Chapter 10.

Projects in Fabric Sensing:

Spanning Fashions, Musical Instruments and New Physical Interfaces

The ultimate goal of my early work in fabric sensing was to create a multi-channel sensor skin that I could shape into a musical instrument. These early projects, including the first row and column, *Piecework Fabric Keypad* (1997), the *Musical Jacket*, (1997) and the *Electronic Tablecloth* (1998)[1],[2], do use fabric for multi-channel sensing on a single surface, but only allow for the sensing of "on and off". Two different methods for

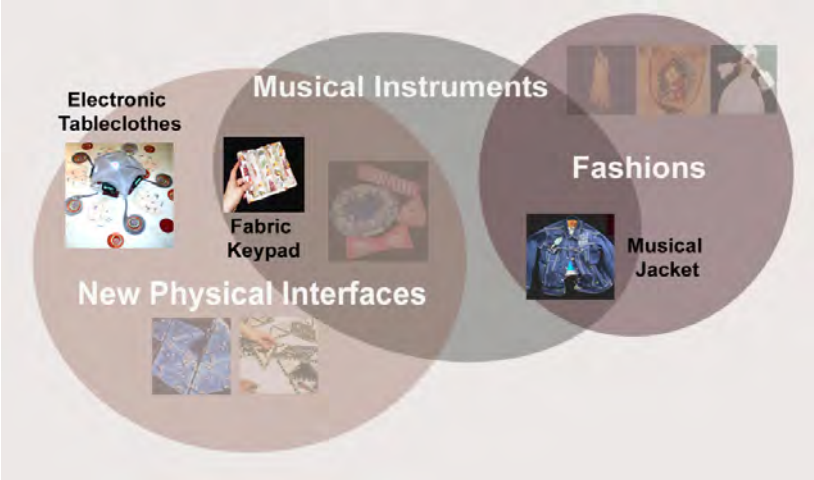

Figure 10.1 Fabric sensing projects within the Tree of Projects.

[1] Post, E.R., Orth, M., *Smart Fabric, or Washable Computing,* the Digest First IEEE International Symposium on Wearable Computers, Cambridge, MA, (1998) pp. 167-8
[2] Post, E.R., Orth, M., Russo, P.R., Gershenfeld, N., *E-broidery: Design and Fabrication of Textile-based Computing*, IBM Systems Journal, Vol. 39, Nos 3&4, Armonk, NY, IBM Corporation, (2000).

sensing on and off are used. The fabric keypad was a hand-made piecework structure that used mechanical fabric switches to sense on/off. The embroidered keypad relied on the complex impedance sensing[3] of high impedance machine embroidered electrodes, which were designed in a commercial CAD environment. This manufacturing process allowed far more flexibility in the design and shape of sensors and the fabric objects that contained them. Like patchwork quilts, objects sewn with piecework usually have square edges and can only get so small. Machine embroidery allowed the sensors to be almost any shape or size, and to be sewn on a single layer. It also allowed us to easily make multiples. And though CAD-based, it was a relatively direct and immediate process. Through the CAD system, I could quickly make a design and IMMEDIATELY print it on the embroidery machine to see what it looked like and how it behaved electronically.

Ultimately, the machine embroidery system gave me the freedom to truly control the shape of sensors and electrodes. This led from more simple keypad designs, like that of in the *Musical Jacket*, to truly expressive and decorative designs like those in the *Electronic Tablecloths*. In many ways, the *Electronic Tablecloth* represents my first chance to REALLY shape electronics that to expressed both my ideas and aesthetic goals. It also represents a more advanced foray into *functional ornament*.

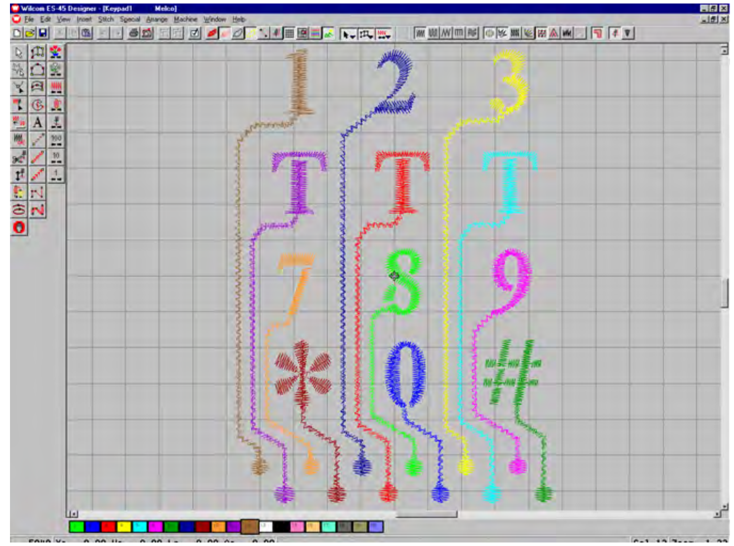

Figure 10.2 Image of *Musical Jacket* keypad in commercial embroidery CAD environment from Wilcom software.

[3] See Chapter 13, Complex Impedance Sensing.

Piecework Fabric Keypad [*]

This was the first addressable, multi-keyed, fabric keypad. This keypad was a row and column switch matrix made from conductive metallic organza and non-conductive cotton. This piecework keypad had sixteen switches, and was incredibly soft, flexible and durable. It could be rolled up and wadded into a ball, or just gently stroked. Each key was mapped to different note through MIDI. When squeezed or rubbed, the keypad created a simple medley of notes from a MIDI device. The physical softness, and gestural immediacy of the music made by this prototype instrument, suggested that fabric instruments had real potential for expressive and higher level musical exploration. The keypad also suggested a way to make a soft sensor skin or musical instrument.

The top and bottom layers of the keypad were sewn from alternating rows of conducting metallic organza and non-conducting cotton. The two layers were then sandwiched around a central layer of tulle or netting, which acted as the insulation and mechanical "spring" between rows and columns. When the keypad was pressed the two conductive rows and columns squeezed together and the tulle compressed. The holes in the netting let the two make electrical contact and the switch triggered. The keypad used snaps to attach to circuitry and wires.

As a layered, piecework structure this keypad was tedious to manufacture. Using piecework also required

Figure 10.3 *Piecework Fabric Keypad*, 1997 rolled up and wadded into a ball.

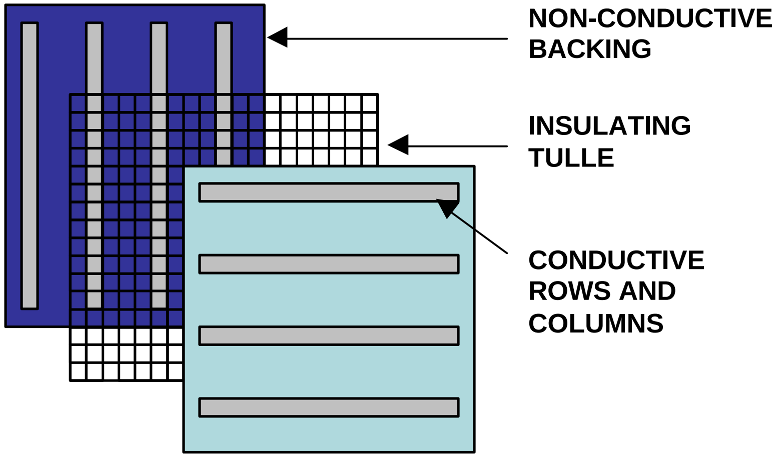

Figure 10.4 Diagram of *Piecework Fabric Keypad*.

[*] In collaboration with Emily Cooper.

working with linear fairly large pieces, and limiting the size and shape of the rows and columns. (This was limiting because most switch matrixes are not made with simply straight rows and columns, but with a complex geometric pattern.) Finally, because there are no non-linear fabric components (i.e. transistors or diodes), to place at the switch points, the keypad registered false positives. We were anxious to create a less labor-intensive fabrication method that allowed us to control the shape and size of the circuit elements precisely, that used a single layer to sense, and that eliminated false positives.

material references*:* metallic silk organza.

Musical Jacket[*]

The *Musical Jacket* incorporates an embroidered fabric keypad, a conductive fabric bus, a battery pack, a pair of commercial speakers, and a miniature MIDI synthesizer[*] into a stand-alone, wearable, musical instrument. My specific contribution to the *Musical Jacket* includes guiding the overall physical design and concept for the jacket, collaborating with Rehmi Post on the design and sewing process for the *Embroidered Keypad*, and the design and creation of the fabric busses. I also directed (if not executed) the manufacture of the fifty *Jackets*. The *Embroidered Keypad* used in the *Jacket* is sewn from a composite stainless steel thread, (the first thread we could get

[*] In collaboration with Rehmi Post, Emily Cooper, Josh Smith and Josh Strickon.
[*] MIDI synthesizer by Josh Smith and Josh Strickon.

through the needle of a sewing machine)[4], and senses on/off through a complex impedance method. When the wearer touches any key on the keypad, a note is played or rhythm triggered. The *Embroidered Keypad* communicates through the fabric bus to the MIDI synthesizer, which generates notes. The synthesizer also sends audio to the speakers over the fabric bus. Power from the batteries is distributed over the fabric bus as well. The *Embroidered Keypad* and fabric bus eliminated the need for most of the wires, connectors and plastic inserts that would make the jacket stiff, heavy and uncomfortable. The electrically active textiles and electronic embroidery used in the *Jacket* are multifunctional and smart materials. They act as sensors, wire, electrical contact pad and the physical substrate or design material of the object.

In many ways, I think of the *Musical Jacket* as the ultimate demo. It truly captured peoples' imaginations in a way I had not envisioned, and demonstrated how computing technology could completely transform an ordinary everyday jean jacket into a fun and creative experience. People loved wearing this *Jacket*. They would put it on, play it, and laugh. The musical application developed by Josh Strickon was essential to this success. This application let wearers create music with both note-by-note control and the generation of higher-level rhythms. In its initial mode it allowed users to touch a key and play a single note. This let people experience how well the keypad worked and gave them a sense of music control. In its advanced mode, it let them initiate a computer

[4] See Chapter 14 on sewability.

generated rhythm, speed it up, slow it down, add voices or individual notes. Because playing the *Jacket* is ultimately a public performance, having higher-level, quantized, and pre-composed rhythms accessible to the player is essential. No wants to walk around in public with a musical jacket and sound bad.

The design and placement of the *Embroidered Keypad* used in the *Musical Jacket* demonstrates how creating a demo requires making very different design choices than one might make when designing a product. The *Embroidered Keypad* is placed on the lapel of the *Musical Jacket Jacket*. This was driven not by ergonomics, but by the need to communicate a story about the potential of sewn circuitry and smart textiles. The *Embroidered Keypad* was designed to look like a circuit and standard keypad, making people imagine sewn circuits in many fabrics and also implying that this technology could become a calculator or a cell phone. The *Keypad* was placed on the lapel of the jacket for visibility, not ease of use. (Many people have asked me why it is not on the sleeve.) This location makes a great photo. You can see the *Embroidered Keypad* and the player's hand touching it. This location also unexpectedly let people play each other while looking at each other.

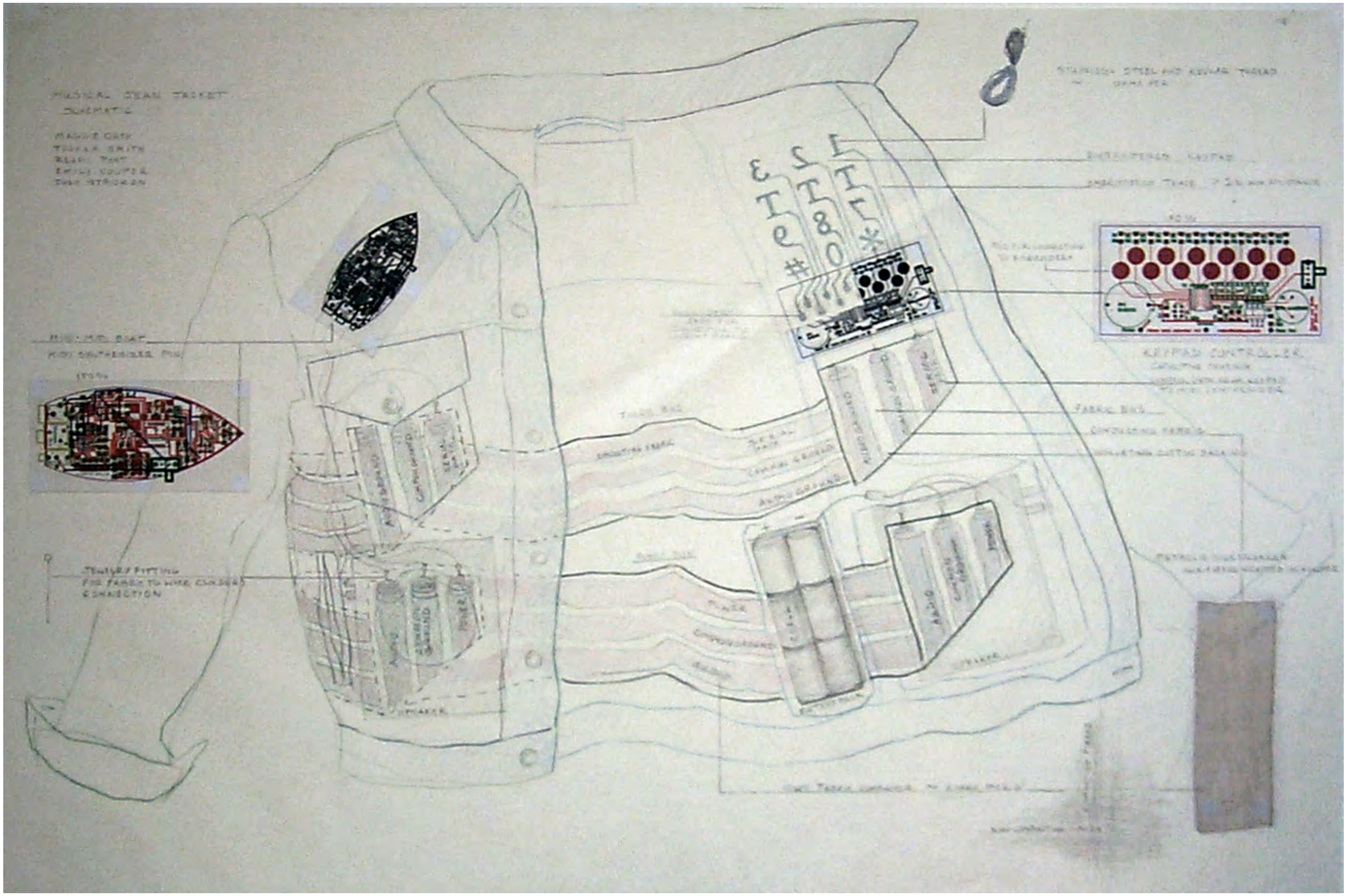

Figure 10.6 Fashion illustration/circuit diagram of the *Musical Jacket*, Maggie Orth, 1998.

Embroidered Keypad

In the *Embroidered Keypad*, each embroidered key was a high impedance electrode whose change in capacitance/complex impedance, when touched, was sensed by a microprocessor in the time domain. The embroidery process used to create the keypad overcame many of the limitations of the *Piecework Fabric Keypad*. The keypad was sewn on a single layer, designed in a CAD environment that allowed precise control of the size and shape of the electrodes, and sewn on a commercial embroidery machine with a composite polyester and stainless steel thread. Until we found this thread, we simply were unable to machine sew any conductive thread. Wrapped or gimped threads (like those used in the metallic silk organza and the fashions in Chapter 9) always stripped under the mechanical stresses of sewing. 100% stainless steel threads bunched and jammed the machine. With this high resistance, flexible, composite thread we were able to machine sew a conductive trace, or stitch, for the first time. This thread was commercially available, and had in the past been used for static control in carpets. Using capacitive/complex impedance sensing to sense every electrode individually also overcame the problems of false positives in the row and column keypad. The embroidery also allowed us to stitch electrical paths and contact pads to reach the circuitry. This avoided the mechanical complications of using wires to connect the fabric keys to the sensing electronics.

While the *Embroidered Keypad* made many technical and process advances over the *Piecework Fabric*

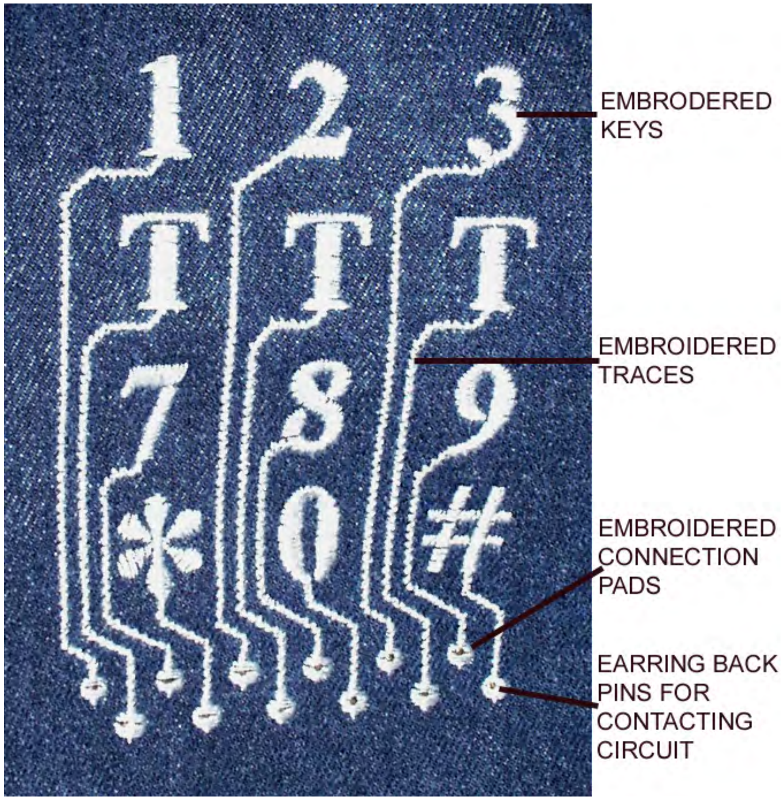

Figure 10.7 *Embroidered Keypad*, 1997, from the *Musical Jacket*.

Keypad, it still had many drawbacks for musical applications. The sensing method did not provide a means for sensing continuous information, or pressure, which is very important for expressive input in musical instruments. In addition, because the composite stainless steel thread was *so* high in impedance (in the mega ohms), we had to design our electrodes practically stitch-by-stitch. Any needle punch through a previously sewn trace caused a dramatic decrease in conductance. This was incredibly painstaking and time consuming. It also limited the types of stitches and designs that were usable. Finally, the *Embroidered Keypad* was still attached to the sensing electronics in a manner that made half of the keypad rigid. We had yet to find a flexible means for attaching the fabric electrodes to the electronics.

material references: stainless steel and polyester composite thread (BK 50/2), and metallic silk organza.

technical references: Complex Impedance Sensing.

Figure 10.8 The back of the *Embroidered Keypad* attached to sensing electronics.

Electronic Tablecloth[*]

The *Electronic Tablecloth* was designed to encourage guests at a cocktail party to mingle by playing a personalized game of Jeopardy on a beautiful, interactive tablecloth. Each *Tablecloth* contained five interaction stations, which enabled people to play a game together as they gathered around the table. Each of the five stations had a *unique* embroidered keypad (each station had different symbols), an embroidered electrostatic, RF ID tag reader electrode, and a text-based display in the centerpiece (which was connected to central PC). Each player received an embroidered coaster that contained a commercial, capacitive ID tag, linked to the player's identity. The player threw his or her coaster onto the embroidered tag reader and touched it to start playing. Once logged in he or she could use the keypad to pick categories, or answer personalized questions, which were displayed on the screen in the centerpiece. The centerpiece also contained sensing circuitry and links to a computer.

In the *Electronic Tablecloth*, the embroidered keypad and tag reader were truly physically transformed. Each embroidered key on the keypad was shaped to convey a specific meaning. The "yes, no, a, b, c, and d" keys let players choose their answer to questions. The image shaped keys (the Mona Lisa or the car), let players choose a category like art or cars. In this way, the embroidery on the tablecloth was shaped as an

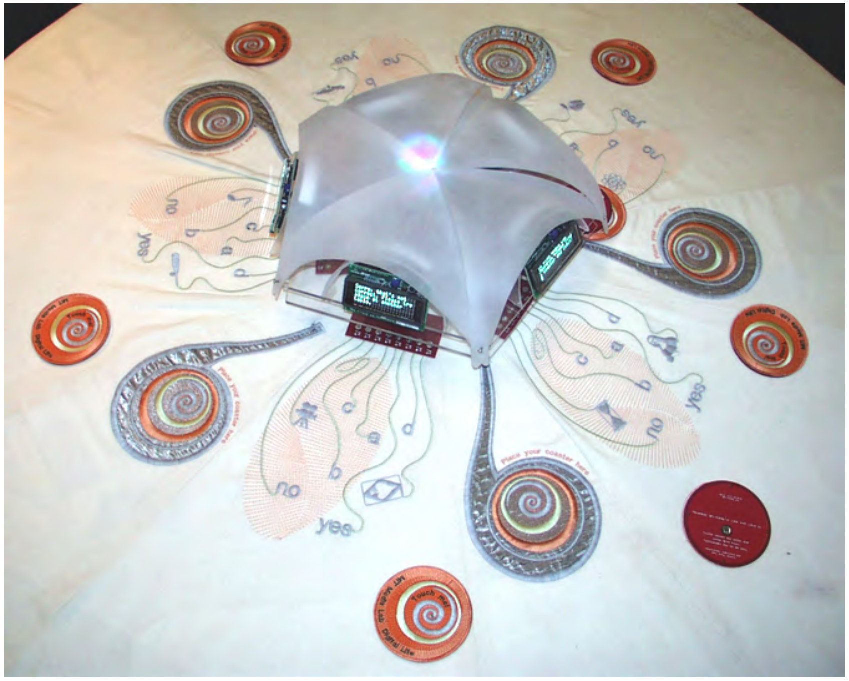

Figure 10.9 *Electronic Tablecloth,* 1998.

[*] In collaboration with Andy Lippman, Rehmi Post, Peter Russo and Pam Mukerji.

icon, an image or a word, just as the pixels on a screen can be shaped in a GUI. Directions to players, like place your coaster here, were also embroidered directly on the *Electronic Tablecloth*. With the embroidery design process I was also able to simultaneously shape and control the artistic content, (the shape and aesthetics of the letters and icons), and the electrical properties of the sensors.

The aesthetic transformation of the keypad and tag reader into a beautiful fluid pattern gave players a very different relationship to the game than they would have to plastic keyboards and tag readers arranged on a table similarly. Guests at the party found the technology emerging out of what they normally expect at a party, a beautiful table setting, and like the partygoers, the technology was dressed up for an elegant occasion. They were excited to see the coaster ID tags and tablecloth. If the *Tablecloth* were at a child's party the images on it could be designed appropriately to communicate to children.

The *Electronic Tablecloth* is an excellent example of the design potential of smart textiles as sculptural and active computing material. In many ways, this project was the first time I got to truly have some fun with the design of electronic fabric. I used various art nouveau patterns as a starting point for this piece. Because I had found a process where I could simultaneously and directly design both electronics and ornament, this was also the first project in which functional ornament started to become more advanced. Many of the decorative elements, like the gray keys and big gray swirl were electronically functional. Yet, I still did not

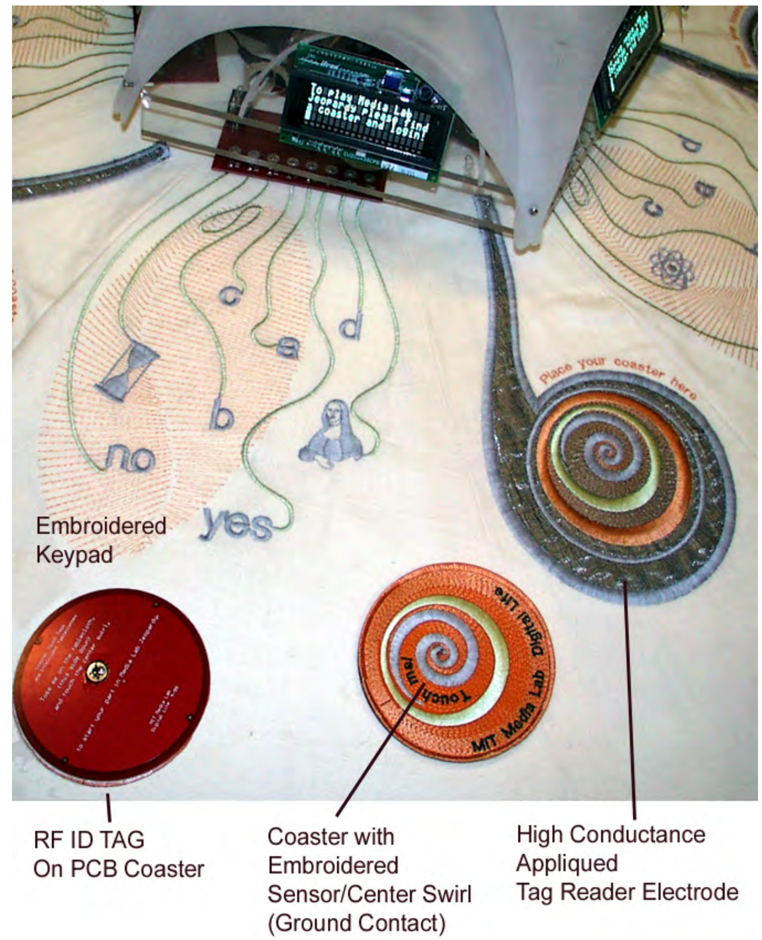

Figure 10.10 Details of *Electronic Tablecloth*, keys represent information in images and words.

feel that there was a meaningful design relationship between the ornament and the electronic needs. Even though the design of the conductive embroidery was incredibly painstaking, involving stitch-by-stitch control to insure the best electrical continuity and highest level of conductance, this did not have a tremendous effect on the visual design. Certainly, there were some very definite stitch patterns that led to highly conductive embroidery. Satin stitches were undeniably the best.[5] One continuous thread was also necessary. But these factors limited, rather than expanded, what I could do as a designer. There was still room for more variety in the visual style of embroidery I used, and a more intimate link between the images and conductivity or electrical properties of the electrodes.

The *Electronic Tablecloth* had many problems that were related to its integration into a larger game system that, unfortunately, was never completed. Consequently, speaking about the interaction of guests with the *Tablecloth* in depth is difficult. All of the tag-reader and keypad technology worked, so guests did get to log in and use the keyboard. However, they never got to play the larger game where they interacted with other guests. Moreover, the centerpieces of the *Electronic Tablecloth* demonstrated the sculptural problems that still exist when integrating prefabricated display materials into computational objects. The shape and physical properties of these displays were fixed. The best transformation of these materials that could be achieved was incorporate these displays into

Figure 10.11 Close-up of stitched Mona Lisa.

[5] See Chapter 16, Sewing Process Timeline.

a fancy housing. This housing was not offensive, but of very different style than the cloth itself.

material references: stainless steel and polyester composite thread (BK 50/2) and metallic silk organza.

technical references: Complex Impedance Sensing.