Textile Interfaces: Embroidered Jog-Wheel, Beaded Tilt Sensor, Twisted Pair Ribbon, and Sound Sequins

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Abstract

Electronic textiles (or e-textiles) attempt to integrate electronics and computing into fabric. In our efforts to create new e-textile interfaces and construction techniques for our Electronic Textile Interface Swatch Book (an e-textile toolkit), we have created a multi-use jog wheel using multilayer embroidery, sound sequins from PVDF film and a tilt sensor using a hanging bead, embroidery and capacitive sensing. In order to make capacitive sensing over long leads possible on the body, we have constructed twisted pair ribbon and demonstrated its effectiveness over more typical sensing techniques. We detail construction techniques and lessons learned from this technology exploration.

1. Introduction

Toolkits of Graphical User Interface (GUI) widgets and other chunks of pre-made code act as a great starting point for interface designers. These toolkits can be used both as grab and use databases and also as inspiration springboards. As the wearable community becomes more diverse and includes those outside computer-focused disciplines, we need to expand such toolkits. The textile widgets showcased in this paper broaden the scope of our original work the Electronic Textile Interface Swatch Book [1] which was developed to act as a toolkit for textile, fashion, interior, and furniture designers. Such designers are accustomed to fabric swatch books and use them in much the same way a interface designer or researcher would use a GUI toolkit.

2. Related Work

Post and Orth introduced the wearable computing community to interfaces embroidered using conductive thread [2]. Touches to the conductive thread interfaces could be sensed using simple capacitive circuits. Soon many other textile interfaces widgets like keyboards and sliders were explained [3]. Even though this exciting research was published, much work in the area has been limited to niche professionals that have both technical and craft based skills. Research continues to innovate textile electronics in many directions [4, 5, 6], and electronic textile toolkits are also being used to excite and educate future generations [7].

This paper furthers our ESwatchBook [1] effort by describing the construction, sensing, and interface techniques used to create a new variant of an embroidered jog wheel, sequin speakers, and a tilt sensor constructed from a hanging bead. For the latter, we were particularly influenced by Perner-Wilson and Buechley's work on beads that lie against conductive embroidered pads to make connection [8]. We wish to push Perner-Wilson and

Buechley's idea to its limit by attempting to determine the angle of a hanging bead using the in-air capacitance between the bead and surrounding embroidered electrodes. However, capacitive sensing using fabric worn on the body is a significant challenge. To overcome this challenge we introduce twisted pair ribbon and demonstrate its benefit for capacitive sensing for e-textiles on the body.

3. Embroidered Jog Wheel

To sense the interactions with the jog wheel we are using the microcontroller and sensing circuit within the ESwatchBook [1]. The hybrid capacitive-resistive sensing technique used means each pair of pads needs direct contact with a fingertip to trigger. To create these touch sensing pads we have found that we can use both a very conductive thread [9] that has limited sewing capabilities and also a less conductive thread [10] that sews much more easily with our commercial Meistergram PRO1500 embroidery machine.

The jog wheel detects jogging interactions around two rings of electrodes, as well as a press-and-release in any single direction. A mound of non-conductive simple cotton thread is used between the inner and outer jog paths to help the user follow the circular path with little visual attention (see figure 1). We found that we could embroider on top of simple craft foam making embroidery stand up higher from the surface of the fabric, thus adding to the 'gropability' of the interface [11]. The jog wheel is made from three layers of fabric. The bottom layer carries the leads to the jog wheel, and the top layer is the embroidered interface (see figure 1). The middle layer prevents shorts between the leads and the underside of the jog wheel interface. Each of the spokes connects to a different lead and the outer ring acts as a separate ground from the inner ring (see figure 1), thus the exact location of a finger on the jog wheel is known.
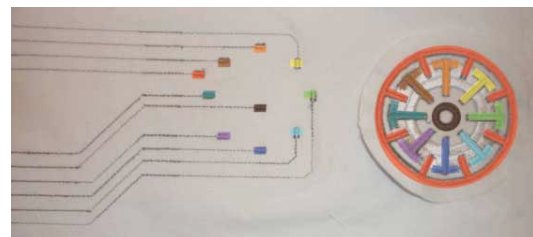

Figure 1 Color-mapped key of the conductive areas on the jog wheel

This design allows an inner loop jog where the user can scroll quickly and imprecisely through content such as folders or categories. The outer loop jog allows the

user to scroll more slowly and precisely through content such as individual files. This arrangement also enables interactions such as a swipe and tap. To compensate for the difficult nature of the jogging interaction the jog wheel software performs smoothing of the directional information from the swatch. [13].   The jog wheel interface is fully functional and works with the ESwatchBook's on-screen mp3 player for a demonstration of usability.

4. Hanging Bead Tilt Sensor
4.1 Capacitive Sensing

The hanging bead swatch uses capacitive sensing to detect the angle of a metallic bead suspended from the center of an embroidered swatch. An Analog Device AD7746 capacitive sensing IC is mounted on a custom-made board, with connections to the textile made as shown in Figure 2.
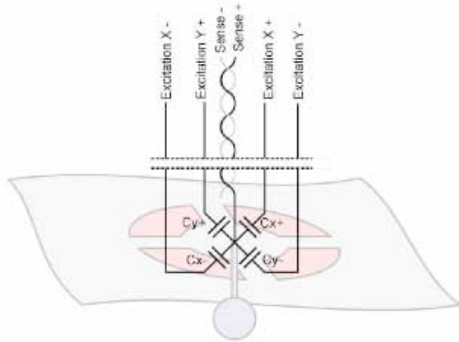

Figure 2 Hanging Bead connections

We use the IC with both of its "excitation" lines enabled, giving us a positive excitation and a negative excitation. Assuming that there is no noise from the environment and no stray capacitances, a sense line equally spaced between the two excitations should give a zero value. For each axis of bead movement, the excitation lines are connected to the two embroidered pads on either side, and the sense line is connected to the bead itself.

4.2 Twisted-Pair Ribbon from Conductive Thread

Unfortunately, any stray capacitances can have a large effect on detecting the position of the bead, as the capacitance between the bead and the fabric can be small. Ranges for the change in capacitance are around 100-500 pF per degree. The presence of a user's arm near an excitation line or the sense line can cause noise that overwhelms the capacitance from the bead itself. Additionally, the sense line cannot be shielded, as any amount of shielding adds significant capacitance, putting the capacitance of the sense line over the sensing limits of the IC. Even if we were to shield both excitation lines, the stray capacitance from the excitation pads of the swatch itself, in close proximity to the user's body, would still wreck havoc with readings.

For our sensor's differential sensing mode, we can not rely on a pair of parallel, equally-spaced differential sensing lines to have the same stray

capacitance to an 'excitation' line – each movement of the fabric or of a person near it changes the values, introducing noise that drowns out any proximity sensing we would try to perform. In short, performing capacitive sensing at a distance on textiles presents some unique challenges but is necessary for some types of sensors. Our solution allows us to place the capacitive sensing IC at a large distance from the area to be sensed and uses only textile connections to the area. The first part of the solution involves putting the AD7746 into its differential sensing mode. In this mode, the chip measures the difference between a pair of sense lines.. By running a pair of lines out to the bead swatch, and then only connecting one of them to the bead, the other line can be used to correct for the stray capacitance. For best results, it is important for the two lines to get equal exposure to the stray capacitances.

To this end, we developed a simple method to sew two conductive lines in a 'twisted-pair' configuration (Figure 3). While the twists in our twisted-pair are farther apart (2cm) than that found in high-speed data communications, the idea is the same. Both lines are exposed to the same electromagnetic fields, and any effect that is common to both is canceled by a differential measurement. The only detriment is that the capacitance between the two lines results in some capacitance from the bead itself, and thus reduces the differential output. However, the interference is negligible compare to the decrease in stray capacitance.
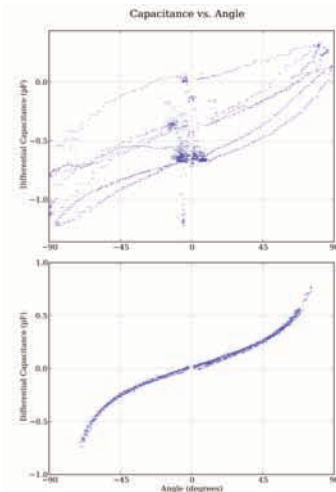

Figure 3 Data from the hanging bead taken without & with the twisted-pair

Our design uses one strip of fabric with two lines sewn on it, wrapped around a central strip of fabric that acts as an electrical insulator and mechanical core for stitching. The stitching on the outer strip is sewn with the conductive thread facing inwards so that the outside of the strip has no exposed conductive thread. The results from Figure 3 were obtained through a section of twisted-pair ribbon that is approximately one meter long.

We compared the twisted pair ribbon's performance against that of a single conductive thread [9] sensing line

and a pair of non-twisted parallel sensing lines [9], as shown in Figure 4. In our test, we brought a conductive plate near the textile lines connected to a two-pad proximity sensor. We then brought the same conductive plate near the sensor itself. To simulate the 'noise' in the readings from the extreme proximity of a person's arm, the plate was brought within 17mm of the sensing lines. To simulate the farther reach of a proximity sensor, the plate was then brought within 50mm of the proximity-sensing pads. In the case of the single sense line (Figure 5 top), the stray capacitance change is much larger than the capacitance change from proximity. Additionally, the overall capacitance values vary widely based on surroundings, such that even a leg under a desk would change readings. The parallel differential pair of lines performed better (Figure 5 middle), and its baseline reading was less dependent on its surroundings. However, bringing the conductive plate near the sensing lines still interfered significantly. Finally, the twisted differential pair performed very well (Figure 5 bottom), effectively canceling all of the stray capacitance from the proximity of our test plate.
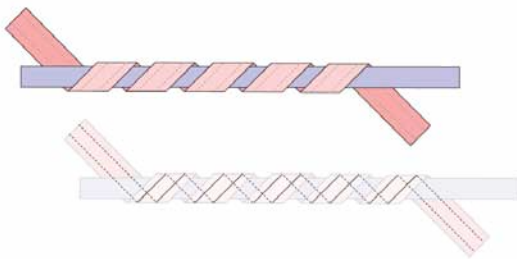

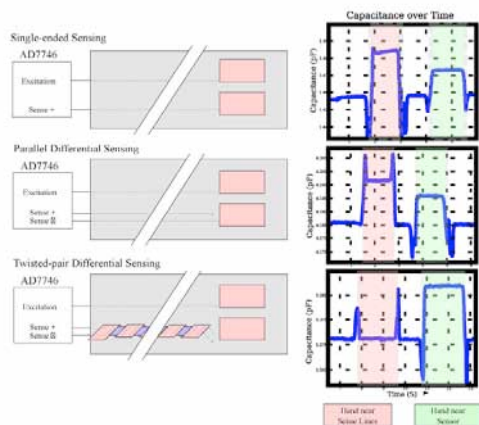**Figure 4 Conductive Thread Twisted Pair Ribbon**

Figure 5 Three test conditions used to evaluate different methods of running capacitive sensing lines across textiles, along with data collected from a test apparatus. Each was tested for response to proximity near the sensing line and near the intended conductive pads at the end of the sensing line

We then put our test piece on top of a user's arm, roughly simulating the effect of running lines down a shirtsleeve. We ran a hand over the entire length of the test fabric, only seeing a significant change when the hand was over the proximity-sensing pads at the end of the fabric (see Figure 6).
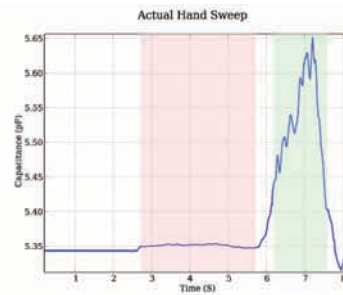

Figure 6 Graph of an actual hand sweep over twisted pair fabric.

5. Sound Sequins

Sequins in a classic shape are a ubiquitous form of textile embellishment. PVDF film is very beautiful and comes in both matte (manufactured through a screen printing process with silver ink, part number 2-1004346-0 [12]) and a more chrome like metallic version (part number 2-1003702-7 [12]), and these finishes lead themselves to a fashion application. We cut the film into sequins and sewed them to fabric as an array, which allows the fabric to still have good drape (see figure 7A & 7B). Some examples of application might be an avant-garde dress with sequined epaulettes that 'ring' for her phone, or a set of sequined drapes or decorative pillows that whisper message to you.
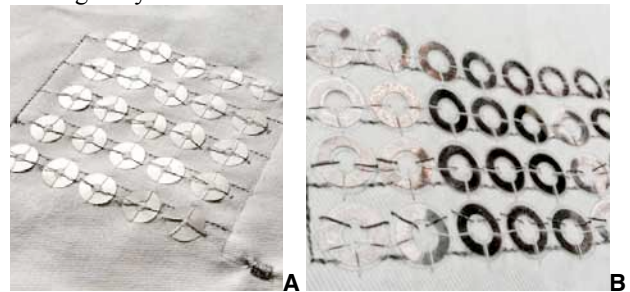

Figure 7A- A silver ink [13] piezoelectric sequin array and Use of non-conductive thread to secure sequins. 7B- A metal film [13] piezoelectric sequin array and use of non-conductive thread to secure sequins

There are many manufacturing suggestions in producing the individual sequins. The silver ink [12] sequins should be cut with computer aided vinyl cutting device. This produces cuts that do not short the front and back of the sequin as laser cutting would. In the case of the silver ink PVDF that we used [12], the voltage has to be applied between the top and bottom conductive layers. Unfortunately, the thinness of the PVDF layer can be a problem: when the material is cut, it leaves an exposed edge where a high enough voltage can arc from one side of the film to another, producing a rather dramatic failure. For the thinnest of the films we were working with, this was calculated to occur at a voltage of around 85 volts; too low to produce adequate sound. This could be avoided in the manufacture because the conductive ink is printed onto the plastic film and it could be printed in such a pattern as to leave borders for each sequin (see figure 8).
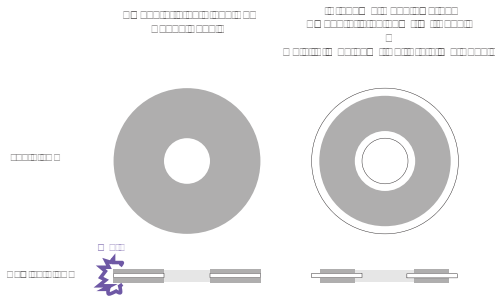
Figure 8 Illustration of shorting issues on sequins

When working with the metalized film [12] creating borders is much easier. We coated the film with photo emulsion in the areas we wanted to keep the conductivity and used ferric chloride metal etchant to remove the rest of the conductive surface (see figure 7A, 7B, & 8). This also allowed us to use the laser cutter to cut out the sequins.
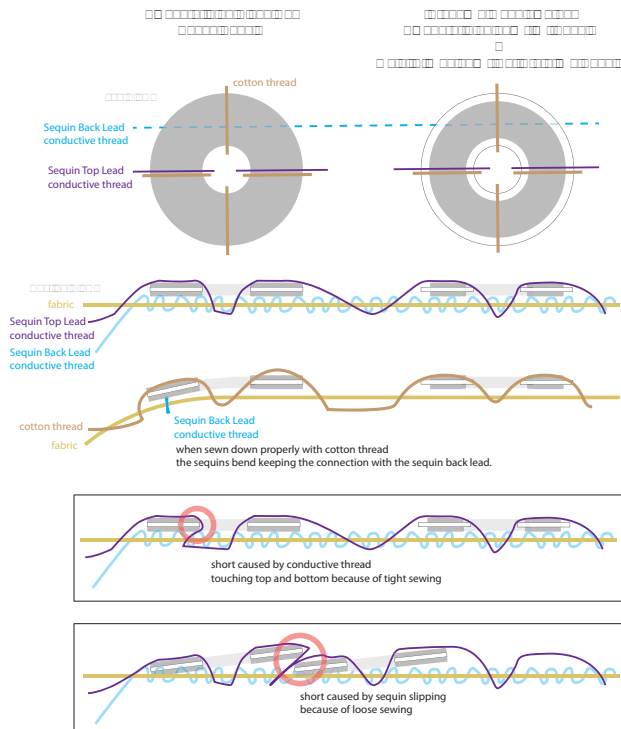

Figure 9 Sewing techniques for optimal sound sequin performance.

We were able to create sound by applying a 5.5khz, 470V peak-to-peak square-wave across 18 sequins in parallel. In this test condition, the sequins produced 48.7 db of sound at a distance of 4 inches, similar to the distance between a person's shoulder and ear. We also tested the sequins at lower frequencies, where the piezoelectric is not as responsive, and they produced 37.6 db at a frequency of 1kHz at 320V. These sound measurements were taken with an Extech 407768 sound level meter. While this is not an especially loud sound, it's enough get someone's attention if it is coming from their own clothing, and a larger number of sequins or higher voltage should yield a louder tone. The sequins are powered by high voltage drive circuits as detailed in a longer form of this paper [13].

It is also important to note that in sewing the sequins down tightly to the fabric in all four directions with cotton thread also ensures a better connection to the conductive thread stitched to the fabric as a lead to the underside of the piezoelectric film sequin even when the fabric bends. It is also important that the conductive thread is not sewn onto the top of the sequins in a way that the thread might touch the bottom of the sequin. A diagram of how the sequins should and should not be sewn to the fabric can be seen in figure 9.

6. Future Work

We are currently beginning a series of workshops with fashion, interior, and furniture designers to see how they respond to the ESwatchBook. We also plan on continuing to look into the potential of the swatches we have shown here. [13]. Our hope is that by creating these e-textile widgets, we can inspire designers to create designs using e-textiles. By making a toolkit of these e-textile widgets we endeavor to make a platform from which designers and computer scientists can work together more easily.

7. Acknowledgements

8. References

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