Soft computation through conductive textiles

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Abstract

This paper will outline various methods for constructing electronic textiles within a framework of what we call 'soft computation' – the design of electronic technology that is composed of soft materials such as textiles and threads, as well as predicated on traditional textile construction methods such as sewing, embroidery, and appliqué with various conductive and active materials to create interactive fabrics. We will outline several methodologies deployed in the construction of a particular electronic textile, the XS Labs 'Animated Quilt,' a soft, reactive, addressable, visually animated fabric display. This textile uses thermochromic pigments as well as conductive fabrics and fibers for power delivery, communication, and networking. It is constructed from multiple fabric swatches that are individually addressable (with conductive threads) and can slowly change color from black to white. Each color change can be programmed in the custom electronics board or controlled in real time. The textile can be used to display animated low resolution images on garments. We used four different kinds of conductive threads, with varying electro-mechanical properties, in the construction of this textile. The technical issues that we will discuss in this paper involve (1) a comparison of currently available conductive threads and their different properties and applications, (2) construction details for creating reliable yet flexible connections between various conductive components of the soft circuit, and (3) different approaches for insulating the conductive components from each other, while maintaining predictable electro-mechanical characteristics. XS Labs is a research studio that focuses on innovation in electronic textiles and wearable computing. Many of our electronic textile innovations come from the fact that we look at the technical but also cultural history of how textiles have been made for generations but use materials with

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technology

different electro-mechanical properties, which enables us to construct more complex textiles with electronic properties.

Introduction

Electronic textile research is still in its infancy, but we can clearly see several important research directions that suggest appealing near future applications. Some of the more important efforts include applications that (1) aid in patient health monitoring through sensor-embedded garments that track and record biometric data, (2) help improve athletic performance both by analyzing sensor data and by adapting to changing conditions so as to improve performance over time, (3) provide environmental sensing and communication technologies for military defense and other security personnel, and (4) present new structural and decorative solutions for fashion design. We are naturally most interested in this fourth direction and, since fashion is predominantly visual, we are particularly interested in developing technologies that will enable the construction of garments that have the ability to change color, texture, transparency, or shape over time. The field of textile design, (including weaving, felting and embroidering) which involves the creation of many complex patterns from different colored yarns, threads or fibers, is centuries old. Today, efforts are being made to create flexible, fully addressable displays on fabric and textiles, which will allow a textile to display any pattern.

Designers and consumers alike are quite excited by the future vision of a world populated with magical garments that can adapt and respond to various interaction parameters and change based on time of day, mood, or the designer's whim. This vision is predicated on the technological development of visually animated materials that can be embedded or incorporated in a fabric. Existing materials for display usually 'light up': light emitting diodes (LEDs), electroluminescent (EL) material, or woven optical fibers transmitting the light of high brightness LEDs offer potential for wearable displays or animated fashion. Non-emissive materials such photochromic pigments (which change color when exposed to light) or thermochromic pigments (which change color when exposed to heat) are materials that simply change color and offer more interesting and more subtle possibilities for color-change textiles.[1]

This paper describes the Animated Quilt (AQ), which represents one of our more important research endeavors to develop a textile substrate capable of changing color in a pre-determined, animated way. AQ is a 100-pixel soft, tangible, and tactile display screen, made entirely out of fabric. We use a variety of conductive textiles and threads in combination with thermochromic ink to stitch square ‘pixels’ that can change color from black to white and can be controlled by our custom circuitry to create dynamic patterns and animations. This soft, low-resolution display suggests applications both for consumer electronics (the possibility to develop soft computer screens) and for fashion (the above-mentioned magical clothing that can be animated in the same way as computer screens).

The Animated Quilt

The Animated Quilt (AQ) is a dynamic quilt whose square swatches change color over time. This electronic textile can display different patterns and change from one pattern to another, producing a smooth transition between different designs and images. There is a conscious effort to ensure that the aesthetics of the display mirror the soft qualities of the construction. AQ changes in a slow and contemplative way, referencing the process of weaving, knitting and other textile construction techniques. Resulting imagery blurs the boundaries between digital image and textile surface. The aesthetic of the patterns and the animation references the concept of pixel, traditional quilting and embroidery practice, as well as emerging research in visual display technology.

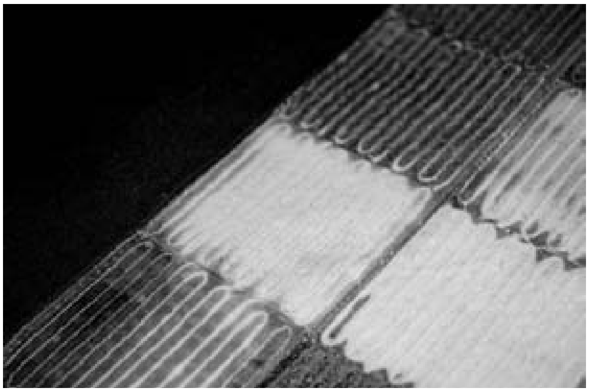

Figure 1. The Animated Quilt (AQ)

The slowness and subtlety of the piece references and is critical of the fact that current technological development is largely focused on speed and hard edges. The very concept of a textile display is innovative and challenging in a field where such devices are traditionally hard, square and emissive devices. Textiles, on the other hand, have a uniquely intimate relationship with the human body. Designers of electronic textiles need to focus on personal expression and the social, cultural and economic history of textiles instead of striving to replace (or 'augment') human experience. In a time that is more and more dominated by the visual image and the cult of communication, this textile will also have the ability to display our needs and desires, as well as our artworks.

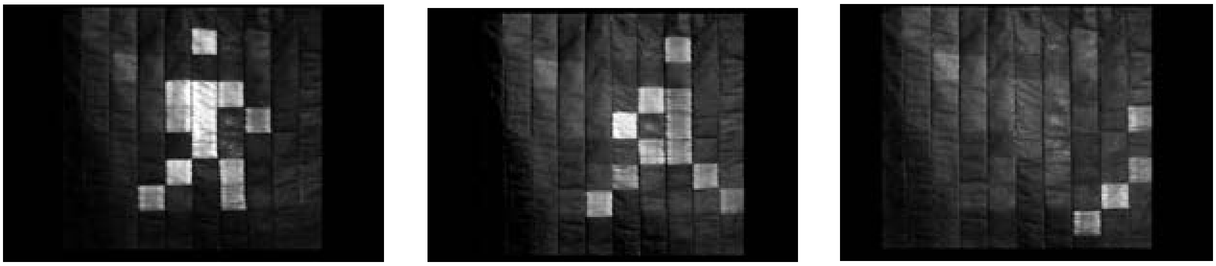

Figure 2. Animation of a stick figure walking across the AQ

How it works

The research focuses on the idea of incorporating digital technologies into traditional textile production techniques in order to enable new functionality. This functionality is accomplished through the development of a good intuition and understanding of the potential and limitations of electronics as well as the properties of conductive threads and textile constructions. Using traditional construction techniques, together with some unusual materials, the AQ deploys a simple technology for non-emissive, color-change textiles. It is a quilted 'soft screen'. The materials we used include conductive threads and fabrics, thermochromic inks, and custom electronics components. The goal is to achieve a seamless integration of technology into the tradition of textile design and fabrication techniques.

Conductive threads

Conductive threads are either spun or twisted and incorporate some amount of conductive material (such as strands of silver or stainless steel) to enable electrical conductivity. These yarns can have various electro-mechanical properties. They can be woven, knit, or felted together with non-conductive yarns to create the substrate for an electronic textile. Recently, the heating of fabric using conductive yarns and threads woven into the textile has been demonstrated for the purpose of keeping people warm. We use conductive threads in two different ways: (1) to embroider a specific pattern on the surface of each pixel to allow us to heat it and change its color and (2) to transmit electricity from the controller board to each pixel.

Thermochromic pigments

Thermochromic materials have different color states at different temperatures. They literally change color when heated. They are an example of a non-emissive 'active material', together with photochromics, electrochromics, or shape memory alloys. Non-emissive materials are materials that do not emit light. Thermochromic leucodye materials are especially interesting because they can be engineered to change from a specific color to a clear state at an arbitrary temperature between 13°F (-25°C) and 150°F (66°C). A wide range of colors is available and unexpected color changes can be obtained by combining thermochromic inks with regular ones. By mixing inks that change at different temperatures, a more complex effect can be achieved. The inks can be applied with a number of printing processes, including screen-printing. [2]

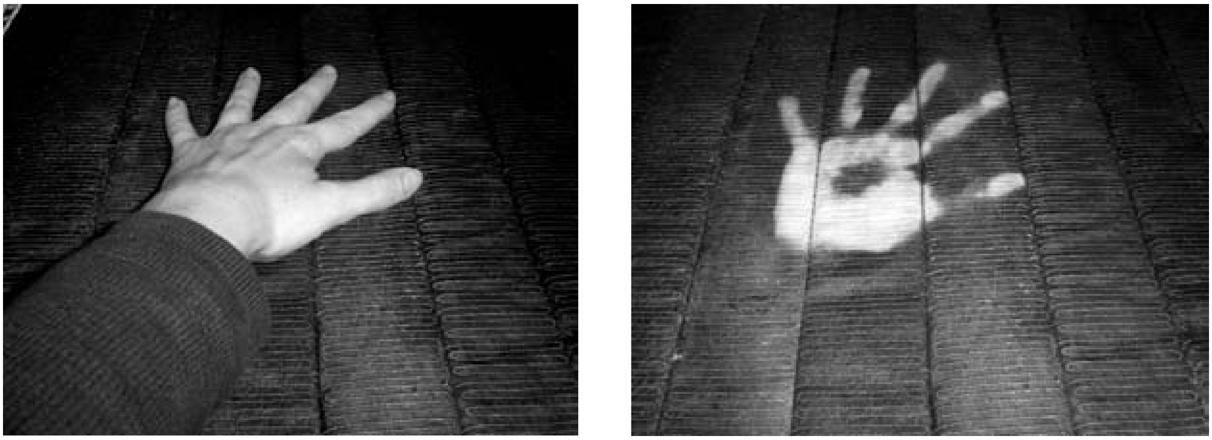

Figure 3. Using body heat to change the color of the AQ

One major issue discovered over the time it took to create this piece is the relatively short life expectancy of thermochromic inks when exposed to natural light. UV radiation deteriorates the pigments over a period of months and the inks become less saturated and start losing their color-change abilities.

Resistive heating

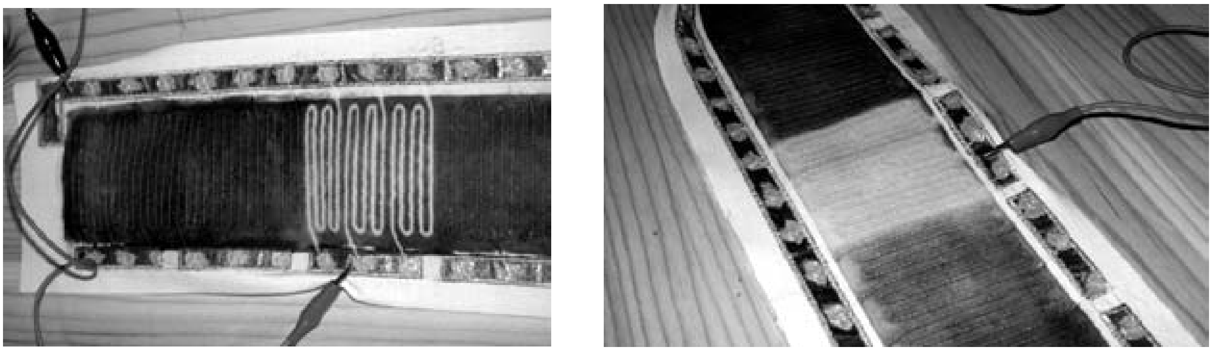

Figure 4 .Using resistive heating to change the color of a pixel

In existing products, color change is activated by body heat. AQ, on the other hand, uses resistive heating to create the change in temperature. We allow current to flow through embroidered conductive threads that have some degree of resistance. Resistance is the measure of how much an object impedes the flow of electricity. If we allow current to flow through a resistive material, the current will lose energy as it struggles to get through the material and the current's lost energy will become thermal energy in the material. The higher an object's resistance, the less current will flow through it.

Control electronics

AQ has 100 fabric pixels arranged in a 10 by 10 matrix. Each piece of fabric is individually addressable (with conductive threads) and can be controlled to slowly change color from black to white and back again, passing through a whole range of grayscale values. Each color change is programmed in the custom electronics board or controlled in real time when the display is connected to a desktop computer through the serial port. Control electronics are necessary to drive the textile display. The term refers to a printed circuit board (PCB) with various electronic components that is used to send power to different areas of the electronic textile in order to activate the thermochromic inks.

Materials for electronic textiles

XS Labs is a design research studio based in Montreal, where we develop electronic textiles and reactive garments. We are concerned with the exploration of simple interactions that emphasize expressive qualities of electronic circuits and of the body. We define electronic textiles as “textile substrates that incorporates capabilities for sensing (biometric or external), for communication (usually wireless), power transmission, and interconnection technology to allow sensors or things such as information processing devices to be networked together within a fabric.”[3] An important technical consideration comes from the fact that conductive materials used in traditional electronics, such as wires or printed conductive traces on a circuit board, need to be replaced with similarly conductive materials that can more easily be integrated into a textile. We replace some of the wires and other connections with different kinds of conductive threads that can be woven, stitched, or embroidered into the flexible textile substrate. Conductive threads are usually spun or twisted with conductive material (such as strands of silver or stainless steel).

Conductive threads and textiles

Since the field of electronic textiles is in its infancy, we have to be very creative in sourcing these conductive materials. When searching for conductive threads, we come across sources that include information for repairing fencing vest (which are conductive to aid in keeping score[4]) as well as suppliers who sell conductive textiles and threads used for electromagnetic shielding.[5] We have also found several American and European companies developing new and traditional metallic fibers for a variety of medical, aerospace, and industrial applications, such as Bekaert, a Belgian company that develops an array of high tech products in advanced metal transformation and advanced materials and coatings.[6] We need to think outside the box and re-appropriate these products to create electronic textiles.

AQ uses 2 different Bekeart threads: Bekinox® VN type 140NY/35/2/140NYL/350 and Bekinox® VN type 12/1X275/100Z. The first is a 2-ply steel and nylon thread with a high electrical resistance, measured at 380 Omhs/m. Its resistance causes some of the current to be converted to heat energy through resistive heating, which causes the thermochromic ink to change color. Using the resistive thread, one can control the location of the color change, unlike the Hypercolor T-shirts from the 1980s, which used body heat to activate color change and where the armpits were always the first place to change color. The nylon is white in color and is twisted together with two tiny filaments of steel. One of its important qualities is that it does not fray easily and can fit through the bobbin of a sewing machine. Unfortunately the company no longer makes this thread.

The second Bekeart thread is spun from 100% stainless steel fibers to create a continuous filament. Each strand of this thread has a resistance of 31.6 Ohms/m and we can further lower the resistance to 3.3 Ohms/m by twisting ten strands together. This thread looks and feels like a shimmery silk and is grey in color. An interesting characteristic of this thread, which AQ does not utilize, is its magnetic properties.

We have also worked with the German company Karl Grimm,[7] which develops a variety of technical and decorative conductive threads. AQ uses High Flex 3981 7x1 copper bare, with a resistance of 2.3 Ohms/m, for its thinness and highly conductive qualities and Karl Grimm High Flex 3891 7x3 copper tinned, with a very low resistance of 0.75 Ohms. This company has silver, copper, copper tinned, gold, and steel threads available with both nylon and Kevlar® cores in a variety of thicknesses. The company suggests that the Kevlar® metal thread can also be soldered although we have not conducted tests.

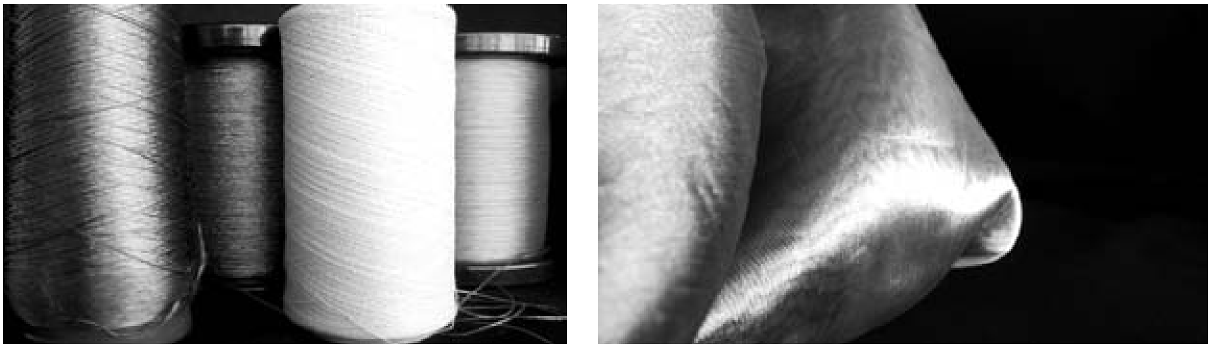

Figure 5. An assortment of conductive threads and metallic silk organza

The conductive fabric used for the low-resistance connections in AQ is metallic silver organza, a fabric woven with a silk warp and a silver-wrapped silk weft. The silver organza was purchased from B&J Textiles in New York City and is manufactured in India. The metal thread is called ‘Zari’ in Hindi and is often used in saris for special occasion such as weddings.

Three other conductive textile manufactures and suppliers who were not used for this particular project but are worth mentioning are Less EMF[8], Lamé Lifesave[9] and Saunders Thread Company[10], all located in

North America. Less EMF sells an inexpensive sample package that is useful for experimenting with conductive textiles. Lamé Lifesaver, a British Columbia company dedicated to repairing fencing lamés, sells small spools of conductive silver coated nylon thread that can be used for transmitting low amounts of electrical current through a textile. The thread has a resistance of 88.5 Ohms/m and is particularly useful as it can be used in the bobbin of a sewing machine. A similar thread can be sourced in large quantities from companies such as Saunders Thread Company.

Construction process

The Animated Quilt is constructed out of ten strips of ten ‘pixels’. Each pixel consists of (1) a cotton base, (2) two highly conductive connection electrodes on opposite sides of the pixel, made out of metallic silver organza, that serve to deliver power to the pixel, and (3) an embroidered pattern linking the two electrodes, made of the resistive thread, used for generating the resistive heating. The mechanical and electrical connection points between the thread and the organza are reinforced with conductive epoxy. The pixel is then overprinted with thermochromic ink.

Figure 6. Testing the pixel strips

Sewing the heating pattern and the connection pads on each pixel

AQ is made up of a variety of soft pliable textile materials. The base fabric is white cotton. The embroidered appliqué is created with metallic silver organza and Bekaert 2-ply steel and nylon thread. The silver organza and the 2-ply steel and nylon thread were stitched to the cotton using a Huskvarna embroidery machine, using a custom embroidery file we created using the Embird 2000 software. The organza is first appliquéd to the cotton, the edges are trimmed and the 2-ply steel and nylon thread is sewn over the appliqué assuring good connection points. In order to machine sew this thread (this is true for most conductive threads), it needs to go through the bobbin because it is too thick to fit through the needle of a sewing machine and the tension may damage the conductive properties of the thread. The design was derived mathematically to achieve an optimal and even heated surface. The connection point between the conductive organza and conductive thread is reinforced with a zigzag stitch and later with conductive epoxy. This embroidery was sectioned into strips of ten pixels, and repeated ten times to create one hundred pixels.

Printing with thermochromic inks

These ten panels where then screen-printed with Dynacolor™ thermochromic ink that is black in its cold state and changes to clear at 31ºC. The ink was purchased from Chromatic Technologies, Inc. (CTI). "CTI is a world leader in developing and manufacturing special effect inks, coatings, and materials for a variety of commercial and security applications".[11] This is a thick Plastisol ink so a mesh count of 160 was used for best printing results. This thermochromic ink is a solvent based and has to be cured at 300 ºF in order to achieve best results. This can be done using a heat gun (for prototypes) or a curing machine: an oven with a belt that allows the textile to glide through an evenly distributed heat.

Constant testing

Constant testing was needed at each step of the construction process. It was crucial to keep testing the connections and the resistance of each embroidered heating element to ensure that each pixel required the same amount of current. It was not uncommon to find bad connections or to discover that the 2-ply steel and nylon thread may have broken somewhere. The steel in this thread is hardly visible by the naked eye so there is plenty of room for error. Since textiles are soft and flexible, mechanical and electronic connections are not as reliable as they are on a PCB (printed circuit board).

Putting the quilt together

The back of panels was insulated with interfacing to prevent short circuits. In each panel, we use one long piece of organza as a grounding

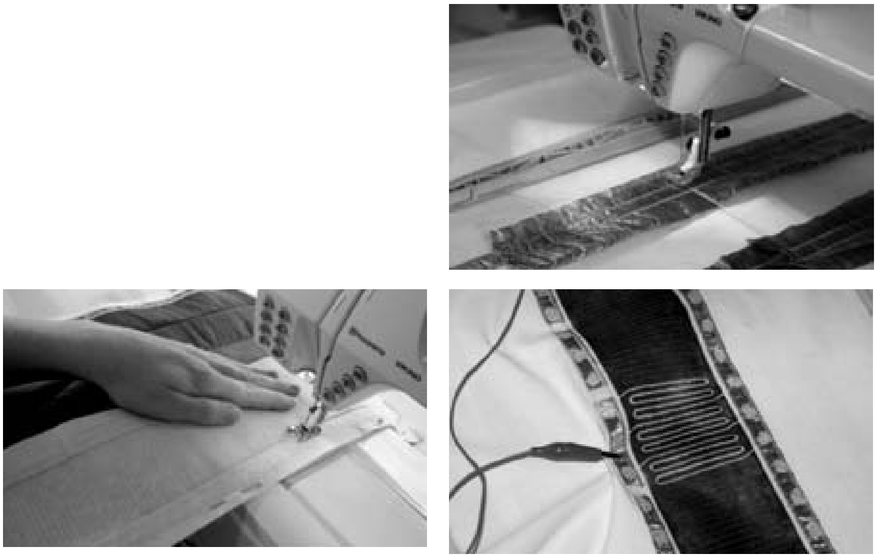

Figure 7. The sewing process

electrode connected to the PCB, which we will refer to as the y-axis and ten short pieces, which form points on the x-axis. Each short strip can be addressed independently to activate each pixel. We use a multiplexing system to send power to individual pixels, which means that a signal is sent through one x-axis line and one y-axis line and meet at their point of intersection. We use pulse width modulation (PWM) to control the amount of electricity that heats each pixel. The thermochromic ink does not cool down very quickly so the gradual accumulation of heat allows images and animations to be layered and slowly change over time.

The power lines or x-axis were hand stitched together with ten-ply Bekeart 100% stainless steel thread. This thread was insulated with a small tube of fabric so it would not touch the silver organza causing a short circuit. A diode and mini PCB were sewn between the connection points of the 100 silver organza strips and steel thread to direct the flow of electricity. This was sewn with the Karl Grimm Copper Bare 7x1 thread because it was thin enough not to damage the woven silver organza and create a good connection point. All connection points were reinforced with a small amount of conductive epoxy.

Connecting to the circuit board

A second layer of fabric was created to house the PCB and connect it to each of the twenty connections on the quilt, using the conductive thread.

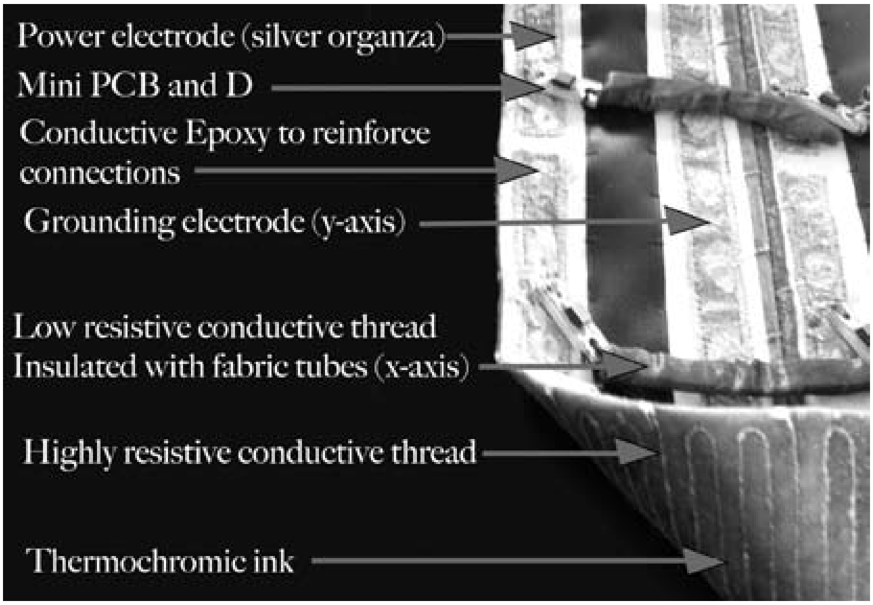

Figure 8. A didactic illustration of the components

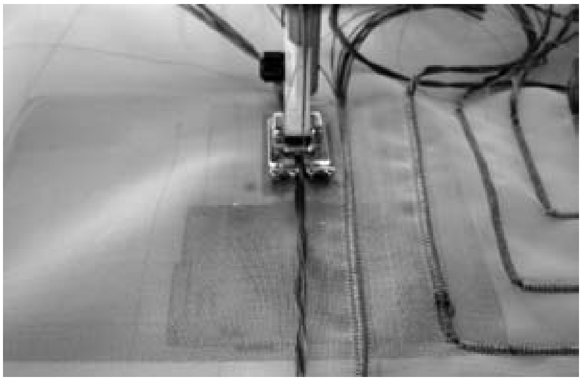

Figure 9. Stitching down the conductive thread to connect to the PCB


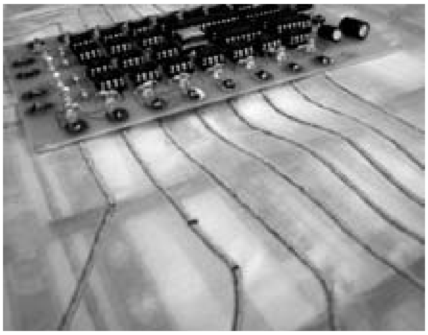

Figure 10. Using conductive epoxy to reinforce the connections. The controller board

The second layer was made from sheer silk organza, dense enough to prevent short circuits but sheer enough to see all the intricate details underneath. The Karl Grimm High Flex Copper Tinned 7x3 thread was used for the connection stitches because it is very low resistance.

Future applications

This research has strong implications on the future of 'wearable technology'. It focuses on the fact that fashion is visual, while digital technology and computation facilitate change over time. Animated textiles are a big part of the future of wearables (new technologies such as color-change and shape-change as well as new display technologies).

The proposed design allows for the creation of many dynamic and diverse designs on a textile. Its visual properties (color and pattern) are determined by the pattern and physical configuration of the conductive/resistive and thermochromic inks integrated into its surface. The use of control electronics, and the sectioning of the textile into distinct electrical areas – or animation cells – allows for the creation of a variety of animated imagery. The fabric 'pixels' can be activated in many ways. They can be turned on in succession, creating a visual wave across the surface of the fabric, or in alternating patterns that will create dynamic alternating stripes. The control electronics allow for the programming of a number of animations or dynamic patterns across a single fabric. Control electronics programming must take into account the time it takes for the thermochromic ink to change color.

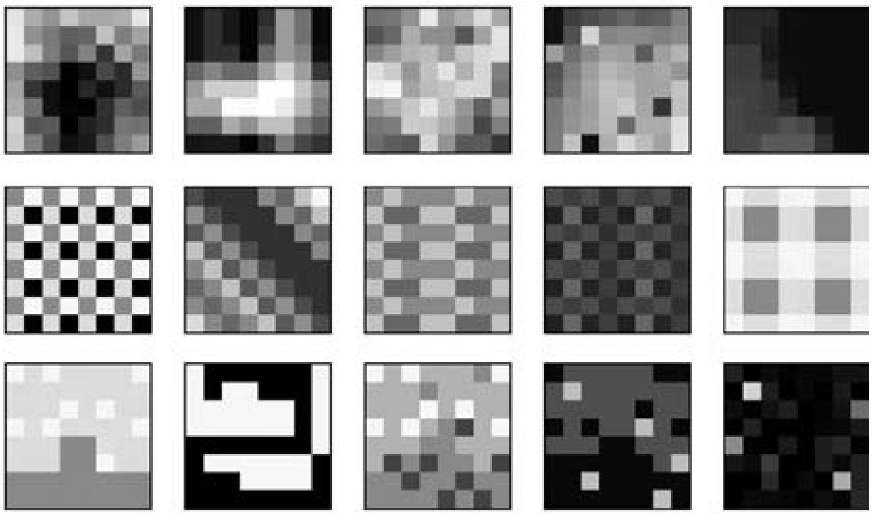

Figure 11. Different pattern and animation possibilities

These textiles can be deployed in a variety of ways. They can enable many different interior decorating, furniture and architectural applications. They can enable animated quilts, tapestries and wall hangings. They can be used in various sculptural applications such as woven or knit sculptures, reactive fabric dolls that change colors, and a whole world of soft responsive sculpture. The textiles also have wearable applications, but constraints exist regarding power requirements and potential discomfort associated with resistive heating.

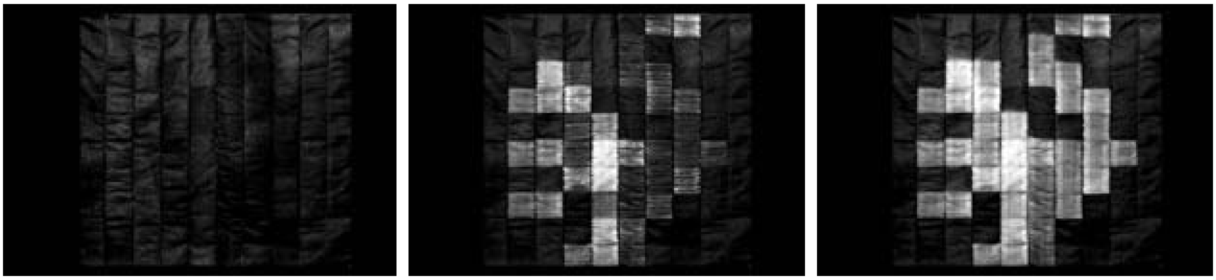

Figure 12. Turning on the image of a squirrel

Notes

1 Berzowska, J. (2004), 'Very Slowly Animating Textiles: Shimmering Flower',*Sketches and Applications of the Technical Program of SIGGRAPH '04* ACM

2 Berzowska, J. (2004), 'Very Slowly Animating Textiles: Shimmering Flower', *Sketches and Applications of the Technical Program of SIGGRAPH '04* ACM.

3 Berzowska, J. (2005). Electronic Textiles, Textile 3 (1), pp. 2–19.

4 Electrically conductive fencing apparel is used in combination with fencing implements (such as a foil) connected to an electronic scoring apparatus. When a foil contacts the conductive portion of the opponent's garment, the scoring apparatus registers a hit.

5 Electromagnetic shielding is the process of limiting the flow of electromagnetic fields created by electrically charged objects, by separating them with a barrier made of conductive material.

6 NV Bekaert SA. (2004). *Bekaert Markets and Products* Retrieved March 5, 2007, from: http://www.bekaert.com/corporate/products.htm

7 Karl Grimm. (n.d.), *Tradition & Technik* Retrieved March 5, 2007, from: http://www.karl-grimm.com/navi.swf

8 Less EMF Inc. (2007), *Shop The EMF Superstore* Retrieved March 5, 2007, from: http://www.lessemf.com/

[9] Smith, Robert. (n.d.) *Lamé Lifesave* Retrieved March 5, 2007, from: http://members.shaw.ca/ubik/thread/index.html

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[11] Chromic Technologies, Inc. (2007), *Chromic Technologies, Inc. Innovations with Interactive Colors* Retrieved March 5, 2007, from http://www.ctiinks.com/

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