Dynamic Displays at Wrist for Real Time Visualization of Affective Data

Abstract
Emotions are vital to our lives but could be difficult to recognize and understand. Traditional visualizations of emotions tend to be time-series graph on screen displays limiting user engagement in their real-time sense-making. This paper explores the feasibility of smart materials for developing novel dynamic displays on skin for real time visualization of affective data. We report prototyping two such displays and their evaluation with 6 participants, and discuss their qualities such as ambiguity, slowly unfolding change, and lack of light emission together with their temporal constraints and private-public tension for affective meaning disclosure.

Author Keywords
Affective displays; ambiguity; slowness, experience.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

Introduction

Emotions are vital part of our everyday lives signaling events of significance, but sometimes difficult to recognize and understand. The emergence of wearable technologies for tracking physical and mental health [12] shows increased interest in self-understanding and behavior change. Traditional wrist-worn displays

Figure 1: The Spiral display uses a spiral shaped nichrome wire for generating heat. A 35–40 °C self-adhesive thermochromic liquid crystal sheet is added on the top. The whole assembly is placed on polypropylene substrate for insulation. Increase in arousal is conveyed by varying current in nichrome wire, which generates color changing from red (left), green (middle) to blue (right) in a spiral shape from inside out.

Figure 2: The Heart display involves a digitally created art design printed on adhesive tattoo paper. The design was transferred to paper and a 30–35 °C thermochromic pigment was applied at the center. A heart shaped nichrome wire was placed on polypropylene substrate. The thermochromic and heating layers were integrated with clear tattoo paper. Increase in arousal is represented by the change in heart's color from purple (left) to pink (right).

represent affective data in time-series graphs [8] which provide limited user engagement for reflection. This paper explores the feasibility of smart materials for developing novel, thin and flexible wrist-worn displays for real time visualization of affective data to better motivate reflection [10]. We report the design and evaluation of two prototypes exploiting the value of ambiguous representations of emotional intensity.

Related Work

Fabrication of on-Skin Output Displays

Our focus on wrist-worn displays guided us to HCI work on thin, easy to fabricate, and flexible on-skin thermochromic displays [15]. Thermochromic displays undergo color change when heat is applied; they are non-emissive but sensitive to temperature changes in the form of paper-like displays [7] or dynamic textiles [1]. An example is DuoSkin [5] using adhesive tattoo paper to fabricate displays resembling body art. Thermochromic displays have low power requirements [7], slow response time, and subtle qualities, but low resolution because precise heat control is challenging.

Emotion Visualization

Much HCI research has focused on designing systems for emotion recall [11], processing [14], or visualization. For instance, AffectAura [8] presents a lifelogging tool to visualize valence and arousal in the form of a timeline based interactive interface. Other approaches providing time-series graph-based visualizations include tools for self-tracking moods [19]; while easy to understand, they provide limited support for reflection on real time data [6,10]. In contrast, other systems have explored ambiguous clothing based-displays [1] to represent emotions in social settings [4], which support stronger user engagement and reflection. For example, AffectiveDiary [6] displays historic affective data into colorful and abstract body shapes, while Affective Health [10] uses electrodermal activity, electrocardiogram, and accelerometer data to create ambiguous designs [2] aimed to engage users in reflection on their affective states. To conclude, emotion visualization displays support reflection but are limited because their mobile- or desktop-based interfaces are not always on sight. In contrast, on skin-output displays potentially always on sight, but seldom integrate biosensors. Our work uniquely integrates these two strands of work.

Prototyping Affective Displays

To support real time reflection on affective data and engagement within this practice [13], we developed two color changing displays for ambiguous representations of arousal: Spiral (Figure 1) and Heart (Figure 2) differing in color, shape and movement. We employed a material exploration method [16] consisting of an experimental and playful approach for fabricating three layers [5,18]: thin and low-cost thermochromic materials layer, custom shaped heating mechanism layer, and insulation layer (Figure 3). For material layer, we explored thermochromic liquid crystal sheet and pigments for their ability to display color changing effects and discard the ones actuating above 40°C for safety reasons. The choice of heating element is crucial as it can limit the resolution of thermochromic displays [15]. We explored copper, aluminum and nichrome as heating elements and chose nichrome wire over others because of its relatively high resistance. Insulation is important for thermal applications to avoid skin burn, and we considered several materials such as epoxy resins, polypropylene and polyimide insulation tape.

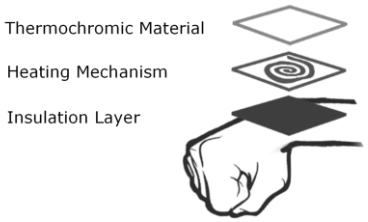

Figure 3: Multilayer approach to digital fabrication of affective displays

User Study

The study explores people's understanding of thermochromic displays visualizing ambiguous affective data. We recruited 6 students (3 males and 3 females, age ranged 24-36), and used autobiographical recall for inducing emotions [3], i.e. writing about memories of anger/fear, and happiness/excitement, while wearing the prototypes on their wrist. We asked about their perception of displays, interpretation of affective data, and how they envision using the affective displays. Sessions were audio recorded and transcribed for content analysis, and participants were rewarded £10.

Findings

An important finding is that as opposed to screen displays, thermochromic materials are more preferred. Participants referred to affective displays as something to be worn: *"I see that it does not glow. I don't like the glow from conventional displays […] I don't want a screen on my hand"* [P2]. Such findings align with people's perception of other types of dynamic worn displays such as clothing-based ones and their different qualities contrasting with the rigid displays of smart phones and watches [1]: *"it feels kind of homely. It's a textile you wear rather than a piece of hardware"* [P3].

Understanding Ambiguous Affective Data: Color

Findings indicate different mappings between representations and emotional arousal, indicating their potential value in understanding affect. Red and blue can activate different motivations within the cognitive domain [9] and can be associated with different meanings: *"blue and green [in Spiral design] are more calming, whereas red and yellow indicate to me that maybe there is some nervousness going on"* [P3]. This mapping was more difficult for the Heart display as people were challenged to subscribe meanings to the limited color range: *"When I feel angry, [it was] purple to slightly pink but when [I was] happy it completely changed to pink"* [P6]. Our findings contrast those on thermochromic clothing-based display [4] using only arousal as source for ambiguity. Arousal in the clothing-based display is represented by binary color change (grey to white), which however is less preferred and has not been explored with respect to people's understanding of colors' affective meanings.

Understanding Ambiguous Data: Movement & Speed

Participants also appreciated the richer movement and change in the shape of the Spiral, compared to Heart display, and related the circle's diameter with emotional intensity: *"[Spiral] contains more information, whereas the Heart shape is either black or white"* [P3]. When asked about the speed of change of colors, participants related it to the changes of their heart rate: *"when the Spiral lights up it means you're feeling some change in heartbeat"* [P6]. Most participants also perceived Spiral design as more responsive, and raised concerns about the slow change of color in Heart display: *"I want to be fast to see when emotions change"* [P6], and its inertia: *"it took a while to get back to original color"* [P3].

Envisioning Affective Displays' Contexts of Use: Privacy

Participants expressed contrasting views on displays' value in daily life, from triggering awareness to the need to calm down *"If I see it, I would think, I need to calm down"* [P4], to being somehow distracting: *"I don't want to be more stressed"* [P5]. Participants also expressed interest in knowing the feelings of their loved ones: *"I would like to know if my partner is sad to comfort her"* [P4], as well as privacy concerns: "*I would value privacy more than information*" [P2], hence the

Figure 4: All three layers were joined by using self-adhesive materials because of their easy application. The displays are controlled by a 5V Arduino Nano and made wearable by mounting them on a Velcro band. To capture emotional arousal, Arduino was connected to galvanic skin response (GSR) sensor with electrodes attached on fingers to measure changes in skin conductance.

desire to personalize the colors. They found the displays capable of disclosing affective data but without revealing the meaning: *"I know what colors means but for someone else it is color coded"* [P3]. They were also interested in sharing publicly positive feelings and privately negative ones: *"for friends or family to know my mood"* [P5].

Discussion

We designed and evaluated two dynamic displays visualizing emotional arousal. Study findings suggest their specific qualities differing from traditional screen- and time-series graph-based visualizations of emotions. Participants liked them more, and appreciated the slowness of real-time changes in arousal, their more cloth-like interface, as well as the inherent ambiguity of affective data whose control allows navigating the trade-off of private-public disclosure of meaning.

Taming the Ambiguity of Affective Displays

The two affective displays differ in colors, shapes, and movements allowing the comparison of people's understanding. In contrast to Heart display, the multiple colors of Spiral display support stronger meaning making for mapping discrete emotions to different colors. With only two colors available and limited intermediate stages of color changing, Heart display offers a binary visualization of emotions. In addition to multiple colors, the Spiral design is also appreciated as the circle's diameter provides additional information. Our findings extend Gavers' ambiguity [2], by reinterpreting the relationship between artifact, wearer and public as suggested for clothing-based displays [1]. We argue however, that the coupling between artifact and wearer is even tighter for affective displays representing private bodily data.

Temporal Constraints of Dynamic Affective Displays

Findings also indicate that while a slow change of colors is appreciated, too slow changes become a hindrance. In this respect, the distinct material properties of thermochromic liquid crystal sheet and pigment offer different affordances. The former is activated quicker (6 vs 15 seconds) when arousal increases and is less inertial in reversing to original color (2 vs 75 seconds). The temporality of affective display also relates to long-term use. While initial meaning tends to be shaped by cultural perceptions of colors, long term use may allow people to test and revise these meanings.

Tension of Private-Public Affective Meaning Disclosure

All participants envisaged using affective displays for self- or co-regulation of emotions with loved ones. They showed openness to share publicly their positive emotions and privately the negative ones. While participants appreciated the inherent ambiguity of colors' meaning, they liked even more the ability to control it through personalization of colors. To summarize, our findings extend previous work on clothing-based thermochromic displays [1,17] and skin conductance in social interactions [4]. They suggest the value of added ambiguity [2] regarding color and speed of change of affective content.

Conclusion

We developed two dynamic affective displays and evaluated them with 6 participants. Findings indicate that participants were able to construe affective meaning and to envision contexts of use. We discussed the qualities of affective displays in terms of ambiguity, slowly unfolding change, temporal constraints and private-public disclosure of affective meaning.

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