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Smart Textiles- New Possibilities in Textile Engineering

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Abstract

In the twenty-first century, product development has progressed tremendously in every field of engineering and technology. Textiles are not lagging behind on the race of such development. Smart textiles are the most exciting innovation in the field of textiles and clothing. Smart textiles can sense and analyze the signals and response in an intelligent way and the response can be electrical, thermal, mechanical, chemical, magnetic or from other source. The extent of intelligence can be divided into three subgroups such as passive smart textiles, active smart textiles and very smart textiles. In smart textiles basically five functions can be distinguished, they are sensors, data processing, actuators, storage and communication. But it must be compatible with the function of clothing such as comfort, durability, resistant to regular textile maintenance processes and so on. Now it is not seen only in the Hollywood movie, it is not limited in our fantasy; it comes in our practical life with tremendous possibility. It is now widely used in various fields like healthcare and safety clothing, fire fighting clothing, intelligence clothing, military clothing, e-textiles, bio-medical application, sports clothing, protective clothing, space exploring activities and so on. So it can also be called the next generation clothing. This study aims to present the overview of smart textiles, its types and functions. Current smart textiles products and their applications as well as market overview of smart textiles have also been discussed.

Keywords: *Textiles, Clothing, Smart textiles, Interactive textiles, Sensors.*

1. Introduction

The term “smart textiles” is derived from intelligent or smart materials. The concept “smart material” was for the first time defined in Japan in 1989. The first textile material, in retroaction, was labeled as a “smart textile” was silk thread having a shape memory.

What does it mean exactly, ‘smart textiles’? [1] Textiles that are able to sense stimuli from the environment, to react to them and adapt to them by integration of functionalities in the textile structure. The stimulus as well as the response can have an electrical, thermal, chemical, magnetic or other origin. Advanced materials, such as breathing, fire resistant or ultra strong fabrics, are according to this definition not considered as intelligent, no matter how high technological they might be. The first applications of smart textiles can be found in clothing.

Smart clothing is defined as a new garment feature which can provide interactive reactions by sensing signals, processing information, and actuating the responses [2]. Similar terminology such as interactive clothing, intelligent clothing, smart garment, and smart apparel is used interchangeably representing for this type of clothing.

Smart textiles are materials and structures [3] of textiles which can sense and react via an active control mechanism for the environmental conditions called stimuli. They are capable of showing significant change in their mechanical properties (such as shape, color and stiffness), or their thermal, capital, or electromagnetic properties, in a handy manner in response to the stimuli. They are systems composed different apparatuses and materials such as sensors, actuators, electronic devices together [4]. Good examples are fabric and dyes that will change their color with changes in P^H[3], clothes made of conductive polymers which give light when they get electromagnetic signals, fabrics which regulate the surface temperature of garments in order to achieve physiological comfort.

2. Types of Smart Textiles

According to the manner of reaction, smart textiles can be divided into three subgroups [1]: Passive smart textiles can only sense the environment, they are sensors; Active smart textiles can sense the stimuli from the environment and also react to them, besides the sensor function, they also have an actuator function; Finally, very smart textiles take a step further, having the gift to adapt their behavior to the circumstances.

3. Functions of Smart Textiles

Basically, five functions can be distinguished in an intelligent suit, namely: Sensors, Data processing, Actuators, Storage and Communication. They all have a clear role, although not all intelligent suits will contain all functions. The functions may be quite apparent, or may be an intrinsic property of the material or structure. They all require appropriate materials and structures, and they must be compatible with the function of clothing: comfortable, durable, resistant to regular textile maintenance processes and so on.

3.1 Sensors

The basis of a sensor is that it transforms a signal into another signal that can be read and understood by a predefined reader, which can be a real device or a person. As for real devices, ultimately most signals are being transformed into electric ones.

Textile materials cover a large surface area of the body. Consequently, they are an excellent measuring tool. Bio signals that are mentioned in literature are: temperature; biopotentials: cardiogram, myography; acoustic: heart, lungs, digestion, joints; ultrasound: blood flow; motion: respiration; humidity: sweat; pressure: blood.

It will be clear to the reader that this list is not exhaustive. A lot of work needs to be done on finding the right parameters for measuring certain body functions, as well as on developing appropriate algorithms for interpretation of the data.

Suits are available already for measuring heart and respiration rate, temperature, motion, humidity, but they mainly use conventional sensors integrated in a cloth. Some examples are already available of real textile sensors for heart and respiration rate and motion, with quite satisfactory results [5].

3.2 Data Processing

Data processing is one of the components that are required only when active processing is necessary. The main bottleneck at present is the interpretation of the data. Textile sensors could provide a huge number of data, but what do they mean? Problems are: large variations of signals between patients, complex analysis of stationary and time dependent signals, lack of objective standard values, lack of understanding of complex interrelationships between parameters.

Apart from this, the textile material in itself does not have any computing power at all. Pieces of electronics are still necessary. However, they are available in miniaturized and even in a flexible form. They are embedded in water proof materials, but durability is still limited.

Research is going on to fix the active components on fibers [6]. Many practical problems need to be overcome before real computing fibers will be on the market: fastness to washing, deformation, interconnections, etc.

3.3 Actuators

Actuators respond to an impulse resulting from the sensor function, possibly after data processing. Actuators make things move, they release substances, make noise, and many others. Shape memory materials are the best-known examples in this area. Shape memory alloys exist in the form of threads. Because of its ability to react to a temperature change, a shape memory material can be used as an actuator and links up perfectly with the requirements imposed to smart textiles.

Until now, few textile applications of shape memory alloys are known. The Italian firm, Corpo Nove, in co-operation with d'Appolonia, developed the Oricalco Smart Shirt [7].

3.4 Storage

Smart suit often need some storage capacity. Storage of data or energy is most common, sensing, data processing, actuation, communication; they usually need energy, mostly electrical power. Efficient energy management will consist of an appropriate combination of energy supply and energy storage capacity. Sources of energy that are available to a garment are for instance body hear (Infineon [8]), mechanical motion (elastic from deformation of the fabrics, kinetic from body motion), radiation (solar energy [9]), etc.

3.5 Communication

For intelligence textiles, communication has many faces: communication may be required within one element of a suit, between the individual elements within the suit, from the wearer to the suit to pass instructions, from the suit to the wearer or his environment to pass information.

Within the suit, communication is currently realized by either optical fibers [10], either conductive yarns [11]. Communication with the wearer is possible for instance by the following technologies: for the development of a flexible textile screen, the use of optical fibers is obvious as well. France Telecom [12] has managed to realize some prototypes (a sweater and a backpack).

4. Fibertronics

Smart textiles are made by embedding computing and digital components into fabrics. The main aim of smart textiles, also known as electronic textile, is the integration of electronic components. The science of embedding the substances is known as fibertronics [13].

Just as in classical electronics, the construction of electronic capabilities on textile fibers requires the use of conducting and semi-conducting materials such as a conductive textile. There are a number of commercial fibers today that include metallic fibers mixed with textile fibers to form conducting fibers that can be woven or sewn. However, because both metals and classical semiconductors are stiff material, they are not very suitable for textile fiber applications, since fibers are subjected to much stretch and bending during use. One of the most important issue of E-textiles is that the fibers should be made so that it can washable as the clothes should be washed when it is dirty and the electrical components in it should be a insulator at the time of washing.

A new class of electronic materials that are more suitable for e-textiles is the class of organic electronics materials, because they can be conducting, semiconducting, and designed as inks and plastics.

Some of the most advanced functions that have been demonstrated in the lab include:

- Organic fiber transistors [14, 15]: the first textile fiber transistor that is completely compatible with textile manufacturing and that contains no metals at all.
- Organic solar cells on fibers [16].

5. Applications

Smart textiles are on the world market since the late 80's. Their application is getting wider and wider since then. These days, it is not hard to get self-cleaning carpets, shape memory and environment-responsive textiles [3], temperature regulating suit and shoes [17]. They are on applications in geo textiles, bio medical textiles, sports, protective clothing's, casual clothing's especially for winter wears.

5.1 Gore – Tex Smart Fabric, Jacket

The Gore-Tex is the first truly smart fabric designed by Gore Company in the year 1978. It has the capability of letting water and moisture flow in one direction and not in the other; this property makes it waterproof, windproof and breathable [18].

The fabric membrane has pore density of 10 billion pores per square inch. Since the diameter of the pores is on the microscopic level, they are 20000 thousand times smaller than a water droplet [18]. Because of this GORE-TEX fabric membrane is waterproof from the outside. The pore diameters are about 700 times larger than a water vapor molecule; they allow perspiration and water vapor to escape from the inside. On the fabric surface, an oil-hating substance uses in preventing the penetration of body oils. It also repels insects that can affect the membrane. There is lamination between high-performance fabrics that are extremely breathable.

5.2Wearable Motherboard

Georgia Tech was the pioneering institute for the development of SFIT that integrates electronics. During a project funded by the US Naval Department in 1996, they have developed a "Wearable Motherboard" (GTWM commercial name is Smart shirt) [19, 20], which was manufactured for use in combat conditions. The garment uses optical fibres to detect bullet wounds and special sensors that interconnect in order to monitor vital signs during combat conditions. Medical sensing devices that are attached to the body plug into the computerised shirt, creating a flexible motherboard. The GTWM is woven so that plastic optical fibres and other special threads are integrated into the structure of the fabric. The GTWM identifies the exact location of the physical problem or injury and transmits the information in seconds. This helps to determine who needs immediate attention within the first hour of combat, which is often the most critical during battle.

Furthermore, the types of sensors used can be varied depending on the wearer's needs. Therefore, it can be customised for each user. For example, a fire-fighter could have a sensor that monitors oxygen or hazardous gas levels. Other sensors monitor respiration rate and body temperature, etc.

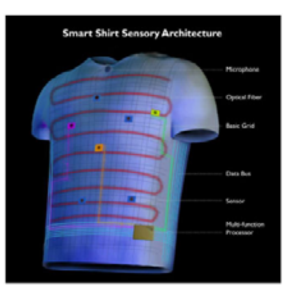

Fig.1. Left: The GTMW of the Georgia Tech, Right: The Smart Shirt by Sensatex [21]
The smart shirt could be used in a large variety of fields and the Sensatex Company currently manufacture it for commercial applications such as: medical monitoring, disease monitoring, infant monitoring, athletics, military uses.

5.3 Smart Running Shoes

Adidas's smart shoes commenced to the market in 2004 and it was the first smart shoe. It consists of a microprocessor, electric motor and sensor into the actual material. The shoe allows the wearer in the running methodology. It adjusts its cushioning dependent on what surface the wearers are travelling over and how they run or walk [22].

- The sensor reads 20,000 readings in a second, with the aid of a 20MHz processor.
- It able to do 10,000 calculations in a second.
- The small motor in the heel changes the tension of a metal cord to assist the wearer.
- It has shock absorption mechanism for an appropriate style of the runner's, etc.

The latest smart Nike brand running shoes come to the customer's recently. It uses a special sensor that tracks the wears' running by doing a lot of interactive activities. It communicates with information technology tools. It sends the running condition, speed, total distance run and other data to personal iPod. The transmitted data can automatically upload and post a status report on Face book [23].

5.4 Biosensor Underwear

The University of California San Diego's Laboratory [24] for Nanobioelectronics has demonstrated a method for direct screen-printing of biological sensors onto clothing [25]. By printing the sensors on the elastic bands in men's underwear, the researchers ensure the sensors maintain tight contact with the skin. The sensing electrodes detect hydrogen peroxide and enzyme NADH, which are associated with numerous biomedical processes. Testing indicated the sensors could withstand the mechanical stress of a wearer's daily activity (flexing and stretching) with minimal effect on the measurements.

5.5 Smart Bra

One of the best examples for improving comfort thanks to electronics is an Australian invention: the Smart Bra. Wallace et. al at the University of Wollongong, have developed a bra that will change its properties in response to breast movement. This bra will provide better support to active women when they are in action [26]. The Smart bra will tighten and loosen its straps, or stiffen and relax its cups to restrict breast motion, preventing breast pain and sag. The conductive polymer coated fabrics will be used in the manufacture of the Smart bra. The fabrics can alter their elasticity in response to information about how much strain they are under. The smart bra will be capable of instantly tightening and loosening its straps or stiffening cups when it detects excessive movement.

5.6 Motion Detecting Pants

Recently the research teams in Virginia Polytechnic Institute and State University in Blacksburg coordinately have developed a pair of pants. The special feature of the developed smart fabric is to sense the movement, speed, the rotation and location of the wearer. It reports to the stored data about the details of the movement to the computer by the wireless signal. These smart and interactive pants work through a loom that helps sew the wires and fabric together [27].

5.7 NASA Aero Gel Jacket

Aero gel materials are the best insulation material for smart clothes. Due to their very low density, weight and often translucent appearance, aero gels are often called solid smoke [NASA Spinoff for 2001]. Their flexible nature making blankets, thin sheets, beads, and molded parts. Their products are not bulky and heavy. When thermal insulation needed like in the design of 2001 NASA jacket, they are highly preferred.

5.8 The Sensory Baby Vest

At the ITV Denkendorf, an interdisciplinary team of researchers has been developing a special vest for babies [28]. The sensory baby vest is equipped with sensors that enable the constant monitoring of vital functions such as heart, lungs, skin and body temperature which can be used in the early detection and monitoring of heart and circulatory illness. It is hoped to use this vest to prevent cot death and other life-threatening situations in babies. The sensors are attached in a way that they do not pinch or disturb the baby when it is sleeping.

5.9 Intelligent Garment for Fire Fighters

The Denmark originated company called VIKING designed the new brand fire fighters jacket in 2009. The thermal sensors integrate with the interior and exterior layers of the coat so as to control the temperature near the fire-fighter and inside of the coat close to the body. The sensors connected to two LED displays, on the sleeve and one on the back.
The LED display on the upper left shoulder indicates critical situations. The LED display on the lower sleeve indicates hazardous heat levels in and outside the turnout gear. The power supply batteries are rechargeable and removable. The microelectronics chips are washable. They can with stand up to 25 cycles. The display gives flash of light slowly at critical and hazardous outside temperature of 250ºC. it becomes rapid at 350ºC, and slow flashing at 50ºC and at 67ºC the display light flashes rapidly because the inside of the coat near the skin reaches 79ºC is the critical situation [29].

5.10 Fashion

There have been a number of commercially available and prototype garments manufactured that use smart textile technology. The range of functions of these garments has been diverse; some enable control of integrated music players (i.e. MP3 Players), some are meant to display emotion, some are purely demonstrate the capabilities and potential uses of smart textile garments.
In 2000 Philips and Levi Strauss launched their ICD+ jacket [30] which combined a remote-controlled mobile phone and an MP3 player and, on removal of all the electronic devices, was washable. The ICD+ jacket was apparently the first wearable device to be marked to consumers, although it was only available in Europe.
Canesis, in conjunction with Australian Wool Innovations [31] developed electrically warmed wool socks through the use of conductive yarns and wool, aimed at the hiking/ walking market and expected to go on sale in late 2004 or early 2005. They are battery powered and suitable for those who worked in very cold environments or for people who suffer from poor circulation, as the amount of heat generated by socks was to equal the rate of heat lost [32] through the foot.
Eleksen’s touch-sensitive fabric was employed in the wireless keyboard introduced in 2006 by G-Tech, and in 2007 it launched an iPod control business suit [33] for sale in a major department store. Fibertronic, launched the iPod control system for the new RedWire DLX jeans, to be launched by Levi’s in 2007, and Burton Snowboards has added Fibretronic’s PTT (push to talk) technology to its Audex range of jackets and packs.

6. Market Overview

According to a US report published by Venture Development Corporation (VDC) [34], the smart fabric and interactive textile (smart textile) market totaled $248 million in 2004 and $304 million in 2005, with expectations that it would grow to $ 642 million in 2008, with a yield of a compound annual growth rate of 27%.
The global market was worth more than $2.5 billion in revenue in 2012 and is expected to cross $8 billion in 2018, growing at a healthy CAGR of 17.7% from 2013 to 2018. In terms of products, wrist-wear accounted for the largest market revenue in 2012, with total revenue of the most established wearable electronic products - wrist-watches and wrist-bands combined, crossing $850 million.
Among application sectors, consumer applications accounted for the largest market share, with revenue crossing $2 billion, as of 2012. However, that of enterprise and industrial application is expected to grow at the highest CAGR (more than 21%), during the forecast period of 2013 to 2018. North America, with U.S. accounting for more than 80% of the market is the single largest revenue base for this global market, and is expected to maintain its dominance during the forecast period as well. However, the market in Asia–Pacific, with China leading the way, is likely to grow at the highest CAGR during the next five years [35].
Smart textiles is now limited in the developed countries. It will be the next generation’s textile. So, there will be possibility of developing countries to earn huge profit. But they need more research and funding as well as technologies to implement this innovation.

6.1 Market Segmentation

This industry is classified based on following application segments: Consumer Products, Military & Homeland Defense/Public Safety Applications, Computing, Biomedical, Vehicle Safety & Comfort, Others (Logistics & Supply Chain Management, and Signage, among others). Major geographies areas include North America, Asia Pacific, Europe, and Rest of the World [36].

6.2 Major Players

Some of the major players dominating this industry are E. I. Du Pont De Nemours and Company, Intelligent Clothing Ltd., Interactive Wear AG, International Fashion Machines Inc., Kimberly-Clark Health Care, Milliken & Company, Noble Biomaterials Inc., Outlast Technologies Inc, QinetiQ North America, Royal Philips Electronics N.V., Toray Industries Inc, and others [36].

7. Conclusion

Smart textiles are the most exciting innovation in the field of textile engineering. The development of smart textiles reaches far beyond imagination; some stories may seem science fiction. The economic value and impact of smart textiles is gigantic. The advent of smart textiles makes it possible to being the traditional textile sector to a level of high-technological industry. Moreover, it appears that this is only possible by intense co-operation between people from various backgrounds and disciplines such as microelectronics, computer science, material science, polymer science, biotechnology, etc. Also more research needs to make it more convenient in our practical life.

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