DESIGN INNOVATION: SENSORS AND FABRICATION

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ABSTRACT

Technical Textiles is a rapidly developing sector based on cutting-edge technology, performance materials. Smart products, including wearable electronics have generated significant interest among both manufacturers and consumers.

Initial research concentrates on technical textiles that integrate smart materials. These could be developed as wearable or portable products. The potential of these ‘kinetic’ fabrics has other industrial in addition to commercial design applications.

The stretch sensor is examined, using the latest 'smart' material technology. It has uniquely flexible attributes that can undertake measurements when it is shaped around corners or is woven into fabric. As a flexible sensor with small profile characteristics, it has simplistic functionality and the output of the sensor allows for relatively straightforward integration and control utilising solid state and/or passive electronic components.

This research explores the potential to integrate the stretch sensor into simple woven and knitted structures in order to evaluate and develop a range of functional fabrics of varying quality and densities. Working exclusively with the designer and sole supplier of the sensor, a research and testing strategy has been developed. This includes examination of the properties and potential modifications to the existing device to further enhance its suitability for its inclusion into constructed textile fabrics. The integration of the sensor demonstrates the potential for numerous commercial opportunities within the domestic market, including sport and medical applications.

Keywords: smart materials, smart products, stretch sensor integration, constructed textile fabrics

1. BACKGROUND

This research takes place at an increasingly important juncture between commercial and contemporary arts interests. European organisations are aware that to sustain competitive advantage the textiles and clothing industry must “relentlessly innovate in its products…and focus on…the constantly evolving needs of its customers” (Euratex 2004). Berzowska (2005) has articulated one of the issues for the future of aesthetically as well as functionally driven wearable technology as being the development of integrated design and manufacture processes whilst Euratex (2004). identifies among other issues a significant problem in the difficulty of translating “research results into product- and process- innovation” It is undertaken against a broad background of increasingly resolved conceptual work and experimental projects to found in fashion and textiles in collaboration with technology and draws inspiration from the integrity of such projects as Di Mainstone’s *Share Wear* (Mainstone 2008), Elena Corchero’s successful integration of delicate machine embroidery

(Corchero 2007) and solar power and Peter Schmitt's use of knitted structures and knitting technology platforms to create building structures (Schmitt 2008).

While there have been encouraging first steps towards the integration of aesthetics and functionality in such research, with the notable exception of Centexbel (2008) and Heriot Watt (RIFleX 2008), the bulk of the work done to date has been conducted with non-stretch fibres. In addition, as far as the authors are aware, this particular stretch sensor has not been tested in textile structures to date (Merlin System Corp. 2008b). This paper therefore reports on the early stages of what the authors hope will be a longer term research project, focusing on initial experiments with this novel stretch sensor in knitted, woven and embroidered fabrics.

2. APPROACH

The initial approach was to create a series of basic swatches using three knit technologies – hand knitting, the domestic machine (a Brother KR260), and the Dubied, the industry standard. This early stage threw up the need for decisions regarding small hidden issues such as the finishing technique to be used on the samples: cast off edges do not stretch, but an overlocked edge will, potentially influencing later measurements. Making samples larger than needed allowed for clamping to a standard size which later could be put in header cards and using a standard number of needles in action on the machine bed rather than calculating this to give a standard end sample width. Silk was also rejected as being too soft, and therefore likely to go too 'fuzzy', as was linen, being without any stretch at all, and unlikely to tell us any more than working with cotton. Yarns were then sourced from Texere Yarns in the UK (Texere 2008).

This exercise allowed the research fellow and the knit technician to each start building some understanding of the research direction and the materials that would inform it, an important stage in interdisciplinary work, where individuals necessarily have different fields of expertise and expectations (Votila, Mattila & Hanninen 2006). It also allowed thinking about the different criteria brought to the project by those disciplines – even at this stage, for example, when it was understood we had not started from an aesthetic perspective, samples were being discussed in terms of their 'personality'. A simple design constraint was imposed by constraining the colourway to a monochrome palate, giving results commonality and working with the aesthetic of the rubber, which is available in black only.

The first approach had been envisioned as a comparative one: sample swatches of wool, cotton and man made fibres in different stitch structures would give the team control information on objective properties of handle, such as tensile and shearing properties, bending and compression, and surface characteristics. Using a method such as the KES-F, developed by Kawabata or the FAST system (Fabric Assurance by Simple Testing) would have been the preferred route to creating a table of properties of knitted and woven control samples without the stretch sensor (Choi & Ashdown 2000, Saville 1999 Taylor 1991). Following this, samples would be made up that incorporated the 2mm conductive rubber 'yarn' in different mechanical ways and at different densities, for example, laying in every course of a knit sample, and then every fourth course of a similar knit sample, giving comparative data on the resulting fabrics' handle. This would then be combined with analysis of the dynamic electronic feedback of the stretch sensor embedded within the various structures.

However, two significant issues were encountered that shifted the focus of the early investigation: firstly, the equipment required to give reliable results was not available to the researchers at the right time, and secondly, it became apparent very quickly that the rubber stretch sensor would not be suitable for creating knitted structures on its own. The first of these problems is one that may be overcome in the future with dedicated funding or collaboration with organisations outside of the University, and leads in the short term to a something more akin to a case study, with an emphasis on subjective appraisal. This of course remains valuable, if only for a different audience. The second problem, of the intractability of the yarn itself, is discussed in Section 3.

3. THE MERLIN STRETCH SENSOR

Merlin Systems Corp was established in 1998 to deliver human-in-form service robots (Merlin System Corp. 2008a). As part of this vision, the company invents, designs and manufactures novel enabling technologies and platforms, such as the air muscles used to give Snake its 27 degrees of freedom (Breedon 2007, Merlin Robotics 2008), and the stretch sensor being discussed here (Merlin System Corp. 2008b). This rubber contains carbon particles that allow it to reliably conduct an electrical current. When it is stretched, the resistance is increased, allowing dynamic measurements to be made anywhere there is movement or pressure (Figure I).

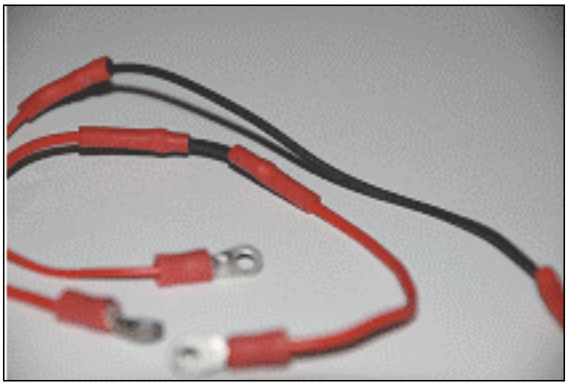


Figure I: Merlin stretch sensor with connectors

It was anticipated that the 2mm stretch sensor could be knitted using the same stitch structures as in the control samples, and then tested for both its mechanical and electronic properties as a new composite fabric. A number of factors meant that this was not possible, notably the thickness of the cord, friction and snapping behaviour.

Figure II: Snapping behaviour

Figure II shows the result of attempting to knit with the stretch sensor on a domestic machine. Almost every stitch snapped during the process and those that did not are under severe pressure. This ability to snap is unusual in ‘rubber cords’ and we believe that it may be due to the dispersion of the carbon particles which give the sensor its electrical properties. Figure III gives an electron microscope view of the surface of the rubber, showing extrusion lines and a dispersion of carbon particles of similar size and angularity.

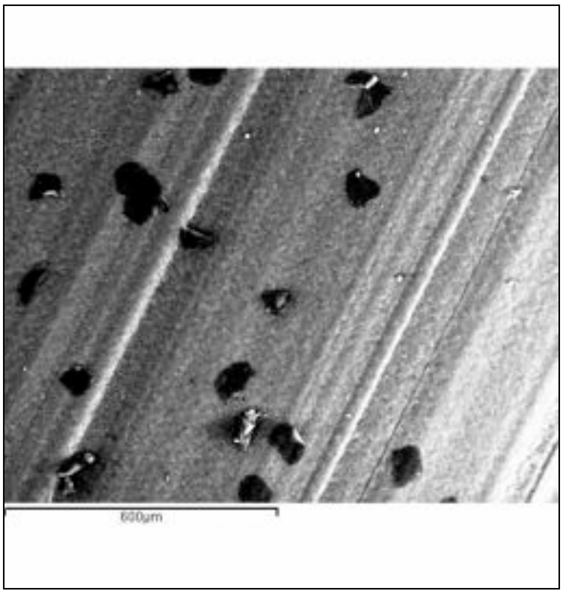


Figure III: Scanning electron microscope image carbon particles

The pressures resulting in breakage are also due to the mechanical characteristics of the material itself. At 2mm diameter, the stretch sensor is equivalent to a bulky yarn and requires the coarsest of combs and needle settings to be workable on a machine. A 0.6mm sensor may become available once manufacturing problems are resolved, and in the shorter term it may be possible to purchase a 1mm cord - however, at the time of writing, only the 2mm diameter was available (Merlin 2008). This is compounded by the tackiness of the material, and the high level of friction between it and the needles.

This becomes a consideration even in laid in methods, as the cord pulls against the outer selected needles creating drag and distorting the fabric (Figure IV). In this sample, the cord snapped after 45 courses.

Figure IV: Sensor laid in every course with 100% wool, single bed looping and deformation as a result of drag front face and back

4. INTEGRATION

As a result of these issues, the research team are now pursuing a strategy for the integration of the rubber cord into other fabrics through lacing, embedding and surface laying. These may be created horizontally, vertically or in freeform and used in conjunction with knit, weave and embroidery techniques (see Table I).

	knit	**weave**	**embroidery**
lacing	eyelets: horizontal, vertical, zig zag	eyelets: horizontal, vertical, zig zag; freeform on jacquard loom	eyelets, lace; freeform
embedding	horizontal or vertical using channels	horizontal or vertical using channels; floats	couching; freeform
surface laid			partial/full; flat or looped; freeform

Table I: A strategy for integration of sensor into fabric

To date the cord has been laid in with knitted wool and cotton on every course, and on every fourth course (Figures IV and V), and has been integrated with channels in knitted fabrics (Figure VI).

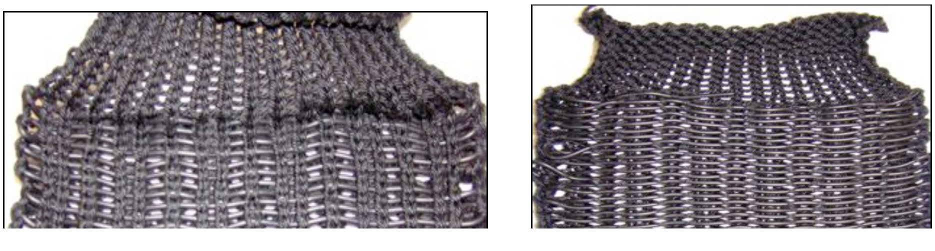


Figure V: Sensor laid in every course with 100% cotton single bed knit front face and back

Laying in at every course creates some interesting aesthetic and electromechanical effects. The samples in figures IV and V were opened up by the elasticity of the cord, causing visual patterns that triggered visual research into Japanese armour for example, while making the fabric very rigid in the course direction with some stretch remaining vertically along the wales (the wool sample less so than the cotton). It was also the wool sample that exhibited the looping behaviour visible in Figure IV, while the cotton, having far less elasticity itself, knitted up with almost no looping at the edges. Obviously these could be pulled through manually after the fabric has been made, but this would be time consuming and prone to more breakage. Instead, focus has been placed on:

(i) Processes that have the potential to be used in the commercial sector; and
(ii) Results that would be interesting to the contemporary textile community.

The looping falls into the second of these and such manipulation would destroy one without being beneficial to the other.

4.1 Embedding

The use of channels in a knitted fabric opens different design opportunities and considerations for the use of the sensor. So far swatches have been made up in 100% wool, 100% cotton, a cotton/lycra mix, and a pure Lycra (Figure VI). In the threaded samples, the aesthetic restrictions introduced by the black rubber are somewhat removed as it is encapsulated, and the handle of the fabric supporting it could be much finer. It is also possible to imagine this being translated into existing garment manufacturing processes where such tubular structures are already common, for example, in the necklines of knitted garments.

Figure VI: Embedding - Lycra knit with channels threaded flat and ruched

Further possibilities exist in weave for the embedding of the cord, and this is being explored through the use of a Jacquard loom, creating horizontal and vertical channels using floats (Figure VII). In addition, work using the floats left by spot patterns is also planned, as well as an investigation into the potential for double faced fabrics to create shifting planes where the sensor might give interesting feedback.

Figure VII: Large woven sample with float constructed channels

The scale of such samples, quick to produce on the power loom, allows stakeholders and other parties to think on a different scale, automatically suggesting a different class of products and application areas than the smaller swatches (see Figure XV taken in a brainstorming workshop). What the technology can usefully add to such textile products is a part of the research question and, the approach being taken towards this is discussed later in this paper.

4.2 Surface laid

Figure IX: Quick embroidery samples fully couched on a stretch fabric and partially couched on satin

Couching, in which a yarn is overlaid with finer thread, thereby binding it to the base fabric, has the potential for highly decorative effects and offers a much freer visual approach then the orthogonal constraints of the tubular structures in knit and weave. The colour of the cord can become a feature in a pattern, or be subsumed beneath layers of other yarns; the cord can be worked flat, or left to loop up between small tacked down areas, offering scope for new kinds of physical interaction with it. Further, like the embedded cord, it can be pulled to ruche the fabric around it, creating new decorative and structurally interesting areas. The samples shown in Figure IX were ruched by hand after the stitching had been done. The sample shown in Figure X was ruched as it was sewn due to the snug fit of cord to stitch width.

Figure X: Ruched while sewn static fabric (cotton organdie)

The introduction of pleats adds further design interest to the application of the sensor. Figure XI shows how knife and box pleats are used to investigate three dimensional effects and the pattern potential provided by thread colour. Each end of the cord needs to be secured to prevent the pleats being destroyed and to allow the sensor to give meaningful feedback.

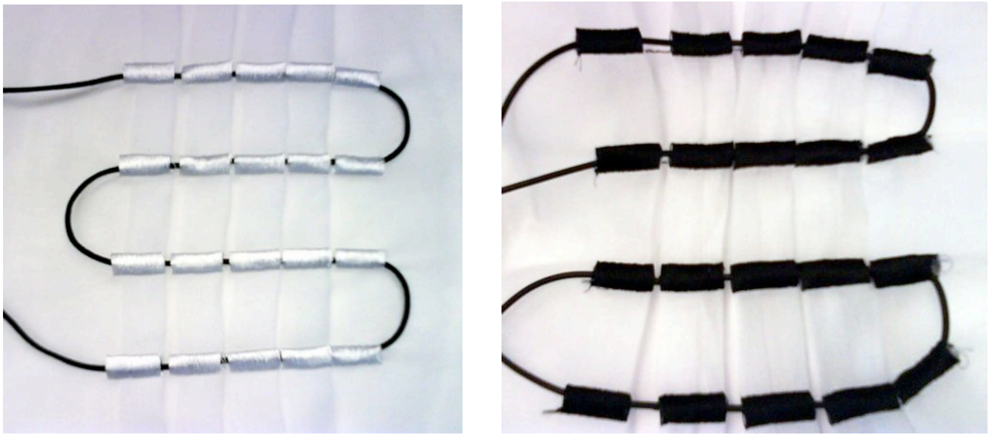


Figure XI: Knife and box pleats flat and distorted when pulled

5. DESIGN VALUES - FUNCTIONAL AND AESTHETIC MOTIVATIONS

To date, embroidery has offered the quickest route to a design-led approach, mostly through surface laying techniques such as couching, with some examples also exploring embedding. The samples above point to promising directions for work that can be aesthetically driven, taking into account the properties, both mechanical and sensual, of the base fabrics in relation to the stretch sensor, and the decorative properties of the stitching used to overlay the cord.

It is easy for interdisciplinary projects to become dominated by one particular kind of design thinking, often as a result of mundane organisational details. It can also be surprising how fundamental the differences can be in the ways creative disciplines approach design, and the playful and apparently risky processes employed in one area can easily be lost to the goal driven process of another. At this stage it is important for the team to grasp the potential for creating desirable and perhaps beautiful artefacts that these early samples present, and to allow playfulness by removing any anxiety associated with using the unfamiliar and ‘precious’ material.

6. CONDUCTIVE PROPERTIES IN FABRIC STRUCTURES

When a piece of the stretch sensor is pulled, its resistance increases and its conductivity decreases. Because the stretch is variable, the output is dynamic and simplistic: an LED for example, can be dimmed and brightened by stretching any calibrated length of the sensor, which effectively becomes a dimmer switch. However, in some samples, for example in the knitted piece with the sensor laid in at every course, it was found that this behaviour is reversed. That is, instead of a decrease in conductivity when stretched, the conductivity is increased. This is most likely because the sensor comes into contact with itself as the fabric is manipulated, shortening the effective length being measured.

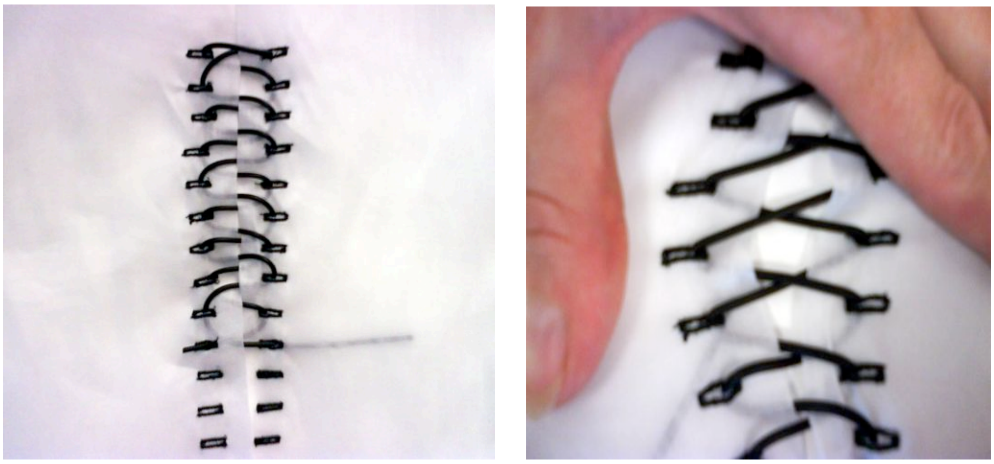


Figure XII: Explaining reversal of electrical properties eyelet samples in organdie

This can be demonstrated with the eyelet and lacing sample produced in embroidery (Figure XII). When the two fabric pieces are ‘at rest’, the stretch sensor is separated from itself by the fabric and by the spaces produced by the angle between opposing eyelets. As the sample is pulled that angle decreases and the sensor must cross over itself at the same time as it is being stretched, thereby creating an effectively shorter conductive path. The images in Figure XIII illustrate the drop from approximately 13 kΩ for this length of sensor to approximately 4 kΩ when stretched.

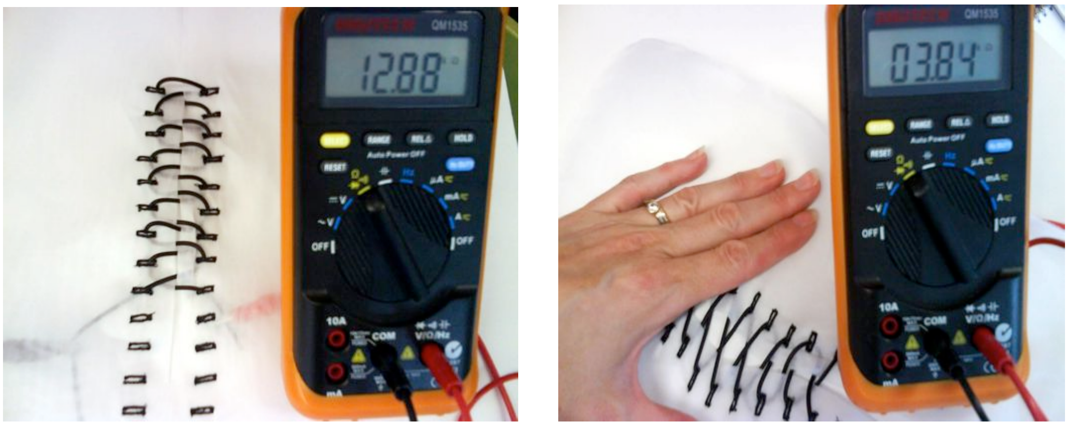
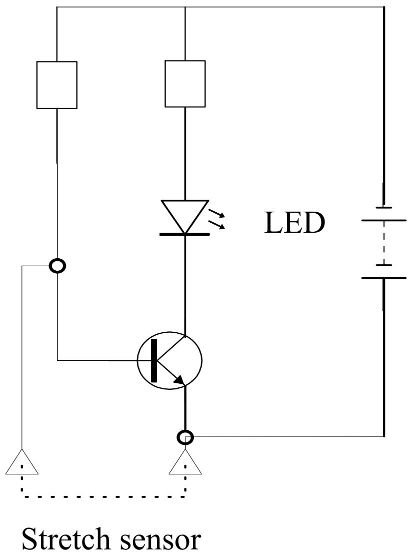


Figure XIII: Reducing resistivity with laced sample

6.1 Stretch Sensor

The Merlin Stretch Sensor uses the latest 'Smart' material technology and has uniquely flexible attributes that can undertake measurements when it is curved around corners or woven into fabric. The sensor performs like a variable resistor; the more it is stretched the higher the resistance value.



This simplistic function and output of the sensor allows for relatively simple integration and control utilising solid state and/or passive electronic components.

Figure XIV illustrates a simple circuit diagram, the basic schematic diagram shows two resistors, an NPN transistor, an LED and a power supply (battery). As the sensor is stretched the light emitting diode (LED) increases in brightness.

Stretching of the fabric will increase the resistance of the sensor providing a simple ‘control’ function that is to be investigated for controlling LED’s or other electronic devices.

Figure XIV: Circuit schematic diagram, stretch sensor & LED

7. TOWARDS APPLICATION

The key motivation for including a functional material such as the stretch sensor is going to be dependant on application – so far the results may have just as easily been achieved using standard rubber cord, and in fact a cheaper way of making up samples would be with a rubber cord with a similar modulus value. In effect we have been dealing with a solution without a problem and need to think laterally to bring the two together in any meaningful way. To do this we have so far employed two methods: ongoing heuristic brainstorming, and brainstorming with physical samples.

The heuristic brainstorming occurs within the regular meetings with up to eight individuals present from Product Design, Knit, Printed Textiles, Weave, Embroidery, Jewellery and Wearable Technology, Materials Science, Fashion, and Architecture. Comments are captured by the group’s research fellow and ideas are built upon through multidisciplinary discussion. There may be resources in the future to organise a more strategic approach to brainstorming, such as the processes documented by the Smart Textiles Network (2006 and 2006a), although these reflect a far larger scale of network. Ideas include reactive architectural spaces for the monitoring of through traffic volume and aesthetic feedback, bio-sensing combined with mechanical support in trusses and sports support products, light emission in enclosed spaces such as bags or containers when opened, and comforting sculptural objects for the home after soft furnishings.

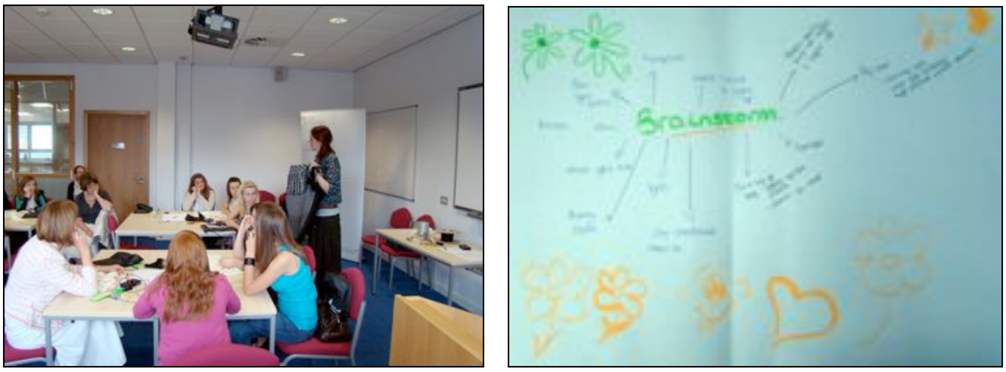


Figure XV: Extreme Materials Workshop, NTU, 10 July 2008. Woven fabric as a design prompt and example of brainstorming results

Brainstorming with physical samples was implemented at a workshop designed for high school students by The Industrial Trust and Nottingham Trent University's Centre for Effective Learning in Science (CELS 2008, The Industrial Trust 2008). In this half hour workshop, students between the ages of fourteen and sixteen were introduced briefly to the research and given an electronics prototyping board and stretch sensor to 'experience' the material in action. The fabric samples were distributed and the students were asked to brainstorm applications and product ideas in groups of up to five. The aim was to let the students think in 'a hands on way' about the design process(es) involved in the development of products using novel technical materials. This also opened up an opportunity for the research group to begin thinking about applications and products. The range of applications suggested was wide and included a number of new ideas as well as resonating with some of the research teams (see Table II).

In order to establish the specific considerations required to use the given stretch sensor in a particular application, it has been decided that a single product concept will be developed as far as possible towards commercialisation. This will form the core of the rest of the research project with the potential to involve the key stakeholders in an intensive interdisciplinary design process, while other smaller investigations can be supported through discussion and the exchange of expertise. It is envisaged that the core and the branch activities will actively inform each other throughout and give rise to further insights into both the material and the design and manufacturing processes that will facilitate the integration of this novel technical textile.

Personal alarm
Light sensor
Visibility at night via movement
Activity wear (biking, riding)
Development of disabled children
Austin Powers party
Drawstring bags
Light switches
Belt
Carpet
Kitchen – extractor hoods
Wallpaper
Advertising
Toys
Counter in kids’ games, wearable
Disco lights
Stairs in public buildings
Bicycle suspension
Trampoline
Biosensing, health monitoring
Recognition in the street
Tyres
Car dashboard lights up
Bouncy castles
Fairground rides
Signage
Lighting – domestic, street, car
Fridge doors
Intruder alarms on doors and windows
Skipping ropes
Sound identification of rooms for the blind
Exercise resistance bands
Dog leads, with dog whistle response
Boob tubes
Trying on clothes
Baby weight/growth monitor
Toddler trainers
Tennis racquet strings
Hammock
Toddler blanket
Rape alarm, in belt
Musical jewellery, braces
Massaging
Glo sticks
Pressure sensitive walls and floors – light responsive
Boat sails – lit at night, wind measurement

Table II: Application and product concepts captured at schools workshop

8. REFLECTION AND FURTHER WORK

More experimental techniques, such as manipulating the surface of the rubber sensor itself with heat and printing on the surface are planned, as is an investigation into the impact on calibration of using different lengths in similar samples. We also intend to develop a range of product scenarios towards the creation of prototype garments and interiors products for user testing.

Electromechanical connections also offer further opportunities to engage with the aesthetics and materiality of the fabrics and yarn within product designs. This is of particular interest to the jeweller in the group, drawing on related work in Wearable’s such as Buechley and Eisenberg’s use of crimps (2007), and improving aesthetically on the current method suggested by Merlin (2008b) (Figure XVI).

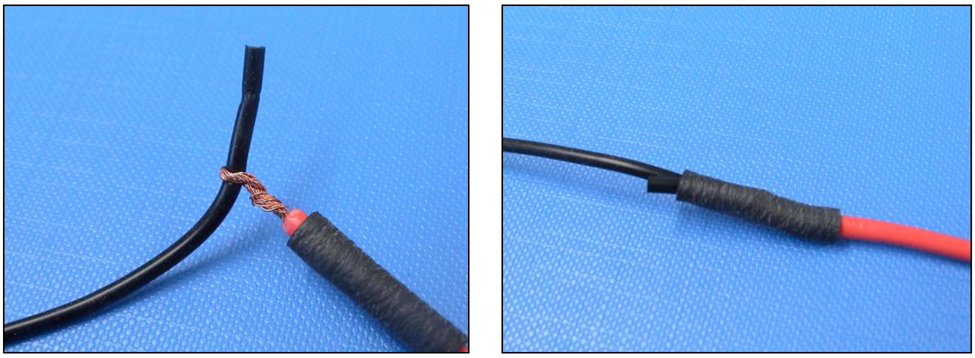


Figure XVI: Electromechanical attachment method**,** Merlin Systems Corp.

A fashion designer will shortly be joining the research team to help realise initial concepts as compelling tactile samples. These can then be used to refine fabric designs and can be used as props with potential ‘users’ to generate grounded applications, whether decorative or pragmatic.

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