Actuating Mood: Design of the Textile Mirror

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ABSTRACT
In his 1962 short story, "1000 Dreams of Bellavista," sci-fi author J.G Ballard describes a future in which "psychotropic" homes exist and are designed to "feel and react" to the emotions of their occupants [1]. Today with the rise of affective computing, and advancements in e-textiles, smart materials and sensor technologies, we must consider the ramifications of technology that could actively mirror, alter and transform our feelings through the materials that make up our buildings and environments. This work provides discussion and insight around the binding of material and sensor technologies with affect. We investigate how emotions could be mapped to our environment through textiles. We present two online surveys designed to enable people to map emotions to textiles. We then use the results of these surveys to inform and inspire the design of the Textile Mirror prototype, a 60x92 cm wall panel that is composed of industrial felt interlaced with Nitinol wire, and is designed to shift its textural structure upon receiving emotional signals from its viewer.

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Design, Shape Changing Interfaces, Affective Objects

INTRODUCTION
Imagine you have just experienced an emotional event, and as you enter the room, the walls begin to recede and

crumple into tight patterns reflecting the pain you feel inside. Perhaps you are implicitly broadcasting your emotions via sensors either from your phone or via a wearable. Perhaps you have expressed an emotional state on a mobile application only to discover its effects on your environment. Would the exposure alter your current state or reinforce it? Rosalind Picard coined the term, "Affective Computing" and introduced an interdisciplinary field that included computer science, psychology, and cognitive science [11]. Her vision was to enable machines to interpret the emotional state of humans through a variety of methods including facial and speech detection as well as the physiological monitoring of bio signals such as heart rate and galvanic skin response. In her 1999 paper titled, "Affective Objects," Picard goes on to explore the idea of affective communication through physical objects and how they might be interpreted by humans [10]. In this paper, we expand on Picard's research on affective objects to explore their impact on our emotional state, our physical environments, and ultimately our relationship to them.

This work seeks to investigate how emotions could be translated into our physical environment through the use of fabric. To do this, we explore people's emotional association to textiles through surveys designed to map mood to textiles. We use the results of these surveys to inform and inspire the design of the *Textile Mirror*. Our goal is to reflect the current emotional state of the viewer by shifting the textile to map to the correlating emotion being experienced by the viewer in real-time.

RELATED WORK:

The *Textile Mirror* is a wall panel which aims to influence a person's affect through its state. Background material and precedents for the *Textile Mirror* come from two related fields of research: interactive architectures that utilize soft or flexible computational materials with sensors *and* affective wearables or electronic wearables. The overlap of work and development in these two fields makes a potentially rich new space of invention.

Interactive Architecture

Interactive architecture is an emerging area within the field of architecture that in its simplest form is architecture that is programmed to respond to a person or inputs by changing its shape, color, temperature, humidity, or other quality. In its more complex form, interactive architecture not only responds to a person or input, but can be programmed to learn from its inputs or a response that a person gives to it, so that it can mediate that environment. [10]. Some interesting approaches to developing an interactive and affective architecture have been Kas Oosterhuis' un-built, visionary projects with swarming robot sensors and Akira Mita's prototyped swarm robot sensors [11, 9].

Oosterhuis proposed that the swarming sensors make up the very walls of the building [11]. In Mita's vision these hundreds of tiny sensors would swarm within a building, follow and learn from an inhabitant so that they could control the environment through implicit feedback from that inhabitant [9]. These sensors would get to know all inhabitants so that the environment could react organically in tune with the occupants. Mita sees his swarm as providing a biological response that goes far beyond the responses now possible with smart architecture solutions that principally address building efficiency and human comfort. The architecture would not only react to temperature, lighting, etc. but also to human mood by taking data from the human body.

Although most of the examples discussed in Green and Gross (2012) are not textile based (which allow for integrated electronic textile circuits and textile sensors), the article provides a summary of interactive architecture or reconfigurable building experiments and the challenges presented by reconfigurable architecture [6]. The discussion of these examples is focused on the problem of how people could interact with robotics at the scale of the environment, not so much focused on that interaction that transforms mood or emotion at the scale of the environment or why the environment should reconfigure. Other recent works of reconfigurable architecture by Threatt et. al includes a prototype of a robotic learning environment for kindergarteners, which changes shape to support learning through physical acting out [18]. Three visionary projects shown as scaled architectural models about reconfigurable monuments by Moktar et. al discusses three architectural monuments that morph to reflect the dynamic quality of collective memory [8]. Because the works are architectural models rather than 1:1 prototypes one must speculate on the interplay between emotion and memory sparked by the activated environments.

Lastly, looking at environments made from textiles and soft materials, Thompsen and Lovind's *Vivisection* project is a silk steel textile membrane with embedded sensors that signal the presence of people underneath the ceiling mounted textile [17]. The sensors activate a series of fans that fill balloons inside the textile with air. The inflation and deflation of the balloons actuates the movement of the textile, changing the shape and size of the occupied space. While this piece does not base its response on human mood, one can imagine how the expansion and collapse of the space may affect what a person feels in the environment. The Maria Osende Flamenco Dance Company stage set by Sarah Bonnemaison of @Lab is a laser cut, folded textile embedded with Nitinol strands and colored LEDs that are actuated by flamenco dancers and musicians to change the scenery and set the mood on stage during a performance [3]. The stage can be unfolded and folded into different configurations to provide an actively changing space for the performing dancers.

Affective and Electronic Wearables

In the last few years, there has been significant work done in the wearable space, particularly around actuated fabrics. With the increase of sensor technologies (e.g., proximity, light, sound, biometrics, etc.), artists and researchers have been given the means to gather and send data to anything, including fabric. The notion of physical objects reacting to a user's emotional state was first introduced by Picard [12, 13]. Since then, there has been little, if any, exploration around exposing people's emotional states in real-time through the manipulation of fabric. The authors selected fabric for its versatility in functionality, in addition to its obvious role with personal identity and self-expression.

We have noted some work in this space that we believe is relevant to our own. Berzowska and Coehlo's *Kukkia and Vilkas* introduced the notion of kinetic garments with two dresses that change or move over time [2]. The Kukkia dresses consist of three flowers that open and close over a 15 minute duration. Built with Nitinol wire and felt, the wire shrinks when heated, thus closing the flowers. In our case, the *Textile Mirror* shifts its original form based on emotional feedback from the user rather than from an automated timer. The dress makers have introduced the notion of emotional clothing through the idea of automated change.

Ying Gao's *Conceptual Fashion* is a beautiful collection of work that strives to redefine our social and urban spaces by releasing the constraints of traditional garments by allowing them to freely move and respond to their environments [5, 16]. By incorporating electrical components, such as proximity, camera, and light sensors into the fabric, Gao is able to alter the fabric's form through fluid movement in response to what is happening around the wearer. While Gao's fabric inspired us, her work only responds to properties of light and proximity, not emotions.

Above all else, the most relevant work noted here is that of Picard's *Galvactivator* [14]. This work explores the merge of both wearables and biological signals. The glove-like device essentially detects the skin conductance of the wearer while mapping it back to an LED display. Increase in skin conductance suggests a strong indication of physiological arousal and hence increases brightness of the light. We feel that *Textile Mirror* is an extension of this work in that we have attempted to reveal a user's emotional state in real-time but through the experience of emotion-reactive, shape-changing fabric rather than a wearable.

METHODOLOGY: MAPPING EMOTION TO TEXTILES

The *Textile Mirror* is a prototype wall panel that changes shape in response to people's emotions. In particular, we envision that our prototype could be used to help a user modify their emotional state from stressed or angry to happy and calm, simply by transforming the shape of the fabric. Our intent was for the user to observe the fabric changing, and then reflect on their emotional state. Before we could build this prototype, we first had to: select and prototype textures; determine what emotions were evoked by these textures; and finally, design the transformative path that the shape-changing fabrics would follow.

We approached the first goal of designing and building prototypes by finding textiles that could reflect a variety of emotional states. Many of the textiles we selected were modified by us, and we also paper prototyped some of our own textiles. All textiles were made of paper or cloth. We generated roughly 50 original textures, ranging from sharp or clear-cut edges, to smooth and fuzzy edges; linear to curvilinear and triangulated shapes. In order to determine what emotions were evoked by each textile, we created and deployed two online surveys which displayed a photograph of each of the textures and asked people to rate their emotional reactions to the images. All texture images were displayed in black and white photographs to focus the emotional reaction to the texture itself. We intentionally avoided the use of color as we felt it added another

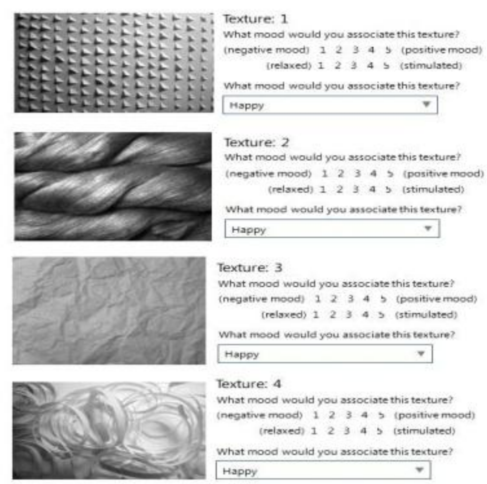

Figure 1. We deployed two versions of this study on Mechanical Turk to investigate what textures people associate with different emotions.

dimension to the interpretation. Despite using only black and white images, it is likely that lighting in each photograph played a large role in how each texture was received emotionally. In future work, we plan to investigate the difference lighting makes in an emotional reading of textures.

User Surveys

Two user surveys were created and deployed for a total of 600 survey responses. These surveys were deployed on Amazon's Mechanical Turk (MTurk), which is a website that allows users to complete short tasks for small monetary compensation. In order to participate in our online survey, MTurk users were required to have previously performed at least 50 MTurks tasks and to have at least a 95% reliability rating. All users were from the United States.

In Survey 1 (n=300), our participants answered three items for each of 23 textures, for a total of 69 responses. The average age of participants was 36.41 years old (SD=13.09). For Survey 2 (n=300), we added additional textures for a total of 50 textures and 150 responses (50 textures x 3 items). The average age of these participants was 32.27 years old (SD=11.49) with 44.7% males and 54.6% females. We inadvertently did not collect gender information for Survey 1; therefore, collecting gender was one of our motivations for deploying the second survey in addition to the extra textures tested.

Some examples questions from the surveys are shown in Figure 1. For all textures, participants responded to three items. The first question, "How does this texture make you feel?" has two rating scale items on a scale of 1-5. In the first item, participants are prompted to rate their emotional reactions to the texture based on negative (1) to positive (5) emotions. In the second item, participants are prompted to rate their emotional reactions to the texture based on relaxed (1) to stimulated (5). These rating scale items are based on the Circumplex model of emotions [13] with emotions being represented two-dimensionally based on x and y coordinates. Specifically, valence (i.e., negative-positive) is represented on the x-axis and arousal (i.e., relaxed-stimulated) on the y-axis. For the second question, participants were asked, "What mood would you associate with this texture?" They were given seven words to select from: Happy, Sad, Angry, Bored, Excited, Stressed, and Calm. We collected emotional responses to the textures using both the Circumplex model of emotions and the seven emotional words, in order to give users two ways to rate their emotional reactions.

ANALYSIS AND RESULTS

The Mechanical Turk surveys were analyzed by creating a scatterplot of the Circumplex ratings of emotion. Specifically, we normalized both the negative-positive ratings and the relaxed-stimulated ratings to be on a scale of 1 to -1. We then plotted the average negative-positive ratings for each texture to the x-axis and the average relaxed-stimulated ratings to the y-axis. From these x and y coordinates, we created scatterplots for both Study 1 (Figure 2) and Study 2 (Figure 3). For clarity of visual interpretation, all of the textures have not been added to these scatterplots. Rather, we added corresponding images around the edges of the scatterplot, in order to showcase the textures that had the most extreme values.

In both of these studies, we also looked at the ratings of emotional words for each texture. We found that it was difficult to find consensus for textures based on emotional words. For example, we looked at the words that were rated the highest for each texture and found that many images were rated as both Bored and Calm, or Happy and Excited, or Stressed and Excited. Due to these results, our analysis is focused on the scatterplot of Negative-Positive ratings and Relaxed-Stimulated ratings, which seemed to generate much better consensus across users.

In this section, we will discuss the survey results for Study 1 and 2, and finally, we will discuss how we designed the transformative path, which is based on the results from these scatterplots (Figure 2 and 3).

Study 1

The Study 1 scatterplot (Figure 2) has 10 textures at the outer edges of the Circumplex ratings. For this scatterplot, we only added images for the textures with the highest average values per emotional valence and arousal. The average Negative-Positive ratings are mapped to the x-axis, and the average Relaxed-Stimulated ratings are mapped to the y-axis.

Textures in the upper-right quadrant (i.e., positive, pumped) of the scatterplot are textures with repeated shapes of well-defined edges, linear or curvilinear. Textures in the lower-right quadrant (i.e., positive, relaxed) are curvilinear with

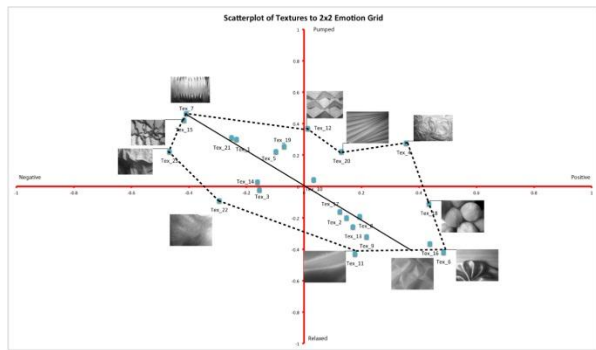

Figure 2. Scatterplot of Textures Mapped to Circumplex Ratings of Emotion in Study 1.

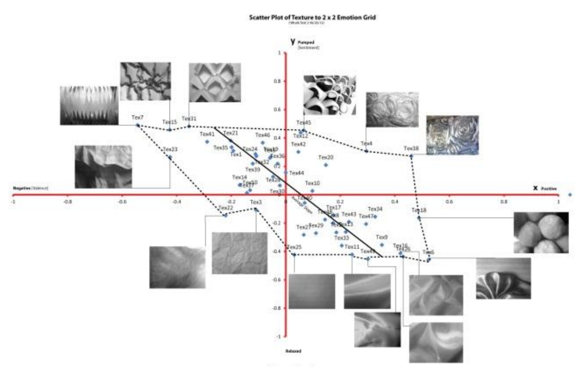

Figure 3. Scatterplot of Textures Mapped to Circumplex Ratings of Emotion in Study 2.

defined edges, curves with less defined edges, and are smooth and curvilinear. Textures in the upper-left (i.e., negative, pumped) mostly have well-defined edges, with sharp and triangulated forms. Textures in the lower-left (i.e., negative, relaxed) had ill-defined shape qualities.

We were able to map a strong linear trend between the upper-left quadrant (i.e., negative, pumped) to the lower right-quadrant (i.e., positive, relaxed) with slope -0.68, and y-intercept at 0.003 which provided us with a clear insight into how we might actuate the fabric from one emotional state to another; in our case, from “stressed” (upper left quadrant) to “calm” (lower right).

Study 2

We repeated the first study in order to validate our earlier findings and to collect gender information. In addition, we added 31 new textures that we hoped would fit into the lower left quadrant of the Circumplex model (e.g., negative, relaxed), as we did not find many textures that mapped to this quadrant in Study 1. The results for this second study confirmed the results found in Study 1 between the average rated visual qualities of the textures to specific quadrants of the emotion scatterplot. Figure 3 shows the scatterplot results of Study 2. Once again, we utilized images for the textures that had the highest average emotional values, which corresponded to 16 of 54 total textures. Similarly to Study 1, we were also once again able to map a strong linear trend between the upper-left (i.e., negative, pumped) quadrant to the lower-right quadrant (i.e., positive, relaxed) with -0.8 negative slope, and a y-intercept of .064. Since we collected gender differences in Study 2, we also looked to see if there were any significant differences in ratings for our textures based on gender. On a few textures, we did find significant differences, but even for these textures, ratings for males and females still tended to fall into the same quadrants. We found that, overall; females’ ratings were more varied, reporting more extreme values for negative/positive and for relaxed/stimulated.

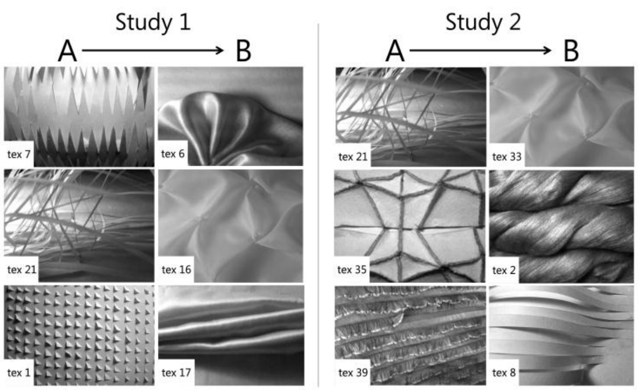

Figure 4. Transformational path between textiles A (upper left quadrant) to textiles B (lower right)

Transformative Path

From the scatterplots in Study 1 and Study 2, a clear linear trend was found between the upper-left quadrant (i.e., negative, pumped) and the lower-right quadrant (i.e., positive, relaxed). Therefore, this linear trend (or line, as seen in Figure 2 and 3) became our transformative path that our emotionally-reactive, shape-changing fabric would follow. In other words, this provided us with appropriate textures that could potentially aid a person’s emotional transformation through awareness, bringing them from an angry, excited state to a calm, serene state. Select textures were paired along this path starting with the outermost textures in the upper-left quadrant and matched with the outermost textures in the lower-right quadrant. Textures were successively paired inward along the obtained transformation line. This gave us textures that we could consider using to show awareness from ‘state a’ to ‘state b’. These pairings were useful in that they showed on a basic level what kinds of pattern characteristics we would need to transform. Figure 4 shows the pairs of textures along this path of emotion ratings.

As seen in Figure 4, some images would be easier to transform from one to the other in real material. We selected textile 35 as a practical starting point to indicate the emotion of stress or anger in our prototype. Again, our initial goal was to inform the viewer that an emotional state of stress was being articulated by the fabric. We selected this pattern for several reasons, but the most obvious to us was that the simple geometric pattern enabled us to work better with the Nitinol wire. The transformation from textile 35 (stress) to textile 2 (calm) would be too ambitious to attempt, therefore we collectively decided to accentuate the three dimensional structure of textile 35 to indicate a heightened sense of stress while leaving it’s flattened state as the temporary calm state.

Figure 5. Textile Mirror Prototype (left) relaxed (right) stressed

TEXTILE MIRROR PROTOTYPE

The *Textile Mirror* is a 60 x 92 cm prototype wall panel that is made of felt interlaced with Nitinol wire that is actuated by a person’s mood (Figure 5). Comprised of 88 cut pieces of felt, each one being sewn together, the entire piece hangs off of an 80/20 aluminum frame. When a signal is sent from the mobile phone, power is fed through the circuits causing the Nitinol wires to contract. The felt canvas then proceeds to buckle and recede away from the edges. As the wires cool, the hanging weights pull the canvas back into its original state. Ideally, we had aimed to drive this prototype implicitly with bio-signals; however, for proof of concept, a mobile input was sufficient.

Mirror Materials

Felt was selected as the base material, because not only was it soft to touch, it was quick to prototype, and provided a thick enough interface to the Nitinol wire base so that one did not directly feel wires upon touch of the mirror. There were no edges to finish, and most importantly, it provided the highest material tolerance to heat. [4] This characteristic of the fabric is important to consider when dealing with actuators that respond to heat. The pattern was cut on a laser cutter and then assembled with a sewing machine. Nitinol shape memory wire was used for actuating the fabric. Nitinol is a combination of nickel and titanium that can be trained at 900F into a shape at the high temperature. After training the metal can, cooled and unfolded. Heating the wire with a hair dryer will return the wire to the shape it was trained.

Figure 6. Laser cut felt, pinned felt, felt with sewn insulated Nitinol.

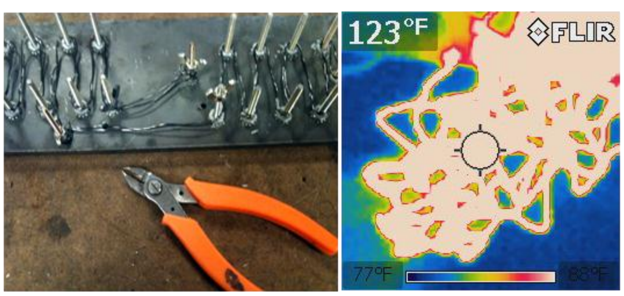

Figure 7. Nitinol wire trained on steel jig (left) and heat reading of wires with 2.5 amp current flowing (right).

Nitinol memory wire at .762 mm diameter was used as an actuator for the felt fabric because of its ability to change shape without having to use motors. The wire was trained on a steel jig in a ceramic oven at 500C for 10 minutes and left to cool slowly to room temperature in its jig. The slow cooling allowed us to use less current in the wire to actuate it, thus keeping the wire cooler when actuated. Our pattern used 35 cm wires looped to and formed on a jig. The current we ran was between 2 and 3 amps with 3 amps as the highest. See Figure 7.

The temperatures were quite substantial to consider when using Nitinol to actuate fabric, especially with the heavier gauges of wire and at a larger architectural scale. Temperatures from a group of eight wires with a current of 2.5 amps, at the point of actuation ranged between 86F and 130F (See Figure 7). At lower amperage such as 2.20 amps the actuation time for the *Textile Mirror* was around 80 seconds, and at 3 amps around 45 seconds. Our concept, not yet studied, would suggest that the slow response time of the Nitinol would lend itself to personal reflection and contemplation [7]. The wires were shrink-coated to insulate them further from the fabric and stitched into the felt (Figure 6).

Implementation

We implement a mobile phone application that enables users to self-rate their current emotional state. The user interface consists of the same Circumplex grid we used for our surveys (X as sentiment, Y as Valence). Upon selection, an X/Y coordinate is sent to the cloud, which is then received by a PC. A signal is sent, via wireless, from the PC to the microcontroller, which turns the power supply on for the allotted time needed to heat the wires, in our case

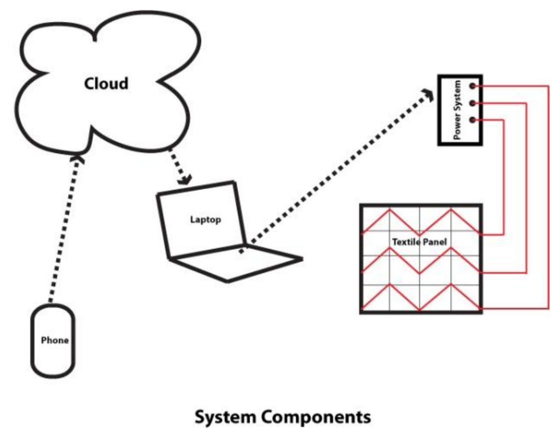

Figure 8. System diagram comprised of five major components and Circuit Design

approximately: 80 seconds at 2.5~amps. The power is then shut off which allows the wires to cool and resume their original form. For V1 of this prototype, we only trigger the fabric to respond if either the top left or lower left of the quadrants are selected. Again, this was to inform the user that by selecting a negative state, they were explicitly triggering the textile to respond.

We used a .NET Gadgeteer device as our microprocessor. This provided a simple C# programming environment enabling: high level cloud IP I/O, Bluetooth phone interface, and simple programming of a low level I^2C interface to the Power System. In contrast to many other low level programming systems, very few lines of code were required even for this high level functionality due to the richness of the C# language. Please see Figure 8 for system components.

Circuit Design

Figure 9 shows details of both the Power System and the Textile Panel. The Textile Panel contains 40 Nitinol wires of .75mm diameter where each wire is 32 cm long with a typical resistance of 2 ohms. We discovered that a constant current of 2.5 amps provided a good compromise between wire heating, pulling strength, and activation time. We selected a constant current drive as an additional safety measure so that the Nitinol power per unit length is always constant even if there are inadvertent shorts of the wire loops as the textile moves and twists. An I^2C bus provided the control interface between the Control System and the Power System.

The Power System design was based on an average voltage drop per loop of 5 volts (2.5amps * 2 ohms). We modularized our system into 8 looped groupings. Each module used one 2.5 amp and 40 V maximum (8 loops * 5 Volts per loop) constant current source. We replicated this modular approach 5 times to control 40 loops.

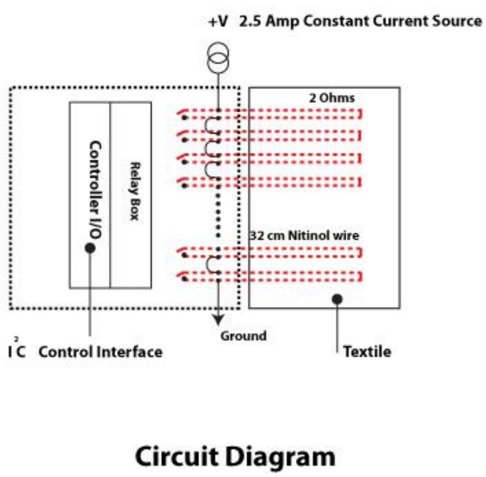

Figure 10. System diagram comprised of five major components and Circuit Design

CONCLUSIONS AND FUTURE WORK

We have surveyed over 600 people online to investigate a general assessment of mapping mood ratings to patterns/textiles. These ratings were helpful in terms of indicating what textile patterns users find to be more indicative of "stress" and "anger" and which patterns tend to be viewed as more "neutral", "calming" and "happy". We chose fabrics based on images of textures which users told us conveyed stress and calm in order to design *Textile Mirror*, a fabric that moves in order to indicate a user's emotional state. Future work in textures will include a user study where users map affect to textures that they can feel and touch. We will also include a user study that will measure users' responses to the Textile Mirror and examine if current emotional states are accurately recognized by them and whether the experience assisted in an improvement of their emotional condition.

In J.G. Ballard's vision of the future [1], it is the home that reflects and is shaped by the emotions of its owners. In the Mirror we have made reflection of emotion the central focus of these preliminary studies. We speculate that in seeing the reflection of stress in themselves, a person is given the power to change that situation for themselves to relieve their stress. Therefore the mirror, together with that person becomes an active participant in the alteration of that stress.

The *Textile Mirror* is just one instance to consciously design the intersection of smart technologies, and human emotion. In its function, it is designed to "reflect" what is being experienced internally by the participant who in turn responds back through introspection and possible adjustment. Over time, this dialogue between human and machine bridges us closer to managing our own emotional landscapes.

Our goal with *Textile Mirror* is ultimately not only to reveal to users when they are stressed, but also to help them mitigate the effects of stress by calming them down. Our next step is to evaluate *Textile Mirror* and its ability not only to reflect a user's current affective state, but also whether or not it can move a user from a stressed out state to a calmer, happier state. We have since the writing of this paper done preliminary work via 2 additional user studies. One study examines how touch of textures changes assignment of emotion to that texture. The other user study looks at how the *Textile Mirror* reflects and then transforms people's emotional states from stressed to calm by seeing and touching the mirror. There needs to be much more work in user studies examining the triad of relationships between the affect reflected by the mirror, a person and the environment.

A limitation of the *Textile Mirror* design is the fact that it can only be one texture of fabric because it is real material, unless a patterning system is developed so that a variety of textures can emerge from one fabric. A digital or virtual material may provide a more flexible visual alternative on a screen like interface, however this solution does not offer the very strong tactile sense that we feel is important in transforming stress or emotion. Another limitation is its size, as we have seen in previous work. To really understand how affect operates at the scale of the environment, it would be best tested at the scale of a room height curtain or a wall structure.

Another technical lesson learned is that it takes a great deal of energy from power boxes to drive the Textile Mirror, making it noisy in user studies meant to evaluate people's emotional states. Nitinol also needs quite a bit of time to cool down to obtain a full return to its baseline shape. After repeated activations in quick succession, the *Textile Mirror* therefore loses some of its clarity of shape, until cooled to room temperature or less.

CONTRIBUTIONS

The *Textile Mirror* makes new contributions to the field of architecture, design and affective computing. These include creating the design of a soft architectural prototype that maps affective data through shape changing interfaces.

We have designed a system in which users can see their emotional state reflected by a shape changing canvas. The design demonstrates an actual scenario for people to assess its value and function.

In addition, the project's user studies frame a method to map affect to texture. The user studies demonstrate that textures do have affectual states associated with them. This information can be used in many other design spaces.

The project further demonstrates a method of working with Nitinol in larger scale textile constructions and frames the problems and benefits of working with a Nitinol actuator.

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