PNEU-SKIN

A Haptic Social Interface with Inflatable Fabrics

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Abstract. Wearable electronics endow us a great capacity to see clothing as an extension of our body and an interface to interact with our physical and social environment. The fashion industry is experimenting with new tectonics and materiality, however, few projects have explored wearables in the public and social domains and how it can dynamically respond to a wide range of interpersonal distances in social interaction. PNEU-SKIN is a pneumatic wearable that uses critical making as a research strategy to explore interactive and soft interfaces to create soft boundaries between private and public space. This paper proposes an embodied computation agenda and describes the design and prototyping process of a multi-sensory smart skin in response to varying social distance in interpersonal communication. By looking at adaptive behaviors in nature and the way that certain animal species respond to external stimuli by increasing their size and providing multi-sensory responses, PNEU-SKIN looks into how our clothing could become an adaptable skin to redefine interpersonal communication experience within everyday social interaction.

Keywords. Pneumatic Wearables; Interpersonal Communication; Embodied Computation; Critical Making; Sensory Feedback.

Figure 1. Final Design and Prototype of PNEU-SKIN.

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1. Introduction

Artists have been designing wearables to explore new relationships between body and space for a long time. For example, the fashion collection of Rei Kawakubo, Body Meets Dress, Dress Meets Body (1997), rethinks our perception of the human body by using filler and padding, altering the anatomical boundaries of it. Another example is the work of Lucy Mcrae who defines herself as a body architect, "speculates on the future of human existence by exploring the limits of the body". She understands the body as a combination of spaces and structures that can be reconstructed as an architectural space.

Figure 2. Rei Kawakubo. Comme des Garçons. Body Meets Dress–Dress Meets Body (1997).

Figure 3. Lucy McRae, Evolution (2008).

Technology is allowing us to see our clothing as an extension of our body and an interface to interact with our environment. Nowadays, wearable electronics are becoming everyday objects and designers found an opportunity in combining traditional techniques with technology to explore more complex ways of communication. As Sterlac observes, with the use of technology "the body has become an extended operational system, performing beyond the boundaries of the skin and beyond the local space that it inhabits." Artists, designers, and architects are now crossing disciplines to explore the realm of fashion, utilizing digital fabrication and electronics they are proposing new wearables from the point of view of performance, new tectonics, and materiality. Architect Behnaz Farahi exposes social issues such as gender and intimacy through the creation of robotic wearable technology. For example, her project Caress of the Gaze is a 3D printed actuated cape, which retracts and expands, changing its shapes according to external stimulus sessed by a camera embedded to the wearable. Another architect, Neri Oxman also uses technology in fashion stating "The future of wearables lies in designing augmented extensions to our own bodies that will blur the boundary between the environment and ourselves". The Mushtari is a 3D printed wearable that uses sunlight to generate consumable energy mimicking phenomena found in nature.

Figure 4. Caress of the Gaze: A gaze actuated 3D printed garment by Behnaz Farahi (2015).

Figure 5. Mushtari, Jupiter’s Wanderer by Neri Oxman (2014).

As the fashion industry is experimenting with new tectonics and materiality, however, few projects have explored wearables in the public and social domains and how it can dynamically respond to a wide range of interpersonal distances in social interaction. In this paper, we describe the design and prototyping processes of PNEU-SKIN, a pneumatic wearable that uses critical making as a research strategy to explore interactive and soft interfaces to create soft boundaries between private and public space.

There is no doubt that men dominate the use of public space. In public transport, for instance, we often see that the space used by men is considerably more significant than the one used by women. Women are taught to make themselves small and be considerate of the space they occupy. Men, on the other hand, spread their bodies and invade others’ personal space to make themselves comfortable. An example of this is ”Manspreading”, which is the practice of men sitting in public transport with legs wide apart, thereby taking up more than one seat. This kind of invasion of personal space is closely related to the study of Proxemics - human use of space in interpersonal communication. The most generally agreed taxonomy of human distances in space, according to Edward T. Hall, indicates that the interpersonal distances of man are categorized into four distinct zones-’intimate (<0.5m)’, ’personal (0.5m-1.2m)’, ’social (1.2m-4.0m)’, and ’public (>4.0m)’. (Sussman and Justin 2015) These four interpersonal distances have their own uses and characteristics (Figure 6).

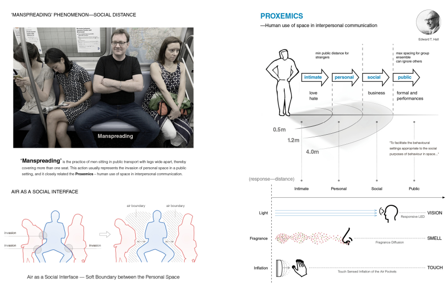

Figure 6. Manspreading Phenomenon on Public Transit and Critical Making Agenda with Sensory Feedback Integrated into Proxemics.

Leslie Kanes Weisman affirms "The appropriation and use of space are political acts. The kinds of spaces we have, don't have, or are denied access to can empower us or render us powerless." The relationship between power and space can be also found in nature. Species like pufferfish blow themselves up several times their normal size when they feel threatened by predators, while female toads inflate their bodies as a widespread mechanism to defend themselves from male toads and prevent them from mating with them. Like these two, several other species in the animal world can inflate their bodies, some of them use this ability to modify their sound and volume, but in general, the main purpose is a visual demonstration of prominence and power. In this study, the questions that emerge from this social issue are: What if our skin could respond to the invasion of our personal space redefining our anatomical perimeter? Would this empower women to reclaim their personal space? Digital technologies are used to design and fabricate a pneumatic wearable device that reacts to external stimuli through microcontrollers, sensors, and actuators. Utilizing a critical making approach and human-computer interaction concepts, this wearable acts as a reactive interface between the human body and the surrounding environment so that the bodily functions can be augmented, enhanced, and expanded.

The term Critical Making was introduced by Matt Ratto in 2008. It refers to a pedagogical practice and also a research strategy used to explore the intersection between critical thinking and hands-on practices to generate critical reflection about social issues. In Ratto's words, the emphasis of critical making is on "critique and expression rather than technical sophistication and function". (Ratto 2011) According to Ratto, a critical making project involves three stages: research, making, and reflection. The research stage implicates the study of relevant literature and the gathering of appropriate theories and concepts. The making stage involves the creation of material prototypes that are not focused on aesthetics, but in a conceptual exploration through fabrication to extend knowledge and skills in significant technical areas. The reflection stage involves an iterative process of exploration between different prototype alternatives where conversation and reflection begin. Architects and designers have been taking advantage of technology to communicate ideas better, design more efficiently, and reduce costs. However, the critical making approach steps back from this consumer-oriented culture and enables designers to reflect on social implications of the use of technology and practice design as a form of activism. Coming back to the idea of redefining human anatomy to reclaim personal space and empower women, the intention of creating a wearable as a second skin capable of interacting and reacting, is also an exploration of how art, design, and technology can reveal and challenge power relations in our society that emerge from the use of public spaces.

2. Method: Embodied Computational Workflow with Critical Making Agenda

We develop a critical making agenda with an embodied computational workflow through which sensory feedback is provided to form a haptic social interface responding to varying interpersonal distances.

Starting with ideating novel ways of social interaction, specifically, how our design responds to varying interpersonal distances, we prototyped and tested with inflatable fabric modules and translated selected partial interaction to the body scale according to ergonomic principles. Through parametric patterning, digital fabrication, electronic interactive prototyping, and Arduino programming, we achieve the embodied computation agenda through system integration. A holistic approach is critical in this method as we intend to unify and synthesize the embodied computation agenda, sensory feedback mechanism, and inflatable material systems.

- **Material and Interactive Prototyping with Inflatable Fabrics** Material prototyping approaches the critical making agenda by conducting material experiments with inflatable fabric modules in different shapes and structures and testing various sensors and actuators in different sensory modalities. When activated with flowing air, inflatable fabric modules inflate and deflate in turn, and modules of different shapes and structures demonstrate different characteristics and behaviors. Iterations are made with selected pneumatic performance to achieve desired sensory responses.
- **Parametric Design and Patterning** Parametric design approaches the agenda by translating three-dimensional strategies on the body surface into a two-dimensional surface pattern. The pattern is determined by ergonomic Langer lines along which skin has minimum tension.
- **Digital Fabrication and Physical Prototyping** Digital fabrication approaches the agenda by laser cutting on nylon fabric materials for prototyping purposes. The cutting pattern is guided by ergonomic principles. This helps understand the actual material performance and behavior through interactive experiments.
- **Pneumatic Control and System Integration** Pneumatic control approaches the agenda by encoding how prototyped inflatable modules behave and provide sensory responses with simple hinging transformations and texture change in response to different interpersonal distances. The dynamic transformation of the garment can be achieved by controlling inflatable fabrics. The material layer, sensing layer, and the human body are integrated into a holistic system.

3. Results and Discussion: A Pneumatic Wearable Design Encoding Social Interaction

The proposed workflow was developed and tested in a design workshop the authors were instructed in Tongji University in 2018, taught by Behnaz Farahi and Jifei Ou. The authors designed and prototyped a pneumatic wearable that functioned as a haptic social interface that can provide sensory feedback to varying interpersonal distances.

3.1. MATERIAL EXPERIMENTS AND INTERACTIVE PROTOTYPING

PNEU-SKIN augments the body with novel interpersonal communication through enhancing sensory perception and feedback. Three types of sensory responses, namely touch, smell and vision, were mapped respectively to ‘intimate (<0.5m)’, ‘personal (0.5m-1.2m)’, ‘social (1.2m-4.0m)’ interpersonal distances according to Edward T. Hall’s Proxemics theory.Material experiments and inflatable module prototyping was then conducted. After cutting the non-sticky nylon fabric into testing shapes, two nylon layers with one connector in between are stuck together with adhesive thermoplastic TPU through heat pressing. An air tube with another connector is then inserted into the air pockets. When activated with flowing air from a syringe, inflatable fabric modules inflate and deflate in turn, and modules of different shapes and structures demonstrate different characteristics and material behaviors. We also incorporated distance sensor (HC-SR04 ultrasonic distance sensor module) and touch sensor (TTP223B digital capacitive touch sensor) to detect interpersonal distances and touch behaviors. The touch sensor is small enough to be embedded inside the air pocket while the ultrasonic distance sensor is placed outside the air pocket. Responsive LEDs (WS2812B NeoPixel digital addressable RGB LED light strip) were placed inside the air pockets to provide visual cues through color and blinking patterns (faster blinking frequency in the closer distance) in response to interpersonal distance and perfume were also placed between fabric folds to provide olfactory feedback when inflated and deflated with inflatable modules. Through a series of material experiments and pneumatic tests, we selected the muscle-like inflatable module to develop further. It can expose the hidden layer when inflated (Figure 7).

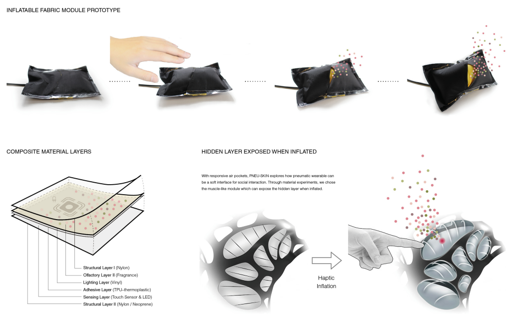

Figure 7. Inflatable Fabric Module Prototype with Touch and Distance Sensors.

The muscle-like module's inflatable layer is generated by a series of air pockets which are fabricated with two layers of Thermoplastic Polyurethane(TPU) and paper in between (Figure 8). TPU is a textile that can be fused by applying heat. The purpose of using paper is to allow only the edges to be fused and create an air pocket. The study introduces Box pleats on the TPU fabric to allow the pocket to grow in three dimensions. Pleating is a technique of folding fabric to create texture and changes in the shape of garments. Box pleats are made up of two knife pleats which are the most basic and commonly used techniques to pleat textiles. Knife pleats consist of two folds of equal width, a visible outside fold and a hidden inside fold. In a Box pleat, the two knife folds face away from each other. After developing a few prototypes, the pocket was made by the combination of two types of TPU fabrics; translucent for the inside fold and opaque black for the outside fold, so when the pockets inflate the translucent fabric is visible and also the light from LEDs placed behind the pockets.

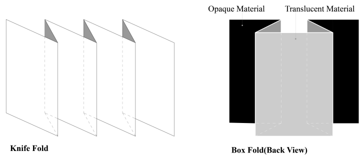

Figure 8. Fabric Pleat techniques used in the study.

3.2. PARAMETRIC PATTERNING AND DIGITAL FABRICATION

The three-dimensional body surface was unfolded into two-dimensional for pattern mapping and laser cutting. Voronoi patterns were laid out on the unfolded surface to accommodate the inflatable modules in procedural design software (Grasshopper) according to Langer lines, along which skin has minimum tension so that the patterns inform the air pockets and their form transformations (Figure 9). In this way, the pneumatic wearable reflects the architecture of the human body, as well as it is capable of being reconfigured according to the movement of the wearer's body. The resulting design was fabricated with a laser cutter in non-sticky nylon fabric materials for interactive prototyping and testing.

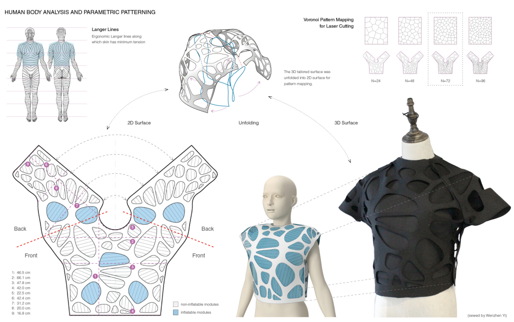

Figure 9. Body Tailoring, Parametric Patterning, and Laser Cutting.

The core structure containing the pockets is covered by two layers of Neoprene fabric, a synthetic rubber sandwich structured textile. The morphology of this fabric provides stability and maintains the flexibility needed for the wearable. The inside or base layer, facing the skin of the user, covers the pockets providing support for placing sensors, air pipes, and electronics. The front layer is designed in Grasshopper cutting out the air pockets to allow them to grow when the air is pumped in. The design of this piece is provided from the 3D model as one flat piece and cut precisely by using a laser cutter. Finally, the three layers (Figure 10) are assembled by the use of Double Sided Fusible Interfacing, a fusible fleece web that works like glue when it is heated. This layer was also laser cut, one with the shape of the outside layer and another one with the shape of the base layer.

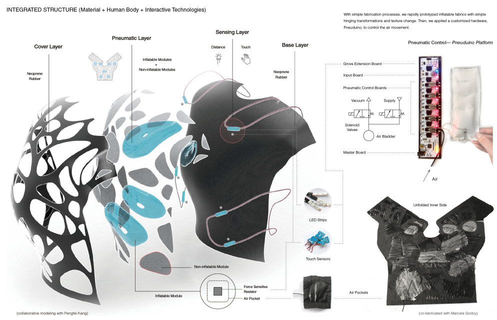

Figure 10. Material, Inflatable, and Electronic System Integration.

3.3. SOCIAL INTERACTION ENCODING, PNEUMATIC CONTROL, AND SYSTEM INTEGRATION

Three types of social interaction scenarios (Sussman and Justin 2015) were encoded into the pneumatic system's behavior and formed a novel embodied computation agenda. (Figure 11) PNEU-SKIN has no reaction at or beyond social distance (>1.2m). When someone approaches personal distance (0.5m-1.2m), the responsive LEDs turn on and inflatable modules will be slowly inflated to release perfume as a soft olfactory sensory response. The inflatable modules will be fully inflated as a strong haptic sensory response (Figure 12) when someone approaches an intimate distance (<0.5m) and touches the inflatable module.

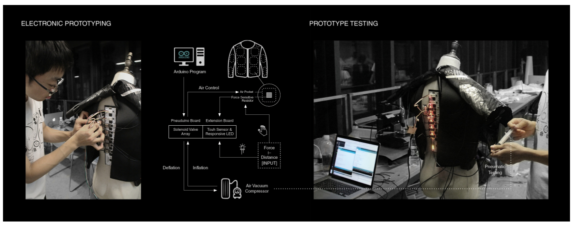

Figure 11. Electronic Prototyping and Testing.

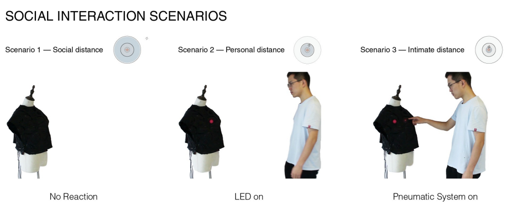

Figure 12. Social Interaction Scenarios and Interactive Prototype Testing.

The pneumatic system is primarily controlled by a customized modular hardware platform, the Pneuduino board (Yao et al. 2013) developed by MIT Media Lab Tangible Media Group, through Arduino microcontroller in order to control airflow and air pressure (Figure 4). The distance sensor and touch sensor were programmed in response to distance and pressure detection as mentioned above in Arduino IDE. Embedded with sensory technologies and elements, including responsive LEDs, distance and touch sensors, and perfume, PNEU-SKIN achieved original intentions of providing dynamic sensory feedback to varying interpersonal distance in social interaction and forms a soft boundary between private and public space (Figure 13).

Figure 13. Touch Sensed Inflation.

It is also important to note that, during the user testing, the noise caused by using the air pump has some negative impact on user experience, it could be improved with better insulation of the air pump with smaller noise in the future. The thickness of the fabric also weakened the sensitivity of touch detection of the touch sensor embedded inside the inflatable module, and it took several rounds of calibration with different types of fabric and interactive testing.

4. Conclusion

Unlike the common task-oriented approach to computational making, PNEU-SKIN goes beyond an investigation of HCI, soft robotics, and digital fabrication. As Neri Oxman states, “Digital technologies cannot and should not serve only our formal aspiration” (Dvir 2019), the project stimulates the neglected discussion and debate about gender and space. PNEU-SKIN explored wearables in the neglected public and social domains and how it can dynamically respond to a wide range of interpersonal distances in social interaction. Using critical making as a research strategy and embodied computation workflow, A pneumatic wearable was developed as an interactive and soft interface to create soft boundaries between private and public space. With easy access to digital fabrication, small electronics, and microcontrollers, this rapidly prototyped second skin speculates the limits of the human body and its implications of the relationships between body and space (Farahi 2016). Similar relationships in nature served as inspiration for developing PNEU-SKIN. Reactions observed in animal skin for defense mechanisms are mimicked, postulating new attractive possibilities for human interaction.

Future Projections. Architecture is more than just designing buildings and spaces. It embodies the experiences of those who occupy them. In this regard, male domination in all spaces is undeniable, including professional, social, and intimate spaces, allowing us to reflect on the role of women in society. Consequently, it is crucial to contextualize architecture in relation to gender issues. Through the use of novel technologies, PNEU-SKIN presents a critical perspective on current practices and the norms of society. It advocates the critical making agenda and calls on greater awareness of gender inequality, power relationship in space, and other critical social issues in the computational making domain.

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