**Government Engineering College, Thrissur**

**Department of Electronics and Communication Engineering**

**Seminar Report 2004**

# Smart Fabrics

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# ABSTRACT

Based on the advances in computer technology, especially in the field of miniaturization, wireless technology and worldwide networking, the vision of wearable computers emerged. We already use a lot of portable electronic devices like cell phones, notebooks and organizers. The next step in mobile computing could be to create truly wearable computers that are integrated into our daily clothing and always serve as our personal assistant. This paper explores this from a textile point of view. Which new functions could textiles have? Is a combination of textiles and electronics possible? What sort of intelligent clothing can be realized? Necessary steps of textile research and examples of current developments are presented as well as future challenges.

# INTRODUCTION

Today, the interaction of human individuals with electronic devices demands specific user skills. In future, improved user interfaces can largely alleviate this problem and push the exploitation of microelectronics considerably. In this context the concept of smart clothes promises greater user-friendliness, user empowerment, and more efficient services support. Wearable electronics responds to the acting individual in a more or less invisible way. It serves individual needs and thus makes life much easier. We believe that today, the cost level of important microelectronic functions is sufficiently low and enabling key technologies are mature enough to exploit this vision to the benefit of society. In the following, we present various technology components to enable the integration of electronics into textiles.

Electronic textiles (e-textiles) are fabrics that have electronics and interconnections woven into them. Components and interconnections are a part of the fabric and thus are much less visible and, more importantly, not susceptible to becoming tangled together or snagged by the surroundings. Consequently, e-textiles can be worn in everyday situations where currently available wearable computers would hinder the user. E-textiles also have greater flexibility in adapting to changes in the computational and sensing requirements of an application. The number and location of sensor and processing elements can be dynamically tailored to the current needs of the user and application, rather than being fixed at design time.

As the number of pocket electronic products (mobile phone, palm-top computer, personal hi-fi, etc.) is increasing, it makes sense to focus on wearable electronics, and start integrating today's products into our clothes. The merging of advanced electronics and special textiles has already begun. Wearable computers can now merge seamlessly into ordinary clothing. Using various conductive textiles, data and power distribution as well as sensing circuitry can be incorporated directly into wash-and-wear clothing.

# Textiles gain intelligence

Advances in textile technology, computer engineering, and materials science are promoting a new breed of functional fabrics. Fashion designers are adding wires, circuits, and optical fibers to traditional textiles, creating garments that glow in the dark or keep the wearer warm. Meanwhile, electronics engineers are sewing conductive threads and sensors into body suits that map users' whereabouts and respond to environmental stimuli. Researchers agree that the development of genuinely interactive electronic textiles is technically possible, and that challenges in scaling up the handmade garments will eventually be overcome. Now they must determine how best to use the technology.

The term 'smart dresser' could soon acquire a new meaning. An unlikely alliance between textile manufacturers, materials scientists, and computer engineers has resulted in some truly clever clothing1-4. From self-illuminating handbag interiors to a gym kit that monitors workout intensity, the prototypes just keep coming. But researchers have yet to answer the million-dollar question, perhaps critical to consumer acceptance; will they go in the wash?

Designers have been quick to jump onboard the high-tech fabric bandwagon, adopting electronic display technologies to create colorful, novelty clothing items. For example, the Italian-made fabric Luminex®, which contains colore light emitting diodes (LEDs), has been used to make a glow-in-the dark bridal gown, sparkly cocktail dresses, and costumes for opera singers. Luminex is made by binding LED fibers into the ends of ordinary fabric, which then form the seams of tailor made clothing. The fibers are powered by tiny, rechargeable batteries that are turned on by the wearer via a hidden switch. Flicking the switch causes the fibers to glow in one of five different colors, giving Luminex garments an overall appearance of shininess when the lights are dimmed.

France Telecom has gone one step further, developing a flexible, battery-powered optical fiber screen that can be woven into clothing6-7. Each plastic fiber-optic thread is illuminated by tiny LEDs that are fixed along the edge of the display panel and controlled by a microchip. The threads are set up so that certain portions are lit when the LEDs are switched on, while other sections remain dark. These light and dark patches essentially act as pixels for the display screen. A prototype version integrated into a jacket displayed crude but readable symbols. More sophisticated versions may support advertising slogans, safety notices, or simply a range of different geometric patterns can be switched on and off.

The marriage of woven fabric with electronics is finding favor in the world of interior design as well. Maggie Orth, cofounder and CEO of a Massachusetts Institute of Technology start-up, International Fashion Machines, is currently producing one-of-a-kind, electro-textile wall panels. Instead of self-illuminating optical fibers, she is working with a fabric known as Electric Plaid™ that exploits reflective coloring. The novel fabric contains interwoven stainless steel yarns, painted with thermochromic inks, which are connected to drive electronics. The flexible wall hangings can then be programmed to change color in response to heat from the conducting wires (Fig. 1).

Elsewhere, garment manufacturers are focusing on functional benefits rather than aesthetics. The simplest of these so-called ‘smart clothing’ items are made by adding the required circuitry, power sources, electronic devices, and sensors to standard fabric garments. Batteries can be sewn into pockets, wires fed through seams, and wireless antennae attached to collars and cuffs.

The design of such clothing items is still important, although appearance is not the sole criteria, according to Lucy Dunne, a Masters student in wearable technology and smart clothing at Cornell University. Dunne devised her own ‘functional fashion garment’ as part of an undergraduate project last year, producing a low-cost jacket for joggers and walkers with a pulse monitor stitched to the left cuff. Embedded sensors control conductive material on the back of the jacket to keep the wearer warm should the temperature drop, while electroluminescent wires are fixed to pockets and hems to light up in the dark as a safety feature (Fig. 2). “It doesn’t exist simply to look good, or to attract attention, nor does it simply meet needs without regard to aesthetics,” says Dunne. “Appearance is also a functional need, so it was taken into account in the design of the garment. I would like to see smart clothing ultimately indistinguishable from the clothing we are used to now, except in function.”

Realization of this vision could be possible with the advent of wearable electronic textiles, where functionality is incorporated into the fabric. More sophisticated prototypes for smart clothing items use conductive threads to weave switches, circuits, and sensors into the fabric itself. These threads can be made from very finely drawn conductive metals, metallic-coated or metal-wrapped yarns, or conductive polymers. Ideas touted to date include jacket sleeve keypads for controlling cell phones, pagers, or MP3 players, and sportswear with integral fabric sensors and display panels, ideal for monitoring heart rate and blood pressure during a gym workout or morning run. Clothing fitted with textile global positioning system technology could also be suitable for watch on locating skiers or mountaineers in bad weather or even for keeping young children.

Fig. 1 Optoelectronic fabrics may find a market in the world of interior design owing to their originality and aesthetic appeal. (Courtesy of Maggie Orth, International Fashion Machines.)

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## Wearable intelligence

Self-heating hats and glow-in-the-dark sweatshirts might correctly be labeled as ‘smart’, but how about a shirt that ‘knows’ whether you are free to take a cell phone call or retrieve information from a 1000 page safety manual displayed on your inside pocket? Such items, termed ‘intelligent’ clothing to distinguish them from their lowertech cousins, have proved more difficult to patch unobtrusively into everyday apparel. Indeed, the first prototype ‘wearable computers’ of the early 1990s required users to strap on a head-mounted visor and carry heavy battery packs in their pockets, leading some to question the appropriateness of the term ‘wearable’.

Batteries are now smaller and lighter, and sensors far less cumbersome. But researchers are going to have to integrate electronic components into the fabric itself, if this technology is going to fulfill its potential, says Tom Martin, assistant professor in the department of electrical and computer engineering at Virginia Tech.

“People don’t want cables all over their body. If you’re in an industrial environment, you don’t want cables because you’re crawling around in a tight space, the cables get caught on bolts or other protrusions, they break, and they get tangled all the time. If you’re a consumer, they just look ugly,” he says. “If nothing else, if we can weave those connections into the fabric so I can look at you and think you just have a normal shirt on, that’s a big step forward.”

Sewing in electrical networking capability is just the first stage though, Martin says. Genuinely intelligent clothing would be woven from a selection of thread-like electronic sensors and battery fibers, as well as flexible, conductive fibers. Garments would then be able to function as standalone computers, providing wearers with information about their environment. For example, a context-aware shirt for the blind might be woven with tiny vibrating motors to provide warnings about approaching objects, while workers in the chemical industry could wear overalls capable of detecting a nearby spillage.

The cost of developing and manufacturing such sophisticated fabrics is likely to put them beyond the reach of the fashion industry for the time being. “I think the main applications are going to be medical, military, and industrial,” Martin says. “Those are the only places that are going to be able to bear the additional cost of the clothing, at least at the outset. And they are also the kind of places that have some compelling applications where it is difficult to use discrete components strapped onto the body.”

Virginia Tech researchers are currently one year into a three-year project, funded by the US National Science Foundation (NSF), to turn electronic textiles into wearable computers. Team members are using the $400 000 grant to develop a ‘design environment’, simulating the functionality of planned garments, along with some prototypes to prove that the simulation concept works. They are also aiming to devise a set of generic design guidelines for electronic textile products. “If we have a simulation environment and a set of design rules, then other people won’t have to reinvent the wheel," Martin says. "We'd like people to think broadly about their applications, not the low-level, practical details about tailoring the garments."

***Fig.2 Lucy Dunne models the smart jacket she designed in an undergraduate project.***
***(Credit: Komposite. © Cornell University.)***

The simulation environment is already being used to model a garment that can sense its own shape. Patients undergoing a physical therapy regime could wear such a shirt to find out if they are doing their exercises correctly, and if their range of motion is increasing, says Martin. Professional golfers and tennis players could also use the shirt to perfect their swing or serve. The finished item is likely to be fabricated from cloth containing piezoelectric film fibers that produce a voltage in response to a force and vice versa. “The film strips allow us to detect movement of the limbs so that we can find their position,” Martin says. “We are also looking at discrete accelerometers to give us this information. It is not clear yet which choice will be better, but the films are our preference. We can sew them on in the way you might sew on a ribbon.”

Team members are also working to create a wearable version of a giant textile ‘sensornet’ designed to detect noise. The fabric, developed with support from the US military, is fitted with an acoustic beamformer capable of picking up and pinpointing the location of an approaching vehicle. Electrical connections are made by weaving wires into the heavy-duty cloth, and discrete microphones are attached at suitable points (Fig. 3), though these could also be replaced by piezoelectric film sensors in the future.

"The film's sensing properties will be different from a discrete microphone, because the sound will hit a larger surface area," Martin says. "Our guess is that the shape of that surface will give us information about the direction of the source, because a soundwave traveling across the film will apply a different force than a wave traveling the length of the film."

## Complexity versus durability

Moving from large-scale sensornets to wearable attire means ore than simply scaling down the components. Sensornet mats or drapes can be woven from a single sheet of fabric, whereas overalls, shirts, or T-shirts, for example, are generally stitched together from several different pieces of material. Cutting electronic cloth clearly makes it more difficult to make good connections between different parts of the same garment. One solution could be to manufacture seamless clothing, which would avoid the cutting and stitching problem altogether. Matching the electronic network to a pattern on the fabric is another option, according to Martin. Some garment makers already produce clothing with unbroken patterns running across seams, so all the researchers have to do is weave their networks into the same pattern. "This may solve our alignment problem for the wires," he says. "Now we just have to come up with some way of making the connections."

The group is trying to stay as close as possible to conventional large-scale cutting and sewing techniques when thinking about how electronic textile clothing could be made. For example, the researchers are using standard metal snap fasteners (press studs) to make electrical connections between ‘e-buttons’ and conductive fibers. The e-buttons, essentially small PC boards, contain the garment’s core electronics. One part of the fastener is attached to the button, and the other to the item of clothing (Fig. 4). Buttons can then be fixed on when required, swapped with different e-buttons if alternative functionality is required or removed entirely when the garment is washed. “We have actually had two reviews from the NSF that said, ‘How do you wash electronic textile clothing?’” Martin laughs. “Do you wear it once and throw it away? I don’t think so. It’s too expensive.”

Tünde Kirstein, a member of the Wearable Computing Lab at ETH Zürich, Switzerland, agrees that wash ability will be critical to the commercial success of intelligent clothing. ETH researchers have developed prototype textile networks, using interwoven Cu fibers as data transmission lines (Fig. 5). The conductive fibers are wrapped in a polymer coating that protects them from daily wear and tear. Fibers are joined to external components, such as batteries or sensors, with conventional soldering or adhesive techniques, and it is these connections that cause the main point of weakness. “The fibers themselves are quite robust so they could even be put into a washing machine without damage,” Kirstein says. “But the connections between the fibers and the chips tend to break and so we have to make them mechanically resistant.”

Kirstein regards the development of interwoven electronic textiles as a significant advance in the field of wearable computing, though she accepts that the materials'complexity will keep intelligent garments off the market for a few more years. The ETH team is currently trying to integrate as much functionality into their fabrics as possible. Textile antennae developed at the Zürich labs will let the cloth computers communicate with each other or the outside world (Fig. 6). The next step forward will be the creation of conductive thread-like elongation sensors to monitor body movement, Kirstein says.

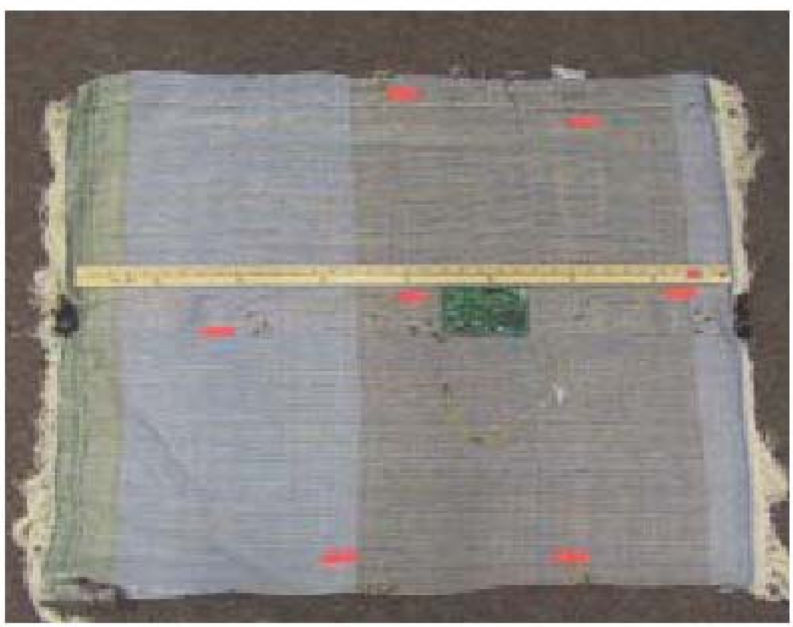


***Fig. 3 The cloth sensornet developed at Virginia Tech could help military personnel detect and locate approaching enemy vehicles. (Credit: Zahi Nakad.)***

The team is hoping to have such fibers embedded in a prototype context-aware garment within the next couple of years.

Devising a novel way to power the clothing is a further challenge. Batteries may have reduced in size, but wire connection to a pocket-held power source still goes against the grain of ready-to-wear computing. “Our prototypes at the moment use simple rechargeable batteries but, of course, if we really want to sell these products we have to think about alternative energy generation,” Kirstein says. “Integrating fabric solar cells, for example, is a very promising idea because you have a large surface area on the clothing, so you could use that for generating energy.”

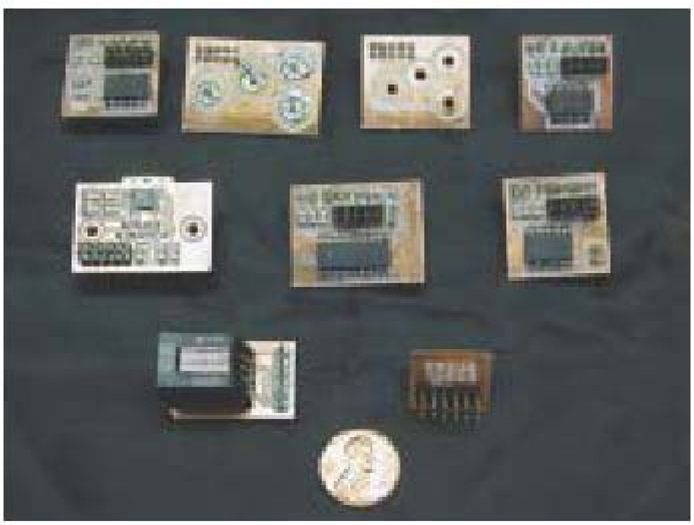


***Fig. 4 Use of established mass-manufacturing techniques may help keep the cost of intelligent clothing down. Electronic ‘buttons’ are fitted with metal snap fasteners that garment makers are already familiar with. (Credit: David Lehn.)***

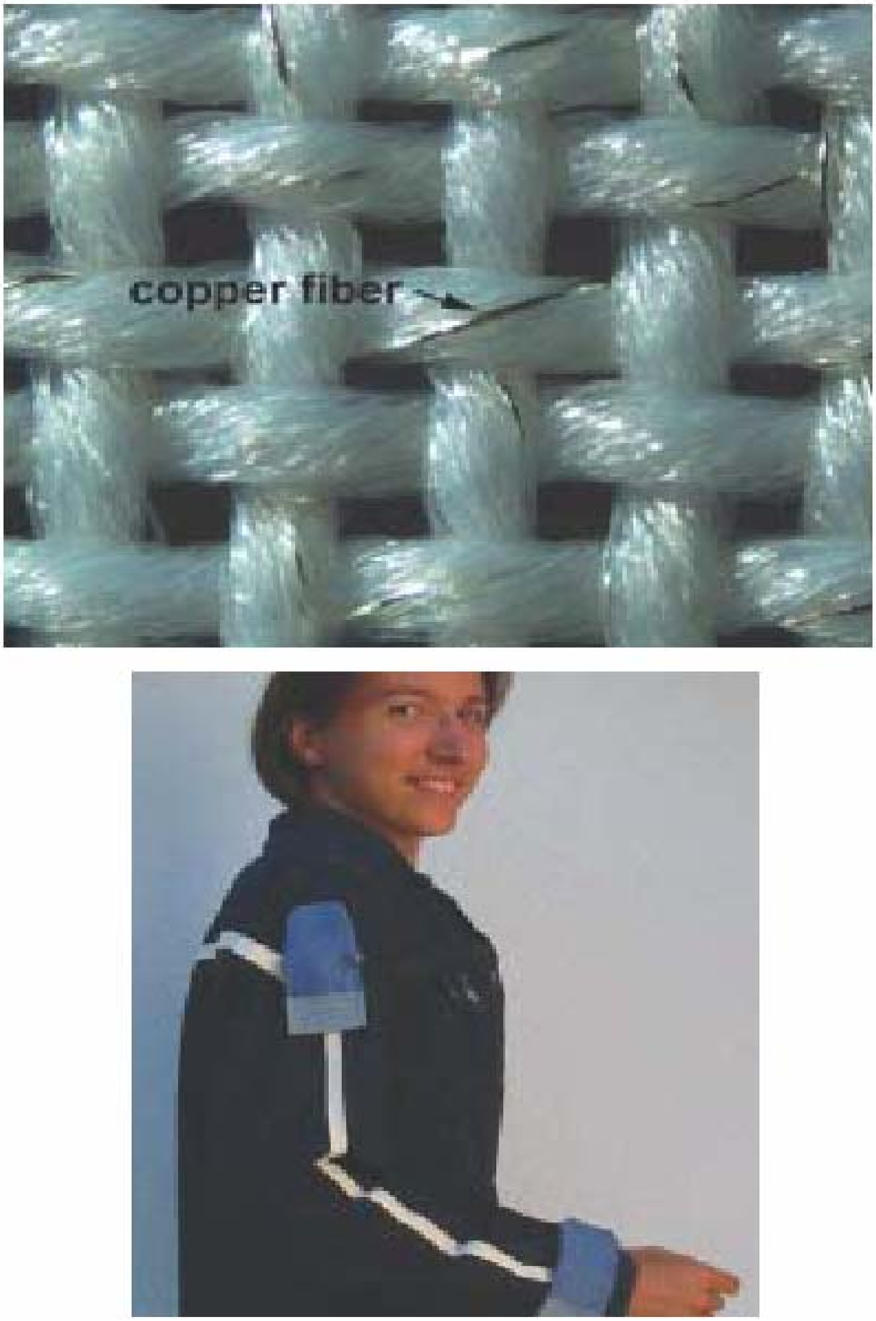



***Fig. 5 (a) Researchers at ETH Zürich are using woven fabric with embedded Cu fibers to produce context-aware clothing. (b) Their prototype 'intelligent' jacket uses the conductive fibers to transmit data between different sensors and to measure body movements. (Courtesy of Tünde Kirstein, ETH Zürich)***

## Wireless world

Whatever the technical obstacles, researchers involved in the development of interactive electronic clothing appear universally confident that context-aware coats and sensory shirts are only a matter of time. Susan Zevin, acting director of the Information Technology Laboratory at the US National Institute of Standards and Technology (NIST), would like to see finished garments fitted with some form of data encryption system before they reach consumers. After all, wearing a jacket that is monitoring your every movement, recording details about your personal well-being, or pinpointing your exact location at a moment in time, adds a whole new dimension to issues of wireless security and personal privacy.

"The challenge, I think, for industry is to build in the security and privacy before the technology is deployed, so the user doesn't have to worry about having his or her T-shirt attacked by a hacker, for example," says Zevin. "People don't want to have to upload and download intrusion detection systems themselves. Pervasive computing should also mean pervasive computer security, and it should also mean pervasive standards and protocols for privacy." She notes that the level of security required for electronic textile garments will vary according to their applications.

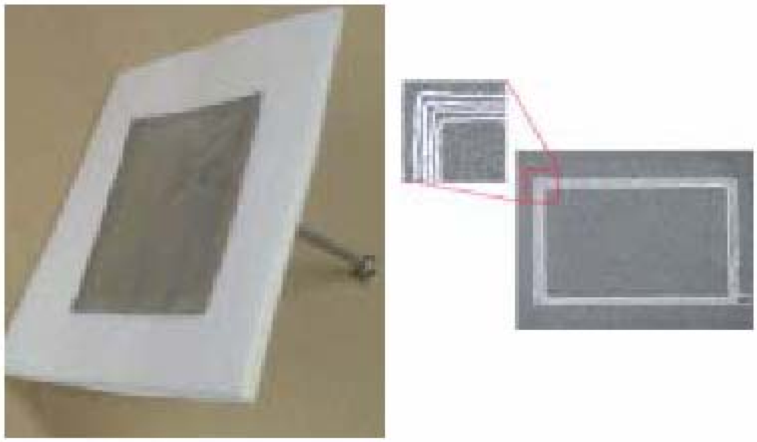


***Fig. 6 (a) Textile antenna developed for external communication between an item of clothing and its environment. (b) Conductive yarn embroidered onto fabric becomes a coil that uses near field inductive coupling for communication between different pieces of clothing. (Courtesy of Tünde Kirstein, ETH Zürich)***

Military battle dress, medical monitoring suits, and fashion garments, for example, could each be installed with a different level of data protection software. Universal communication and encryption standards will also be required to ensure different products work together in an efficient and secure manner.

Daniel Siewiorek, director of the Human-Computer Interaction Institute at Carnegie Mellon University, suggests that users should be allowed some input on the accessibility of information generated by wearable devices. Using tracking devices, for example, raises questions about when an individual's location should be given out and when it should not, he says. The sensitivity of this issue became evident earlier this year following reports that fashion giant Benetton would be fitting a tracking chip to its clothes. Fears that consumers would be monitored as they entered other shops using the same scanning technology prompted a hasty clarification that the system was still under consideration8,9.

Siewiorek has watched wearable computing devices shrink in size and increase in functionality over the past decade. He has no doubt that the technology is now sufficiently small for clothing to be made with built-in computing power. The main challenge for researchers, though, will be working out which applications to address, he says. "If you've got all that capability, the question is, what do you do with it?" he says.
"Whether I have this technology sewn into a button or hidden in my clothes is not as important as how we use it."

# PROJECT EXAMPLES

## WEARABLE ANTENNAS

In this program for the US Army, Foster-Miller integrated data and communications antennas into a soldier uniform, maintaining full antenna performance, together with the same ergonomic functionality and weight of an existing uniform. We determined that a loop-type antenna would be the best choice for clothing integration without interfering in or losing function during operations, and then chose suitable body placement for antennas. With Foster-Miller's extensive experience in electro-textile fabrication, we built embedded antenna prototypes and evaluated loop antenna designs. The program established feasibility of the concept and revealed specific loop antenna design tradeoffs necessary for field implementation.

This program provided one of the key foundations for Foster-Miller's participation in the Objective Force Warrior program, aimed at developing soldier ensemble of the future, which will monitor individual health, transmit and receive mission-critical information, protect against numerous weapons, all while being robust and comfortable.

# Georgia Tech Wearable Motherboard

Georgia Tech developed a "Wearable Motherboard" (GTWM), which was initially intended for use in combat conditions. Georgia Tech's research was funded by the US Department of Navy. The Sensate Liner for Combat Casualty Care uses optical fibers to detect bullet wounds and special sensors that interconnects in order to monitor vital signs during combat conditions. Medical sensing devices that are attached to the body plug into the computerized shirt, creating a flexible motherboard. The GTWM is woven so that plastic optical fibers and other special threads are integrated into structure of the fabric. There are no discontinuities in the GTWM. The GTWM is one piece of fabric, without seams. Because the sensors are detachable from the GTWM, they can be placed at any location, and is therefore adjustable for different bodies. Furthermore, the types of sensors used can be varied depending on the wearer's needs. Therefore, it can be customized for each user. For example, a firefighter could have a sensor that monitors oxygen or hazardous gas levels. Other sensors monitor respiration rate and body temperature or can collect voice data through a microphone.

*Figure 1: the third generation GTWM*

*Figure 2: the GTWM worn underneath combat fatigues*

Before the GTWM was adjusted and improved for commercial use, the information was transmitted via a "personal status monitor" that connects to the shirt and is usually worn at the hip. It also served as a personal computer so that wearers can access the internet, listen to music, or check e-mail. Now, the personal status monitor has been integrated into the shirt itself. The system is also completely wireless. (See Figures 5 and 6for the "Smart Shirt".)

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.

## Other Uses for the GTWM

Although the GTWM is intended for use in combat and is likely to be used by the military, police, and firemen, it is more widely applicable. Since the GTWM provides a framework for incorporating sensors, monitors, and information processing devices, it could be used for any purpose that requires around the clock monitoring of vital statistics. For example, the elderly and others with fragile health conditions could also benefit from this technology. The GTWM could enhance communication between the wearer and his or her health professional. For example, the GTWM could be outfitted for patients who return home from surgery, so that their doctors could monitor their vital information. This kind of monitoring would also be helpful for patients in rural areas who are far from medical professionals. Often people in geographical areas with sparse medical facilities feel uncomfortable about leaving the hospital since they are no longer under the care of medical professionals. This uncertainty and insecurity can often hinder their recovery. Wearing the GTWM and knowing that their health is continuing to be monitored remotely may allay their fears and help them recovery more quickly and successfully.

The GTWM could also be used to learn more about mentally ill patients. These patients need constant monitoring in order to get a better understanding of how tier vital signs are related to their behavior patterns. This information could help doctors determine the effects of the treatment mentally ill patients receive and could help doctors decide how and if the treatment should be adjusted.

Astronauts also need constant monitoring of their vital statistics, and the GTWM could help people on the earth understand the effects of the environment in outer space on the body.

Additionally, the "Smart Shirt" can be tailored to fit anyone, like any other shirt. For example, a baby wearing a GTWM could have his or her vital signs monitored. This would be especially helpful since some babies are prone to sudden infant death syndrome (SIDS), which often strikes unexpectedly during sleep. (See Figure 3)

*Figure 3: An infant wears a tailored "Smart Shirt"*

Athletes could also use the monitoring system during practice and competitions to track and enhance performance.

Moreover, healthy people could wear the GTWM during exercise in order to make sure that they are exercising within safe parameters, and the GTWM encourages individuals to take an active role in diagnosis and maintenance. The other side of this issue is the possibility of promoting hypochondria. As in the case of medical students who first learn about symptoms of diseases, the users of a health-monitoring device such as the GTWM, may become paranoid about their health with the added information.

## The Value Added by GTWM

The GTWM is a breakthrough technology because it is the first unobtrusive and noninvasive way of monitoring vital statistics. Furthermore, the GTWM is worn comfortably underneath clothing, like an undershirt, and can be sized to fit a variety of people. Therefore, it is flexible and customizable to the wearer. Another interesting feature of the GTWM is that it is washable.

The GTWM could be classified as a wearable computing device. Once the wearer has plugged the sensors into the GTWM, he or she proceeds as if wearing any other item of clothing. It is intended to be as unobtrusive as possible, and no direct manipulation of the device is required once the initial setup is completed. It is unlike other wearable computers in that it is nearly invisible since it is worn underneath normal clothing.

Steve Mann, a wearable computing pioneer, suggests that "Smart" clothing is a form of existential media. "Existential media defines new forms of social interaction through enhanced abilities for self expression and self actualization, as well as through self-determination."

## Availability and Success of GTWM

The GTWM is currently being manufactured for commercial use under the name "Smart Shirt". Sensatex/Lifelink is manufacturing the "Smart Shirt", which should be available early next year. The company plans to develop relationships with firefighter groups, doctors and others in order to create "wearable motherboards," that meet their different needs

The commercial applications for the "Smart Shirt" are: (See Figure 4)

- Medical Monitoring
  - Disease Monitoring
  - Infant Monitoring
  - Obstetrics Monitoring
- Clinical Trials Monitoring
- Athletics
- Biofeedback
- Military Uses

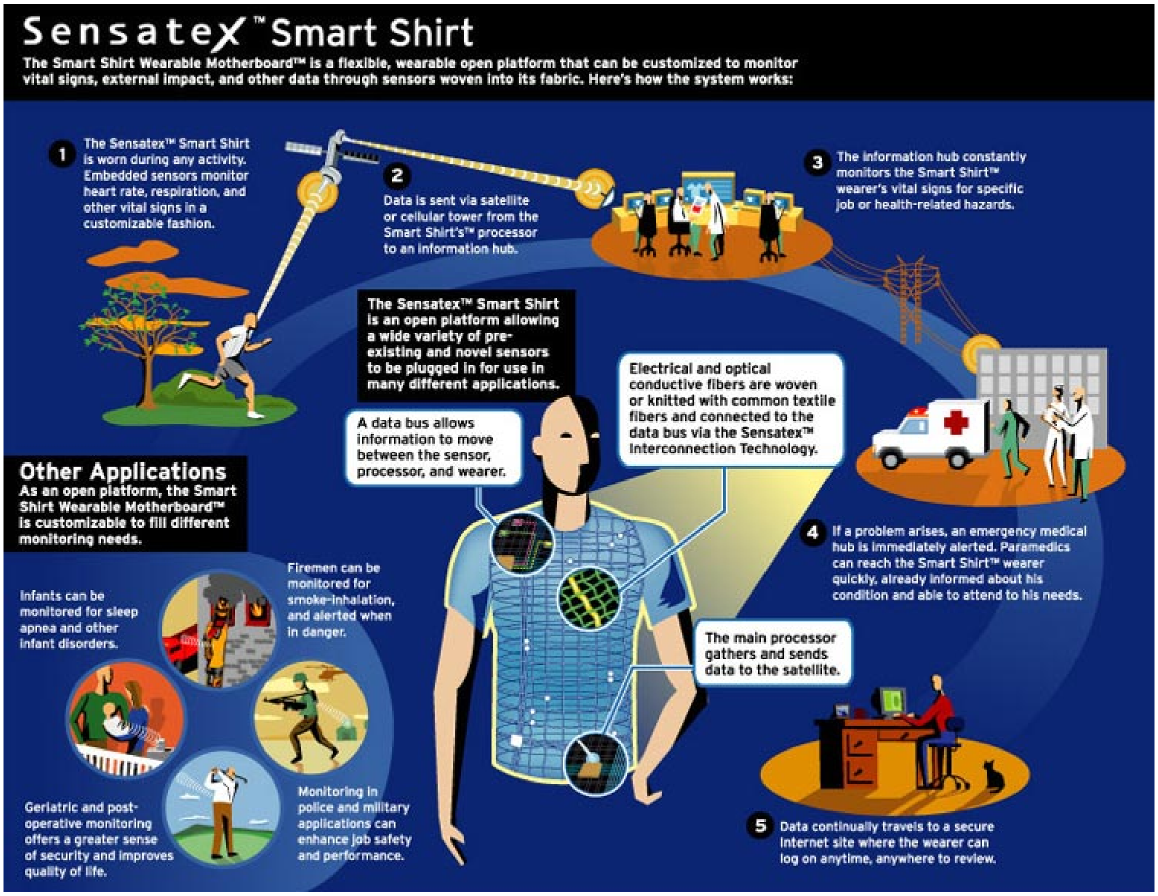



*Figure 4: Scenarios of Use for the "Smart Shirt"*

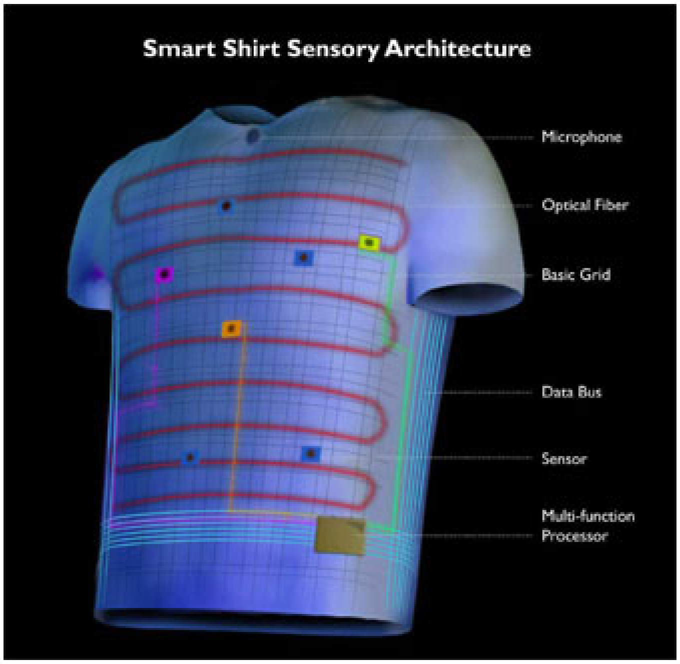



*Figure 5: the "Smart Shirt" Sensory Architecture*

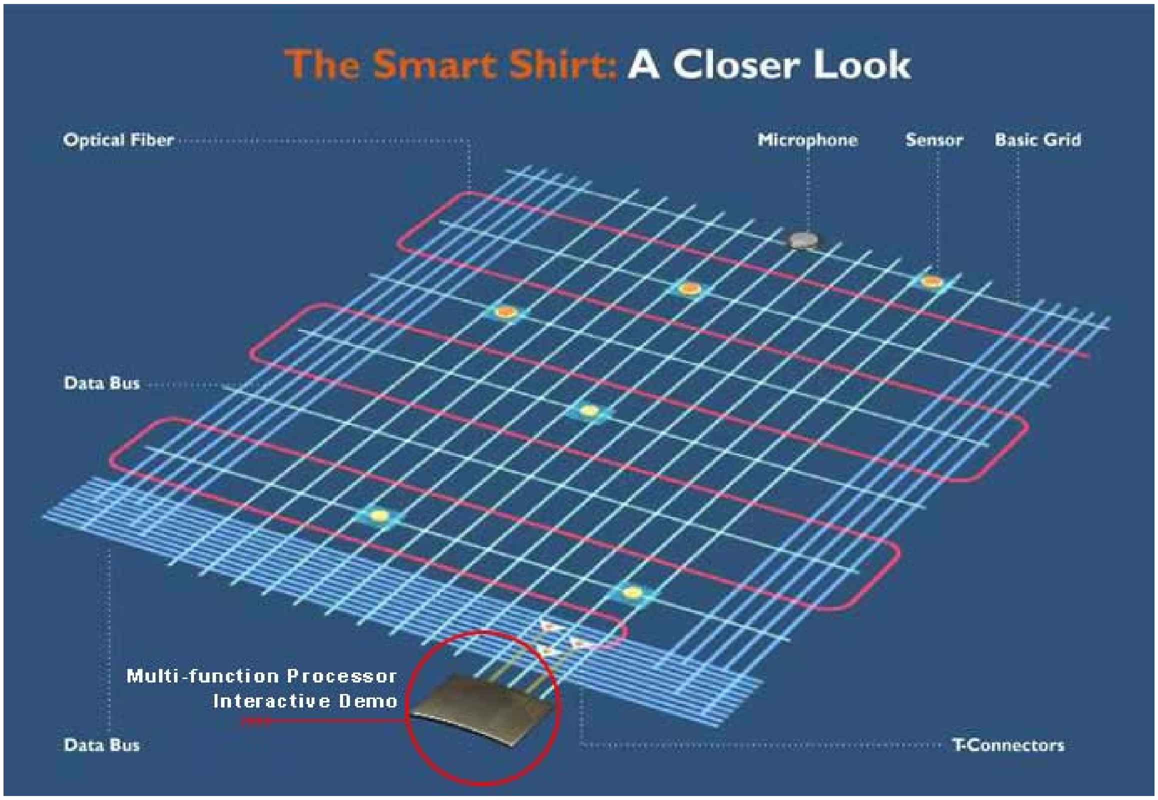



*Figure 6: Detail of the "Smart Shirt"*

## Limitations and Issues of the "Smart Shirt"

Some of the wireless technology needed to support the monitoring capabilities of the "Smart Shirt" is not completely reliable. The "Smart Shirt" system uses Bluetooth and WLAN. Both of these technologies are in their formative stages and it will take some time before they become dependable and widespread. (See Figure 7)

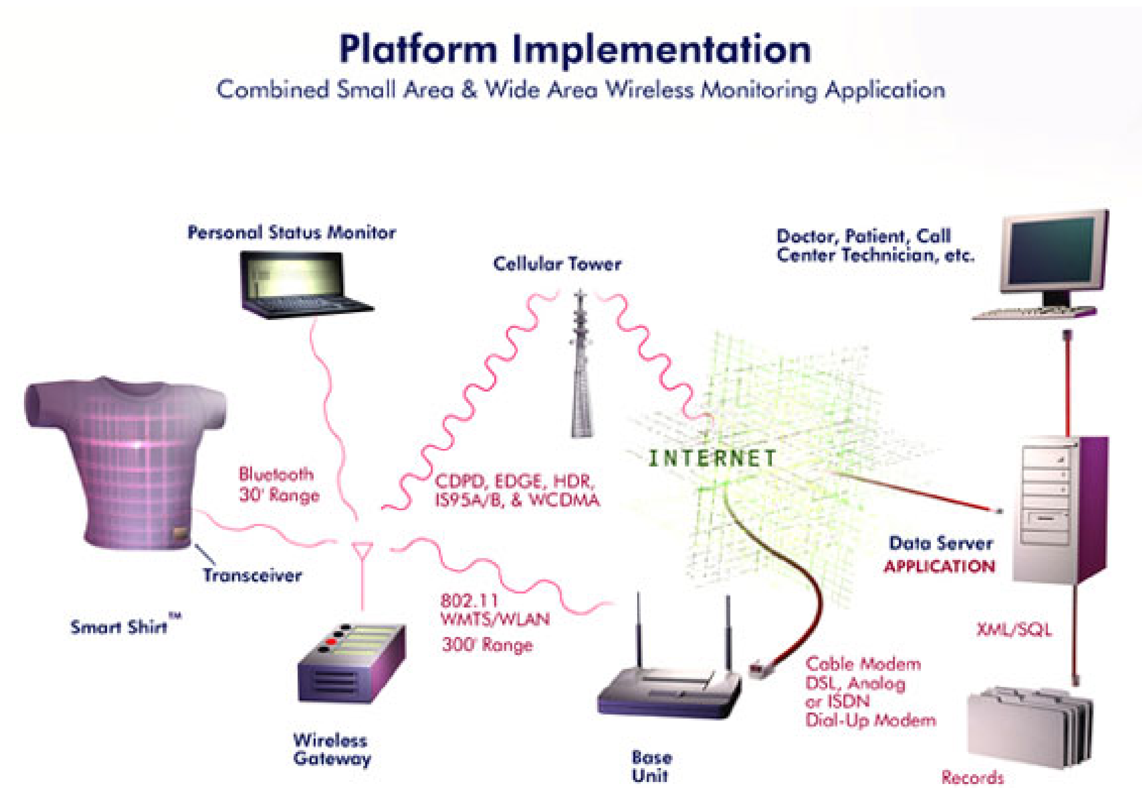



*Figure 7: "Smart Shirt" Platform Implementation*

Additionally, the technology seems to hold the greatest promise for medical monitoring. However, the "Smart Shirt" at this stage of development only detects and alerts medical professionals of irregularities in patients' vital statistics or emergency situations. It does not yet respond to dangerous health conditions. Therefore, it will not be helpful to patients if they do face complications after surgery and they are far away from medical care, since the technology cannot yet fix or address these problems independently, without the presence of a physician. Future research in this area of responsiveness is ongoing.

As is the case for any monitoring system, the privacy of the wearer could be compromised. For example, a GTWM that is outfitted with a microphone or GPS may compromise the wearer's privacy. Additionally, the data that is transferred by the "Smart Shirt" could be used for purposes other than the intended, and could be viewed by unauthorized people. Databases about individuals could also be linked to provide more information than is necessary for this application. All of these possibilities could compromise the privacy of the individual.

Furthermore, Dr. Molly Coyle, founder of Health Technology Center in San Francisco, a non-profit organization that researches the role of technology in improving health, believes that monitoring for healthy people may exacerbate hypochondria.

In my research on "Smart Clothing", there was never any mention of the cost to manufacture or keep up the system that it requires. This suggests that the cost may be somewhat prohibitive for widespread use. Furthermore, since its most noble applications seem to be in the area of medical monitoring and telemedicine in particular, where the likelihood that patients are already spending a lot of money on medical care, it is uncertain whether this population will be able to afford this kind of technology.

In the case of telemedicine and the aforementioned scenario of use with patients recovering from surgery, there is also the possibility that patients may be released from hospitals prematurely because doctors may depend on this technology to monitor them.

## Other Interesting "Smart Clothing"

There are also other "Smart Clothes" that are aimed at consumer use. For example, Philips, a British consumer electronics manufacturer, has developed new fabrics, which are blended with conductive materials that are powered by removable 9V batteries. These fabrics have been tested in wet conditions and have proven resilient and safe for wearers. One prototype that Philips has developed is a child's "bugsuit" that integrates a GPS system and a digit camera woven into the fabric with an electronic game panel on the sleeve. This allows parents to monitor the child's location and actions. Another Philips product is a live-saving ski jacket that has a built in thermometer, GPS, and proximity sensor. The thermometer monitors the skier's body temperature and heats the fabric if it detects a drastic fall in the body temperature. The GPS locates the skier, and the proximity sensor tells the skier if other skiers are nearby. Philips suggests that wearable computers will be widely used by the end of the next decade.

# Textile Integration of an Audio Player System

A speech-controlled MP3 player system is realized which is based on a DSP/µC-two processor system. The demonstrator system architecture is composed of four units: the audio module which is a miniaturized PCB containing the audio chip and a number of auxiliary components, a detachable battery and data storage pack, an earphone and microphone module, and a flexible keyboard sensor module. All four units are electrically connected via ribbon-like narrow fabrics with conductive threads.

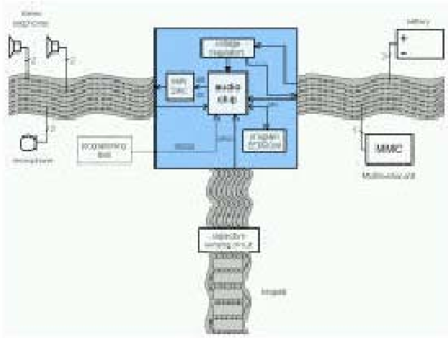


*Fig. 3: System architecture of the audio player system (top) and implementation into a sports jacket (bottom).*

Attention has been paid to an appropriate textile design for the tailoring of smart clothes. In a cooperation with the German Fashion School in
Munich (Deutsche Meisterschule für Mode, München) clothing designs have been realized using the developed hardware (Fig. 3).

**polysilicon**

# Thermoelectric Power Generator

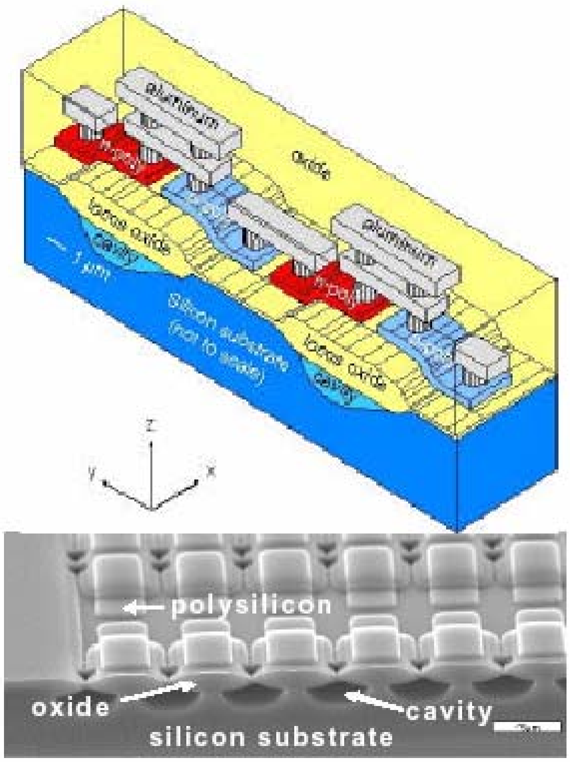



*Fig. 2: Schematic view (top) and photomicrograph (bottom) of the thermogenerator.*

Micromachined CMOS-compatible thermoelectric generators have been realized, as shown in Fig. 2. They produce an electrical output power of 1.0 µW per cm² under load and achieve an open circuit voltage of 10 volts per cm² for a temperature drop of 5 K across the device. These values are comparable with expensive thermoelectric generators made of high-end compound semiconductors. The power delivered is suitable for application in wristwatches.

The thermoelectric generators have been implemented directly into the fabric of clothes. For coupling to the outside world small copper plates are placed both at the warm and cold ends utilizing the high thermal conductivity of this metal. Excellent thermal contact both to the skin and to the ambient air is achieved.

# The Intelligent Knee Sleeve

## What is the Intelligent Knee Sleeve?

The Intelligent Knee Sleeve is a biofeedback device that monitors the wearer's knee joint motion during activity. The device consists of a fabric sleeve that fits over the knee similar to a conventional knee guard,

on which are mounted a disposable electronic fabric str ain sensor and a signal processing system.

As the knee bends, the electrical resistance of the fabric sensor changes, and when the knee joint reaches the correct angle for safe landing, the signal processor emits an audible beep. When used in training the beep provides athletes with real-time feedback about lower limb orientation during jumping and landing and reinforces the correct landing technique.

The device is currently being trialled by the Australian Football League to help players correct the poor techniques responsible for knee injuries such as rupture of the anterior cruciate ligament.

# Further Applications of Textile Sensors

**Injury Prevention:**

Textile sensors, such as the Intelligent Knee Sleeve, can be used to teach people the correct way to perform movement skills to reduce their risk of injury.

**Performance Enhancement**:

Technique is often the key to success in most sporting pursuits. Textile sensors can be used to enhance performance and increase efficiency of motion by assisting people to learn the optimal way to perform skills involving precise limb orientation.

**Rehabilitation:**

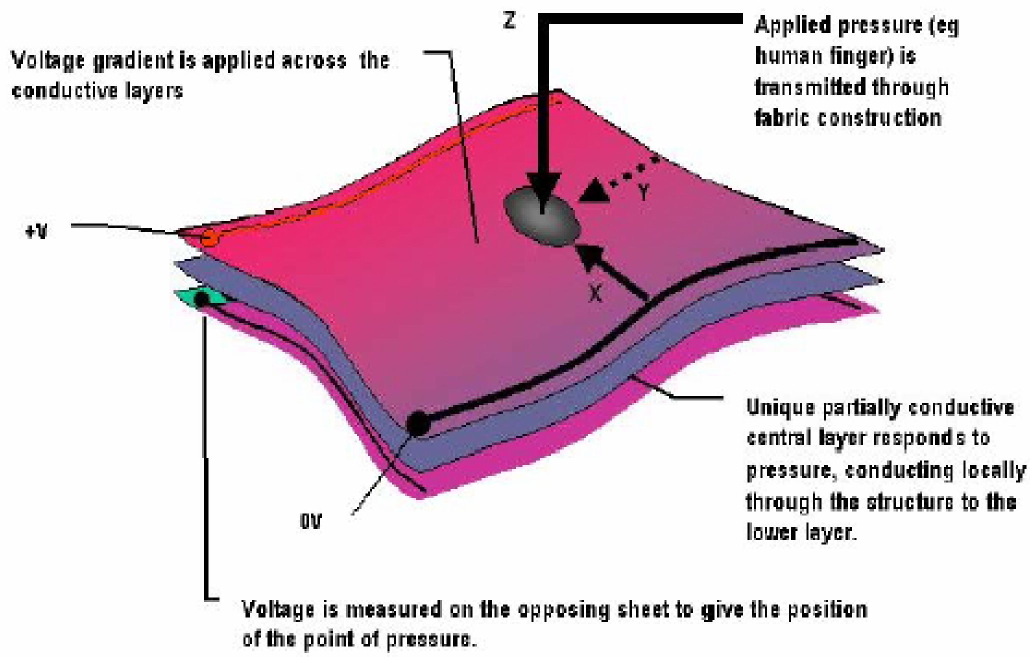
The primary goals of rehabilitation following injury or surgery are to regain full joint range of motion and to recover muscle strength and neuromuscular control. Textile sensors can be incorporated into wearable sensing systems to assist patients to learn how to move their joints through a desirable range of motion throughout typical rehabilitation exercises to improve the rate of recovery.

# ELEKTEX

ElekTex is a highly versatile and innovative technology that provides the basis for a soft, flexible, and lightweight interface between users and electronic devices. This unique fabric structure can accurately sense location on three axes – X, Y, Z – within a material that is less than 1mm thick. Therefore ElekTex not only senses where it is being touched (the X and Y axes), but also how hard it is pressed, the Z axis. The ability to conform to complex solid forms using the flexibility inherent in ElekTex and the ability to sense the applied pressure are major advantages ElekTex has over previous technologies, such as plastic touchpads.

**PRINCIPLES BEHIND ELEKTEX**

ElekTex is essentially a laminate of textiles comprising two conductive outer layers separated by a partially conductive central layer. The outer layers each have two conductive-fabric electrode strips arranged so that the upper conductive layer has tracks which make contact across its opposing top and bottom edges and the lower conductive layer has conductive tracks up its left and right sides. The partially conductive central layer provides the magic which makes ElekTex work. Its role is to act as an insulator in the resting state which, when touched, allows electrical current to flow between the top and bottom layer. Pressure applied to the ElekTex fabric causes two effects. First, the conducting fibres in the central layer are locally compressed allowing contact between neighbouring conducting fibres to form a conductive channel through the central layer. Second, the applied pressure brings the two outer layers into contact with the conductive channel running through the central layer allowing a local circuit to be established between the upper and lower layers.



ElekTex™ fabric construction in touch sensing phase

**X, Y SENSING**

The conductive outer layers are constructed using moderately resistive components so that when a voltage is applied across the sheet, via the electrodes, there is a distinct voltage drop across the conductive sheet. When the voltage is measured at points across the lower sheet, it acts like the track of a potentiometer allowing the x-position to be calculated from the voltage which can be measured, when the sensor is pressed, via the top sheet. The y position is made by applying a voltage to the top sheet and measuring on the lower sheet. These measurements can be made up to 1000 times a second providing, in effect, continuous X,Y positional data.

**Z AXIS PRESSURE SENSING**

When pressure is applied to an ElekTex sensor, for example when it is touched, a conductive channel is formed. If the pressure is light the conductive fibres in the central layer will only just make sufficient contact to open up a continuous channel and the resistance of the channel will be high. Conversely, when a high force is applied to an ElekTex sensor many more of the conductive fibres in the central layer will be brought into close proximity and thus the resistance in the channel will be relatively low. The variable resistance in the channel is, therefore, dependant on the pressure applied. To determine the Z axis force the electronic controller supplies a current to the upper and lower conductive layers which in the resting state presents an open circuit and no current flows between the outer layers. When the sensor is touched and the pressure increases, a conductive channel of decreasing resistance forms the circuit whereupon the resulting current flow is high and related to the pressure applied.

## KEYMATS FROM A SINGLE SENSOR

One of the most exciting uses of ElekTex technology is in the formation of soft texters (keyboards) for mobile computing and communications devices such as PDAs and mobile phones. For these, typically, a single sensor provides X, Y and Z data as described above, revealing when and where the sensor is pressed. When used in a soft texter, a microprocessor within the electronic controller compares the X and Y coordinates with a reference map for the qwerty-keyboard printed on the sensor surface and translates the precise electrical information into digital keypress data. Similarly, the size of the Z axis force is used to separate real keypress events from momentary touches made by the user, and controls other functions like scroll speed. Sophisticated software allows fast, fluid typing, even when keypresses overlap and enables a simple four connector single sensor to be used. Once the chip has translated the analogue electrical data into digital keypress data the information is passed on to the host PDA/mobile phone.

### Other applications

Some applications, for example games controllers, may require the detection of pressure at several locations concurrently. For these applications more complex constructions will allow the surface to be multiplexed into multi-area XYZ sensors, enabling simultaneous presses to be processed independently.

## GENERAL CONSTRUCTION INFORMATION

One of the surprising facts about ElekTex is that it is not composed of wires – instead it is composed of conductive fibres, combined with other more traditional textile fibres. It is flexible, washable, expandable, durable and lightweight; yet sensitive to light pressures. The ability to use a single sensor for interfaces as complex as a soft texter means that only four connections are required between the sensor and its controlling microprocessor –simplifying construction. ElekTex brings existing technology in switching and sensing together in a new way. Its soft position-sensing system sends electrical impulses to its controlling microprocessor that can be translated into digital commands for conventional electronic equipment of all kinds. The sensitivity of ElekTex sensors can be adjusted both in software and through the fabric construction. Because of its flexible fabric construction, ElekTex sensors can be used with a wide variety of soft or textile based products. Typically the sensors live just under the surface of a conventional cover such as a fabric. This surface can be more or less any kind of soft material, allowing a broad range of design options to fulfill a mixture of functional and aesthetic demands.

# FABRIC COMPUTING INTERFACES

## FABRIC COMPUTING DEVICES

Designing with unusual materials can create new user attitudes towards computing devices. Fabric has many physical properties that make it an unexpected physical, interface for technology. It feels soft to the touch, and is made to be worn against the body in the most intimate of ways. Materially, it is both strong and flexible, allowing it to create malleable and durable sensing devices. Constructing computers and computational devices from fabric also suggests new forms for existing computer peripherals, like keyboards, and new types of computing devices, like jackets and hats.

**Sensitive Fabric Surfaces**

Creating sensors that are soft and malleable and that conform to a variety of physical forms will greatly change the way computing devices appear and feel. Currently, creating beautiful and unusual computational objects, like keyboards and digital musical instruments, is a difficult problem. Keyboards today are made from electric contacts printed on plastic backing. These contacts are triggered by mechanical switches and buttons. Digital musical instruments rely on film sensors, like piezoelectric and resistive strips. All these sensors require rigid physical substrates to prevent de-lamination, and the mechanical incorporation of bulky switches. This drastically limits the physical form, size and tactile properties of objects using these sensors.


Fig. 1 Embroidered Keypad

**Two Fabric Keypads**

Our fabric keypads offer far greater physical flexibility and softness than existing flexible keyboards. Unlike fabric sensing of the past, these keyboards offer the precision and repeatability necessary to create reliable sensing devices. These keypads can be used to interface with Fig. 2 Quilted Fabric Keypad, Flat, Folded and Rolled everything from a desktop computer, to a pager and an interactive dress.

Fig. 2 Quilted Fabric Keypad, Flat, Folded and Rolled

***Quilted Switch Matrix Keypad (Figure 2.)***

This row and column switch matrix is sewn from strips of conducting metallic fabric, (the electrical switch contacts), and non-conducting cotton and nylon tulle, (the insulating layers). Because no plastics or non-textile materials were used in this keypad, this quilted computer keyboard is soft, can be scrunched into a small ball, folded up and wrapped around an object of any shape, with no damage. This keypad is highly responsive, so users can rest their fingers on the sensing areas and press lightly to get a response on the computer screen.

***Embroidered Capacitive Key Pad (Figure 1.)***

This keypad is embroidered from a resistive kevlar and stainless steel thread, and uses a capacitive sensing technique to recognize touch. Each embroidered number registers a key press when touched. These sensors can be easily made on a computer controlled embroidery machine. Using this entirely new method, sensors can take on any size or shape and conform to any surface. These sensors can easily be made to look like butterflies as well as calculator pads.

**Smart Fashions, Sewn Circuits, and Fabric Computers**

For the MIT Media Lab's "Wearable Computing Fashion Show" (10/14/97), we created a series of "smart fashions" that incorporated fabric sensors, busses, ground planes, power planes and electrodes.

***Musical Jacket (Figure 3.)***

The Musical Jacket incorporates an embroidered fabric keypad, a sewn conducting fabric bus, a battery pack, a pair of commercial speakers and a miniature MIDI synthesizer.

Fig. 3 Musical Jacket

When the fabric keypad is touched, it communicates through the fabric bus to the MIDI synthesizer, which generates notes. The synthesizer sends audio to the speakers over the fabric bus as well. Power from the batteries is also distributed over the fabric bus.

The embroidered keypad and fabric bus allow the elimination of most of the wires, connectors and plastic insets that would make the jacket stiff, heavy and uncomfortable.

***Firefly Dress and Necklace (Figure 4.)***

The Firefly dress and necklace uses conductive fabric to distribute power throughout the dress. As the wearer moves, LED's (small lights) to which we attached fuzzy conductive p ads (the electrical contacts), brush lightly against the fabric power and ground layers, creating a dynamic lighting effect. The necklace, (having no power supply of its own), creates dynamic light effects when its conducting beads and tassels brush against the surface of the dress. These "opportunistic" connections allow power to be distributed without hard and fast connectors and wires. The dresses design is reminiscent of the 1920's and suggests a level of detail and romance rarely associated with technology.

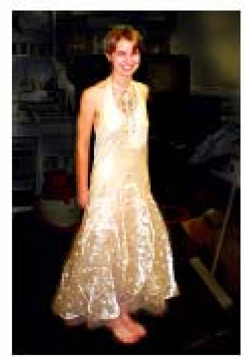


Fig. 4 Firefly Dress

# CONCLUSION

What smart fabrics cannot is not as important as what it can. This intelligent textiles have managed to pervade into those places where you least expect to find them. That is the real charm of knowing them. It can engender a myriad of wild imaginations which are not impossible.

Right from the technically versatile battlefields of the future to the very core of wearable, pervasive, ubiquitous computing technologies that have vowed to make computing an activity so tightly bound with the normal life, will the smart fabrics make their presence felt. One may not be able to forfeit the joy of being in a smart-wear.

It will get hold of your rhythm like a lover. It will enlighten your ways like a mentor. It will care for you like a mother. It will be cautious like a friend. The smart-wears will definitely make you feel in good company, how alone you maybe.

One day we may correct Seneca of his saying “As often I have been with men, I have come back less a man”, and suggest that “As often I have been in a smart-wear, I have come back wiser a man”.

One day will our senses become superfluous?

# And thus spake these papers….

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