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Intellectual Output IO4: eBook

BOOK OF BEST PRACTICES SMART SENSORS BASED TEXTILES FROM PRODUCTION MANAGEMENT TO END-USER

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ABSTRACT

DigiTEX project aims to support innovative approaches and digital learning technologies to accelerate innovation, teaching and learning in the field of medical, protective, sensorial and smart 3D textiles design, testing and manufacturing of the innovative advanced products for healthcare (protective equipment, wearable monitoring devices) in the context of the digital economy.

This book is Intellectual Output N° 4 of DIGITEX Project. It covers a range of best practices that have been designed and developed in the field of health care and protective textiles, providing also the perspective of the final user and the potential for market success.

The book is aimed to act as an introduction to the area, an overview of cases that are already in place and stimulate the interest in the sector, as well as an innovation process that must be applied in order to design and develop relevant technologies and applications.

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Chapter 1 Evolution of sensors-based textiles

Ioannis Chronis, Georgios Priniotakis, Athanasios Panagiotopoulos UNIWA, GREECE

Introduction

Research in the scientific field of Textile sensors dates back to some decades, and comes along with the evolution of the so-called *Smart Textiles, Wearables* and *e-Textiles*. The start was when non-conventional materials that changed property due to external stimuli were introduced into the yarns or fabrics. Textiles and clothing are the most widely used commercial products, used onto the human body and the ability of the garment to transmit information to humans was considered not only very useful for the customers, but also very promising and attractive from the marketing point of view. Textile sensors are one of the vital components of a smart textile and It is needless to detail further that the evolution of textile sensors goes hand in hand with the evolution of smart textiles in general.

In the rest of this chapter, we distinguish three generations of textile sensors (Figure 1.1), we should make clear that all of these generations of technologies are still evolving and applications are still developing, with promising results for all of the three described generations of textile sensors.

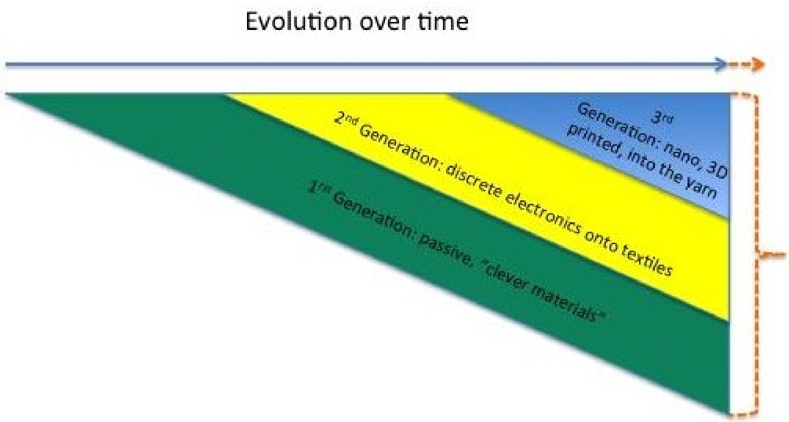

Figure 1.1. Evolution with time of textile sensors

First generation of textile sensors

The first generation of textile sensors is defined by materials that could create a simple and low quality/information signal, like a change of the shape or of the colour according to a change in the environment of the textile (stimuli). This sensing ability was attributed to new, by that time, materials, the most typical examples of which are the Shape Memory Polymers, Chromic and Phase Change materials etc. These materials are passive: there is no need for power supply and no need for an Input/Processing Unit/Output system and act as both a sensor and an actuator in terms of a typical automation system.

Phase Changing Materials have the ability to change phase, according to the temperature, usually from solid to liquid and vice versa. The most common materials used for this purpose are solid hydrocarbons (waxes), contained in foams or microcapsules, that are added into the fabric by layering or wet spinning. These materials possess both the sensing and the acting function and are usually used for heating garments according to the environmental temperature [1], [2].

Shape Memory Polymers are organic polymers that can modify their shape according to a stimulus like heat, pH, radiation etc. They are a blend of two polymers (co-polymer) with different melting points, which is the mechanism of the change of shape. Their main advantage is that they can spined into yarn and create a fabric with Shape Memory action [3].

Some other materials in this category are Chromic textiles that change their colour, Optical fibres, that transmit, detect and transmit light and pH sensitive dyes, that change colour according to the pH of the liquid absorbed in the surface of the fabric. The dyes contain pH indicator substances [4]. They must be fixed on the yarn or fabric. Integration is good, but sensing capabilities are minimal, so these products remain prototypes and have not been commercialised.

Capacitive pressure sensors are another application that was developed in this era [5]. In contrast to piezoelectric pressure sensors, they can be integrated much better to a textile with embroidery or even sewing. A relevant application is the embroidered keyboards, that used a pressure sensing array of conductive and non-conductive yarns, in order to create a binary signal (0/1, yes/no). Simple, washable, manufacturable (by embroidering), reliable but of course of low quality/information as an electronic signal. Although keyboards are typically not sensors themselves, they could be included in this category, since they provide communication of the textile with the user/wearer and are parts of the smart part of the smart textiles, like the sensors do [6].

Second generation of textile sensors

The second generation of textile sensors was based on discrete conventional electronic sensors, with wire or wireless connection to microcontrollers or Printed Circuit Boards (PCB's). These applications became popular due to the mass production and availability of a vast array of sensors, as well as the digitization of electronics and communication. This generation of textile sensors depicts the creation of prototypes that could provide really useful signals and information. The applications were mainly in biometrics of the human body and health and well-being monitoring. This is quite reasonable given the always active nature of the garment and the non-invasive nature of the biometrics sensors.

An emblematic example is the Arduino Lilypad ecosystem, that due to its small size, can afford for a better inclusion (sewing-on, stitching etc) in conventional textile substrates (fabric, garment). The Arduino Lilypad was introduced in 2007 and is a microcontroller board of the Arduino family, designed for textiles, meaning that it has holes for sewing onto the garments and having a flower resembling shape that can be better aesthetically accepted as an accessory of a garment [7]

The Arduino Lilypad ecosystem includes several sensors of a small size, affordable cost and for various parameters: sound, temperature, humidity, flame, photo restive, motion, level and many more. They were connected to the CPU (Arduino Lilypad) with embroidered or sewed conducting threads. From the technical point of view, Arduino Lillipad is not a great evolution, since it is an ecosystem of conventional electronic components, with poor integration in the garments and an aesthetically rather poor result. However, it was a big push to Do-it-yourself efforts and prototypes in the smart textiles sector, and it provided a good starting point for several efforts for prototypes mainly due to:

- the simple, and cheap handwear (input and output devices like sensors),
- the simple and easy programming environment for non-computer programmers and
- the big community that supported the creators.

In this aspect, it is an almost ideal bridge for the designers of smart systems (electronics) with the fashion designers of textile products. It is a good base for the novices in this sector, some of which will move to better functionable and fashionable creations.

Another solution of this generation is The Smimmer® ecosystem of wearable sensors, that was introduced in 2006 and has developed since then, into a complete solution for applications mainly targeted to medical and well-being solutions [8].

Applications and prototypes of this generation of smart sensors, had the problem of washability of the electronic parts, especially for the portable power supply (battery) but for the sensors as well. The solution was to detach the electronics part of the garment and wash the substrate garment and then attach back the electronic part. Alternatively, the electronic parts were encapsulated in water proof containers, a solution technically right, but of course the fashionable element is very limited. Dry cleaning is the most preferred solution in this case, but it is an expensive one and not without problems, since it is not done in the household, but in shops where the condition of the smart textile and of its parts/ constituents, cannot be guaranteed.

Third generation of textile sensors

Third generation is based on enhanced textile materials with inherent sensing properties, due to coatings of nanoparticles or included in the fabric or yarn during the spinning process. More technically sophisticated fabric structures-sensors with multilayer material of electroconductive metals or inherently conductive polymers (ICP) can be created. Integration is much better and the product looks and feels like a normal textile product. [9]. The expansion of nanotechnology is the base for these new textile sensors and it will probably mark the start of real products that will be massively commercialised, due to the availability of massive production techniques, as well as the appeal of the smart textile product that will look and feel like a conventional one.

3D printing of textile sensors is another recent development that can afford a massive production process, which is a big step forward towards commercialization of smart textiles. The sensors are manufactured by both conductive and flexible polymers and in this way, they are much better integrated onto the garment, avoiding the problem of hard-on-soft of the discrete electronic components on smart textiles. [10]

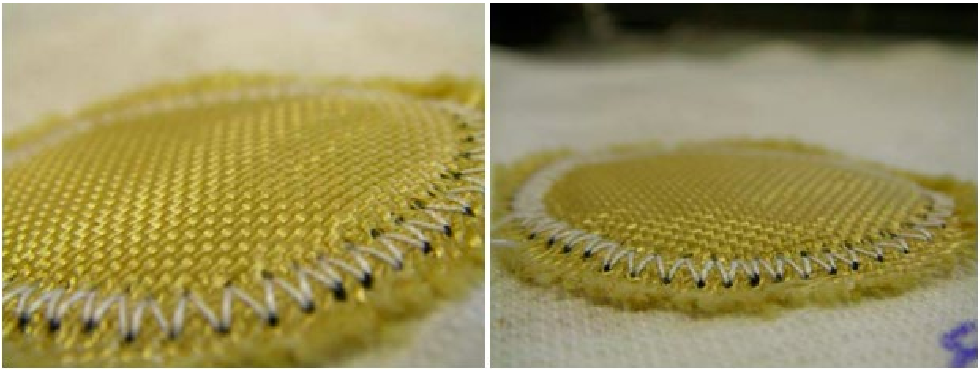

Figure 1.2. Gold coated para-aramid textile electrode pads (Tzerahoglou et al. 2011)

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Chapter 2 Textile materials requirements for sensors, actuators, batteries and wearable devices

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Introduction

Combination of fabrics and sensing properties lead to the creation of what we call smart fabric sensors. They are sensitive to multiple physical and chemical stimuli such as changes in temperature, pressure, force, and electrical current, etc. Sensing elements can be incorporated into fabrics at any level depending on the structural fabric element being modified or sensitised. These smart fabric sensors can be considered as part of the more general term of smart fabric transducers [1].
We can divide the smart fabric transducers into three main categories which are sensors, actuators and batteries.

Sensors

The textile materials often used in sensors can be roughly divided into fabrics, yarns and fibers. For pressure sensors, in order to detect or sense changes in strain, touch and pressure and convert them into electrical signals, conductive fibers, such as stainless steel fibers and carbon fibers, are usually required to conduct electricity [2].
Different materials and techniques used in the creation of sensors based on fabrics. Some techniques that have been used are soaking, screen printing, dip-coating, electrospinning, in situ growth and vapour phase polymerization [3-4].
Different kinds of combinations to materials and procedures are necessary for the fabrication of different kinds of sensors which are based on textiles. These sensors could include capacitive pressure sensors, piezoelectric sensors, triboelectric pressure sensor

Actuators

In order to categorise actuators we could use properties such as stress, strain, strain rate, cycle life and elastic modulus. The different actuation mechanics are including [5]:
-Electric field actuation
-Ion based actuation

-Pneumatic actuation
-Thermal actuation
-Other actuation mechanics

While some of these mechanics consist of rigid components others allow the usage in smart textiles. Polymer actuators have been used for smart textiles. actuators are operated under the mechanism of a dimensional change of the material which is caused by addition or removal of charge from the polymer structure [6].
Under this category the following actuators are included. Carbon nanotube actuators [7], CNT based actuating textile [8], shape memory alloy actuators [9]. Twisted and coiled synthetic fibre actuators [10], knitted CNT/spandex yarn as smart textiles [11].

In overall the actuating mechanism should be selected with a major emphasis on end user requirement. For smart textiles focus has been to thermally driven actuators. This may be mainly due to the utilisation of electrothermal heating as a reliable and clean source of energy.

Batteries

Even with all the technological progress and the really big steps that have been made, there are things that don't change. And one of those is that batteries are still the way to store energy. Talking about flexible batteries requires examining the components of which a battery consists.
A battery has mainly four components. Anode, cathode, separator and electrolyte [12]. In order to make a battery flexible we should make its components flexible. A flexible electrode could be carbon based, graphene based or metal oxide based. Until now lithium-ion batteries have attained attention in fiber base flexible batteries. For a fiber electrode graphene or CNT are the main options. Techniques for that would include two-fold spinning and coating [13].
A flexible electrolyte is another important aspect of what would be a flexible battery. Gel-polymer and solid-state electrolytes have been reported for flexible batteries [14].

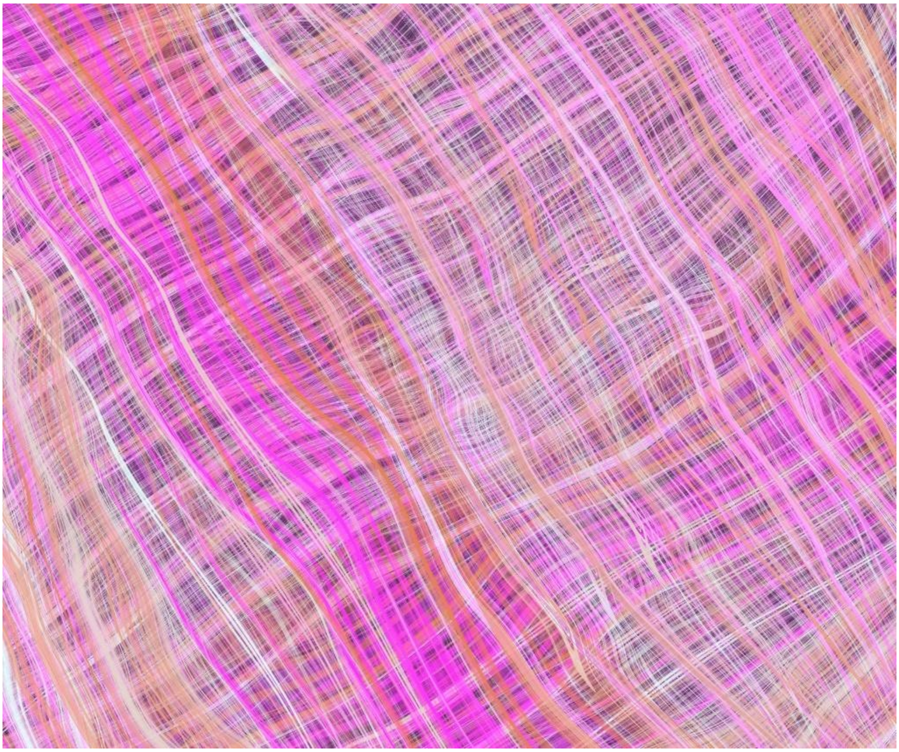

Figure 2.1 - Smart wearable based on textiles

Flexible Wearable Devices

For the creation of wearable devices that would be flexible and would have textile as a base the options are different conductive fibers. These are metal wires, metal-plated fibers, conducting polymers, CNT neat fibers and CNT-polymer fibers.

Metal wires have high electrical conductivity but also high density, are easy to oxidate and have low tensile strength. Metal-plated fibers can control the electrical conductivity by the thickness of the coated layer but the metal layer is thin then there is high resistance. Also, the durability of the metal layer is weak. For conducting polymers properties are similar to those of conventional fibers. Low conductivity and processability are the main obstacles for this category. For the CNT neat fibers there are some safety issues for nanomaterials but the presence of high tensile strength and high electrical conductivity are promising. CNT-polymer composites have similar physical properties with conventional fibers while the surface is rough and there is high resistance [15].

Other parts that could consist of some form of fiber are the textile circuit boards [16], the fiber-based transistors [17] and electronic circuitry in textiles [18].

Applications

All these devices or components of a device that are made to some degree from textiles could find action in a variety of fields such as human health monitoring, sports, military, everyday life, food habits.

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Chapter 3 Co-design of sensors and integration into PPE products for fire and water protection

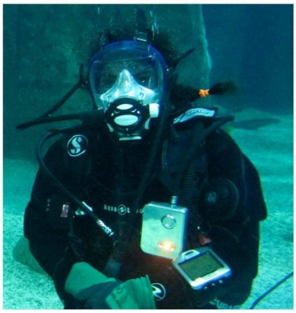
Aileni Raluca Maria, Cristina Stroe, INCDTP, Romania

Abstract

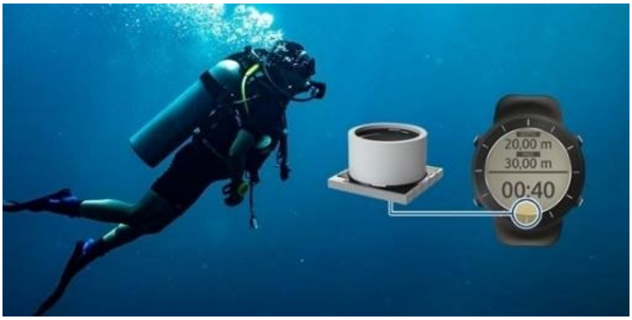
Co-design of smart sensors and integration into firefighters or dives PPEs includes the integration of different sensors containing microcontrollers, communication modules and adequate software applications for data processing to measure biomedical (pulse, temperature, pulse, oxygen level) or environmental parameters (oxygen level, depth, pressure, temperature, gas composition) to help workers in their activity and ensure that working conditions are safe. The integration of wearable smart sensors into textile products is mainly based on sensors' flexibility and miniaturisation, while integrating some smart sensors for diving or fire protection consists of integrating some rigid components.

Introduction

Under normal conditions, the thermoregulatory system of the human body acts as a temperature or humidity controller. However, in harmful environments (underwater, fire), unfortunately, the human body has insufficient control to compensate for the increased pressure at depth or excessive heating because of fire, which may lead to severe accidents and body injuries that can endanger the lives of divers [1,2]. Usually, for diving, the monitoring system that should provide information about pressure, respiratory rhythm, and location is protected using plastic covers and attached to divers (Figure 1.1.a). In general, underwater situations involve diving with small and robust computers capable of computing information about water depth, water temperature, pressure, oxygen level, battery level, respiration rhythms or body temperature. The underwater pressure is influenced by submersion depth and can be monitored using a diving computer connected to a digital pressure sensor offering information about submersion depth, local water level, gas remains in breathing tanks and safe time for a dive. For such systems in harsh environments, resistance to corrosion (e.g., salt water) and low power consumption in remote applications is essential for a prolonged period [3, 4]. For underwater monitoring, piezoresistive sensors are used because they are resistant and can operate in such conditions, integrated into smartwatches (figure 1.1.b), sonar buoys and tanks. In this way, we can observe that these sensors cannot be integrated into textiles because they are very robust, without flexible components [4]. **Mainly, all smartwatches and depth tools have been analogue devices, but the design sensors for pressure have significant advantages because piezoelectric components and transducers are integrated and can be easily integrated with computers compared to analogue ones.**



a. Diver equipment



b. Smartwatch based Merit Sensors

Figure 3.1. Diver equipped with the recording system and a video camera (above left/right arm) [3]

Smart sensors for fire/water PPE

Integrating smart sensors into water or fire PPE is a requirement, ensuring autonomy and continuous monitoring of the wearer. Even if analog sensors based on flexible textile electrodes (fibres, yarns) can be integrated into a textile through sewing, embroidery, weaving, knitting, or nonwoven technology, for water and fire, PPE, compact smart sensors have demonstrated resistance in harmful environments (corrosive environment, high temperature, humidity). In addition, the textile surface electrodes for human body temperature or humidity sensors can be used if they are not in direct contact with water or fire. Otherwise, these electrodes can be destroyed and cannot guarantee the accuracy of the monitoring. Smart sensors contain several components, such as a microprocessor, sensor, wireless communication technology (e.g., WiFi) and software technologies (ADC, data processing), user interface through aggregators (smartphone, tablet) and generate digital signals when a physical measure (e.g., temperature, pressure, humidity) is monitored. Smart sensors that are used in PPE equipment can offer information about the wearer's health status, environment (chemical composition of the atmosphere (e.g., nitrogen dioxide (NO_2), nitric oxide (NO), and carbon monoxide (CO), temperature, humidity, depth, radiation level) or about the devices that ensure survival in a toxic environment (oxygen level on the diving tank) [4]. For example, in the case of dives, it is essential to monitor the pressure, depth and O2 concentration because decompression illness may occur, generated by intravascular or extravascular bubbles because of a reduction in environmental pressure [5, 6]. In addition, oxygen toxicity occurs when the pressure of oxygen is 1.4 atmospheres or greater at a depth of 57 metres when breathing air (e.g. for 10 m depth in the water, a diver is exposed to an additional pressure of 1 ATA [7]) or shallower depths when breathing oxygen concentrations are greater than 20% [8, 9].

The smart sensors for water or fire PPE contain the following components:

- sensors;
- microprocessor;
- communication module;
- software (ADC, data processing);
- aggregators (smartphone, tablet).

Co-design of fire/water personal protection equipment

Co-design method of fire/water personal protection equipment (figure 1.2) with integrated sensors consists of establishing the objectives, specifications, properties and constraints for sensors using a group of specialists with relevant skills:

a. Fireman PPE   b. Diving PPE   c. Water PPE

Figure 3.2 . PPE for water and fire protection

- ✓ End-users - firefighters/divers/workers with water jets (offering user perspective, real use cases, needs, aspects related to comfort, and product acceptability)
- ✓ Engineers with specialisations (bachelor's degrees, master's and PhD studies) in textiles (spinning, weaving, knitting and textile garments) offering information about product design, manufacturing and standardisation;
- ✓ Engineers with specialisations (bachelor degrees, master's and PhD studies) in informatics/computer science, offering information about possibilities to develop adequate software for the proposed hardware (sensors + microcontrollers);

- ✓ Doctors (offering medical perspective: aspects related to the parameters to be evaluated considering the specific use cases (fire/water));
- ✓ Engineers with specialisations (bachelor's degrees, master's and PhD studies) in electronics offering information about sensor design, manufacturing and standardisation

The diversity of the approaches will lead to the design of a complete product considering all possible risks and design specifications for the interface in different complex conditions.

Sensor integration into PPE for fire protection

Depending on the flexibility and the degree of miniaturisation, smart sensors may be integrated into PPE for fire protection.
Smart sensors should be integrated into PPE for fire protection for remote monitoring:

- Pulse sensor;
- Gas sensor (oxygen level monitoring);
- Temperature sensor;
- Humidity sensor;
- Location module (GPS) and audio device (AD)
- Accelerometers/gyroscope

Sensor integration into PPE for water protection

PPE for personnel working underwater or in contact with water should integrate remote monitoring to prevent hypoxia or other injuries:

- temperature sensors;
- Oxygen level and concentration;
- Humidity sensors;
- Localization (GPS) & communication modules (audio device);
- Air time
- Depth
- Pressure

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Chapter 4 Co-design of smart sensors and integration into medical devices

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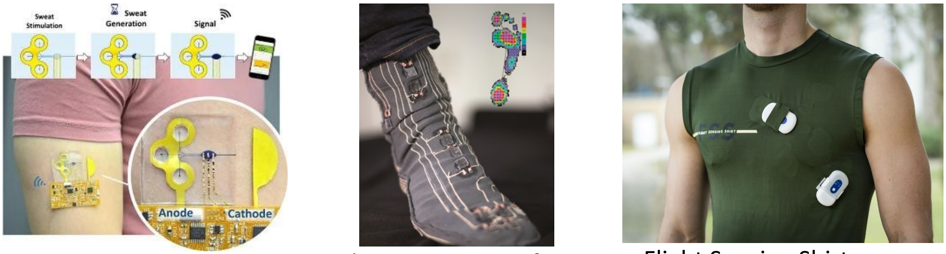
Abstract

Co-design of the smart sensors and integration into medical devices includes the appropriate integration of the different sensors containing microcontrollers, communication modules and adequate software applications for data processing in order to measure biomedical parameters (respiration rhythm, blood pressure, pulse, oxygen level, glycemia), other biomarkers that can be used for diagnosing or treat (e.g., sweat analysis using wearable microfluidic devices) different diseases, to assist patients in rehabilitation. The integration of wearable smart sensors into textile products is based on sensors' flexibility and miniaturisation. Without flexibility or miniaturisation, these sensors can be damaged by mechanical actions that may occur in textiles, considering that the textile is not a continuous surface but discrete.

Introduction

Numerous wearable innovative platforms integrating sensors have been developed in microfluidics technology for sweat analysis [1] to evaluate the biomarkers or act as lab under skin consisting of multiplexed system-based microneedles with transdermal sensors for monitoring of biomarkers (metabolites, electrolytes) [2, 3]. However, these techniques require flexible and transparent materials that can not adequately integrate into the textile surface. Integration of the smart sensors into textile articles (socks, shirts) to be used for medical purposes include the integration of the flexible sensors into socks [4] through sewing or integration of the smart sensors such as ECG, Bio-impedance, and acceleration by printing on the textile [5].



a. Wearable microfluidic sensor for sweat analysis [1]

b.Smart sensors for pressure monitoring [4]

c. Flight Sensing Shirt – Aeolus Physiological monitoring for military pilots [5]

Figure 4.1. Wearable devices for smart biomedical monitoring

Smart sensors for healthcare

Attaching wearable medical devices to textiles is desirable, ensuring autonomy and continuous monitoring. However, the analog sensors based on flexible textile electrodes (fibers, yarns) can be integrated into a textile through sewing, embroidery, weaving, knitting, or nonwoven technology. In addition, the coating of the textile surface for obtaining surface electrodes acting as electrodes for pressure, temperature or humidity sensors can be used. Analog sensors generate analog signals (e.g., voltage variation) from a physical measure monitored. The most used analog sensors include sound sensors, light sensors, temperature sensors, and pressure sensors. A smart (digital) sensor contains several components (figure 1), such as a microprocessor, sensor, wireless communication technology (e. g., WiFi, LoRa) and software technologies (ADC, data processing), user interface through aggregators (smartphone, tablet) and generates digital signals when a physical measure (e.g., temperature, pressure, humidity) is monitored. Smart sensors are used in medical devices to diagnose, prevent, physiologically monitor, rehabilitation assist, treat diseases, and validate medical devices.

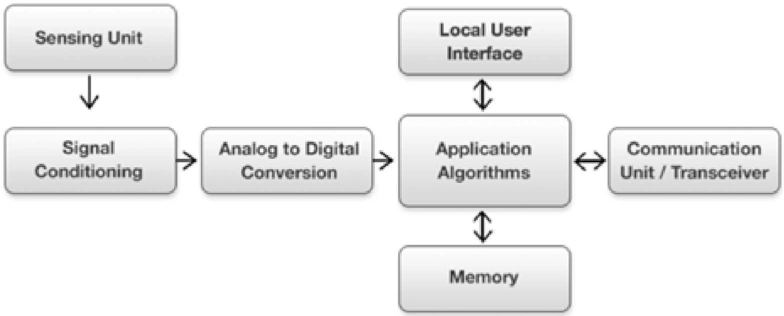


Figure 4.2 Smart sensor building blocks (Image © Premier Farnell Ltd.) [6]

Co-design of smart biomedical sensors

Co-design method of the smart biomedical sensors consists in establishing the objectives, specifications, properties and constraints for sensors in the framework of a working group of specialists with the relevant skills:

- ✓ End-users (offering patients perspective, needs, aspects related to comfort, and product acceptability);
- ✓ Doctors (offering healthcare perspective: aspects related to the parameters to be evaluated, sensors position);
- ✓ Engineers with specialisations (bachelor's degrees, master's and PhD studies) in textiles (spinning, weaving, knitting and textile garments) offering information about product design, manufacturing and standardisation;
- ✓ Engineers with specialisations (bachelor's degrees, master's and PhD studies) in electronics offering information about sensors design, manufacturing and standardisation
- ✓ Engineers with specialisations (bachelor's degrees, master's and PhD studies) in informatics/computer science, offering information about possibilities to develop adequate software for the proposed hardware (sensors + microcontrollers).

Furthermore, these diverse specialisations and experiences generate tangible 'products' such as design specifications for intelligent sensors and integration.

Smart sensors integration into medical devices

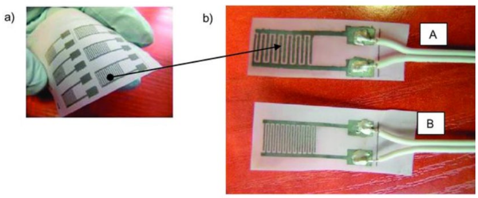
Depending on the flexibility and the degree of miniaturisation, smart sensors may be integrated into medical devices.

Smart sensors integrated into medical devices for biomedical monitoring:

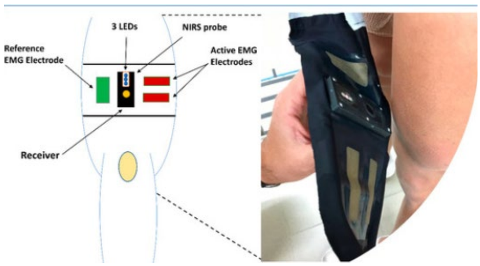
- Pulse sensors (challenging to integrate into textile structures) [7, 8];
- Temperature sensors (figure 1.3 a.) [7];
- Humidity sensors (figure 1.3 c) [9];
- Respiration monitoring (textile monitoring belts) (figure 1.3 a) [7, 8];
- ECG monitoring (with textile electrodes) (figure 1.3 b.) [10];
- oximetry sensors for monitoring oxygen levels (figure 1.3 d) [11];
- EMG for monitoring muscle activity (figure 1.3 d) [11];
- Gate monitoring sensors (smart insole integrating accelerometer gyroscope) [12-16].

a. Sensors integrated into knit for monitoring temperature, respiration, and heart rate (e-TECS) [7]

b.Movisens -belt for ECG monitoring [8]



c. Humidity sensor electrodes based Ag [9]



d. wiNIREM system-based EMG sensors and the NIRS-oximetry [11]

Figure 4.3. Smart sensors integrated for medical use

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Chapter 5 Co-design of actuators-based textiles for rehabilitation

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Abstract

The benefits of flexible actuators are their light weight, softness, and ability to assume any shape while displaying significant deformation in response to outside stimuli. Even though the expertise behind flexible actuators used in smart textiles is still in its infancy, the ability of actuator-based textiles to generate force and change shape could lead to some innovative new features and boost their intelligence. At the moment, smart textiles only very rarely use flexible actuator technology. However, a variety of applications are conceivable when combining flexible actuators and smart cloth. They can be used in multidimensional areas including healthcare applications. In this chapter, the design of actuator-based textiles for rehabilitation is reviewed and discussed. Undoubtedly, the field of smart textiles will be considerably impacted by the usage of flexible actuator knowledge in the coming years.

Introduction

Smart textiles are fabrics that allow the encapsulation of electronic components, such as micropower supplies, computers for processing, interconnected circuits, and smart materials. Passive smart textiles are those that have a sensing function, whereas active smart textiles are those that have an actuation function because they notice environmental stimuli and respond to it (Tao 2001). In smart textiles, the actuators' job is to respond to the signal sent by the sensor or data-processing unit, respectively. A reaction could take the shape of movement, noise, or the emission of a material. Interesting research is being done in the area of mechanical functioning for use in smart fabrics. It will become significantly smarter after being processed with actuators.

The fundamental characteristics of textiles are their adaptability to the body, comfort to the touch, softness, and wearability. Traditional actuation materials, like shape-memory alloys, magnetostrictive materials, and piezoelectric ceramics, are frequently rigid and brittle and difficult to integrate into fabrics. A new kind of actuation material known as flexible actuators is on the rise. These materials are soft and flexible and have the ability to transform electrical energy into mechanical energy, which can then be used to produce a force or motion. In any case, flexible actuator technology is a relatively recent development that is currently being established in a variety of textile applications. Flexible actuators may be woven into a cloth much more easily than standard actuators.

In the quickly evolving field of printed electronics, the conventional screen printing and digital ink-jet printing techniques have gained new significance. Electroactive polymer layers can be printed onto flexible substrates like inks in addition to being sewn on a textile like patches. Being connected to digital components by flexible printed circuits is also highly practical. There aren't many specific uses for flexible actuator technology in smart textiles at the moment. The development of smart fabrics is still in its infancy. However, in this field, there are a huge number of potential applications. The use of flexible actuator technology in the near future is certain to have a substantial impact on the field of smart textiles.

Actuator and classification of flexible actuators

An actuator is a component of a machine or equipment that aids in generating mechanical force by converting energy, frequently electrical, air, or hydraulic energy. It is, to put it simply, the part of any machine that permits movement. Actuators are devices that can produce work under control. Figure 1 indicates the different types of actuators.

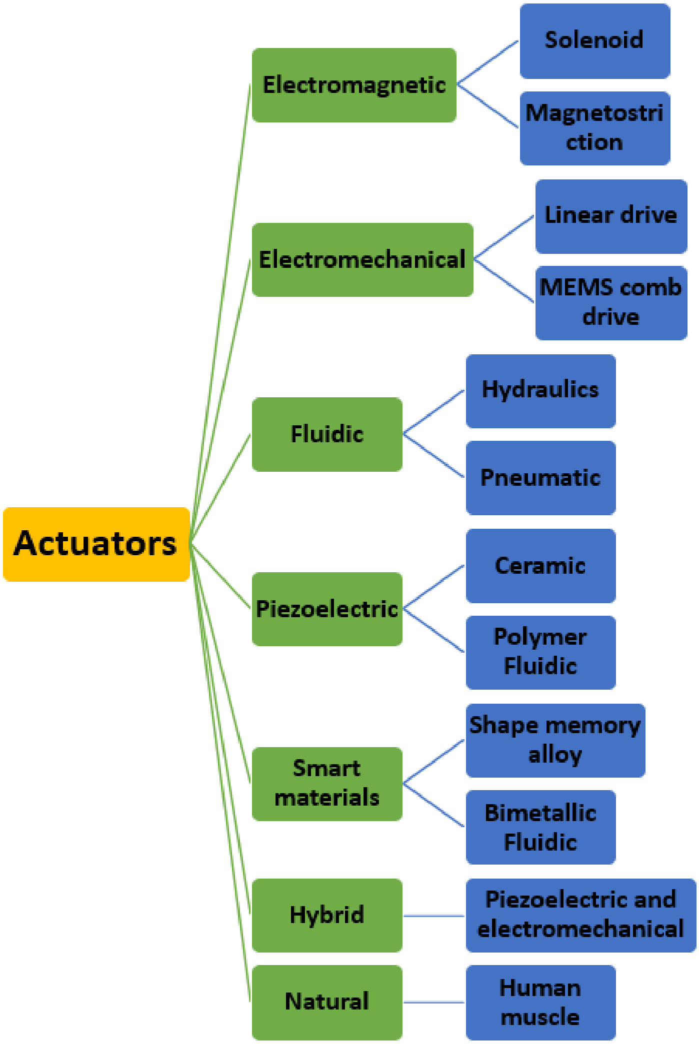

Figure 5.1. Classification of actuators.

Application actuator-based textiles for rehabilitation

The two primary purposes of traditional clothing are protection and attractiveness. And up until this point, a lot of additional features have been added to clothes, including warmth, communication, mechanical, optical, and chemical sensing. The response of the actuators can take the form of significant deformation, movement, vibration, significant force, and material discharge. Typically, the term "conventional flexible actuator" refers to pneumatic artificial muscles that have been created to support medical equipment for rehabilitation.

These bulky, inconvenient wearables are more akin to mechanical than textile devices and have a big volume. There are currently few examples of smart textiles being employed as the flexible actuators stated above. It is primarily because, in comparison to pneumatic actuators, they have low actuation performance. Numerous studies are still being done to improve their actuation activity. Further, soft and film-like actuators are excellent candidates for textile processing.

The number of old people around the world has been continuously increasing in recent decades. Both developed and developing countries are experiencing the same tendencies. Ageing results in a general slowdown of biological processes. Interest in the related issues has grown as a result of the rise in the older population and the rising demand for rehabilitation therapy. Many persons experience brain lesions as a result of diseases that cause cognitive and motor impairments, in addition to age-related difficulties. There are a great number of persons who need special care, whether for rehabilitation or help.

Most rehabilitation treatments primarily consist of two ways. One is ongoing exercise that prevents the general state of chronic patients from getting worse; the other is ongoing exercise for trauma patients that may allow them to regain full or partial muscle function. Systems and methods for rehabilitation might vary greatly and need to be tailored. High social costs are the result. Using robotized equipment to provide support and carry out rehabilitation is one solution that is conceivable. Pneumatic actuators have been created to help humans by using a hard frame, such an exoskeleton, or by placing straps in the right places. These rehabilitation tools are for the following purposes based on the movements or actuation functions carried out by the pneumatic actuators ([1]:

Hand actuation: Pneumatic muscles, which are attached at the back of the fingers, are made specifically to bend fingers. A soft robotic glove with a fluid-driven actuator was able to help the hand's grasping motion. To create a conventional gripping motion, different actuation modes for the thumb and the other fingers were used (Figure 2a) [2]. For individuals with hand deficits brought on by neurological conditions, the soft robotic thumb rehabilitation system described in a study duplicates and recovers proper thumb motor function (Figure 2b) [3]. At Okayama University, Sasaki and co-authors designed a power assist glove for hand gripping to enhance Activity of Daily Living (ADL) in a simple and safe approach. The opposable thumb is moved by two linear-type pneumatic muscles located at the base of the thumb, one on the back of the hand and one on the palm. Curved pneumatic rubber muscles linked to the back of the fingers allow for finger bending [4].

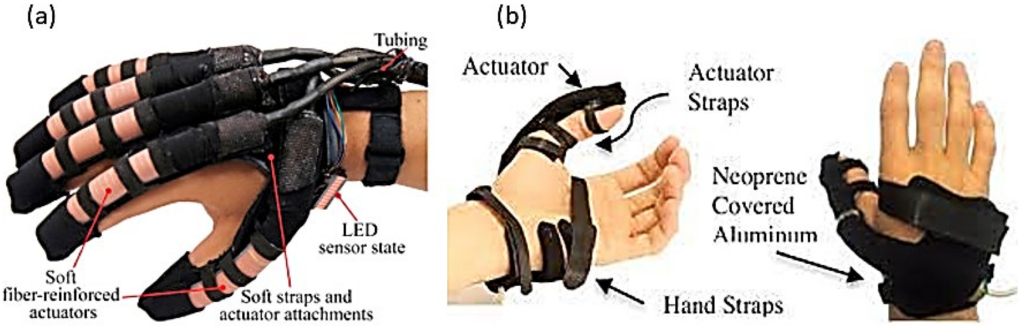

Figure 5.2 (a) A hydraulic soft glove for combined assistance and at-home rehabilitation [2], (b) The developed hand attachment with the incorporated segmented soft actuator[3].

Elbow actuation: The muscles are made to help move the elbow or help the joint regain function. For proper patient elbow joint articulation, a medical rehabilitation exoskeleton using SMA wires as the actuator for the elbow has been proposed. The proposed exoskeleton is quiet and light, which enhances patients' capacity to do daily tasks and the medical rehabilitation process [5]. An innovative concept for a textile-based actuator was put forth; it consists of an inflatable tube folded inside a fabric enclosure. The suggested actuator performs well when holding weights; tests with a wearable glove and an elbow-sized flexor used 9 kg and 20 kg loads. It is suggested to use a structure with changeable curvature to alter the actuator's shape when pressurised ([6]. Koh and his co-authors from National University of Singapore have designed a soft robotic elbow sleeve with passive and intent-controlled actuation[7].

Figure 5.3 (a) A medical rehabilitation exoskeleton for proper patient elbow joint articulation [5]; (b) Design of the soft robotic elbow sleeve [8]; Arm configurations during the use of the soft robotic elbow sleeve. (c) Flexed configuration and (d) Extended configuration [7].

Upper limbs actuation: The shoulder, arm, and forearm of the upper limb mobility assistance device are joined by two motor-driven joints [9]. The power assist splint for the upper arm, created by a research team at Okayama University, powers the wrist and elbow joints to help with upper limb motion. A soft material like a glove is insufficient in this situation to act as an interface with the patient. Greater stiffness is needed because the actuators transmit stronger forces to the limbs [10]. The researcher, Ciaran from Harvard University, has developed textile-based soft wearable robots for upper-limb rehabilitation and assistance [11] . To begin with, unfolding textile-based pneumatic actuators were constructed to transfer torques directly to the target joint, and a variety of physical prototypes were used to model and evaluate the actuators' actuation processes. Several distinct kinds of upper limb assistance devices have been researched. The muscles power the movement of the elbow joint.

Trunk and waist actuation: The apparatus designed to help waist motion is made up of two stiff pieces joined together by a hinge and attached to pneumatic muscles that have a curved appearance[12]. The human body is equipped with a wearable power assist device to help the muscles perform more efficiently. This device assists daily activities, rehabilitation, heavy work, training, and other tasks [13].

Lower limb actuation: The parallel muscles utilised in the active lower limb power the knee joint. The device is designed to give an old or disabled person who can walk, but has trouble sitting and standing up from a seated posture, more independence [14]. The three main challenges in designing these kinds of wearable devices are weight, power, and deformability. Pneumatic muscles still have a huge capacity and require a pressurised gas source to be driven in a wearable device. Actuators that are safe, small, light, and nimble are needed to meet these objectives. For people with disabilities, a wearable rehabilitation device should be as basic as everyday clothing. The optimum option is a flexible sheet-type actuator, like those discussed above. Fig. 14 shows a wearable rehabilitation aid suit with DE stack actuators arranged for various help actuations.

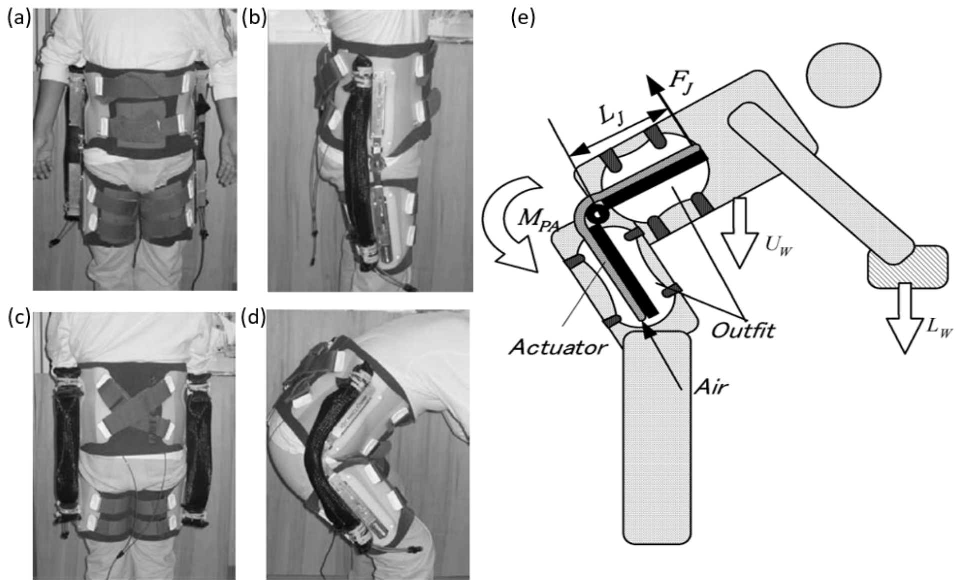

Figure 5.4. (a) front side, (b) flank side (erect), (c) rear side, (d) flank side (anteflexion) and (e) operation principle of waist power assist [12].

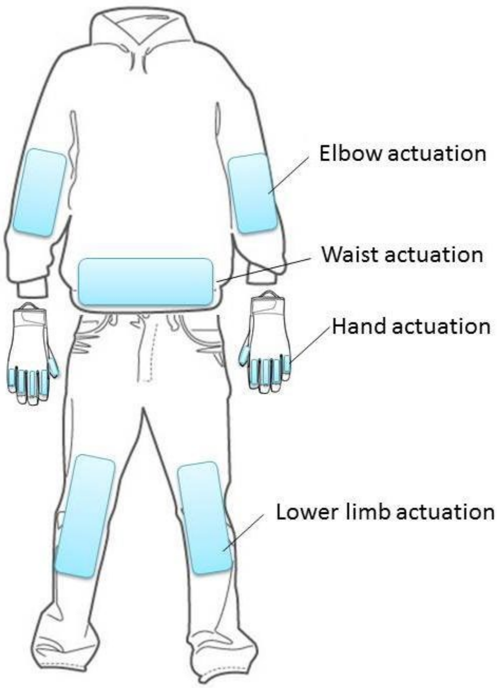

Figure 5.5 : Stack DE-based wearable rehabilitation aid suit [15].

Conclusions

Recent years have witnessed a growth in the development of textiles with actuators for use in wearable applications, particularly for rehabilitation. The flexible actuators can be utilised for healthcare and wearable medical equipment. They can assist in making these gadgets by incorporating garments with features that will be quite helpful for therapeutic massage treatments, rehabilitation, and assistance. However, because it is difficult to predict the soft and compliant behaviour of the textiles, the design of these textile-based actuators is often an iterative process. A textile or article of clothing will become smarter if these features are included into it. While there is still a long way to go and a difficult road ahead, the flexible actuator technology is essential for making them a reality. Future smart textiles are expected to benefit greatly from some of these flexible actuators, which some researchers say may be akin to natural muscles.

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Chapter 6 Harvesting devices based on textile electrodes

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Abstract

Energy harvesting devices based on textiles represents an alternative to the classical battery with limited file and energy because it can obtain energy from different sources (solar energy, kinetic energy, thermal energy, chemical energy and electromagnetic waves). This chapter presents the main aspects of wearable energy harvesting devices, textile materials used, and technologies used for developing harvesters.

Introduction

An alternative to batteries that have limited energy storage capacity are harvesting devices because various sources of energy such as kinetic, thermal, electromagnetic, and even chemical are found in unlimited quantities and can be used to be transformed into electrical energy and stored to ensure the power supply of various wearable autonomous devices. General principles (electromechanical, thermoelectric, electromagnetic, piezoelectric) are starting points for developing harvesting devices. Numerous studies investigate the realisation of these devices using textile materials made of electroconductive fibers/wires or by deposition of polymer films with magnetoelectric properties (e.g., PVDF).

Harvesting device types and manufacturing

Energy harvesting devices (EHD) can solve the energy supply problem in the case of autonomous wearable devices (wearable systems-based actuators or sensors). This independent power supply is especially essential in a harsh environment or for wearable implants (pacemakers) because, for example, the battery autonomy for pacemakers is around 12-13 years. Input energy (thermal, electrostatic, mechanical, electromagnetic, solar) coming from different sources (human body heat, human body movement, environment, sun, wind) in order to be captured and converted into electrical energy for powering wearable autonomous devices, required the use of thermoelectric, piezoelectric or triboelectric materials/devices integrated into wearable systems. A pneumatic harvesting system can recover a maximum of 3W power and outperform electromagnetic, piezoelectric, and triboelectric conversion energy efficiency by 20%. Harvesters consist of materials/ systems (e.g., textile micro cable for simultaneously harvesting solar and mechanical energy) that can convert another type of energy (mechanical, light, thermal, etc.) into electrical energy)

- electrostatic induction and the triboelectric effect generate small amounts of power from mechanical motion. In figure 1.1. is presented the 3D double-faced interlock fabric triboelectric nanogenerator (3DFIF-TENG) based on interlock knit fabric that can produce electricity by bending and stretching the fabric [1].

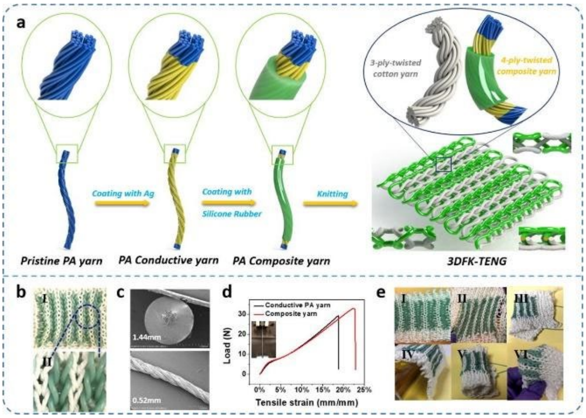


Figure 6.1 Fabrication process and mechanical behaviour of the triboelectric nanogenerator 3DFIF-TENG [1]

- The generation of direct current (DC) electricity from ambient wireless signals can be achieved using conductive and dielectric textile materials (fibres, threads) processed by spinning, weaving, knitting, embroidery and deposition of conductive inks on insulating materials, patch antennas for energy harvesting can be made applications [2]. Moreover, obtaing electric current from electromagnetic waves (RF) can be achieved by using a patch antenna and a rectifier fabricated using embroidery of conductive thread on the textile insulator substrates [3].

- The generation of electricity from thermal energy can be achieved by using p-type and n-type materials based on silver yarns and textile yarns functionalized by deposition of conductive polymers (PEDOT: PSS) and sewing/embroidery to make thermoelectric textile generators [4, 5] (figure 2).

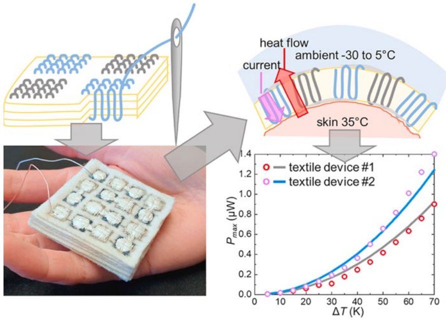
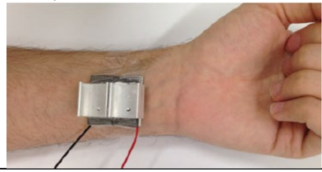
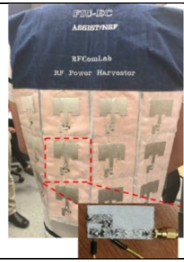
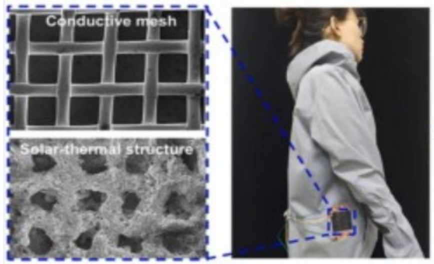


Figure 6.2 Materials used in our thermoelectric textile [4]

In order to be used to power wearable devices, the harvesters [6] (Table 1) should transform the different types of energy (thermal, mechanical, RF and solar) into electricity based on different effects (Seedbeck, EM energy harvesting, Piezoelectric, Photoelectric).

Table 6.1 Harvesters Type

Harvester type	**Effect**	**Input energy**	**Source of energy**	**Wearable device type and integration**	**Domain***	**Example**
Thermoelectric (TEG)	Seedbeck	Thermal	Human body heat	System on chip (SoC); Wrist [7] 	M, P, A, S	**Turning heat into electricity**
Piezoelectric (PE)	Piezoelectric	Mechanical	Human body movement	Harvester based on the pneumatic system [8] 	M, P, A, S	**Piezoelectric fiber for motion sensitive textiles** **Textile based pneumatic energy harvester** **Fiber-based triboelectric nanogenerators**
Radiofrequency (RF)	Scavenging energy in RF bands (GSM (900 MHz); WiFi, ISM (2.4 GHz)	Electromagnetic	Environment	Wearable RF power harvesting shirt[9]	M, P, A, S	

						
Solar	Photoelectric	Solar	Environment	Wearable solar harvesters integrated into jacket [10] 	M, P, A, S	[Photovoltaic power from textiles]()
Hybrid nanogenerator	Photoelectric and Piezoelectric	Mechanical and Solar	Human body and environment	Jacket with solar and piezoelectric generator [10] 	M, P, A, S	[Twisted yarn actuator]()

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Chapter 7 End-users requirements and perspective in selecting the smart products

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Abstract

The world economy and market demands have been rapidly evolving over the past few years, and the demand for smart products is rising. Smart products with new facilities have been designed as a result of recent technical advances. However, producing smart products requires significant adjustments to product development procedures, which have seen numerous advances in recent years in terms of theory, methodologies, and approaches. Smart products can collect, process, and deliver the information. This chapter discusses the end-user requirements and perspective in selecting the smart products.

Introduction

The "smart product" has gained popularity over the past 10 years among tech experts and academics. At the beginning of the decade, smart products were primarily used to promote cutting-edge technology at trade shows. But as a result of technological breakthroughs, smart products are already a reality and, in some cases, have already helped to disrupt established businesses at the start of a new era marked by the Internet of Things (IoT) and technologized marketing and innovation [1],[2] [3]. Cyber-physical systems (CPS) that also employ and integrate Internet-based services to carry out necessary functionality are referred to as smart products [4];[5]. CPSs are described as "intelligent" mechatronic devices or systems that may interact and communicate with other CPSs via various communication channels, such as wireless LAN or the Internet ;[6], [5].

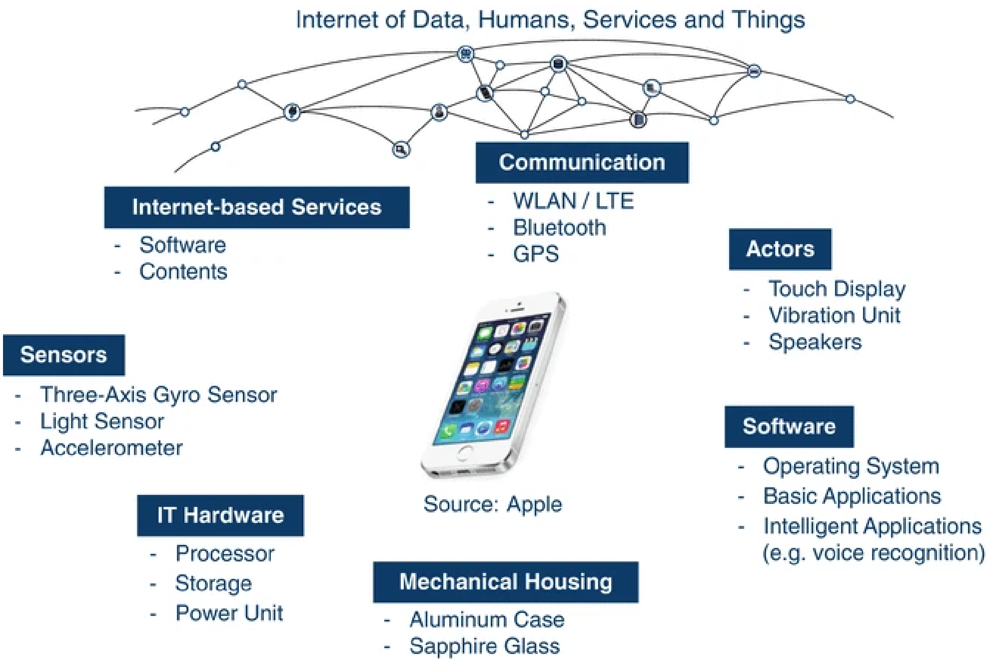

Figure 7.1. Essential elements of a smart product using the example of a smartphone [5].

Physical and virtual components, as well as product and internet-based services, are all dissolved by smart products. Figure 1 illustrates the essential elements of a smart product using the example of the most well-known smart product, the smartphone. Figure 2 illustrates the applications and main characteristics of smart products [5], [7].

(a) (b)

Figure 7.2. Applications (a) and main characteristics (b) of smart products.

End-user requirements and perspective of smart products

Smart products differ from ordinary products in that they share a few functional skills. These include autonomy, dependability, and individualization, as well as intelligent interactions with human users. These functional skills are the result of a number of technical properties, including resilience, intelligence, and connectivity supported by sensing and reconfigurability. One of the key characteristics of smart products is their intelligence, which encompasses capacities like recognition (speech, vision, language, etc.), reasoning, and learning. Intelligent user interactions are the first meaning of the term "smart" in relation to products. The second component is what is referred to as intelligent control, which goes beyond conventional feedback control. Third, other traits, such as autonomy and reconfigurability, benefit from intelligence [8], [9].

Smart products should have smart sensor and sensing capabilities. Smart products can sense external stimuli and accumulate the information through the sensor. The collected data can be used for long- and short-term purposes. Radio frequency identification sensors and IoT chips have made it possible widely [10], [11], [12], [13].

Verbal, visual, tactile, and other modes of engagement are all necessary for intelligent human interactions. The best smart product, however, should be understood to be one that communicates with users in very intelligent ways while requiring the barest minimum of human interaction. The touch screen user interface allows for bidirectional communications, but not traditional one [8], [9].

Product-service systems should be included in smart products. Through the use of sensors, they collect operational data and put it to better use for maintenance and life cycle management. For intelligent vehicles utilised for autonomous MaaS services, these types of characteristics may be essential. Technically speaking, this indicates that substantially higher reliability and dependability are required. New service delivery techniques, such as continuous real-time health monitoring, proactive maintenance, and predictive maintenance, are faster and more efficient [14], [15].

All of the characteristics of smart products are built on the foundation of connectivity to other agents on the Internet. It will make data collection possible, but it will also make self-identification and location determination easier. The limits of wireless communication are currently being pushed to 5G and beyond by the developments in wireless communication technologies [16]. Many applications will also have the opportunity to switch from local computing to cloud computing, edge computing, or fog computing. If the ecosystem of smart products is really data-centric or data-driven, a high speed connection is required [17].

Smart products must possess a high degree of autonomy. In several disciplines, interest in autonomy is growing. Autonomous systems have the ability to sense information from the outside, make intelligent decisions without the help of humans, and take appropriate action [18]. A drone or a deep-sea robotic submarine is frequently capable of flying or swimming by itself without the use of a remote control. They must not injure any outside parties or become disoriented while carrying out their mission. An autonomous system may also exhibit non-deterministic behaviour through self-learning. A modular product that configures itself after the modules are assembled is an example of autonomous self-learning [19], [2], [20].

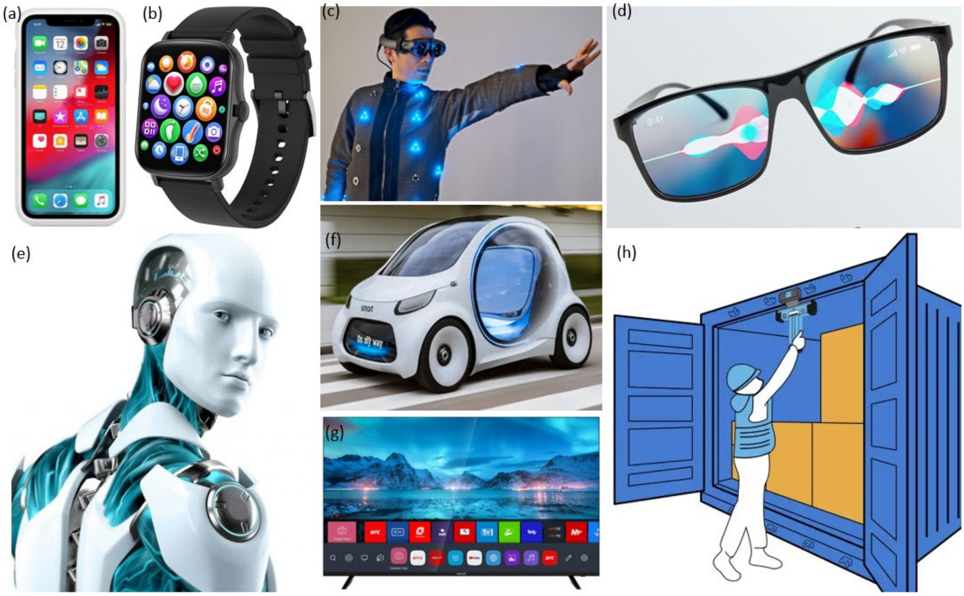

Figure 7.3. Some examples of smart products: smart phone (a) [21]; smart watch (b) [22]; smart cloth (f) [23]; smart glasses (g) [24]; smart robot (d) [25]; smart self-driving car (e) [26]); smart TV (c) [27]) and smart container (h) [28].

Customization, individualization, or personalization are essential to provide the customer with extra value. Reconfigurability could be used to facilitate customization, individualization, or personalization of smart products to satisfy explicit or implicit user requirements [29], [30]; [31]. The reconfiguration of smart products can occur at any time during their lifetime. In contrast to run-time reconfiguration, which can take any form of control to adapt the machine to changing external environments and worsening internal circumstances, design-time reconfiguration entails changing the design of the machine to adapt an old model to new user requirements [32], [4], [32].

Smart products have the potential to perform better in terms of maintainability, end-of-life treatment, and energy consumption by monitoring status and environmental characteristics and analysing the collected data later using data analytics. This could help to promote sustainability. Figure 3 indicates the examples of some smart products available in the market.

Conclusions

The definition of smart products, i.e., CPS with incorporated Internet-based customer services, is now becoming more specified. This suggests software-intensiveness, data-drivenness, and multidisciplinarity. But creating smart devices involves more than just adding more software-related capabilities. Compared to how earlier generations developed, it is very different. Smart services add value to smart products, increasing the value of user experiences. This chapter provided a quick overview of several smart products, and then went on to talk about common characteristics and end-user requirements.

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CHAPTER 8 Influence factors for usability and acceptability of the electronic components integrated into textile products

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Introduction

A smart textile is a functional textile material that reacts actively with its environment and responds actively and automatically to inputs received from the environment. These textiles react to external stimuli (light, temperature, humidity, pressure, etc.), and can communicate with other devices, to conduct energy, to transform into other materials, and to protect the wearer from environmental hazards.

Smart textiles bring functions to end-products and are used in sectors with high added value such as the health and medical industry; automotive & aeronautics; personal protective equipment; sports; construction; and interior design, among many other sectors.

The electronic components integrated into textile products open a range of endless applications in many fields, having an enormous potential to make our life better and easier. While some have embedding electronics devices in fabric, others have layering conductive electronics into textiles as we will see in the prototype below.

Smart textiles are a relatively new product in the textile industry. Even though these textiles have a promising future, they are not exempt from challenges. Integrating electronic materials into the core yarn of smart textiles is technically very complicated and it still requires research to be done. Many companies may not have the infrastructure to manufacture these textiles and they are required to re-program their production processes. The high production costs are probably an entry barrier for many small-medium sized companies.

The scope of smart textiles addressed here refers to textile-based products with embedded electronic components, whether these components are conductive yarns or sensors. These kinds of products are important and represent an opportunity for the textile sector to evolve and enter the domain of smart products.

Examples of textile smarty products exist, many still in the form of a prototype or advanced prototype. For example, a firefighter's uniform equipped with a heartbeat sensor that can send this data remotely, or a worker wearing a suit that can detect bad postures issuing a warning signal. The aspect that is important in these examples is the added-value service that can complement the product, that in many cases can be the basis of a new business model.

This is the opportunity for the textile and clothing sector to expand itself into other business areas, and to attract people with different skills and competencies, such as electronics and programming.

Influence factors for usability and acceptability of the electronic components integrated into textile products

The *Smart-horse-riding* is a good example of the influence factors for usability and acceptability of the electronic components integrated into textile products.

The smart half pad fits within POLISILK product portfolio strategy of fabric end-use diversification towards higher added value products integrating flexible electronics.

This innovative initiative consists in a smart half pad for the dressage (an equestrian discipline) market. This new product integrates flexible electronics through printed conductive yarns and pressure sensors within pad (blanket placed between the horse and the saddle). An also new creation developed virtual app monitors the several pressure points generated by the horse rider.

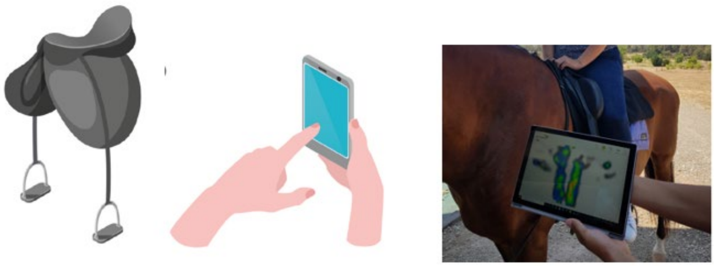

Figure 8. 1 - Smart-horse-riding product

Following, we would like to highlight the value proposition of the *Smart-horse-riding*:

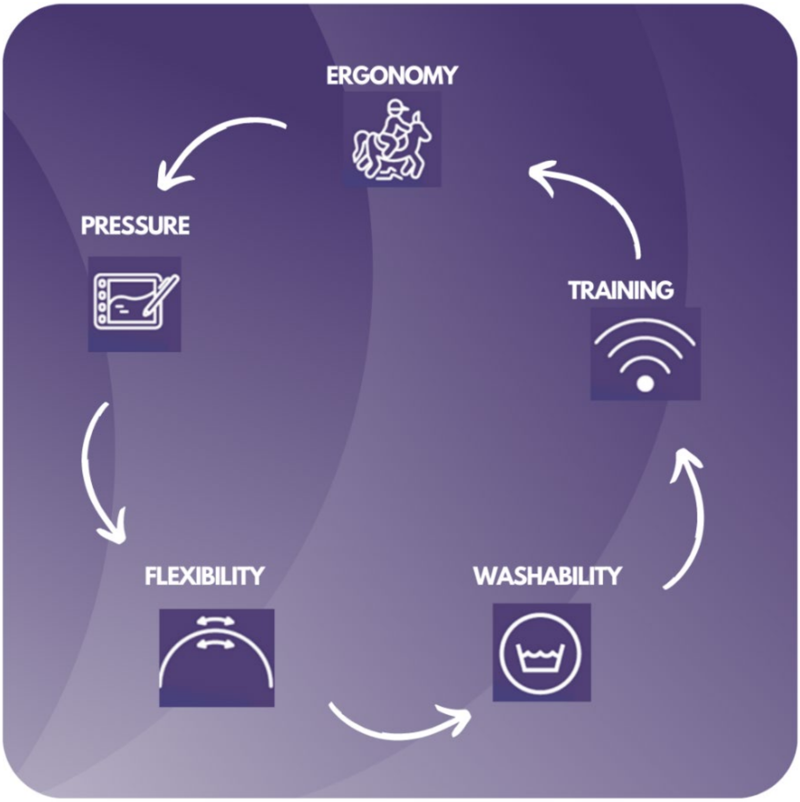

Figure 8.2 - Smart-horse-riding phases

1. Its **ergonomic** shape helps to avoid injuries in the horse back and rider due to improper saddle fitting.
2. With its Wi-fi connectivity, the smart-horse-riding sends in real-time data gathered by the coach which improves performance during **training**.
3. **Washability**: Heavy duty protective fabrics that can be removed and washed in a washing machine.
4. Being a half-pad **flexibility**, it's a specific alternative that provides a 10% elongation of the half pad preventing the sensors to be damaged. It also allows the horse-riding dynamics as well as a greater durability.
5. It has very precise **pressure** maps. It means that with its very high number of sensors (+500) which uncover excessive pressure points, it is very optimum for training and preventing horse and rider injuries.

Conclusions

The Sm*art-horse-riding* prototype has shown us how conductive yarns are implemented for integration of sensors and other electronic devices that

integrate textile fabrics. It is a good example to see how the electronic components integrated into textile products open a wide range of uses in many fields.
It consists of a smart half pad for the dressage market. This advanced prototype is integrated by flexible electronics through printed conductive yarns and pressure sensors within a half pad and the different pressure points generated by the rider position on the horse are visualised through a custom app developed during the prototype stage. The smart-horse-riding offers a high value proposition as mentioned above for both: the horse and the rider.

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Chapter 9 Smart sensorial comfort - objective and subjective analysis for smart textiles

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Abstract

Comfort is an essential characteristic of smart fabrics to maximise their practical effectiveness. The use of smart textiles has boosted due to the advancement of electronic functionality for a variety of applications. Smart textiles still pose comfort challenges during wear. Comfortable clothing is a basic requirement for textile-based items that come into intimate contact with the skin. This chapter provided a brief overview of subjective and objective analysis used to evaluate the sensorial comfort of smart textiles. The motivation for the requirement of sensory assessment for smart textiles has been stated.

Introduction

Clothing is one of the most fundamental necessities that everyone needs in order to cover their bodies and protect them from harsh environmental factors such as weather. Although today's clothing functions as protection, adds additional functionality, and is utilised for health monitoring, support in sporting events, and as a channel for communications due to the diverse demands of the human [1], [2]. Smart textiles are growing rapidly and the demands are increasing, but there is also dissatisfaction with use due to their heavy weight and rigid nature. They can be pressed on the body and have ridges, which can be uncomfortable. Smart textiles have the ability to alter their usual behaviour in response to environmental signals such as peripheral features or technical stimuli [3].

The alteration may be influenced by mechanical, thermal, electrical, chemical, or other external sources. Although they have advanced far beyond their beginnings, consumer wearable electronics are still very much in their infancy. One of the causes can be problems with comfort in several aspects. Nevertheless, in contrast to research on the innovation and promotion of wearable technology, the field of research on the comfort assessment of smart textiles is not expanding as quickly. Most of the research in wearable electronics is concentrated on certain topics such as sensors, actuators, and electronic health record sharing platforms. The user is more concerned with the advantages of smart textiles than with comfort of use [4].

The most important characteristic of materials that come into blunt touch with the skin is comfort. There are three types of clothing comfort: sensory, psychological, and thermos-physiological. While psychological comfort is all about being at peace with oneself, thermos-physiological comfort is concerned with the body's heat balance throughout varying levels of exertion. The ability of a fabric to handle touch, wetness, pressure, and heat sensations is known as sensory comfort [5] [6]. If the manufacturing process for smart textiles is not constrained and handled clearly, the wearer's comfort may be compromised. The impacts on the comfort of the fabric while wearing cannot be ignored because functionality can be added mechanically (by weaving, for example), chemically (through printing, for example), or both [2] [7]. It is a truth that the integration of materials or processes might affect the user's wellness. When we touch cloth, we can experience sensorial comfort such as softness, stiffness, stickiness, smoothness, roughness, and prickling. Itching and prickliness indicate pain and discomfort. Thermal sensations such as warmth, coolness, breathability, hotness, and chilliness can also be felt by touch in the same way. The objective and subjective analysis of sensorial comfort for smart textiles are discussed.

Factors concerning sensorial comfort

The properties of fibre affect the yarn properties and handle and consequently on fabric. Regarding the sensory comfort of the final fabric, all these qualities are interrelated. Dyeing, finishing, and all other processing parameters also affect sensory comfort [8], [9], [10]. The key components of textile products that can significantly alter the feeling of the fabric are listed in Figure 9.1 .

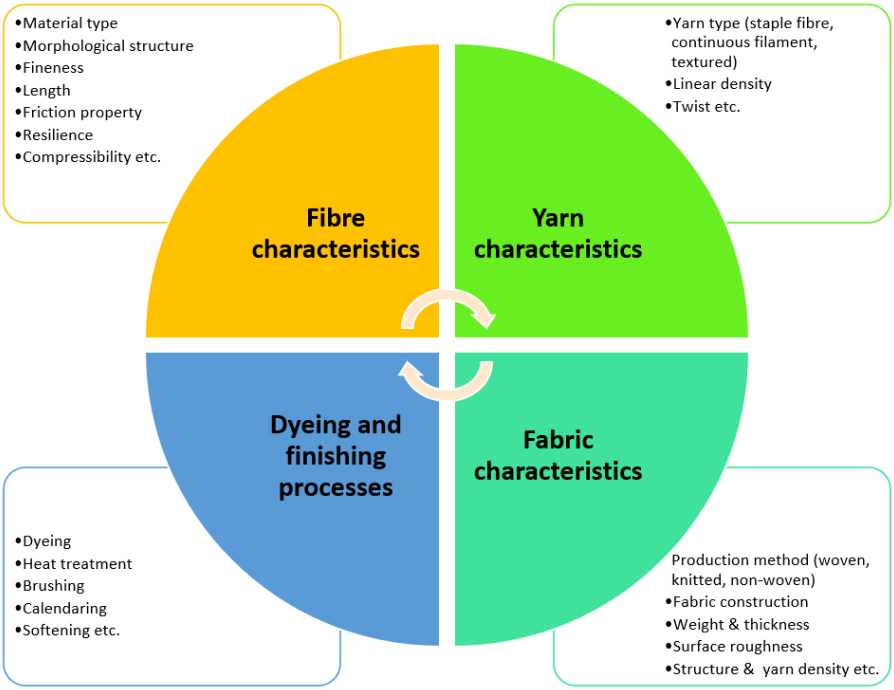


Figure 9.1. Factors concerning sensorial comfort of textile products.

Objective evaluation of sensorial comfort

Equipment-based objective procedures provide the possibility of consistency and reproducibility of outcomes, which are difficult to achieve using subjective techniques. Measurements of thermal conductivity, thermal resistance, thermal diffusion, and relative water vapour permeability have been used to predict the comfort characteristics of functional fabrics. An approach of comfort measurement applying objective tools was the prognosis of thermal comfort, which was made possible by measuring the thermal properties related to functional fabrics [11].

Kawabata's evaluation system (KES) has been introduced to determine the sensory comfort of the textile product along with the low stress mechanical properties, such as tensile, shearing, bending, compression, thickness, weight, surface and frictional properties by Kawabata and his colleagues [12]. Smoothness is the most crucial element in hand judgement. Thus, when evaluating smart textiles by sensory means, smoothness should be taken into account. Fabric assurance by simple testing (FAST) [13] and fabric touch tester (FTT) [14] methods have also been thoroughly achieved to measure the handle of the textile-based product effectively. Different methods of objective evaluation of textile comfort are indicated in Figure 9.2.

In a study, it has found that printing has a significant impact on the comfort of clothing. The authors examined how the perceptions of clothing comfort by human participants were affected by pattern and colour using a trained descriptive panel of experts [15]. In another study, it was discovered that finishing could negatively affect the handle of textile products. Using KES methodologies, the authors looked at how the finishing affected the fabric's handling characteristics. They discovered that the finishing process had a significant impact on the fabric's ability to bend. This demonstrated a connection between low-stress mechanical qualities and fabric handling [16].

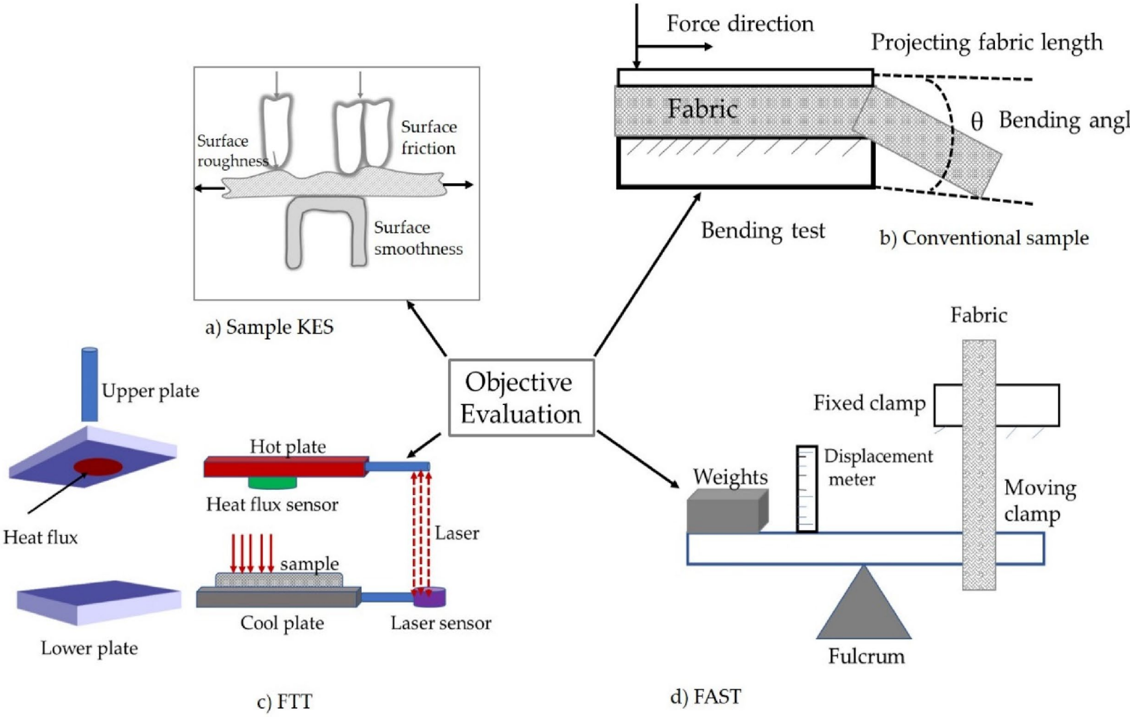


Figure 9.2. Systems of objective evaluation of fabric comfort. (a) KES [13], (b) bending measurement vs. comfort [7], (c) FTT [17]), and (d) FAST [18].

Yoo et al. have explored how the end-use circumstances and thermos-physiological and sensory characteristics of heat-resistant protective workwear affected the wearer's comfort response. Heat resistant workwear materials with varying fibre content, yarn qualities, weave types, and functional finishes are evaluated for their thermos-physiological and sensory capabilities. More distinct comparisons can be made using measured sensory qualities that are derived from the mechanical, surface, and liquid moisture management properties of the fabric. The findings of the wet cling, contact area and surface roughness analysis demonstrate that softer yarns, finer fibres, and twill weaves produce noticeably smoother fabrics with small contact [19]. In a paper, the sensory comfort of protective functional clothing, according to the authors, may be greatly influenced by the resilience of the fabric, which also has an impact on the surface property of the fabric [20].

The PhilaU Haptic Device, utilised to provide a touch/feel response, the Shirley stiffness tester and drape metres for draping, thickness gauges to examine thickness and compression performance, and a robotic system are also used to analyse sensory comfort qualities. Several models have been created and validated for determining the handle qualities using such objective approaches [21]. The Handfeel Spectrum Descriptive Analysis (HSDA) method makes it possible to compare fabrics' sensory characteristics in a practical way. The HSDA approach, which is utilised in US, British, Canadian, and Australian military uniforms, was employed in a research of 13 fabrics to analyse sensory hand feel [22].

Subjective evaluation of sensorial comfort

The market for wearable electronic textiles is always looking for new innovations to improve user satisfaction in the continued use of functional textiles for quality of life. But the ease of wearing clothes has an impact on how often functional textiles are used. Therefore, assessing comfort is a crucial first step. An alternative to objective measurement of comfort in functional textiles is subjective evaluation. The development of several sensory bipolar phrases to assess the comfort of functional textiles can be used to study subjective feelings of people [16]. To evaluate the comfort of functional textiles using blind and visual methodologies, specific sensorial words related to fabric contact with the skin have been devised and the results have shown that subjective evaluation may be a viable alternative. Figure 9.3 demonstrates the subjective evaluation of sensorial comfort.

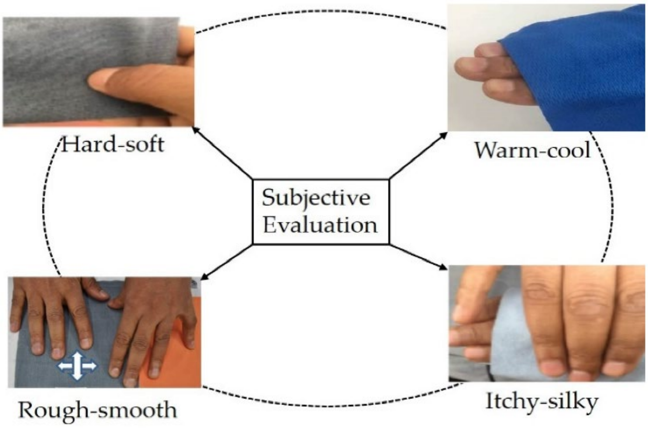


Figure 9.3 Subjective evaluation of sensorial comfort.

Due to the sensation of touch, subjective analysis links the hand of a cloth with a psychological outcome (Bakar 2004). When a person runs their fingertips over a fabric surface, a succession of sensory reactions occurs, causing the person to feel and think. A specific hand parameter is given to the sensation that is perceived. This choice can be impacted by variables such as personality, environment, prejudice (such as desired or anticipated results), emotions, and ranking or scale criteria (Aliouche and Viallter 2000). Independent judges have subjectively evaluated fabric handling in the textile sectors. Decisions are heavily dependent on personnel standards (Yick et al. 1995). It is crucial to pick the appropriate expressions to describe a fabric handle parameter to ensure the validity of subjective assessments. Numerous authors have identified various sensory qualities; mentioned in Figure 9.4 [23].

Figure 9.4. Various sensory attributes.

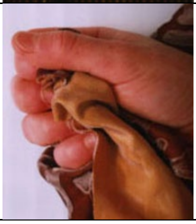
Finding a correlation between objective measurements in order to examine statistical evaluation requires the conversion of subjective assessment results to numerical values. Consequently, it is recommended to use the scale and time for sensory evaluation; mentioned in Table 9.1 .

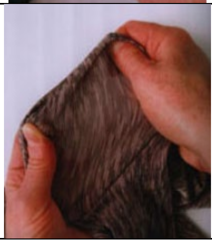
Table 9.1. Scale and time for sensory evaluation [1], [23].

Sensory attribute	Scale			Time (s)
Thickness/thinness	1	5	10	15
	thinnest	medium	thickest	
Softness/stiffness	1	5	10	20
	softest	medium	stiffest	
Roughness/smoothness	1	5	10	15
	smoothest	medium	roughest	
Total handle	1	3	5	15
	not proper	medium	most proper	

Years of expertise are necessary for the subjective hand evaluation, which can also be clearly influenced by the assessor's own preferences. A cloth may feel smooth, crisp, heavy, harsh, harsh, furry, fuzzy, or downy soft. It can also feel light, gentle, mellow, or soft. Therefore, it is necessary to replace the expert's subjective evaluation of the fabric with an objective machine-based approach that will produce consistent and repeatable findings. Table 9.2 indicates the assessed qualities based on the handle techniques.

Table 9.2. Handling techniques (Moody et al. 2001).

Handle Technique	Image	Properties Evaluated
Touch-stroke		Surface quality (texture), temperature
Rotating Cupped Action		Stiffness, weight, temperature, comfort, overall texture, creasing

Multiple Finger Pinch: Rotating between the Fingers action with one hand (thumb and1 or 2 fingers)		Texture, stiffness, temperature, fabric structure, both sides of a fabric, friction, stretch (force-feedback)
Two handed rotation action		Stretch, sheerness

Conclusion

Researchers are focusing on the evaluation of sensory comfort to assess performance during wearing. The comfort of products can be subjectively evaluated by specialists on the subject or objectively evaluated by evaluating mechanical characteristics with a variety of tools. Mathematical and soft computing/intelligent strategies have been used to integrate the subjective and objective data. In the subject of comfort science, it is projected that intelligent systems will continue to be employed in the integration of human knowledge and instrumental data. Some sophisticated algorithms could eventually replace conventional comfort modelling techniques for textile products. Future studies are likely to focus on the use of various intelligent soft computing methods in the area of smart textile comfort modelling.

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Chapter 10 Ethics and requirements for smart sensors and actuators integrated in textile products

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Abstract

Ethics related to smart textiles have a lot to tackle. Ethics, understood as the way how the new and smart applications that smart textiles provide, are a sensitive topic. And it is sensitive because most of those applications manage not only personal and private data of the person who is using the wearable, but also vital (physiological) data, especially when we are talking about smart protective equipment.

Furthermore, not only the data management is a key factor to consider in guaranteeing a safe use of the smart textiles, but also safety issues directly related with the health and/or potential health damages a wearable could generate on humans.

This paper attempts to explain how both data and physical care are crucial factors to take care about when we are using smart textiles products in order to ensure its safety in all its dimensions, not only when it is being used but also afterwards. Particularly, the paper will focus on the data protection regulation on the European Union and on some theory and practical cases about physical security and ethics.

EU Data protection regulation – GDPR

General Data Protection Regulation (GDPR) legislation adopted by the European Union (EU) is the main and highest norm about data protection and management that whole EU members must follow. It is a non-superficial issue, as the EU Charter of Fundamental Rights establishes that all EU citizens have the right to keep their personal data protected [1].

This directive was approved in 2016 and not only attempts to protect the mentioned data, but also to establish the same data protection standards for all the EU members and their citizens.

In this field, the data becomes particularly important if we are talking about physiological and health data -which is the one addressed in this paper as it is strictly linked with the smart textiles and electronic wearables.

If we talk about the United States of America (USA), the privacy regulations go through HIPAA. And in both cases, UE and USA, these norms aim at preventing data misuse scandals, mitigate the impact of data leakages, and endorse legal privacy regulations with a common framework [3]. Still, a worldwide regulation about this issue has never been agreed [5].

This information is applied in the field of smart textiles in several aspects related to the user's relationship with electronics. It is implemented from the privacy policy acceptance in a website to the field of smart textiles.

Safety data aspects

In this last case and, considering some data is considered as very sensitive, some preventive mechanisms must be designed and implemented. They would minimise cyberattacks or other kinds of threats from external actors, or not. The trustworthiness of these mechanisms is a key factor to keep this sensitive data protected.

For instance, the monitoring of the metrics -and whether they are abnormal or not- can facilitate the detection of the quality of the service and if it is under an attack and the data threatened.

Then, the authentication factor to access the data (through a device or a smart wearable) has become in the last years a determinant element. This authentication goes from classical elements such as a password, with also classical requirements such as avoiding simple ones, to the incorporation of new elements such as possession ones (cards) and biometric access. The combination of all those elements will endorse the system with robustness to the first door where the data can be accessed, stolen, interrupted...

In this sense, traceability is another factor to be considered. That means the ability to detect, the footprint of the attacker once the attack has been done and in the way it is possible, determine where it comes from, its identity, aims and, in general, the maximum amount possible of useful information that helps to repair the damage in case an investigation takes place afterwards.

Furthermore, it is important to underline that the data vulnerability can appear at several moments where it is managed. From its generation, in real time, to its transfer or when it is stored. For this reason, the mentioned preventive elements and actions should be designed and prepared to avoid threats at any of those stages.

Table 10.1. Summary and classification of security solutions in smart health systems [4]

Type	Solution	Actor	TCP/IP Layer	Requirements Protected
Secure communications	Lightweight cryptography	Nodes Communications HIS	Network interface	Confidentiality Integrity Non-repudiation Authentication
	Key management	Nodes HIS	Network interface	Confidentiality Authentication
Always-on systems	Secure routing	Communications	Network	Availability
	DDoS countermeasures	Nodes Communications HIS	Network	Availability
Trust management	Authentication protocols	Nodes HIS	Transport Application	Authentication Confidentiality Privacy
	Access control mechanisms	HIS	Application	Authentication Confidentiality Privacy
	Intrusion detection systems	Communications HIS	Network Transport Application	Confidentiality Integrity Availability Authentication Privacy
	Traceability of digital evidence	HIS	Application	Integrity
Data protection	Privacy protection models	HIS	Application	Privacy
	Awareness programmes	Users	-	Privacy

Conductive textiles technologies and safety

Another aspect to talk about in the field of safety and smart textiles is the safety of a textile with conductive properties.

Sensors cannot impact the skin in any meaning, and the same for human health and safety. From the functionality and user perspective, sensors and actuators should be reliable, otherwise their users cannot rely on alarms and alerts given from the APP or other devices.

In order to produce a fabric with conductive properties, there are two main common methods:

Wire drawing According to A. Angelucci, et al., wire drawing is a mechanical process that transforms the raw material into microfilaments […] applying forces with industrial machines. After the drawing, the microfilament is annealed at a high temperature of 600–900 ◦C to restore its mechanical and electrical properties. Afterwards, the wire is cooled and wrapped in a revolving cylinder.

The most used metals for this process are copper, silver, bronze, steel, and silver plating copper [4].

Fibre coating. *Fibre coating consists of applying metals or conductive polymers on the surface of a non-metallic substrate to make it conductive […]. The substrate can be either a fibre, a yarn, or a fabric. In the presented review, the fibre is considered as a conductive unit for the purpose of clarity. The different techniques used to make conductive fibres are sputtering, chemical polymerization, electrodeposition, and dip coating* [3].

The important aspect at this point is that both methods end up creating safe electronic textiles in the sense of previous testing of the sensors to be used. This way, we can be sure the electrical devices become safe and the product is able to be used.

Figure 10.1. Most common manufacturing techniques of conductive textiles: knitting, weaving, embroidery; coating methods; printing [3]

Practical cases

An example of a prototype recently developed that was designed following the GDPR guidelines is the project of SmartWorkwear [5]. It was confectioned by CP Aluart, and incorporates several sensors able to monitor physical constants of the person who is wearing the product. In this case, the tested and validated sensors are being integrated into a functional shirt.

Particularly, it gathers data about temperature, moisture, heart rate and other health related data that is considered sensitive and that can prevent, in this case, the worker of a risk related with the environment such as fainting, for instance.

Figure 10.2 SMART-WORKWEAR [5]

Conclusions

During the last decades, personal data generation has increased with the implementation and extension of virtuality and the internet. Particularly health related one, is sensitive information susceptible to be stolen and used for dishonest aims. So, it becomes crucial to keep it safe.

Up until now, this need has been tackled by the EU and the USA by the creation of a general framework for each territory. Still, they are not contrasted with each other, and the rest of the world, mainly, have not implemented such a regulation extensively .

Furthermore, more aspects have to be taken into account about the user's security. And they go from the cybersecurity where continuous improvements will be needed to face the evolution and adaptation of the virtual threads, to the physical ones, that must guarantee the electronic devices added into any wearable are safe to the user.

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Chapter 11 Boost innovation in smart sensors, actuators, wearable by co-design and co-development

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Abstract

Cluster paper in the boosting innovation field is not relevant but determinant. Clusters advice companies in their way to find out and exploit their capabilities, their strategic direction, and improve their weaknesses. Nowadays, these objectives are directly in line with the transformation of the sector, with the update of the textile industry from the XX century to the XXI century. Specifically, this improvement is about two key innovation pillars (among others) sustainability and digitalisation.

Clusters also approach these aims by actuating as an optimal ecosystem for companies' interaction, facilitating symbiosis, exchange of experiences and confidence among them.

Some examples of these kinds of facilitating activities are the company collaboration or the simple participation -each one by their own- in several programs for the development of new products or the improvement of their companies and factories.

Also, some funding programs are targeted to several companies to find out a way to introduce to an existing product a smart application or directly to design a new product that comes from companies' ideas.

In many cases, the result of these initiatives led by clusters end up producing new products and new applications that involve sensors, actuators and many other innovation forms to the market.

This paper attempts to explain the particular experience of the Catalan Cluster of Advance Textile Materials, AEI Tèxtils, and their companies' innovation initiatives as an example to illustrate how a cluster boosts innovation and how it and its companies act as a facilitating ecosystem for co-design and co-develop innovation in the sector.

Introduction

AEI Tèxtils, the Catalan Cluster of Advanced Textile Materials, has been advising some of their member companies during last years to develop projects that would be presented to several calls “*dedicated to helping innovative companies digitalise their businesses thanks to flexible and wearable electronics testing, experimentation and manufacturing support.*[1]

The cluster regularly supports its companies in terms of pre-advice and assessment of their innovative projects before they are sent to the evaluation call.

Particularly, it has been active in two kinds of funding programs that boost innovation among companies and support economically the development of products such as actuators, sensors and wearables in general: SMARTEES [2] program and GALACTICA project [3].

It is highlightable the success rate of such activity is very important, as on the las SMARTEES call for proposals three members were granted to develop their projects.

SMARTEES

SMARTEES is a project that calls for proposals to “*help innovative companies digitise their businesses thanks to flexible and wearable electronics (FWE) testing, experimentation and manufacturing support*”. It was founded by the program Horizon 2020 of the European Union and has enabled the development of multiple innovative projects within the textile sector.

It focuses on “*Flexible and Wearable Electronics Technologies*” and “*is one of the Digital Innovation Hubs (DIHs) which are ecosystems that consist of SMEs, large industries, start-ups, researchers, accelerators and investors*”.

Among its objectives, we can find the aim to a) help EU companies in their business digitalisation, b) support EU companies in testing and experimentation prototypes before they decide to invest on them and launch a new product and c) create a Digital Innovation Hub that acts as a network that foments digitalisation among EU stakeholders.

The last edition of this program covered the period 2020-2022 and, as mentioned, some companies’ member of the cluster were beneficiaries as their projects were evaluated as highly competitive and innovative. Also, in previous editions there had been grants for Catalan industry.

Arpe [3] is the company that developed the first example of co-designed wearable that the cluster is going to provide. In front of the difficulties of COVID-19 pandemics and the evident challenges regarding the washing process for reusable masks (necessarily to be washed at high temperatures and large amounts of water consumption), Arpe developed a Smart-Facemask [4].

It consists in a mask that is elaborated with a yarn pattern that adds electric interconnections within to enable the self-heating to eliminate potential virus presence.

Figure 11.1. Infographic explanation of the Smart-Facemask concept

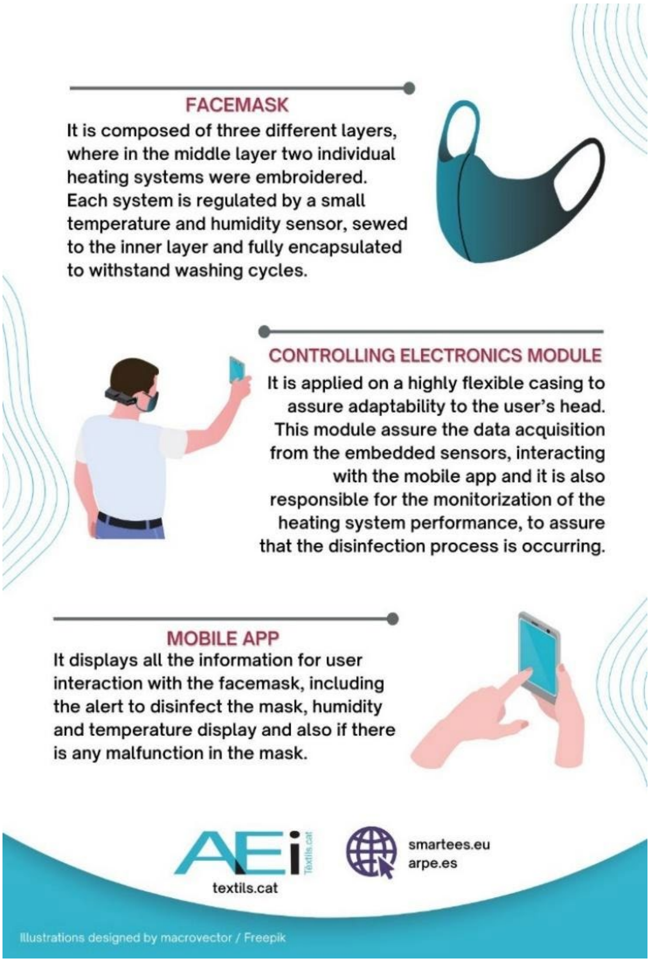

Figure 11.2. Infographic explanation of the Smart-Facemask concept

Polisilk [5], in its project, proposed to create a prototype called Sm*art-horse-riding* [6].

This concept consists in a smart half pad for the dressage market within equestrian discipline. “*This product is composed of flexible electronics through printed conductive yarns and pressure sensors within a half pad (blanket positioned under the horse saddle). The different pressure points generated by the rider position on the horse are visualised through a custom app developed during the prototype stage”*.

These improvements added to a classical product endorse the new version with several advantages related with the ergonomics, preventing possible injuries to the rider and to the horse back; with the training, allowing to track in real time some data to improve the rider performance; with its washability, allowing the product to be washed in a conventional washing machine and with the flexibility quality, among others.

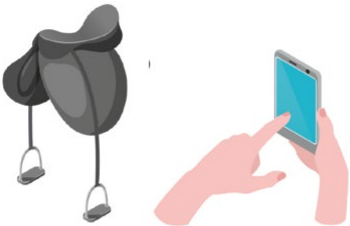

Figure 11.3 Draw of the Sm*art-horse-riding* concept

Figure 11.4 Sm*art-horse-riding* real performance

Finally, C.P. Aluart [7] developed another idea targeted to worker conditions. Through multiple and flexible sensors integrated in a conventional worker indumentary, the company prototyped a smart skin-contact garment that measures the users' physiological conditions in real time.

This way, it is possible to measure in any moment the conditions the worker is exposed to outdoors (temperature, moisture,…) and determine possible risks he or she is likely to suffer such as fatigue or heat strokes.

The name of this product is SMART-WORKWEAR [8].

Figure 11.5 SMART-WORKWEAR

Galactica project

Galactica Project is another initiative funded by the program Horizon 2020, from the European Union that aims at supporting SMEs through mainly financial support mechanisms -apart from others- on innovation. Particularly those projects that implement cross-sectorial dynamics in the fields of textile, aerospace and advancing manufacturing.

According to the Cluster, *"GALACTICA is a key strategic project by AEI Tèxtils to promote technological innovation and new business models as a driver of growth and competitiveness of SMEs in the sector. It serves to promote cooperation among partners and with other innovative systems such as aerospace and* *advanced manufacturing. Its strong cross-sectorial approach enables the generation of business opportunities and cross-sectoral innovation, promoting transversal cooperation to develop novel applications and markets* [9].

Through this initiative, and boosted by the cluster's support, five member companies managed to get a grant that would help finance their innovative ideas and prototypes. Those are Cinpasa [10], E.Cima [11], Texfire [12], Maccion [13], Fello [14] and Triturats la Canya [15].

Among others, the mentioned companies developed from an active cooling textile system to prevent heat-stress in outdoor workers [16] to a disruptive and environmentally friendly data transmitter tape for the aeronautic industry [17] or a smart textile tape with embedded fiber optics solutions wither higher accuracy and flexibility for applications in structural health monitoring of composite aeronautic structures [18].

Conclusions

Boosting innovation and create co-design and co-development capacity is not easy.

Of course, companies can lead their own projects by their own, but to study, design, test, prototype and launch a new product is not only a high time-consuming task but also requires large amounts of money.

Companies in the textile industry are more than capable to lead this revolution on the innovation paradigm, but it is needed to create the proper environment to achieve such an ambitious objective.

To do so, the cooperation and the advice within the sector is key, and the existence of financing lines determinant, as a small group of companies would be able to afford such costly investigations to develop new and innovative products.

Through that economic funding and a good role played by the clusters the innovation bosting is wider and deeper than if these factors would not exist or work properly.

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Chapter 12 Creative methods for co-design of the smart textile product

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Introduction

Co-design is a process. The possibility of approaching the codesign process in several ways creates the opportunity to use different methods, principles and models. All of these, being able to be applied to different people.

There is no one-size-fits approach, but there are patterns and principles that can be applied in different ways with different people.

The interdependence elements of co-design are: production, delivery, design, evaluation, planning (figure 12.5). Co-design refers to the collective creativity of collaborating designers.

The place of co-design in the design process is presented in figure 12.1 [5].

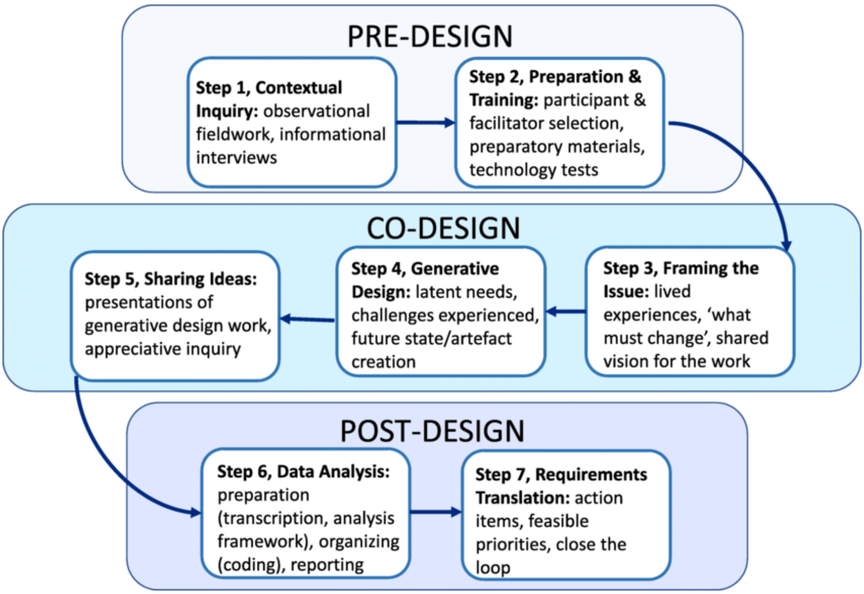

Figure 12.1 The place of co-design in design process

From figure 12.1 it can be observed that there are three levels in design process:

1.**pre-design** that contains two steps: contextual inquiry and preparation & training;
2.**co-design** that contains three steps: sharing ideas, generative design and framing the issue;
3.**post-design** that contains two steps: data analysis and requirements translation.
The co-design is like a puzzle formed from two pieces: users and designers (figure 12.2). When the two pieces fit perfectly, the result is co-design.

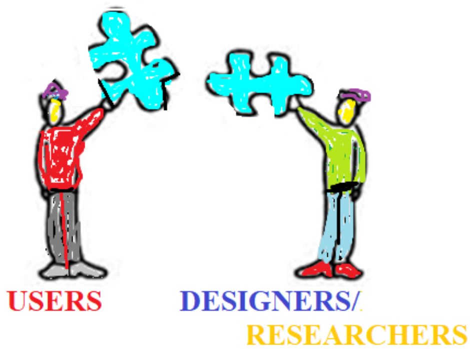

Figure 12.2 Collaboration between users and designers

The difference of co-design and other approaches of design

The difference of co-design and classical design are presented in figure 12.3 [4].

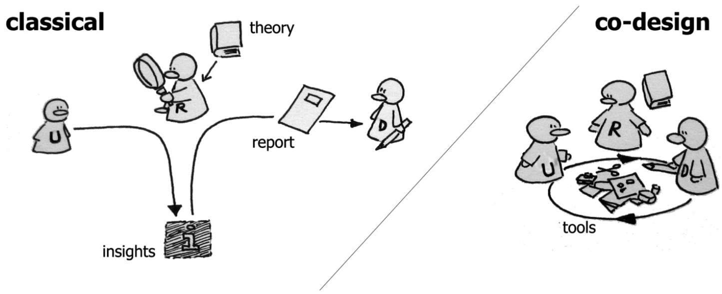

Figure 12.3 Comparisons between co-design and classical design

The components of co-design process are presented in figure 12.4.

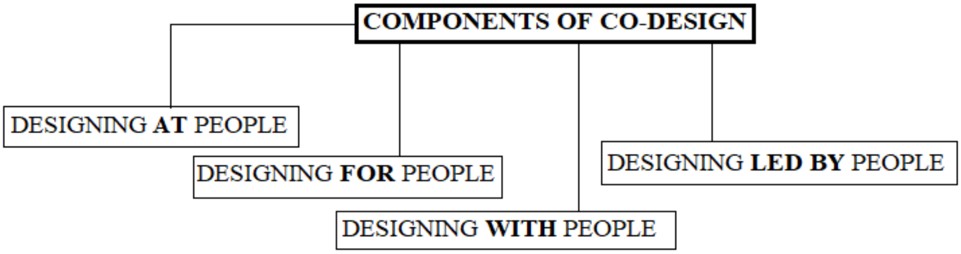

Figure 12.4 The components of co-design

While in the classical design, the researcher is a translator between the 'users' and the designer, in co-design, the researcher (who may be a designer) is a facilitator.

Creative methods for co-design

The creative methods for co-design are presented in figure 12.5 [3].

1.Participatory design, as a creative method of co-design, consists in the active involvement in the design process of all those who are involved in this process. (figure 12.5) [3].

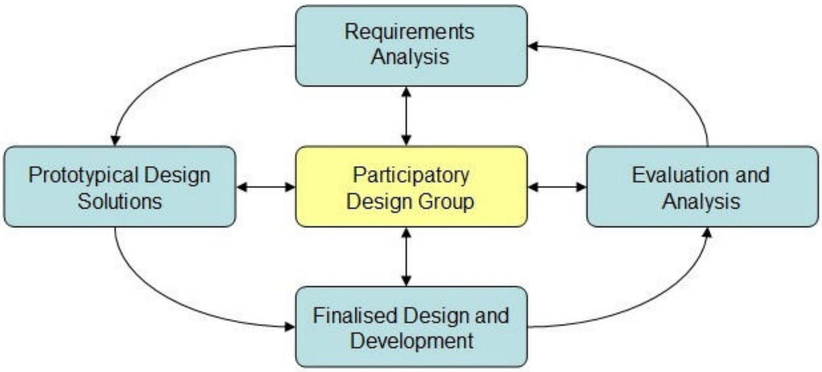

Figure 12.5 The classification of creative methods for co-design

2. The possibilities of applying the design method in a partnership with users [1] are presented in figure 12.6.

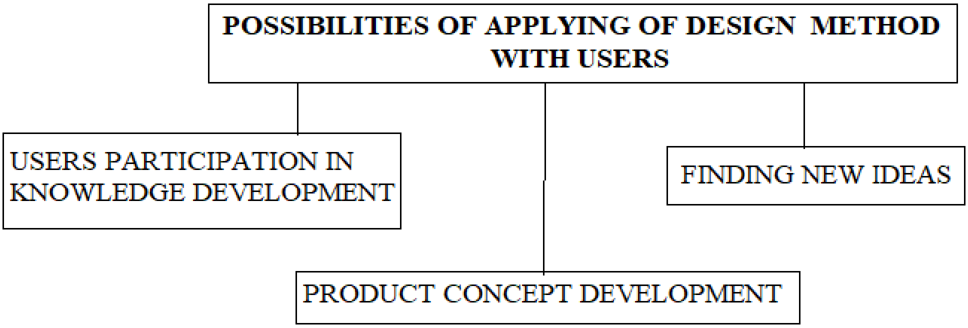

Figure 12.6 Design method with users

3. The contents of **self-reflection research method [1]** and possibility for application are presented in figure 12.7.

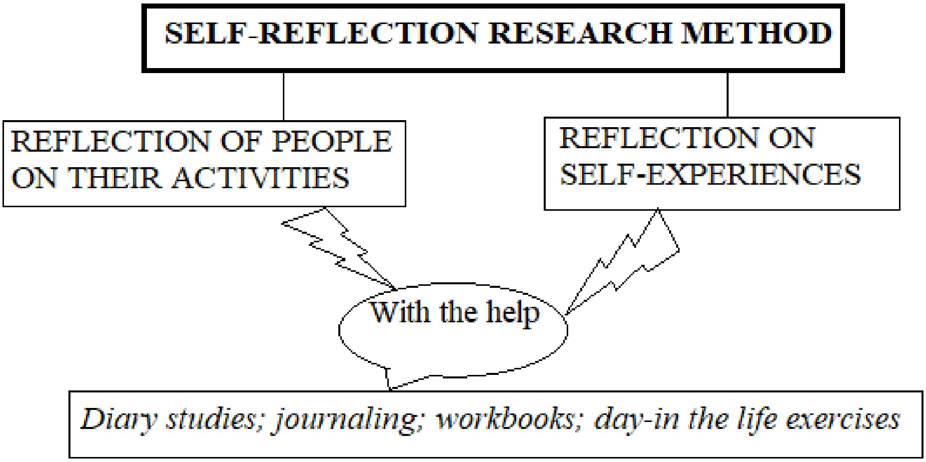

Figure 12.7 Self-reflection research method

The principles for co-design are suggestively presented in figure 1.8.

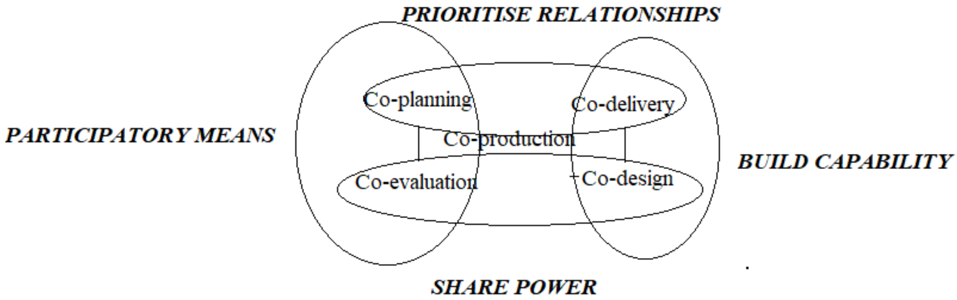

Figure 12.8 The principles of co-design

Textile materials for smart clothing

When for obtaining of smart clothing are applied creative methods of co-design, it must to know the textile materials (figure 1.9) [6] from its structure.

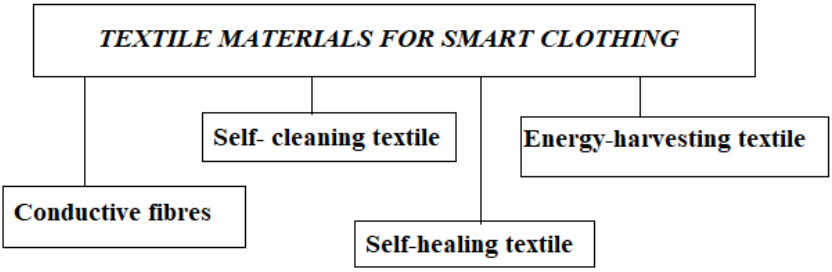

Figure 12.9 The main textile materials for smart clothing

By using fibers with a high conductive capacity, antistatic, EMI, IR absorption effects can be obtained [2].
Self-cleaning textiles (3D copper, silver nanostructure) through their mechanism (nanostructures, metal atom excitation by light) are used for obtaining shirts, jackets, etc. [2].
In medicine and not only, you can use self-healing textiles (based on magnetic ink, carbon powder), which have the ability to slowly release the healing agent.

The functions of smart textile are presented in figure 1.10 [2].

Figure 12.10 The functions of smart textile

Smart textiles require new technologies, new fibers and new textiles.

Conclusions

Currently, due to the development of human society, the focus is on the appearance of new smart textiles (development in textile technologies, by new materials, nanotechnology and electronics) for smart clothing, which will lead to an increase in the quality of life. So, the next-generation textiles are smart textiles.

But the main requirement from smart clothing remains the comfort in wearing clothing.

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Chapter 13 Co-design of smart sensors and integration into military PPE products

Farima Daniela, Iovan Dragomir Alina, Bodoga Alexandra Gheorghe Asachi Technical University, Romania

Introduction

For a soldier the physiological and physical capabilities are very important for the activities performed. For this reason, these capabilities must be monitored, using wearable systems and smart clothes [1].

The main requirements of smart clothing [2] are presented in figure 13.1

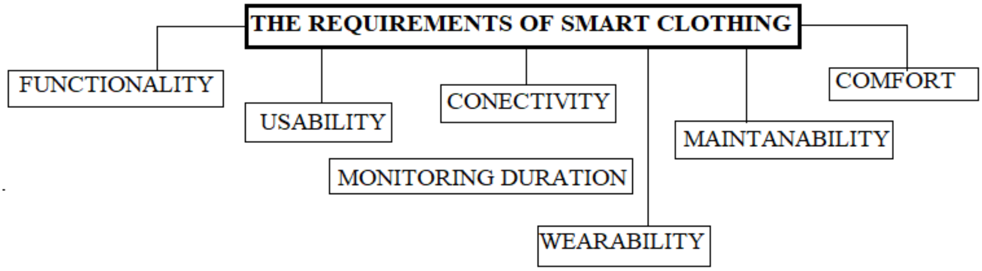

Figure 13.1 Requires of smart clothing

Figure 13.1 shows the requirement regarding the comfort of smart clothing. This requirement is very important in the use of wearable system monitoring technologies [3].

The portable systems interact physically, physiologically and functionally with the human body.

The two fields involved in the design of a smart garment are presented in the figure 31.2) [1].

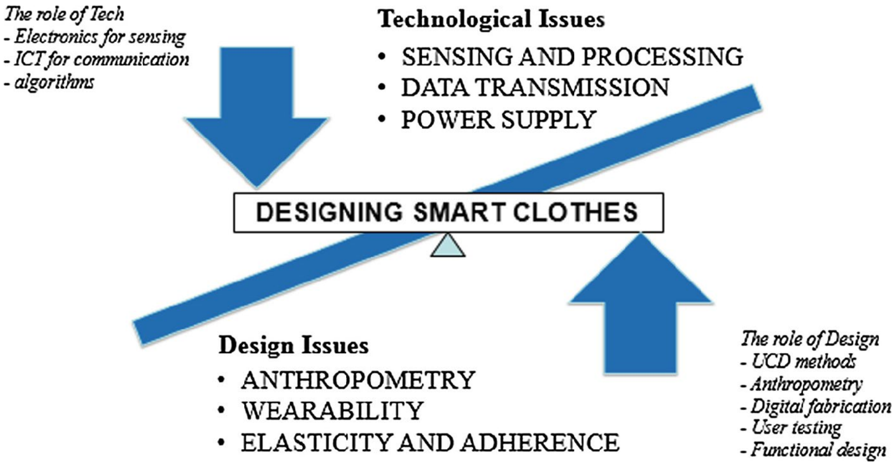

Figure 13.2 The designing smart clothes

For the design process to run smoothly, the wearer's requirements must first be known [1] (Figure 13.3) [4].

Figure 13.3 The design thinking process

Strain sensors

Deformation (mechanical or thermal) is due to a force, when the length of an element changes relatively (elongation or compression).

For example, the mechanical deformation is measured with the help of sensors, which indirectly record the deformation force.[5]

From figure 13.4 can see that the strain can be: positive and negative [5]

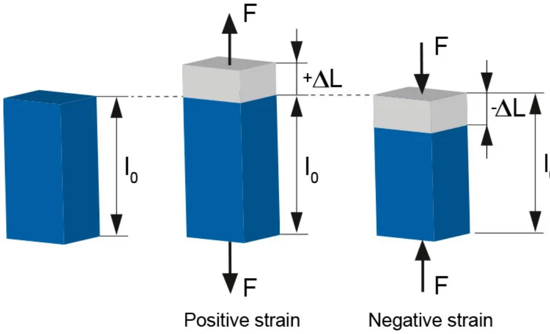

Figure 13.4 The types of strain

The force measurement with strain sensors is presented in figure 13.5 [5**]**

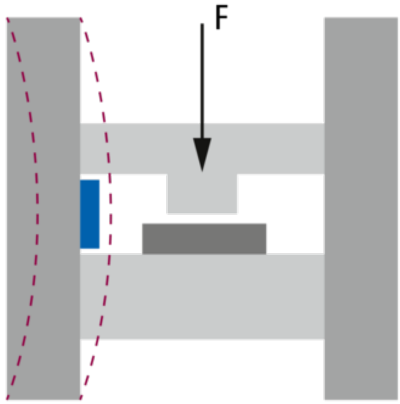

Figure 13.5 Indirect force measurement with strain sensors

The types of strain sensors are presented in figures 1.6, 1.7, 1.8, 1.9 [4].

Figure 13.6 Miniature strain sensor **Figure 13.7** Strain sensor performance

Figure 13.8 Standard strain sensor **Figure 13.9** Robust sensor for harsh outdoor environment

Because this type of strain sensor is applied in a limited space, it will be used for harsh industrial environments as well as a passive plug-in sensor (figure 13.6).
The features of strain sensor performance (figure 13.7) [5] are:

- optimised for small and large measuring range;
- integrated amplifier electronics for application-specific
- industrial indoor application.
-

In PPE military are many and complex and different sensor types (figure 13.10) [6,7]

Figure 13.10 The PPE military

Conclusions

Co-design of smart sensors and integration into military PPE products, supposes knowledge of the requirements of the field of wearing military PPE and the comfort felt by the wearers.

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Chapter 14 Co-design actuators based sensorial materials

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Introduction

In order to create materials with increased performance, sensory materials are used. Identification of materials and sensorial evaluation is necessary , together with technical specification (strength, performance characteristics, flexibility, elasticity, comfort) [1].

Classification of sensations is presented in figure 14.1.

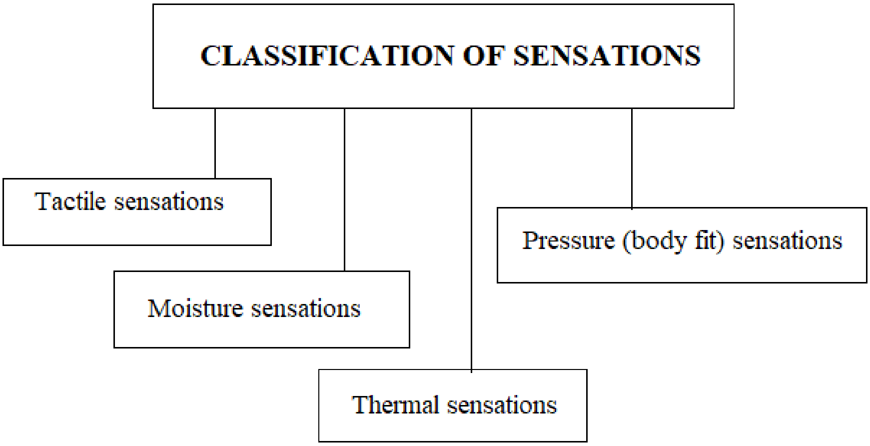

Figure 14.1 Classification of sensations

Main factors which influencing the fabric sensorial comfort are:

- Fiber characteristics;
- Yarn characteristics;
- Fabric characteristics;
- Finishing processes, methods and types of dyeing.

To obtain textile materials with different sensory comfort characteristics, it is necessary to choose, first of all, the nature of the raw materials.

The sensory comfort of a textile material can be improved by applying chemical treatments. Through these treatments, fiber-fiber friction is reduced, obtaining a material with a special texture [1].

The yarn type (simple yarn, continuous filament, textured, twist, linear density) is very important for the sensorial capacity of fabrics.

The bending, stiffness and shearing property are influenced by the degree of twisting of the yarns [2].

The factors which influence the sensorial comfort, are presented in figure 14.2.

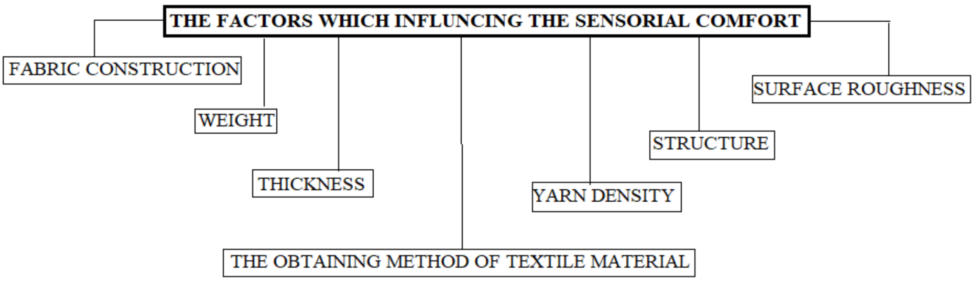

Figure 14.2 The factors of influencing of sensorial comfort

To reduce the coefficient of static and dynamic friction, softening and stiffening treatments are applied.

The properties of fabric that influencing sensorial comfort

The sensory comfort of textile materials is influenced by their surface properties (texture) and their mechanical properties (figure 1.3, figure 1.4).

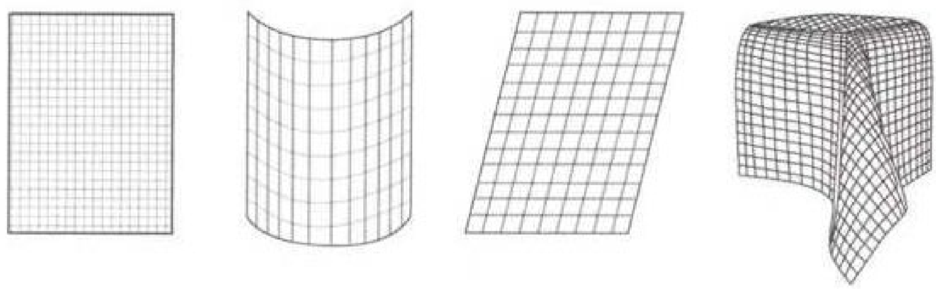

Figure 14.3 The deformation of fabric (Hu, 2004)

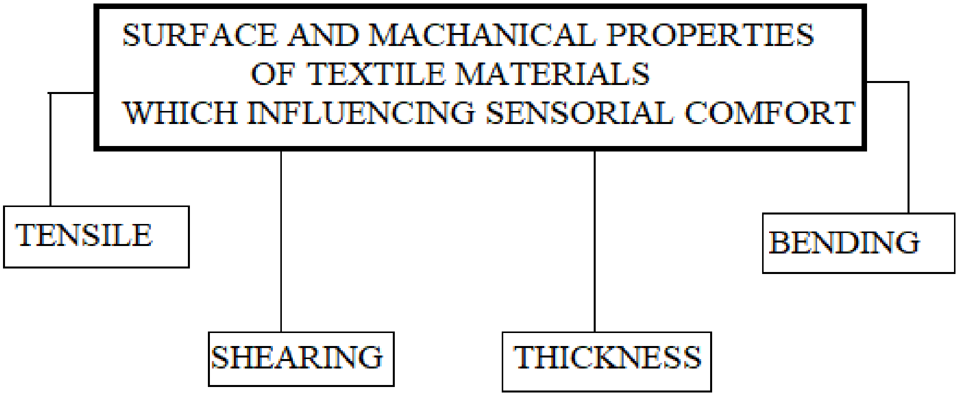

Figure 14.4 The factors of influencing of sensorial comfort

Tensile properties of woven

The tensile is the most important because, regardless of the type of deformation, it will cause some movement of the fibers and yarns (Hu, 2004) [1].

During extension of fabric appear there are three stages:

1. The Inter fiber friction;

2. Orientation of the yarn in the direction of application of the load;

3. The load extension curve due to wire extension (figure 1.5) [4].

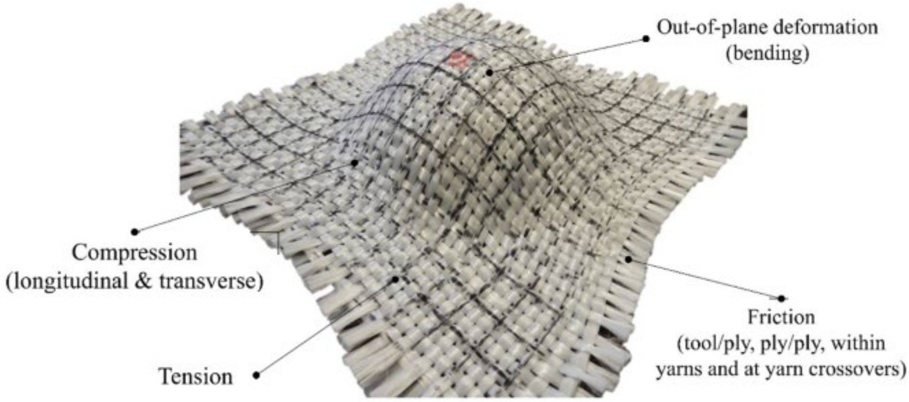

Figure 14.5 Properties of woven

The bending properties of a fabrics (bending rigidity and bending hysteresis) are determined by yarns and finishing treatment of the fabric (Schwartz, 2008).

Bending stiffness is defined by the resistance of the textile material to flexion (Pavlinić & Gerśak, 2003).

Shear of fabric

The shear properties influence the capacity of drippiness, pliability and handling of woven fabrics (Schwartz, 2008).

During the wearing of clothing, due to body movements, shear deformation occurs (Hu, 2004).

Thickness and compression of woven fabrics

The main factor that influences the compression is structure of the fabric (Mukhopadyhay et al., 2002).

In wearing clothing, the thickness of a fabric offers information on its thermal insulation, heaviness or stiffness.

Sensorial comfort of fabrics

There are many sensory attributes of fabrics handling (table 1).

Table 14.1 Sensory attributes of fabrics

Stiffness/crispness/pliability/flexibility/limpness	Anti-drape/spread/fullness
Softness/harshness/hardness	Tensile deformation/ bending/surface friction/sheer
Thickness/bulkiness/sheerness/thinness	Compressibility
Weight/heaviness/lightness	Snugness/loosenes
Warmth/coolness/coldness (thermal characteristics)	Clinginess/flowing
Dampness/dryness/wetness/clamminess	Quietness/noisiness
Prickliness/scratchiness/roughness/coarseness/itch iness/tickliness/stickiness/	Smoothness/fineness/silkiness
Looseness/tightness	

Depending characteristic type , the evaluation methods are objective or subjective approaches .

Conclusions

Sensory materials are characterised by their capacity for self-detection and active response. Due to the adaptive and sensory capabilities, these materials will be used more and more to obtain multifunctional clothing products.

For describing fabric handle it can use the following terms [ASTM Standard D123 (2003)]:

- the flexibility refers to ease of bending;
- the density describes the mass/unit volume;
- the resiliency is the ability to recover from deformation;
- the compressibility consists in ease of squeezing;
- the extensibility to refers at ease of stretching;
- the surface is characterised by resistance to slipping;
- the surface contour – divergence of surface from the fabric plane;
- the thermal character that is defined by apparent temperature difference between fabric and skin.

Fundamental knowledge of the relationships between the structure and properties of these materials is the key to success in obtaining new multifunctional products.

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Chapter 15: National and European legislation concerning smart, sensorial and wearable Products

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Policy recommendations

Several policy recommendations can be made based on the analysis of drivers and obstacles that may help create a business environment more favorable to the development and adoption of wearable technology. Entrepreneurs operating in the field of wearable technology could benefit from a regulatory framework that is better suited to their needs, particularly with regard to privacy concerns associated with the collection and storage of personal data by wearable devices. [1].

Additionally, improving the regulation of mobile data roaming costs could lead to increased adoption of wearable technology. Finally, policymakers could encourage the integration of wearable technology into medical devices to promote its development and adoption. [2]

Adapting regulatory framework to wearable technology

With the rise in the number of personal devices, the storage and privacy of data are becoming increasingly important. However, the current regulatory framework in Europe may not be equipped to handle the complex privacy issues that may arise from these developments. Companies and public organizations can store personal data collected by wearable technology devices indefinitely in digital clouds for pattern analysis of customer data. [3] While health insurance companies are rewarding their participants for using health-improving wearable technology devices, it also presents opportunities for the misuse of the collected data. Directive 95/46/EC on the protection of personal data and its movement should be reevaluated to determine if the data collected through wearable devices is adequately covered by the current regulatory framework. Additionally, the growing use of technology while driving, including smartphones and smartwatches, is a major cause of driver distraction and preventable accidents. [4] Laws and regulations need to be reviewed to include the use of wearable devices while driving, as even hands-free devices can reduce a driver's ability to react to unsafe situations on the road.

The fashion industry is likely to be impacted by the new regulatory framework of GDPR, as wearable devices and smart clothing gain more importance in the years to come. While some data protection issues are common across all businesses and modern devices, others are unique to wearable devices. In particular, managing the big data of customers and workers [5] collected through these devices, profiling, and commercial activity aimed at refining this data, will be a major issue in the future. Although this element is not unique to the fashion industry, the close relationship between data and the individual will be a distinctive feature of the relationship between fashion and data security. For the first time, the user's clothing will also serve as sensors, collecting a vast amount of data in real-time, which may be viewed as intrusive and require legal regulation. The sensitivity of data needs to be considered, not just for its commercial value, but also for its close association with the individual. The development of a security and privacy policy specifically tailored for the fashion industry is becoming increasingly important, just as it is in other sectors such as banking, insurance, telecommunications, and government.

The focus is on implementing a policy that can effectively address data security breaches. This policy would involve understanding what constitutes a data breach, including internal flaws or weaknesses that could cause the uncontrolled spread of data.

Once a breach is detected, it's essential to act quickly and provide information to assess the severity of the situation, while enabling transparent communication with regulatory authorities and customers. Limiting the damage is also critical, and one solution is to use anonymous or encrypted data. [6]

It's important to understand how to manage data across the enterprise, especially when it comes to analyzing customer behavior and preferences across offline and online interactions. Mobile technologies are particularly relevant, as data collected through them can be integrated with artificial intelligence to offer personalized advice. [7]

While many fashion houses are hiring data scientists to analyze this data, there's a need to focus on hiring legal and cybersecurity professionals. The challenge is that true anonymization is increasingly difficult, as wearable technologies collect intimate data related to one's behavior and health, making it an unprecedented tool for advertising potential. [8]

Regulation of roaming costs

To increase the usage of wearable devices with mobile internet connectivity, reducing roaming charges in the European Union (EU) and other parts of the world is crucial. According to reports, network providers are making high profits, with margins as high as 90 percent. [9] To address this issue, the European Commission has implemented the Eurotariff cap, which has led to an 80% reduction in prices for phone calls, SMS, and data since 2007. The European Parliament has also voted to ban roaming charges entirely from December 2015 onwards. [10] Despite these measures, there is a need for further pressure on telecom providers to adjust global roaming tariffs.

Encouraging the integration of wearable technology in medical devices

Healthcare systems worldwide are facing significant challenges due to rising costs and demand, coupled with advancements in treating complex conditions. The increasing share of GDP [2] allocated to healthcare is unsustainable, and technology may be the most viable solution to address this challenge. Policymakers can promote the integration of wearable technology in medical devices, allowing entrepreneurs to transition from providing consumer electronics to regulated medical devices that provide accurate data and can be integrated into patient health records. [3] Policymakers may also encourage demonstrations of the value of wearable technology in medical devices to convince healthcare providers and insurers of the benefits they offer. However, the regulatory framework must be flexible enough to foster rapid innovation while safeguarding public health, and claims made by wearable providers or app developers need to be thoroughly examined, as only a small proportion of health apps claiming to treat or cure medical problems have been clinically tested or approved. [11]

Conclusions

The first conclusion drawn is that it is crucial to process data in a way that maintains anonymity. The second key aspect is data encryption, which is the most effective technological tool for safeguarding collected data, particularly when communicating with fashion companies via wearable devices. The GDPR and other standards underscore the importance of protecting customers who use such devices. Additionally, Allday identifies four areas of focus that connect wearable devices, cybersecurity best practices, and GDPR. The first area is ensuring that staff members are aware of what constitutes a data breach and how to prevent and report them [12]. The second area is investing in customer relationship management to provide a human point of contact for customers with questions and to maintain engagement. Data breaches are considered the most significant threat to wearable device data, and it is essential to take measures to prevent them.

The second aspect discussed in this context is about protecting the consumer's data, which is also emphasized in many regulations and requirements of the GDPR. It is crucial to be transparent with customers about their rights, how to request more information, and how to have their data deleted. Transparency and honesty are essential to retain customer loyalty and ensure their safety on the Internet, especially in light of past scandals such as Cambridge Analytica and Facebook. It is also important to promptly respond to all customer requests for data, particularly requests for the removal of information. Finally, social media marketing and advertising should focus on providing personalized content that engages individual customers without compromising their data or exploiting it. It is important to balance the need for data protection with the need for data processing.

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Chapter 16: Synthetic analysis -textile, sensors, wearables

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Introduction

Smart textiles are a new sector that seems to reach its maturity phase. So far, the sector has been oriented to the exploitation of advances in electronics and communication, failing however to intergrade them in a product that fulfils the requirements of a textile. The prototypes are becoming more "textile", thanks to the development of new textile materials that are conductive and/or have inherent functions.

Analysis of smart textiles

The wearables are garments or human body accessories that can execute some function. In this aspect, the model of a wearable textile should be an integration of a garment or accessory, with the classical model of an automation system is also valid:

- Signal Input devices: sensors
- Input (data) processing microcontroller, PCB, smartphone
- Signal Output: actuators, LED's, screens, input (Signal) to a software application
- Data storage: smartphone, the cloud via an app
- Communication between the parts. electronic, wireless, optical
- Power supply: battery, photovoltaic panels, kinetics, tribolelectric

All of the above parts should be integrated seamlessly, as far as possible. In fact, the evolution of smart textiles is divided in three categories, depending on the level of parts integration on the product. On the first and second generation of smart textiles, these were simple garment with discrete active materials or conventional electronics attached to the garment. The fabric should be able to be the substrate that will host the other parts, or at least some of them. This configuration has given some products like Iconic Levi's® Trucker jacket [1] and several products for harvesting of biometrics data (smart vests), but not really any success story.
Another quite successful and typical technology of this generation, have been the ecosystems of Arduino [2] and Adafruit [3]: Small CPU's (boards) and sensors, easily programmable in a simple Integrated Development Environment (IDE).

The third generation seems to the promising, one, where the functioning components are seamlessly intergraded in the garment.

It is true, that there is no market for smart textiles so far. A technology life cycle and network analysis method analysis by Qian Xu et al. [4] based on data from patents, has revealed that technology convergence in smart textiles will reach its peak at 2030, which means that the sector is now reaching its mature phase. Furthermore, this study presents the main technological sectors that are involved with smart textiles: electronics (the leading sector), mechanical and chemical engineering, computer science and product design.

In the recent prototypes and products, a lot of the above parts have been replaced by the smartphone, given that it it can provide the data storage and the data processing element, as well as the screen as an output device.

An incompatibility is fundamental in wearables: they must be flexible as garments are , but the electronics are hard. This affects mainly the aesthetics aspect, since the give an image of a strange garment. It also relates to the comfort of the item. The solution to this problem can be either the design and manufacturing of textile electronic parts, or the attachment of micro (or even nano) electronics in the textile substrate. Both options have been applied in prototypes and products and both can give promising results, but the problem of luck of mass production methods, is not solved yet.

Heitor Luiz Ornaghi Junior et al. [5], provide a complete overview of the methods and material that have been applied in the manufacturing of smart textiles products. According to this paper, the main fabrication categories are:

- use of conductive textile yarns
- weaving and knitting
- finishing touches on the textile, where a specific capability is incorporated into the textile after fabrication

The main categories of smart fabrics are:

- Smart Color-Changing Fabric Textiles
- Fabrics for temperature control
- Shape memory textiles
- Electronic textiles

A model for design for smart textiles

The requested attributes of the wearable are comfort, protection, duration, washability and aesthetics/fashionable . However, designing for these, needs a lot more requirements.

The design model of a wearable is quite complicated, but not established yet. A good model is the one proposed by Francés-Morcillo et al, [6], which consolidates the design requirements in a *wheel* model of 9 groups, introducing the ergonomics and user interaction requirements in addition to the physical ones, which is the novel aspect of this model. The wheel model is shown in picture 16.1 below. We should mention though, that what is missing from this model, is the new aspect of the ecodesign, which is becoming more and more important and will be sooner or later a mandatory requirement for wearables, as well as for electronics and garments.

The wheel model also lucks another design requirements, which is the manufacturability. This is a very important aspect, because it relates to the commercialization of smart textiles that is not yet a reality. Automated production methods are needed, that will provide mass production, in affordable cost and reliability. It is quite probable, that new textile production techniques like 3D knitting and 3D printing will prevail to the convention ones in the short term, but in any case, the product has to be designed accordingly and suitable materials (flexible, light weighted conductive yarns) have to be developed. So far and according to our knowledge, efforts for new innovative materials are targeting new functions and comfort and the manufacturability element is neglected. This is the reason that smart textiles do not exist beyond the Technology Readiness Level of 2, which are prototypes in essence [7].

It is clear that this calls for a multidisciplinary design team. So far, garments are designed by fashion designers, focusing on cost, aesthetics and comfort. On the other hand, the textiles are designed by engineers aiming at functionality and reliability of the function. The distance between these two designer teams, is described very well by the term ” *United Intention with Divided Focus*” by Rebecca R. Ruckdashel, et al. [7]

For instance, Natascha M. van der Velden et al. [8] highlight the importance of materials selection, and suggest the use of copper for conductors and acryl for substrate, against silver and acryl respectively, as examples of materials with reduced environmental impact and a more eco-friendly character.

Conclusion

A synthetic analysis of smart textiles reveals that that there is not an established paradigm for design and manufacturing. The sector is driven by significant available advances in smart materials and technologies but is also restricted by luck of an efficient integration into a textile product. Electronic textiles can be a solution to this problem, as long as mass fabrication and production technologies are also available.

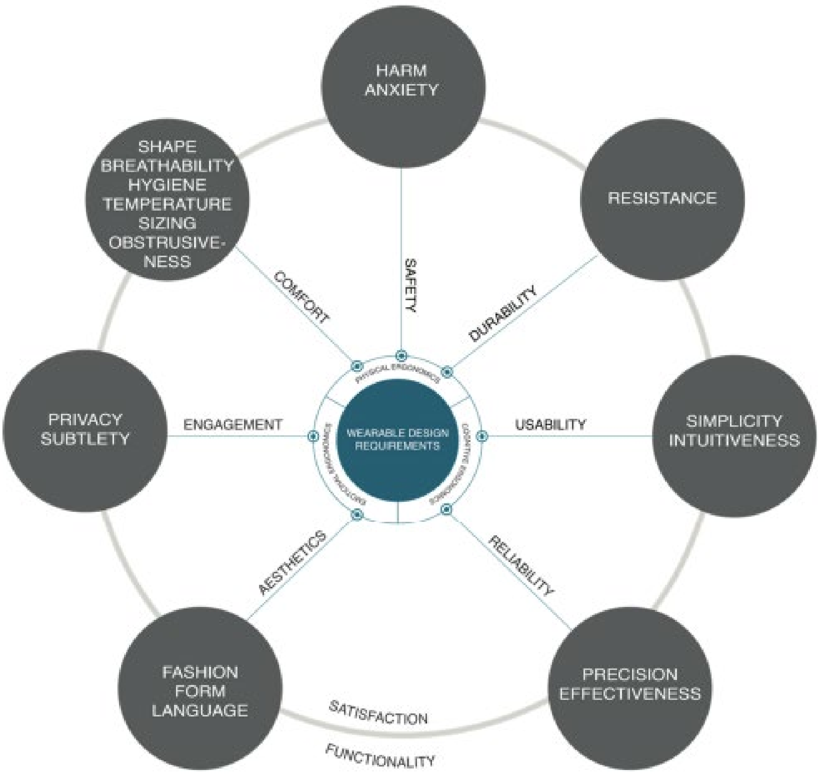

Figure 3. Wearable design requirements wheel model.

Figure 16.1 Wearable design requirements wheel model [6]

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Chapter 17: Market dynamic for smart electronics-based textiles

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Market potentials

The growth of the smart textiles market is being driven by the trend of electronics miniaturization and the increasing integration of smart textiles with wearable devices. In the fields of health and sports, smart textiles are being used more frequently to monitor muscle vibrations, regulate body temperature, and protect against hazards. The development of compact electronic components such as sensors, batteries, and control panels has also made it easier to integrate smart textiles into wearables and electronic devices. Moreover, the defense sector is introducing more products, which is also contributing to market growth. (1)

Wearable healthcare devices, which allow consumers to track vital health information both inside and outside of hospitals, are expected to remain a major sector favored by cellular connectivity. (2)

The smart textile market is predicted to reach US $30.45 billion by 2029, with an annual growth rate of 28.4%, especially in the active/ultra-smart textile segment. (3)

The North American smart textile sector dominated the market in 2021, driven by strong demand from various sectors such as military and protection, healthcare, fitness, and sports, particularly in the United States. The region is home to major smart textile manufacturers such as DuPont (US), Gentherm (US), Sensoria (US), Alphabet (US), and Jabil (US), who are actively contributing to the growth of the market. Major players such as Google, Apple, Samsung, Qualcomm, and Microsoft are already heavily involved in the wearable technologies sector, particularly in the health and fitness industry. With the current developments in the industry, the wearable technology segment is expected to be characterized by intense competition. A recent study by ABI Research shows that the number of wearables shipped worldwide in 2020 reached 259.63 million, with 112.15 million sports, fitness, and wellness trackers, and 74.30 million smartwatches. The market for wireless headsets, which is the leading smart accessory, reached 502.7 million shipments by the end of 2021 and is expected to exceed 700 million by 2026, with a CAGR of 7.6%. (4)

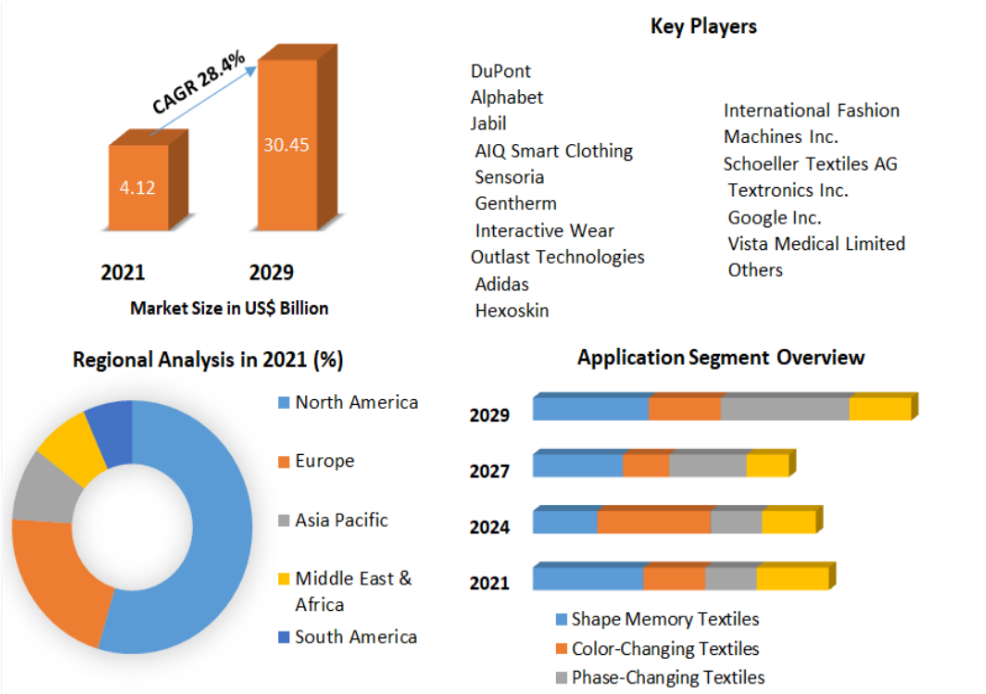

Figure 17.1 Global Smart Textile Market – Maximize Market ResearchPVT. LTD. (2)

Social potentials

Wearable devices have a range of socio-economic benefits that span different industries. For example, these devices can be used as training tools to facilitate the on boarding of new employees. In the retail sector, wearables can improve sales services by increasing the speed of purchases, while in manufacturing, they can support the production process by providing free guidance tools. Wearable devices can also enhance the accuracy of information and rationalize procedures in healthcare, speed up clinical trials, and reduce medical costs when used in conjunction with fitness equipment and the right incentives to encourage users to exercise. All of these examples highlight how wearable technology can benefit both businesses and users.

The widespread adoption of wearables is also expected to create new job opportunities. A study conducted by Wanted Analytics found that in May 2014, there were 1,018 job ads specifically related to wearable technology, a 150% increase compared to May 2013. The demand for wearable technology experts was primarily from US-based enterprises, with Intel having the most job postings related to this technology. Nike, Zoll, and Microsoft were also among the companies with the highest demand for skilled candidates in wearable technology. The survey found that most of the job vacancies were for software and web developers, marketing managers, and electrical engineers. Currently, marketing managers with expertise in wearables are the most sought-after and relatively difficult to recruit compared to software developers and electrical engineers. (6)

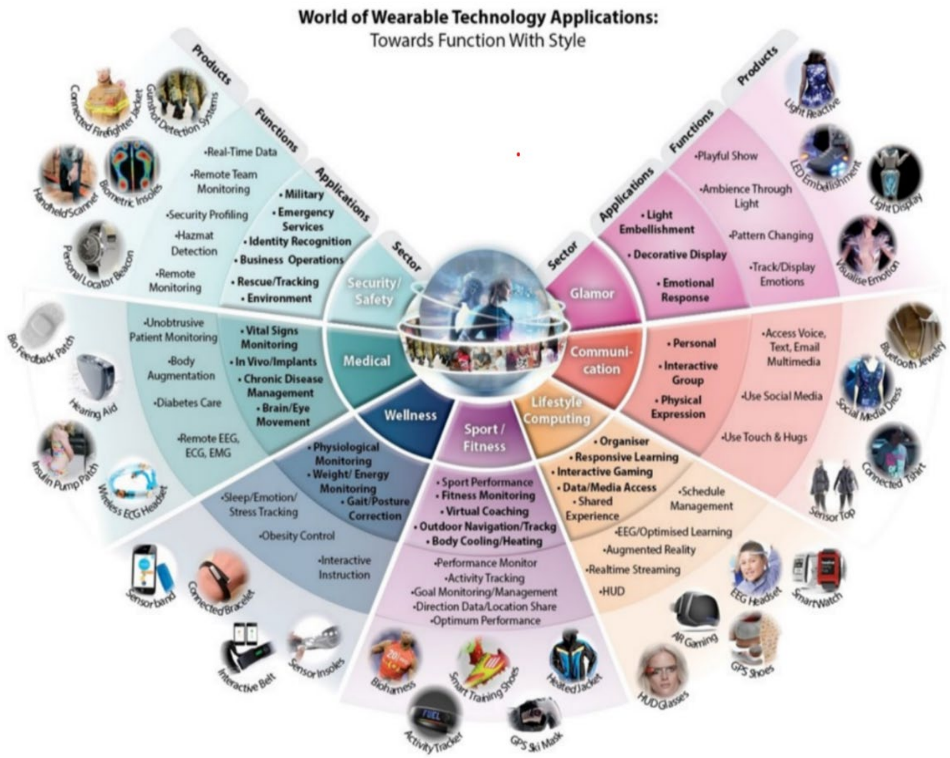

Figure 17.2 Applications of wearable technology in the consumer market - Beecham Research Ltd. (5)

The integration of wearable technology is driving innovation in traditional industries like fashion and jewelry. In the past, the primary goal of jewelry was to look beautiful, while functionality was often overlooked. However, with the emergence of wearable devices like Jawbone fitness trackers and GlassUp Wi-Fi-enabled glasses, traditional jewelry is facing competition. Although it is unclear whether smartwatches will fully replace traditional watches, it is evident that both traditional watchmakers and new players like Apple are vying for a spot on consumers' wrists. (7)

As a result, businesses must develop effective strategies, such as incorporating wearable technology into their products or emphasizing functionality over aesthetics, to compete. (8)

The convergence of fashion, jewelry, and wearable technology could also lead to new partnerships between fashion and jewelry manufacturers and wearable technology providers. For example, Nike has already created a sportswear line that integrates wearable technology, allowing interaction with smartphones and MP3 players.

Value chain dynamics

The value chain of smart textiles comprises three industries, namely textile, ICT (Information and Communication Technology), and electronics, each with different players. Therefore, cross-sectoral partnerships are essential for combining expertise and strategies. Textile companies often lack specialized knowledge in electronics, which hinders their active participation in the expansion of the smart textile industry.

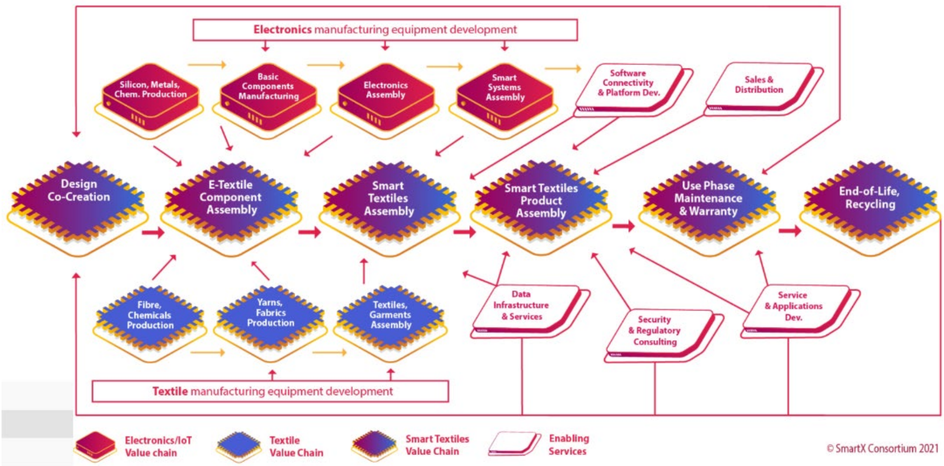

Figure 17.3 Smart Textile Value Chain. SmarteX Consortium 2021 (9)

The SmarteX Europe partners have developed a comprehensive value chain map of smart textiles, as shown in Figure 17.3. This cross-sectoral value chain includes the hardware, software, textile, and end-product components. Smart devices or systems are created by combining smart textile products with additional software. These devices are part of a larger "Smart Network" that consists of interconnected smart devices utilizing cloud-stored data for security, data analytics, and processing. These networks and devices are then integrated into "smart applications." (9)

The wearables market is expected to grow rapidly, with an estimated €21.5 billion spent on composites and materials for wearable technology by 2025. (10)

Enterprises seeking to gain greater market shares will need to develop new designs that provide the advantages of smaller, more flexible, and comfortable devices that can be worn discreetly or even implanted, made of transparent materials, or designed for disposable use. The ability to collect and store energy will also be an important consideration in future wearable device designs. Along the value chain, the relationship between product solution manufacturers and service providers is having a significant impact on the industry. For example, delays in the launch of Google Glass and its app ecosystem led many app developers to abandon their projects and seek alternatives such as GlassUp. (11)

The dynamics of the value chain can also be indicated by the interconnection between mobile data network and product solution providers. Unlike smartphones, wearable product manufacturers or service providers typically integrate network provisions for mobile data services into their solutions. As a result, solution suppliers and network providers negotiate over the price of data transfer. Yepzon, the Finnish company responsible for the wearable child tracking device, provides a good example of this. By using machine-to-machine (m2m) technology (12), Yepzon will manage subscriptions for its products across markets, enabling the Yepzon Group to enter new markets and handle substantial subscription volumes through a single user interface. The platform also allows Yepzon to offer a single interconnected device that will function in the US, Russia, and all of Europe. Additionally, the two largest application platforms, Android and iOS, are vying to become the top platform for app creation, just as they did for the tablet and mobile device markets. Since the demand for a wearable gadget depends partly on the apps that will operate with it, this power has an impact on actors in the upstream and downstream of the value chain.

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Chapter 18: Market dynamic for sensorial textiles

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Recent developments of Smart Garments

The dynamics of the value chain can also be indicated by the interconnection between mobile data network and product solution providers. Unlike smartphones, wearable product manufacturers or service providers typically integrate network provisions for mobile data services into their solutions. As a result, solution suppliers and network providers negotiate over the price of data transfer. Yepzon, the Finnish company responsible for the wearable child tracking device, provides a good example of this. By using machine-to-machine (m2m) technology (12), Yepzon will manage subscriptions for its products across markets, enabling the Yepzon Group to enter new markets and handle substantial subscription volumes through a single user interface. The platform also allows Yepzon to offer a single interconnected device that will function in the US, Russia, and all of Europe. Additionally, the two largest application platforms, Android and iOS, are vying to become the top platform for app creation, just as they did for the tablet and mobile device markets. Since the demand for a wearable gadget depends partly on the apps that will operate with it, this power has an impact on actors in the upstream and downstream of the value chain.

The PROeTEX project has created advanced E-Textile smart garments that monitor the physiological parameters of workers in emergency situations. Three prototypes were developed: an inner garment (IG), an outer garment (OG), and a pair of boots. The IG measures heart rate, breathing movement, sweat, dehydration, electrolytes, stress indicators, oxygen, carbon dioxide, and internal temperature, while the OG and boots measure activity, chemical environment, and outside temperature. The PEB, housed in the OG, collects all the data and transmits it via Wi-Fi to a local coordination workstation using two textile antennas and an embedded PC board. An immediate alarm is sent to intervention managers in case of a serious danger. [1] Monitoring of children's cardiorespiratory systems is also gaining importance, and specific clothing for newborns and youngsters is being developed. [2]

The emergence of 5G technology allows for more systematic use of wearable sensors and sensorized clothing for telemedicine and sports applications, such as the Astroskin smart shirt. [3]

5G enables simultaneous data collection from multiple sensors and the ability to scale up solutions to large groups without degradation of performance, with the two-hop architecture being a typical design for a 5G-enabled telemonitoring system. [4] How it is shown in Figure 18.1.

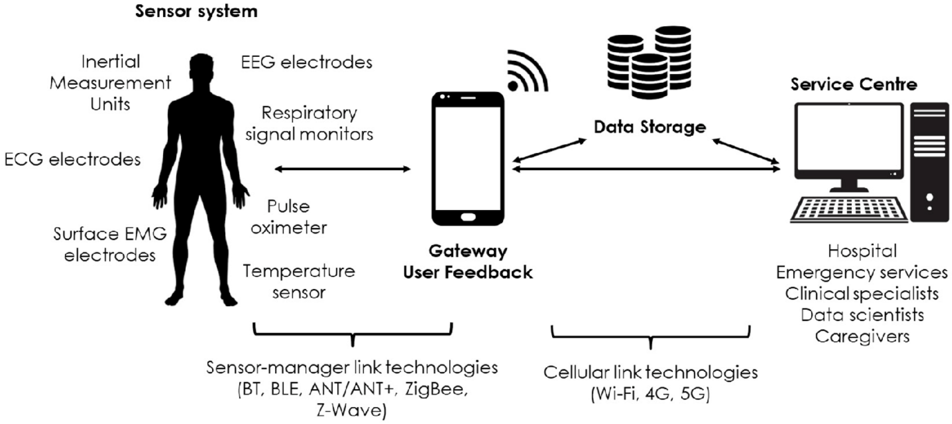

Figure 18.1 Telemonitoring system with a two-hop data transmission architecture. [5]

Flexible epidermal electrical technologies offer a promising alternative to traditional fabric electrodes due to their high transparency and resistance to mechanical deformation. [6] These properties make them well-suited for continuous and long-term monitoring of essential physiological signals, such as heart rate, pulse pressure, temperature, blood flow, and blood oxygen, during daily activities.

Sensorized Garments

Clothing may be categorized into five areas based on its area of use, including clothing for:

- Healthcare, to monitor health disorders.
- Sport, for tracking athletic performances during practice or contests and monitoring of physiological markers.

- Fitness, to educate ordinary customers and provide them a better grasp of their overall wellness.
- Social, to aid users in recreational activities.
- Work, to support performance and provide safety assistance when users are engaged in work-related activity.

Wearable garments in the market are mainly focused on healthcare, sport, and fitness, although there are some examples of sensing components used on the head and lower limbs. The system architecture includes subsystems such as interconnection and software, control, communication, location, power, storage, display, sensing, and actuator. Sensor and actuator units can be non-textile and integrated into the electronic board, or they can be textile-based and connected to the electronic board. [7]

On-body sensor data is transmitted to a Personal Digital Assistant (PDA) through short-range communication nodes such as ANT+, NFC, or Bluetooth. The PDA, which has data storage and processing algorithms, can be a smartphone, computer, or FPGA. The data can be sent to a remote medical server through another connection node. [8]

Textile technologies are being used in various clothing categories, with examples in the health and sport/fitness categories. One such example is the Hexoskin Smart Garments by Carré Technologies Inc. in Montreal, Canada.

These comfortable garments for men, women, and children are embedded with textile sensors for accurate and continuous monitoring of cardiac, respiratory, and activity and sleep data. The electrocardiograph reports metrics such as heart rate, heart rate variability, stress monitoring, and fatigue assessments, while respiratory ventilation is continuously measured with chest and abdominal respiratory inductance plethysmography sensors. The garments also track activity intensity, peak acceleration, steps, cadence, positions, and sleep with a 3-axis accelerometer. [9] The Hexoskin Smart Device, a commercial t-shirt made of textile electrodes, collects a single-lead ECG and features breathing and movement sensors, with a battery life of over 36 hours and rechargeable with a USB cable. The accompanying vest is made of knitted fabric that is antibacterial, UV protective, quick-drying, breathable, anti-odor, and washable. The Hexoskin device can be connected to the Hexoskin App via Bluetooth, allowing the user to visualize, manage, and interpret the collected data. The data can also be viewed on Hexoskin's online dashboard, while healthcare professionals, researchers, and technicians can use the VivoSense analysis software to import/export data, perform batch processing, and create graphs suitable for publication. [10]

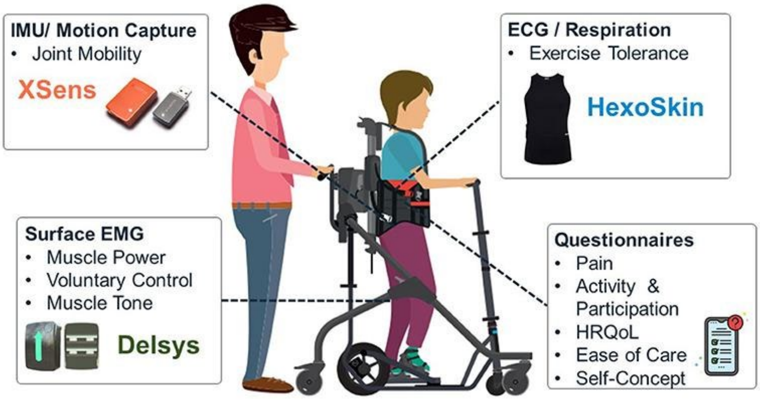

Figure 18.2 user-prioritized domains of interest and selected sensor technology [11]

The second example illustrates Sensoria, a company that offers products designed to aid both professional and amateur runners in their training and coaching endeavors. The available clothing items include machine-washable, comfortable, and breathable smart socks, a bra, and a T-shirt. The socks come equipped with an embedded textile pressure sensor that communicates with a detachable and rechargeable anklet via Bluetooth. This anklet tracks the user's steps, walking time, distance, speed, calories burned, altitude, cadence, and foot landing style while exercising. The bra and T-shirt provide accurate and dependable heart rate monitoring [12] and work seamlessly with the E-modulo sensoria HRM (Heart Rate Monitor), which has a battery life exceeding 8 months and connects via Bluetooth Smart and ANT+ to the Sensoria Run 2.0 smartphone app and the Sensoria Virtual Coach. These tools also offer experienced runners advice on proper running postures and mechanics to help them refine their running style.

The third example features the smart shirt developed by L.I.F.E. Italia Srl, which offers two variants—one for athletics and another for medical purposes. The medical compression garment BWell from L.I.F.E. Italia Srl, Milan, Italy, includes an accelerometer, five breathing strain sensors, and twelve ink-based dry electrodes for ECG monitoring. The electrodes are designed with an adhesive layer, a conductive ink layer, a binder layer, a solvent layer, a thickening layer, and a gradient area between the adhesive and conductive ink layers. The garment's anterior surface hosts the five respiration sensors, which are constructed using an elastic ribbon infused with conductive ink, electrical connectors at each end, and a compression fabric cover. On the other hand, the sports Performer Wearware version from L.I.F.E. Italia Srl, Milan, Italy, focuses on performance tracking and features two ECG leads, two circumferential respiration sensors, and ten accelerometers. This version includes a shirt and shorts, which monitors the movement of the user's thighs. [13]

Figure 18.3 Sensoria Smart Socks [12]

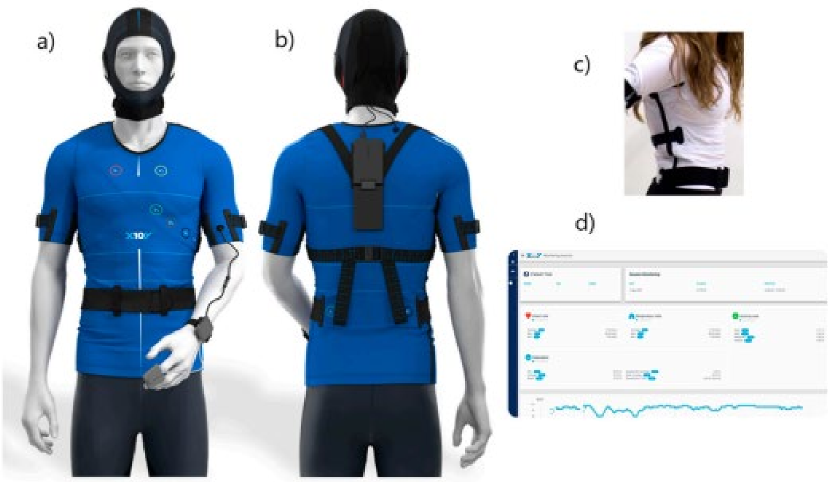

Figure 18.4. (a) Front and (b) back views of L.I.F.E.'s medical compression garment (BWell). The back view (right) shows where the plug is placed when the garment is worn. Both views show a cap to perform EEG which is currently being developed by the company. (c) An example of BWell's fitting when worn. (d) Real-time data visualization dashboard. The figure was adapted from the website of the company producing the garment. [13]

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Chapter 19: Eco-design for sensors, batteries and actuators

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Abstract

By adopting an eco-centred design of smart and sensorial wearables and personal protective equipment, the environmental impact may be effectively reduced and the challenge of end-of-life disposal mitigated in the frame of a circular economy. In this chapter, the main aspects of eco-design will be briefly explained. Specific key points focusing on eco-design for wearable sensors, batteries (and other energy storage devices) and actuators are addressed.

Introduction

Eco-design approach for sensors, batteries and actuators for wearbles aims at minimizing the environmental impact of the entire life cycle of the products, from the origin of raw materials to disposal. Eco-design of wearable sensors, batteries, and actuators involves consideration of certain key-points, which involve selection of the materials, energy efficiency through the entire life cycle, exploitation of renewable energy sources, durability and extended product lifespan, minimisation of packaging, life cycle assessment and end-of-life disposal design.

Eco-design of wearable sensors, batteries, and actuators should be based on a holistic approach that can create products which minimize the overall environmental impact and achieve high performance while promoting a circular economy model.

Selection of Materials

The selection of material is one of the most important steps in eco-design, as many materials used in sensors, batteries, and actuators can have a significant environmental impact. Designers should consider the entire environmental footprint of the chosen materials, including:

- Extraction and processing, which may involve deterioration of the natural environment and destruction of ecosystems, release of toxic substances and threat to biodiversity, excessive use of non-renewable energy and greenhouse gas emissions.

- Transportation and supply chain, which may involve a large carbon footprint which could be avoided if alternative, local or traceable, raw materials are used.
- Toxicity of the materials. Non-toxic materials should be selected. Batteries based on heavy metals such as lead, mercury and cadmium should be avoided in favour of more eco-friendly energy storage solutions.
- Use of recycled, recyclable and biodegradable materials can effectively reduce environmental hazards associated with raw material production and end-of-life disposal.

Circular design and life cycle assessment

Besides the use of sustainable and eco-friendly materials, it is of equal importance to design the products, the sensors, batteries and actuators, as well as the wearables (clothes, shoes, accessories, personal protective equipment etc.) taking into account their whole life cycle, possible reuse and end-of-life disposal. Circular design aims at creating products which will not produce waste during manufacture or after use. Some key guidelines for designers are the folowing :

- Design product that can easily be assembled and disassembled. This allows components like sensors, energy storage devices and actuators to be reused if the wearable becomes deteriorated. It also allows separation of recyclable materials in different recycling flows.
- Provide information on materials and how to be handled at end-of-life disposal. Clear instructions and guidelines for the users are very important in achieving the circular design goals. Conduct a life cycle assessment through the supply chain, use traceable raw materials.
- Use durable material and high-quality fabrication techniques in order to extend the product lifespan. Try to avoid using materials that have significantly shorter life span than the rest of the product, unless these are replaceable parts.

Energy efficiency and renewable energy sources

Design wearable devices having in mind optimisation of energy consumption throughout the product supply chain and life span. Minimizing power consumption may involve using low-power components, optimizing circuitry, and implementing power management techniques. Use rechargeable batteries or other energy storage devices, like supercapacitors. Favour energy harvesting to charging from the electrical network. Energy harvesting wearable devices may be based on photovoltaics (PV), piezoelectric generators (PEGs), triboelectric nanogenerators (TENGs), thermoelectric generators (TEGs), kinetic energy harvesting by magnets, electromagnetic energy harvesting by antennas et.al.

Eco-design of wearable sensors

Specific considerations on eco-design of wearable sensors should include the following points:

- Reduction of size and weight: Compact and lightweight sensors reduce both material consumption and energy requirements. They are also more comfortable and easier to integrate.
- Prefer passive over active sensors: In case of use of active sensors, design for minimum power consumption and energy harvesting over external charging should be preferred.
- Utilize flexible substrates: Flexible substrates allow for comfortable integration with clothing or accessories, making the product more likely to be used. Better ergonomics encourage long-term use and minimize waste from prematurely discarded sensors.
- Design for easy disassembly, repair and end-of-life management: Easy disassembly and repair of wearable sensors will extend the product lifespan. Modular designs that allow for the replacement of individual components will reducing waste, promote repairability, promote recycling and facilitate re-use of the sensors.

Eco-design of wearable batteries, energy storage and harvesting devices

Specific considerations on energy storage and harvesting devices eco-design should include the following points:

- Selection of non-toxic material: Hazardous heavy metals such as lead, mercury, and cadmium should be avoided. Attention should also be paid to nanomaterials which if they escape from their matrix become toxic as can penetrate biological tissues.
- Optimization of energy density and efficiency will allow to maximize capacity while minimizing the size and weight of the battery. Energy efficiency is enhanced by reducing energy losses due to resistance and self-discharge rates.

- Use rechargeable energy storage devices coupled with energy harvesting devices: Energy and power consumption needs of integrated sensors or actuators can take advantage of the energy produced by the motion and body heat of the wearable user. Energy harvesting technologies may be used for charging batteries, when energy should be stored over longer periods, or supercapacitors when the devices require quick delivery of the energy.

- Batteries and supercarpacitors lifespan: Another consideration for selection of proper energy storage/charging method/active sensor or activator system is to manage energy storage and optimize charging/discharging cycles according to energy and power consumption needs in order to prevent overcharging or over-discharging that can reduce energy storage device life.

- Modular energy storage devices design: A modular design approach for replacement of individual cells or units, promoting repairability.

- End-of-life disposal and recycling: Batteries may include toxic material such as heavy metals or materials with a very heavy environmental footprint such a lithium, supercapacitors also produce toxic waste, thus it is imperative that they can easily be separated and recycled in the specific flows that exist for batteries and electronics.

Eco-design of wearable actuators

Specific considerations on eco-design of wearable actuators should include the following points:

- Focus on energy efficiency: Optimization of the energy efficiency of wearable actuators should minimize power consumption and extend the battery life. Use of efficient motor designs and control algorithms that reduce energy waste are recommended.

- Compact, lightweight and repairable design: Compact and lightweight actuators reduce material usage and energy requirements, while allowing easier integration to the wearable. Modular design makes the components easily repairable and replaceable while reducing waste and extending lifespan.

- User-oriented design: Actuators should be designed to meet the different needs of different users, so the usage is encouraged and the likelihood of premature disposal of the wearable or insufficient usage is avoided.

- Disposal and recycling: As is the case with sensors and energy storage devices, specific design for the end-of-life recycling of wearable actuators in specific flows or specific plan for reuse should be a central point.

Conclusions

The basic concepts of eco-design of wearable sensors, actuators and energy storage systems involve:

(i)the selection of non-toxic, reusable and recyclable raw materials and an overall design that will enable end-of-life disassembly and sustainable waste management.

(ii) systems that offer energy efficiency.

(iii) technologies that guarantee an extended lifespan and easy repair.

(iv) user-defined, adjustable features that would allow comfortable integration with garments and personal protective equipment.

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Chapter 20: Co-design of smart sensors and integration into PPE for chemical and biological hazards

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Abstract

This chapter presents the fundamental aspects involved in the co-design of high selectivity smart sensors adjusted to PPE, employed for the detection of chemical and biological hazards in diverse working environments. Different types of chemical and biological sensors for PPE (face masks, respirators, gloves and clothing) have been outlined, in order to highlight the technological progress, selection and evaluation criteria and potentials of particular categories of functional materials and detection techniques.

Introduction

The co-design of smart sensors integrated into personal protective equipment (PPE) takes advantage of the rapid development of materials engineering, as well as Internet of Things, computing, algorithms, ambient intelligence, machine-learning and artificial intelligence [1, 2]. The innovations introduced in PPE enhance the safety and health conditions for many categories of workers facing health and life hazards in their everyday occupation. Professionals employed in heavy and light industry manufacturing sector, chemical, pharmaceutical and biotechnological research and industry sector, agrifood sector, medical sector, security sector and forensics are some indicative categories of smart PPE end-users with particular need for sensing technologies that would protect them against chemical and biological hazards. Apart from portable sensing devices, clothing, face masks and gloves with smart sensors have been designed to meet the particular needs of specialised users.

Basic design concepts

Surveys targeted to both specific groups of professionals (e. g. firefighters, miners, health care staff) and safety experts or external evaluators that are aware of the latest technologies, highlight needs that should be considered by PPE designers and also serve assessment purposes during laboratory and field testing of the products [3].

Specifically selected flexible, responsive sensing materials can provide mechanical, thermal, electrical, optical, chemical, biological and anti-radiation functionalities for PPE [4, 5]. In the case of chemical and biological sensors, the workplace hazards that must be addressed are chemicals and toxics (solids, liquids, gases), particle contaminants, biological fluids, pathogens and toxins. The sensor integration technology to PPE is an important step towards the product development, involving advanced textile treatments and manufacturing processes. The energy supply and storage of self-powered smart sensors is perhaps the most challenging design aspect [6]. These systems should exhibit compatibility with the selected textiles and sensor materials and provide sufficient autonomy. Other important design criteria mentioned by Basodan et al [3] are ergonomics, as well as experience, interface and interaction of users and facilitation of connection to and communication with a smart working environment. The authors review many smart sensor systems from literature along with their technological design.

The performance of the designed sensors is evaluated in terms of selectivity, accuracy and precision within determined detection limits and of course is expected to offer satisfactory repeatability [6].

Applications and characteristics of smart chemical sensors

The most commonly used types of chemical sensors are miniature optical, electrochemical, mass-sensitive, electrical, paramagnetic detection and monitoring systems embedded or attached on PPE. Multiple subdivisions of these categories can be found in literature, each of which is related to the principle of a physical/chemical phenomenon or change of a physicochemical/electrical property measured by a particular technique [6]. Electrical circuits, electrical micro-devices with energy harvesters and filters with piezoelectric or tribo-generators are frequently employed for the detection of toxic gases and volatile organic compounds (CO, CO_2, H_2S, SO_2, NO_x, NH_3, HCN, acetone, methanol, ethanol etc.) or particulate matter. CNTS, Zn nanoparticles and graphene are typical materials employed to absorb gases and vapors and can support the design as gas-specific sensors for smart face masks and respirators [4].

Sensors integrated into gloves facilitate sampling from various surfaces and give quick results either by optical indications or after in situ analyses with handheld or portable devices. ~~The optical sensors are often based on fluorescence or Raman scattering phenomena.~~ The samples attached to electrochemical sensors – acting as working electrode- are connected to three-electrode configuration and miniature potentiostat, providing with voltammograms. Both optical and electrochemical sensors on gloves have been developed for the detection of toxic chemicals (such as fentanyl and trifluralin) and pesticides on vegetable and fruit surfaces. Specially designed hydrophilic adhesives on glove fingertips with colour indicators are capable of assisting the detection of Cu^{2+}, Ni^{2+}, Cr^{6+} trace elements in water samples [2]. Kazemi et al. [7] have designed a wearable PPE sensing system for the detection of hazardous aqueous chemical solution droplets. The sensor consists of an antenna attached in hydrophobic textile and a remote monitoring unit. The authors stress that, after suitable modifications, this detection principle could be utilized for the detection of other hazardous solid, liquid and gaseous chemicals. A vast range of similar sensor systems for gloves, their characteristics, applications and future perspectives have been outlined by Tsong et al. [2]. The technological advances of energy generation and storage in smart chemical sensors has been reviewed by Aaryashree et al. [6]. Chemical sensors of electrically autonomous wearables collect and convert energy by various methods, including batteries and supercapacitors, solar cells, piezoelectric and triboelectric generators, thermal energy harvesters etc. The stored energy is used to power the sensor and other attached systems such as control and communication systems.

Applications and characteristics of smart biological sensors

The simplest application of antimicrobial protection for PPE is the coating polymer materials and fibers either with Ag nanoparticles or nitrogen-halogen macromolecules (such as N-halamine), that disinfect the exposed PPE surfaces. Shi et al. in their review [4] also have included responsive functional materials that are capable of generating reactive oxygen species that destroy or deactivate pathogens. An interesting adoption of this type of filter, presented within the COVD-19 pandemic period, uses TiO_2 nanowires, the activity of which is catalyzed by visible light [8]. The sensor can be integrated to produce reusable protective face masks.

Biological smart sensors of high selectivity integrated on PPE, enable the monitoring of diseases progression and, most importantly, the exposure to biological hazards [9]. The main categories of biological hazards are: viruses, bacteria and toxins. According to the type of hazard, the design of biological smart sensors implement techniques such as enzyme-linked immunosorbent assays (ELISA) and polymerase chain reaction (PCR) that allow screening of specific pathogens. Electrochemical smart sensors on gloves have been developed for the fast detection of Pseudomonas aeruginosa, while optical sensors can detect bacteria such as Escherichia coli [2]. Nguyen et al. [9] developed a biological sensing system - suitable for wearables- for the detection of nuclei acids related to specific pathogens, as well as metabolites. This system was employed for the design of a SARS-CoV-2 sensor integrated on face masks that detects the virus in emitted aerosols.

Conclusions

The design approach for a particular sensing system integrated to PPE depends both on the type of hazard that is being addressed and the working environment characteristics and safety standards. The final product should be comfortable and customized to the needs of individual workers and offer fast and accurate detection. To achieve that, several steps are necessary: Surveys before the design and during performance assessment, selection of suitable sensor materials that are compatible with PPE substrate fabrics and integration methods, as well as incorporation of effective power generation systems. Different stages of extensive laboratory and field testing are necessary for the development of the final commercial products. The mass production of highly selective chemical and biological sensors is feasible for several types of hazards and many new promising sensing systems have been developed in laboratory scale within the last three years and are at an experimental phase. The design and manufacture of biological smart sensors for PPE is generally considered more challenging and was less advanced before the COVID-19 pandemic outbreak.

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Chapter 21: End-user centred production of smart sensors, actuators

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Abstract

The basic principles of end-user centred design of smart sensors and actuators in PPE are outlined along with state-of-the-art workplace safety culture and risk management. The integration perspectives to ambient intelligence and the problems linked to complex and less developed production technologies are being highlighted.

Introduction

The emergence and evolution of smart sensor and actuator technologies, the production of smart PPE prototypes and the design of advanced computational monitoring and integration systems have been remarkable within the last few years. On the other hand, the industrial production processes based on an end-user centred approach are still not well established and the relevant scientific and technical literature is limited. This chapter briefly presents the guidelines upon which the production technologies of wearable components should be developed and the expected characteristics of personalized smart PPE in a context of a smart working environment.

Challenges in the production of end-user centred smart PPE components

As has already been described in previous chapters the design of all types of smart sensors for PPE should primarily be based upon occupational safety and health requirements and working environment conditions of the professional groups that are considered as end-users.

Furthermore, an end-user centred design is supposed to achieve comfort (by means of tailored ergonomics), allow customized settings based on personal needs, preferences and apparent exposure risk and facilitate interactive communication with monitoring and control systems. The COVID-19 pandemic has accelerated progress in smart PPE for healthcare workers. Manchanda et al. [1] with their work provide with an example of sensor-adjustable PPE for individual users. An end-user centred face mask was realized by combining 3D-printing technology and IoT sensing tools.

The integration of end-user centred sensors and actuators in ambient intelligence environments is the next step towards a smart working environment. It is worth mentioning indicative examples of computational systems and networks that have been designed in order to monitor data transmitted by wearables, interconnect smart components, process data and evaluate environmental risks. Bernal et al. [2] developed and presented a safety platform for energy industry, which ensures real-time monitoring and interaction with wearable PPE components. This system has been designed to support user-centred smart wearables. Another publication by Adjiski et al. [3] introduced a safety system developed to meet the needs of mining industry and protect against harsh underground working conditions and potential preventable accidents. It is comprised by:

- PPE (garments, safety glasses, casques) with multiple attached sensors to detect environmental hazards (smoke, heat and noise levels, toxic gases) and cameras.
- a smartwatch for monitoring of vital health indicators, location and motion speed, with embedded magnetic metal detector,

all connected via Bluetooth sensors to a smartphone. The authors have described the architecture of the prototype and the personalized safety and information that would assist evacuation and rescue in case of an accident.

The design of functional PPE that adapts all innovations on smart textiles, sensors and actuators and cutting-edge fabrication and integration technologies exhibits an escalating complexity. A clear confirmation of this fact is the replacement of the former EU directive 89/686/EEC describing the specifications, technical requirements and certification procedures for the commercial production PPE [4], with the currently existing EU regulation 2016/425 [5]. It is understandable that the production of personalized smart PPE poses additional technical and computational challenges that have to be addressed by adapting sophisticated design concepts and different priorities.

Recent trends in OHS risk management & guidelines for PPE production technologies

Podgórski et al. [6] in their study have described the ongoing transformation of the traditional approach strategies of occupational safety and health management.

The current priorities of occupational health and safety (OHS) management – also reflected on the production technologies of all types of smart PPE sensors and actuators - are orientated towards:

- Dynamic and real-time risk assessment at working environment and minimization of risk
- Customized protection for individual workers, taking into consideration the exposure levels to particular hazards.

According to Stephanidis [7], the key concept of user-centred design is the creation of a user-friendly, interactive product that optimizes the user experience.

To this end, the designer should proceed according to the following working algorithm:

- 'Immersion' in the context of the product use and collection of direct information on the user professional profiles and their particular needs.
- Determination of the product functionality, specifications and requirements by potential customers(organizations) and end-users.
- Production of a series of prototypes
- Evaluation and feedback by users.

In order to support the design and mass production of smart sensors and actuators the abovementioned concepts should be digested and creatively embodied in the future production technologies of customized smart PPE. An end-user centred final product is highly dependent on: (i) surveys and interview sessions during different phases of the prototype as well as the commercial product design, production, and piloting (laboratory and industrial scale), (ii) consecutive phases of product testing and development, (iii) training procedures and (iv) temporary and accessible support systems for each workplace and each individual professional [6].

Conclusions

The available design procedures and manufacturing technologies are not mature enough to sustain mass production of end-user centred multicomponent smart PPE that would address the highly demanding OHS requirements by a series of economic sectors and security professionals. Thee of the major weaknesses are:

- the difficulty in the effective incorporation of additional computational and mechanical systems, necessary to support customization for individual users.
- the lack of well-established integration technologies that would ensure compatibility between PPE multiple components (smart materials, miniature devices and various electronics).
- the incomplete technical and legal framework for standard testing and authorizing the production of commercial products.

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