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A NEW REALITY: SMART FABRICS AND WEARABLE TECHNOLOGY

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Abstract: *The paper presents relevant aspects related to smart fabrics, e-textiles and smart clothing, current implementations of high textile technology, wearable electronics and wearable computers respectivly. Shape Memory Materials have the potential to return to their original form, due to external stimuli and therefor can have multiple applications to functional textile as presented in the second chapter. Phase Change Materials are a solution for energy management, storage and generation of energy appearing when changing the state of aggregation, being influenced by the temperature, with current usages in the aerospace industry or other, as shown in the same chapter. The property of chromatic textiles was also investigated as well as the huge potential of conductive textiles. Electronic systems integrated in textiles are used for image sensors, flexible displays, biomedical devices and other emerging applications. The possibility of such a combination has motivated researchers and companies to offer on the market jackets with remote controls, embedded displays and even airbags. Structural features and technologies for production were described, emphasizing their most important applications, such as medical, sports or military. Maintenance operations of smart products must ensure their repeated utilization and do not degrade their electrical components. Several products proposed by well-known IT companies in collaboration with textile brands or by research laboratories were presented in the last part of the paper.*

Key words: *e-textile, smart clothing,* conductive textile*, wearable electronics*

1. INTRODUCTION

In our daily lives, we are in contact with textiles up to 98%, and they have become adaptive, receptive, interactive or connected, extending their traditional functions and having the capacity to do many things that traditional materials cannot do: communicating, transforming, directing energy or growing [1], [2].

In the current conditions in which the products must be attractive, as well as to function properly in the most diverse situations, including those that have an effect on the safety and security of people, textile designers have a new alternative in choosing a textile material that follows to be processed: in addition to appearance, resistance or price, is added its ability to conduct electricity. This property is characteristic of e-textiles, electronic textiles or smart clothing, which must keep pace with the revolution in wearable electronics.

The terms “e-textiles” and “smart clothing” refer to textile fabrics and garments made of high-tech textiles in which new technological elements have incorporated, including electrical parts. ISO/PRF TR 23383:2020 and ASTM D8248:2020 define a smart textile as a functional textile that interacts with the environment, reponds to the action of external stimuli (temperature, chemicals, magnetic field or mechanical actions), but does not necessarily contain an electronic element in its structure.

E-textiles are a combination of advanced textile technology and information technology and electronics. Electronic textiles are distinct from wearable computers because they contain textiles integrating with electronics such as microcontrollers, sensors and actuators. In addition, e-textiles do not have to be wearable. For example, e-textiles can be used in interior design.

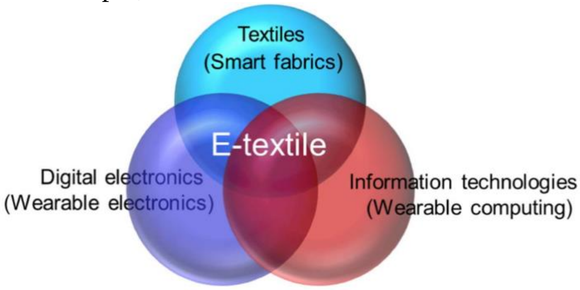


Fig. 1*: Relations between e-textile and wearable technologies [3]*

Some components and interconnections can be hidden in the material by the way the structures themselves are built. A wide range of textile fabrics have been used as base layers for smart products. Accordingly, new production processes have been developed and specific techniques have been adapted to obtain wearable intelligent textile systems [4]. New fibers and yarns, together with electronic microcomponents make it possible to create products that are truly useful to people. The use of metal yarns or especially nanotube-based in woven fabrics improve the portability and flexibility of these intelligent textile systems, participating in attached or laminated circuits [5], [6]. Medical applications have been made based on textile platforms in which the knitted material is improved with new redundant detection capabilities, preserving the mechanical properties of structure that make the material durable, breathable, elastic and soft [7].

Some textiles, such as warm blankets and clothing, have developed over the past 20 years, integrating into notable markets, where millions of products are sold each year. But the range of e-textiles is extremely diverse: from clothing to medical products, bedding to industrial fabrics; and as this technological area explores more and more, other new products are emerging. But regardless of the application itself, they put together one or more defining components of smart textiles (Fig. 2).

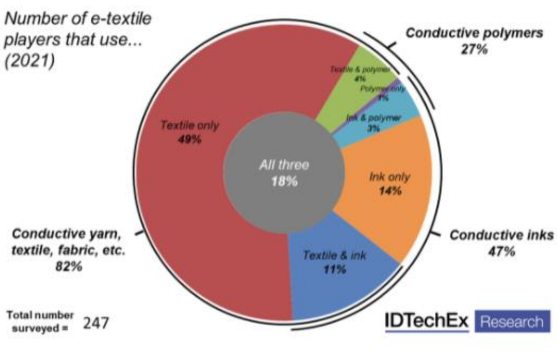


Image source: E-Textiles & Smart Clothing 2021-2031 (IDTechEx Research)

Fig. 2*: Distribution of raw materials for e-textiles [8]*

Considering a wide range of raw materials (polymers, metals, fibers, yarns, knitted, woven, embroidered and nonwoven fabrics) and components (sensors, connectors and interface with traditional electronics, etc.) used for e-textiles and smart clothing in [8], one can observe a priority of conductive textile threads and structures, followed by conductive inks and polymers, respectively, which are also an important alternative for e-textiles.

The e-textile industry influences and is influenced by the emerging technological ecosystem (production of conductive inks, extensible electronics, wearable technology, printed electronics and and flexible sensors, Internet, emerging energy storage, healthcare and life sciences, etc.). Every these individual product ecosystems has its own needs and expectations, thus "being e-textile" is not necessarily sufficient to be a successful product.

2. SMART FABRICS

The first research on smart adaptive systems was recorded in the 1980s in the U.S. as part of a Smart Skin Program that focused on military aircraft and the integration of projectors on their outer surface. In 1985, the New Glass Forum was established in Japan, with the field of research being the sensory ceramic materials, which are obtained by varying their properties.

The concept of smart fabrics was developed in the 90's with the aim of materials (textiles, plastics, metals, etc.) which, when stimulated by action, change their properties, by adding substances with specific properties (paraffin, metal alloys, polymers, etc.).

Both the nature of the stimulus and the response can be diverse, and hence a classification of smart fabrics. Thus, the stimuli can be electrical, magnetic, mechanical, thermal, etc., and the response of the material may consist in changing the phase, dimensions, electrical properties, appearance etc. [9].

Smart systems perform functions similar to those of living organisms, actuators, sensors or controls. To these, in the case of very intelligent materials, is added the function of learning and adapting to variations in the environment by changing their own characteristics [10].

Actuators refer to smart materials that can respond by thermal stimuli, electric or magnetic field variations. They are able to change their shape (with the formation of kinetic energy), stiffness, position, frequency of internal vibrations, damping capacity, internal friction or viscosity, as a reaction to variations in temperature, electric or magnetic field. This category includes shape memory materials, piezoelectric materials, electrostrictive and magnetostrictive materials, as well as electro and magnetoreological materials. Sensors refer to detection systems that identify changes in the environment and transmit signals depending on the structure of the material. They can perform the following functions: defect control, vibration damping, noise attenuation and data processing. A structure can have external or internal sensors, and sensory materials refer to shape memory materials, piezoelectric materials, electrostrictive materials, optical fibers and marking particles [11].

Control systems or the processors ensure communication between sensors and actuators, including their reaction and control. They classify the information received from the sensors and protect by reducing the accuracy of the processing their operation. The simplest smart material structure (a set of smart materials) is that which consists of a sensor, an actuator and a feedback amplifier. The concept of "a-life" characterizes such a structure that is also adaptive (reactive or can learn), but also ensures the transmission of information to people [10].

Smart textiles are those textile materials capable of sensing environmental stimuli, reacting to them and adapting their behavior to circumstances by integrating functionalities into the textile structure. Stimulus and response can have an electrical, thermal, mechanical, chemical, magnetic origin. External conditions can be felt by smart textiles in three distinct ways: passive (textiles that only detect the external stimulus: portable sensors, built-in GPS), active (due to sensors and actuators, textiles have the ability to detect and operate or move part of their environment: chromatic materials, shape memory materials, phase change materials, hydrogels and membranes, clothing that changes the density of the material according to the outside temperature) and very intelligent (it is about the third generation of textiles that can feel, react and adapt to external conditions or stimuli, based on previous experience, and which are able to respond to perform a function in a pre-programmed way: space suits, thermoregulatory clothing, health-monitoring clothing, shirts containing a keyboard embedded in material to which information can be sent via Bluetooth to a computer) [12].

2.1. Shape Memory Materials in textiles

Shape Memory Materials (SMM) may return to their original form from a form in which they are due to external stimuli, such as temperature, mechanical stress (pseudoelastic applications), pH, light, magnetic or electric field, water or various chemicals. In this case, the material acts as an actuator for the textile product.

There are several types of alloys (SMA) that help to monitor the shape of a material, but the best known is the Nitinol alloy, Ni-Ti. It has been estimated that 50 l of Nitinol can store as much energy as a car engine [10]. Other alloys with shape storage properties are those based on Au, Ag or Cu (these being the cheapest). When it comes to textiles, it is a challenge, as the incorporation of excessive use of alloys will reduce the feel of this fabric.

In the case of a stimulus, such as temperature, 2 phases of the material can be identified: austenite and martensite, being characterized by a certain molecular structure (order) (Fig. 3). Figure 4 shows the principle of memorizing the shape of a material. Below the MF temperature, the alloy is completely in a martensitic phase; above the AF temperature, it is an austenitic state. AF temperature is the critical temperature for modeling, so when we heat the material over AF, it will return to its original shape. This specific alloy has very good electrical and mechanical properties and a high corrosion resistance. Moreover, Nitinol has the quality of inducing transformation through electricity. When enough electricity is transmitted through the wire, the heat generated will cause the transformation [13].

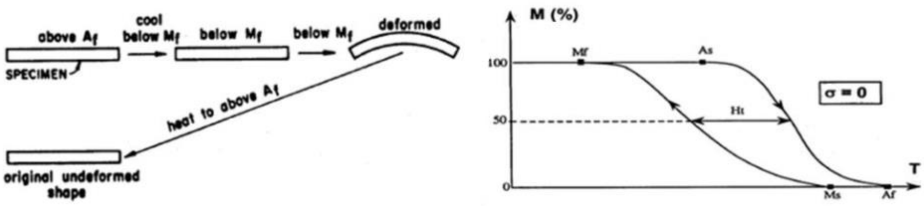


Fig.3*: The principle of memorizing form [14]*

An application conected with the textile field is made up of bras with shape memory (support wire), products that have both aesthetic and structural requirements. NiTi alloy support wires offer high comfort due to their much lower modulus of elasticity than conventional steel wires, while Cu-Zn alloy lamellar springs have a flat shape at a lower temperature and are arched at a upper temperature [9].

The longitudinal modulus of elasticity (Young's modulus) is the main characteristic regarding the deformability (rigidity) of a material. Of the two identical and stressed parts with equal stresses, the one whose material has the lowest modulus of elasticity will deform the most: a material is stiffer if it has a higher modulus of value E [15]:

$R = E * I_z$, where **(1)**

R - bending stiffness [Nmm^2]; E - Young's modulus [N/mm^2]; I_z - moment of inertia [mm^4]

In the case of knitwear used for clothing / footwear [16]:

$I_z = l_t * g_t^3 / 12$, where **(2)**

l_t – knit width [mm]; g_t – knit thickness [mm]; I_z – moment of inertia [mm^4]

An additional advantage is that the elastic NiTi alloy wires counteract the permanent deformation that can occur after washing and drying cycles.

An application for SMA is represented by a shirt designed by Corpo Nove from Italy (Fig. 4), which shortens its sleeves when the temperature rises and does not require its ironing.

***Fig.4**: Oricalco shirt [17]*

Laminated or polyurethane films (Shape-memory polymer) can be used to obtain vapor, water and air impermeable clothing. They give good flexibility, hence the belong to the category of "flexible materials" [18], a higher extensibility, softer touch, low specific mass and they are considered very suitable for the garment industry. In the case of segmented polyurethane, the specific shape recovery temperature varies over a wide range, and the permissible shape recovery deformations can reach 400%, with low manufacturing costs. These textiles are mainly used for functional textiles, with special properties, most often using the laminated complex of polyester fibers and SMP in garments with controlled permeability and insulation, as well as an increased comfort.

An example is the DiAPLEX material, designed by Mitsubishi Heavy Industries, using a polyurethane polymer on the textile material for waterproofing in case of intense physical activity or sudden climate change. The laminated complex made of 2 component layers: the fabric and the Diaplex membrane, respectively, have special characteristics: elasticity, texture, durability, wind resistance, thermal insulation, water resistance [19], [20].

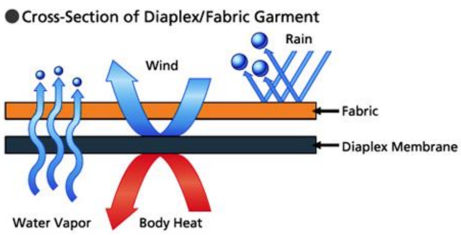


***Fig.5**: Diaplex Layered Complex Section [19]*

When the temperature in the clothing is low, the Diaplex membrane responds by lower permeability to prevent the passage of air and water molecules through it, thus maintaining body temperature. As the temperature inside the garment increases, the microbrownian movement will increase the permeability of the membrane, causing the expulsion of water vapor into the outside air and increasing the volume of air absorbed. This "flexible barrier function" allows clothing to adjust its insulating properties in response to temperature changes, ensuring optimum comfort in any possible environment, especially at extreme temperatures [21].

In the case of a protective clothing product for firefighters, the fibers with the shape memory inserted between the thermally insulating layers of the laminate complex will influence the amount of embedded air and thus will more effectively protect the body at high temperatures (Fig. 6) [22].

Shape-changing textiles are used for fireproof underwear or clothing (using of alloys), as well as for footwear, high permeability products, with good thermal insulation and resistant to bending (with polymer films).

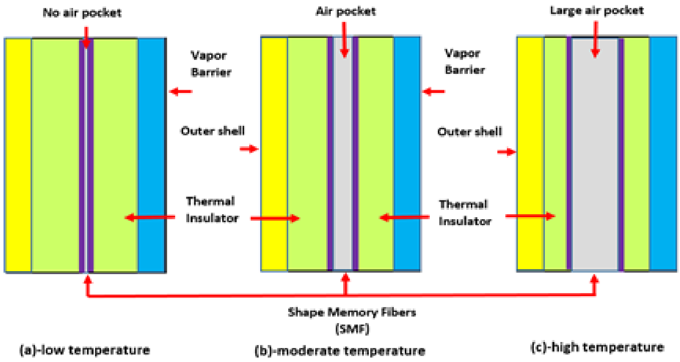


Fig.6*: Adaptation to temperature of smart textile product [23]*

2.2. Phase Change Materials in textiles

These materials (PCM) are also called stored latent energy materials, due to their availability to store energy when there is no demand for it and to generate it for consumption when the demand exceeds its production [24]. They are one of the solutions for energy management, storage and generation of energy appearing when changing the state of aggregation (melting / solidification). The behavior of PCM materials can be described as follows: upon solidification, the material releases large amounts of latent heat of solidification, while with its melting, an equal amount of energy is consumed from the environment. A thermal cycle can be established. Water is a PCM, it becomes ice or vapor when energy is added or consumed. PCM technology benefits from exactly the same law of physics, and other such substances would be inorganic salts, mixtures of wax and paraffin.

There are several types of phase change, such as: solid-gas and liquid-gas transformations with latent heat with the highest value, complemented by a considerable change in volume; solid-solid transformation with the lowest latent heat, as well as minimal volume variation at the change of phase. The latent heat in case of solid-liquid transformation (the most important PCM) has a higher value, while the volume variation is approx. 10%.

PCM materials are therefore directly influenced by the temperature factor, ensuring its regulation and being used in the aerospace industry, textile industry (clothing, linen and footwear), construction, agriculture, telecommunications etc.

To keep the body temperature constant and ensure the comfort of the wearer in varying environments, Burlington Worldwide, Outlast Technologies and Ciba have designed Smart Fabric technology based on the use of versatile materials to adapt to changes in outside temperature.

This technology is based on the introduction into the fibers and structures of some PCM microcapsules (Thermocules) (Fig. 7). They maintain a constant body temperature, by absorbing and releasing heat for increased comfort, without compromising the characteristics of the fabric [25]. The technology is used for outdoor sporting goods, bedding, mattresses, blankets, duvets and pillows, clothing (T-shirts, blouses, dresses, fabrics or knitwear), footwear, but also packaging, military or medical applications, as well as car covers (Fig. 8) [26].

A PCM paraffin absorbs 20kJ / kg of heat during the melting process, which is then released into the environment during cooling. More recently, this technology is used for clothing for motorcyclists, snowboard boots, cushions and wheelchair covers, which keep the skin drier and cooler to prevent pressure escares.

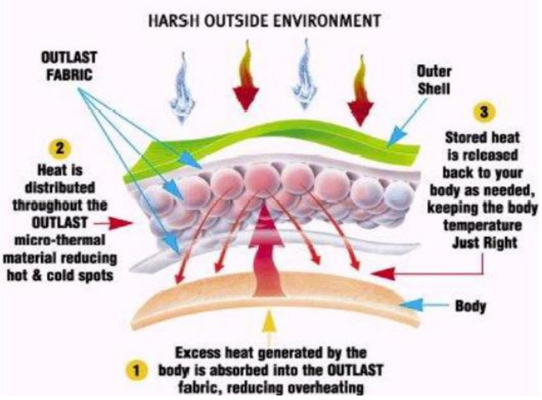


Fig.7*: Smart Fabric technology principle [9]*

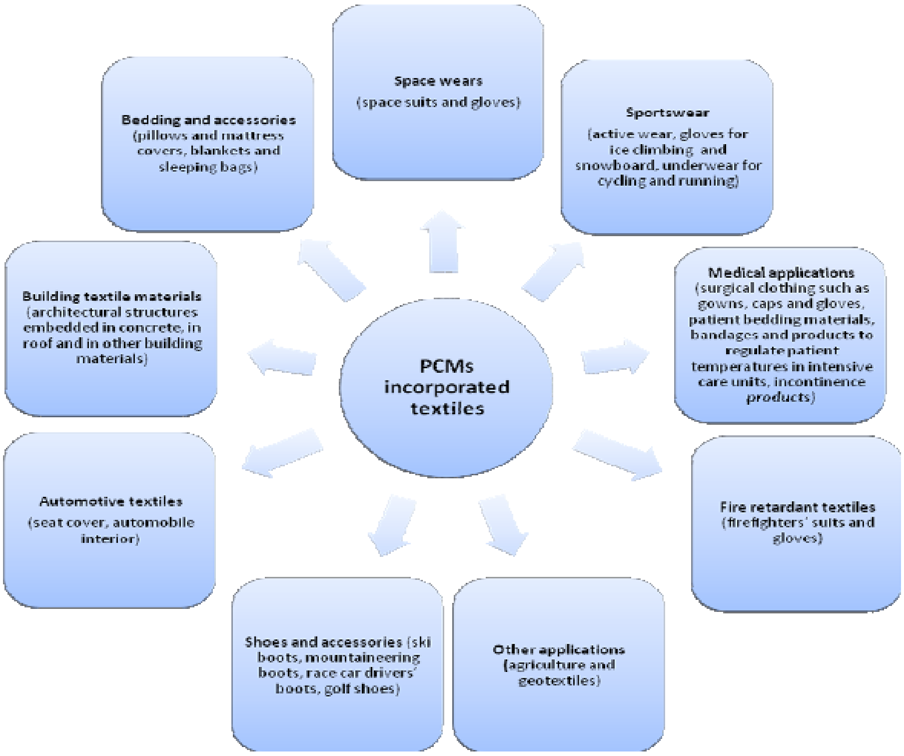


Fig.8*: PCM applications [26]*

There are certain limitations in clothing products from PCM materials design, the most important issue being the phase change temperature (approximately 30-35°C, close to body temperature).

2.3. Chromatic textiles

These materials have the ability to change color due to external stimuli. Depending on the nature of the external stimulus, chromatic materials can be classified into:

• Photochromic: reacting to external light stimulus
• Thermochromatic: external stimulus - heat
• Electrochromic: external stimulus - electricity
• Piezochromatic: external stimulus - pressure
• Solvatochromatic: external stimulus - liquid or gas

Photochromic materials change color under the action of light, an example known for them being sunglasses lenses, but also other products, T-shirts or footwear, reactive in the presence of this factor (Fig. 9) [28].

***Fig.9**: Changing the color of an umbrella to a) shadow and b) in sunlight [28]*

Thermochromatic materials are influenced by heat in the presence of cells with thermochromic dyes, which are activated when certain temperature levels are reached. They are used in the case of protective clothing in low visibility conditions, clothing for firefighters, for signaling emergency routes, making toys, etc.

Figure 10 [27] shows the color change cycle of a printed knit using the Americos Thermochromic Red pigment.

a) b) c) d)

***Fig.10**: Stages of thermochromatic material under the action of temperature [27];*
a) original printed drawing at a temperature below 31 ° C
b), c) discoloration of colors towards white after ironing; d) cooling with return to the original colors

Electrochromatic materials change their appearance repeatedly and reversibly under the action of electric current. One way to make electrochromic textiles is to cover the conductive nanofibers with specific dyes (Fig. 11).

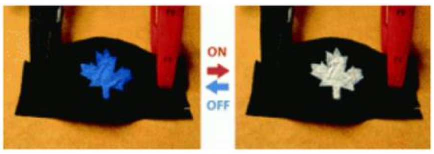


***Fig.11**: PEDOT carpet with thermochromic dye [28]*

2.4. Conductive textiles

Conductive textiles allow the passage of electricity through them, having properties such as: low mass, durability, low production costs, high flexibility, having the ability to be glued and subjected to textile processing. It is made using conventional technologies made of synthetic yarn with particles of carbon, nickel, gold, silver or metal or coated with conductive polymers.

As cotton, polyester or nylon are not conductive and therefore cannot perform the communication and power supply functions necessary for smart clothing, it is preferable to combine them with metallic wires, such as copper.

In this direction, researchers at MIT Media Lab used silk threads wrapped in copper foil. The wires thus made have a high conductivity. The warp thread (called organzin) is obtained by two simple threads, twisted in the opposite direction of the twisting of the threads and wrapped with a thin strip of copper. This band gives the assembly increased conductivity and flexibility, and the design is similar to a telephone cord. Because the construction thus made is durable, the thread can be used for sewing or embroidery operations with the help of industrial machines.

The addition of Ni, Cu or Ag as surface layers with different thicknesses in a textile material gives it special electrical and physical properties, such as thermal conductivity, which, in the case of fabrics, will increase substantially after the process of metallization of fibers.

An example is the wires made of synthetic and metallic fibers produced by DuPont, which can conduct electricity. Aracon fibers are made of a Kevlar core (an amide with special mechanical properties, being 5 times stronger than steel, considered at an equal weight) coated with silver, nickel, copper, gold or tin. They combine the strength of the core with the conductivity of metals, the result being stronger than steel, more flexible and lighter than copper and a good conductor of electricity. The yarns can be woven or knitted together with cotton or polyester in e-textiles.

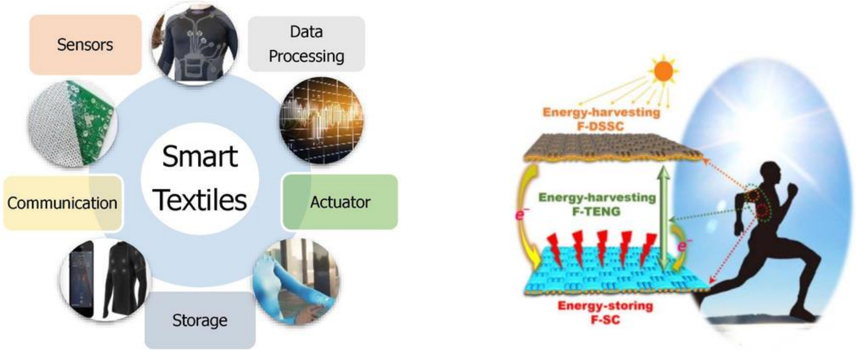
Fig 12:*Textile electrode for ECG measurements [48]*

In order to create and combine properties such as flexibility, user comfort and the ability of the device to be miniaturized and fashionable, the designers use different solutions such as carbon nanotubes, graphene, polymers and elastomers and dielectric composites, depending on the requirements of the applications and of their behaviors to different stimuli.

ECT (Electric Conductive Textiles) are the materials made of glass fibers coated with a few nanomers of carbon and which can be woven or knitted with any type of glass fibers or yarns. Carbon provides electrical conductivity and electrical resistance, and the latter can be a source of electric heating.

3. E-TEXTILES

E-textiles can be defined as textile fabrics with additional functions determined by the conductive elements or electronical components (sensors, actuators and control units) [29], [30]. Suplimentar caracteristics for the new functions can be sensitivity, heating, lighting, parameter measurment and recording. In the same time, e-textiles can be considered electronic products with textiles properties derived from the textile platform. Conventional textile features are needed to assure the mechanical properties during use and maintenance: tensile, abrasion, shearing, torsion, compression, bending. If the e-textile is designed to be worn close to the body, it had to satisfy the requirement of the wearer: to be comfortable and breathable.



a) *b)*

Fig.13*: a) E-textiles applications; b)Principle of the fiber-based, self-charging power system consisting of fiber-shaped triboelectric nanogenerator, fiber-based, dye-sensitized solar cell energy harvesting fabric, and fiber-based supercapacitor energy-storing fabric [31]*

E-textiles have the great advantage of the flexibility and, in some cases, extensibility, which means that they can be processed, tailored to the human body like conventional textiles for clothing (such as shirts, dresses), allowing a person to "wear" electronic devices effectively. At the same time, they can take the form of household or even decorative objects. Regardless of their destination, one can notice properties and functions that they must fulfill and which are typical of conventional textiles (aesthetics, comfort and protection), but unlike traditional electronic devices, e-textiles must have different properties:

• Low power consumption. Due to the impossibility of having external energy sources and high mass accumulators, the energy consumption must be very low. Finding an architecture that minimizes the number of processing and communication nodes is required. There are also methods of generating energy, including photovoltaic or solar cells, thermoelectric generators, piezoelectric nanogenerators, triboelectric nanogenerators, biofuel cells, electromagnetic generators and radio frequency harvesters, kinetic or thermal energy, but the energy consumption of smart clothing must be as low as possible [31]. The energy sources structure, size, power density and energy output are designed according to the type of product. They have to conform to the body and be flexible, resistent and nontoxic.

• Distributed processing capacity. The limitation of the processing power of a single node is due to constraints such as cost, size and consumed energy. Modern techniques such as parallel processing will be needed to maximize the computing power of existing nodes. At the same time, the constraint related to energy consumption implies finding optimal processing solutions and optimal use of computing power.

• Multiple communication channels. The existence of several processing nodes implies the use of several communication channels. The presence of faults requires a topology and protocol that take into account both communication errors and the reconfiguration of the network.

The complex nature of smart textiles requires special attention in cutting operation, which must consider the arrangement of integrated circuits on the material and the right connections. Simple devices such as resistors, capacitors or coils can be sewn directly onto the fabric. Other components, such as LEDs, quartz crystals, or surface mount components (SMDs), are tinned to the existing metal structure. Devices such as integrated circuits can take the form of staples or buttons. They can use fabric-mounted plinths to be removed during the cleaning process.

Electronic systems integrated in textiles are used for image sensors, flexible displays, biomedical devices and other emerging applications. In this regard, organic conductors and semiconductor materials with good flexibility and processability at low temperatures are designed. The deposition of thin films of inorganic materials or carbon nanotubes, graphene wafers, nanoparticles, nanowires, nanoribbons or semiconductor nanomembranes allow the obtain of high performance circuits that are not only flexible but are, in some cases, reversibly extensible, with elastic responses to compression and tensile deformations of 100% or more [32].

Figure 14 shows an example of a fabric-fixed CMOS (complementary metal-oxide semiconductor) inverter. Even after bending by about 5 mm, the inverter works well, as shown in the lower right frame of Figure 15 bottom. This type of e-textile offers better performance than yarn or fiber-based alternatives, but there is a limitation given by the manufacturing process. PDMS (Polydimethylsiloxane) adhesion layer covers the fibers of the fabric to achieve pasting without forming chemical bonds with the fibrous substance [33].

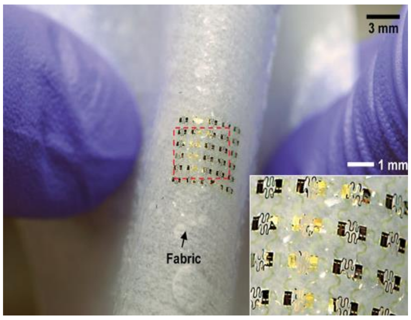


***Fig.14**: Electronic circuit integrated on a laminated complex with a thin layer of PDMS [33]*

As the existing metal structure in some e-textiles cannot be rebuilt as a result of cutting and sewing operations, it is preferable to design intelligent products from as few parts as possible. However, by synchronizing the conductive network with the fabric design, the electrical network of the product can be reconnected by sewing. The endurance of wearing and washing smart clothes can be improved by protecting the metal wires and components with a synthetic polymer. It has been found that the adhesives and the conventional way of gluing cause the connections between the fibers and the chips to break under conditions of automatic washing. A viable alternative to these may be dry cleaning.

Because most applications of e-textiles are used in the medical field, protective clothing and sportswear, special attention is paid to product maintenance activities. For repeated use of e-products, both household and industrial washing are required, especially for medical and protective equipment. Sometimes, an operation is required to restore the serviceability of the products after cleaning.

Regarding the production process of e-textiles, testing must be done to ensure client compliance. The life of the products is influenced by the washing resistance, evaluated in relation to the most appropriate standards. Standards for household washing of textile materials (ISO 6330:2021) industrial washing of work equipment (ISO 15797:2017) or leisurewear and sportswear e-textile systems (IEC 63203 204-1:2021) are used. IPC 8981 are new standards that clarify the issues of washability and reliability [29].

4. SMART CLOTHING SYSTEMS

The most popular products that work as wearable technology are:

• Smart watches: Connected watches, such as the Apple Watch or Samsung Galaxy Watch, that allow the wearer to answer phone calls, track fitness, track sleep, and more.

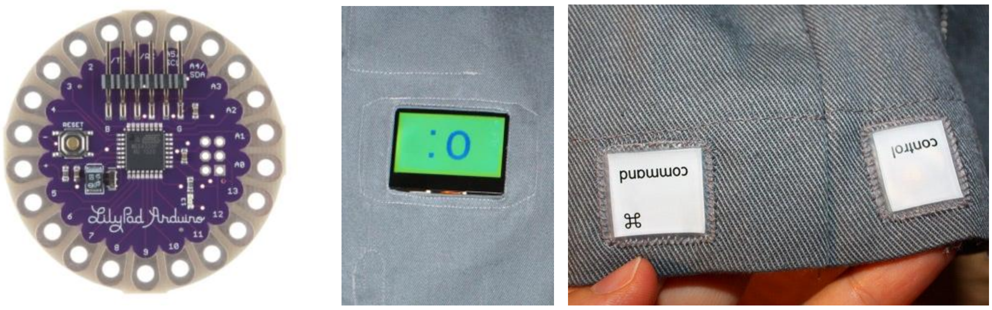
• Smart rings: technical jewelry that concentrates the functions of a smart watch in a ring.

• Smart clothing: clothing made of technologically advanced material or incorporating electronic command, control or monitoring devices.

• Advanced medical technology: "holter" type systems that allow the monitoring of the electrocardiogram or other physiological parameters and that transmit data to the cardiologist or to the first aid units.

• Head-mounted displays (HMDs): VR virtual reality headsets or other types of displays (on glasses) that allow you to identify, recognize various objects and situations, or interact in a game.

Many smart clothing and wearable technology projects involve the use of e-textiles [34]. They fulfill their main role, that of barrier for the human body, but they extend their functionality by informing, protecting and relaxing the wearer. By integrating electronic components, sensors and interconnectivity directly into garments, the number of functions of traditional clothing is increasing, creating new applications. Smart clothing products have a new property; they allow the exchange of information. They participate in the recording, analysis, storage, sending and display of information, with applications in protection (danger detection and request for help), medicine (for monitoring health and treatment of injuries), army (uniforms with motion detection, temperature measurement, health assessment), sports (monitoring parameters), IT (textile keyboard, computer interface and games).



a) *b)*

***Fig.15**: a) LilyPad Arduino [39]; b) Jacket with an LCD display [38]*

The hardware based on Arduino micro-controllers has remarkable potential [35]. LilyPad Arduino 328 is a microcontroller programmed by Arduino, designed to be easily integrated into e-textiles and wearable technologies. It offers the same functionality as the Arduino, in a lighter, round wiring, designed to minimize clamping with a profile with wide ears that can be sewn and connected with conductive thread. It works with supply voltages from 2V to 5V and has large fixing holes that make it easy to sew and connect. Each of these pins, except (+) and (-), can control an attached input or output device (such as an LED, motor, or switch) [37].

LilyPad (Fig. 15a) was developed by Leah Buechley and designed in cooperation with SparkFun, which allows the connection of a limited number of input, output and sensor devices, but with the great advantage that it is washable.

The web page from [37] presents a jacket that integrates a LilyPad, two buttons and a display to select and display emoticons (fig. 15b). In addition, in the direction of making interactive clothing or for expressing emotions using Arduino controllers, an evening dress was implemented that achieves various lighting effects using LEDs. Another example would be the use of an accelerometer to detect gestures and the display of groups of LEDs in the form of constellations on a dress (Fig. 16) [39].

***Fig.16**: An evening dress with light effects depending on the condition of the wearer and an example of a dress that displays constellations [39]*

Levi’s Trucker jacket with Google Project Jacquard technology (Fig. 17b) is the second version (2017) of the smart jacket designed for cyclists, after The Commuter line (Fig. 17a) developed in conjunction with Schoeller in 2011. This jacket applies built-in Jacquard technology, which allows it to be used without looking at the screen. It is equipped with a touch-sensitive remote control element for phones in the cuff of the left sleeve that connects wirelessly to the phone. The technology allows using touch gestures, such as swiping and tapping on the left cuff of the jacket to give commands about taking photos, requesting useful information, visual and haptic timing, pausing music, or choosing a song. In terms of maintenance, the denim jacket is usually washed after removing the Jacquard label [40], [41].

Dainese Airbag D-Air Smart Jacket [42] (Fig. 17c) monitors the rider 1,000 times a second with a waterproof sensor. The D-air airbag system at the rear and front offers maximum protection to the rider. It is well ventilated and easily foldable. The material is abrasion resistant, tear resistant and antipiling and has a rechargeable battery of up to 26 hours.

Project One is the world's first smart sailing jacket (Fig. 17d), produced by Plastic Logic and 878, including a small rectangular display in the sleeve with navigation information. The jacket is made of graphene material, with a high flexibility and weather resistance, and a low weight. This material fits the display, which also has high flexibility and low power consumption. The information will be obtained from the on-board systems of the boat and will be transmitted in real time on the display via Bluetooth. The display is powered by a small system that is built into the jacket, with an integrated battery, requiring the jacket to be charged from time to time. A mobile application allows users to choose the information they want to see on the sleeve screens in almost any visibility condition. [43]

The heated jacket has five heated areas, 2 at the front, 2 at the back and 1 at the neck. By pressing a button on the jacket, one can choose three temperatures. The Bluetooth application sets the heating time on the mobile phone. The base material of the jacket is made of DuPont Eco Cotton, being also waterproof. Washing can be done manually or by machine at a temperature of up to 30 C, with the specification that the battery must be removed from the jacket pocket before washing. The filling of this jacket is made of nylon / polyester and 80% duck down and contains carbon fiber heating elements with a fast warm-up time of 10 seconds.The jacket is resistant to cold wind and good thermal insulation, promoting blood circulation [44].

a) b) c) d)

***Fig.17**: a) Levi's – Commuter Jacket; b) Smart Denim Jacket, from Google and Levi's; c) Dainese Airbag D-Air Smart Jacket; d) Project One, the smart sailing jacket; e) Heated Jacket*

Additional functions of intelligent systems refer to the continuous monitoring of vital signs (breathing, heartbeat, and temperature), biosensors (sweating, dehydration, and stress indicators), position and activity control. Communications uses low power wireless devices, including integrated fiber antennas, which automatically transmit data to a monitoring station, improved visibility, external chemical detection, including toxic gases and vapors, flexible displays integrated with sensor output display, power generation and storage [45]. These functions are noticeable both in protective equipments and in military and medical applications.

***Fig.18**: Wearable antennas and military applications [46]*

The military uniform can be developed by creating a textile that detects noise with the help of microphones, which can be replaced by film-type piezoelectric sensors. Antennas built into military uniforms are made of a cloth with conductive threads, which is the radiant part of the antenna and is sewn over the uniform. Fire protection equipment, equipped with gas and temperature sensors can be another application of smart textiles.

Ordinary clothing usually dries naturally and requires a period of drying depending on environmental factors. In this case, it is passive drying. The presence of a moisture sensor in the fabric that measures the increase in humidity and activates an internal heat source defines an active drying process (Fig. 19).

Athletes' suits (jackets, pants or underwear) equipped with motion, temperature and impact sensors, as well as GSM and GPS systems may in an emergency send location and fitness information directly via SMS to a control center [34].

The Luminex material madely first in Italy is realized by inserting LED fibers of different colors in the fabric (Fig. 20a). A certain position of the switch will activate the LEDs in one of the available colors. The lighting effect can be created with optical fibers that have a long length and a thickness comparable to that of human hair, which can be woven into a fabric and connected to LEDs.

***Fig.19**: Smart textile clothing; a),b) jacket with Airvantage insulation (Goretex); c) MET5 heated jacket (North Face)*

Philips, in collaboration with Photonic Textile Group, has designed Lumalive technology that allows the wearer to change the appearance of the clothing product (mutant clothing) to convey messages or emotions, using different combinations of colors, light and textures (Fig. 20b) [47].

The technology refers to the incorporation of LEDs with three basic colors in a flexible polymeric support and the introduction of the laminated complex inside the various subassemblies of clothing products. Connecting it to an electric system and covering it with layers of textile fabric allow light to diffuse and highlight different motifs on the surface of the material (fig. 20b).

a) *b)*

***Fig.20**: LED technology a) Luminex garments; b) shirt created using Lumalive, developed by Philips*

Medical products are the main concern of researchers in the field of smart textiles. Levi Strauss has designed anti-radiation clothing to protect against possible radiation emitted by mobile phones, and the Hohenstein Institute Textile Research Center has developed products that combat dermatitis and rheumatism. The power supply problem for medical and sports equipment has found a practical solution in using a semiconductor as a heat generator (according to Infineon Technologies). Its operation is based on the transformation of the temperature difference between the human body and clothing into electricity.

Newborn clothing is another example of the use of e-textiles. They detect when the child is out of breath or need care and send the alarm to the parents. By monitoring heart function, respiratory function, and body temperature, sudden death syndrome can be prevented.

Nuubo had designed a medium / long-term ECG monitoring system that replaces the classic electrode application and connection technology with textile electrode technology embedded in a stretchable vest (Fig. 21a). The Nuubo textile electrode is a Silver textile-electrode composite with ECG cream and avoid the skin allergies. The seamless elastic fabric in both axes has flexibility and allows patients to move freely, beeing comfortable and washable. NuuboREC with two ECG Leads allows up to 30 days continuous recording, Bluetooth low energy transmission for real-time monitoring and signal evaluation [48]. The system allows a remote diagnostic in order to improve the early illness detection.

a) *b)* *c)*

***Fig.21**: a) Nuubo ECG patient monitor; b) Weartech Men's Gow Smart T-Shirt; c) Xiaomi Mijia ECG T-shirt*

Another medical application is consisted by Weartech Men's Gow Smart Sports T-Shirt (Intergrated Cardiac Sensors) [49]. Seamless fabric of 92% Polyamide and 8% Elastane technical yarns with Bosy thermoregulation ensures good comfort and moisture transfer to the outside. The T-Shirt has integrated textile sensors to measure heart rate, calorie, fat and carbohydrate burn (Fig.21b).

Xiaomi Mijia Sports ECG T-shirt (Fig. 21c) made of 49% cotton, 48% polyester and 3% spandex has completed with Mijia ECG Bean connected by Bluetooth 4.0. The T-shirt monitors the heart rate in real time during a 1-minute exercise with a high sampling rate of 250 times per second. The smart ADI ECG chip is attached to an elastic Co-tech nylon band on the chest of the shirt and signals the heart rate in different colors to prevent injury. The shirt can be washed and the waterproof rating is IPX7 [50].

5. CONCLUSIONS

The e-textiles are combining the warp or weft structure with electronics devices in order to control, measure, communicate, command and serve the purpose of the owner. As most of the textile products are washable, versatile, lightweight and cheap, their incorporated electronic components are the opposite, unwashable, delicate, fragile and electrically powered. Therefore, the future e-textiles must be water and mechanical resistant, in order to comply with the traditional textiles qualities.

In comparison with electronic sensors, the composite textile equivalent have many advantages. For instance, e-textiles are malleable and subtle; therefore, they can pass unobserved by the bearer or the observer. Depending on the base material, the can be also smooth and breathable offering an important advantage. Nowadays, most of the smart textiles are embedded in high-technology products and could be found on the shelf of many stores. Although, the medical application are still subject to approval and standard compliancy by the national authorities.

However, reusing them without losing their qualities is a significant concern. One of the most significant issues for e-textiles is to make them reusable and efficient enough, as well as to make them durable and reusable beyond the washing process. Another challenge with electronic textiles is figuring out how to combine the best materials to achieve the needed properties and produce hybrid materials from both a textile and an electrical standpoint. Because of the miniaturization of the electronics industry, these electrical components are now available on the market, and study into their inclusion into textiles has piqued academics' attention. In addition, by developing methods for incorporating electronic chemicals into fabrics, some of the disadvantages that come from the maintenance process of e-textiles can be eliminated.

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