# Chapter 16.

# Sewing Process Timeline

The final sewing process developed for this thesis allows designers to create highly conductive textile electrodes with a variety of visual and tactile effects, and relatively little intensive labor and design time. The early, electrode sewing process (used to create the keypad in the *Musical Jacket*), required the hand placement of almost every stitch with a commercial CAD embroidery program (Wilcom software), and limited the stitch patterns that could be used to zigzag and satin. In addition, many stitches had to be hand placed. This is because, most commercial embroidery programs create objects by generating a stitch pattern based on parameters. For instance, when creating a piece of embroidery text, like the letter T, the designer picks the font, size, stitch density, stitch pattern, and the number of underlay stitches. Then the program generates the letter T as an object, complete with stitch placement (more advanced designers can pick the way that the corner is sewn, etc.). In the early sewing process (as used in the *Musical Jacket*), if a single

### Timeline Summary

Piecework Circuit Elements Sewn from Metallic Silk Organza.

Composite Stainless Steel Thread, (BK50/2) Passes Through Needle of Commercial Sewing Machine.

High Impedance Circuit Elements Designed in CAD Environment and Embroidered on Commercial Machine with Composite Stainless Steel Thread, (BK 50/2).

Electrode Impedance Reduced by 10X by using Composite Stainless Steel Thread, (BK50/2) in Bobbin.

Electrode Impedance Reduced by Improved Stitch Pattern and Continuous Stitch Path Between Objects.

Electrode Impedance Dramatically Reduced by using 100% Non-Continuous Stainless Steel in Bobbin, but Causes Short Circuits Between Close Elements.

Electrode Impedance Dramatically Reduced by Nylon Wrapped with 3 Continuous Stainless Steel Fibers in Bobbin without Sewing Problems.

Sensing Stability and Resolution Improves when Electrode Area and Density are Increased.

Tying a Knot Creates a Simultaneous Mechanical and Electrical Connection with a Twine of Continuous Stainless Steel Core Wrapped with Stainless Steel and Polyester Composite Thread (BK50/2).

Contour Underlay Stitch Decreases Electrode Stiffness.

Contour Stitch Overlay Decreases Stitch Density and Increases Conductivity.

needlepoint pierced a previously stitched thread, the conductivity would be dramatically reduced. This meant going through the labor-intensive, hand placement of many of the machine generated and placed stitches. Separate objects also had to be integrated in a painstaking manner. This process involved literally taking the layers apart and reordering how they were sewn. The final electrode sewing process lets the designer avoid most hand placement of stitches, and accept the objects and stitch configuration generated by the program. It also lets designers create electrodes using objects sewn with many different stitch patterns, including the tatami and contour stitches (Figure 16.1). Using a variety of stitch styles lets designers make electrodes that were bumpy or soft, and with different visual effects and density. The layered spatial effect in the *Big Ring* ground sensor was made possible by the use of different stitch styles.

The final sewing process consists of:

1) Using a highly conductive bobbin thread (one that is not necessarily sewable in the needle) and a less conductive, more flexible top thread.
2) Sewing a loose and flexible contour stitch as an electrical back plane.
3) Arranging denser and multi-layered, more tactile design objects over the plane. (These can be sewn in many stitches and densities, including tatami, or satin stitch). These objects should interconnect the parallel traces of the contour stitch.
4) Create a continuous stitch path between all objects.
5) Overstitch denser objects with another loose contour stitch, which should perpendicularly intersect with original contour stitch.

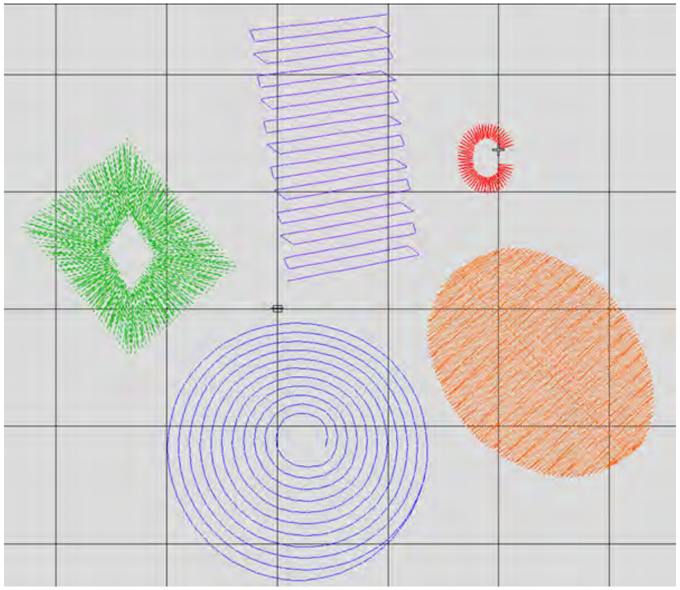


Figure 16.1 Stitch pattern examples:
Satin stitch (green square and “c”).
Tatami stitch (orange oval).
Loose Contour stitch, (blue swirl and purple rectangle).

The final sewing process developed in this thesis involves the use of two different stainless steel composite threads. The very sewable, high impedance composite stainless steel thread BK 50/2 is used in the needle. In the bobbin, a less sewable, low impedance thread of nylon wrapped with three strands of continuous stainless steel is used. (The resulting structure is far more conductive on the bottom than the top.) A loose contour stitch (see Figure 16.1) is used as a flexible conductive plane. The contour stitch is then sewn over with many denser objects. These objects interconnect the paths of the contour stitch, creating massive resistive network. They also create a large conductive and fuzzy area for the player's hand to couple to. Finally, a second loose contour stitch is placed over the more densely sewn objects and the original contour under plane. This second contour stitch ties the less conductive top fibers more tightly to the highly conductive bottom fibers. It also creates a shorter conductive path between objects. Because of the long stitching, tatami objects were simply too resistive to use before the top contour stitch was used.

## Expansion of the Sewing Timeline

### Piecework Circuit Elements Sewn from Metallic Silk Organza

**Projects:** *Firefly Dress and Necklace*, *Serial Suit, Piecework Fabric Keypad*, and the fabric ribbon cable in the *Musical Jacket*.

These piecework circuits were sewn from the highly conductive, metallic silk organza, which was sewn onto a non-conductive fabric backing. Piecework is labor intensive, time consuming and limits shape and size of the circuit element. (Quilts are made form square blocks whose smallest size is one inch for a reason.) Moreover, creating electrical connections by sewing two pieces of conducting fabric together was time consuming and not electrically reliable.

### Composite Stainless Steel Thread, (BK 50/2) Passes Through Needle of Commercial Sewing Machine

BK 50/2 is a composite thread of non-continuous stainless steel fibers and polyester. It was the first thread that we could get through the needle of the sewing machine without it stripping, wadding, or knotting. Though it created very high impedance traces, (mega-ohms), it was useful in tying together the conductors in the anisotropically conductive metallic organza.

### High Impedance Circuit Elements Designed in CAD Environment and Embroidered on Commercial Machine with Composite Stainless Steel Thread, (BK 50/2)

**Projects:** *Embroidered Keypad* in the *Musical Jacket.*
Using a commercial CAD embroidery environment (Wilcom software) to design circuit elements was much like using a PCB program. It also meant that these elements could be made any shape and far smaller than piecework elements. Using commercial

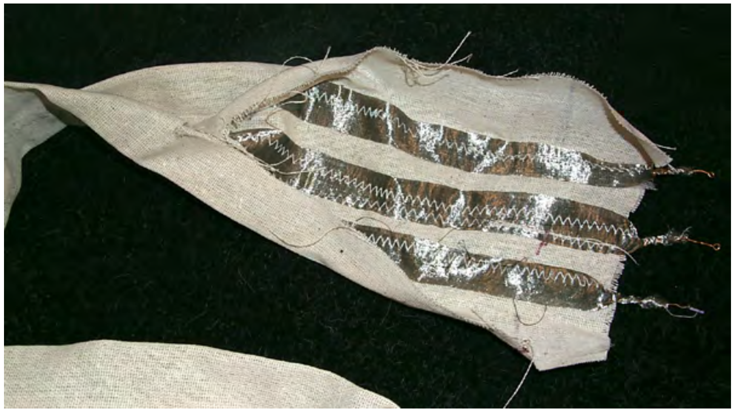

Figure 16.2 Piecework fabric ribbon cable from the *Musical Jacket*.

embroidery machines meant that multiples could be easily made.

### Electrode Impedance Reduced by 10X by using Composite Stainless Steel Thread, (BK 50/2) in Bobbin

**Projects:** *Embroidered Keypad* in the *Musical Jacket*.
The decrease in resistance, and increase in durability and reliability gained by using conductive thread in the bobbin made sewn keypads a reality. Running the conductive thread through both the bobbin and the needle decreased the resistance on the embroidered electrode by 10 times. This is a dramatically greater reduction than the usual change that occurs with parallel resistances ((R1+R2)/(R1xR2)). This also made the electrode far more electrically reliable, varying less under wear and flexure.

### Electrode Impedance Reduced by Improved Stitch Pattern and Continuous Stitch Path Between Objects

**Projects:** *Embroidered Keypads* in the *Musical Jacket* and *Electronic Tablecloth.*
Altering the standard stitch pattern to improve conductivity involved a number of steps:

1) Creating redundancy by layering stitching.
2) Eliminating single object sewing by creating continuous inter-object sewing in layers.
3) Moving by hand any stitch that sent the needle directly through a previously sewn thread.
4) Loosening the density of stitches.

Achieving these steps was incredibly painstaking because it involved the hand manipulation of the stitch pattern on a stitch-by-stitch basis. Most embroidery CAD programs create a stitch pattern on the basis of parameters of individual objects. For instance, the outlines of square can be drawn, the program generates stitches to fill it. The designer can choose the type of stitch, like zig-zag or tatami. These objects can be created with under-stitching (multiple layers), which dramatically improves the conductivity of the object, by creating redundancy and numerous parallel resistance paths. A typical satin stitch object is first sewn with a single straight under-stitch, then a loose zigzag under-stitch, and finished with a dense satin stitch on the top. Then the next object is sewn. But simply sewing one object, like square, after or slightly on top of a previously sewn object will not create a good electrical connection between the two. To create a keypad involved making three objects, the trace, the pad for connecting to the circuit, and the number or key. But without the integration of the separate objects into one, the electrical connection between them was always poor. The objects had to be sewn as if one, with the understitching going continuously between each object. Stitch density in the top stitch had to be reduced. (This is an empirical observation). Any needle punch marks that passed through a previously sewn thread had to be moved by hand. This was painstaking, but reduced the resistance enough that the 12 inch traces and shaped keys used in the *Electronic Tablecloth's* keypads were still under 2k ohms. Unfortunately these electrodes were still not conductive or consistent enough for pressure sensing.

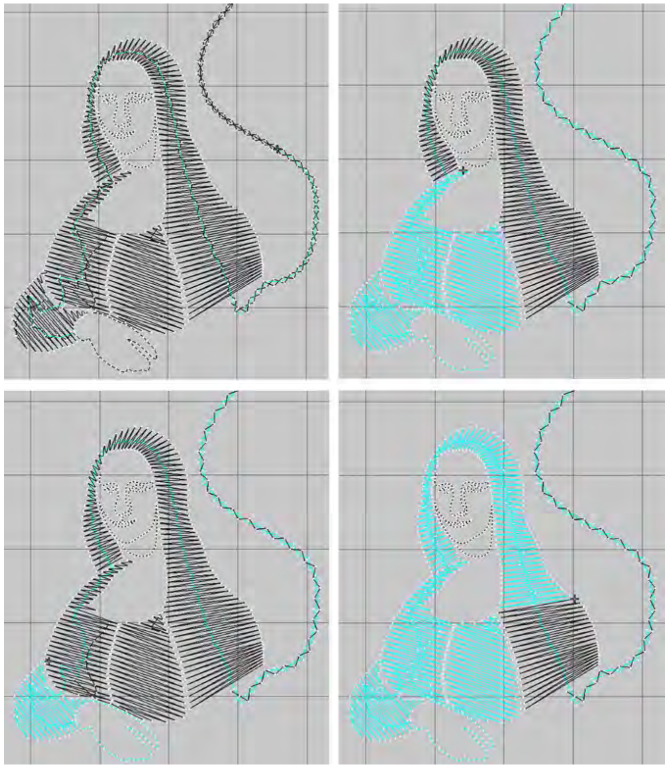

Figure 16.3 Continuous stitch path in Mona Lisa key from *Electronic Tablecloth*, blue lines indicate sewn stitches, black unsewn.

### Electrode Impedance Dramatically Reduced by using 100% Non-Continuous Stainless Steel in Bobbin, but Causes Short Circuits Between Close Elements

**Projects:** *Ball 3* and *4.*

Using this highly conductive thread in the bobbin created EXTREMELY conductive electrodes. The top thread remained the highly resistive BK50/2, but because it only had to conduct the short distance from the topside to the underside of the electrode, its high resistance was not relevant. Unfortunately, the hairy bobbin thread caused many short circuits between electrodes, and skin irritation. Short circuits were eliminated by sewing each electrode on an individual panel, and then lining it with non-conducting cotton backing. Unfortunately, this process meant that there had to be a certain distance between the sensor and the ground electrodes. This did not allow for the creation of physically interdependent sensors. It was not easy to interweave the sensors, or create close proximity of the ground and sensor electrode, which created an easier and more natural playing style.

### Electrode Impedance Dramatically Reduced by Nylon Wrapped with 3 Continuous Stainless Steel Fibers in Bobbin without Sewing Problems

**Projects:** *Ball 5, 6, Pyramid, Big Ring* and *Tube.*

This process replaced the hairy 100% stainless steel bobbin thread with a tidy, highly conductive, nylon yarn wrapped with 3 strands of continuous stainless steel. The electrodes it created were highly conductive. Using this thread eliminated much of the need for the stitch-by-stitch editing that was necessary when using BK50/2 in the bobbin. The lack of hairy conductors and tidiness of this thread also eliminated the need for each electrode to be sewn on a separate panel and lined. Unfortunately, the initial electrode patterns that were sewn with this yarn in *Circle Ball 5,* did not work well as sensors. These patterns had worked well when the 100% non-continuous yarn was used in the bobbin, in *Circle Ball 4*. The only reasonable explanation for this was the dramatic reduction in the AREA of the conductor. Capacitance and in this case resistance is directly related to area, and while this new thread was highly conductive, it did not have a lot of conductor area. The sensor pattern of *Circle Ball 4* and *5* was thin. When sewn with the thick 100% stainless steel the conductor had a lot of area. When sewn with the wrapped thread the same electrode had too little area. This meant that the successful electrodes sewn with it (the *Generic Musical Ball*), were at first very dense and stiff. It is important to note that this thread really must be used in conjunction with the BK/50. The steel wrapping on this thread is very fine and almost impossible to electrically connect to. Using it with the BK/50, which has lots of loose little steel fibers, provided a good contact surface for both connecting to circuitry, and coupling with the hand.

### Sensing Stability and Resolution Improves when Electrode Area and Density are Increased

**Projects:** *Generic Musical Ball*.

By increasing the density and size of the embroidered area of the electrode, the sensing stability and sensitivity increased. At this point, a satin stitch was used to create a wide trace that was stitched in numerous layers. By folding the satin stitch traces against themselves, the electrodes became an almost continuous shape, with the maximum surface area filled in by dense conductors. (A tatami stitch is usually used to fill solid shape like a square, but they did not conduct well at this point.) The electrodes were still sewn on separate panels to prevent short circuits. This process gave the *Generic Ball* sensitive, durable, and isolated electrodes. The sensing was responsive and stable. From the success of this instrument I was able to iterate and experiment. Unfortunately, creating a good area made these electrodes a bit stiff and bulky. Because the satin stitch had to be continuous, the electrodes also had to be made in a sort of swirl-like pattern. This was both visually and tactilely limiting.

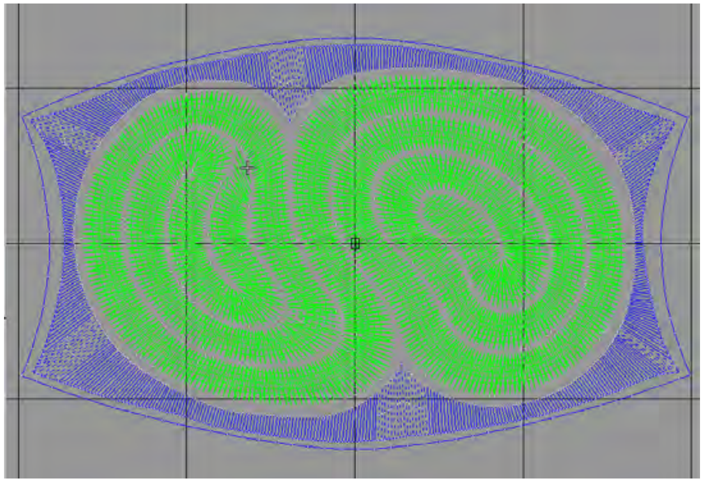

Figure 16.4 Embroidery CAD file of sensors electrode from *Generic Ball*. Green conductive thread is sewn in continuous satin pattern.

### Tying a Knot Creates a Simultaneous Mechanical and Electrical Connection with a Twine of Continuous Stainless Steel Core Wrapped with Stainless Steel and Polyester Composite Thread (BK 50/2)

**Projects:** *Ball 6, Pyramid, Big Ring* and *Tube.*

The importance of this braid cannot be emphasized enough. Creating a reliable connection to the fabric is one of the main problems encountered when testing or working with it. Technically, this braid provided a quick, mechanically stable, and durable way to connect the central circuit to the fabric. I had used numerous strategies to do this, including wires coupled to 100% stainless steel threads. None them were mechanically reliable, and they all broke under the stress of squeezing. In addition, creating these connections was

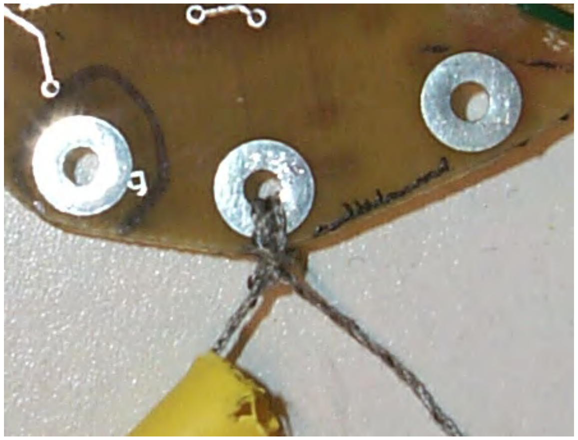

Figure 16.5 Close-up of mechanical/electrical knot with contact impedance of .2 ohms.

TIME CONSUMING. This braid of 100% continuous stainless steel wrapped with BK 50/2 allowed me to quickly mock up sensors, and tie them to the sensing circuitry. It let me test and iterate on both individual sensor and overall instrument design easily. Before this, yarn and electrode testing was difficult, because getting a good connection between the circuit and fabric electrode was so time consuming.

### Contour Underlay Stitch Decreases Electrode Stiffness

**Projects:** *Pyramid* and *Big Ring*.

A large shape filled with a loose contour stitch provided a means to decrease electrode stiffness, but maintain surface area and therefore sensitivity. Sewing a single trace in a tight spiral spaced by 5-8 mm created a good electrical under plane and overall area for the sensor. Overstitching that plane with a satin stitch that crossed the perpendicularly tied the single thread together and created a surface area for the hand to couple to.

### Contour Stitch Overlay Decreases Stitch Density and Increases Conductivity

**Projects:** *Big Ring* and *Tube*.

Using a contour stitch on top of a satin stitch, or a tatami object, not only increased the charge build up area, but also increased the overall conductivity of the electrodes, dramatically. This technique provides an enormous amount of design freedom. Using this technique I could work with the thinner tatamei objects, and build up visual depth. This overstitch also tied down long loose satin stitches that might come loose over time and wear. The electrodes I have created with

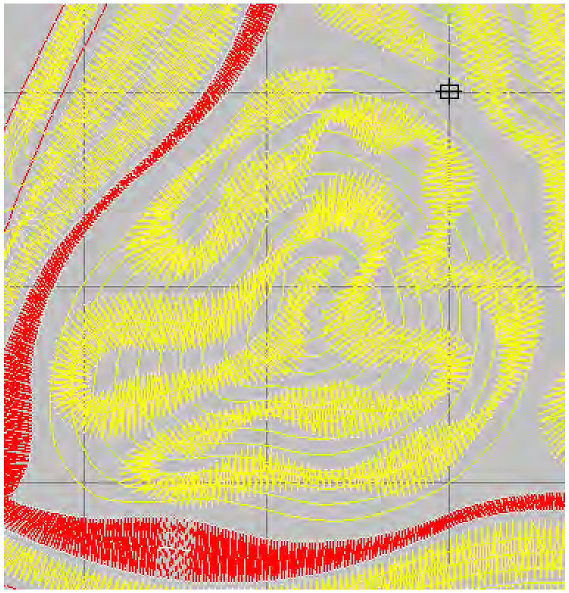

Figure 16.6 Contour underlay, beneath satin stitch swirl.

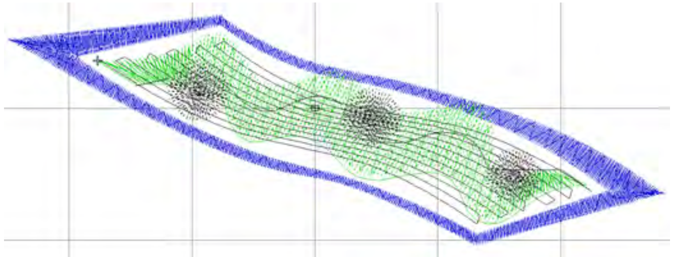

Figure 16.7 Contour overlay in *Big Ring* Sensor, black stitches represent contour overlay over green satin stitch.

this process can be designed quickly, and have a lot of visual and tactile variety. Moreover, their layered visual effect is directly related to their electrical needs.