NugiTex: An Interactive, Affective Wearable that Informs Users of a Plant's "Comfort" Level through Haptic Cues

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Figure 1: (a) NugiTex arm warmers constructed of tubular soft materials that constrict when actuated (b) Neck warmer with embedded circular soft material (c) AirSpec*, an environmental sensing device for to capture ambient temperature and humidity (d) FlowIO [12], a development platform for soft robots and programmable materials for controlling the airflow of NugiTex. (e) A user wearing NugiTex, AirSpec, and FlowIO.

ABSTRACT

NugiTex is a line of interactive, affective wearable garments that convey the embodied experience of plants using device-initiated haptic cues. The haptic cues reflect a plant's "comfort" level based on proximal environmental conditions, aiming to increase awareness and induce feelings of closeness, symbiosis, and empathy with the user's natural environment. Composed of inflatable silicone and non-elastic textile layers, NugiTex responds to nearby atmospheric conditions such as temperature and humidity levels, which are measured in real-time by AirSpec, smart eyeglasses fitted with sensors to collect environmental data. Variations in temperature and humidity in a room are then interpreted and translated into three types of haptic cues - shrinking, hard pushing, and mild pushing - each a metaphorical representation of the plant's condition. Users are given these real-time haptic cues through FlowIO, a pneumatic platform for controlling the airflow and pressure of soft devices. We predict that the increase in awareness of natural entities through interactive embodied experiences will promote the Inclusion of Nature in Self (INS), and encourage pro-environmental behaviors.

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CCS CONCEPTS

• **Human-centered computing → Haptic devices**; *Interaction design theory, concepts and paradigms*; HCI theory, concepts and models.

KEYWORDS

Affective Device, Connectedness with Nature, Wearables, Soft robot, Inflatable, Embodied Experience

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1 INTRODUCTION

Climate change and associated shifts in temperature and precipitation affect plant ecophysiology, reproduction, and interactions with other organisms, including humans ourselves [2, 10]. Encouraging pro-environmental behaviors requires unique strategies, including reminding people that humans are connected to and part of nature. People tend to ignore or minimize environmental problems when they are not immediately observable, or when damaging effects are temporally removed from causes. Allowing users to personally experience a direct causal connection with other living beings in their immediate environment can reduce perceived temporal distance and engender more critical scrutiny of the effects of individual behaviors.

1.1 Haptic and Visual Cues for Increasing INS

When people take on the perspective of another person, plant, or animal, they often experience an increased mental overlap of the self and other, which induces feelings of closeness and empathy and increases helping intentions and behaviors [7]. Schultz [11] introduced three levels of Inclusion of Nature in Self (INS): cognitive, affective, and behavioral. The cognitive component refers to how strongly a person sees nature as part of themself; the affective component refers to the extent of care or concerns a person feels about nature; and the behavioral component explains whether a person is motivated to act in the best interests of nature.

Several studies have suggested that experiences within Immersive Virtual Environments (IVEs) with haptic feedback may help to increase users' INS. Within the IVE, participants adopt the perspectives of other natural entities, and thereby generate feelings of interconnectedness with nature (INS). Experiments with IVE have explored a variety of contextual immersions and environmental concerns. One IVE-based study explored the sensorimotor experience of cutting down a tree in a virtual forest as compared to mentally simulating the same experience [8]. The study found that the virtual experience was more effective than mental stimulation in increasing pro-environmental self-efficacy and behavior in the physical, non-mediated world [1].

1.2 Interspecies Empathy for Encouraging Pro-environmental Behaviors

The effect of evoking empathy for a natural object (e.g., a plant) can impact the willingness to act toward protecting the environment was identified in previous studies [3]. In the field of HCI, plants' natural abilities to respond to their environments are of particular interest to researchers, artists, and architects for designing interspecies interactions [4], united within the topic of Human Plant Interaction (HPI). Chang et al. indicated that interspecies empathy through HPI has been vastly accomplished via translating plant-relevant environmental signals to human-centered means (e.g., written word [13], sound [9], and smiley faces [5]) but plants' true perceptual world and its link to human's connection with nature lacks investigation [4]. They encourage HPI research to have a better understanding of plants' capabilities, preferences, as well as functional properties and explore the non-human experiences that communicate these sensations and signals.

We hypothesize that increasing the salience of nature through a combination of visual and haptic experiences is a viable method of fostering pro-environmental behavior. Based on the precedents above, we developed two research questions: (1) Can haptic cues collected from nearby plants' environmental data promote INS?, and (2) How can we increase the salience of nature through haptic experiences to foster pro-environmental behaviors (PEB)? We believe that by haptically representing sensory and physical-state information, NugiTex presents users with an embodied experience of their nearby plant, thereby enhancing information processing and positively influencing behavior. Instead of using VR goggles or other visual simulations, we developed wearable garments consisting of textile and elastomer layers to provide a sensorimotor experience of plants' comfort in the user's nearby environment. To enable a rapid collection of environmental data and control of a haptic device, we connected FlowIO to AirSpec, allowing instantaneous data transmission via Bluetooth. To summarize, the paper presents the following contributions:

- Demonstration of haptic cues that encourages INS and pro-environmental behaviors by inducing feelings of closeness and empathy toward the environment, which could increase helping intentions and behaviors.
- Development and presentation of the fabrication process for embedding elastomer layers between textile layers to create intrinsically compliant and flexible smart garments with pneumatic actuators.
- Development and presentation of an easy data transmission process between atmospheric data and the pneumatic platform, eliminating the need for developing haptic controllers and atmospheric sensors.

2 DESIGN PROCESS

NugiTex consists of top and bottom layers with non-elastic knitted textile, and a middle layer with inflatable elastomer - as shown in Figure 2. A combination of material properties, textiles, and basic geometric configurations of the elastomer is used to achieve the desired motion and force output. Two prototypes worn on users' arms or neck were developed to test two different actuated behaviors - shrinking and pushing.

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[0] AirSpec is an environmental and physiological sensing wearable device extended from Captivates [6], an open-source smart glasses system for in-the-wild psychophysiological monitoring. Its system design is described in a submission to CHI 2023 Late-Breaking Work.

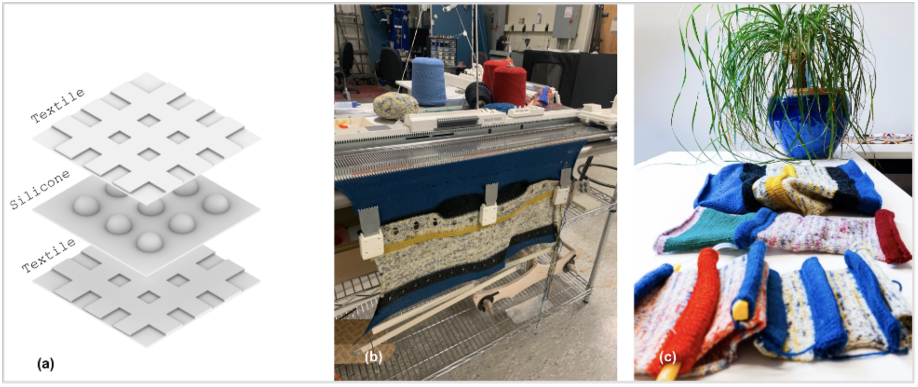


Figure 2: (a) NugiTex consists of two layers of knitted textile and a silicone layer (b) fabrication of the textile layers of NugiTex using a single-bed knitting machine (c) textiles with shrinking and pushing actuation behaviors.

2.1 Elastomer Design

Flexible and airtight materials such as elastomers have been utilized to design inflatable bladders and stiffness-changing structures. The design and casting process for tubular and circular-shaped elastomer designs have different fabrication procedures. For the tubular-shaped elastomer, a simple cylindrical shape with a diameter of 5 mm and a height of 150 mm was designed. The elastomer precursor was slowly poured on the surface of the cylinder and allowed to set for one hour. Then, we flipped the cylindrically shaped mold with the first elastomer layer and repeated the previous procedure. The thickness of the tubular-shaped elastomer varies according to curing time. As the thickness of the final elastomer reached 1mm, we slowly separated the elastomer from the cylinder. Inspired by McKibben muscles consisting of a cylindrical shell with a braided mesh, the tubular-shaped elastomer was then spun with 0.5 mm yarn to make it capable of radial expansion, yet inextensible at a maximum threshold.

The circular-shaped elastomer design consists of three steps. First, top and bottom mold designs for silicone casting are created using a 3D-modeling tool, Rhino. The bottom mold has no inner pattern, and the top mold is designed with three consecutive inner circles. These molds are then fabricated using an additive manufacturing method of extruding PLA on a 3D printer. Second, using EcoFlex 00-30 rubber, two silicone solvents are mixed in a 1:1 ratio, and injected into the mold, and cured for 3 to 5 hours. Before the mixture is completely cured, it is vacuumed to de-gas to eliminate any entrapped air in liquid rubber. Third, the elastomers are slowly separated from the molds, and the top and bottom elastomers are attached by applying a thin layer of silicone solvent on the intersecting part. After another 3 hours of curing, the finalized elastomer design is connected to a tube, and another end of the tube is connected to the pneumatic device FlowIO. [12].

2.2 Textile Design

A single-bed knitting machine is used to fabricate textile layers of two wearable garments: an arm warmer and a neck warmer. By transferring stitches to an adjacent needle using a single-eye transfer tool, six lace holes (eyelets) on a neck warmer are designed to simulate both gentle and hard haptic pushes from elastomers patterned with six 30 mm-diameter circles. Transferring the bottom purls to stitches creates a tubular-shaped space to insert an elastomer for shrinking behavior when actuated. The wearable garments are re-fitted with a series of holes and a gap to accommodate both tubular and circular-shaped inflatable silicone. The elasticity of the fabric allows it to change shape in response to the actuation behaviors of the inner silicone layer, as shown in Figure 3.

3 TECHNICAL DEVELOPMENT

Actuation is controlled using FlowIO, a miniature, modular, pneumatic development platform with a software toolkit for the control, actuation, and sensing of soft robots. Relative humidity and ambient temperature are collected using the SHT45 sensor on AirSpec, and live data were streamed via Bluetooth to a laptop. Both AirSpec and FlowIO were BLE peripherals, while the laptop acted as a central interpreter to parse the environmental data, benchmark them according to the characteristics of the plant, and decide the resulting action. The detailed mapping is shown in Figure 4.

Actuation occurs in response to changes in the surrounding environment which is adjusted using heaters, humidifiers, and fans. Emulating the responses of plants to changing atmospheric conditions, the haptic responses of wearables are mapped as follows: In temperatures above 80°F and lower than 60% humidity, the wearable garment with tubular-shaped elastomer produces shrinking behavior. The shrinking haptic cue is repeated until the surrounding temperature drops below 80°F. For temperatures between 60 and 80°F and humidity above 60%, the wearable produces releases the air from the elastomer, but provides no haptic cues, on the assumption that this temperature range is better for the plant's thriving. When the temperature drops below 60°F, the circular-shaped elastomer expands for 2.6 seconds and provides hard-pushing cues to the user.

4 INTERACTION SCENARIOS

Thus far, we have demoed a single NugiTex prototype, allowing visitors to either wear or touch the garment laying on a table. For our final demonstration, the interaction with the haptic wearables will be set up in the form of an art installation capable of accommodating two participants at once (see Figure 5). Both users will wear

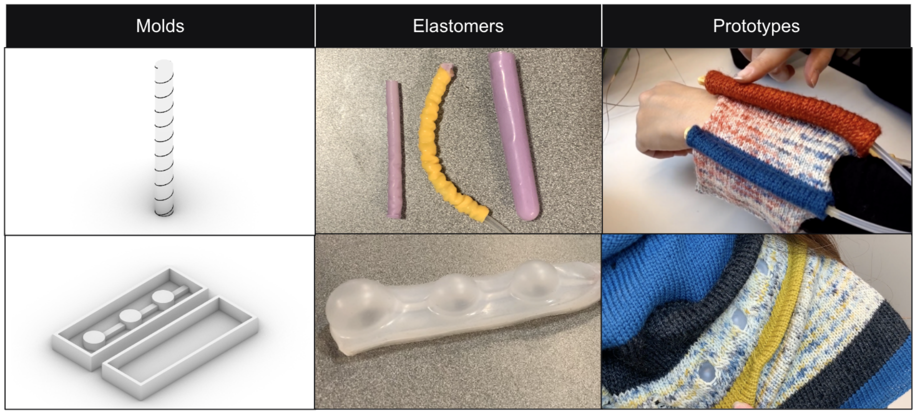
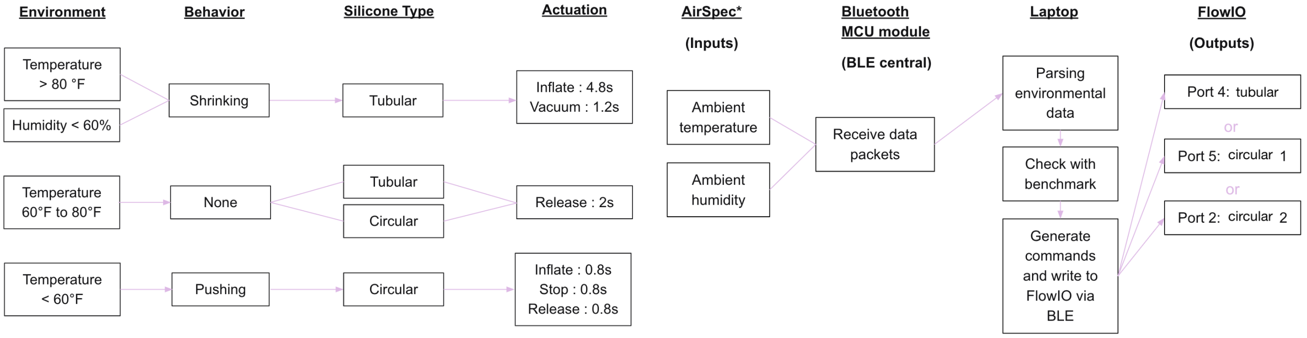


Figure 3: Two types of silicone molds were designed. The tubular and circular silicon layers were inserted inside two textile layers.



(a) Mapping **(b) Data transmission**

Figure 4: Technical mapping and data transmission of NugiTex based on temperature and humidity levels of the surrounding environment.

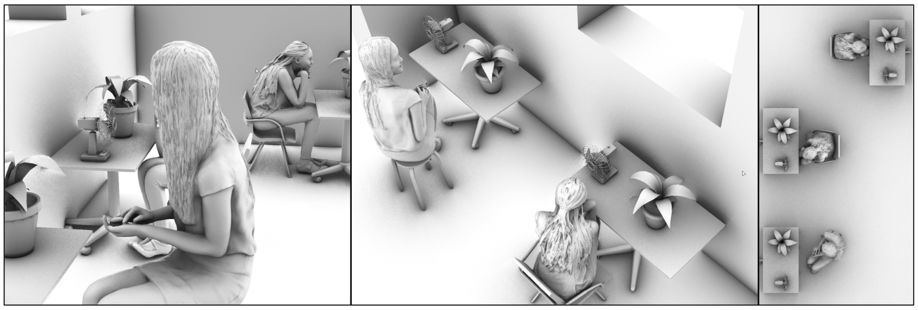


Figure 5: Users interacting with a NugiTex.

the garments with AirSpec and FlowIO in a space within the "ideal" temperature and humidity range (i.e., producing no haptic cues). They will then be asked to move around the 3 x 6 square meters area containing plants in three different environmental conditions generated by a humidifier, a heater, and a fan. Users will be asked to spend at least 60 seconds near each plant in order to allow the AirSpec glasses enough time to acquire environmental data. Adjustments to the atmospheric conditions will then produce haptic and visual feedback from each user's garments, thereby communicating information about the environmental conditions of each plant they approach in real-time.

5 CONCLUSION

In this paper, we have introduced and detailed the development of wearable garments with elastomer actuators for humidity and temperature-responsive transformable interfaces for increasing connectedness with nature. Increased attention on environmental issues has led researchers to explore several strategies for encouraging pro-environmental behaviors, such as recycling, energy-saving, and the use of biodegradable products. We have concentrated on promoting pro-environmental behavior with methods aimed at engendering users' feelings of interconnectedness with nature (INS). Advanced, responsive wearables that convey haptic and visual cues can help users more readily adopt the perspectives of other natural entities, thereby promoting helping intentions and behaviors.

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