# DIY Wearable Technology

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## Abstract

DIY practice of wearable technology allows individuals to explore personalized wearable scenarios, ranging from the modification of existing interfaces to artistic and performative practice and the critique of mainstream wearable technology trends.

## Introduction

This paper introduces a number of fabric sensors that can be handmade from off-the-shelf, off-the-internet materials using low-cost, low-tech techniques. These fabric sensors offer soft, customizable and affordable alternatives to premanufactured sensors that can be tailored in shape and size to the forms and actions of the human body.

## Materials

The sensors described in this paper are constructed primarily from the following materials. Relatively thin Silver Plated Nylon 117/17 2ply conductive thread manufactured by Shieldex [1], and 66 Yarn 22+3ply resistive thread, both distributed by LessEmf [2] and the former also by Sparkfun [3]. A thicker, more conductive thread, that is available from Lame Life Saver [4] and Mutr [5]. Highly conductive fabrics that we purchase tend to be sold for Electro Magnetic Field (EMF) shielding purposes. MedTex E 130 DS produced by Shieldex and distributed by LessEMF as Stretch Conductive Fabric is one of our favorites. Anti-static fabrics are less conductive, with the intention to shield sensitive electrical components against static charges. They often have piezoresistive qualities. The piezoresistive effect describes the changing electrical resistance of a material under mechanical pressure [6]. Velostat [7] is an anti-static carbon impregnated black polyethylene film produced by 3M, commonly known as the material from which black ESD bags are made. Velostat is a great choice as a piezoresistive material because of its performance and availability. Eeonyx [8] coats a range of anti-static woven and non-woven fabrics in an inherently conductive polymer, giving them piezoresistive properties. These textiles run under the name EeonTex and offer a great alternative to Velostat, but are less available. We frequently use a heat fusible interfacing (“iron-on”) to glue conductive fabrics to each other or to non-conductive fabrics. Neoprene is a non-conductive synthetic rubber that provides nice qualities when working with conductive materials, such as that it allows for conductive threads to travel within its rubber center, isolating them and preventing fray. The thickness of the neoprene also keeps the sensors from wrinkling, especially when worn on the body in an area that is constantly being bent. We purchase our neoprene from Sedochemicals [9] in 1.5 mm thick sheets with a layer of polyester jersey fused to either side.

## Pressure and Bend Sensors

This fabric version of a Force Sensing Resistor (FSR) builds on the piezoresistive properties of Velostat. A technique that has been nicely documented in tutorials by both the Pulsar Project [10] and by Images [11]. The technique can be used to make pressure sensors in all different shapes and sizes at extremely low cost. The structure of these sensors is sensitive to pressure but can function as a bend sensor since pressure is exerted through the bending of the materials. Our fabric version [12] of this technique uses stitches of conductive thread as conductive layers on either side of the Velostat. By stitching both sides identically the stitches will crisscross when the layers face each other, this ensures that the conductive surfaces will overlap with a very minimal surface area through the Velostat.

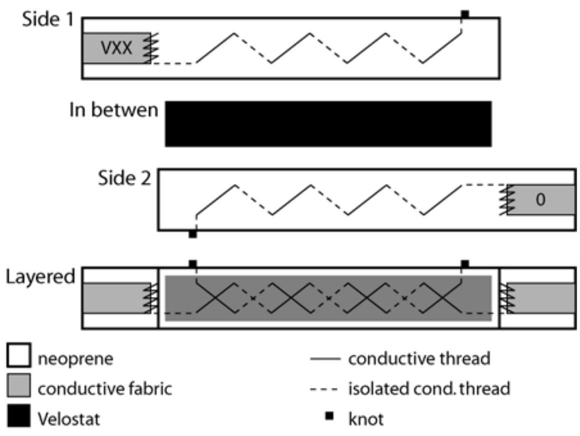


**Fig 1. Bend Sensor, construction (15 mm width)**

The conductive surface to Velostat ratio is one of the aspects that dictate the pressure sensitive range of the sensor. Sensitivity can also be adjusted by adding more than one layer of Velostat. The sensor is finally held in place by stitching both neoprene layers together with regular thread. The initial pressure caused by this sandwiching also plays a role in the sensor's range. To simplify the connection of this sensor throughout a range of different applications and projects we end the sewing of the conductive stitches by sewing the conductive thread to a tab of conductive fabric at either end of the sensor. The tab is additionally fused to the neoprene with fusible interfacing.

**Figure 2. Bend Sensor, complete**

The resistance of this sensor, when manufactured as seen in Fig. 1 ranges from 2K ohm, under the initial pressure of holding the sensor together, to bellow 100 ohm, when pressure is applied by a finger pressing down very hard. This lowest resistance will normally not be achieved by bending the sensor. When used to detect pressure this sensor still detects slight shifting in weight when mounted under the feet of a standing person, as demonstrated in the JoySlippers [13].

The sensor's decrease in resistance

under pressure is stable but not linear. The sensor is bi-directional, it does not differentiate which direction it is being bent. The sensor can also not differentiate between amount of pressure and surface area over which the pressure is applied. If you touch lightly over a larger surface this will be interpreted with a change in resistance equal to that of more pressure applied to a smaller area.

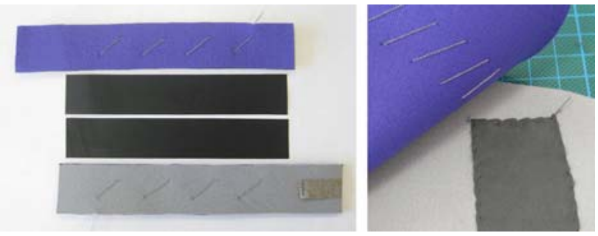

**Figure 3. Bend sensor with Velostat and pressure sensor with EeonTex in JoySlippers**

One problem we've had with these sensors after being worn repeatedly in performance and hand washed, was that the Velostat within the sensor became creased and bunch up, sliding to one end of the sensor, allowing for a direct connection between the conductive threads. We recently discovered a great alternative to Velostat, EeonTex RL-5-137 SL-PA coated stretch fabric. It can be sewn in place between the neoprene layers, covering the area in which the conductive stitches overlap. So far we have only implemented this in a wireless pair of JoySlippers (see fig. 3).

To lessen the layers in the fabric pressure and bend sensors we are prototyping examples where the conductive traces run next to one another, rather than facing each other.

## Fabric Potentiometer

This fabric version of a potentiometer uses the EeonTex RP-3-128 Sl-PA coated non-woven fabric as a resistive track in place of commonly used resistive polymer pastes. The EeonTex fabric is cut in the shape of ring that is not fully connected. This EeoTex fabric is not only resistive over distance, but it's resistance changes when pressured. An interesting property, that makes this sensor less accurate.

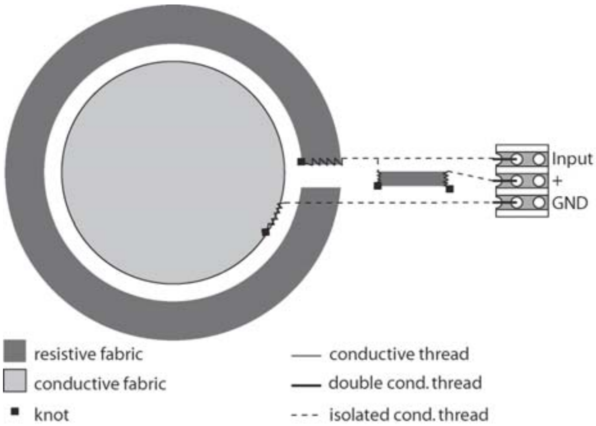


**Figure 4. Fabric Potentiometer**

As an example this sensor was implemented in the Time Sensing Bracelet [14]. The first version used a conductive finger cap sewn from Stretch Conductive Fabric as a conductive wiper finger to make contact along the resistive track. A second version replaced this with a wire extension from a metal popper that was pierced through the central conductive circle. This could turn freely, but had to be pressured to the resistive fabric to make good contact. The pull-up resistor for this sensor was made from a 0,5 x 2 cm piece of the same EeonTex fabric and included on the bracelet.

**Figure 5. Fabric Potentiometer with finger cap and rotating wire hand**

The resistive track can also be sewn with conductive thread. Syuzi Pakhchyan describes this method in her book Fashioning Technology [15], using a magnet to keep the wiper finger in place.

### Tilt Sensor

The conductive fabric and metal bead tilt sensor makes use of a very obvious conductive element, the heavy metal bead and its behavior under the influence of gravity. In the example of the Tilt Sensing Bracelet [16] the tilt sensor is made as a circular series of six contact switches. The metal bead constitutes the common side of all these switches and six petal shaped patches of conductive fabric that are fused to the neoprene constitute the individual other sides of these switches. The conductive bead is strung on a metal thread and each of the conductive petals is also connected via conductive thread to a distant connection point. In this example these threads are sewn to a piece of perfboard.

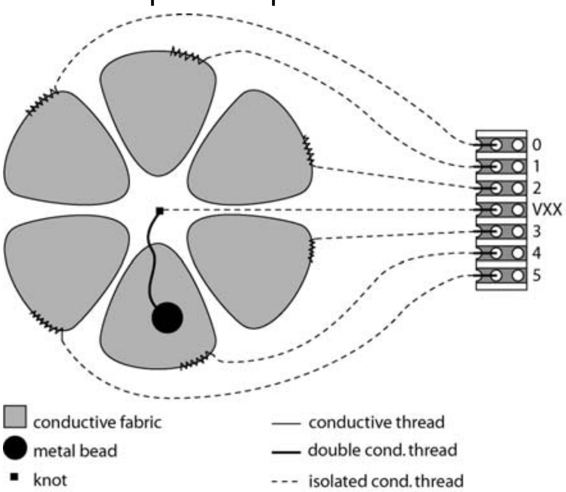


**Figure 6. Tilt Sensor**

The thread leading up to the final metal bead is isolated by non-conductive glass beads, this isolates the thread and helps stop it from fraying. The floral design of this sensor lends itself because of the simple shapes and arrangement, but many other shapes, patterns and arrangements are possible.

**Figure 7. Tilt Sensor**

The metal bead can close up to two switches at once, since it can make contact with two conductive fabric petals when lying between these. The principal of this sensor is very simple, yet the results are very reliable and easy to predict.

### Stroke Sensor

This sensor is a very recent development and we are still exploring its full potential. Its basic functionality is that of a contact switch. Pieces of 117/17 2ply conductive thread are sewn in and out of neoprene, similar to the hooked rug technique [17]. The friction of the thread sewn into the neoprene is enough to keep it from coming loose, even when stroked repeatedly.

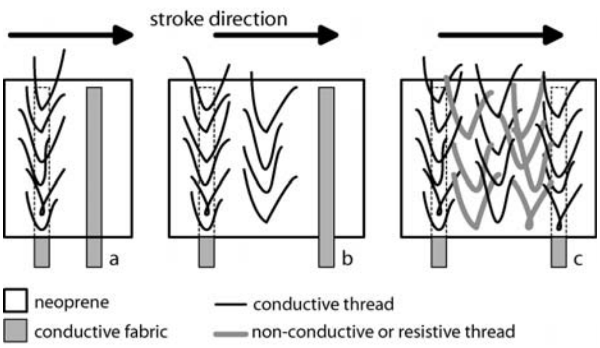


**Figure 8. Stroke Sensor, variations a, b and c**

Although some of the examples in the photos were stitched with a thicker conductive thread it turned out that these curled over time and that the thinner conductive threads gave much better results.

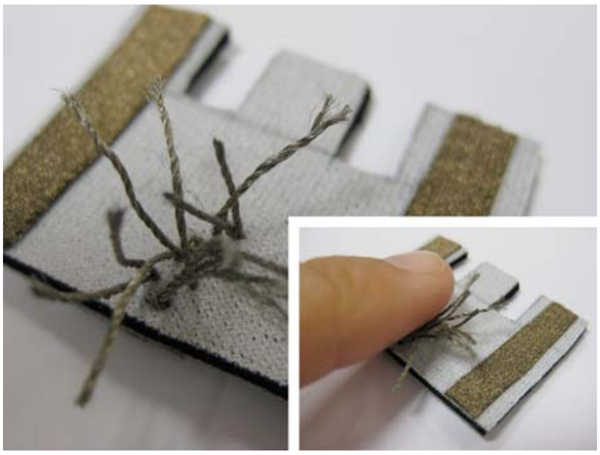

**Figure 9. Stroke Sensor, variation a, two directions, close-up of making contact through stroking**

a) A very simple example of the stroke sensor is to have a row of conductive threads that are connected to one another on the reverse side, by stitching them through a strip of conductive fabric. When stroked flat, these threads are long enough to make contact with another piece of conductive fabric mounted on the top of the sensor. Closing the switch.

**Figure 10. Stroke Sensor, variation b, two directions, close-up of reverse**

b) Instead of being able to directly connect, the two sides of the switch are distanced from one another and an additional row of conductive threads that are not bound to either side of the switch are inserted in between. This forces the *stroker* to stroke a greater surface, flattening more threads over a larger surface, in order to bridge the distance and make the connection.

**Figure 11. Stroke Sensor front, variation c, with non-conductive wool, close-up of reverse**

c) Sees the introduction of non-conductive or resistive threads between the conductive connections. In the case of non-conducive threads these tend to create an isolating barrier when stroked, making contact difficult. By using resistive threads in place of non-conductive it is possible to detect the applied pressure and area of stroking, though one cannot differentiate between the two.

**Figure 12. Stroke Sensor front, variation c, with resistive thread, close-up of reverse**

## Discussion

Besides the fact that all the sensors described in this paper can be hand crafted from accessible materials, tools and techniques, these sensors were designed with fabrics, fabric elements and techniques in mind. We hope that this will make a positive impact on their implementation, as they can be integrated within the garment, rather than included in a *pouch*. The connection of the sensors within the whole of the wearable circuit remain a week point to be tackled in future.

Our fabric sensor versions function due basic material and physical properties. We believe that making these visible and self-explanatory is a great way to encourage customization and individual experimentation.

## Conclusions

The DIY approach to manufacturing our own wearable sensors and the publication of our techniques throughout their development opens up our work at a stage where contribution is crucial and most helpful. We receive numerous comments on our Instructables [18], which is a great way for us to perceive our work from the perspective of others, who are often looking to implement these solutions in their own context. This kind of exchange enables us to create and learn, more so than if we were to simply embed our solutions in final pieces, without exploring and sharing the solutions themselves.

## References


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[2] LessEMF >> www.lessemf.com/fabrics.html

[3] Spark fun >> www.sparkfun.com

[4] Lame Life Saver >> www.members.shaw.ca/ubik/thread/

[5] Mutr >> www.mutr.co.uk

[6] piezoresistive effect >> http://en.wikipedia.org/wiki/Piezoresistive_effect

[7] Velostat manufactured by 3M >> www.3m.com

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[9] Sedochemicals >> www.sedochemicals.de

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[16] Tilt Sensing Bracelet >> www.instructables.com/id/Fabric_amp_Bead_Tilt_Sensing_Bracelet

[17] Hooked rug technique >> en.wikipedia.org/wiki/Traditional_Rug_Hooking

[18] Instructables >> www.instructables.com/member/Plusea


Links to photos and videos supporting this paper can be found here >> www.kobakant.at/papers/diywearabletech.php