Smart Fabric, or Washable Computing

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Wearable computers can now merge seamlessly into ordinary clothing. Using various conductive textiles, data and power distribution as well as sensing circuitry can be incorporated directly into wash-and-wear clothing. This paper describes some of the techniques used to build circuits from commercially available fabrics, yarns, fasteners, and components.

Introduction

While wearable computers are empowering fashion accessories, clothes are still the heart of fashion, and as humans we prefer to wear woven cloth against our bodies. The tactile and material properties of what people wear are important to them, and people are reluctant to have wires and hard plastic cases against their bodies. Eventually, whole computers might be made from materials people are comfortable wearing. To this end, we have built electronic circuits entirely out of textiles to distribute data and power, and perform touch sensing. These circuits use passive components sewn from conductive yarns as well as conventional components, to create interactive electronic devices, such as musical keyboards and graphic input surfaces.

Materials

For years the textile industry has been weaving metallic yarns into fabrics for decorative purposes. The first conductive fabric we explored was silk organza which contains two types of fibers, as seen in Figure 1. On the warp is a plain silk thread. Running in the other direction on the weft is a silk thread wrapped in thin copper foil. This metallic yarn is prepared just like cloth-core telephone wire, and is highly conductive. The silk fiber core has a high tensile strength and can withstand high temperatures, allowing the yarn to be sewn or embroidered with industrial machinery. The spacing between these fibers also

permits them to be individually addressed, so a strip of this fabric can function like a ribbon cable. This sort of cloth has been woven in India for at least a century, for ornamental purposes, using silver, gold, and other metals.
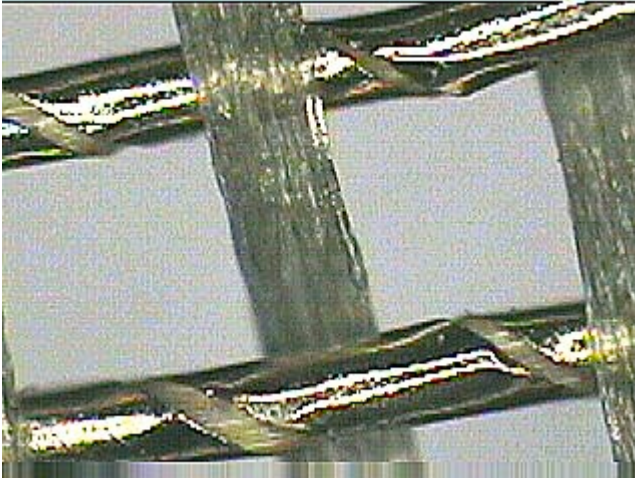
Micrograph of silk organza.

Circuits fabricated on organza only need to be protected from folding contact with themselves, which can be accomplished by coating, supporting or backing the fabric with an insulating layer which can also be cloth. Also, circuits formed in this fashion have many degrees of flexibility (i.e. they can be wadded up), as compared to the single degree of flexibility that conventional substrates can provide. There are also conductive yarns manufactured specifically for producing filters for the processing of fine powders. These yarns have conductive and cloth fibers interspersed throughout. Varying the ratio of the two constituent fibers leads to differences in resistivity. These fibers can be sewn to create conductive traces and resistive elements. While some components such as resistors, capacitors, and coils can be sewn out of fabric, there is still a need to attach other components to the fabric. This can be done by soldering directly onto the metallic yarn. Surface mount LEDs, crystals, piezo transducers, and other surface mount components with pads spaced more than 0.100 inch
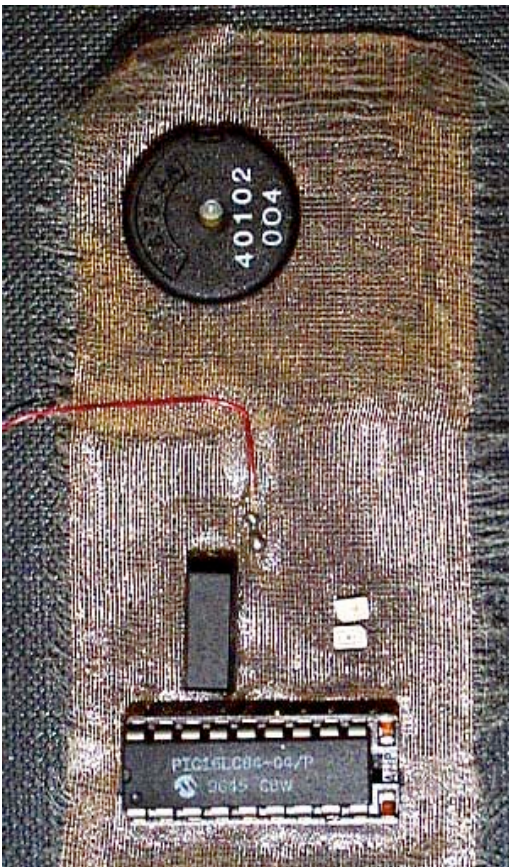
apart are easy to solder into the fabric. Once components are attached, their connections to the metallic yarn may need to be mechanically strengthened. This can be achieved with an acrylic or other flexible coating. Components with ordinary leads can be sewn directly into circuits on fabric, and specially shaped feet could be developed to facilitate this process. Gripper snaps make excellent connectors between the fabric and electronics. Since the snap pierces the yarn it creates a surprisingly robust electrical contact. It also provides a good surface to solder to. In this way subsystems can be easily snapped into clothing or removed for washing.

Implementations

A fabric breadboard or "smartkerchief".

Several circuits have been built on and with fabric to date, including busses to connect

various digital devices, microcontroller systems that sense proximity and touch, and all-fabric keyboards and touchpads. In the microcontroller circuit shown in Figure 2, a PIC16C84 microcontroller and its supporting components are soldered directly onto a square of fabric. The circuit uses the bidirectional I/O pins on the PIC to control LEDs and to sense touch along the length of the fabric, while providing musical feedback to reinforce the sense of interaction. Building systems in this way is easy because components can be soldered directly onto the conductive yarn. The addressability of conductors in the fabric make it a good material for prototyping, and it can simply be cut where signals lines are to terminate.

All-fabric switching contact keyboard.

One kind of fabric keyboard uses pieced conductive and nonconductive fabric, sewn together like a quilt to make a row- and column-addressable structure. The quilted conductive columns are insulated from the conductive rows with a soft, thick fabric, like felt, velvet, or quilt batting. Holes in the insulating fabric layer allow the row and column conductors to make contact with each other when pressed. This insulation also provides a rewardingly springy, button-like mechanical effect. Contact is made to each row and column with a gripper snap, and each snap is soldered to a wire which leads to the keyboard encoding circuitry. This keyboard can be wadded up, thrown in the wash, and even used as a potholder if desired. Such row-and-column structures can also be made by embroidering or silk-screening the contact traces.
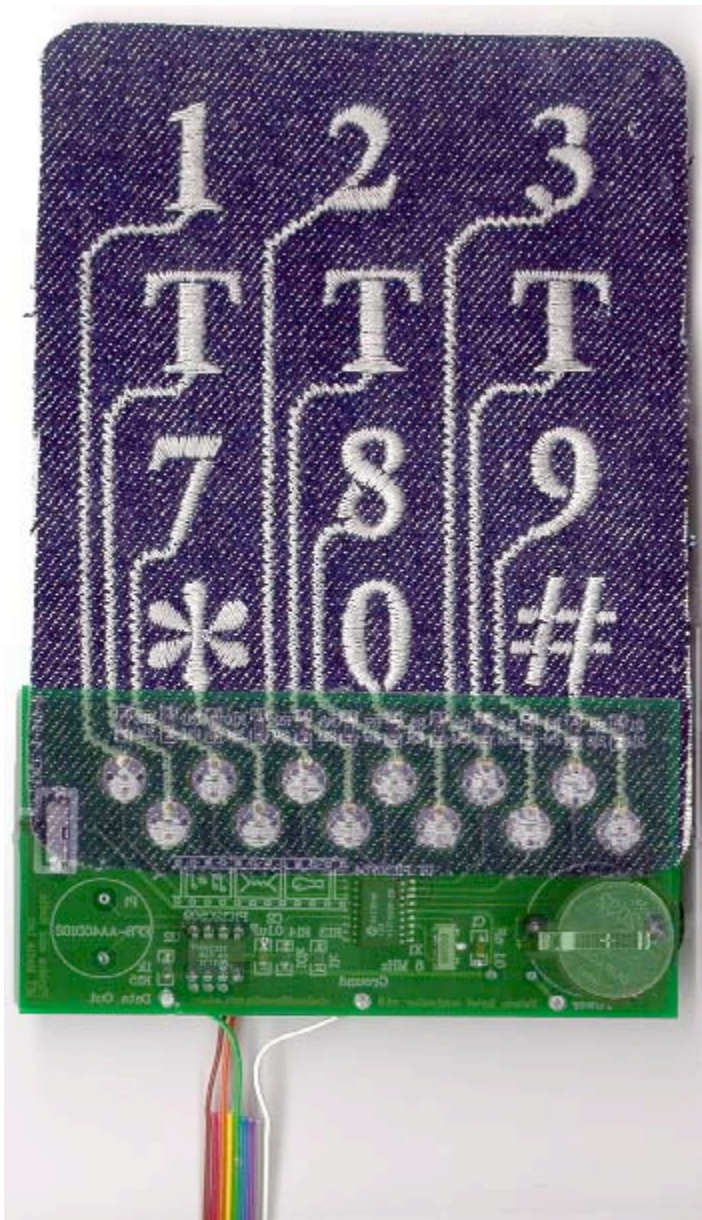
All-fabric capacitive keyboard.

Keyboards can also be made in a single layer of fabric using capacitive sensing **[Baxter97]**, where an array of embroidered or silk-screened electrodes make up the points of contact. A finger's contact with an electrode can be sensed by measuring the increase in the electrode's total capacitance. It is worth noting that this can be done with a single bidirectional digital I/O pin per electrode, and a leakage resistor sewn in highly resistive yarn. Capacitive sensing arrays can also be used to tell how well a piece of clothing fits the wearer, because the signal varies with pressure.

The keypad shown here has been mass-produced using ordinary embroidery techniques and mildly conductive thread. The result is a keypad that is flexible, durable, and responsive to touch. A printed circuit board supports the components necessary to do capacitive sensing and output keypress events as a serial data stream. The circuit board makes contact with the electrodes at the circular pads only at the bottom of

the electrode pattern. In a test application, 50 denim jackets were embroidered in this pattern. Some of these jackets are equipped with miniature MIDI synthesizers controlled by the keypad. The responsiveness of the keyboard to touch and timing were found by several users to be excellent.

A view of the component side of the circuit board has been superimposed to show its extent and its connections to the fabric. A flexible circuit board can be substituted for the rigid one used in this implementation. Ultimately we hope to do away with the circuit board entirely.

Printed sensors

To sense changes in environmental factors, the electrical characteristics of an embroidered element can be measured by observing the element's response to a finite impulse of voltage or current. This response can be analyzed to determine changes in impedance, capacitance, and inductance of the element. This is crucial in using the fabric to sense a material's response to changes in humidity, temperature, or other factors. By layering a row-and-column addressable structure with, for example, a layer of temperature-sensitive resistive material, one can quickly create an array of temperature sensors addressable through the fabric. The spatial resolution of the array is limited mainly by the thread pitch of the fabric (approx. 50 to 200 per inch).

Conclusions

We have shown how to combine conventional sewing and electronics techniques with a novel class of materials to create interactive digital devices. All of the input devices can be made by seamstresses or clothing factories, entirely from fabric. These textile-based sensors, buttons, and switches are easy to scale in size. They also can conform to any desired shape, which is a great advantage over most existing, delicate touch sensors that must remain flat to work at all. Subsystems can be connected together using ordinary textile snaps and fasteners. Finally, most of what has been described can be thrown in the wash if soiled by coffee, food, or sand at the beach.

Acknowledgments

References

[Baxter97]   Larry K. Baxter, *Capacitive Sensors: Design and Applications,* IEEE
Press, 1997.

 [Sources]   [Purchasing Sources for Conductive Textiles](#)