Textiles gain intelligence

by Paula Gould

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 clothing[1-4]. 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 colored 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[5].

France Telecom has gone one step further, developing a flexible, battery-powered optical fiber screen that can be woven into clothing[6-7]. 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

ISSN:1369 7021 © Elsevier Ltd 2003

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

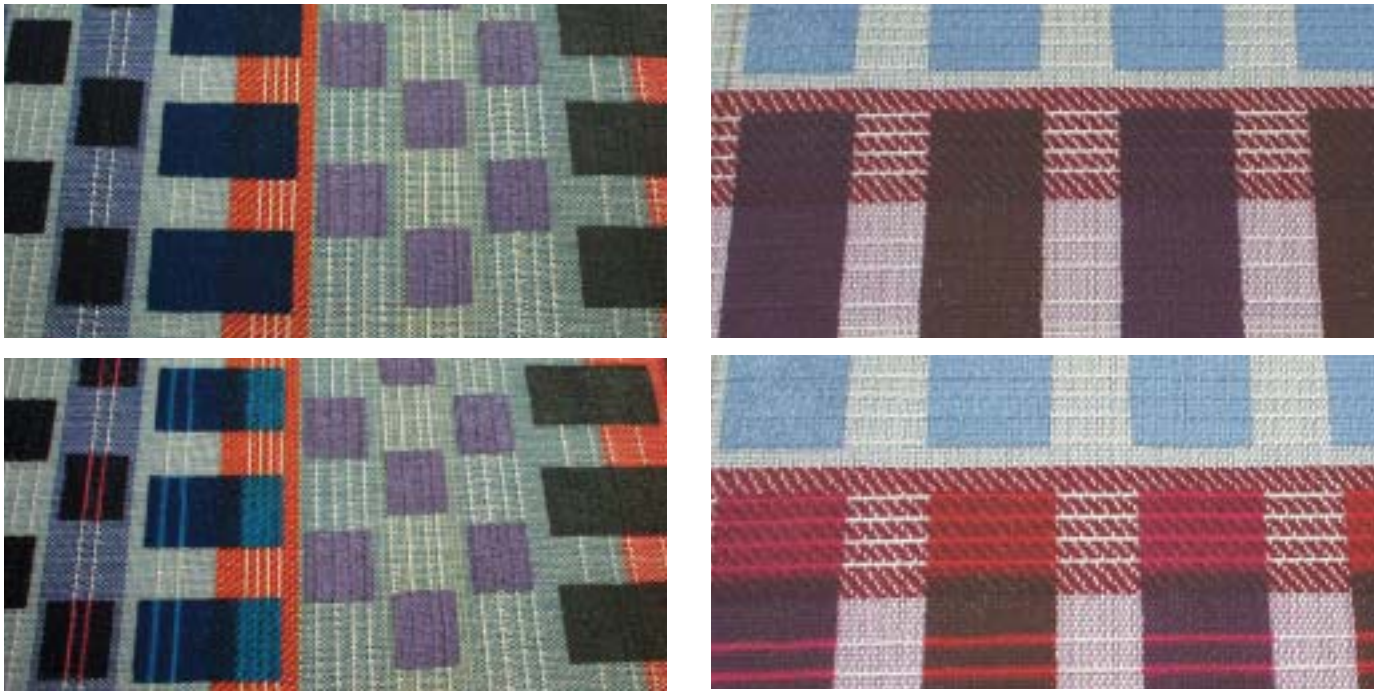

Fig. 1 Optoelectronic fabrics may find a market in the world of interior design owing to their originality and aesthetic appeal. (Courtesy of Maggie Orth, International Fashion Machines.)

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

pressure during a gym workout or morning run. Clothing fitted with textile global positioning system technology could also be suitable for locating skiers or mountaineers in bad weather or even for keeping a watch on young children.

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 lower-tech 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 stand-alone 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."

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."

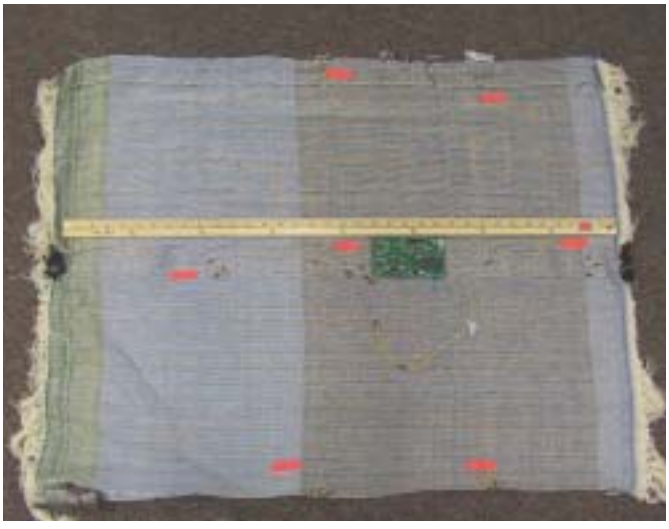

Fig. 3 The cloth sensornet developed at Virginia Tech could help military personnel detect and locate approaching enemy vehicles. (Credit: Zahi Nakad.)

Complexity versus durability

Moving from large-scale sensornets to wearable attire means more 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 washability 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

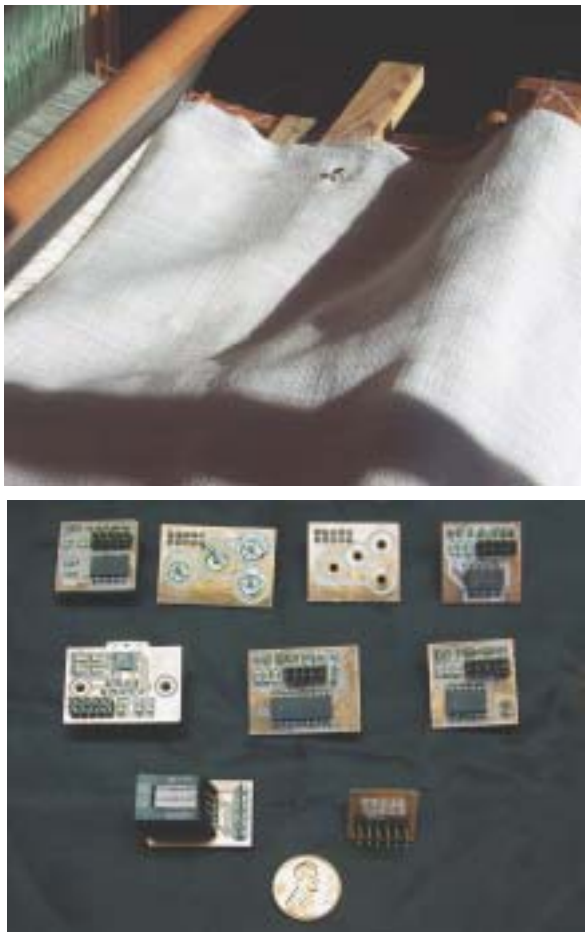

Fig. 4 Use of established mass-manufacturing techniques may help keep the cost of intelligent clothing down. (a) Fabric for the acoustic beamformer sensornet is woven on a standard loom. (Credit: Zahi Nakad.) (b) Electronic 'buttons' are fitted with metal snap fasteners that garment makers are already familiar with. (Credit: David Lehn.)

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. 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

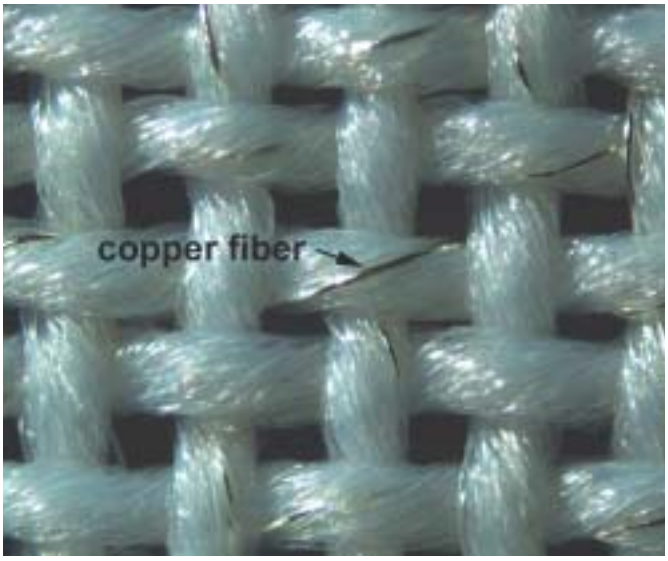

Fig. 5 (a) Researchers at ETH Zürich are using woven fabric with embedded Cu fibers to produce context-aware clothing. (b) Their prototype 'intelligent' jacket uses the conductive fibers to transmit data between different sensors and to measure body movements. (Courtesy of Tünde Kirstein, ETH Zürich)

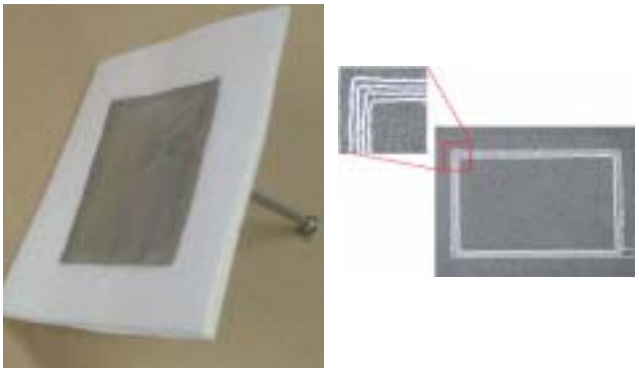

Fig. 6 (a) Textile antenna developed for external communication between an item of clothing and its environment. (b) Conductive yarn embroidered onto fabric becomes a coil that uses near field inductive coupling for communication between different pieces of clothing. (Courtesy of Tünde Kirstein, ETH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

idea because you have a large surface area on the clothing, so you could use that for generating energy."

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. 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 consideration[8,9].

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." MT

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