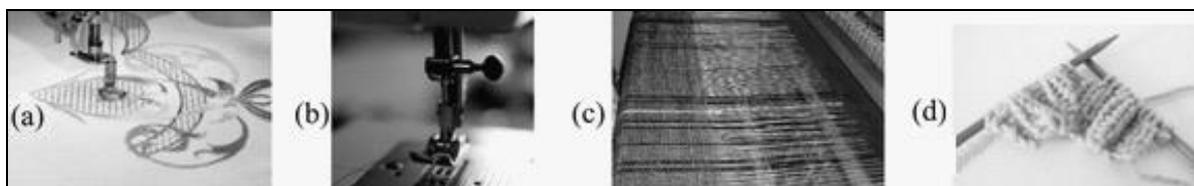
Figure 1. Three types of conductive yarn structures

Nowadays it is of high interest surface treatments of fibers/yarns which can be considered as a novel kind of textile finishing. For example, the SOL-GEL method consists in the chemical coating of polyethylene terephthalate (PET) and polypropylene (PP) yarns with the conductive polyaniline polymer (PANi) "doped" with DBSA. Mixtures of PANi-based electrically conductive polymer can be obtained using conventional solution or melt processing techniques. The electric and physico-mechanical properties of the conductive yarns vary depending on polyaniline content in the conductive composition and show an optimal value at 6% PANi concentration. It was tested that bulky textured and twisted yarns incorporate better the conductive composition by comparison with the elongated and smooth ones [7, 8, 10].

3. Manufacturing techniques of conductive textiles

The conductive fabrics production has a quickly growth because it is a high demand for this kind of textiles used for data transfer in clothing, monitoring vital signs, germ-free garments, brain-computer interface, etc. Nowadays there are more than 15,000 manufacturers of conductive textiles all over the world.

Conductive fabrics can be done by incorporating into the textile structure the conductive fibers / yarns. The technologies differ - as shown in *Figure 2* - from embroidering, sewing, weaving, knitting to obtaining nonwovens.



a. embroidering; b. sewing; c. weaving; d. knitting.

Figure 2. Technologies for obtaining conductive textile structures [13]

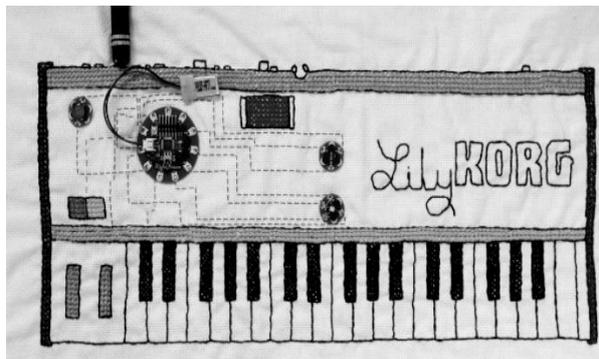
Embroidery process

Machine or hand embroidery is a stitching method to create patterns onto woven fabrics with coloured yarns (silk, cotton). Usually this method is used to decorate textile surfaces.

If there are used conductive yarns, the purpose is to create (Figure 3):

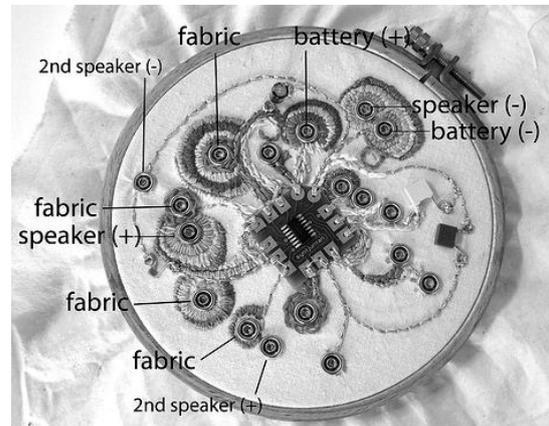
- conductive areas as mobile keypad, piano keyboards, electronic tablecloth - they replace the traditional pressure sensors;
- complex geometrical conductive patterns - they replace circuits printed of plastic surfaces.

The first stage is to find a suitable conductive yarn and a textile material. The second stage is to design the circuit traces or the area that will be obtained by numerically controlled embroidery [11]. The next stage is automated embroidery process and testing the results. The areas/circuits are highly durable, very flexible, washable and replace the traditional sensors or electrical circuits.



Source: Alisa Wronski, *Circuit embroidery*

a. Piano keyboard & Arduino Lilypad components (Afroiditi Psarra work)



Source: <http://smarttextiles.se>

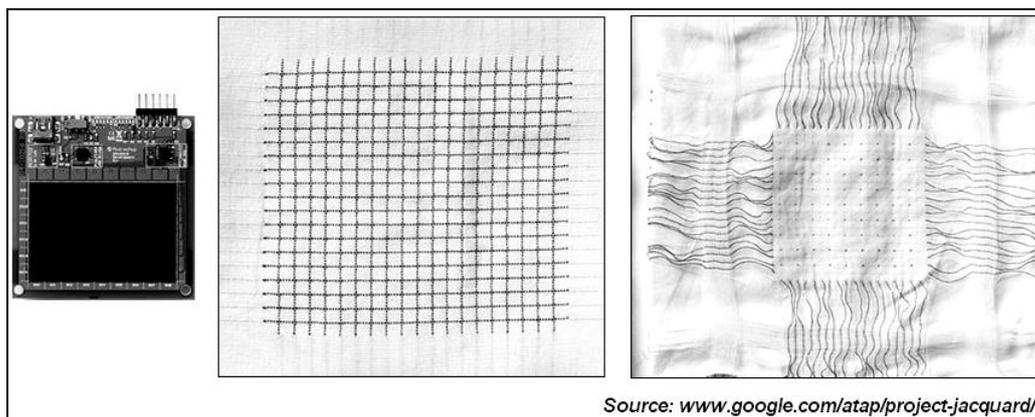
b. Embroidered circuits as a link between a knitted glove and a computer

Figure 3. Examples of embroidered circuits with conductive yarns

The main advantage of the embroidery process is a precise control of the design. The conductive threads must be strong and flexible enough for high-speed embroidery machines because if they break will occur an electrical disconnection.

Weaving process

Jacquard yarn structures combine thin, metallic alloys with natural and synthetic yarns (cotton, polyester, silk), making the yarn strong enough to be inserted in the woven structure on an industrial loom - Figure 4 [17]. These plain structures act as sensor grids and create interactive areas.



Source: www.google.com/atap/project-jacquard/

Figure 4. Woven structure containing conductive yarns

Also small electronic devices can be embedded, not larger than a button. "These miniaturized electronics capture touch interactions, and various gestures can be inferred using machine-learning algorithms" (Google - Project Jacquard) [17].

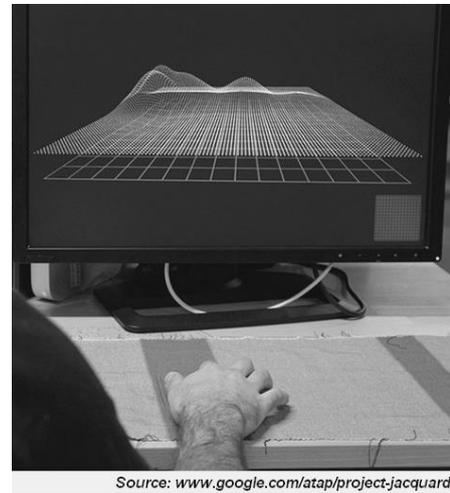
Touches and gestures are captured by flexible woven structure and wirelessly transmitted to mobile phones / electronic devices which activate different services, applications or phone features - Figure 5.

Jacquard components have the advantage to be efficiently produced with accurate dimensions and locations on standard weaving looms, in an infinite variety of patterns.



Source: www.google.com/atap/project-jacquard

Figure 5. Denim woven fabric connected wirelessly with a mobile phone



Source: www.google.com/atap/project-jacquard

Figure 6. Woven surface activated by hand touch (as shown on screen)

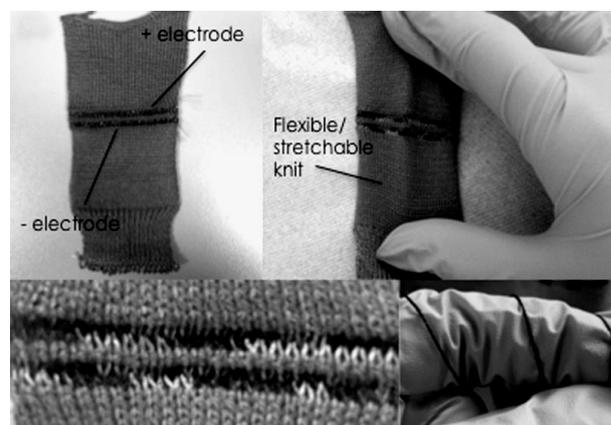
Knitting process

The most known example of knitwear made from conductive yarns is winter gloves. When you use a touchscreen of the mobile phone or PC tablet, skin acts as a conductor to send a low voltage. By using gloves knitted from conductive threads, the material conducts electricity and allows the proper using of the device - Figure 7.



Source: www.knitty.com/ISSUEwbis11/PATTteknika.php

Figure 7. Glove containing conductive yarn



Source: <http://drexel.edu/now/archive/2015/March/capacitive-yarn/>

Figure 8. Stretchable knitted structure

Researches conducted at *Drexel University (Philadelphia, USA)* in collaboration with *Shima Seiki Haute Technology Laboratory* and *U.S. Naval Academy* changed simple knitted structure from conductive yarns into energy storage devices - Figure 8. These cotton yarns were obtained by a process called "natural fiber welding" [14]. The technology consists of the next stages:

- yarn is first treated with a molten salt, which causes the polymer chains to swell and to open. Optionally, the yarn can be twisted with steel prior to welding;
- embed the yarn with a functional material (such as activated carbon particles) by inserting the yarn through a syringe filled with a mixture of the material in the ionic liquid;

- the yarn is pulled through the needle of the syringe, which physically presses the carbon into the fibers, and it is wrapped onto a spool;
- the ionic liquid is removed by washing the yarn with water, which also re-solidifies the cotton fiber, trapping carbon particles in the surface. The result is a complex composite fibrous material that is flexible and has capacitive properties of activated carbon;
- the activated carbon-natural fiber welded yarn is twisted with a highly conductive stainless steel yarn prior to testing. Activated carbon on its own is not conductive enough for energy applications, so the stainless steel yarn allows the materials to be charged more easily.

The technology that creates electrode yarns can be applied to any commercially thick or thin yarns made of cellulose as cotton, linen, bamboo, viscose, and rayon. The knitted structures can be used in wearable electronics - Figure 9 [4].

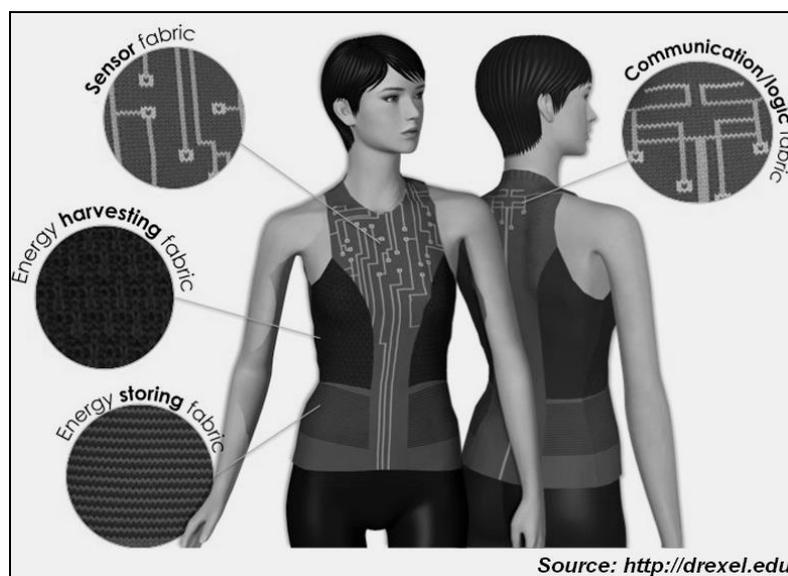


Figure 9. Clothing with knitted structure that stores energy

Braiding process

Researches are focused on braiding technology because the braiding angle and the surface density can be changed. Also the braided structure allows twisting, shearing and impact resistance better than woven fabrics. Conductive yarns can be inserted in the braiding process. They can act as force sensors and improve the functional safety of braided ropes and lines made from synthetic fibers [1].

The heating elements (Thermotech N yarns) are braided alone or together with other reinforcement synthetic yarns on the outside of the product for a better heat transfer - Figure 10. The core is a wire or a flexible tube [15].

Producing nonwovens

Electrically conductive nonwovens from carbon fibres are already in use for static dissipation. They can be produced with an excellent drape and suitable bonding properties either in a spunlace or needle punch process. The main advantages are low weight, flexibility and easy handling.

3M nonwoven conductive tape is used for applications requiring excellent electrical conductivity from the substrate, through the adhesive, to the conductive backing (Cu/Ni plated). Common uses include grounding and EMI shielding equipment, components, and shielded rooms. "The unique, thin metallized backing offers the additional benefits of excellent flexibility and conformability, very light weight, and exceptional strength" [16].

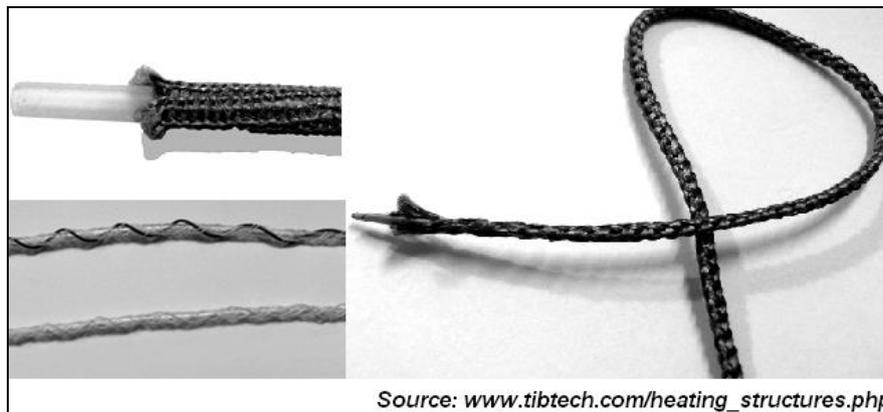


Figure 10. Flexible electro heating braids (THERMOBRAID & THERMOTRESS)

Also can be produced highly conductive coatings on nylon-6 microfiber mats that are flexible and thin nonwovens with conductivity of approx. 1000 S/cm.

The printing of conductive inks (polymer thick films) - Figure 11 - directly on nonwovens surface creates circuits and embedded systems. The interaction between ink droplets and nonwoven substrate determines the in-plane flow and through the plane flow [5].

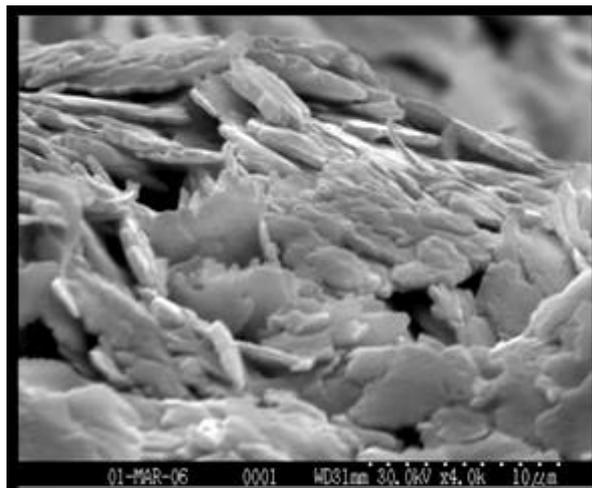


Figure 11. Scanning electron microscopy picture of conductive ink silver particles printed on nonwoven [5]

The flexible printed circuit boards are widely used in the area of electrical interconnectivity because they are lightweight, durable, washable and they are a low-cost alternative for traditional rigid circuits.

4. Conclusions

Electrically conductive textiles have many structures and many applications. Beginning with the twentieth century, more useful textiles having electrical functionality were produced, such as the electrically heated gloves for drivers.

The development of electrically conductive polymers and technologies gives new directions for further researches in the field of fashion, heated clothing, but also for flexible circuits, electrical interconnectivity, energy storage devices, brain-computer interfaces, wireless transmission to mobile phones / electronic devices for activating different services, applications or phone features, etc.

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