

The Textile Interface Swatchbook: Creating Graphical User Interface-like Widgets with Conductive Embroidery

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Abstract

The Textile Interface Swatchbook demonstrates how conductive embroidery can render graphical user interface-like (GUI) widgets on fabric. Such widgets might be used to control mobile electronics such as a music player, mobile phone, or projected display. At present, six swatches have been created for the swatchbook: pleat, menu, rocker, multi-touch gesture, zipper, and proximity. The three most diverse and original are discussed here. In addition, we develop a hybrid resistive-capacitive touch sensing technique designed to be more tolerant to the flexing typical of fabric. We hope to develop the Textile Interface Swatchbook into a reference tool for textile interfaces.

1 Introduction and Related Work

In 1997, Rehmi Post and Maggie Orth introduced the wearable computing community to interfaces that could be embroidered using conductive thread [7]. Touches to the embroidery could be sensed using low cost capacitive circuits, and soon Post, Orth, and their colleagues would design keyboards, jogwheels, and other elements [8]. However, the use of such textile widgets remained limited to professionals and hobbyists with specific skills and hands-on knowledge in circuitry and sewing. Researchers continue to advance textile electronics along various dimensions [4, 5, 6], and electronic textile toolkits have been developed for interesting middle and high school students in electronics [1]. However, little has been done to extend Post and Orth's pioneering work in embroidered interfaces.

We suggest that a systematic exploration of embroidered textile interfaces should be performed based on the common widgets available in GUI Toolkits. GUI widgets (buttons, sliders, menus, etc.) are familiar to most users and are often adapted for use on mobile phones and devices. Thus, textile interface widgets that adopt similar forms and metaphors should benefit from “walk-up” familiarity with users.

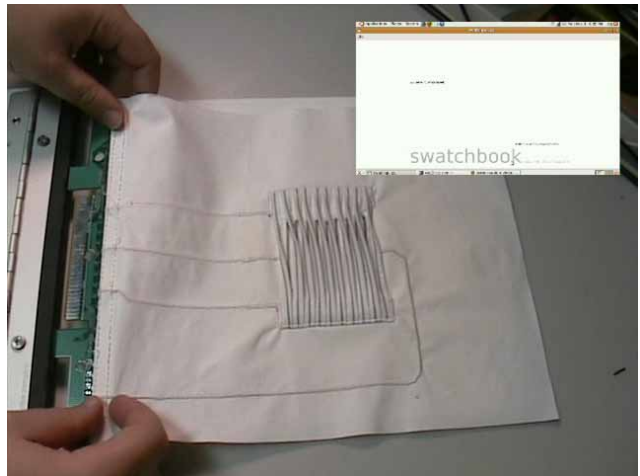


Figure 1. A swatch being inserted into the Textile Interface Swatchbook's interface spine. The spine connects the swatch to a laptop through USB. As each swatch is inserted, the system automatically switches to the appropriate GUI (inset).

However, textile interface widgets have physical benefits, and limitations, that GUI widgets do not. For example, raised embroidery can be used to guide the user's hand naturally into position to use the interface without sight [2], whereas creating a tactile guide for GUI widgets is often impractical. On the other hand, GUI widgets are not concerned with potential shorting when they are folded or crumpled. Thus, we do not wish to limit the design of textile interfaces to just those in GUIs.

We propose the Textile Interface Swatchbook (TIS) as a means of demonstrating interface widget concepts and distributing practical knowledge on the manufacture of textile widgets. The Textile Interface Swatchbook consists of three binders: one with an embedded microcontroller in its spine for interfacing swatches to a laptop's GUI (Figure 1), a sec-

ond that stores the functional textile widgets, and a third, currently being produced, containing electronics, manufacturing, and fashion tips for each swatch. The Textile Interface Swatchbook employs a familiar form factor to designers — the swatch. Designers often use swatches to help visualize the look of a color in a design. With the Textile Interface Swatchbook, designers insert a swatch into the interface spine to use the interface and gain experience with its affordances. Once satisfied, the designer pins the swatch to a garment to determine if the interaction is appropriate at that particular place on the body. We have noted that one of the best benefits of textile interfaces is the low time required to access them. Access time is a major factor in whether or not a mobile interface is used [3], and by allowing designers to place textile interfaces on the body easily, the TIS empowers designers to optimize for accessibility.

The TIS may also embolden computer scientists and electrical engineers to attempt their own variants of textile widgets. While engineers are often comfortable with the electronics involved in textile widgets, the hands-on, practical knowledge of producing electronic embroidery is often a barrier. The TIS overcomes this barrier by providing working prototypes of each widget.

In the following sections we describe the electronics of the TIS, three sensing methods including an improved resistive-capacitive hybrid touch-sensing circuit that is less sensitive to the cloth changing shape than the typical capacitive sensing circuit, and general principles of constructing embroidered textile interfaces. Next we discuss three novel swatches in detail. We conclude with a discussion of swatches currently being prototyped and future improvements to the TIS itself.

2 Interface electronics

The TIS hardware consists of two circuit board designs: a swatch board which is sewn to the fabric swatches, and a spine board which is built into the spine of the swatchbook (see Figure 1). The swatch boards each plug in to the spine board. This modular design allows for all of the logic to lie on the spine board, which needed to be built only once, while all of the fabric interfacing can be tested on a replaceable swatch board.

The spine board houses an Atmel Atmega168 microcontroller, and an FTDI USB-RS232 allows the Atmel's RS-232 interface to function as a USB serial interface. It also contains a 64-pin right-angle card-edge connector, allowing our swatch boards to plug directly into the spine board without any additional parts on that board.

We built the system with three main methods of sensing in mind: analog sensing of resistance, capacitive touch sensing, and a hybrid resistive-capacitive touch sensing.

2.1 Analog sensing

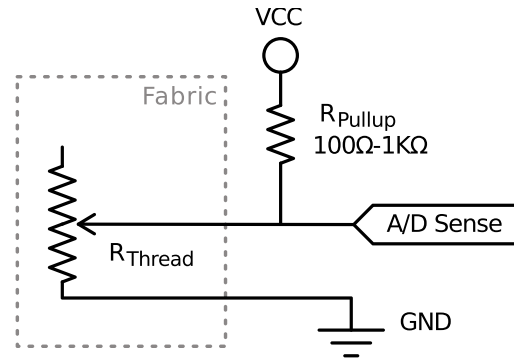


Figure 2. Analog sensing technique used for zipper and pleat swatches.

Here, conductive thread as a variable resistor, which changes depending on the length of the thread used. The circuit is a simple voltage divider, with the thread acting as one of the two resistors (Figure 2). The value for the pullup resistor is chosen based on the average resistance of the thread to be measured. The voltage present in the middle of that voltage divider is then read using the Atmega's 10-bit analog-to-digital converter.

This sensing technique is used for the zipper swatch, as well as for detecting which pleat is pressed all the way down on the pleated swatch. In both cases, we sewed a zig-zag stitch with the conductive thread to maximize the resistance of the thread, making it easier to sense its value.

2.2 Capacitive sensing

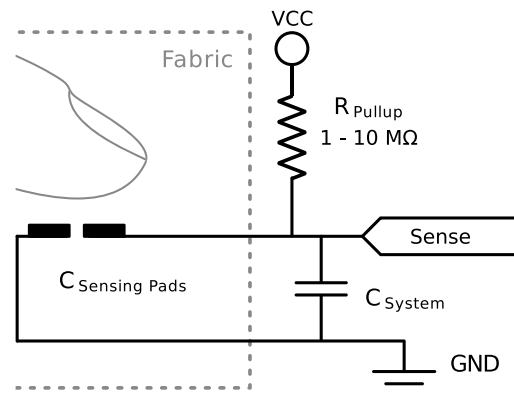


Figure 3. Capacitive sensing technique used for the proximity swatch.

With this method, a pair of conductive sensing pads acts

as a weak capacitor (Figure 3). The capacitance of those pads relates to the proximity of large conductive objects (like hands and fingertips).

To read the pad's capacitance, the Atmel discharges the capacitor by switching the sense pin to output and driving it to 0V (Figure 4). The other pad is already grounded. Once discharged, the pad on the sense pin is allowed to charge through a known resistor (we use 1 to 10 Megaohms). The Atmel switches the sense pin back to input and continuously checks it, waiting for the pin to read as a '1', which occurs around 2.7V (when VCC is 5V). By measuring the amount of time that the capacitor took to charge, we can determine the capacitance between the plates and, thus, whether a finger is touching the sensing pads.

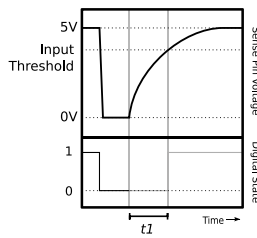


Figure 4. Capacitor recharge time (t_1) varies with the presence of a finger.

The advantage of capacitive sensing is that it does not require a direct short of the conductive thread — the proximity of a finger or hand is enough to change the capacitance, even with a very simple detection circuit. This sensitivity is what allows capacitive sensing to work when a user is wearing gloves.

This ability can also be somewhat of a hindrance. The only way to diminish sensitivity is with increased distance from the pads or with conductive shielding. When adding conductive shielding, however, it is important that the shielding stay a constant distance from the pads, as any variance results in a change in capacitance of the system. When working with capacitive sensors in rigid material, this technique is robust; when working with conductive fabric, shielding is impractical.

For our swatches, the pads and the lines running to them are sensitive to conductive materials on both sides. If this design were integrated into a shirt sleeve, putting an arm into the sleeve would appear very similar to putting a hand over it. Further, any body contact with the sense line or pad will cause the whole body to act like an extension of the sense pad, causing a very large increase in capacitance. While this effect is useful, all of the conductive thread used as a capacitive sensing line needs to be routed carefully and be electrically isolated to be useful in a real application.

2.3 Hybrid resistive-capacitive sensing

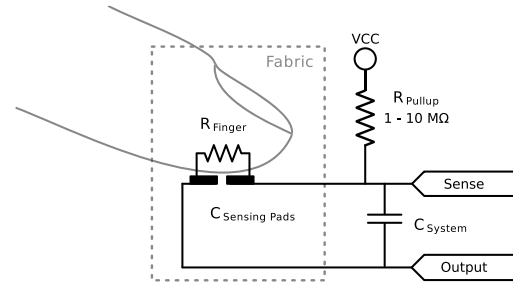


Figure 5. Resistive-capacitive technique used for all other touch sensitive swatches.

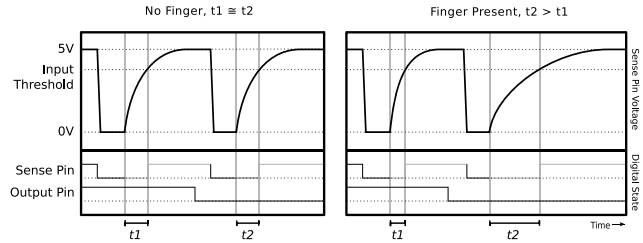


Figure 6. When the fingertip is not present, $t_1 = t_2$ (left). Otherwise, $t_2 > t_1$ (right).

Our hybrid resistive-capacitive sensing is a form of resistive touch sensing — it measures the resistance between the textile finger pads (Figure 5). This approach avoids the problems of capacitive sensing with fabric. The skin has a fairly high resistance, so the current through a fingertip is small and difficult to measure directly using a microcontroller. Instead of amplifying that current, we sense it by watching its effect on the charging of a capacitor.

First, our microcontroller drives the 'output' line high, causing the current through the finger to help charge the capacitor as we take a capacitance reading on the 'sense' line (Figure 6). Then, the microcontroller drives the output line low, letting the current through the finger slow the charging of the capacitor as we take a second capacitance reading.

Both readings reflect the combined capacitance of the system and touch pads, but when current has flowed through a fingertip across the pads, the recharge time is shorter than the second. If the two readings are taken in rapid succession, then the capacitance of the system will not be able to change much between them, and they will cancel out when we subtract one from the other.

We prefer this method over other ways to measure large resistances (like amplifying current with a Darlington pair), as it takes only one external resistor per sense line. This

simple hardware allowed us to have very little of the swatch-book electronics tailored for each swatch — only the pull-up resistors on the swatch boards were specific to a given swatch. It also allows us to perform capacitive sensing with the exact same hardware, giving us some sense of user proximity to an interface before they touch both pads.

3 Embroidered Textile Interface Guidelines

Creating textile interfaces using embroidery involves significant experimentation to discover the right combination of thread, cloth, needle, and embroidery machine. In the following sections we describe the equipment we discovered provides the best combination for quick prototyping. In later sections, we will describe the particular interfaces we created using these techniques. Please note that the term “embroidery” encompasses many types of application of thread (and more) to fabric. However, during this discussion we will use the term to refer to the raised embroidery used in this project.

3.1 Thread

We use a thread that is coated with silver. There are many variants on these types of threads; a summary can be found at www.fashioningtech.com/profiles/blogs/conductive-thread-overview. Often, thicker conductive threads are wound from thinner ones, and the thicker ones will have less resistance per unit length. In our case the thicker thread is constructed from 4 thinner threads.

A thread or needle breaking indicates a problem with the thread or tension of the machine. The thicker thread is less flexible and may have difficulty feeding through a domestic embroidery machine, possibly causing the machine damage. To be able to use the thick thread in a domestic embroidery machine or a domestic sewing machine, one needs to wind the thread onto the bobbin. With the thicker thread on the bobbin, the thread will be on the outer layer of the garment, and one must sew upside down. The thicker thread will usually break the needle or clog the machine before the actual thread breaks. We tend to use the thinner thread for embroidery as one can simply change the width of the embroidery instead of using the thicker thread.

When using thinner conductive threads, the thread usually breaks before the machine experiences a problem. However, the thread can break quite often unless the tension is set properly (usually a low setting - on our machine the tension number is usually set at 3).

With either the thick or thin thread there are problems with the thread embroidering on top of itself. As the thread pierces through a portion of embroidery embroidered with conductive thread, the friction between the thread in the needle and the thread on the cloth adds too much tension,

and the thread breaks. This issue can be solved by designing patterns that do not require this kind of embroidery. If one wants to make an embroidering that is raised more off the fabric, the best technique is to use plain or non-conductive embroidery thread first as a base embroidery and then embroider on top of this thread.

3.2 Embroidering Machines

Brother Domestic Embroidery Machine line: These machines are inexpensive but use the same format instructions and memory cards as the larger machines. The entry-level machine accepts the needle that we found to work the best for conductive thread, but the way in which the machine applies tension (by raising and lowering a mechanical arm) adds too much tension in too short of a time, often creating a break in the thread.

Brother Entrepreneur PR-650: This semiprofessional machine seems to currently work the best out of the three options presented here for embroidering conductive thread. With this machine, tension is being placed on the thread in a constant manner as opposed to the jerk and pull manner on the domestic machines. This machine also works well because it accepts the metallic novelty thread needle, where as the professional machine does not.

Brother Industrial Machine This industrial machine is very good at controlling the tension at a constant rate but would not accept the needle that we found to be the best for the conductive thread. After extensive searching and comparisons with other industrial machines we found this fact to be true industry-wide.

3.3 Needle

We have found the best needle for sewing thin conductive thread is a Schmetz Metallic Needle 90/14. The length and width of the needle eye gives the conductive thread enough room to flex while piercing through the fabric, thus preventing a thread break.

When working with thicker conductive thread, it is better to use a denim or leather stitching needle with the largest hole possible. The thicker and heavier duty needle helps prevent needle breakage from the stronger and thicker thread. If the needle breaks this can be because the eye of the needle is not big enough for the thread, or because the tension on the machine is set to high.

3.4 Fabric

There are two main considerations when choosing a fabric for embroidery. First, the fabric should be appropriate and aesthetically pleasing for the garment or final end use.

For example, a lightweight blouse should not be made from a heavy weight fabric just to allow for easy embroidery.

Second, the fabric should be sturdy enough to withstand the embroidery process. This goal can be achieved by either picking a heavyweight fabric, or by picking a lightweight fabric with strong yarns or strong fiber content. Within the design of CAD-based embroidery, there are many options as to how to treat each aspect of the design: pull compensation, stitch density, stitch direction, etc. These settings allows a designer to compensate for issues that the fabric may present. The designer requires knowledge all the way down to the construction of the textile. The designer must ask himself “will this fabric even allow this particular design.” As an analogy, imagine drying oneself with tissue paper rather than a towel made from terry cloth.

Lighter weight fabrics should be embroidered with a stabilizer backing. The lighter the fabric, the easier it gathers around a stitch, causing wrinkling. Stabilizer comes in many different forms. For really light weight fabrics that need a stiffer stabilizer we choose to cut away the stabilizer after the embroidery is complete. With a medium weight fabric one may be able to use a water soluble stabilizer.

The looser the fabric is when hooped, the more the fabric can gather and wrinkle. When the fabric and stabilizer are hooped properly, the result should resemble a drum. One should be able to flick a finger at the hooped fabric and hear a thump.

When wrinkling occurs, it can also mean that the thread tension is set too high. The threads used on an embroidery machine tend to be a little elastic, so that as the machine works with a design, it can tug on the fabric causing it to gather. There is no one answer on what tension is correct due to the nature of each thread and fabric. Some wrinkling should be expected. When using a cotton fabric, an iron set with high heat and steam can remove a majority of this wrinkling.

When creating our Textile Interface Swatchbook, we screen printed the back of the cotton fabric with plastisol screen print ink to eliminate the fraying of the edges of the fabric. This process also insulates the conductive thread on the back of the fabric.

4 Textile Interfaces

4.1 Rocker Switch

While capacitive sensing for embroidered touch points (buttons) has been known in the literature for some time, the rocker switch is a textile interface hitherto not described to our knowledge. In operation, the user can “grope” for the interface [2], feeling for the raised embroidery so as to know where to place his fingers. The non-conductive (white) embroidery creates wells to help guide the user’s fingers. This

feature is particularly desirable so that a moving user can orient his fingers properly when the interface is mounted on a jacket or other article of clothing. Each of the five buttons sense contact in a hybrid capacitive/resistive manner, and the interface can be used in a variety of ways (as five separate buttons, for chording, for gestures, etc.). The novelty to the new approach is that the interface can be used as a rocker switch as well (see the following figures).



Figure 7. Rocker: To select the middle (green) slider in the GUI, the user places his middle finger in the middle well. As he swivels his hand so that his ring finger touches the left large pad, the system recognizes the touch, and reduces the slider value. If his index finger touches the right large pad, the slider value increases.

Because the middle finger is sensed in combination with the index or ring finger, the “rocker switch” gesture is distinguishable from other gestures. Thus, the other gestures (single button presses, pinches, etc.) can be used for controls as well without ambiguity. If ambiguity is not an issue, the interface above could be used to control three sliders (or other controls). To select the first slider, the user places his finger into the leftmost of the three smaller touch points. To select the second slider, the user places his finger into the middle touch point (and so on). The embroidery could be designed to allow the control of many sliders by increasing the number of touch points stitched between the bigger touch points on either end. While the user initially fumbles for the interface, the system does not falsely recognize a gesture as intending to increase or decrease a value because two, and only two, well-separated touch points must be active at the same time.

Note that such interfaces can be mass-produced with current commercial embroidery machines. The interface could take many different designs. Also note that the interface (minus the control electronics) can be stitched onto a garment and washed, crumpled, or folded.

4.2 Menu

The goal for the textile menu is to create an electronic fabric interface (using conductive thread) that can be used to control appliances (e.g. MP3 players) on or around the user. The interface is similar in concept to selecting options from a pull-down menu on computer windowing systems.

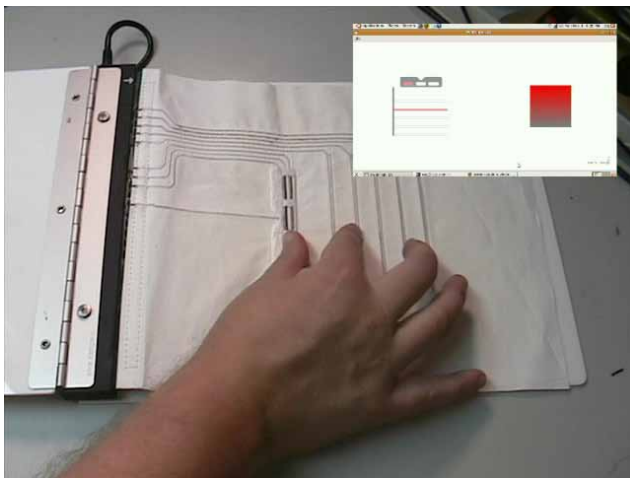


Figure 8. Menu: The thumb selects the first of three menus while the index finger swipes through five possible values in that menu.

In this particular instantiation, the menu has three top options, each with five possible selections. The user feels for one of the three embroidered buttons with his thumb. Once he finds the proper button, he slides his index finger to the first crossing line to the right of the three buttons. Once his index finger touches the first line, the system displays the menu on a screen (for example, on a head-up display, a wristwatch display, or a display mounted on the forearm). Alternatively, the physical interface could be used to control an audio menu, and the system would announce the first option as the index finger touches the first line. The user can then slide his index finger back and forth to the second, third, fourth, or fifth crossing line to see (or hear) those options displayed. To select an option, the user simply releases the touch point under his thumb. Note that any combination of fingers and thumbs could be used for this interaction. We use thumb and index finger here for illustration purposes. As with the rocker, the user can grope for

the menu interface, feeling for the raised embroidery so as to know where to place his fingers.

Each of the three touch points sense contact in a hybrid capacitive/resistive manner. Contact with each of the five lines to the right of the three touch points can be sensed with a single line of conductive thread since the thumb of the user remains in contact with the ground line at one of the three touch points. Many variations of this interaction and hardware are possible. For example, with the current hardware, the top menu can be displayed as soon as the user touches one of the three touch points. Alternatively, the ground line for the three buttons could be eliminated if the desired interface should only display the top menu when both one of the three touch points and one of the crossing lines is being touched (the touch points and crossing lines can act as two sides of the needed electrodes). More experimentation is necessary to determine which of these variations are the fastest to use, which can be rendered in the smallest space, which are the most intuitive, etc. so as to better guide a designer as to which is most appropriate for a given garment and application.

4.3 Electronic Pleat

The goal of the electronic pleat is to create a textile interface where the user can stroke the rows of pleats left or right (as shown in the figure below) to effect a change in a visual display (e.g., a slider on a graphical user interface moving left or right) or in an auditory display (e.g. the volume increasing or decreasing). The interface can also track the location of the user's finger through the pleats mid-stroke or can even track two fingers as they make a pinching gesture.

This sensing is performed by embroidering several rows of conductive thread between the pleats. The first electrode is sewn as rows on the base piece of cloth between the pleats. These rows are electrically connected as a single electrode. Importantly, the conductive thread we use has a noticeable resistance which increases as the embroidered path gets longer. Another electrode is sewn onto the left side of each pleat. All the left sides of the pleats are electrically connected in this fashion. Finally, a third electrode is sewn on the right hand side of each pleat. All right sides of the pleats are electrically connected as one electrode.

Note that since the pleats are sewn on to the base fabric with a 180 degree twist, the pleats stand up distinctly and avoid shorting either the left or right sides of the pleats with the electrode on the base cloth. However, as the user runs his finger along the pleats left to right, the right side of the pleats short against the base electrode. Thus, a computer or consumer electronic device hooked to this interface senses that the user is stroking the pleats left to right. Since the circuit's resistance increases with the length of conductive thread, the system also detects the nearest pleat being de-

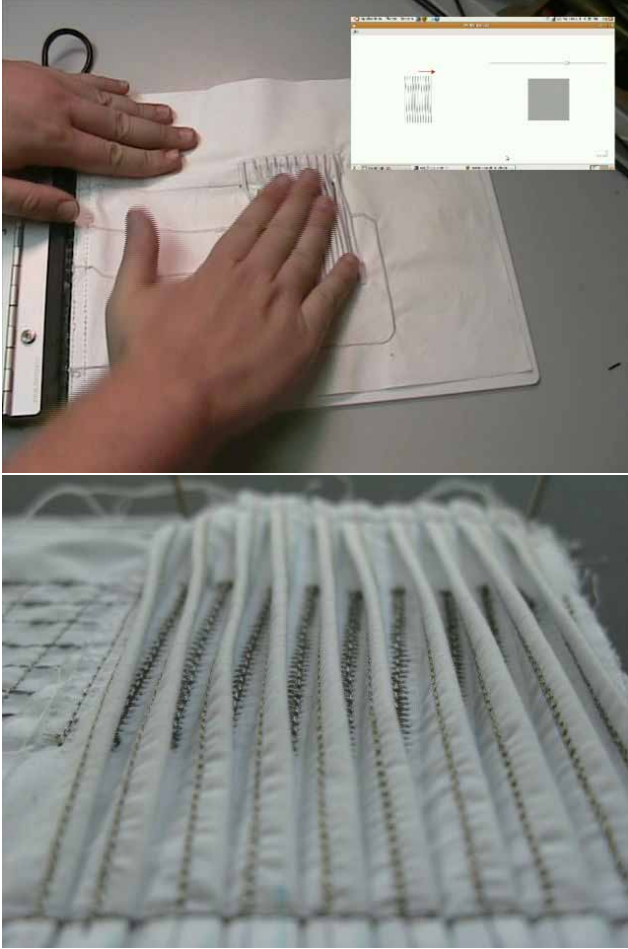


Figure 9. Pleat: This knife-edge pleat is constructed with three electrodes. Depending on in which direction the pleat is crushed, different circuits are completed.

pressed at any given moment. If the user strokes the pleats right to left, the left side of the pleats makes electrical contact, and, again, the sensed resistance indicates which pleat is being depressed. Since the left facing and right facing conductive threads form distinct circuits, a pinch gesture (e.g. where the thumb moves right across the surface and the index finger moves left) can also be sensed precisely.

Note that the circuit required is relatively simple, consisting of the 3 electrodes, a microcontroller with analog to digital converters (or the construction of several 1-bit capacitive DACs), and a few known resistors for a variation of a Wheatstone bridge to compare the sensed resistance values in the circuit precisely. We have also programmed this swatch such that it can act simultaneously as a proximity sensor using the capacitive sensing technique described above. Thus, one can program an interface that announces

usage directions while the user hovers over the pleat and then allows the user to perform selections by strokes.

5 Fashion Industry Professional Feedback

We presented the Textile Interface Swatchbook to a group of five fashion industry professionals for feedback at the Savannah College of Art and Design (SCAD) Atlanta campus. All of the fashion industry professionals reporting using current swatchbooks for inspiration and trending. After seeing the Textile Interface Swatchbook, a former vice president of global fashion and trend direction of the Material World Textile Trade Show said “I wish I had this when I was setting up the trend areas for Material World. This is the future in your hands.” A SCAD Professor remarked “I could really see using this in our design process, before I always thought of high tech fabrics as performance fabrics, but with this I see so many uses for the everyday.” The group as a whole liked the format but would like more detailed information in the swatchbook about washability and possible uses for each embroidery. Suggestions included having some swatches in color and to do the embroidery on different types of fabric to show design versatility.

6 Future Work

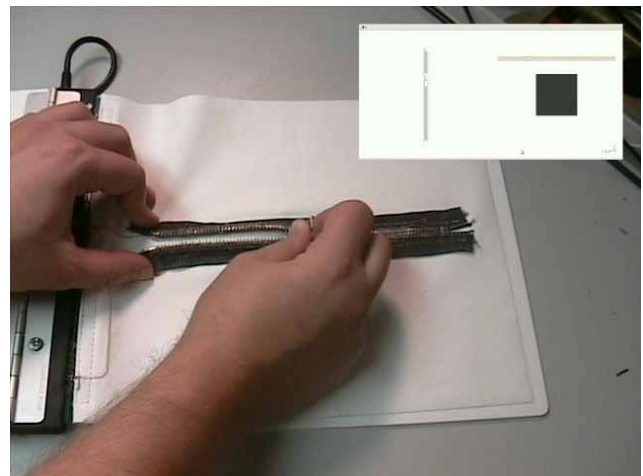


Figure 10. Zipper: The position of the zipper changes the position of a slider.

We continue to create new swatches, including concepts already in the literature (Figures 10-12) implemented in new ways. Some, like jogwheels and sliders, explore GUI interfaces or interfaces on current consumer electronics. Other, more experimental swatches, explore the particular advantages of conductive thread. For example, we

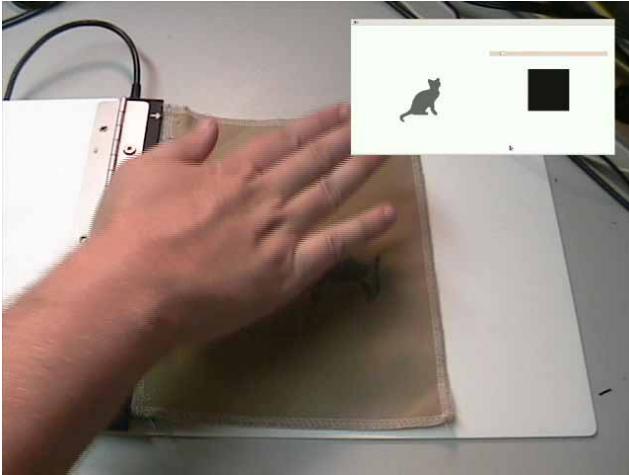


Figure 11. Proximity: The closeness of a hand to the swatch is sensed by embroidered electrodes.

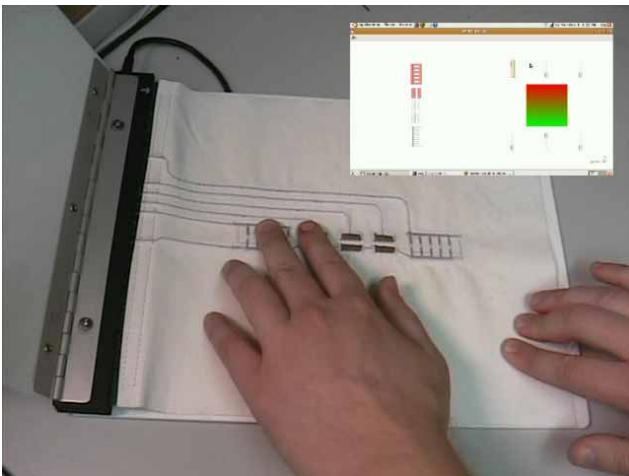


Figure 12. Multi-touch gesture: Five embroidered buttons can be used for selecting one of six sliders. The slider's value is changed by swiping the hand up or down the buttons.

are currently prototyping a variant of the hybrid capacitive-resistive touch sensor above that, after sensing contact, responds with a shock calibrated so that the user feels a sense of vibration. In this manner, the user receives confirmation that the touch was sensed; however, no moving parts are required.

Based on suggestions from colleagues in the area, we wish to create a wireless Bluetooth device which can be pinned to the swatches and allow them to be operational as they are being worn. In this manner, designers can try

using different interfaces at different parts of the body for extended periods of time. We will also explore a version of the TIS that is more appropriate for home embroidery hobbyists.

7 Conclusion

The Textile Interface Swatchbook explores the use of conductive embroidery for creating GUI-like widgets that can control mobile devices. We have shown a hybrid sensing technique that tolerates the changing system capacitances of interfaces embroidered on a flexible fabric base. Finally, we have introduced several textile interface widgets and discuss ways of using tactile features of embroidery to help guide the user into proper use of the interfaces.

8 Acknowledgements

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