User-Controlled Multi-Zone Jacket for Thermal Microclimate Regulation

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ABSTRACT

The ability to control one's personal microclimate allows for customized comfort, reduced energy expenditure, and better human performance. Here we present the design of a multi-zone user-controllable heated jacket. The garment uses a multi-layer textile approach to provide e-textile heating and thermal insulation. Heating zones are controlled by the user through a sleeve-mounted multi-sensor e-textile interface. A custom textile-integrated 3D printed strain-relief support protects the interface and provides a counter-force for manual interaction. The garment is designed for everyday wearability in a physical and aesthetic form intended to blend in with everyday clothing.

CCS CONCEPTS

• **Human-centered computing** → Human computer interaction (HCI); • **Applied computing** → Physical sciences and engineering; Electronics.

KEYWORDS

E-textile, Smart Clothing, Heated Clothing, Thermal Comfort, Personal Microclimate

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1 INTRODUCTION

Thermal comfort is a necessity for human health and well-being, but is also a significant source of energy use and energy waste. The body works to maintain a consistent core temperature and will adjust its functions in order to achieve this [4]. Facilitating thermal comfort benefits mood as well as cognitive and physical performance [3, 5, 6]. Maintaining comfort is especially challenging in shared environments where ideal temperatures differ between individuals. However, individual preferences for thermal experiences vary considerably from person to person. Most commercial products enable heating of one body area, while in prior work we found substantial variability between individuals in preferences for local heating, making it unlikely that a single device could satisfy a range of user preferences. Adaptable, customizable heating that allows the individual to select where and how much they are heated may help overcome this challenge. Further, on-body heat supplementation may also lead to significant energy savings by allowing ambient temperatures to be reduced in underused spaces,

To address this need, we have developed a jacket that enables the user to dynamically control on-body heating. This extends our previous work, which has led to the characterization of stitched textile-based heating technologies [1, 2], but has primarily focused on the hand [1], and is informed by our prior investigations of the variability of user preferences for on-body heat. This work extends the textile-based wearable heating system further around the body, and provides the user with control over the location and degree of heating. This evidence-based approach facilitates localized heating in the body areas shown to drive thermal experience for different users.

2 SYSTEM DESIGN

2.1 Garment Design

The garment consists of two layers and mimics the design of a common zip-up fleece jacket with detachable fingerless gloves (Figures 1 & 2). An outer layer constructed of Polartec 200 fleece (100% polyester) provides thermal insulation. This material was chosen based on previous work that found it offered a balance of thermal insulation and comfort (acceptable vapor transport value) [1]. Compared to other materials evaluated, it also provided texture and aesthetic properties more traditionally used in this style of garment. The garment was lined with an active liner made of a crepe scuba knit (96% polyester, 4% spandex, described in section 2.2), which heats the garment through stitched conductive traces following the Joule heating method from Foo, et al. [2]. Heating controls are located on the left sleeve and are used to adjust the heating intensity and body location (described in section 2.3). This

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Figure 1: (left) Jacket Exterior

Figure 3: Glove Attachment

style of garment was chosen because of the familiar form-factor, for easier integration into the home wardrobe. It is loosely fitted to allow a larger population to be fitted in a smaller number of sizes.

Pockets at the front of the Jacket allow access to the microcontroller. The gloves attach to the ends of the sleeves using $\frac{3}{8}$" metal snaps, which secure and connect them to the power source. The gloves are fingerless to allow manual dexterity, as the garment is designed for indoor use.

When the garment is active, different zones can be individually controlled in order to heat the locations the user prefers. Up to seven zones are controllable: upper chest, abdomen, upper back, lower back, arms, neck, and hands. Though the gloves (Figure 3) are detachable from the jacket, they must be attached in order to be activated. The user can also choose between high and low heat settings. Preliminary characterization shows that the High heating setting (8.56 Watts) increases the garment internal temperature by 7.1C (+/- 3C), and the Low setting (4.24 Watts) increases the temperature by 3.8C (+/- 1.4C).

2.2 Active Liner (Heating Component)

The garment's heating element is contained within the lining of the jacket. Resistive heating is afforded through stitched conductive thread (Syscom Liberator 40®silver-coated Vectran™ thread), as seen in Figure 4. A pattern stitching machine (Brother BAS342G) was used to produce consistent and even stitched patterns. Lines of stitching were spaced 6.5mm apart. Trace layouts were designed to cover as much of the body surface as possible and to provide even heat distribution throughout the textile. This was constrained by the maximum working area (19 x 28 cm) of the pattern stitching machine.

The placement of heating elements are shown in Figure 5. Note that in order to properly cover the larger areas of the body (e.g. chest, back and abdomen) two separate pieces were stitched and then connected during construction. The right and left sleeves and gloves are controlled together. Wires were soldered at each end of the trace layouts and routed around the garment towards the right pocket where the microcontroller is housed. Routing was guided using textile loops and a fusible tape, to facilitate full range of motion and provide strain relief. Solder points were secured with fusible tape.

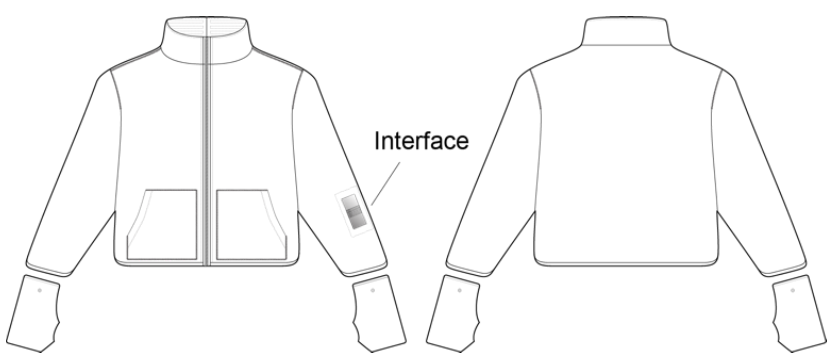

Figure 2: (right) Technical Drawing of Jacket

Figure 4: Stitched Thermal Element (left) and Thermal Image of Active Trace (right)

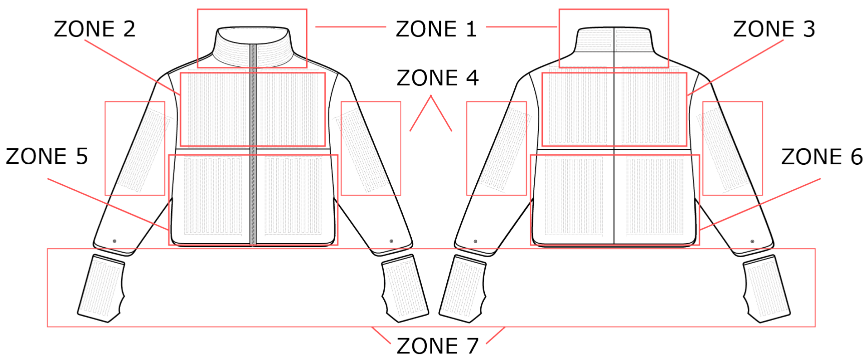

Figure 5: Technical Drawing Showing Trace Layout

2.3 Touch Control

The user controls the temperature level and heating locations by pressing and swiping an interface on the left forearm. The design was informed by a user study, where seven participants familiarized themselves with an early prototype, experimented with different positionings, and submitted a questionnaire discussing design preferences (Figures 6 & 7). Results indicated that the non-dominant bicep and forearm were the preferred sites for input controls, and participants generally expressed a desire for simpler designs. Subsequent iterations positioned the sensors on the forearm to facilitate dominant hand accessibility. The study also assessed preference for positioning of an LED array as visual feedback, and results showed an equal preference for visual feedback on either forearm.

The interface design features two capacitive touch sensors that are accessible via cutouts in the garment's outer fleece, as can be seen in Figure 1. These are backed by a non-stretch insulating layer separating the capacitive touch sensors from a pressure sensor, made of Velostat sandwiched between two layers of conductive fabric, as shown in Figure 8

The input design was developed to mitigate accidental inputs. To "activate" the interface, the user must first apply pressure anywhere on the sensors. Pressing on the interface after activation changes the zone of the garment that is being controlled with LEDs changing color to indicate which zone is being controlled. Swiping from one sensor to the other increases or decreases the temperature level. Swiping towards the hand increases temperature, and swiping towards the elbow decreases temperature. For more advanced temperature control, a swipe and hold gesture will quickly scroll

Figure 6: User Trial Setup

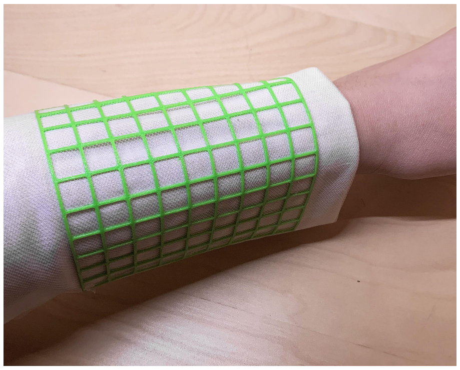

Figure 9: Test Design of the 3D Printed Layer

Figure 7: Early Interface Design

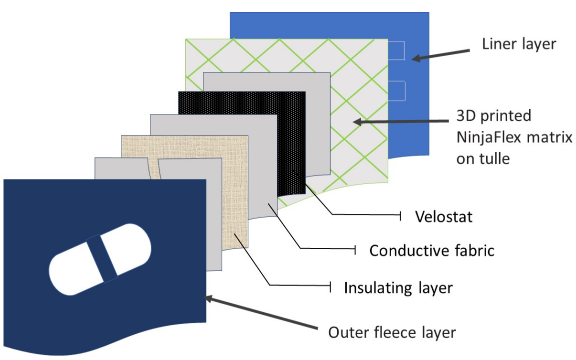

Figure 8: Diagram of Touch Control Layers

through these settings using the same directions for increasing and decreasing temperature. The interface remains active until neither sensor is touched for 3 seconds. Additional feedback is provided by a vibration motor that buzzes at a valid input.

To mitigate textile motion artifacts in the input sensors, the interface is supported by a flexible 3D printed layer that fortifies the sleeve (Figure 9). The layer is made of a thermoplastic polyurethane (TPU) (NinjaTek NinjaFlex) filament printed onto a nylon tulle fabric in a grid pattern. The open structure of the tulle allows the 3D printed layers to adhere together through the fabric. The flexibility and shore value (85A) of the TPU filament make it easy to integrate with soft goods and more comfortable than a more rigid material.

The design of the 3D printed support was developed through an iterative process. Parameters such as the thickness of the layer, the pattern, and the density of the filament to negative space in the layer were adjusted. This was done to determine the optimal design to support the hardware while remaining flexible enough to be comfortable for the user.

The flexibility of the 3D printed layer was evaluated by varying the spacing sizes. Early designs were tested by human users. Feedback from user testing indicated that the negative spaces should be between 10 square millimeters and 25 square millimeters so the layer achieves the desired mechanical properties.

3 CONCLUSION

Controllable on-body heating has the potential to dramatically reduce energy expenditure while allowing multiple users of a shared space to maintain their individual thermal preferences. This design allows users to achieve this level of individual control, through a comfortable and everyday-wearable form factor. Future development will involve testing the system on users to ensure functional efficacy and user comfort.

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