# Smart Fabric, or "Wearable Clothing"

E. Rehmi Post

Physics and Media
MIT Media Laboratory
Cambridge, MA 02142
rehmi@media.mit.edu

Margaret Orth

Opera of the Future
MIT Media Laboratory
Cambridge, MA 02142
morth@media.mit.edu

## Abstract

*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.

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.

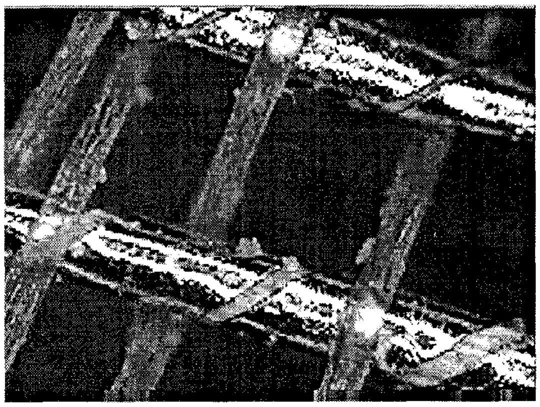

Figure 1: Micrograph of silk organza.

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

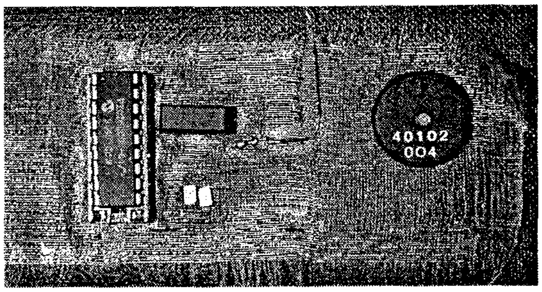


Figure 2: A fabric breadboard or "smartkerchief".

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.

## Implementation

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 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.

One kind of fabric keyboard (see the top of Figure 3) 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.

Keyboards can also be made in a single layer of fabric (see the bottom of Figure 3) using capacitive sensing [1], 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.

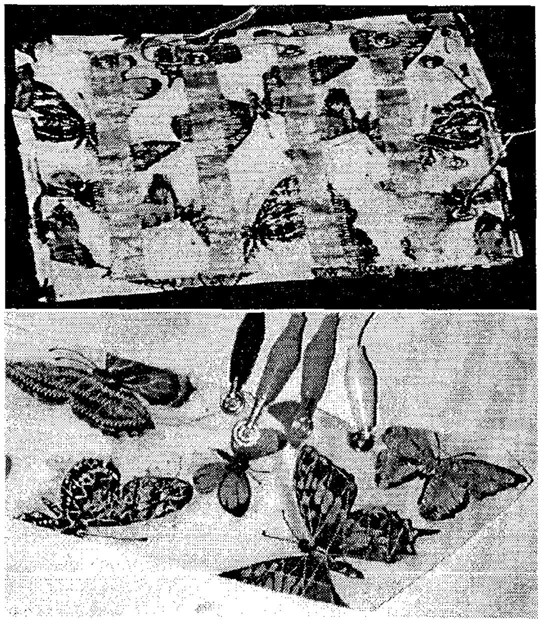

Figure 3: All-fabric switching (top) and capacitive (bottom) keyboards.

## 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

Emily Cooper built the musical potholder shown at the top of Figure 3. Professors Neil Gershenfeld and Tod Machover have been particularly supportive of this work, as well as the Media Lab's Things That Think Consortium. Special thanks to Zehra Post for help in finding some of the textiles described above.

## References

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