Application of new Fiber and Malleable Materials for Agile Development of Augmented Instruments and Controllers

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ABSTRACT

The paper introduces new fiber and malleable materials, including piezoresistive fabric and conductive heat-shrink tubing, and shows techniques and examples of how they may be used for rapid prototyping and agile development of musical instrument controllers. New implementations of well-known designs are covered as well as enhancements of existing controllers. Finally, two new controllers are introduced that are made possible by these recently available materials and construction techniques.

Keywords

Agile Development, Rapid Prototyping, Conductive fabric, Piezoresistive fabric, conductive heatshrink tubing, augmented instruments.

1. INTRODUCTION

Many human activities have a variant form optimized to deliver results in the shortest time. The idea is the same although the names vary: short story writing, hacking, sketching, composing esquisses, short-order cooking, improv., fast-turn, live coding, rapid prototyping etc. Rapid and agile development of augmented instruments and controller prototypes is valuable because many of the important insights that guide design refinements are unavailable until performers have experienced and used a device. The best predictor of the effectiveness of new controller design is usually the number of design iterations available.

Controller projects usually involve co-design of musical mapping software, electronics for the sensor data acquisition, and the physical interface. Providing an approximate physical interface early speeds development of the other components of the system by providing both a real data source and time for performance skills to be acquired.

This paper focuses on new physical design techniques and materials. We will not explore electronic interfacing and music control structure programming issues because mature rapid-prototyping methods [2] are already well known to the

community – notably: high channel count, high resolution data acquisition [1, 5, 12]; OSC wrapping, mapping, scaling and calibrating [17]; and visual programming dataflow languages [15] tuned for media and arts applications, e.g., Max/MSP, Pd, SuperColider, Processing, etc.

The paper is structured as follows. Section 2 introduces new materials that facilitate rapid processing by describing a series of variations on a single theme: the humble footswitch. Section 3 shows how existing controllers can be rapidly improved using those new materials. Section 4 describes novel controllers made possible by the new materials. A conclusion considers the challenges of teaching the design and construction techniques that these new materials demand.

2. Variants of the footswitch

A simple controller perhaps, but the humble footswitch finds wide use in technology-based musical performance contexts because the performer's hands are usually actively engaged playing an instrument. The traditional approach is to mount a heavy-duty mechanical switch into a solid metal box. These "stomp boxes" are standard tools of the electric guitarist. As a vehicle for exploration of new fiber and malleable materials we will improve on the traditional stomp box by adding the requirement that switch operation should be silent.

The basic design pattern for a switch is to combine an interruptible electrical conduction path (contact system) with a device that returns the contacts to a stable rest equilibrium when the actuating force is removed. The additional challenge we face is that the motions created by these forces have to be dampened to minimize the sounds they make.

2.1 Floor Protector + FSR

Figure 1 shows a solution that can be assembled in a few minutes.
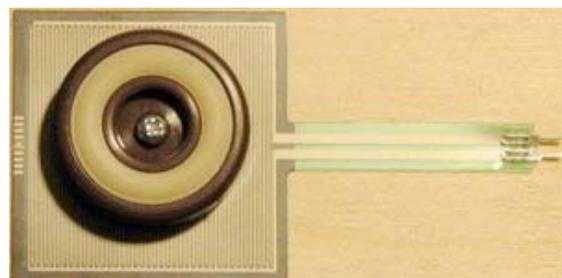
Figure 1:FSR Footswitch

The foot/switch interface is provided by a soft but "grippy" toroidal ring of molded rubber embedded in a hard PVC disk.

These disks are sold as "floor protectors" for furniture. A flat ring of polyurethane foam with a peel-off adhesive is on the opposite face of the disk. This foam provides the restoring force for the "switch" which is implemented with an Interlink Force Sensing Resistor (FSR). A screw provides the necessary adhesion to resist kicks of the foot and also preloads the FSR. Although not generally a good idea, punching a hole at the center of the FSR (with an office hole punch) provides a clear path for the screw to reach the wooden substrate below. Dust is prevented from entering the gap between the interdigitated conductor layer and the piezoresistive film layer by the foam. This sensor works adequately but the tension adjustment is delicate as the FSR saturates easily at the range of forces a foot can easily apply.

2.2 Floor Protector + Piezoresistive Fabric
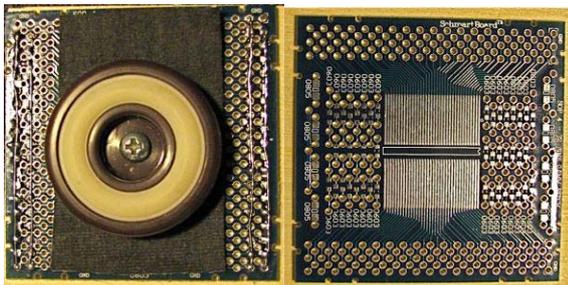
Figure 2: Fabric/PCB Footswitch

In Figure 2 we have replaced the FSR package with a PCB containing dozens of adjacent conducting strips and a patch of piezoresistive fabric made by EEonyx (http://eeonyx.com). The measuring principle is basically that of the FSR except we have exchanged the position of the conducting elements and piezoresistor with respect to the foot. This interface took a few minutes longer to integrate because the circuit board needed to be wired so that alternating traces were connected. The board is a Schmartboard surface-mount prototyping board (http://schmartboard.com). The tension adjustment is unproblematic because the piezoresistive fabric supports very high dynamic range of forces. By combining plies of fabric or selecting a thicker felt substrate the foam layer could be eliminated from the design – the fabric itself providing the restoring force. This would be a higher reliability solution as polyurethane foam breaks down, especially on PVC substrates [14].

2.3 Floor Protector + Piezoresistive Fabric+Conductive Adhesive Copper Tape and Conductive Fabric

The sensor shown in Figure 3 uses the same piezoresistive felt fabric as that of Figure 2 but avoids the need to print a conductor pattern by using a conductor on either side of the fabric. The base conductor is a series of overlapped adhesive copper strips. They form a single conductor because the adhesive itself is a conductive acrylic.
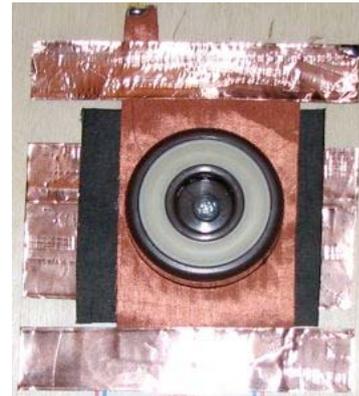
Figure 3:Fabric/Foil Footswitch

The top conductor is a copper impregnated nylon fabric. The advantage these materials offer is that the sensor can be scaled in either direction simply by cutting more tape or cutting larger pieces out of the base fabric stock. Wires can be soldered directly to the copper tape and with some practice even to the copper fabric.

Many interesting variants of this design are possible by substituting the copper tape with conductive fabric and using conductive and insulating thread for adhesion. These techniques are the basis of many wearable switches and sensors [3, 4, 11].

2.4 Half-round + Piezoresistive Fabric+Conductive Heatshrink + Copper Tape

The previous designs are limited by the sizes of floor protecting disks available. The construction illustrated in Figure 4 is free of these size constraints.

Figure 4: Fabric/Heatshrink Footswitch

A half-round wooden strip is cut to the desired length and two separate strips of copper tape are employed on the flat length and the curve. A strip of piezoresistive fabric is trapped and preloaded under the flat copper tape by a length of ShrinkMate heat-shrink tubing that is conductive on the inside (http:// methodedevelopment.com). This tubing connects one side of the fabric to the top conductive strip.

If we ground the upper strip and measure the resistance from the inner conductor to this ground the whole sensor is self-shielding. We chose the half-round configuration for the footswitch application but this technique can be used for cylinders and other shapes. Figure 5 shows a grip sensor built with a larger dowel.

Figure 5: Fabric Round Touch Rod

The inner conductors are strips of separate conductive tape allowing for separate pressure measurements around the dowel.

By carefully controlling the time of application of the heat gun the amount of shrink has been controlled to allow the tubing's inner conductor to "self connect" to tape on the dowel without constricting the piezoresistive fabric. This can be clearly seen on the left of Figure 5. These structures are mechanically stable without adhesives.

Figure 6: Bendable Pressure sensor

The sensor in Figure 6 uses the same design principal as the foot sensors but used a 1/4inch malleable aluminum tube as the substrate. The interesting feature explored in this configuration is that the shape of the entire sensor assembly can be adjusted after construction. The key to this design is the helical wrap of the piezoresistive fabric under the flexible conductive heat-shrink tubing. The overlap in the wrap avoids a short circuit path. The stray fabric end illustrates the value in rapid prototyping of the "measure-once cut and trim" principal which is in direct opposition to the traditional carpenter's maxim "measure twice and cut once". The majority of prototypes illustrated in this paper were sized "on the fly" with reference to other instruments or the performer's body rather than to numerical measurements.

2.5 E-field (capacitive) Sensing

The previous implementations use the same physical sensing principle: gesture modulating current flow. Capacitive or e-field proximity sensing is an interesting alternative principle to apply for rapid prototyping. Only one conductor is needed and more flexibility about where the conductor is placed is available. It can be under glass, plastic or wood or other non-conducting material.

Figure 7 shows a foot switch built with an approach that can be used to create sensors in less than a minute. A wire with a crocodile clip is attached to a conductive spandex fabric (http://eeonyx.com) that is stuffed inside a length of plastic door insulation. The fabric needn't be very conductive for this to work well as no current flows through it.

Figure 7: Capacitive footswitch

Although useful for rapid prototyping we have found that most capacitive sensing integrated circuits are challenging to apply for musical applications. In stage situations we have found them to be susceptible to external electromagnetic fields (from lighting dimmers for example) and reliable sensing often requires careful calibration and multiple measurements resulting in delays that are unacceptably long, i.e. hundreds of milliseconds.

2.6 Position sensing strip + Rubber Door Threshhold

To create multiple foot switches we can simply tile out arrays of the previously described devices. There is a better, faster way with the additional convenience that the switch functions are built into a single strip that is constructed quickly in a few steps. Instead of employing the principal of piezoresistivity change we employ a printed-resistor position-sensing strip such as the SlideLong (http://infusionsystems.com) or a Softpot (http://spectrasymbol.com).

Modifying an existing interface in this way is often the fastest way to develop a new controller. These position-sensing strips were originally designed for finger touch interaction. To protect the sensor strip and provide tactile feedback we attach it to the base of a length of rubber door threshold. This is molded with corrugations that grip the sole of the foot well and a curved surface above the sensor. The flat sensor stays where it is put on smooth flooring and carpets.

Unfortunately the lateral sensitivity region of position sensing strips is narrow and the top of the door threshold may simply collapse and not activate it. The solution is to fill the gap above the sensor with a lightweight flexible incompressible material. Two lengths of nylon rope worked well in the prototype shown in figure 8.

Figure 8: Position Switch

This device was designed to roll up and fit into a guitar case. The electronics is configured to measure the positions of up to two concurrent depressions of the strip.

3. Augmenting controllers

3.1 Pressure sensing buttons

In a project augmenting the cello [6, 7] the author discovered many situations where it was as easy to install a pressure sensor as a switch. Many microcontrollers have built-in A/D converters so often there is a tiny or no additional cost to using pressure sensors for switches. Continuing this idea -that the fastest route to a new controller may be to modify an existing sensor- we see in Figure 9 how to retrofit the Monome button array with pressure sensors, the grey octagonal disks.

Figure 9: Pressure Sensitive Monome Adaptation

Monome (http://monome.org) interfaces are square arrays of lit switches interfaced over USB using OSC messaging. A large part of the desirability of this interface is the tactile quality of the buttons created with careful design of the silicone molding. Each button has a ring of conductive rubber attached to connect with a circular array of interdigitated contacts. The conductivity of this connection does change with pressure but the conductivity is so effective it is hard to measure the change accurately. By cutting a small disk of piezoresistive fabric with a central hole we can retrofit a higher resistance range pressure sensor. With careful design of the interface electronics we can even eliminate the array of diodes needed to scan concurrent depressions of the buttons [9, 13].

3.2 Dual Touch Pad

Because of the number of connections required for matrix scanning it is difficult to rapidly prototype multi-touch systems. Even optical systems that avoid matrix scanning on the surface itself are hard to build quickly because of the difficulties of sufficiently illuminating the interior of the touch surface and the complexities of calibrating the optical path of the camera [8].
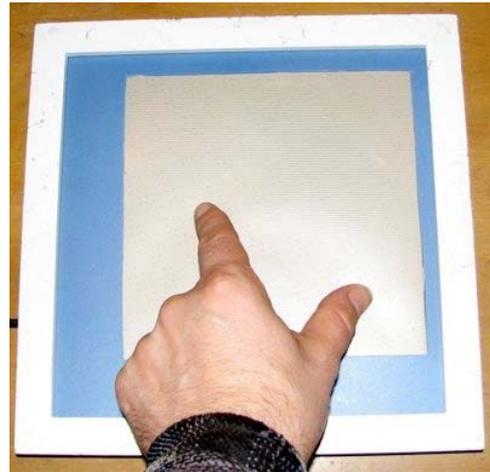
Figure 10: Dual Touch Pad

We can still explore some multitouch gestures by assembling a pad that senses two simultaneous touches as shown in Figure 10. A pair of SlideWide sensors (http://infusionsystems.com) are stuck to each other at right angles.

Instead of measuring single touch position for each axis using the well-known potential divider method we ground the "wiper" contact and measure the two end point resistances to this ground node to estimate the position of the outer most touch point pair. This idea was patented in 1972 for duophonic analog synthesizer keyboards (USPO3665089). This method was independently rediscovered for resistive touch applications by the author and Mr. Loviscach [10].

The controller in Figure10 also includes a sheet of piezoresistive fabric to measure a single pressure estimate. The SlideWide sensors flex sufficiently for a useful touch pressure range.

3.3 Touch Pad

Most computer laptop touch pads use capacitive measuring techniques because of the low costs of high volume PCB production. Touch pressure cannot be measured by these pads which is unfortunate as it is an extremely useful control parameter in musical applications - specially in combination with spatial location [16]. Resistive touch pads by contrast provide x,y and z axis sensing, require simple calibration and are less prone to electrical interference and variations in ambient humidity.

Interlink, the main supplier of resistive xyz touch pads offers them in only a few small standard sizes. They are rather expensive and technically challenging to employ in large arrays. By combining Velostat (http://3m.com), an electrically resistive plastic sheet material and piezoresistive fabric we can rapidly build xyz pads for modest cost and in a wide range of sizes as illustrated in figure 11.
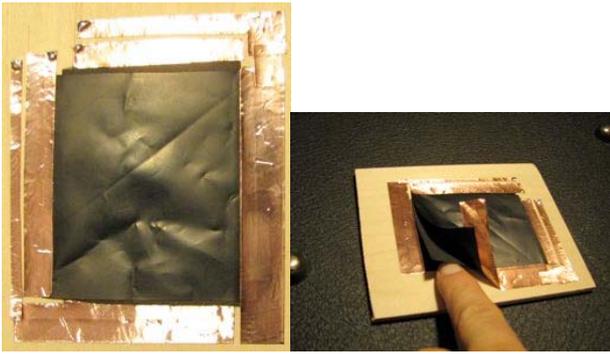
Figure 11: Conductive Plastic XYX TouchPad

The spatial sensing principal has long been used in touch screen sensors. Conductive strips at the edge of each sheet of resistive plastic form the nodes of a wide resistor. Two such sheets are arranged at right angles to each other. An intervening layer of piezo-resistive fabric establishes current paths at the point of connection between the two sheets. With a carefully designed interface circuit the three desired parameters can be extracted from the four nodes of the sensor [16]. As well as size flexibility this design avoids the need for a fine array of insulating spacer dots or the special air gap used in Interlink touchpads.

4. New Controllers

4.1 Kalimba

Figure 12 shows a simple controller inspired by the kalimba. It illustrates application of rapid prototyping practice integrating the materials and techniques we have seen earlier into a complete controller that can be assembled in an hour or two. The core kalimba design lends itself to rapid assembly because of its use of a single central bar held down by two screws to trap the array of tines between two pivot bars.
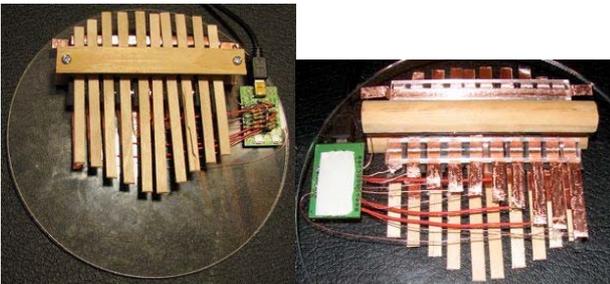
Figure 12: Fabric and Stick Kalimba

Wooden tines are used in this prototype because they are faster to shape than the traditional metal and this controller doesn't require the tine's resonances to be tuned. The flexibility of copper tape is exploited as strips follow the contour of the flat base around the curve of a half-round pressure pivot.

Each tine is covered in conductive copper tape. Trapped between this copper strip and the base strip is a piece of peizo-resistive fabric. The rear pivot of the tines also has a copper strip that is a grounding bus for the tines. The 18F2553 controller has 10 ADC's and sends an OSC-encoded estimate of the voltage formed by a pull-up resistor and the variable resistance pressure sensor of each tine.

Notice that the length of each base copper strip is trimmed to simplify the wiring flow of the conductors to the microcontroller.

4.2 The Tablo

The novel controller of Figure 13 exploits recently available conductive stretchable fabric and an approximation to the curve known as the witch (sic) of Agnesi.

Figure 13: Tablo Fabric Multitouch Controller

The fabric is stretched in an embroidery hoop and draped over an inverted circular bowl.

A piece of conductive plastic cut in a special shape forms a corolla on the surface of the bowl. The tips of each petal are folded inside the bowl and taped with conducting adhesive copper tape. The microcontroller board measures the electrical resistances of these petals from their tips to a common center established with a conductor at the flat of the bowl. As the conductive stretchable fabric (the "calyx" to complete the flower analogy) is displaced towards the bowl it shorts out different lengths of each conductive plastic petal.

The result is a circular array of nearly mass-less displacement sensors. Unlike the Continuum Finger board (http://HakenAudio.com) the gesture-to-displacement relationship changes sensitivity according to distance from the center of the bowl. This allows for several different playing styles. One style – similar to hand drum technique – involves tapping the fabric surface directly onto the bowl with the fingers of one hand and leaning towards the other side of the bowl with the palm.

Another style involves both hands interacting from the outer hoop towards and around the base of the bowl. The latter style affords some interesting parameter mappings. One fruitful approach is to divide the circular petal array into two halves and compute the direction and amplitude of a pair of vectors by summing contributions of sensors accessible to each hand. An additional third parameter for each hand representing the "size" of the gesture is obtained by computing the ratio of the arithmetic and geometric means of the displacement values.

Two refinements were added recently: a pressure sensitive "aftertouch" using fabric on the base around the bowl and a pressure sensing fabric disk at the very center of the controller.

5. Conclusion

New fiber and malleable materials present interesting challenges and potential beyond the rapid prototyping advantages described here. It is surprisingly hard to find learning materials or a learning environment to exploit this

potential. Most engineering departments still focus on high manufacturing volume materials made with standard milling and printing techniques.

A difficult problem for experienced designers is that they have to abandon standard assumptions, such as "conductors are metals and plastics are nonconductive". Polymers exist now that are nearly as conductive as copper and are expected soon to be more conductive. Even translucent concrete is now available.

Physical computing books mostly encapsulate workable recipes that are twenty years old. Vendor application notes usually address very narrow application spaces.

Effective application of the new materials requires a new curriculum based on emerging design patterns and will require a context where the wisdom and experience of fiber and malleable materials artists can be melded with that of material scientists and application developers.

6. ACKNOWLEDGMENTS

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