Machine-Stitched E-Textile Stretch Sensors

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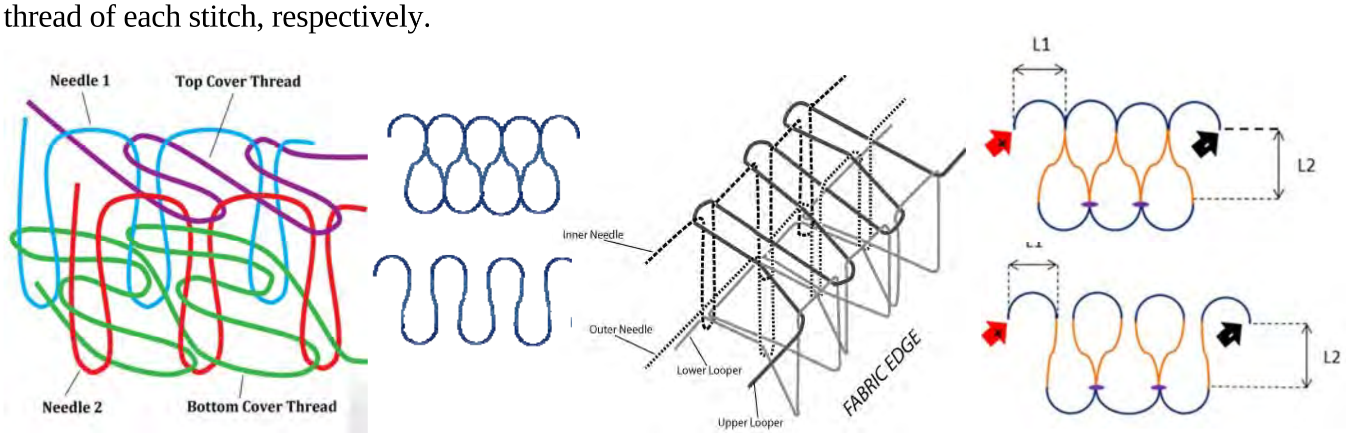
Introduction

Wearable, garment-integrated sensing is a distinct challenge for many reasons. Significant among these reasons is the challenge of fabricating sensors that are unobtrusive and comfortable for long-term daily wear. Here, we present a novel method for fabricating e-textile stretch sensors using industrial sewing machinery. The resulting sensors are perceptually similar to existing stitches used in garment fabrication, offering improvements in comfort and ease of manufacture compared to other types of sensors.

Theory of Operation

Stitched sensors are produced using the "looped conductor" approach to detecting stretch. Un-insulated conductors of specific resistance per unit length are manipulated into a looped geometry, in which parts of the conductor's length are shorted. As the structure is stretched, loops are lengthened or shortened, and pass into or out of contact with one another. These changes in geometry result in corresponding changes in electrical resistance of the entire length of the sensor structure. Looped structures can be formed with many industrial sewing machines. Figure 1 illustrates two such stitches, the 602-class coverstitch and the 514-class 4-thread overlock, along with the corresponding changes to looped structures of the top cover thread and upper looper thread of each stitch, respectively.



(a) (b) (c) (d)

Figure 1: Coverstitch (a) top-cover loop structure (b) overlock stitch (c) upper-looper structure (d)

Bottom-cover Stitched Sensor

While the top-cover thread and the overlock stitch looper threads assume a relatively simple sinusoidal geometry (illustrated in Figure 1), the bottom-cover thread takes a more complex shape, in which smaller loops of the bottom-cover thread are pulled through the needle threads as the two-needle lockstitch is formed. These smaller needle-loops on one side are already shorted in the relaxed position. On the other side, needle loops are elongated when the stitch is stretched, pulling the zig-zag structure of the interior stitch closer together, and shorting the loop. The equivalent effect on the sensor's resistance property is illustrated in Figure 2. Crossed out portions of the model are shorted.

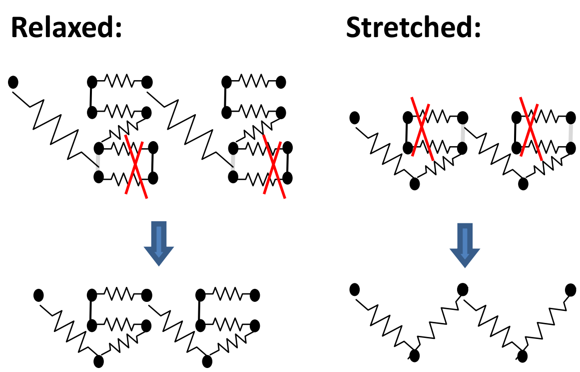


Figure 3: Bottom-cover thread loop structure

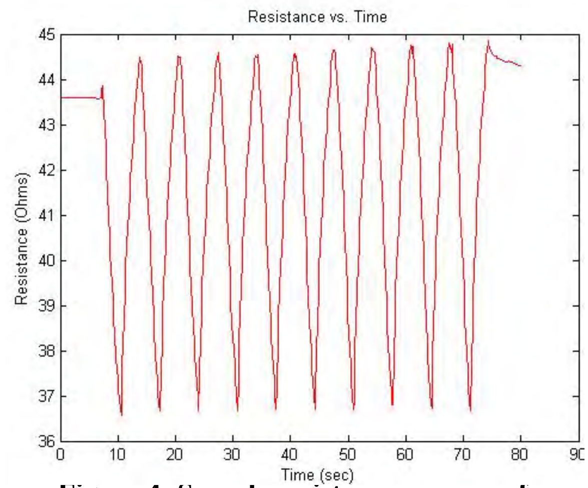


Figure 4: Sample resistance response from bottom-cover sensor

Sensor Fabrication and Response

Figure 3 shows an example response for a sensor of total length 7", elongation length 3" (2" on each end of the sensor is clamped into the tensile test apparatus), stretched 25% for 10 cycles using an Instron tensile tester. This sensor was fabricated using a Juki MF-7723 high-speed, flat-bed coverstitch machine. The conductor used was Shieldex PN# 2601510 235/34oz silver-coated nylon, rated at 50 Ohms/meter.

As Figure 3 shows, the sensor has a very linear response in in the elongation and recovery cycles for 25% stretch. The sensor response is the inverse of the extension: resistance decreases as elongation increases, as the second set of needle-loops are shorted and pulled through to shorten the internal zig-zag resistance structure.The resistance change is on the order of 8 Ohms peak-to-peak, or approximately 18% of maximum resistance. An observable initial resistance change is seen in the first cycle, as the fabric and stitch are "conditioned" during the first elongation.

Conclusion

The sensor fabrication method presented here is particularly well-suited to sewn products and wearable sensing, as it leverages construction methods already in common use in cut-and-sew operations. The sensor response for the bottom-cover stitched sensor shows a reliable, repeatable linear response for 25% stretch, following an initial conditioning elongation. Implementation using the machines illustrated here offers flexibility in sensor response and on-body location.