Chapter

Smart E-Textile Materials

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Abstract

Smart textiles are one of the areas that provides added value to textile materials. It is a sector that has been developed with new technologies, new fibers, and textile materials. The production of smart or intelligent textiles cooperate with other branches of science like nanotechnology, materials science, design, electronics, and computer engineering, etc. Smart textiles are classified into three groups as passive smart textiles, active smart textiles and ultra smart textiles according to their performance characteristics. Passive smart textiles are the first generation of smart textiles and sense the external conditions; for instance, UV protecting clothing, conductive fibers, etc. As active smart textiles respond to external conditions, ultra smart textiles sense, react, and adopt themselves to conditions. Shape memory materials, chromic materials, heat storage, and thermo-regulated fabrics are the typical applications of active smart textiles.

Keywords: smart textiles, E-textiles, intelligent textiles, color-changing materials, phase-changing materials

1. Introduction

Textiles, with the basic characteristics of clothing, protection, and esthetics, are the indispensable part of our lives, but in recent years with the development of technology and the variation of requirements, the demand to smart materials and intelligent textiles grows increasingly all over the world. In other words, technology has also taken control of textile industry. Smart textiles have superior performance and functionalities for the applications ranging from simple to more complicated uses such as military, healthcare, sportswear, etc. Smart or intelligent textiles can also be called as the next-generation textiles.

Many classifications related to smart textiles are available in the literature. In this chapter, the classifications based on the esthetic and performance functions are mentioned as two categories. Esthetic smart textiles use the technology for fashion design, because of their ability to light up and change color. Light-emitting clothes and luminous dresses are the typical and commercial examples for esthetic smart textiles. As for the performance, smart textiles are classified into three categories as passive smart textiles, active smart textiles, and ultra smart textiles.

Passive smart textiles can only sense the environment, as they are just sensors. UV protecting clothing, conductive fibers, plasma-treated clothing, and waterproof fabrics are the typical examples of passive smart textiles. Active smart textiles can sense the stimuli from the environment and also react to them; besides the sensor function, they also have an actuator function. Phase change materials, shape memory materials, and heat sensitive dyes are active smart textile applications.

	Sensing external conditions	Reacting	Responding and adopting
Passive smart textiles	√		
Active smart textiles	√	√	
Ultra smart textiles	√	√	√

Table 1.
Classification of smart textiles.

Ultra smart textiles take a step further. Ultra smart textiles are materials that sense, react, monitor, and adopt themselves according to the stimuli or environmental conditions, such as thermal, mechanical, chemical, magnetic, or other sources. An ultra smart or intelligent textile essentially consists of a unit which works like a brain, with cognition, reasoning, and activating capacities. For instance, spacesuits, musical jackets, and wearable computers are ultra smart materials [1, 2] (**Table 1**).

In the mid-1970s, with the development of personal computers, a technological explosion was recorded in all the areas of human activity for any purposes. In the early 1990s, the benefits of smart textiles became apparent. Many researchers have studied on smart materials and textiles. Chan Vili studied the use of shape memory materials in developing high performance smart textiles, taking into consideration the ways for enhancing the esthetics of woven interior textiles. Dunne et al. provided an overview on textile integration strategies and component attachments. Choi and Jiang presented a system intended for cardiorespiratory measurement to monitor sleep condition. Mattmann et al. analyzed a yarn sensor that is nearly hysteresis-free while measuring elongation along body parts, for example, the back. Paradiso et al. presented a smart garment that can be used as wearable healthcare system. Cho et al. compared different conductive textiles and their performance for measuring joint angles.

The market for smart textile is growing with a high potential globally. The rise in demand for smart textile products is causing the existing market to expand, leading the way to new players to enter the smart textile market. In the emerging economies, the market share of smart textile consumed relative to conventional textile products is increasing. The global smart textile market size is expected to reach $5369 million by 2022 from $943 million in 2015, with a CAGR of 28.4% from 2016 to 2022. The global smart textile market is thriving and witnessing significant growth owing to the numerous applications in various industries.

2. Functions of smart textiles

Smart textiles are smart systems that can both perceive or communicate the environmental conditions and can detect and process the wearer's condition. They can use electrical, heat, mechanical, chemical, magnetic, and other detection systems to detect them. Smart garments are separated from wearable computing systems by revealing the importance of the garment on which they are integrated. Wearable computing systems are formed by the traditional systems being attached to the garment in some way. The equipment used is placed in non-textile ways without being integrated. Although some electronic materials have been reduced to be used in garments, the actual smart garments should use materials made entirely by textile production. The electronic materials to be placed must not impair the comfort of the standard textile material garment. Therefore, providing this combination is vital for wearability in smart garment and textile manufacturing. It is clear that smart textiles are simple computer systems and have five functions basically

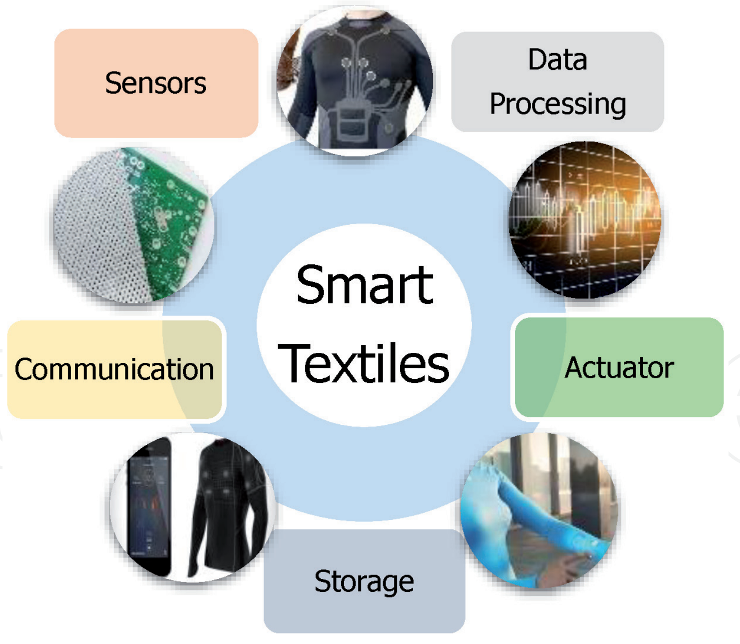

Figure 1.
Functions of smart textiles.

as sensors, data processing, actuators, storage, and communication (**Figure 1**). But it must be compatible with the function of clothing such as comfort, durability, resistant to regular textile maintenance processes, and so on [1, 2].

2.1 Sensors

Sensors are the components that transform one type of signal into another type of signal. There are already systems in the textiles that measure heart, breath rate, temperature, movement, and moisture, but these systems work with the installation of traditional sensors in textiles. At the present stage of intelligent textiles, the sensors are produced from real textile material, and the heart, breath, and movement sensitive sensors are already produced with satisfactory results. There are also different materials and structures that have the capacity of transforming signals:

- **Thermal sensors:** a thermal sensor detects thermal change, for example, a thermistor that changes resistance due to thermal change. Another example is the stimuli-responsive hydrogels that swell in response to a thermal change.

- **Light sensors:** these sensors that convert light energy into voltage output, for example, photoresistors.

- **Sound sensors:** these converts sound into an electrical signal, for example, piezoelectric materials.

- **Humidity sensors:** these sensors measure absolute or relative humidity. An example that can be interesting for textile use is the capacitive device that changes dielectric properties with the absorption of moisture.

- **Pressure sensors:** these sensors convert pressure to an electrical signal. A pressure sensor can be based on simple operations such as opening or closing a circuit. But they may also be based on more sophisticated forms like capacitive or piezoelectric phenomena.

- **Strain sensors:** these sensors convert strain into an electrical signal. Strain sensors may be based on semiconducting materials, strain sensing structures, or piezoelectric effects.

- **Chemical sensors:** these are a series of sensors that detect presence and/or concentration of chemical/chemicals.

- **Biosensor:** it is a sensing device that contains biological elements which is the primary sensing element. This element responds with a property change to an input analyte, for example, the sensing of blood glucose levels [3–5].

2.2 Data processing

Data processing is one of the components that is required only when active processing is necessary. According to information theory, it is necessary to process every collected information and data and obtain the desired output. Therefore, in order to obtain the desired output by processing the parameters collected by the sensors, a processor suitable for the relevant purpose is required in smart textiles. The information processing element is only needed when the textile is actively processing information. Textile sensors can provide information to a large extent, but the main problem lies in how the information is evaluated and the processor component comes to the fore. Variation of signals and analysis of signals are main problems for data processors. Furthermore, the energy required for the processor is another problem encountered today. Since the electronic components required for energy do not have sufficient smallness and flexibility, they differ from the structure of the textile. The waterproofing requirement of these energy units and other electronic units is another problem. However, these problems are generally seen more in the garment-type smart textiles. In the case of vehicles, this is not a problem; the information processing elements can be mounted inside the vehicle [4, 6].

2.3 Actuators

Actuators are the devices designed to perform the necessary action according to signals from the sensor or processor. These devices are also called actuators. Actuators act by an effect sent from the sensor and possibly by first passing this effect through an information processor to perform objects such as moving objects, releasing materials, and making noise. Shape memory materials are the best examples in this field. Shape memory alloys can be formed in the form of lattice. Its responsiveness to heat changes enables shape memory materials to be used as an actuator and meets the requirements of intelligent textiles very well. Another type of actuator is the materials that are capable of releasing certain chemicals under certain conditions, which can be trapped in protective microcapsules or chemically bound to the fiber polymer. Such secretory materials have various commercial applications. Odors, skin protectors, antimicrobial products, and so on. Application studies have been started with active secretion methods and some simple projects have been implemented yet. It is contemplated that the release will be effected by triggering other environment variables such as temperature, pH, humidity, chemical substance, and the like. In one view, a system capable of actively controlling drug secretion would integrate the body with a smart suit capable of receiving simple health findings. For this reason, it is expected that the actuators will have some technological and mechanical components and will bring problems in both fields [6, 7].

2.4 Storage

Storage is another component of smart textiles. Although not a fundamental goal, smart suits are expected to need a storage capacity to operate on their own. While the information to be stored in smart textiles is usually information or energy, examples such as textiles that inject or emit drugs or odors indicate that this storage unit will also serve different areas. Detection, computing, actuators, and communication units generally require energy, especially electrical energy. Efficient energy management is achieved by combining the energy source and storage in an appropriate manner. Examples of the energy sources that can be used in clothing are body temperature, mechanical movement (the energy generated by movement resulting from the elasticity of fabrics or kinetic energy from body movement), radiation (solar energy), and so on. The energy source required for the operation of sensors, processors, and moving systems in smart textiles should be combined with energy storage capability. Nowadays, very small and light batteries are available, and this solution of this energy requirement is a method that comes to mind in the first place. Even if the flexible ones are manufactured, they are not sufficient in performance and are still under development. On the other hand, the situation is easier and the energy requirement can be achieved by direct contact with clothing or by wireless connection [8, 9].

2.5 Communication

One of the components of smart textiles is the communication component, which is shaped according to the type and need of communication. There are many types of communication within smart textiles. Some of the basic situations in which smart textiles are contacted are as follows: in one element of the garment itself; can be mounted between two different elements of the garment; and in order to command the garment by the wearer, contact is made to inform the wearer or his surroundings. In today's prototypes, communication within the garment is provided by optical fibers or by conductive fine wires. They are naturally woven and can be placed in textiles without the use of stitches. A specific communication protocol is followed to communicate with the wearer. The outlines of this protocol can be provided by the technologies described below. Optical fibers are used in the creation of optical screens, and France Telecom has managed to produce several prototypes by producing a sweater and a backpack. On the other hand, since it requires more than one fiber for a pixel, it appears that the present situation needs further consideration. Another communication protocol in smart textiles is pressure-transmission systems. Information can be provided to the garment with pressure-sensitive textile materials, and a data processing element needs to process these entered orders. In some intelligent textile applications, communication with wider environmental elements is important. For example, there are many situations in which the suit is required to interact with the vehicle when 41 drivers are handled. The first thing that comes to mind in the communication of the dress with the vehicle is the seat in which it is in direct contact. A wireless connection can be achieved by integrating an antenna into the suit. This antenna is integrated into the clothes. The major advantage of this integration of antennas to the garment is that a large area can be used for communication without the user even being aware of it. In the summer of 2002, a prototype was produced in Philips Research Laboratories. With regard to road safety or driving comfort, a lot of data about the driver, such as heat comfort, concentration etc., can be obtained using intelligent textiles for a better and safer driving quality. For risky human profiles, for example, heart patients can anticipate the problems of clothing and provide information to stop the vehicle or even call for help if necessary.

Although these developments are considered unquestionable, it is thought that these studies can only be implemented in the future with more advanced technology due to the limited information that can be obtained from the human body and the lack of materials and concepts for the systems to process this information [8, 9].

3. Applications of smart textiles

3.1 Shape memory textiles

Materials capable of remembering the original shape are called shape memory materials. Materials are shaped out of its original shape as the temperature change returns to its original shape with a chemical, mechanical, magnetic, or electrical external effect. There are many classes of shape memory materials such as alloys, polymers, gels, and ceramics. Shape memory alloys and shape memory polymers are the types of shape memory materials with applications in textiles. The important point in these applications is that the material used exhibits the shape memory effect at temperatures close to body temperature.

Shape memory alloys are composed of a combination of two or more elements with the properties of hardness and elasticity that vary considerably at certain temperatures. An example of the application of shape memory alloys in textiles is a nickel-titanium alloy, which is used in protective clothing against fire and high temperatures and provides different levels of protection according to temperature.

Under the degree of activation, the easily deformable alloy becomes more rigid at the degree of activation, taking its original shape. Alloy applied to the fabric in the form of a flat surface takes the form of spring with the effect of temperature, increasing the air gap in the fabric, thus increasing the protection of the garment and the formation of second-degree burns under the same conditions.

The degree of activation can be adjusted by changing the ratio of nickel to titanium in the alloy. T-shirts developed by an Italian company Corpo Nove shortens the sleeves with the increase in temperature and do not require ironing, which is another example of the application of shape memory alloys in textiles.

Shape memory polymers can be used in fiber production or can be applied to the fabric by finishing, coating, or lamination processes. Polymers have different water vapor permeability, air permeability, modulus of elasticity, refractive index, and expansion properties below and above the glass transition temperature (Tg).

The shape-memory polymer, placed between two layers of fabric, has a tight structure below a certain temperature and prevents heat, water and wind circulation around the body. By the increase in temperature it starts the molecules motion and becomes a porous structure resulted with the expulsion in body heat. This flexible barrier function makes it possible to adjust the insulation properties of the garment to temperature changes and to provide optimum comfort in any environment.

The crystal structure of a material at a given temperature determines its many physical properties. During the phase change, besides microscopic changes, macroscopic changes such as modulus of elasticity, coefficient of friction, electrical conductivity, and hardness occur. One of the important applications using these changes is surgical yarns.

Self-tangled surgical threads are designed for endoscopic surgery, and implants that are small in normal ambient conditions are designed for use in endoscopic surgery. Thus, it will be possible to perform operations with small incisions, shortening the healing time and reducing the risk of infection. Shape memory textiles can also be used for esthetic and decorative purposes. Textile materials that deform with the stimulating effect acquire a third dimension [1, 8, 9].

3.2 Color-changing textiles

They are intelligent textile materials that have the ability to change color with an external stimulus effect. They are obtained by incorporating color-changing materials into the structure of textile materials. Color-changing materials are chromic materials or chameleon materials. There are many different color-changing mechanisms, but mostly the electron density or molecular structure of the material changes due to the external stimulus effect and the color change occurs; when the stimulus effect disappears, they return to their initial state where they are more stable and get their first color.

Color changing materials are specified according to the effect mechanism. Light, heat, pH change, solution, friction and pressure are basic effect parameters. They are also called by the effect type as photochromic (light effected), thermochromic (heat effected), electrochromic (electric effected), solventchromic (solution effected), halochromic (pH effected), tribochromic (friction effected), mechanochromic (pressure effected).

The application of chromic materials to textile materials can be done by different methods at different stages. For example, a chromic dyestuff can be used for dyeing fibers by conventional dyeing methods; the fibers can be added to the fiber structure at the polymer stage; color-changing fibers can be obtained by melt spinning or wet spinning; they can be mixed with resin and coated onto the fabric surface, thereby using them for fabric printing or dyeing.

Smart textiles change colors depending on environmental factors; they are important because of their esthetic advantages. It is thought that the use of color-changing textiles will become more widespread in the future in the field of fashion and will change the color depending on many other effects besides the existing ones. Photochromic, thermochromic, electrochromic, and solventchromic textile applications can be seen in fashion and decoration. They are available for T-shirts, bags, and hats.

The reversible color-changing property of thermochromic dyes indirectly changes the heat absorbing property of the textile material. While light reflection increases, darker colors increase heat absorption. Because of these properties, thermochromic dyestuffs are used to coat the uniforms of firefighters who turn white under very high temperatures and reflect the heat in this way and also in building coatings. The fact that thermochromic dyes accelerate the dimensional change of fibers provides another thermoregulation effect. At high temperatures, fibers containing thermochromic dyestuff shorten. The pores of the fabric are enlarged so that a large amount of air is introduced in and consequently the body temperature decreases. At low temperatures, the fibers are elongated, the pores are closed, and the fabric maintains the body's temperature [1, 2, 10, 11].

3.3 Phase-changing textiles

Phase change materials, with a textile substrate, are basicly thermo regulating materials. When the melting temperature of the material is reached during the heating process, the transition from solid state to liquid, that is, a phase change occurs, during which the phase change material absorbs and stores a large amount of heat. The temperature of the phase-changing material remains virtually constant during the entire phase change. During cooling of the same material, the stored heat is transferred to the medium and the transition from liquid to solid state takes place. Again, the temperature of the material remains constant throughout the phase change process. If the temperature change continues except for phase change, the temperature of the material also changes.

By using two or more phase-changing materials together, the temperature range at which the phase change occurs can be adjusted so that it can be used in specific applications. Textile materials in which the phase-changing materials are applied have a cooling effect, heating effect, or thermoregulation effect caused by the absorption or dissipation of heat depending on the ambient temperature conditions. The degree of all effects depends on the type of material used, its thermal capacity, and the amount of application. Of course, in order to obtain the desired effect efficiently, the temperature values in which the material changes phase must match the temperature values to be encountered during use.

The application of phase-changing materials to textile materials can be done in different ways. Microencapsulated phase-changing materials can be added to the structure of synthetic fibers during fiber drawing, can be added to the nonwoven structure, or can be coated on textile surfaces. Product design is also very important in all these applications. For example, when changing from a warm indoor environment to a cold outdoor environment, it was seen that the garment containing the phase-changing material showed heating effect on average 12–15 min depending on the phase-changing material content and outdoor conditions.

If the structure of the garment is not designed well, it is also possible to dissipate heat from the phase-changing material. When we look at their usage, they have commercialized usage in hospital beds and pillows. With the effects of thermoregulation, they keep the temperature at levels that do not disturb the patient and ensure that the patient does not sweat and thus contribute to the healing process of the patient. There are also studies on heating or cooling plasters and heating blankets for use in the medical field. In long-term operations, it is possible to provide thermal comfort by preventing surgeons' sweats by providing a coating on the inside of their garments with a phase-changing material. There are commercialized everyday garments, underwear, shoes, and sportswear where phase-changing materials are applied [2, 10–12].

3.4 Wearable smart electronic textiles

Wearable smart electronic textiles make lifes more reliable, healthy and comfortable in many areas. Wearable smart electronic textiles; temperature change, light, moisture, such as environmental stimuli can detect, react to these stimuli, can change itself according to external conditions, store data, these data are used to produce information and communication purposes. In this sense, they are perceived as intelligent technologies that will have the qualities to support the vital activities of human beings such as sensation, movement, communication, taking action, and adapting to environmental conditions.

The four basic elements of wearable smart electronic textiles are conductivity, sensors, wireless communication module, and power supply. Depending on the nature of these components, the degree to which they can be integrated into the textile material varies. As a first method, existing electronic devices can be integrated into the textile material. An example of a life belt to which the existing sensors are attached is an example. The biggest advantage is that the process is very easy. However, the disadvantages of the large, inflexible electronic components used are disturbing the user and washing problems. The second method is the production of electronic components using textile materials and textile manufacturing techniques (textronics) and their use as part of the garment. The disadvantage of this method is that integration processes can be carried out easily, but that a limited number of electronic components can be produced by textile materials and methods. The third method is to produce and use fibers to provide some electronic functions (fibertronics).

Clothing equipped with sensors that monitor vital functions such as breathing, heart rate, and body temperature increases the mobility of the patients while providing the confidence of being constantly monitored and increasing the standard of living for chronic patients and the disabled. High-performance active sportswear provides a performance increase by following the athletes' body functions such as pulse, breath, body temperature, and activity-related values such as speed, distance, time, and calories.

Various applications are available in the field of medicine, sportswear, and protective clothing. Lifeshirt is an example of the protective use of intelligent electronic garments designed for pioneers, hazardous workers, firefighters, and industrial cleaning workers. Lifeshirt is a belt that contains sensors that detect indicators related to vital activities such as respiratory rate, heart rate, and body temperature and can transmit this information to a remote monitor via a modem. Through this belts, the health status of the wearer can be monitored continuously, and strategic decisions can be made by evaluating the general situation of the team.

The Cyberia Smart Coverall with wearable technology is designed to be worn in polar areas. The project was started with the aim of developing a garment displaying the health data of the wearer. The garment displaying health data also includes a global positioning system (GPS) for use in the event of a loss and a GSM module that can automatically send the coordinates and health information to a predetermined number in the event of an abnormal condition [2, 5, 13].

4. Innovations in smart textiles

4.1 Laser-printed waterproof and stretchable e-textiles

The next generation of waterproof smart fabrics will be laser printed and made in minutes. That is the future imagined by the researchers behind new e-textile technology. Scientists from RMIT University in Melbourne, Australia, have developed a cost-efficient and scalable method for rapidly fabricating textiles that are embedded with energy storage devices. In just 3 min, the method can produce a 10 × 10 cm smart textile patch that is waterproof, stretchable, and readily integrated with energy harvesting technologies. The technology enables graphene supercapacitors—powerful and long-lasting energy storage devices that are easily combined with solar or other sources of power—to be laser printed directly onto textiles (**Figure 2**).

4.2 Conductive textiles

A conductive textile can be defined as a fabric which is made from the strands of a metal that are woven, blended, or coated during the creation of the textile. Conductive metals such as silver, titanium, gold, nickel, and carbon are utilized by the textile. Conductive textiles inhabit the property that it can conduct electricity and thus is used in several applications by different end-use industries. The primary function of the conductive textile is controlling the static electricity and protecting from the electromagnetic interference. Based on type, the woven textile segment has significant growth during the forecast period. Woven textiles are widely utilized by various end-use industries such as military and defense, healthcare, and sports and fitness. As these textiles offer high standard performance in shielding and conductivity, they are considered to be the preferred type of conductive textiles utilized across the globe, thereby boosting the growth of the woven textile segment [14].

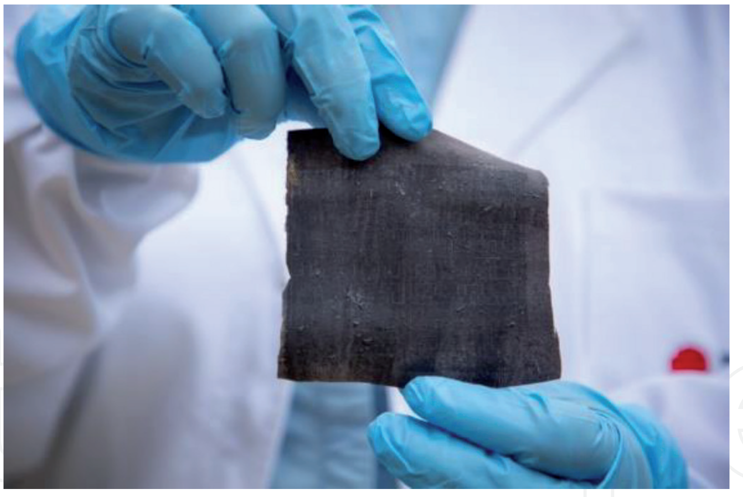

Figure 2.
Laser-printed waterproof and stretchable e-fabric.

4.3 Medical smart textile as a cardiac supporting device

Knitted and woven fabrics are being used as a cardiac supporting device. An innovative medical device has been made by using the knitted and woven fabrics, which corrects the life-threatening conditions of the heart and vascular system. Implantation of the new devices requires less invasive surgical procedures and involves less risk than traditional procedures, while also causing fewer complications in hospital days. Heart failure is a chronic syndrome that occurs when the heart is not getting enough amount of blood. Generally, valve leakage is reliable for this. The treatment of heart failure is only the drug therapies and surgical, but they are temporary treatment. The only permanent treatment is a heart transplant. But most of the patients cannot qualify for heart transplantation. So they have to do the surgical treatment or drug therapy.

So the scientists have developed a device named as a cardiac support device (CSD), which is intended to halt the progression of heart failure. The cardiac support device (CSD) research was conducted to determine the best material, yarn configuration, knit pattern, and processing to use to produce CSD fabric. It is a mesh-like warp knitted fabric. The fabric is fabricated from the multifilament texture (**Figure 3**).

Polyester fabric is used for it. Polyester fabric has biological tissue response and it has the compatibility for the epicardial surface of the heart. The polyester yarns are warp knitted into a mesh configuration using a variation of an atlas stitch. After knitting, the fabric is conditioned to ease its handling during the processing to manufacture the CSD [9].

4.4 Smart clothing with improved comfort and safety for firefighters

Temperature is a major challenge in numerous professions—thermal comfort and occupational safety. For example, in emergency missions of fire and rescue services as well as in mines and construction sites, the working conditions often cause extreme physical strain (**Figure 4**).

Working in hot situations without wearing appropriate protective clothing and equipment often causes high heat stress. It will be perfect if the amount of such stress could be monitored in real time during the performance of different work tasks. To solve this, researchers and companies together developed a wearable technology solution for firefighters. It allows the real-time monitoring of heat stress, thus improving the occupational health and safety in challenging temperatures.

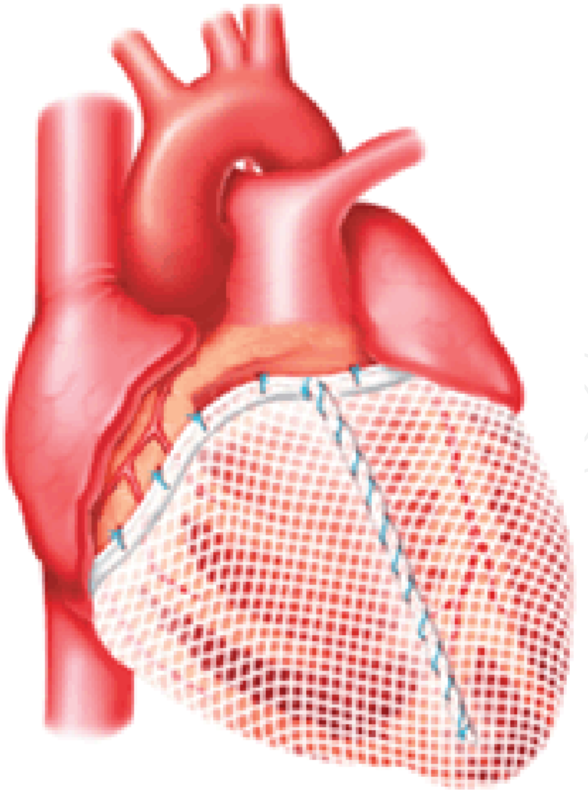

Figure 3.
Medical textiles working as a cardiac support device.

The new method has been tested at the Finnish Institute of Occupational Health in Oulu and at the Emergency Services College in Kuopio. Based on the first tests, it would seem to offer a very promising tool for commanding rescue missions and enhancing the occupational health and safety of firefighters [10–12].

4.5 Graphene-based smart textiles

Graphene has already made a huge blast in the next step of wearable technology. Due to the thermal conductive properties of graphene, the warmth produced by the human body is preserved and distributed evenly in cold climates and allows an even body temperature during physical activity.

A renowned company Directa Plus, a producer and supplier of graphene-based products, teamed up with Colmar, the high-end sportswear company, has launched a new collection of SKI jackets containing graphene-based products.

Figure 4.
Smart clothing, adjusting the heating control autonomously.

The new technology SKI jacket contains graphene Plus (G+) and is worn by the French national SKI team for multiple successful tournaments. It was explained that the key benefit of incorporating G+ is that it enables the fabric to act as a filter between the body and the external environment, ensuring the ideal temperature for the wearer (**Figure 5**).

A Chinese company called Shanghai Kyorene New Material Technology has also developed a graphene fiber that has been used to produce clothes, sportswear, and underwear products.

Recently, researchers have designed a low-cost, sustainable, and environmentally friendly method for making conductive cotton fabrics using graphene. These fabrics could lead to smart textiles and interactive clothes that will find applications in healthcare, wearable, and more. Functionalization of these conductive cotton fabrics was done by thermal reduction of graphene oxide (GO) adsorbed on cotton. Besides, researchers have created two ways to apply thin graphene sheets that either make the fabric super-hydrophobic or super-hydrophilic.

A team of scientists in Korea also announced the successful development of a technology to make a washable, flexible, and highly sensitive textile-type gas sensor. This technology is based on coating graphene using molecular adhesives to fiber like nylon, cotton, or polyester so that the fabric can check whether or not gas exists in the air.

Graphene has also strong cytotoxicity toward bacteria. So, this can be highlighted for maternity clothes to create coatings that prevent the growth of bacteria on the surface of the fabrics, thus protecting the pregnant against the possible diseases transmitted by bacteria. This type of protection will be very useful in gynecologists, nurses, and midwives clothing who assist the birthing woman in order to avoid the spreading of bacterial infections in newborns [6].

4.6 Smart denim jacket

The smart denim jacket designed by Levi's turns a portion of the fabric on the sleeve into a touch-sensitive remote control for phones to be helpful in everyday life. This is a second version of their Jacquard smart jacket first introduced in 2017.

Figure 5.
Graphene-based jacket.

The iconic jacket merges style with innovative Jacquard technology and allows the wearer to answer calls, play music, and take photos right from the sleeve. With the Jacquard technology, the jacket lets you access digital services right from your cuff, wherever you go. Get updates about your day, take a remote selfie, get notified if you leave your phone or jacket behind, and more, so you can stay focused on what is important (**Figure 6**).

The technology allows to use touch gestures, like swiping and tapping, on the left cuff of the jacket to issue commands. The new and improved Jacquard Tag wirelessly connects your Trucker jacket to your smartphone. Jacquard also provides you helpful alerts, like when you have left your phone behind, using lights on the Tag and vibrations in the cuff to get your attention [5].

4.7 Smart film fabric

DuPont Intexar is a revolutionary electronic ink and film that seamlessly transforms fabric into smart clothing for multiple applications. The technology is embedded directly onto fabric using standard apparel manufacturing processes, offering both ease of integration and ease of design. It is currently leveraged for three applications: fitness, heat, and shealth (**Figure 7**).

The technology for fitness and health function similarly with key components that monitor and transmit biometric signals. A thin layer of carbon or silver serves as a sensor, sensing electrical signals, while a conductor, made of a layer of silver, transmits currents throughout. Other films are integrated onto the textiles to shield the technology from water and additional exposure. The data received is captured and monitored via a third-party app. The heat application utilizes a battery-powered technology that includes a resistor, a thin layer of carbon that radiates heat, a conductor, a thin layer of silver that transmits the electrical currents, and additional films for protection.

Intexar is engineered and tested to perform as designed each and every time, with durability to outlast any alternative and offer unmatched comfort with its seamless stretchability. Intexar also offers a powered heating solution in a thin and safe application. The battery-operated technology enables clothing to generate heat, creating actively controlled on-body warming. This technology is particularly well-suited for outdoor activity and industry professionals within the utility,

Figure 6.
Smart denim jacket.

Figure 7.
Smart film fabric.

construction, military, forestry, mining, and infrastructure industries, among others. This technology also delivers advanced wearable health care through the sense and transmission of biometric signals. Primary uses include monitoring of pregnancy, telemetry and respiratory disorders as well as heat and electro-stimulation therapies.

5. Conclusion

Current developments in textile technologies, new materials, nanotechnology and miniature electronics, and wearable makes systems more convenient, but the most important parameter for users to accept wearable devices is comfort is sufficient. This is recognized as a challenging environment for the human body and the environment, mechanics resistance, and durability. In addition, the circuit design of the development of intelligent textiles, the knowledge of intelligent materials, microelectronics, and chemistry is basically integrated with a deep understanding of textile production. It requires a multidisciplinary approach.

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