Weaving Electronic Circuit Into Two-Layer Fabric

Jussi Mikkonen
Aalto University, School of Arts,
Design and Architecture
PL 31000
00076 AALTO
Finland
jussi.mikkonen@aalto.fi

Emmi Pouta
LeeLuu Labs Inc.
Lontoonkatu 6 A 9
00560 Helsinki
Finland
emmi@leeluu.fi

Ubicomp/ISWC'15 Adjunct, September 7-11, 2015, Osaka, Japan.
ACM 978-1-4503-3575-1/15/09.
http://dx.doi.org/10.1145/2800835.2800936

Abstract
This paper describes the creation of a woven two-layer fabric, created using two-warp system. The fabric is designed to contain components inside the two layers, with the power supply signals on top- and bottom-layers. The surface mounted components are prepared for weaving by adding long insulated threads, to be partially removed accordingly just before integrating to the fabric. The final fabric contains a working circuit for detecting magnetic fields as an example implementation.

Author Keywords
weaving; eTextiles; interactive textile; two-warp system

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

Introduction
Fabric has been used as a replacement of the printed circuit board in several different ways. E-broidery is described as "*electronic embroidery, i.e., the patterning of conductive textiles by numerically controlled sewing or weaving processes"* [7]. Several methods are described for combining electronics into textiles, mostly by using flexible circuitboards, but also bonding a

Preparing components for initial design. In the top picture, individual Litz-wires have been soldered to the pins of a SMD-component (SOT-6). In the middle picture, the wires and the component have been isolated and protected using epoxy resin. The bottom picture shows the component with pins extended using long Litz-wires.

circuit to the fabric and welding components directly to steel yarns. E-broidery focuses mostly on embroidered circuits, but has also woven examples. It is similar in approach to the embroidery-approach taken by Linz et al.[3], which has established the use of fabric as the substrate for components.

For larger scale components, an established method for prototyping wearable electronics has been through the use of Lilypad [1], where rigid modules and components are sewn on top of the fabric. Similar but hand-crafted ideology is shown in the Crying dress by KOBAKANT-collective[9], which is a dress with sewn in fabric loudspeakers. It combines traditional electronic components attached on top of the fabric using sewing and embroidery, following their earlier work [6]. Taking the components closer to fabric, pattern resistors [2] was a project focusing on resistive motifs embroidered on the fabric, by using resistive yarns to create electric components decoration patterns.

While adding materials to an existing fabric has been well established, routing connections as part of the fabric structure is at the center of the development[8]. Knitting has been a strong contender as the base for eTextiles, and with the automated knitting machines, seamless structures can be had. The benefit of being able to integrate conductive yarn patterns seamlessly to the fabric has been seen beneficial. One example of such is the medical shirt for monitoring purposes[5], where the electrodes in shirts were knitted with conductive yarns. There have also already been results on the development of semiconductor devices using doped fibers [4]. By intersecting the semiconductive fibers like a woven structure, they form various active components. As intersecting yarns creates them, knitting might not be the best way to utilize them. Knitting typically uses a few different yarns, while weaving, on the other hand, involves potentially thousands of individual yarns. All in all, the field is very well established, although it seems that woven methods are still less explored. Since the weaving machines are much more time-consuming to set up, it is just one of the reasons for not utilizing them in the development of interactive textiles. However, they do offer the possibility to create complex fabric structures to e.g. create pockets, multiple layers and sensor-structures, all possible with mixing in conductive yarns. In order to explore the basis for building more complex circuits with wowen-in components, we used two-warp-weave to create two-layer fabric.

Preparing for the weaving

Creating a two-warp weave requires separate warp systems, as well as loom with several harnesses. While there have been examples of attaching wires to components [7], to simplify the attachment of the components and to create a method suitable for cost-effective lab work, isolated copper wire was used. The pins were soldered to the wire using a standard soldering iron with a 0.25mm tip, and a stereomicroscope was used for detailed work. Each pin of a given component was lengthened with a 30cm long piece of 0.1mm thick strand from a Litz-thread, with the lacquer burned away from the end. After each connection was verified, the component and remaining litz-wire was covered with epoxy-resin. (see sidebar)

Preparing components for the weave. Manual removal of lacquer from the Litz-wire at the desired distance and length, to facilitate attachment to the warp-system.

Creating good connectivity requires replacing parts of some yarns in the warp. By using prepared components, weft can also be without conductive yarn. For weaving, we used TOIKA EWS16 loom. Warps consisted of two different yarns, for upper fabric we used mercerised cotton Nm 64/2, and for lower fabric lyocell tex 74x2. Warp density is 16+8 yarns/cm for upper and lower, respectively. For this experiment, we used Statex Shieldex 235/34 1x4 HC+B yarn, which has acceptable conductivity for low-power applications. In order to create voltage lines (+5V and GND) we replaced four parallel warp yarns on the top-layer fabric system, as well as on the bottom-layer fabric system. This creates several reliable connection points for attaching the component pin-threads. Two different wool yarns were used simultaneously in the bottom layer weft for fuller texture, but only single cotton yarn for the top layer weft. For our test circuit, we chose surface mounted components: SL353HT Hall-effect sensors (SOT-3), and white LEDs (PLCC2). Sensors were going to be directly connected to the LEDs such that the LED is normally on, and when strong magnetic field is present, it turns off. We prepared 5 pairs of each for the weaving.

Weaving

The weave was started with a short binding weave connecting both warp-systems together. After a few centimeters of non-essential weave, roughly 15 cm of two-layer fabric was woven, following the weaving pattern shown in Figure 1. During this two-layer structure, 4+4 warp yarns were replaced with the conductive yarn. Weaving was finalised with another binding weave, closing the two systems together. During the two-layer weaving, components were inserted to the structure, and woven over.

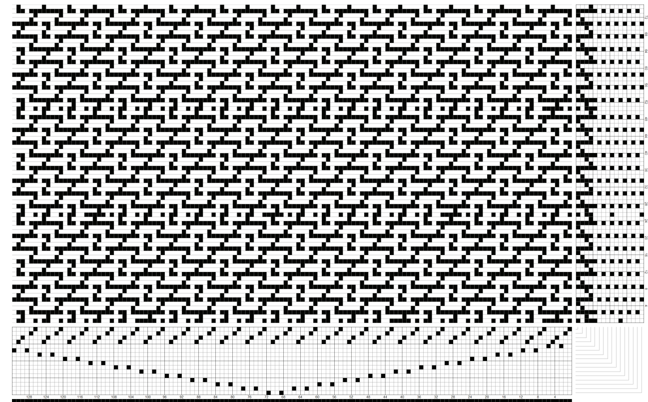


Figure 1. Weaving pattern used for creating two-layer fabric

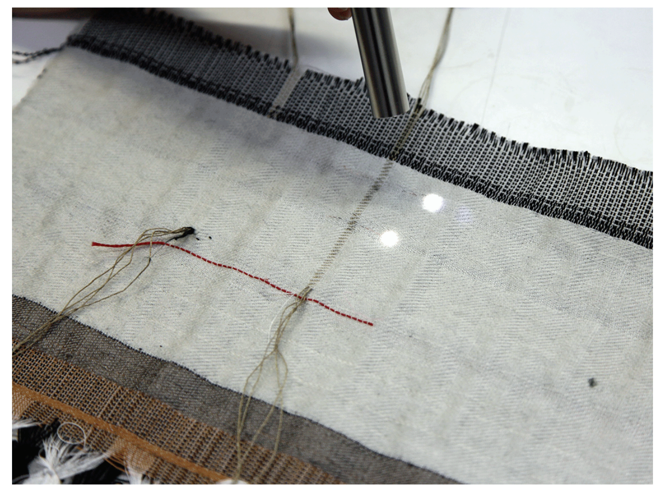
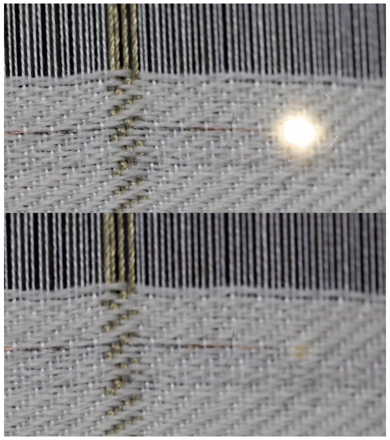


Figure 2. The final fabric being tested using a magnet

When the placement of the components was decided, the lacquer at the corresponding points of the pin-wires was removed (see sidebar) and put alongside current weft. This allowed a galvanic connection to form between the component pin and the conductive yarn.



Testing the attached woven components with a magnet and power supply during the weaving. The LED can be seen through the top-layer, while the hall-effect sensor is not visible. The copper wire used in the pins is barely visible between the weft yarns.

This, in addition to the warp and weft structure, created a two-layer integrated circuit board, where the components are a part of the fabric. The circuit being built is shown in the sidebar, being tested for functionality after being partially woven. The components were designed to rest between the two-layer structure, with the layers separating the supply voltage and GND. The final woven circuit is shown in Figure 2. During the weaving some wires broke, although the reason was unclear. They were noticed within few lines after the insertion of the component, so we suspect mechanical stress during insertion. Regardless, once the components were successfully in, the circuit works reliably, and the flexibility of the fabric is retained.

Conclusion

We described the creation of a two-warp two-layer woven fabric. Sets of components were prepared using Litz-wire and epoxy resin, to be inserted between the two layers of fabric during weaving. The process was straightforward, with the placement of the components manageable. The use of two layers can be used for the creation of an equivalent of two-layer circuit board, while hiding the components inside the layers. While the process can be done using normal looms with limited number of harnesses, there are much more possibilities when using a Jacquard-loom. It would allow the creation of several layers for conductive signals. Finally, the process would benefit greatly from having component casings directly intended for weaving.

Acknowledgements

We thank Maija Fagerlund for helpful comments during the weaving. This project is partially funded with a Finatex grant.

References

[1] Buechley, L., Eisenberg, M., Catchen, J., & Crockett, A. The LilyPad Arduino: using computational textiles to investigate engagement, aesthetics, and diversity in computer science education. *In Proc. CHI 2008, ACM Press.*

[2] Gowrishankar R. And Mikkonen J. Pattern resistors: exploring resistive motifs as components for e-embroidery. *In Proc. ISWC 2013*, ACM Press, 137-138.

[3] Linz T., Kallmayer, C., Aschenbrenner, R., Reichl, H. Embroidering electrical interconnects with conductive yarn for the integration of flexible electronic modules into fabric, *in Proc. ISWC 2005*, 86-89.

[4] Mahiar H. Organic electronics on micro and nano fibers from e-textiles to biomolecular nanoelectronics, Serie: Linköping studies in science and technology. Dissertations, No. 1224, Linköping, Sweden 2008 ISBN: 978-91-7393-763-4

[5] Pacelli, M., Loriga, G., Taccini, N., Paradiso, R. Sensing Fabrics for Monitoring Physiological and Biomechanical Variables: E-textile solutions, Medical Devices and Biosensors, 3rd IEEE/EMBS International Summer School on, vol., no., pp.1,4, 4-6 Sept. 2006

[6] Perner-Wilson, H., Buechley, L., & Satomi, M. (2011). Handcrafting textile interfaces from a kit-of-no-parts. *In Proc. TEI 2011,* ACM Press.

[7] Post, E. R., Orth, M., Russo, P., Gershenfeld, N. E-broidery: Design and Fabrication of Textile-based Computing, IBM Systems Journal, v. 39, (2000), 840-860

[8] Stoppa, M., Chiolerio, A. Wearable Electronics and Smart Textiles: A Critical Review. Sensors 2014, 14, 11957-11992.

[9] The Crying Dress URL: http://www.kobakant.at/?p=222