

Designing a Multi-Touch eTextile for Music Performances

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ABSTRACT

We present a textile pressure sensor matrix, designed to be used as a musical multi-touch input device. An evaluation of our design demonstrated that the sensors pressure response profile fits a logarithmic curve ($R^2 = 0.98$). The input delay of the sensor is 2.1ms. The average absolute error in one direction of the sensor was measured to be less than 10% of one of the matrix's strips ($M = 1.8\text{mm}$, $SD = 1.37\text{mm}$). We intend this technology to be easy to use and implement by experts and novices alike: We ensure the ease of use by providing a host application that tracks touch points and passes these on as OSC or MIDI messages. We make our design easy to implement by providing open source software and hardware and by choosing evaluation methods that use accessible tools, making quantitative comparisons between different branches of the design easy. We chose to work with textile to take advantage of its tactile properties and its malleability of form and to pay tribute to textile's rich cultural heritage.

Author Keywords

Multitouch; piezoresistive; fabric sensor; e-textiles; tangible computing; musical input.

ACM Classification

H.5.2. [Information Interfaces and Presentation] User Interfaces: Input devices and strategies (e.g., mouse, touchscreen), H.5.5 [Information Interfaces and Presentation] Sound and Music Computing: Systems.

1. INTRODUCTION

We present a soft textile multi-touch sensor designed for musical input as an alternative to existing rigid devices. Conventional input devices have materials and fixed shapes that constrict our possible actions to a predesigned set. A textile device, however, does not have such fixed affordances. A sheet, for example, can change its affordances rapidly when reconfigured. It could be tied in multiple knots to create an improvised rope-ladder, it could be spread out over a table to become the decorative backdrop of a meal or it could be wrapped around a person to provide warmth and comfort.

In addition to a textiles dynamic affordances, we are fascinated by the aesthetics of textiles themselves. Textiles, as the end product of a creative process, come with a rich cultural heritage and diversity of fabrication and manufacturing traditions. Simultaneously, there are a large variety of methods that use textiles as a raw material to be further crafted into the desired object of interest.



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NIME'17, May 15-19, 2017, Aalborg University Copenhagen, Denmark.



Figure 1: Simple interactive Canvas using capacitive leads

Inspired by these properties of textiles, we set out to create an interface that would not only provide musicians with a unique and satisfying platform for performing digital music, but also be visually appealing to an audience. We believe that the unique affordances of textiles will open new expressive opportunities for performers [27], while the aesthetic qualities of textiles provide the performance with an additional layer of artistic expression.

While initially exploring large form factors that support full body interaction (Figure 1), we eventually settled on a smaller design, the shape and size of a record sleeve (Figure 2). This relatively small size was chosen as an accessible platform for prototyping and evaluating designs as it reduces material costs and enables faster design iterations. To further advance collaborative research into textile input devices, all hardware and software elements are open sourced and can be accessed on our GitHub account¹.

In this paper we present the hardware design of a resistive matrix sensor that consists of a multi-layer textile. Additionally we present a host application that uses OpenCV to transform the raw sensor data into useful information that can be interpreted by a synthesizer or DAW. We also provide a technical evaluation of the systems performance. Our evaluation uses simple tools, so that people who wish to extend or modify our designs have an easy way of quantifying if and how they improved on the design. We find that the field of textile electronic input devices is ripe with smart one-off prototypes, but that it is often difficult to infer how well these perform or make comparisons between different methods. By

¹ Link omitted for anonymization, will be in final version

sharing our work this way, we contribute to the maturation of these technologies and hope to inspire others to do the same.

2. Contributions

We present a prototype multitouch enabled fabric as music input device. The design is intended as a prototyping and developing platform to enable faster iteration and comparison of both hardware and software parameters. While our device is built on a tradition of music input devices, we offer a series of contributions over previous work. These includes:

- Descriptions of the hardware, improving the ease with which novices and experts can implement such sensors.
- A method of constructing the interface between soft fabric and rigid PCBs, using a fabric bus.
- Blob tracking to better utilizing the sensor data for multidimensional musical input.
- A technical evaluation of the force, spatial and temporal sensing resolution of the sensor.
- Generalizable guidelines for the design of sensors with different temporal or spatial requirements.

3. Related Work

The history of conductive textiles is less recent than one might think. For example, in the 17th century gold and silver yarn were woven into tapestries in France [3] or wedding dresses in Indonesia [22] for decorative purposes. It is only recently however, that we have started taking advantage of the electrical properties of such textiles. Currently when people speak of eTextiles they are typically referring to two complementary concepts: On the one hand there are systems such as Lilypad [5] that are typically used for augmenting existing materials with electronic components. On the other hand efforts exist that try to combine the affordances of the textile and the functions of digital circuitry into hybrid eTextiles [4, 11]. Our work contributes to both traditions. Our sensing approach uses and traditional textile fabrication methods to create an analog electronic device, while our bus system improves over methods explored by researchers and tinkerers that add electronic devices to fabrics.

The motivations for working with eTextiles are varied. A recurring theme are the aesthetic and sensual qualities of fabrics, explored in various artistic installations [2, 9]. Others have approached the topic from a fashion design perspective, using eTextiles to expand the tools available to fashion designers in manufacturing garments that have additional functional elements [1, 13]. A frequent motive is also that the crafting process that results from combining textile and electronic workflows appears to be more approachable than either alone, making eTextiles a popular medium of introducing young people to creating their own interactive technologies [6, 16, 17].

Soft circuitry presents designers both with new opportunities and new challenges. Much creativity, ingenuity and hard work has been invested into finding soft, hand-craftable alternatives to traditional rigid digital components such as switches, multiplexers or sensors [18, 19]. Practitioners have created online open source libraries [15] and physical swatchbooks to share their designs². The communities around this craft of textile electronics typically come together at textile-hackerspaces such as Datapaulette³ in Paris or the Electronic + Textile Institute in Berlin⁴ and at annual events such as



Figure 2: eTextile sensor based on the design described in this paper. Visualization provided by host application.

'Schmiede'⁵ or the E-Textile Summer Camp⁶. It is within this culture of open source exchange of knowledge between the Arts and Technology that the work presented in this paper emerged.

A promising alternative to manipulating fabrics is investigated by Rathnayake and Dias [21] who integrate the electronic elements into the core of yarns. Google ATAP recently published a simpler but related approach [20].

Various methods exist to facilitate fast prototyping of multi-touch input devices. The most common are capacitive touch sensors. Others have used infrared [25], resistive [14], or even skin-conductance based sensors [7]. In combination with fabric, stretch sensing approaches have also been popular [8, 26]. Methods used in flexible or fabric devices include 4 wire resistive touch [24], two wire resistive touch [28] and a variety of other approaches [10]. The sensor discussed in this paper is very similar to resistive multitouch matrices presented by Roh et al. [23] and Zhou et al. [29]. Roh et al. present various methods to design and fabricate such sensors, while Zhou explores what kind of information can be visualized using the raw data. We expand on these devices by showing how the data can be used for input to musical devices and by evaluating their performance in the context of musical input and by making first steps towards generic design guidelines.

The affordances of textile or deformable instruments have been explored within the HCI community, for example Gomes, et al [12] explored flex-input for modulation and effect control while Troiano et al. explored what type of input musicians preferred for what type of control [27], suggesting tapping or pushing for sound generation and deformations for sound modulation. Our own input methods currently are simpler than those suggested by Troiano and Gomes, as we are still evaluating the basics of our design, however going forward we wish to support these as well.

4. Implementation

Our design follows the same principles as sensors presented by Roh [23] and Zhou [29]. The hardware and software design is freely available and documented on Github⁷. The design consists of the textile sensor, a microcontroller board, a custom PCB with circuitry for sampling the sensor and hardware for physically connecting to the sensor, and a computer application that interprets the data to pass it on as OSC messages (Figure 2).

² <http://etextile-summercamp.org/swatch-exchange/>

³ <http://datapaulette.org/>

⁴ <https://etiberlin.wordpress.com/>

⁵ <http://schmiede.ca/>

⁶ <http://etextile-summercamp.org>

⁷ Removed for anonymization



Figure 3: Multi-layer structure of eTextile sensor: non-conductive (outside), piezo resistive (center) and conductive (in strips) materials combine to form the sensor.

4.1 Textiles

The eTextile consists of a ‘sandwich’ of materials with different properties. The outer layer is a non-conductive textile (Figure 3, striped, dark Purple), the core consists of a piezoresistive material (black) and between the outer layer and the core there is a layer of conductive material arranged as a grid (silver).

4.1.1 Conductive

The conductive textile is cut into strips that are fused to the non-conductive backing. The conductive textile must have minimal resistance, as any resistance it has would reduce the measurement precision, and it must be easy to cut into custom shapes. Currently the conductive material is cut into strips by hand. In the future we will explore other patterns to improve the transition between stripes, using a laser-cutting process. Potential materials that can be used include the ripstop line by Statex⁸ - we have successfully used Statex ‘Bremen’ in combination with two layers of iron-on adhesive sheet. Various Chinese manufacturers produce conductive material that have the benefit that they come pre-fused to iron-on glue.

4.1.2 Piezoresistive

The core needs to change its conductive properties when compressed. Materials such as Velostat achieve this by proxy of the quality of the surface contact. Piezoresistive materials change their resistance based on compression. Our current implementation uses a piezoresistive material by Eeonyx⁹ that has a resistance of 20K ohms per square if uncompressed.

4.1.3 Non-conductive

The non-conductive material turns the layers of conductive stripes and piezoresistive core into a single, cohesive object. It also serves the function of an insulator.

We consider the texture of the non-conductive material to also be a functional property (Figure 4). For example the orange textile (Figure 4, top left) has a relatively uniform grain, while the grain of the textile shown in figure 3 and bottom left of Figure 4 has a grain with a clear directionality. This directionality of the grain gives the textile a unique affordance, the experience of moving in one axis can be clearly distinguished from the other.

We are in the process of actively exploring such tactile affordances by designing custom textiles. The overlay seen in Figure 4 (top right) uses neoprene dots fused to a soft elastic sheet, while the overlay at the bottom right has a screen-printed tactile pattern.

4.2 Bus System

One of the challenges of eTextiles is that electronic components typically are rigid while textiles are soft and elastic. Any



Figure 4: Four different tactile experiences: Textiles on the left are the part of the sensor, textiles on right are overlays designed to explore alternative affordances

interface between a rigid and a flexible object will be brittle and a potential breaking point. Additionally, the go-to crafting methods of the two media (sewing and soldering) are inherently incompatible. This makes connections between electronics and fabrics challenging, especially if dealing with a large number of connections as found in our textile

We address this problem by designing a ribbon with integrated conductive thread (Figure 5, right). This ribbon is placed perpendicular to the conductive strips and the conductive strips are connected to the ribbon by sewing them together with conductive thread. Headers can be crimped to the conductive ribbon, using methods otherwise used for flexible thin film cables (Figure 5, bottom). These headers allow connecting the ribbon to rigid electronics. Alternatively, to save space, the ribbon can also be directly sewn to a PCB with a dual-row of holes for standard header pins (Figure 5, top).

4.3 Electronics

We created a custom PCB to use with the Teensy3.x that can be sewn to the ribbon or connected with headers. This PCB includes a resistor array, a button, an LED, a battery connector, a charging circuit and an audio output. The resistor network is used to create voltage dividers. These are used for measuring the resistance between the top and bottom layers of strips. We sample the voltage of each top strip while sequentially pulling each of the bottom strips high. This enables us to infer the pressure at the intersection of each of the top strips with each of the bottom strips, for a total of 265 (16 by 16 strips) pressure values. Whenever the calibration button is pressed or the teensy rebooted, the noise floor is removed by subtracting the state of the resting sensor from all future readings.

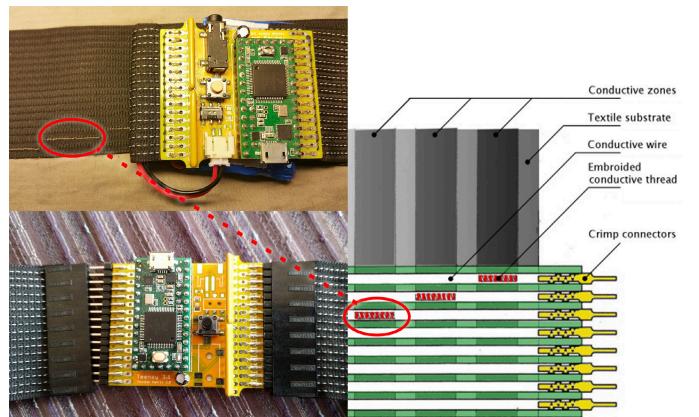


Figure 5: Bus system – Schematic representation (right) and example of ribbon sewn to PCB (left, top) and ribbon crimped to female headers (left, bottom). Connections are made by sewing conductive thread where ribbon and strips overlap (highlighted in red)

⁸ statex.biz/index.php/en/2012-04-06-13-28-47/item/159-shieldex%C2%AE-gewebe

⁹ http://eeonyx.com



Figure 6: Images taken during the evaluation of force sensitivity.

4.4 Software

The Teensy3.x sends the raw sensor readings to a host application over USB. The host application interpolates the data to extend the resolution from 16x16 to 64x64 or more, as this eases the implementation of the blob-tracking.

We treat the raw data as an image and use blob-tracking to identify touch-points. We assign a persistent ID to each touch-point: if a finger is lifted and then placed back at the same position or a position matching its trajectory, it maintains its ID. The host application is written using Open Frameworks. The blob tracking is done using OpenCV.

The host application then sends out an OSC message for each touch-point containing its ID as well as position (x,y), pressure (z) and size (A). Typically the x dimension will control the pitch of the tone and the pressure (z) the volume. The y dimension and the area (A) can be used to manipulate filters or effects. These mappings are not mandatory, other mappings can and should be explored in the context of textile devices. For example, if the y dimension is also mapped to pitch, interesting polyphonic effects can be achieved by folding the textile.

To allow easy exploration of this input-dimension space, we provide sample applications of simple synthesizers made with SuperCollider¹⁰ and PureData¹¹, demonstrating how the dimensions of each touch-point can be used to manipulate sound parameters. The host application can also provide MIDI output to connect to applications such as Ableton Live.

4.5 Embedded Options

We intend to integrate the host application with the embedded application, enabling future eTextile devices to directly communicate with DAW software or allow stand-alone operation. Currently we provide two alternative builds of the embedded software, one version acts as a standard MIDI device¹², and the other version provides direct audio-out¹³, using the DAC of the Teensy3.x. The drawback of the MIDI build is that it currently does not support multi-touch.

5. Evaluations

As more variations of the initial design are being created, it becomes more relevant to compare not just their feel, but also their objectively measurable performance. By doing so we intend to not only characterize the existing sensor, but also identify where improvements to our design are necessary, create generalizable guidelines for future designs and create a benchmark that these future designs can be compared to.

To make our evaluation easily reproducible, the tools we use are as simple as possible. They consist of a series of weights cut out of European 50 cent coins, as well as laser cut round

disks of different sizes to create controllable touch-points of varying size.

The evaluations are not measure of maximum possible performance of this sensor type, but represent the current status quo of one of our sensors. We intend to use this data in the future to describe how changing parameters of our design can improve sensor precision in future iterations.

5.1 Force Sensitivity

We placed objects of varying weight on our sensor to measure how a change in weight relates to a change in output signal. We used €0.05, €0.10, €0.20 and a €0.50 coins to measure light weight. We then increased the weights by stacking 5, 10, 15, 20, 40 €0.50 coins. Finally we placed 0.5kg (64 €0.50 coins), 1kg, 1.5kg and 2kg weights on the fabric (as seen in Figure 6). We recorded blob position as well as raw sensor data for each weight. We used a weighted average of the three highest sensor readings per blob (3:2:1 ratio in descending order) to describe the blobs z-value. We repeated the series of measurements 7 times for a total of 112 measurements (Figure 7).

We found that overall there was a high logarithmic correlation between the applied force and the recorded z-values ($y = 34.128 \ln(x) - 43.016$, $R^2 = 0.98$), however, the measures were divided in two sessions as the entire dynamic range of the sensor cannot be used concurrently. Weights below 10g required a more sensitive blob-calibration that leads to artifacts if heavier weights are used. If the blob calibration is adjusted to work well with heavy weights, the light weights no longer register, and we cannot extract a z-value from them. In the future this can be compensated with a dynamic blob-threshold. Figure 7 shows the maximum, minimum and average sensor output for each weight.

Please note that we are not evaluating the pressure response curve of the piezoelectric core, but rather of the entire system. Had we placed each weight at the same location, our response curve would show less variation, however such an evaluation would not capture the sensors properties, as a performer would currently experience them.

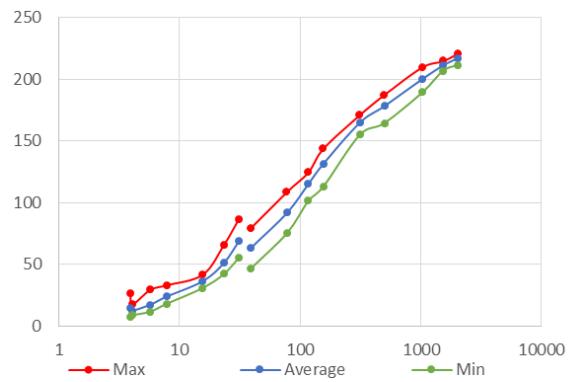


Figure 7: Weight (x-axis, grams) vs sensor output (y-axis)

¹⁰ Link to source code removed for anonymization

¹¹ Link to source code removed for anonymization

¹² Link to source code removed for anonymization

¹³ Link to source code removed for anonymization

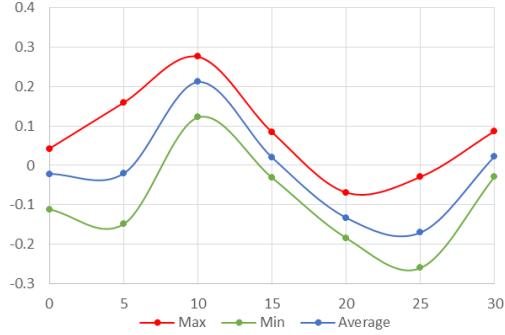


Figure 8: Location (x) vs measurement error (y) in mm

5.2 Spatial Resolution

We laser cut 6 circular chips out of pressboard sheets. The diameter of these circles was 125mm, 20mm, 25mm, 30mm, 50mm and 75mm respectively. We added weights to each chip so that the weight per cm^2 was $\sim 25\text{g}$. We then placed each of these objects on 21 locations of the sensor (3 columns with 10mm spacing by 7 rows with 5mm spacing) for a total of 126 measurements (demonstrated in video figure).

We found that the average absolute error in one dimension was less than 10% of the strip width ($M = 1.8\text{mm}$, $SD = 1.37\text{mm}$). Based on this we calculate the average absolute error to be 12.5% of the strip width ($\sim 2.5\text{mm}$) in two dimensions. Figures 8 and 9 show some systematic properties of these errors. Figure 8 highlights issues with the interpolation: As the pressure point transitions from one strip to the next, it will initially overestimate the actual position of the pressure point, and will then underestimate the position once it has moved beyond the center of the strip. The maximum errors resulting of this motion are typically less than 15% ($<3\text{mm}$) of the width of individual strips (Figure 8).

Figure 9 shows that the different pressure point sizes did not contribute equally to the overall error. We found that pressure points that were 150% the size of the strip (30mm) created the smallest errors: $\sim 6\%$ of strip width ($M = 1.2\text{mm}$, $SD = 0.9\text{mm}$).

5.3 Latency

Especially for percussive instruments the temporal precision of the sensor is important. To better understand the temporal properties we measure the time that the microcontroller takes for executing the readings. The microcontroller measures 256 analog voltages, each measurement is conducted 4 times and averaged to reduce noise. Once the measures are taken the noise floor from the initial calibration is removed and, the data is sent over USB. The total time of this was measured 10 times by creating a timestamp at the beginning of the measurement cycle and comparing that to a second timestamp that marked the completion of the measurements. The total time was 2.1ms ($M = 2100.78\mu\text{s}$, $SD = 2.2\mu\text{s}$).

6. Design Guidelines

Our evaluation points out what aspects of our sensor can be improved. We hope the evaluation to be generalizable to other sensor, which is why we present results in *percentage of distance of sensing elements*. We can also extract some lessons from our evaluation that provide us with useful heuristics for designing future sensors.

6.1 Spatial vs Temporal Resolution

An inherent limitation of matrix-style sensors is that if the resolution of the sensor is doubled, so is its latency. This can be mitigated by, for example, dynamically adjusting the resolution. This can done in hardware by pulling multiple strips high instead of one, or can be done in hardware by temporarily

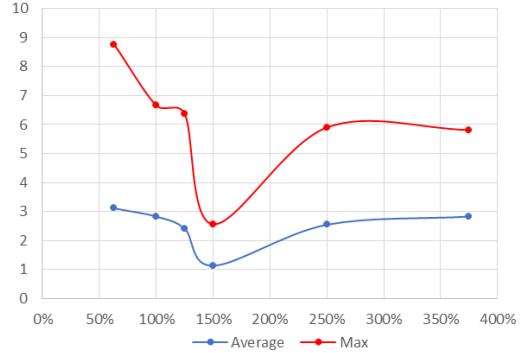


Figure 9 – Pressure point size (x, in percent of strip width) vs absolute error in two-dimensions (y, in mm).

connecting multiple ADC channels and only reading from every other channel. A piece of textile with a series of conductive patches the size of two strips could be folded into the sensor to achieve the hardware modification.

6.2 Strip Width

If we have information on the size of the expected pressure points (think finger, vs cat-paw, vs foot) we can calculate the size of the strips to maximize its size or minimize the error. Our measurements suggest maintaining a ratio of expected pressure point size to strip size of 3:2. For example, when designing a sensor for fingertips ($\sim 15\text{mm}$) the strips should be spaced approximately $\sim 10\text{mm}$ apart. If designing a sensor for cat-feet ($\sim 24\text{mm}$) the strips should be spaced approximately 16mm apart.

If we have no knowledge of the expected pressure points but wish to keep our error below some absolute measure, we should design the sensor so that the acceptable error is less than 12.5% of the strip width.

7. Future Work

So far we have barely breached the opportunities provided by the textile, as we have used it more or less as one would a large touchpad. The soft, malleable nature of the sensor opens up an exciting design space: For example, it could be draped over a drum pad, to trigger multiple synthesizers with a single action. The sensor could be folded for chorded input – reconfiguring the folds provides users with a fast way of programming the composition of the chords (Figure 10, left). The textile can be draped over objects of various shape, enabling musicians to explore concave or convex input devices. Finally its textile

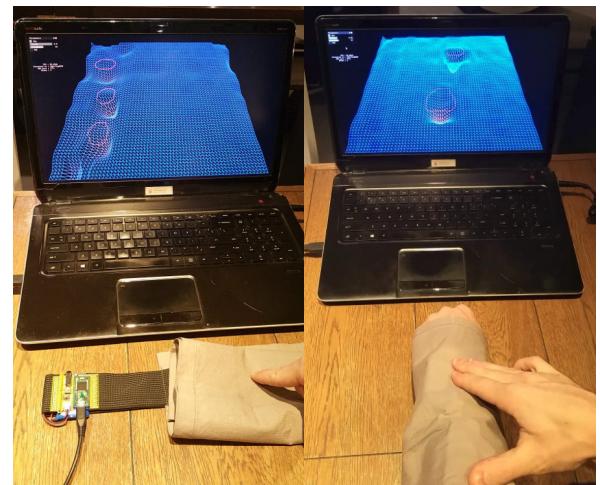


Figure 10 – The sensor is folded for one-finger chorded input and worn as a sleeve for on-body interaction

nature allows it to be draped over the body, be it as clothing or as a soft, malleable wearable (Figure 10, right). We intend the groundwork provided in this paper to support future explorations of this space.

8. Conclusion

We have presented a textile multi-touch sensor, together with ample documentation on its construction and use. For us, working with textile is not a coincidental choice, rather it comes out of a position of respect towards the rich cultural heritage that comes with textile and a fascination of the opportunities that the malleability of fabric and the tactile properties of different textiles provide in the design of musical input devices. Our evaluations demonstrate that the spatial and temporal precision of the sensor is high enough for being used for performing music, but that there is also room for improvement. Most of all we hope that our evaluations will help others make better design choices when designing their own sensors and provide others with a tool to assess if and how their designs improve over the one provided by us.

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