DynamicSkin: Bio-inspired Scaled Sleeve for Body Temperature Regulation and Dynamic Self-Expression

Yuanhao Zhu
Cornell University, Ithaca, USA
yz2696@cornell.edu

Annice Lee
Cornell University, Ithaca, USA
gl383@cornell.edu

Ziyue Hu
Cornell University, Ithaca, USA
zh392@cornell.edu

Hsin-Liu (Cindy) Kao
Cornell University, Ithaca, USA
cindykao@cornell.edu

ABSTRACT

This paper presents DynamicSkin, a bio-inspired scaled sleeve that offers body heat regulation for the wearer while serving as a channel for self-expression and making a fashion statement. We present the design process and system design enabling the dynamic scaled sleeve, exploring the meaning of unobtrusive wearable technology and beautification of features that are often chosen to be hidden instead. This research aims to advance body crafts by exploring a wearable that benefits the human body while providing ample aesthetic value for the user.

CCS CONCEPTS

• **Human-centered computing** → Human computer interaction (HCI); Interaction devices; • **Hardware** → Communication hardware, interfaces and storage; Sensors and actuators.

KEYWORDS

Skin electronics, Wearable Computing, Clothing, Textile

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1 INTRODUCTION

In recent years, "smart clothing" has gained tremendous interest in the public conscious and the field of wearable computing [1]. A study shows form factor and functionality are the top two user requirements for wearable devices [2]. Specifically for the form factor, people want lightweight, comfortable, and visually appealing wearable devices [2]. In this context, we developed DynamicSkin, a fashion smart sleeve that helps maintain the human body temperature while providing opportunities for self-expression. Our goal was to explore fashionable yet functional wearables that worked to benefit the human body.

Prior human augmentation device work has shown us a great example of combining form factor and functionality. Xie et al. used a bionic analogy, proposed a tail device to augment human life [3]. The tail cover can be made in different materials, displaying huge potential in personal expression [3].

The most critical functionality of clothing is to insulate against cold and hot weather. DynamicSkin is inspired by scales on butterfly wings that can help insulate the heat and increase body temperature [4]. Furthermore, as smart clothing, DynamicSkin helps thermoregulation in response to ambiance temperature change and keeps skin in a comfortable temperature range. "Feel & See the Globe," an interactive thermal installation, translates color to tangible thermal sensation [5]. Similarly, as shown in figure 1B and C the position of the scales provides users with a visual representation of the current thermoregulation status. Chromic fabric and dynamic scale movement are visually appealing. The scale shape, color, material, backbone shape are all customizable, providing huge space for self-expression.

2 RELATED WORK

Visual motivation for DynamicSkin came from Iris van Herpen's Earthrise 2021 collection. This collection specifically "explore[d] a symbiosis of high technology and the artisanal craftsmanship of couture," inspiring the layered scale patterns and intricate movement tendon backbones [6].

The bending functionality of DynamicSkin was adapted from ClothTiles [7]. This study explores on-cloth actuation mechanisms via flexible 3D printing and shape memory alloys (SMAs). The essential elements of ClothTiles are anchor points, SMA wire, SMA crimp, and support base layers. When the SMA wire connects to a power source, it will generate heat by Joule heating and activate the SMA wire to bend, then the cloth actuates. The support base layer is the thin bottom layer of the 3D printed structure. It has a counterforce when the SMA wire bends and brings the ClothTile back to the default flat shape when the power source is off. Although DynamicSkin does not use SMAs for actuation, it builds upon the ClothTile 3D printed structure and bending features to explore how on-cloth actuation mechanisms can work to benefit the human body.

3 DESIGN METHODOLOGY

The following section will cover the various system aspects of DynamicSkin, from form factor to system functionality.

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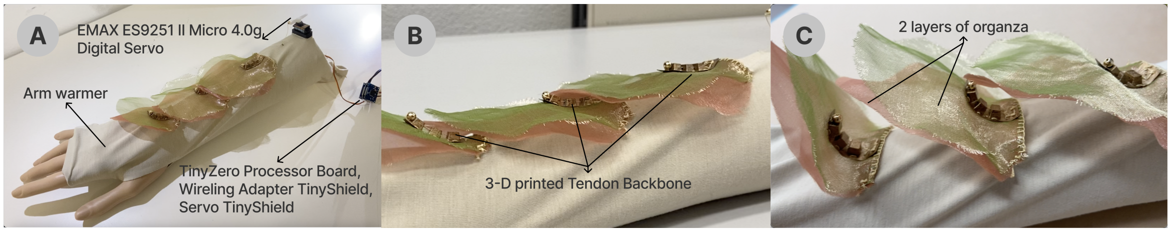

Figure 1: Images showing the DynamicSkin system on a mannequin arm. A. Overview of the DynamicSkin, a pulse oximeter sensor was actively measuring the skin temperature of one of the authors. Sensor was not captured in the picture. B. A close-up view of the DynamicSkin when the scales are closed in response to low skin temperature. C. A close-up view of the DynamicSkin when the scales are lifted up in response to high skin temperature.

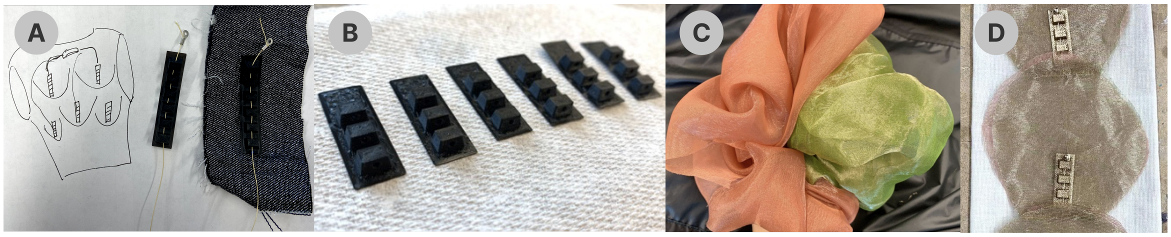

Figure 2: Images showing the design and fabrication process of the DynamicSkin. A. The Sketch demonstrated the idea of placing the DynamicSkin over the back of the human body. In the middle is a six-node tendon. On the right is a six-node tendon glued on a small piece of denim. B.3-D printed uncolored three-node tendon. C. Two contrast colors (peach orange and lime green) of metallic finish organza fabric were selected. D. Tendons were painted in gold and sewed together with scales, laying flat on the arm warmer.

3.1 Early Design Iterations

The first iteration of DynamicSkin was designed to be showcased on a human's back as shown above in figure 2A. A 6-node tendon was glued onto a denim fabric with a thin string threading through the nodes, ending with a steel stopper. By pulling the thin thread, the steel stopper would force the tendon to bend together with the denim layer. Once the proof of concept was realized, we began to explore different fabric materials such as tulle and organza that would contribute to the aesthetic visual of the wearable. In this process, we decided to focus on a smaller part of the human body such as the forearm rather than the back to increase our ability for an advanced, high-level iteration within our timeframe. The shape, material, and color of the scale-tendon combination was finalized after multiple iterations, as shown in figure 2D.

3.2 Form Factor

As mentioned earlier, the initial inspiration came from Iris Van Herpen's terrific art fashion pieces. We were also motivated by butterfly wing scales, which can increase heat capacity to keep body temperature and diffract lights to create different iridescent colors under different angles. Therefore, we tailored the shape of the scales to be round like butterfly scales, but in a double layer of different colored organza, to demonstrate the idea of dynamic color changing.

3.3 Tendon Backbone

The tendons were 3-D printed using a PVC material, referencing the linear form actuation method in ClothTiles. As shown in figure 2B, three nodes plus a flat fastening area are diagrammed with holes in each side of the node to thread a small string that would ultimately connect the tendon to a digital servo. Although we explored different numbers of nodes in previous iterations of the tendon, we finalized the tendon with three nodes with a flat fastening area to maximize bending while minimizing its intrusive nature to the lightness of the scale material. The singular hole at the end of the tendon was used to sew the tendon onto organza scales. The thickness of the 3D print was crucial for the tendon to have bending ability; therefore, the thin base on the tendon was printed at 0.5mm. In further iterations of the backbone, we increased the width of the tendon base and added six holes on each long side for easier sewing onto the scales, and painted them gold to ensure that it would not be visually distracting compared to the colorful scales.

3.4 Materials

Different materiality was explored for the scale form as it had to be lightweight enough to bend with the low servo torque but structured enough for the bend to be clearly visible. After exploring different materials such as denim, tulle, and organza, and testing each material's s with the tendon backbone, we learned that the denim was too thick, the tulle was extremely airy but organza struck the right balance. It carries the lightweight and airy look of tulle but has sufficient fiber structure, similar to denim, to keep its sturdy shape during the bends. Two contrast colored organza fabrics with metallic finish were selected for the scale in order to provide a dynamic color change in different tendon states. When the scale is open, the peach orange fabric is revealed while the lime green fabric is exposed during the closed state.

3.5 Hardware

The circuitry for DynamicSkin was created with the following TinyCircuit components: TinyZero processor board, wireling adapter TinyShield, servo TinyShield, 5-Pin wireling cables, pulse oximeter sensor, EMAX ES9251 II micro 4.0g digital servo, Lithium ion polymer battery.

To fix the servo on the arm as figure 1A, we 3-D printed a bracelet to wrap around the arm underneath the arm warmer. The bracelet has a slot to fix the servo and used PVC as the printing material. We cut a hole on the arm warmer to reveal the servo horn, so it can move freely without being covered by the arm warmer.

3.6 System Functionality

The goal of the system is to maintain skin temperature in a comfortable range. Initially, the entire device is in the resting stage; the pulling string is loose, with scales closing down and flat. The pulse oximeter sensor sends back temperature reading every 300ms. The system checks if the latest reading falls in the comfortable temperature range. If the temperature reading stays in the comfortable range, the system will keep checking the next temperature reading. In other cases, if the system finds the reading is above the upper boundary of the comfortable temperature range, the system will call servo to turn 180 degrees counterclockwise. Correspondingly, the servo horn pulling away the string attached to scales makes the backbone bend and lift scales to increase airflow for cooling. In the same way, when the temperature is lower than the comfortable temperature range, the system will call servo turn 180 degrees clockwise, which will loosen the string and let the backbone reverse its shape, and result in flat scales. During the servo run, the system stops checking the temperature. After each complete servo movement, the system will start to check temperature again.

4 DISCUSSION & CONCLUSION

DynamicSkin can be useful in daily life when extended from a sleeve into a full-body garment and paired with different fabrics. DynamicSkin can be day-to-day wearing to express fashion statements. Infants' ability to regulate body temperature is not well developed as adults. DynamicSkin bodysuits can help maintain their body temperature in a comfortable range. Quadriplegic patients can wear full-body DynamicSkin in response to changing temperature without frequently changing clothing by the caregivers.

There are some limitations in our work, which provide space for improvement. First, the current torque of the mini servo is too low to open up the scales drastically. Balancing the scale weight and the torque of the servo could be a solution. Second, the tendon backbone could not fully reverse shape due to the PVC 3D printing material and the gold paint covering its surface. Future iterations will explore materials that may work more effectively for the tendon backbone, focusing on elasticity and shape-return after intensive bending. We would also like to consider different backbone shapes that might contribute to the fashionable value of DynamicSkin.

Imagining a future with DynamicSkin, we hope to fulfill a unique, full-body coverage wearable that provides both physical and mental benefits to the wearer through accurate thermoregulation and a channel for dynamic self-expression.

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