Initial Investigations into Characterizing DIY E-Textile Stretch Sensors

Ben Trovato
Institute for Clarity in Documentation
P.O. Box 1212
Dublin, Ohio 43017-6221
trovato@corporation.com

G.K.M. Tobin
Institute for Clarity in Documentation
P.O. Box 1212
Dublin, Ohio 43017-6221
webmaster@marysville-ohio.com

Lars Thørväld
The Thørväld Group
1 Thørväld Circle
Hekla, Iceland
larst@affiliation.org

ABSTRACT

This paper evaluates three electronic textile (e-textile) stretch sensors commonly constructed for bespoke applications: fabric knit with a stainless steel and polyester yarn, and knit fabric coated with a conductive polymer. Two versions of the knit stainless steel and polyester yarn sensor, one hand and one machine knit, are evaluated. All of the materials used in the construction of the sensors are accessible to designers and engineers, and are commonly used in wearable technology projects, particularly arts performance. However, the properties of each sensor have not before been formally analysed. We evaluate the sensors' performance when being stretched and released.

KEYWORDS

movement sensing, stretch sensor, strain sensor, knitted sensor

ACM Reference format:
Ben Trovato, G.K.M. Tobin, and Lars Thørväld. 20017. Initial Investigations into Characterizing DIY E-Textile Stretch Sensors. In *Proceedings of Movement and Computing, London, UK, July 2017 (MOCO'17),* 4 pages.
DOI: 10.1145/nnnnnnn.nnnnnnn

1 INTRODUCTION

Electronic textiles (e-textiles) are textiles that conduct electricity and are used to form electrical circuitry. As fabric and thread are already worn next to the body, e-textiles provide an ideal approach for wearable computing that does not inhibit the wearer. While there are significant barriers to fabricating complex circuitry in textiles, e-textile sensors are becoming more prevalent.

Stretch or strain sensors are a class of sensors with a wide range of applications when attached to the body. They can be used to detect large movements such as the bending of a joint [4], or smaller movements such as the expansion and contraction of the ribcage when breathing [7]. Both of these applications have used sensors that measure the change in resistance when a knit conductive fabric is stretched.

A knit stretch or strain sensor has many design parameters including the yarn used to make the sensor, the knit structure of that yarn, and which conductive materials are used. This paper is looking at three sensors that are commonly found within do-it-yourself artistic and hobbyist electronics communities. These communities seldom have the same level of access to new conductive materials and fabrication processes as academic or industrial research facilities, which is the focus of much of the literature. Artistic and design communities also have additional requirements for sensor design than medical or health researchers. The sensor design needs to accommodate the aesthetic of the larger garment in which the sensor is embedded and not dictate it.

Here we will examine two sensors that use relatively inexpensive materials and are simple to make for anyone familiar with knitting. They are compared to a third sensor design using a proprietary knit fabric that is gaining popularity, though has more limited access. The sensors made with these materials do not perform ideally, but exhibit a number of deficiencies. This work fits into a larger context that is looking towards develop signal processing approaches that can overcome the deficiencies of these sensors. This paper takes the first step of characterizing some of those deficiencies.

1.1 Knit Stretch Sensors

Knit sensors that change their resistance when stretched are exhibiting the piezoresistive effect. The properties of this effect come from a number of factors, but are all rooted in the path of the electricity being altered when the fabric is stretched. There are common traits amongst knit sensors, but individual design and construction decisions influence the results preventing a single best sensor design. There are common deficiencies found in the sensors, though the exact cause may vary according to construction details. All knit stretch sensors exhibit some amount of hysteresis and are not completely linear when being stretched or released [2]. They also may drift in their resistance values over time [3].

The first factor is the conductive material being used. Yarns can be conductive by coating or wrapping a non-conductive core like nylon with a metal, usually silver or stainless steel. Alternatively, metal fibers can be mixed with non-conductive fibers and then the yarn is spun, blending the materials. Blended yarns have been found to produce less stable sensors [3], but they tend to feel more like non-conductive yarns than metal coated or wrapped yarns. Non-metal conducting materials like certain forms of carbon may also be mixed with non-conductive yarns, and changing the conductive yarn composition while keeping all other factors the same can change the linearity of the knit sensor [8].

Knitting is the looping together of a yarn to form a fabric. The loop structure provides multiple contact points whose resistance decreases as a strain is applied and pressure increased between the contacts [2]. The construction of the knit material is determined by the number of loops and how tight or loose they are in relation to

DOI: 10.1145/nnnnnnn.nnnnnnn

each other. The textile could be produced using a flat-bed knitting machine with a single or multiple beds of needles to create a flat textile or a circular machine to produce a tubular textile. The textile can also be produced using hand knitting and no machinery. The structure of the loops in relation to each other is a function of the machine or hand tools used and accompanying design parameters. For example, the tightness of the loops in a fabric has been shown to effect the sensor performance. Less compact fabric has better accuracy when relaxed [3]. The placement of the conductive yarn within the knit structure will also influence performance. Conductive yarn knit lengthwise (in the wale) produces more repeatable and stable results than when oriented along the width (in the course) [7].

Knit stretch sensors combine conductive and non-conductive elements. One method is to hold two yarns together while knitting, one conductive and the other not. It has been found that using elastomeric yarns as the non-conductive yarn can increase stability of the sensor [3], though this hasn't been consistently observed in other studies [7].

2 METHODOLOGY

The three sensors were built with identical dimensions, 20 mm x 100 mm. The sensors were stretched with one end held in place and other end extended by a linear actuator. Depending on the elasticity of the sensor, the sensor was stretched or relaxed either 40 mm or 55 mm at a constant velocity of 30 mm/sec. Five measurements of each sensor being stretched and then also relaxed back to its resting state were recorded.

Each sensor formed part of a voltage divider circuit, with a pull down resistor whose value was chosen to provide the maximum range of values from the sensor. A BeagleBone Black single-board computer with a Bela cape was used to control the movement of the linear actuator and record the sensor values[1]. The Bela measured the sensors with a sample rate of 22.05 kHz using a 16 bit analog to digital converter. The sample rate was then filtered and decimated to 2.756 kHz for analysis.

2.1 Sensor Design and Construction

The sensors were constructed to be same size to simulate constraints of placement on the body. Two of the sensors used a commercially produced conductive yarn and varied only the tools and techniques used to construct the sensors. The third was a knit fabric coated with a proprietary conductive fabric treatment. Each of the three sensors can be seen in Figure 1. Online tutorials and guides are available for working with these sensor materials [5, 6].

2.1.1 Machine Knit Conductive Yarn. One sensor was machine knit used a Dubied knitting machine. The fabric construction was a double bedded knit (weft knit) which allows for a greater stretchability in the structure, especially in the wale (lengthwise) direction? up to 300% stretch. The sensor was oriented so that the wale direction was stretched.

The yarn consisted of a conductive, stainless steel (20%) and polyester mix (80%), Nm 10/3 (1 gram per 10m, 3 thread counts). It was knit at a 7gg gauge, as it is a relatively thick yarn. Due to its thickness, there are limits on how thin or light a fabric can be knitted with it; this yarn could be used for outerwear garments such as cardigans, jumpers or accessories (e.g. scarf).

Figure 1: Photographs of each of the knit sensors. Not shown to relative scale. From left to right: Eeonyx fabric, machine knit, hand knit.

2.1.2 Hand Knit Conductive Yarn. The second sensor was hand knit at a gauge to match that of the machine knit, using the same yarn. The sensor was knit in a 1 x 1 rib structure, also the same structure as the machine knit sensor. It was stretched in the same orientation as the machine knit sensor.

2.1.3 Conductive Polymer Coating. The third sensor is a commercial product developed by Eeonyx called EeonTex. It is a stretchable 72% nylon and 28% spandex knit fabric that has no conductive properties inherent in the yarn. It is treated with a conductive polymer coating after the fabric is knit. The sensor fabric was mounted onto non-conductive knit jersey fabric to prevent the fabric from curling on itself during stretching.

The fabric is a much finer gauge of approximately 30gg than the other two sensors. The fabric is a relatively light 163g/m, the same weight as a medium weight t-shirt fabric. The fabric is a single bedded jersey knit, weft knit, with less stretchability than a double bedded rib-like knit. There is little difference between the stretchability in wale or course direction.

3 RESULTS

Each sensor was measured as it was stretched and relaxed five times. Figure 2 shows the measurement signal for a single trial for each sensor. The response is similar to those found in related studies [2, 3, 8]. The sensor value slightly dips when it is initially stretched from its resting state, but quickly transitions to an approximately linear response before losing sensitivity. This response is largely seen in reverse when relaxing the sensor from being maximally stretched back to its resting state, though with a longer linear section. The Eeonyx response is notable in that is contains much less noise than the other two sensors.

3.1 Gauge Factor

The gauge factor as described in Equation 1 can be summarized as the change in resistance divided by the change of length between the relaxed and stretched states.

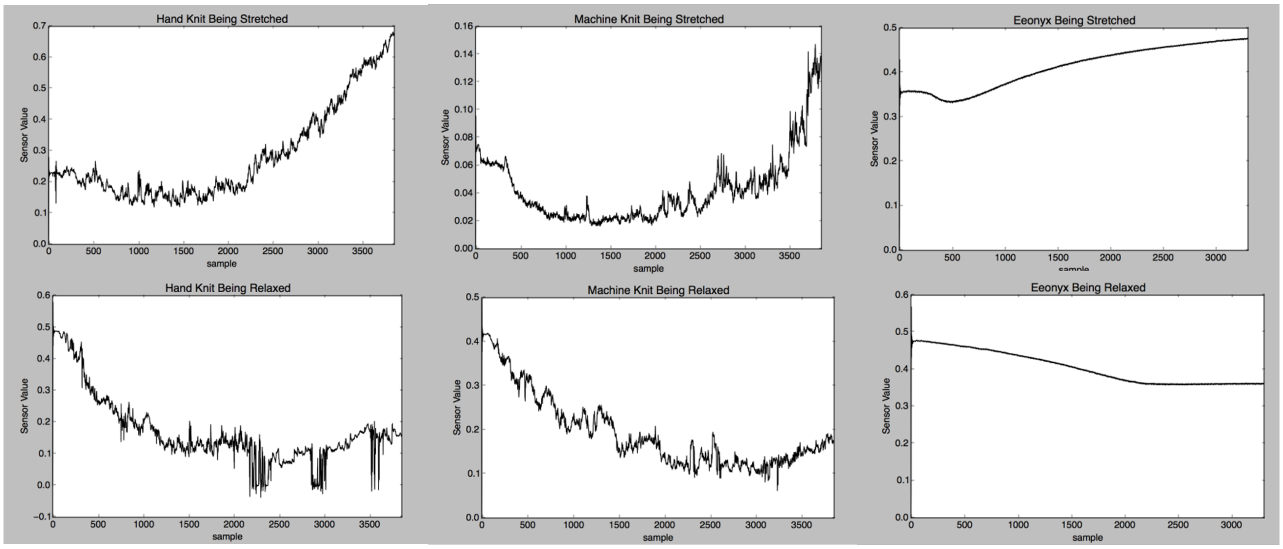

Figure 2: One trial for each of the sensors.

Sensor	No Strain (Ω)	Stretched (Ω)	Gauge Factor
Eeonyx	260k	142k	0.15
Machine	3.8k	260	3.02
Hand	7.5k	480	3.25

Table 1: Sensor resistance values when under no strain, maximally stretched and the gauge factor of the sensor.

$$GF = \frac{\frac{\Delta R}{R}}{\epsilon} \tag{1}$$

$$\epsilon = \frac{\Delta L}{L} \tag{2}$$

where R is the initial resistance, ΔR is the change in resistance, L is the initial length, and ΔL is the change of length.

Table 1 shows the resistance values and gauge factor for each of the sensors. The hand and machine knit sensors have much larger gauge factors due to their ability to stretch much further than the Eeonyx fabric. The Eeonyx fabric is also significantly more resistive than the other two sensors. The Hand knit sensor has roughly twice the resistance of the machine knit sensor in both its stretched and relaxed state.

3.2 Correlation Within Sensor

In order to test whether multiples responses from a given sensor are related to each other, the Pearson correlation coefficients were calculated. The mean and variance of the coefficients between all measurements by the same sensor in same direction can be seen in Figure 3.

The Eeonyx fabric shows the strongest correlation between measurements in both directions of movement. The hand and machine knit sensors are less correlated and are significantly less correlated in one direction than the other. The machine knit shows the weakest correlation for all the sensors and directions when it is being stretched while the hand knit is relatively less correlated when it relaxes.

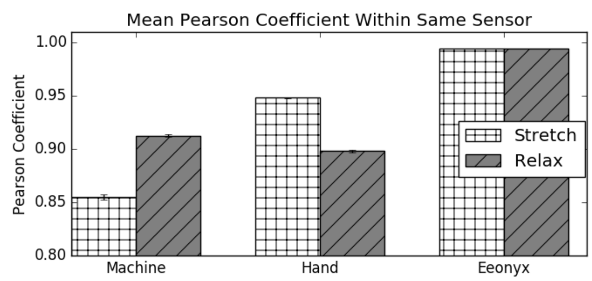

Figure 3: Mean correlation coefficients with error bars showing the variance for each sensor.

3.3 Correlation Between Sensors

A second set of correlation coefficients were calculated to compare whether the responses could have be drawn from the same probability distributions. The mean and variance of the pairwise comparisons of each sensor can be seen in Figure 4.

There is a high correlation between the hand and machine knit sensors both when they are being stretched and relaxed. There is little correlation between the stretching of the Eeonyx fabric with either of the other sensors. However, all three sensors show strong correlations to each other when being relaxed.

4 DISCUSSION

Of the three sensors evaluated, the Eeonyx fabric performs the most consistently across multiple measurements. The two sensors knit

Figure 4: Correlation coefficients between sensors.

at the larger gauge with blended conductive yarn show more noise and less consistency between measurements.

A primary difference between the two knit structures used in the sensors is the way conductivity is applied. While the hand knitted swatch and the Dubied machine knitted swatch are made of yarn that consists of 20% stainless steel, the knit jersey from Eeonyx is initially made of yarns that have no conductivity properties. The latter fabric is given a finishing - a coating - that then gives the fabric the necessary property. This way of manipulating the textile surface, and the stage in which this is done, could be one reason for the change in consistency in the sensors. Moreover, synthetic fibres in general (nylon and elastane for the Eeonyx fabric) provide a good base for any surface manipulation, such as dying - or, in this case, coating. In comparison to natural fibres, synthetics capture colour better and more lasting.

However, the gauge may be the largest influence on the sensors' behaviour. The gauge is dependant from the thickness of the yarn itself. We used a Nm 10/3 polyester and stainless steel yarn for the hand knitted and machine knitted sensor (the Nm system counts metres per gram, in this case 10 grams on 1 metre) which is suitable for a 7 gauge knit fabric (or chunkier). In a finer fabric (we speculate the Eeonyx fabric to be an appr. 20 gauge knit), there are proportionally more contact points which will effect the sensor performance [3] and in general a denser arrangement of the yarn. This could potentially cause more or less consistency and noise overall.

It is possible that any correlation between sensors could be an artifact of using a common test rig, but since there was not a strong correlation shown between two of the sensors and the Eeeonyx fabric when being stretched, that is unlikely.

The high correlation between the hand and machine sensors indicate that there little difference between the probability distributions of the two sensors. This suggests that the tools used to construct the sensor may have less influence over its performance than knit structure and material.

5 CONCLUSIONS

Three stretch sensors commonly used in bespoke textile projects for arts performance or fashion prototypes were evaluated by measuring their change in resistance while being stretched and relaxed. Eeonyx, though the most difficult to acquire of the materials tested due to it being available only through specialist suppliers, has the most consistent measurements. There could be due to a number of factors, including the gauge or tightness of the fabric, which was much looser for the two non-Eeonyx sensors. The literature supports adding additional non-conductive, elastomeric yarns, which these results also support exploring.

These results suggest that if a blended conductive yarn is available, then it can be used to create a stretch sensor, but using a knitting machine to construct the sensor does not necessarily result in a more consistent sensor. If a large percentage of stretch is required for the application, then a hand or machine knit sensor may be preferred, but otherwise a sensor built using Eeonyx fabric will produce less noisy values.

Further work would include stretching and relaxing at different speeds and also different rates of change (accelerating and decelerating), along with observing the response when transitioning from stationary to moving and to stationary again. Further characterizations of the sensors such as fitting to a linear model and measuring hysteresis and drift over time will also be needed in order to compensate for their deficiencies.

REFERENCES

[1] A. McPherson and V. Zappi. 2006. An environment for submillisecond-latency audio and sensor processing on BeagleBone Black. In *Audio Eng. Soc. Conv. 138. Audio Engineering Society, 2015.* 4–9.

[2] Ozgur Atalay, William Richard Kennon, and Muhammad Dawood Husain. 2013. Textile-based weft knitted strain sensors: effect of fabric parameters on sensor properties. *Sensors* 13, 8 (2013), 11114–11127. DOI: http://dx.doi.org/10.3390/s130811114

[3] O. Atalay, A. Tuncay, M. D. Husain, and W. R. Kennon. 2015. Comparative study of the weft-knitted strain sensors. *Journal of Industrial Textiles* 0, 00 (2015), 1–29. DOI: http://dx.doi.org/10.1177/1528083715619948

[4] Ching Tang Huang, Chien Lung Shen, Chien Fa Tang, and Shuo Hung Chang. 2008. A wearable yarn-based piezo-resistive sensor. *Sensors and Actuators A* 141, 2 (2008), 396–403. DOI: http://dx.doi.org/10.1016/j.sna.2007.10.069

[5] Kobakant. 2009. Fabric Stretch Sensors. (2009). http://www.kobakant.at/DIY/?p=1762

[6] Kobakant. 2013. Knit Stretch Sensors. (2013). http://www.kobakant.at/DIY/?p=1762

[7] C.D. Metcalf, S.R. Collie, A.W. Cranny, G Hallett, C James, J Adams, P.H. Chappell, N.M. White, and J.H. Burridge. 2009. Fabric-based Strain Sensors for Measuring Movement in Wearable Telemonitoring Applications. In *Assisted Living*. 1–4. DOI: http://dx.doi.org/10.1049/ic.2009.0042

[8] M. Pacelli, L. Caldani, and R. Paradiso. 2013. Performances evaluation of piezoresistive fabric sensors as function of yarn structure. In *Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, Vol. 2013. 6502–6505. DOI: http://dx.doi.org/10.1109/EMBC.2013.6611044