Zstretch: A Stretchy Fabric Music Controller

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ABSTRACT
We present *Zstretch*, a textile music controller that supports expressive haptic interactions. The musical controller takes advantage of the fabric's topological constraints to enable proportional control of musical parameters. This novel interface explores ways in which one might treat music as a sheet of cloth. This paper proposes an approach to engage simple technologies for supporting ordinary hand interactions. We show that this combination of basic technology with general tactile movements can result in an expressive musical interface.

Keywords
Tangible interfaces, textiles, tactile design, musical expressivity

1. INTRODUCTION
Why is music fun to play? The wealth of actions available to our hands, coupled with the physical shape and material of an instrument allow for a wide range of musical expression. For example, practiced hands can float and glide across the keyboard to lightly tickle the strings, or hammer down and rake across the keys to create thunderous sounds ringing with rage. Musical expressivity is closely related to haptic movement, and traditional interfaces support a wide range of motions, such as percussion, lateral motion, static contact, pressure.

However, in many novel musical devices, this focus on flexibility of gesture and expressive range is downplayed in comparison to the focus on complex sensing free gesture mechanisms (e.g. capacitive sensing[18] or lasers[13]). Instead of focusing on new interactions enabled by technological advances, it is our intention to explore how we simple sensing mechanisms can support routine tactile interactions. Something as commonplace as a stretchy piece of cloth might be quite satisfying for users to interact with and allow for a wide range of musical expressions

2. DESIGN CRITERIA
Fabric is not the first material people think of when controlling music. However, stretching fabric can provide rich and dynamic expression (Figure 1). Fabric can allow for a wide range of interactions (see Table 1). Furthermore, the idea of stretching is

Figure 1. Typical interactions with fabric involve (a) grasping and pulling, (b) scrunching and (c)twisting.

closely linked with musical manipulation. In sound editing software, one can often "stretch" a piece of music by increasing the duration or pitch. In the physical world the deformation of materials is often coupled to sound, as when wooden beams creak as they bend, or when string is bent by plucking motions.

There has been much prior research on integrating electronics into textiles [2,4,11,14,15]. However, these works have primarily focused on the user touching the fabric in special discrete areas, rather than supporting the many actions our hands and bodies can create [5]. The discrepancies in the hardness and texture of embedded electronics often interfere with the haptic interactions at the surface level. The fragility of the components often distracts the hands from the full force of their exploratory motions. Additionally, the specific localization of touch sensors and buttons often diminishes the freedom of interactivity, as performers must focus on targeting instead of being able to expressively interact with a larger surface area.

Some prior work on haptics in musical expression has employed the use of active haptics[3,7,17], exploiting the expressivity of the hands. Other works utilize proprioception, through manipulating tokens spatially [9] to control audio. Beatbugs[8] are a series of handheld toy controllers that control music based on squeezes and taps. We prefer to focus on how an interface can support active haptic manipulation of physical properties for musical control [7] rather than developing specific localized mappings. We are similarly interested in overcoming the learning barrier by supporting existing tactile interaction with fabrics, and the typical range of forces sustained during fabric interaction. People

Table 1. Design Space for Textile Music Controller

Design Parameter	Range
Speed	Slow ⟷ Fast
Motion direction	Normal / Lateral / Surface /Combination
Localization of interaction	Exact Points ⟷ General Area
Independence of controls	Independent ⟷ Coupled
Force	Gentle ⟷ Rough
Handedness	Left / Right / One-handed / Two-handed
Object control	Static / Spatial Placement / Deformation
Form factor	Wearable / Handheld / Wall / Tabletop

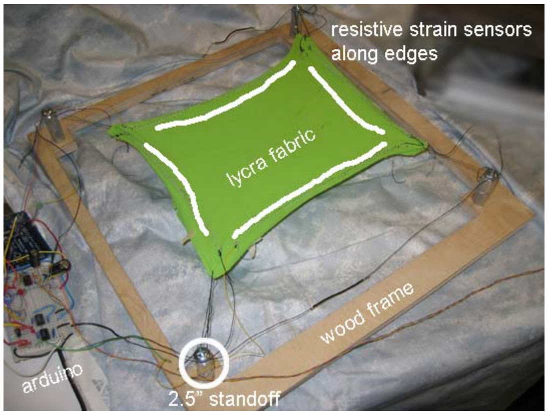

Figure 2. System design of hardware and mechanical setup

typically pull on hems, push shirts under other clothes, and might even scrunch them up to toss a piece of fabric into the hamper.

3. BASIC IMPLEMENTATION

The implementation was guided by 2 main design criteria:

- focus on supporting existing touch interactions of fabric
- exploiting the physical properties of the fabric to alter musical parameters

3.1.1 *Mechanical Design*

The main consideration is that the instrument should feel like fabric—the surface should retain the smoothness and softness of fabric, regardless of the presence of electronics. Another consideration is unimpeded access to grab and manipulate the edges and surface of the fabric. A 14”x14” portable wooden frame was built to support interactions such as stretching, twisting, and pulling. The tabletop frame (see Figure 2) supports the fabric using elastic thread connected to the four corners. A 2.5” vertical distance exists between the base and the fabric.

3.1.2 *Resistive Strain Sensing Circuit*

Another design consideration is that the cost and implementation of haptic sensing interfaces has been costly in terms of resources and equipment. Based on work by [15],we settled on resistive strain transducers because they seemed simple to implement and did not distract from the soft feel of the fabric.

After experimenting with various stitches, *zigzag stitches* were used. Resistivity increased with amount of thread on the fabric, so dense zigzag stitches resulted in higher resistivity, but exhibited less change in resistance when stretched. *Stretch stitches* that had

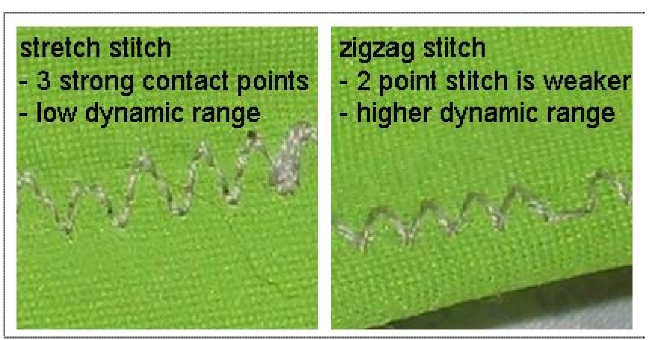

Figure 3. Stretch stitch (at left) is stronger and exhibits lower dynamic range than the zigzag stitch(at right)

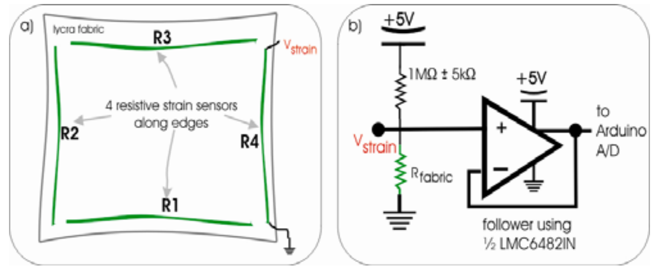

Figure 4. a)Layout of sensors on fabric and b)corresponding circuit diagram for each strain sensor

more contact points were also less likely to rip out of the fabric over prolonged use, although there was less dynamic range for changes in stretch length (see Figure 3 for comparison). A medium-sized zigzag stitch was chosen because it provided the greatest dynamic change of resistivity in proportion to stretch, while also having medium robustness against stitches becoming undone. The edges were sewn using a #4 wide zigzag stitch on a Brother LS-2125 sewing machine. The #4 setting resulted in a zigzag stitch ¼” wide, with approximately 10 stitches per inch. We stitched Bekaert conductive thread on all four sides of a piece of Lycra fabric [6] approximately 7.5" x 9".

The resistance of each side measured approximately 140kOhms at its initial state to 10MOhms when fully stretched. A 1:10 voltage divider was used to increase the dynamic range. A LMC6482 follower circuit improved the impedance of the voltage divider when connecting the signals to the A/D input pins of an Arduino sensor board[1]. The voltage typically varied between 3V and 4.7V. Figure 4 shows the location of the resistive strain gauges along the sides of the fabric, and the corresponding schematic circuit diagram for measuring the change in resistance of one side.

3.1.3 *Software using PD*

A PD patch [12] was created to map the fabric stretch directions to musical parameters. The horizontal sides were mapped to the speed of a preloaded sound loop. The vertical sides would alter the volume of the loops. There were 2 loops that could be loaded. Figure 5 shows the PD screen for controlling the volume and speed of the first audio sample at the lower left and similar controls for the second sample located at the upper right.

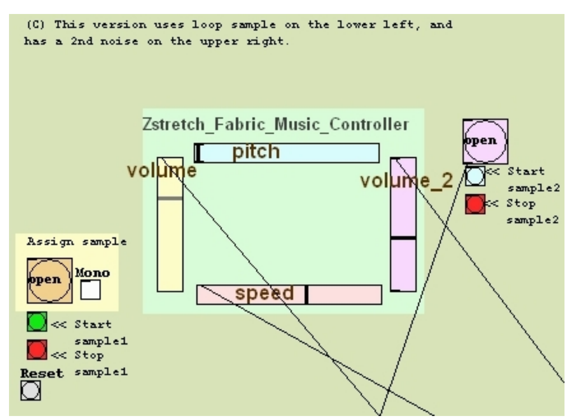

Figure 5. The PD screen showing the interface mapping

4. Operating Characteristics

Impromptu demos of the Zstretch were given to and tried by 10 different fellow graduate and undergraduate students, as well as one performance in a small classroom setting of 12 students. The Zstretch performed satisfactorily, it responded quickly to the speed of user motions. If a user tugged quickly, the audio would respond in real time. The resulting embodiment was also robust enough to support rough and fast stretching, while remaining sensitive to slow and gentle tugging motions.

4.1 Haptic expressions supported

In general, the Zstretch supported normal fabric interactions: stretching, grabbing, and twisting on both the normal plane and edges. Stretching any part of the edges allowed the different parameters to be changed. Users would typically use a combination of one-handed and two-handed movements. The user could alter all of the parameters by grabbing a corner or edge and twisting (as shown in Figure 6). Users often used one hand to tug on the lower left or upper right corners to amplify the two sound loops. In one case, a user pushed down all four sides using a book and caused a cacophony as both samples blared loudly. A similar effect could also be created by pulling the fabric upward from the center.

The Zstretch's coupling of physical properties constrained the musical parameters somewhat, such that it was often hard to control just one parameter. Figure 7 shows how a user might focus the stretch using two hands, either by localizing the stretch to a corner or stretching only one side. In general, when one side was stretched, there was a tendency for the other sides to stretch in proportion to the deformation and place of interaction If the user really wanted to control only one parameter, they might grab just one axis and stretch locally between points.

4.2 Fabric coupling of musical parameters

The spatial coupling of parameters in the Zstretch results in some interesting constraints. As mentioned above, it was often natural for one motion to change multiple parameters. Because of the topological constraint of the fabric, stretching one side will result in deforming and affecting the other sides. In the Zstretch, the coupling of playback speed to volume was intentional. This relationship is reminiscent of the coupling between volume and pitch in many traditional instruments. Timpanis and accordions exhibit the same coupling of parameters. The Zstretch response is analogous to an accordion, where the stretch of the interface alters the note frequency and reverb in a coupled manner. Correspondingly, drums are essentially sheets of fabric stretched across a hollow chamber. In percussive instruments like the timpani, many parameters (pitch, reverb, attack, and amplitude) are proportionally controlled and the instrument has high expressive range.

4.3 Mapping Direction to Musical Parameters

It is important to mention that the choice of mappings presented could be easily reconfigured. Some preliminary investigation was done to mix and match different musical parameters to different locations. In general, an increase in stretch seemed to map well to increases in volume or pitch. However, stretch could be arbitrarily mapped to speed. Stretching the fabric to slow down a loop seemed to be just as reasonable a choice as increasing the speed of playback. In the slowing down case, the fabric represents a time scale. In the speeding up case, stretching represents the physical motion of pulling music, causing it to speed up. Many other musical controls, such as timbre, tremolos, reverbs or filter frequencies may have arbitrary directional mapping.

Figure 6. Some typical one-handed gestures.

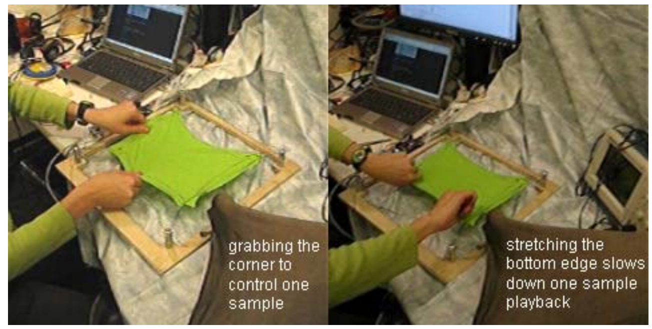

Figure 7. Two handed interactions

4.4 Problems encountered

The general expressiveness of our interactions with fabric started off being quite satisfactory. Over time, however, it was noticed that the sensitivity would drift and recalibration to the voltage divider would have to be performed. As the interface got more use, users had to stretch longer distances on the resistive strain gauges to achieve the same effect. Another problem was the comparatively lower resistance of the body could effectively short part of our sensor. One workaround would be to hem the sides so that the stitches remain insulated from direct contact with the skin.

4.4.1 Stitch Fatigue and Repair

Although stitches had been specially selected for robustness, some of the stitches came out after repeated, forceful use. The repair consisted of shorting these isolated breaks with more conductive thread. There was also a tendency for the sensors to drift over time, as the stitches exhibited lost sensitivity over time, perhaps due to fatigue from cyclic stretching of the fabric threads.

4.4.2 *Fabric Wear*

The performance of the system was also compounded by the relaxation of the fiber mesh over time. As the fabric became more compliant, the stretch was only partially transmitted to the edge with the strain gauge. Perhaps a slightly less stretchy fabric or a more robust fabric should be used so that the stretch is adequately transmitted across the fiber mesh. Another suggestion is to make conductive thread patterns that cover more surface area. Luckily, most users tended to grab the edge of the fabric, so users would inadvertently exert their stretches close to the strain gauge.

4.4.3 Mechanical Considerations
Because users were able to freely exert variable amounts of force (from 0.0 to -0.8 N) on the fabric, the wires connecting the fabric to the Arduino tended to shear off the fabric. One solution was to increase the elasticity and thickness of the four supporting corners of the fabric. A second solution was to reinforce the connections between the conductive thread to the wires by reinforcing stitches around the areas where the wire and thread connect to the fabric. After a few weeks of use, the fabric started to tear. The only solution for fixing the fabric tears was to sew up the holes. Figure 8 shows the wear and tear of the interface.

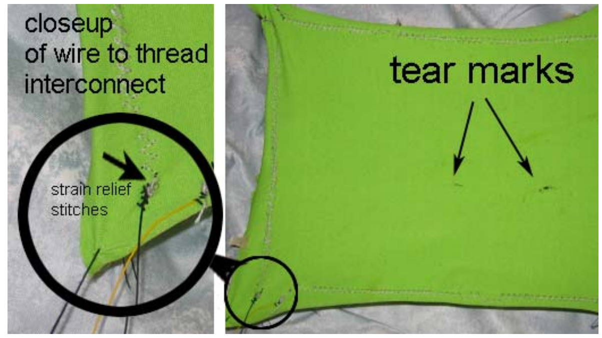

Figure 8. Holes and thread breakages on the fabric surface

5. CONCLUSIONS
We have characterized the haptic design space and implemented a fabric music controller that uses the stretch of fabric. Although the initial directional mappings for speed and volume were usable there is still a lot of work to be done in developing a framework for musical mapping. Sometimes the dueling audio loops caused confusion or too much noise. Instead of using two opposite sides to control two separate sound loops, we intend to try mapping all four strain gauges to different parameters of one sound loop.

The benefits of the Zstretch lie in its very reasonable implementation. It requires very few components and basic sewing skills. The techniques shown in this paper can also be instantiated in many other scales and orientations, such as wearable, wall or handheld installations. Finally, we hope that the articulation of the unobtrusive and experience-focused design criteria will find resonance with fellow music designers.

Michel Waisvisz from STEIM noted during his keynote speech at CHI 2005, "We are too busy inventing new interfaces, instead of pushing the boundaries of the interfaces we already have [16]." One interpretation of this view is to build upon our existing tactile interactions (in this case, fabric gestures) and explore the expressive mapping of known interactions to low-tech music controllers. Users can transfer their existing fabric interaction knowledge to twisting, pulling and pushing the Zstretch. We acknowledge that Waisvisz may be right; even for our "simple interface", many expressive mappings are possible (through altering the scale of interaction, the controller parameters, the stiffness of the fabric, the coupling of the parameters to each other, or adjusting sensitivity), and numerous haptic-fabric taxonomies have yet to be identified, studied, and mastered.

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