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"Integrated Performance Textiles designed for Biomedical Applications"

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Abstract. Textiles, used in medical and hygiene industry, are a significant and increasing important part of the technical textiles. The extent of growth is due to constant improvement in both textile technology and medical procedures. The growth has reached to such a level that electronic devices could now be implemented into the textiles in such a way that they not only possess "wearable" qualities like any other garment, but also have local monitoring, computation and wireless communication capabilities. Such smart fabrics, popularly also known as electronic-textiles, find applications in varied fields, viz. civilian, medical, military etc. In this paper, some unique characteristics and the manufacturing aspects of electronic textiles, mainly devised for biomedical applications have been discussed.

Key words: electronic-textiles; smart shirt, medical implants, health monitoring, communication

1. Introduction

Textile, which was earlier considered only as one of the basic requirements of human beings, has emerged out as an innovative area which is capable of satisfying human desires to its maximum extent. The earlier textiles, referred to as *"First generation textiles"* were focused mainly on the preparatory processes, such as spinning, weaving and processing, employed in the fabric manufacture. Development became quite rapid in the mid of 20th century with the invention of synthetic fibres, also referred to as *"Second generation textiles"*. However, in the new millennium, the latest advancement in medical sciences, nanotechnology and intelligent system has lead to the development of *"Third generation textiles"*, which include technical textiles, smart fabrics, performance textiles, etc. Electronic textiles, also known as "e-textiles" is one such new field of textile, which is finding its unique applications in various fields such as civilian, medical, military and various other sectors. They are now utilized in numerous industries and applications that are greatly beneficial to the mankind. Special care is essential while dealing with electronic textiles employed in the field of medical sciences or health care applications because it involves direct contact with the human body.

2. The basic vision of Electronic textiles

Smart or intelligent electronic textiles are a relatively novel area of research within the textile industry with enormous potential within the healthcare industry. These textiles have electronics and interconnections woven into the fabric to make them wearable. The definition of Electronic textiles as given by the E-Textile Research Group is *"Electronic textiles (e-textiles) are fabrics that have electronics and interconnections woven into them, with physical flexibility and size that cannot be achieved with existing electronic manufacturing techniques.*

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Components and interconnections are intrinsic to the fabric and thus are less visible and not susceptible to becoming tangled together or snagged by the surroundings. An e-textile can be worn in everyday situations where currently available wearable computers would hinder the user. E-textiles can also more easily adapt to changes in the computational and sensing requirements of an application, a useful feature for power management and context awareness."

The functionality for "e-textiles" is based on five important aspects as represented in Figure 1. The basic design of physical fabric or *platform* involves varied materials, structures, and manufacturing technologies. The second important parameter is associated with the *interconnect architecture* in the fabric, which involves the design and incorporation of physical data paths and interconnection technologies, i.e., the realization of "textile electrical circuits". Integration of sensors, microchips, and other devices constitute the third building block *hardware integration*. *Software* is the fourth facet of the e-textile system, which deals with the issues related to information processing such as fault tolerance in light of manufacturing defects and quality of service (QoS) *within* the e-textile and *between* the e-textile and external agents/devices. Finally, the successful evaluation of the e-textile is decided by the *performance metrics,* which analyzes the utilization of various parameters such as physical dimensions, cost, manufacturing aspects, dataflow rates etc.

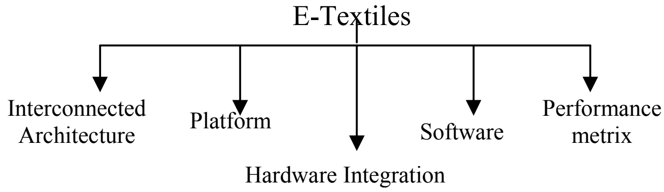


Fig. 1: Fundamental building blocks of e-textile system

E-textiles may be considered as "living designs," consisting of low-cost, simple components and interconnect. The other versatile features of e-textiles are:

- limited processing, storage; and energy per computational node;
- potential failures for *both* nodes and communication links;
- highly *spatially and temporally correlated* node and/or link failures due to topological placement or due to external events;
- need for scalability and flexibility of resource management, as well as local versus global management tradeoff;
- active or smart links which embed simple logic (passive or active components).

3. Electronic textiles in Biomedical Applications

Intelligent medical clothing and textiles have the potential to substantially change the provision of health and healthcare services for large population groups, such as those suffering from chronic diseases, viz. cardiovascular, diabetes, respiratory and neurological disorders; and the elderly with specific needs. Integration of high technology into textiles, such as modern communication or monitoring systems; development of new materials with new functions; Smart sensor system and new approaches to analyze and interpret data together with cost-effective telematics approaches can fundamentally change the interface between patient and the healthcare provider. Patients discharged after major surgeries (e.g., heart bypass), mentally ill patients (e.g., those suffering from manic depression), athletes during practice sessions and in competition, injured soldiers, etc. need to be monitored on a regular basis. This helps to gain a better understanding of the relationship between their vital signs and their behavioral patterns so that the treatment can be provided immediately or can be suitably modified, if necessary. Moreover, information processing via Internet and other suitable means has opened up a new era in the field of e-textile for its utilization in a better way for medical services.

4. Smart Shirt Technology

The Georgia Institute of Technology has developed a "Wearable Motherboard" (GTWM; Figure 2), which was initially intended to use in combat conditions; it is currently being manufactured for commercial use under the name "Smart Shirt" by Sensatex. The commercial applications for the "Smart Shirt" are as follows:

- Medical monitoring

- Maintaining a healthy lifestyle
- Individual Athletes/Team sports
- Continuous home monitoring
- Remote patient examination
- Infant vital sign monitoring
- Sleep studies monitoring
- Vital sign monitoring for mentally ill patients
- Protecting public Safety Officers
- Battlefield combat care solutions

Smart shirt, described as "the shirt that thinks", is a T-shirt wired with optical and conductive fibers to collect biomedical information and basically it functions like a computer. It is one piece of fabric, without seams. The developed interconnection technology has been used to integrate sensors for monitoring the following vital signs: heart rate, respiration rate, electrocardiogram (ECG), and pulse oximetry and temperature, among others. These sensors can be positioned anywhere on the body (locations are decided by a medical specialist) and are easily plugged into the smart shirt. The motherboard or "plug and play" concept means other sensors can be easily integrated into the structure. For instance, a sensor to detect oxygen levels or hazardous gases can be integrated into a variation of the smart shirt that will be used by firefighters. This information, along with the vital signs, can be transmitted wirelessly to the fire station, where personnel can continuously monitor the firefighter's condition and provide appropriate instructions including ordering the individual to evacuate the scene, if necessary. Detailed architecture of the Smart Shirt is illustrated on Figure 2 and Figure 3.

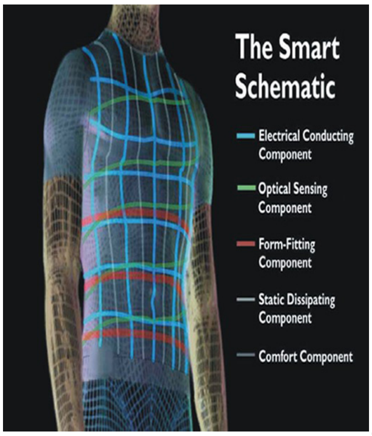


Fig. 2: Woven Wearable Motherboard™

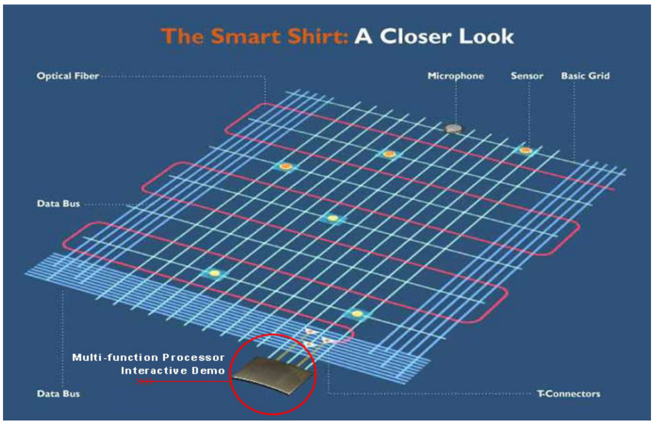


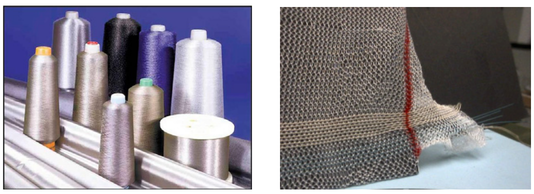
Fig. 3: Detail of the Smart Shirt

The system has shown great promise in effectively monitoring the vital signs of infants, as well as chronically ill patients, obstetric patients and the elderly persons.

5. Main components of Medical E-textiles

5.1 Conductive Textile Materials

The conductive fibres (Figure 4) are of two types, viz. electrical conductive fibres and optical conductive fibres.


(a) (b)
Fig. 4: Conductive yarns and fabric for e-textiles

The electrical conductive fibres integrate the latest wicking finishes with high metallic content in textiles that still retain the comfort required for clothing. Naturally conductive fibres or metallic fibres are developed from electrically conductive metals such as ferrous alloys, nickel, stainless steel, titanium, aluminium, copper and carbon. Metal fibres are very thin filaments with diameter ranging from 1 to 80 microns. However, they are very expensive and their brittle characteristics can damage spinning machinery over time. They are also heavier than most textile fibres making homogenous blend difficult to produce.

The optical conductive fibres use perfloro polymers, which are most transparent in the near infrared region. They are about 120 microns in diameter and are used in conductive textiles to carry signals in the form of pulse of light. Conductive fibres used for the development of military clothing, motion capturing and in tracking of objects. They are developed by drawing molten glass through bushings, creating a filament. Though optical fibres offer excellent strength and sunlight resistance, they are relatively stiff possessing poor flexibility, drapability and abrasion resistance. These fibres can be woven in to fabrics to form radiation shields, optical filters and bar codes.

All these fabrics are easy to cut with scissors and can be sewn with a standard sewing machine. The Knitted super-light conductive fabric can even be welded with a welding iron.

Recently micro-encapsulation technique (Figure 5) has been utilized fabricating electronically *active and sensor fibres,* which will be the basic building blocks of the next generation 'Smart' fibrous materials. The micro-device encapsulation technology involves encapsulating devices with a flexible hermetic seal for mechanical, thermal and electrical protection.

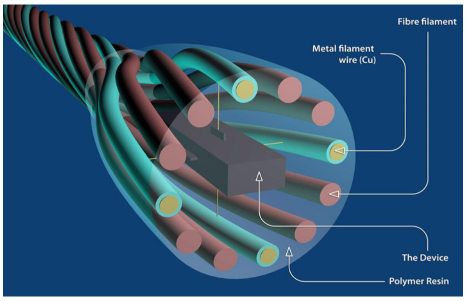


Fig. 5: Conductive yarn containing the device

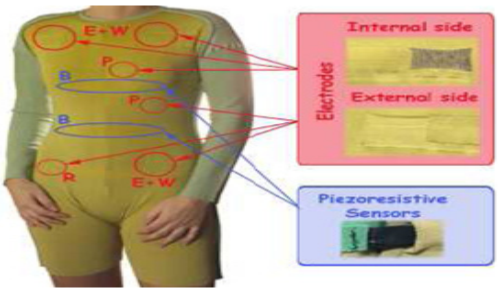


Fig. 6: Sensors positioned on e-textiles

5.2 Electronic Devices

There are many general application sensors and processors used in such medical e-textile systems. Some important sensors (Figure 6) used are accelerometer, magnetometer, light and temperature sensors, pressure and flex sensors, and microphones for various applications like motion capturing, beam foaming, etc. For instance, the accelerometer can regulate the results according to the temperature changes to have most accuracy. The temperature sensors are generally used to measure the body temperature or the environment temperature as per the requirement.

Also, since one of the most important application in wearable computers and smart textiles is telemedicine, many different kinds of medical sensors, suitable to implant in electronic textiles have been made and used by scientists. Sensors like ECG, respiration electrodes, pulse oximeter, blood pressure and galvanic skin response sensor are just some examples of biomedical ones.

In a general set up, the information gathered by sensors should be sent to an analog-to-digital converter (ADC), then to a micro-controller and finally sent to a personal digital assistant (PDA) by a transceiver. The last stage is the transmission of the information from PDA to the center (which can be a hospital or a central military service) probably through a wireless channel. The ultimate processes and conclusions will be done there.

Two processors are generally used to ensure that the information will not be lost under any circumstances. One of them is used as the main processor, while other one as the redundant. During the failure of the main processor, the redundant processor gets activated and continues the operation as the main processor. Processors which are generally used for different electronic textiles and wearable computer applications are ADSP2188, Atmegal128 AVR, MSP430, etc.

Apart from the devices mention above, the transmission of the signals from the e-textiles also requires infrastructural set-up with various facilities, such as cellular tower, internet facility, etc.

6. Some innovative Biomedical E-textiles

- **Life-Shirt**: Developed by Southern California-based health information and monitoring company VivoMetrics, the Life-Shirt (Figure 7a) uses embedded sensors and a PDA to monitor and record more than 30 physiological signs and bring standard monitoring technology out of the hospital and into the real-world environment. The information is uploaded to a computer via a datacard and sent over the Internet to VivoMetrics, where it is analyzed and then sent to the physician.
- **Mamagoose pyjamas:** The Belgian company Verhaerth Design and Development and the University of Brussels have developed a new type of pyjamas, named Mamagoose baby pyjamas (Figure 7b), that monitors babies during the sleep. It has five special sensors positioned over the chest and stomach, three to monitor the infant's heart beat and two to monitor respiration. This double sensor system guarantees a high level of measuring precision. The special sensors are actually built into the cloth and have no direct contact with the body, thus creating no discomfort for the baby.
- **Smart Socks**: Every year, more than 50,000 Americans with diabetes must undergo foot or leg amputations, which is due to poor blood circulation. Researchers estimate that about three quarters of diabetes-related amputations might be avoided by wearing socks with built-in pressure sensors that would alert the wearer to put his/her feet up for a while.

(a) (b) (c)

Fig. 7: Smart Biomedical electronic textiles

- **Smart Bra** (Figure 7c): Scientists at the University of Wollongong in Australia are developing a 'smart bra' that will change its properties in response to breast movement, giving better support to active women when they need it most. Fabric sensors attached to the straps and midriff of a standard bra, worn by a model in motion, will monitor breast movement and relay data in real time to a computer via a telemetry system. Information gathered from the tests will eventually be stored on a tiny microchip that will serve as the 'brain' of the ultimate Smart Bra, signaling the polymer fabric to expand and contract in response to breast movement.

7. LIMITATIONS OF BIOMEDICAL E-TEXTILES

The limitations encountered with Biomedical e-textiles when they are in use are –

- They have power consumption limitations as they are not connected to constant power supply.
- The electronic textile may have physical defects, which may lead to short circuit or open circuit on textile, thereby making the results of the computing components wrong.
- The electronic components are prone to damage during washing.

The researchers are trying to solve these problems by using various latest technologies.

8. CONCLUSIONS

Electronic, computer, and communication devices are also being woven into fabrics so the materials can react automatically to stimuli. E-textiles or Intelligent medical textiles have the potential to substantially change the provision of health and health care services for large population groups, e.g. those suffering from chronic diseases (such as cardiovascular, diabetes, respiratory and neurological disorders) and the elderly with specific needs. When incorporated into the design of clothing, the technology could quietly perform an ECG, monitor the wearer's heart rate, respiration, temperature, blood pressure and a host of other vital functions, alerting the wearer or physician if there is a problem. Although still in the infant stage, the medical electronic textile technology has a great prospectus in the future.

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