A Wearable Meter That Actively Monitors the Continuity of E-Textile Circuits as They Are Sewn

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ABSTRACT

The e-textile landscape has enabled creators to combine textile materiality with electronic capability. However, the tools that e-textile creators use have been adapted from traditional textile or hardware tools. This puts creators at a disadvantage, as e-textile projects present new and unique challenges that currently can only be addressed using a non-specialized toolset. This paper introduces the first iteration of a wearable e-textile debugging tool to assist novice engineers in problem solving e-textile circuitry errors. These errors are often only detected after the project is fully built and are resolved only by disassembling the circuit. Our tool actively monitors the continuity of the conductive thread as the user stitches, which enables the user to identify and correct circuitry errors as they create their project.

CCS CONCEPTS

• Human-centered computing• Human computer interaction (HCI)• Interaction devices

KEYWORDS

E-textiles, debugging, debugging tool, augmentation, wearable device

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1 INTRODUCTION & MOTIVATION

Over the past decade, embedded computing has expanded to include a new landscape of computationally enriched materials, commonly called e-textiles. This e-textile landscape blends electronic capability with textile materiality and provides a new method for beginners and experienced engineers to create microcontroller projects [1]. Through e-textiles, traditional rigid hardware components, such as insulated wire, LEDs, and the now nearly-standard Arduino, have been modified to accommodate the materiality of textiles. Those rigid components have now found commonplace as conductive thread, sewable LEDs, and the LilyPad, where they benefit the strengths of e-textiles. This strength lies primarily in the flexibility of creation; no longer are engineers restricted by static terminals on printed circuit boards or breadboards. Instead they are free to stitch freeform paths that connect the microcontroller to other components. However, this flexibility sometimes leads to circuitry errors that are unique to e-textiles [3]. Although hardware components have been modified for use in e-textile projects, the tools used to diagnose circuitry errors have not. An example is the multimeter, an essential electronic measuring device that has no established equivalent in the e-textile domain [4]. The multimeter is designed for a different making context, rendering its form mostly incompatible with e-textiles, with the probes too big and rough to make good contact with the conductive thread [2]. Additionally, most beginners lack the expertise to fully utilize the device's electronic measuring features [4].

Our tool is a wearable voltage meter that allows engineers to recognize and address common e-textile errors as they stitch their project's circuitry. The goal is an e-textile tool that bridges the gap between the electronic and textile world, and in doing so utilizes the unique affordances that e-textiles offer. While the multimeter is used as inspiration, the device created is different in form and use. It is a wearable device that augments the user's abilities, alerting them if they have made a sewing error as they stitch by detecting the loss of continuity. Not only does this device utilize the voltage readings typical of a traditional multimeter, it also benefits the user by assisting during each stage of e-textile circuitry creation and actively helps the user as they stitch freeform paths.

2 BACKGROUND & RELATED WORK

This research is part of the Debugging by Design project [NSF Award Number: 1742140] grant which focuses on the development of e-textile debugging tools for students. We have identified several electrical problems that students encounter as they construct e-textile circuits using their *E-textiles Technical Guide* [3]:

- Short circuit: A short circuit occurs when two threads of opposite polarity come into contact with each other.
    - Fix: Remove stitching, isolate wires, then restitch the e-textile project.
- Reversed polarity: Reversed polarity is an error that's caused when electricity won't flow through a component due to the positive and negative terminals being connected to opposite terminals on the microcontroller.
    - Fix: Cut loose the component and rotate until the component's terminals are at the correct polarity. Then restitch component to the microcontroller.
- Incorrect pin usage: A common software or hardware error that occurs when the wrong pin is either initialized or sewn onto the microcontroller board.
    - Fix: Modify the program to include the correct pin, or cut thread connected to the microcontroller and reconnect to the correct pin.

The guide doesn't rely on the use of electronic tools to identify potential errors; instead it relies on the user to visually identify whether certain components do not work as expected after they finish stitching the project's circuitry. The guide also suggests potential solutions for the various errors that may occur. Most of these solutions require the user to disassemble their e-textile circuitry to further identify and isolate the problem, and then restitch portions of their project.

Current literature on e-textile tool development has worked towards a similar goal of creating tools that benefit the affordances of e-textiles [2, 5, 6, 7]. Most of these tools have been developed under the concept of taking traditional textile tools and augmenting them with electronic capabilities. Posch and Fitzpatrick have designed three tools that allow for continuity testing. Two of these tools are the eTextile Tester and the eTextiler's Tape, which are respective examples of tools that enhance a traditional textile tool with electronic capabilities and a tool that is specifically designed to benefit the materiality of e-textiles [5]. Additionally, tools have been developed by Posch that focus on creating e-textile friendly probes that can connect directly to a multimeter [2], although these tools have been developed primarily to assist in the creation of e-textile crocheting rather than stitching circuitry.

Perner-Wilson, et al. have theorized and created potential tools for e-textile creation [8, 9]. These tools are openly available at the websites *MAKE TOOLS, NOT PARTS* and *TOOLS WE WANT*. These websites were created to house the theoretical and functional tools designed by that team. The tools created by their team has focused on helping creators identify resistance and continuity in their projects. More recent research has focused on redesigning the multimeter to make a "low-floor" version that is more ergonomic and usable by beginners [4]. The device is targeted towards K-12 students with the intent of reducing the learning curve associated with the traditional multimeter.

3 RESEARCH APPROACH & UNIQUENESS

This paper reports on the development of a device that will help the creation and problem solving of e-textile projects. The main function of this device is to allow for the user to identify the creation of errors as they actively stitch their e-textile circuitry. The device is a wearable conductive wristband that measures the voltage that is passing through a needle and conductive thread as they are used to stitch. If the user creates a circuitry error that causes the voltage to drop below a threshold the device will alert the user, via an audible sound, that will allow for them to immediately identify and correct the error. This novel approach not only allows the user to live debug their circuitry as they stitch, but also utilizes the user's hands as the device's probes. By utilizing the user's hands to gain voltage measurements, this eliminates the difficulty associated with placing traditional multimeter probes on e-textile stitched circuitry. This device recontextualizes the voltage readings of a multimeter by allowing for immediate debugging and problem solving, rather than debugging after the creation of the e-textile project.

The device's design currently has two features that can identify common e-textile circuitry errors:

- Voltage meter: The device can identify voltage at a specific point of contact.
    - This feature can alert the user if the pins set in their code do not match their circuit design. For example, the user can touch the pins on their microcontroller to verify which pins are powered. This feature can also be used to check the polarity of threads that are connected to the microcontroller.
- Continuity meter: The device can detect when a short occurs in a circuit.
    - This feature can be used to alert the user if they have made a stitch that causes a loss in continuity.

Informal testing was conducted for our tool by having a student create an e-textile circuit while wearing the device. The initial feedback was positive, with the user using their hands to explore the microcontroller's pins to identify which ones were ground before stitching. While stitching, the device alerted the user that they had created a short circuit and they undid their stitch to correct the error. The user described the immediate feedback during stitching as helpful as the user had no previous experience with embedded computing, and if unassisted by the wearable meter, wouldn't have been able to identify the circuitry error. Limitations did arise during the informal testing of the tool. The conductive wristband was unable to get accurate readings at times due to the poor connection it was making with the user's wrist, and the user had initial troubles identifying what the device was measuring without a display.

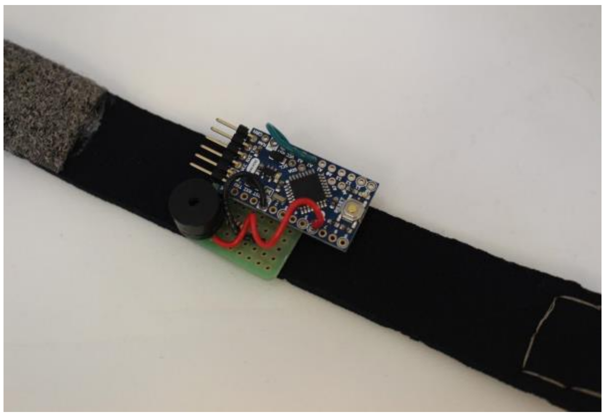

Figure 1: The wearable meter.

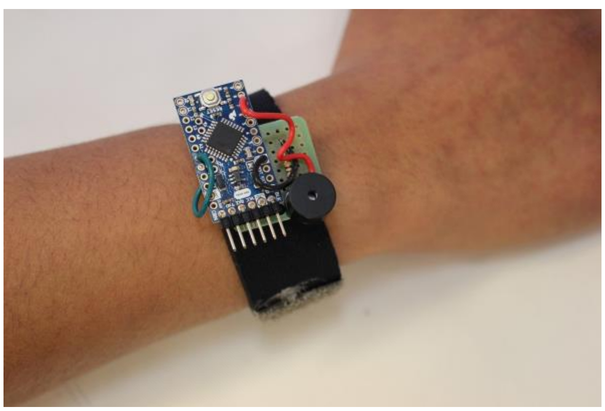

Figure 2: The meter worn on the wrist of a user.

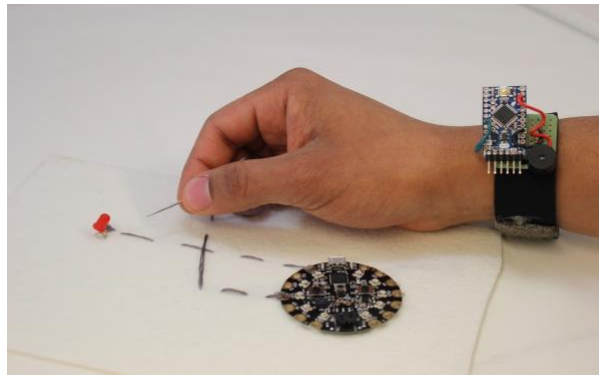

Figure 3: An example of an e-textile circuitry error where the wearable meter will alert the user to undo their stitch.

4 RESULTS & CONTRIBUTION

In this paper we present the first prototype of a wearable e-textile debugging tool. This tool takes advantage of the flexibility that e-textiles affords by enabling creators to recognize and address common e-textile errors while actively creating their project's circuitry and can help the user avoid disassembling their project to problem solve. By helping users avoid disassembling their projects we hope to mitigate the frustration factor that is associated with problem solving e-textiles. This tool is also designed to allow the user to augment their hands as the device's probes to increase usability. By using the user's hands as part of the device they are able to make reliable connections with their project's conductive thread. For future work, the device will be tested by students in a beginner wearables course as they create e-textile projects. The feedback received from the students will be used to iterate on the tool to improve ability and design, as well as classifying what other circuitry errors our device can assist in identifying. In addition, we are developing the tool as part of an effort to create a suite of debugging tools for e-textiles, and we plan to incorporate this device with a dedicated Arduino library.

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