Towards Development of Scalable Garment-Integrated Technologies

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Brief Biographical Sketch

I am a third year Ph.D. student in Apparel Studies at the University of Minnesota, in the United States. My research interests include the development of new wearable systems, the materials and fabrication methods used, and mass manufacturing of garment-integrated technologies. My specific doctoral dissertation work focuses on the development of scalable, durable and efficient manufacturing methods for e-textiles.

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UbiComp/ISWC'18 Adjunct, October 8–12, 2018, Singapore, Singapore
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ACM ISBN 978-1-4503-5966-5/18/10.
<https://doi.org/10.1145/3267305.3277836>

Author Keywords

E-textiles; garment-integrated technologies; apparel manufacturing; surface-mount technology; simulation.

ACM Classification Keywords

CCS Concepts: • Computer applications → Manufacturing; *Computer aided manufacturing*; electronics; • Simulation and Modeling → Simulation output analysis.

Abstract

This research project aims to develop a scalable manufacturing method for garment-integrated technologies that preserve user comfort and work within the constraints of typical apparel manufacturing processes while providing required electrical performance and durability needed by the system. We have developed a method for attaching discrete surface-mount components and rigorously tested the method. To demonstrate the scalability of the method test prototype garments are under development, which will be used to evaluate the durability of the manufacturing process at garment scale as well as the impact of integrating electronic technology on labor, equipment, and cost.

Background

Reliable, durable, and scalable fabrication of garment-integrated electronics is a major barrier to large-scale

Figure 1: LEDs are soldered using a reflow technique (top), and a motion sensor-controlled shirt developed using the method [1,2]

garment integrated applications for wearable technology. The differences in shape and material properties (i.e., textiles/soft goods vs. electronics/hard goods), the inconsistency between manufacturing practices (i.e., manual and slower vs. automated and high speed), and the disparities in product development cycles, technological advances, and work practices make the development of scalable garment-integrated technologies more challenging. The objective of this project is to make electronic circuitry minimally perceptible in clothing by replacing rigid circuit boards with textile-based flexible circuitry, but retain the efficiency and scalability offered by traditional electronics by using typical component packages and soldering techniques. The ultimate goal of this research is to develop scalable garment-integrated technologies following a hybrid manufacturing process while leveraging the benefits of the traditional labor-intensive apparel industry and the automated electronics industry. We propose the following objectives:

- To develop an effective and efficient manufacturing method for integrating electronics into a garment while minimizing the need for new equipment in a cut-and-sew environment.
- To implement this method in a test prototype manufacturable.
- To evaluate via a case-study manufacturing process the impact of technology integration on the labor, equipment, and cost of manufacturing.

The proposed method has the potential to facilitate the development of flexible, adaptable, and distributed garment-integrated technologies for sensing, interface, and displays that will promote the development of a wide variety of applications for consumer, medical, and military industries.

Development of A Stitched Method of Fabricating E-Textiles

For this project, we have developed a stitched method of fabricating e-textile circuits with discrete surface-mount components [1]. In this method, conductive traces made from conductive threads are stitched into a textile substrate and surface-mount electronic components are directly affixed onto the conductive traces with reflow soldering (figure 1). Stitched methods of trace integration offer durability and flexibility benefits, as well as relatively un-constrained layout patterns. A low-melt solder paste along with an equal amount of gel flux was used in the reflow technique. We started with a manual application of solder and heat-gun reflow technique, and then developed into a solder stencil and heat press technique. The solder stencil-controlled distribution of solder onto the fabric, flux made it easier to pass the solder through the stencil, and finally, the heat press ensured even distribution of heat and made solid connections between the conductive trace and the LEDs. The method leverages technologies that are common to apparel and sewn product manufacturing while providing the required electrical performance.

To ensure that the developed samples were able to withstand regular wear and tear, we performed a simulated wear test. Results showed that only 3% of LED joints stopped working after the durability test. The method shows promise for use in large-scale e-textile production.

To demonstrate the feasibility and scalability of the method with a more complex circuit, we developed a 16-LED matrix using RGB LED ICs and implemented it in a white-button down shirt that contained a total of

42 LEDs (Figure 1). The LEDs were connected to an inertial sensor via an Arduino microcontroller. The display got the signal from the inertial sensor system and changed the color depending on the orientation and motion of the sensor. We are currently utilizing the method to develop several e-textile garments in our lab. For instance, recently we used the method to develop a child costume with color changing capabilities [4].

We evaluated the robustness of the technique for machine-laundryable e-textile garments [5]. After performing a laundryability test for around 17 hours based on machine washing and drying, we measured a 1.5% failure rate for component solder joints. In a separate study, we tested the laundryability of surface-insulated e-textile [3]. After around 16.67 hours of rigorous washing and drying, we measured a best-case 0% failure rate for component solder joints, and a best-case 171% maximum reduction in trace conductivity. Liquid silicone seam sealer was effective in protecting 100% of solder joints while two tape-type alternative surface insulation materials were effective in protecting bare traces and component attachment points respectively. Overall, results demonstrate the feasibility of this technique for producing insulated, durable cut-and-sew circuits for smart garment manufacturing.

We are currently developing a button-down shirt with multiple sensors placed in different positions of the body surface to demonstrate and evaluate a fully manufacturable electronically-augmented garment system that includes distributed component attachment, trace insulation, trace and seam crossing, and communication with central processing and power units.

Future Directions

Our method demonstrated the feasibility of a reliable, scalable, and durable method of surface-mount fabrication of stitched e-textile circuits. However, there remain open research questions before the technique is deployable. One of the biggest challenges we have been focusing from the very beginning of our research is how we can make interconnections durable and stronger so that they can withstand regular wear and tear and washing. We completed mechanical and wash-testing of the method. Tangential methods for insulating traces and dealing with trace and seam crossings are under investigation. Our encapsulation investigations are still preliminary and require refinement. Future research will focus on facilitating the selective and strategic integration of reinforcement points to ensure a stronger, durable connection with minimum mechanical effects, and to make efficient interconnections between traces and use of insulators among different traces.

To ensure feasibility of more sophisticated circuits, further studies will be performed to affix more sophisticated surface-mount components, such as multi-pin ICs. We will develop multi-layer stitched circuits where conductive traces are stitched in either side of a fabric layer. In future, some of the manual reflow technique will be replaced by automated stenciling and pick-place operations that will ease the production process.

The next step is to translate the method to high-volume production. Therefore, the method will be implemented in a typical apparel factory where technological integration will be done in-line with the cut-and-sew process. For that purpose, a prototype e-textile

garment will be developed. A time study approach will be used to compare the e-textile garment with a non-electronic version. Manufacturing model variables will be derived from the case-study and abstracted into a manufacturing simulation model for future projection. The impact of the integration of technology on the apparel manufacturing process will be assessed. Finally, the bottlenecks and barriers of the proposed method will be identified and will be further refined to make it suitable for large-scale garment integrated manufacturing production.

Acknowledgements

This work was supported by the National Science Foundation under grant #1253581. A very special thanks to the University of Minnesota, Dr. Lucy Dunne, Steven Goodman, Crystal Compton and all Wearable Technology Laboratory Collaborators.

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