Textile Tools for Wearable Computing *

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Abstract. This paper describes the concept and application of textiles as tools, or components, for garments with wearable computing features. Evaluations of a selection of fabric swatches are presented and their suitability for use in the construction of smart textile systems. The electrical and electromagnetic properties of the textiles are investigated with a fabric recommended for use as a UHF antenna, and another for thermochromatic use. The possibilities for power and signal networking are also explored. An illustrative garment using these fabrics is outlined, and opportunities for further research identified.

1 Introduction

Fashion and clothing function in many ways, such as expressing or communicating one's identity to the outside world. People do this through the clothes they choose and by the way in which they compose them. Wearable computing technologies offer the potential of extending the range of possibilities by encouraging intuitive, and even emotional, connection between the wearer and the product, as well as being framed within the context of ubiquitous intelligence where information and communication technology is embedded within the material environment.

Many proposals for using textiles in conjunction with wearable computers have been made previously [1], indeed practical tests and commercial implementations have also appeared [2, 3]. As well as providing paths for electrical power and signals, potential applications using fabrics include input surfaces, activity monitoring and displays. More recent research has shown the viability of touch sensing and antenna integration into fabrics [4] with manufacturers such as Milliken, Eleksen and Peratech (Softswitch) already starting to produce commercial textiles for these purposes. Nevertheless considerable research is still required in this field and substantial work is required to develop textile technology platforms for wearables, ubiquitous computing/intelligence and intelligent clothing applications.

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This paper describes various electrical tests performed on a selection of fabric swatches intended to determine their suitability for use as part of smart textile systems combining different technologies and materials.

The tests outlined in this paper are intended as an initial investigation into the potential of a selection of fabrics to perform as components of wearable computers integrated into fashion garments. We envision these garments as being 'tools' for the wearer.

2 Clothing as Tools

In order to clarify some of the intentions and research directions of the later parts of this paper, in this section we explore concepts in which textiles can be combined to provide new tools for the fashion designer and ultimately the wearer. We have been focusing on textiles as sensors and as displays. In particular, we are interested in the influence on mood, made through colour and pattern, as understood through the psychology of colour and the culture of symbols and designs. Basic colours are purported to have emotional, physical and behaviourial values e.g. in many Western cultures the emotional value of red is love, vitality, courage, passion and danger. Colour and form are related to the actions of the wearer or user, and the act of activating a textile switch may be based on conventional clothing behaviour and body discursive codes (studied in the area of kinesics), as well as behaviour learnt from using everyday electric devices. For example, a textile switch can be activated by squeezing or stroking the arm of a jacket, or by a folded arm gesture, but the action used to activate the switch may be chosen on the basis of who is squeezing whose arm, and whether the folding of arms might be seen by others as a sign of boredom or disapproval. In other words, a textile switch is not likely to be employed in the sense of a conventional GUI button, but will also be influenced by how we use jacket buttons and other elements of conventional clothing. There appears to be the potential for a rich hybrid to be born, based both on the conventions of clothing and the body as well as the dynamics and personalisation that is feasible with computational devices. We envisage that various configurations of switching actions and design effects can be mapped and programmed into the smart textile systems which the wearer, or user, can customise depending on their emotions or plans, and what they want to express.

By customising the aesthetic values of a garment, the wearer can use clothing as a vehicle for self-expression and exploring their own creativity. For example, a textile switch can be linked to a chromatic display textile so that at any time one might choose a colour or design that suits one's mood or message. Variations in pattern and function can be created through conventional textile construction and patterning techniques, and a number of textile switches and display areas could then be incorporated into a garment. This would allow direct or indirect manipulation of the appearance or function of the garment. In the former case, as envisaged by Headon and Colouris [5], one might trigger a change in the garment through gesture or motion. In the latter, connection with other devices by wireless or wired communication links would let one choose profiles or programs that would change the garment so as to respond to the time of day, the location, to a heartbeat sensor on the body, and so on. Medical applications might be feasible here, for example a garment that would display the readings from physiological monitors; and clothes for work, such as equipment inspection and engineering in the field, where the user's hands may be unable to control a traditionally designed mobile computer [6].

The wearer could also similarly interact with their environment if antennae, communications devices and displays were in the textiles of furniture, furnishings and wallcoverings. One could customise one's home through interacting via clothing as described above, or by using other tools and devices to change the colour and function of the environment. One could also use motion, gesture and configuration in more dynamic ways, and in combination with other displays and input devices to create a 'mixed reality' environment where the user could engage in games, sport or performance.

New forms of social interaction may be afforded by new technical textiles. For example, clothing that displays images shared between a group or team could act as a dynamically selectable 'badge'. More generally, people could interact and even interfere with each other's clothing, by changing the visual appearance of the clothing so as to inspire or instigate interaction with nearby people. Given connection from new textiles to more conventional communications networks, new forms of remote communication would also be feasible e.g. having a display in the lining of one's jacket that displayed a distant lover's heartbeat, rather as suggested by Strong and Gaver [7]. Extending this idea further, actuator textile technology could contract or extend under computer command, as in Corpe Nove's 'Oricalco' shirt (www.gzespace.com), made from thermal shape memory alloy fibre. For instance, if one wrapped one's arms around oneself in a hugging action, to activate a textile switch, a receiver's garment could display a tactile 'hug' as the textile contracted.

3 The Fabrics

Three sets of commercially available fabric swatches were obtained to initiate exploration of some of these concepts. In particular we are interested in their use as antenna; as the underlying panels for thermochromatic displays; and as conductors for electrical signals and power.

The first set of textiles were manufactured by Heathcoat and have type numbers F6524/Z and F6354/A and have electroconductive properties. F6524/Z is a plain weave with a 2mm silver grid structure(see Figure 1). F6354/A has a plain ripstop weave scoured and finished with 5mm silver heatset stripes 14mm apart (see Figure 2). A further Heathcoat fabric, Gardstat, is an anti-static twill containing carbon fibres which, when earthed, dissipate 90% of any charge in less than 0.5 sec.

Five fabrics from the Contex range manufactured by Milliken were tested - types numbers C-109-2, C-364-2, C-399, C-425-1 and C-435-1. These textiles

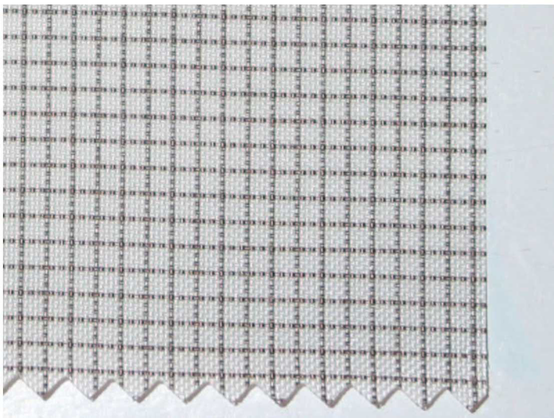

Fig. 1. Heathcoat F6524/Z with 2mm Silver Grid.

have a uniform electrical resistance per (unspecified) unit square resulting from a polypyrrole treatment. Polypyrrole is an inherently conductive polymer due to interchain hopping of electrons. C-109-2, C-364-2 and C-399 are made of a 100% textured woven polyester; C-425-1 is a textured knitted fabric; and C-435-1 is a nylon impression fabric.

Four other swatches were tested from a further unspecified manufacturer(s). These had the following construction:

- 50% silk, 50% metallic yarn (silk organza with copper wrapping on parallel threads)
- 70% steel, 30% nylon
- 90% steel, 10% nylon
- 100% polyester, vacuum spattered with stainless steel

The copper wrap on the silk fibre provided electrical continuity, whereas close examination of the steel/nylon fabrics revealed a segmented construction of disconnected rings of steel around the nylon fibre.

4 Electrical Tests

All twelve textiles were tested for electrical resistance over a 10cm length with 5mm contacts. In the cases of the Heathcoat F6524/Z and F6354/A a single conductive strip was selected. The manufacturer's specified resistance (where available) is shown in column 2 of Table 1 with the measured resistance shown in column 3. 'ins' signifies a resistance greater than 200MΩ - effectively an insulator.

	Resistance (Ohms) Spec. per sq.	Meas. per10cm	Supply Volts for 1Watt
Heathcoat			
F6524/Z	n/a	1	n/a
F6354/A	n/a	9	3
Gardstat	n/a	ins	n/a
Milliken (Contex)			
C-109-2	600	2,700	52
C-364-2	1,100	4,600	68
C-399	50	170	13
C-425-1	5,500	55,000	235
C-435-1	425	2,000	45
Other			
50% silk/50% metal	n/a	0	n/a
70% steel/30% nylon	n/a	ins	n/a
90% steel/10% nylon	n/a	ins	n/a
polyester, spattered	n/a	ins	n/a

Table 1. Summary of electrical measurements

Having established the resistance for each textile a calculation was made of the voltage required to achieve a heating effect of 1 Watt over the 10cm length. These voltages are shown in column 3 of Table 1.

From these initial tests the Heathcoat Gardstat, the steel/nylon weaves and the polyester spattered fabrics can be removed from consideration for further testing as they are all effectively insulators. The voltages at which the insulation breaks down is not known but will be far in excess of any safe voltage which may be worn on the human body. These fabrics are suitable as insulating layers/strips between conducting fabrics carrying low voltages. In addition Gardstat is suitable for dissipating any electrostatic charge.

The Milliken fabrics with their inherent resistances distributed over a measureable area are clearly suitable for heating purposes. Unfortunately all but one of them, C-399, would require a voltage in excess of 30v to achieve a significant heating effect over the nominal 10cm length. The maximum safe voltage which can be applied across the body is estimated between 30 and 50v.

The remaining fabric - 50% silk/50% copper - has properties similar to flat multicore cable and is clearly suitable for further testing. A capacitance test was also carried out on this fabric with less than 3pF measured per 10cm between two fibres.

Tx Antenna	Range
Whip	19m
Fabric (free space)	15m
Fabric (worn)	14m
None	1m

Table 2. Fabric Antenna Range Test

5 Application

5.1 Electromagnetic Field Detection

The simplest method of detecting an electromagnetic field is to use a conductor whose length is inversely proportional to the frequency of transmitted carrier signal, and which is placed in free space. The latter constraint immediately impacts on wearable antenna as the body acts as an absorber of electromagnetic radiation. Experiments with body worn long wave, medium wave and FM radio antenna have all produced disappointing results. Nevertheless the possibility of using fabric antenna is still practical at higher frequencies.

At UHF frequencies, for example those used by ubiquitous computing devices such as Pingers, Smart-Its and Motes [8–10], the wavelength starts to become short enough with respect to the body dimensions to be practical for the integration of antenna into fabrics. This could take one of three forms - a whip, a dipole or a loop arrangement. Of the fabrics supplied, only the Heathcoat F6354/A striped fabric offers this possibility, see Figure 2. To test this a single stripe was connected to a 418MHz Bristol Pinger in a whip antenna configuration. Range measurements were taken with a conventional whip antenna, the stripe connected in free space, the stripe connected and worn over the shoulder on top of a shirt, and with no antenna. A fixed receiver was used with a standard helical coil antenna.

The results showed the viability of this fabric as a worn antenna over a range of 14m (see Table 2). Other commonly used licence exempt frequencies, 433MHz and 868MHz, could reasonably be expected to give similar, if not better, results. Mobile phones operating at around 900MHz and 1.8GHz could also be considered however the RF power levels associated with these devices could cause concern.

It should be noted that though this test used a body worn transmitter, considerable caution should be exercised with such devices. In this case the device was very low power and had a very short range. The localised heating effect caused by higher power transmitters, such as those used by mobile phones, could present a safety hazard. This issue does not arise with receivers e.g. GPS.

At radar and microwave frequences, such as 1.5GHz as used by GPS and 2.4GHz used by Bluetooth and 802.11, the wavelength is short enough to allow specialist antenna using ground planes to be worn comfortably a few mm from the body. However these would require precision tooling and would not be suited

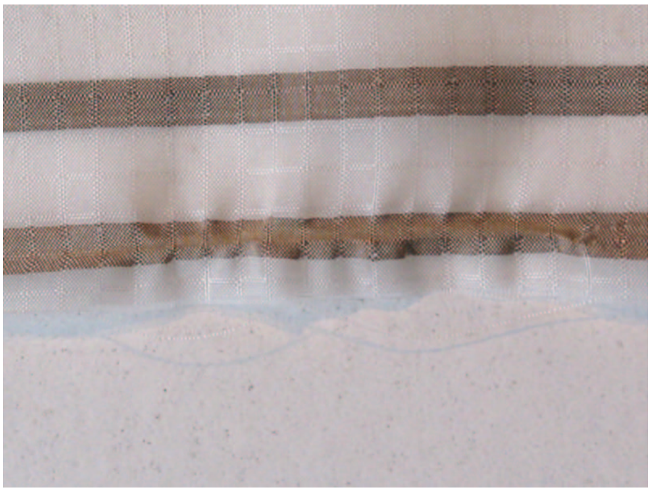

Fig. 2. Effect of excessive current on Heathcoat F6354/A striped fabric.

to the fabrics under test. Foster Miller [11] and Philips [3] are actively pursuing this line of research.

Higher frequencies are not usually used for communications due to their heating effects which would certainly be inappropriate for wearable computing use.

Interestingly a test was carried out to determine the suitability of the fabrics for blocking RF radiation. This was intended to provide an alternative to tinfoil in applications where RF Tags need to be hidden from detectors. This will become increasingly important where RF Tags are incorporated into high value items such as large denomination banknotes. Only one of our test fabrics, the Heathcoat F6524/Z with 2mm Silver Grid, was found to be suitable for this purpose, and could be used as the lining for a wallet hiding tagged notes from malicious detection. The test was carried out using a 13.56 Mhz tagging system.

5.2 Thermochromatic Effects

If a current is able to be passed through a textile there will be a resulting temperature change. Using thermochromatic dyes/inks it should be possible to use this heating effect to change the colour of a thermochromic textile panel. The thermochromic properties of the textile can be set to be more or less sensitive to the temperature effects, so it may be feasible to pre-scale it e.g. so that the colour changes with only a small and safe temperature difference. Unfortunately the electroconductive textile is only available in black and will require the dyed material to be fixed to it to achieve the desired chromatic changes.

The Milliken C-399 was selected for heat testing. A range of voltages was applied ($V_{applied}$) to a 10cm length of the material with 5mm contacts. The

$V_{applied}$	V_{fabric}	I(mA)	P_{fabric}	temp (°C)
0	0	0	0	22.5
5	3.1	25	0.078	23.1
10	6.4	53	0.339	23.8
15	11.3	92	1.040	25.4
20	15.5	136	2.108	28.3
25	19.3	181	3.493	34.3
30	26.9	230	6.187	38.4

Table 3. Heating Effect on C-399

resulting voltage on the material at the point of contact was measured (V_{fabric}) and the current through the fabric monitored. This enabled the power dissipated to be calculated (P_{fabric}). The resulting temperature on the fabric was measured five minutes after the voltage had been increased to allow the fabric to stabilise. The results are shown in Table 3.

ThermoChromic (or ThermoChromatic) inks are designed to offer a visible change in appearance when subjected to temperature. With a wide range of temperature transitions (-10°C to 60°C), these inks remain a given colour until the transition temperature is reached. At that point the colour clears (or disappears), or changes from one colour to another. A 15°C transition is chosen for showing a 'chilling or cooling' effect. The 31°C is good for body temperature 'touch' indication, and a 45°C transition is chosen for 'hot' or 'burn' indications [12].

For our purposes, and from Table 3, a 31°C transition is appropriate and could be achieved with a safe 20-25v being applied to a 10cm length of fabric. This could be configured in many different ways to achieve aesthetic effects subtly changing over time. It should be noted that this technique requires a significant amount of power for a wearable computing application. A battery pack containing three standard alkaline PP3 9v batteries powering a single 10cm strip would only be able to operate continuously for approximately one hour; a typical LiIon camcorder battery (with voltage inverter) would last for about one and a half hours.

During the tests the electrical contacts became very hot to the touch - clearly the voltage drop between the contact and the fabric is not acceptable and further tests are required to establish a satisfactory method for making electrical contacts (see also Section 5.3 below).

5.3 Power and Signal Networking

Of the twelve textiles tested, three were selected as having sufficiently low resistance to be viable for providing a 'hardwired' signal and/or power network. These were the silk wrapped with copper, and the Heathcoat F6354 and F6524. All three fabrics successfully carried 500mA making them suitable for low current sensor applications. The silk/copper yarn started to smoke at 700mA and burnt out at 800mA. Over 500mA applied to the Heathcoat F6354 caused the

Fig. 3. Silk/Copper fabric with LED.

fabric to overheat and distort (see Figure 2) with failure occuring at 1A. The F6524 proved difficult to maintain a reliable connection and failed completely at 750mA.

None of these fabrics was considered suitable for carrying sufficient current to supply a low power processor such as the StrongARM. They are suitable for powering sensors, microcontrollers and low power RF devices, enabling contextual data to be gathered and simple applications to be implemented.

Of special interest was the silk/copper organza fabric with parallel conductive threads spaced at 30 threads per cm. This fabric was considered suitable for mounting small electronic components including integrated circuits. By way of illustration an LED was soldered to the fabric and illuminated using the fabric as a conductor (see Figure 3). Similar more ambitious experiments were carried out and described by Post in his paper 'Smart Fabric, or Washable Computing' [2].

The problems of maintaining a good contact with the Heathcoat F6524, and with soldering the components to the silk/copper yarn illustrated the need for special techniques to be developed to establish good connections between fabrics and electronics. Foster-Miller in particular are developing connection technology using RF welding to address this need. RF welding attaches large polymeric patches to clothing resulting in a secure, washable fabric that can withstand rubbing and abrasion. A simple modification of the technology provides allows fabrication of waterproof electronic packages that are conformal to the textile and resist detachment [11].

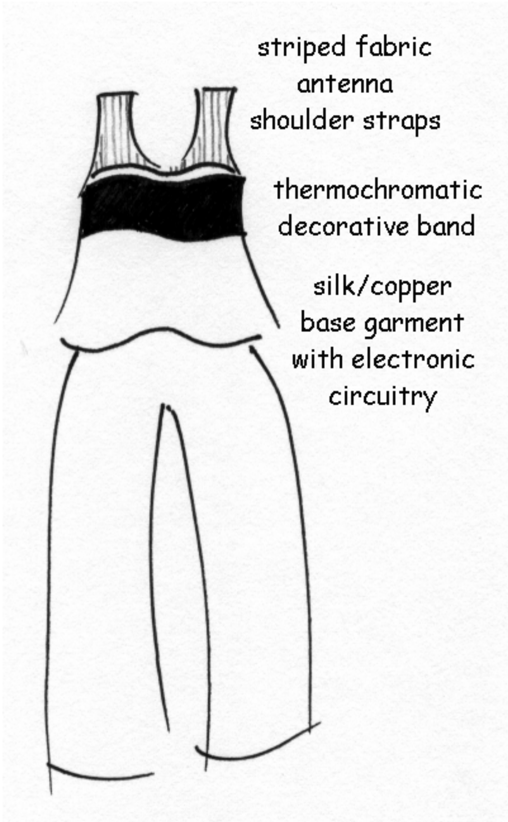

Fig. 4. Concept Garment.

6 Conceptual Application

The preceding tests suggest ways in which some of the fabrics could be employed in a functioning fashion garment. By way of illustration a conceptual garment has been designed and is shown in Figure 4.

The fabrics are combined into a ladies upper garment with the Heathcoat F6354/A providing a dual function of shoulder straps and antenna for a UHF FM transceiver. The antenna are connected to electronic components mounted on a base made of the silk/copper yarn which forms the body of the garment. As the silk/copper fabric is near transparent, the Milliken C-399 provides both modesty and an interesting thermochromatic 'display'. A design on the thermochromatic panel could change colour depending on signals received by the antenna. For example the panel colour could vary according to where the wearer is located, or who is nearby. While it is not suggested that this garment is actually assembled, it does illustrate what is both theoretically and technically plausible.

7 Conclusions and Further Research

This paper has evaluated the properties and potential applications of a number of fabric swatches. A suitable fabric has been selected for operation as a UHF antenna, and a further fabric, Milliken C-399, has been chosen as being suitable for thermochromatic use. An adequate temperature change occurs when 25v is applied to a 10cm strip of this fabric. A silk yarn wound with copper weaved into a parallel configuration is suitable for the mounting of low power electronic components. None of the fabrics were able to carry currents significantly in excess of 500mA.

Establishing a satisfactory connection to the fabrics/yarn proved to be a major challenge and further research is required here, possibly involving RF welding already in use by the textile industry. The application of thermochromatic inks/dyes to a display fabric, and fixing, or bonding, of this to conductive fabric also requires further attention before working garments with colour changing properties can be demonstrated.

Clearly we have only begun to explore the potential application of wearable computing technology to clothing design, however we have identified both practical applications of commercially available fabrics and also significant issues relating to their use.

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