Affective Haptics for Enhancing Access to Social Interactions for Individuals Who are Blind

Troy McDaniel[1], Shantanu Bala[1], Jacob Rosenthal[2], Ramin Tadayon[1],
Arash Tadayon[1], and Sethuraman Panchanathan[1]

[1] Center for Cognitive Ubiquitous Computing,
Department of Computer Science and Engineering, Arizona State University, Tempe, AZ, USA
[2] HeatSync Labs, Mesa, AZ, USA
`{troy.mcdaniel,shantanu.bala,atadayon,rtadayon,panch}@asu.edu,`
`jakerosenthal@gmail.com`

Abstract. Non-verbal cues used during social interactions, such as facial expressions, are largely inaccessible to individuals who are blind. This work explores the use of affective haptics for communicating emotions displayed during social interactions. We introduce a novel haptic device, called the Haptic Face Display (HFD), consisting of a two-dimensional array of vibration motors capable of displaying rich spatiotemporal vibrotactile patterns presented through passive or active interaction styles. This work investigates users' emotional responses to vibrotactile patterns using a passive interaction style in which the display is embedded on the back of an ergonomic chair. Such a technology could enhance social interactions for individuals who are blind in which emotions of interaction partners, once recognized by a frontend system such as computer vision algorithms, are conveyed through the HFD. We present the results of an experiment exploring the relationship between vibrotactile pattern design and elicited emotional response. Results indicate that pattern shape, duration, among other dimensions, influence emotional response, which is an important consideration when designing technologies for affective haptics.

Keywords: Affective haptics, emotions, vibrotactile stimulation, interpersonal interaction, assistive technology.

1 Introduction

Social interactions play an important role in our health and wellbeing: building and maintaining personal and professional relationships; achieving education and career goals; and shaping who we are as individuals. However, social interactions are still not universally accessible to individuals who are blind. Nearly 65% of information exchanged during a typical social interaction is nonverbal, and 72% of nonverbal communication is visual [1]. Visual nonverbal cues include facial expressions, eye gaze, body language, posture and appearance, which are largely inaccessible to individuals who are blind. Awkward and embarrassing situations are not uncommon for individuals who are blind during interactions with their sighted peers due to an

C. Stephanidis and M. Antona (Eds.): UAHCI/HCII 2014, Part I, LNCS 8513, pp. 419–429, 2014.

inaccessible visual channel through which most social cues are conveyed. Such situations can ultimately lead to social avoidance and isolation, and prevent individuals who are blind from fully participating in society.

Previously, we developed the Social Interaction Assistant (SIA) to sense, process and deliver specific visual nonverbal social cues to individuals who are blind using a wearable platform [2-6]. The social cues we targeted include the identity of a user's interaction partner; interpersonal distance between a user and interaction partner; and facial expressions of a user's interaction partner. Facial expressions are communicated through the sense of touch by displaying spatiotemporal vibration patterns on the back of the hand through a custom-made device called the VibroGlove [5-6]. Vibrations were chosen as the communication modality since audio output can obstruct a user's hearing, especially during a social interaction. The back of the hand was chosen for its impressive temporal and spatial acuity. While the palm and fingers are more sensitive (glabrous, hair-less skin), their backs were chosen for display to not limit the use of the hands during social interactions, especially social touch cues such as handshakes and pats on the back. Spatiotemporal vibrotactile patterns were designed to represent the following six basic emotions plus the neutral expression: happy, sad, surprise, anger, fear and disgust. Happy, sad and surprise are represented by displaying their respective common mouth expressions: vibrotactile shapes in the form of a U (smile), inverted U (frown), and circle. Anger, fear and disgust are represented by complex patterns found to evoke these emotions in the wearer of the VibroGlove.

While study participants could accurately distinguish between these patterns with minimal training and found them intuitive, individuals who are blind requested a richer display device. The device requested was one that could switch between symbolic representations to convey emotions being displayed by an interaction partner; and a literal representation that could allow users to feel the facial movements of interaction partners. To address these needs, in this work, we propose the Haptic Face Display (HFD)—an assistive technology to communicate emotions and facial expressions through rich spatiotemporal vibrotactile patterns displayed passively (back of a chair) or actively (tabletop). This technology also provides a useful research platform for exploring Affective Haptics—a subfield of computational science that explores how the emotional state of a user can be stimulated and influenced. As a first step, this work explores how affective haptics can be used to elicit the six basic emotions in a user to naturally communicate emotions of an interaction partner using symbolic vibrotactile patterns. Our implementation is a passive display on the back of a chair, which could be used during dyadic (one-on-one) social interactions. Our implementation, detailed later in this paper, can be easily transformed into a tabletop display for investigating active exploration of symbolic (or literal) vibration patterns.

The rest of the paper is organized as follows: Section 2 provides a literature review of research on affective haptics and communicating facial expressions/emotions to individuals who are blind. Section 3introduces our proposed approach and technology. Section 4 presents the design and results of an Institutional Review Board-approved user study exploring the linkage between symbolic vibrotactile patterns and the emotions they naturally represent using a forced-choice paradigm. Section 5 concludes and presents possible directions for future research.

2 Related Work

Very little work has explored the presentation of facial expressions and emotions to enrich social interactions for individuals who are blind. Rehman et al. [7] proposed mapping the manifold of facial expressions to the back of a chair for vibrotactile rendering. To compute the manifold of facial expressions, they proposed an extended locally linear embedding (LLE) algorithm for analyzing the emotional content of facial expression videos in real-time. Their proposed vibrotactile display consisted of nine actuators arranged into three axes representing happy, sad and surprise where stimulation along one of three axes not only determines the type of emotion but also its intensity. While Rehman et al. have proposed a useful approach to mapping video-based facial expressions to vibrotactile renderings, their approach handles only three of the six basic emotions.

Leveraging existing work in affective haptics, the current work attempts to identify symbolic representations of vibrotactile patterns that evoke the six basic emotions in users by engaging the sense of touch. Existing work in affective haptics has focused mainly on two applications: enriched telepresence or movie viewing. Tsetserukou et al. [8] have proposed haptic devices to augment online and mobile interactions with enriched emotional experiences. Their haptic devices include HaptiHug, HaptiHeart, HaptiButterfly, HaptiShiver, HaptiTemper and HaptiTickler. HaptiHug simulates a hug by generating pressure around a user's chest and back. HaptiHeart conveys heartbeat patterns by generating heartbeat sensations on a user's chest. HaptiButterfly reproduces the sensation of "butterflies in the stomach" through vibrotactile stimulations delivered to a user's abdomen. HaptiShiver reproduces the sensation of "shivers up and down the spine" through vibrotactile stimulations. HaptiTemper reproduces the sensation of "chills up and down the spine" through temperature changes using fans and a Peltier. HaptiTickler simulates being tickled by generating random vibrotactile stimulations on a user's ribs.

To enhance immersion and emotions during movie viewing, Lemmens et al. [9] developed a body-conforming jacket consisting of 64 vibrotactile actuators distributed across the torso. Their proposed device allows the exploration of users' emotional immersion while watching movies and feeling stimulations from the jacket. Rich vibrotactile patterns can be conveyed through the jacket; in their study, they designed 40 vibrotactile patterns created from knowledge of touch behaviors in humans, common expressions (e.g., "butterflies in the stomach") and abstract patterns.

The aforementioned approaches have yet to explore a large set of vibrotactile patterns for conveying the six basic emotions of interaction partners during a dyadic interaction. As described in Section 1, such a system would be useful to individuals who blind, providing universal access to visual non-verbal cues, specifically facial expressions, during social interactions. In the next section, we present the implementation details of the Haptic Face Display. We then present a user study to explore a large set of symbolic vibrotactile patterns via the Haptic Face Display through the use of a forced-choice paradigm, in contrast to commonly-used open-response paradigms [10], to better identify emotional responses across patterns.

3 Haptic Face Display

The Haptic Face Display (HFD) is a research platform consisting of a two-dimensional array of vibration motors (eccentric rotating mass) for exploring haptic representations of facial expressions and emotions between interaction styles—passive or active—and at different levels of mediation—literal, semi-literal, semi-symbolic and symbolic. Examples of different levels of mediation are in Table 1.

Table 1. Literal, semi-literal, semi-symbolic and symbolic levels of mediation for haptic representation of facial expressions and emotions

Level of Mediation	Example
Literal	Facial features and fiducial points as is
Semi-Literal	Lip curved upwards, eye brow curved
Semi-Symbolic	Smile, eyes wide open
Symbolic	Happy

The current work explores the passive display of spatiotemporal vibration patterns represented at a symbolic level to elicit emotional responses. Patterns that naturally elicit emotional responses will be used as part of an assistive technology for individuals who are blind to improve universal access to visual nonverbal social cues during dyadic interactions. For this purpose, the HFD was embedded in the back of an ergonomic chair, depicted in Fig. 1(a). Vibration motors are attached to custom-designed boards, referred to as tactor strips. There are eight vibration motors per tactor strips, and tactor strips may be connected to build larger two-dimensional displays with adjustable spacing between tactor strips. Each tactor strip is embedded within the mesh backing of the chair, but vibration motors are placed on the outer mesh via Velcro for direct contact with the skin, depicted in Fig. 1(b). Horizontal inter-tactor spacing is 2 cm, and vertical inter-tactor spacing is 4 cm. A close-up of an individual tactor strip is depicted in Fig. 1(c).

3.1 Hardware Design

The HFD control module, which communicates with the tactor strips, is based on the Arduino platform for ease of prototyping and community support. The control module uses a custom shield design for the Arduino FIO, and can easily support a range of 10-20 vibration motors to be actuated at the same time. We have also developed and manufactured a custom control module to miniaturize its size and improve wearability for other related research projects. The control module connects to the tactor strips via the I^2C bus, which has an upper limit of 128 devices. Our current software protocol limits the number of devices to 64.

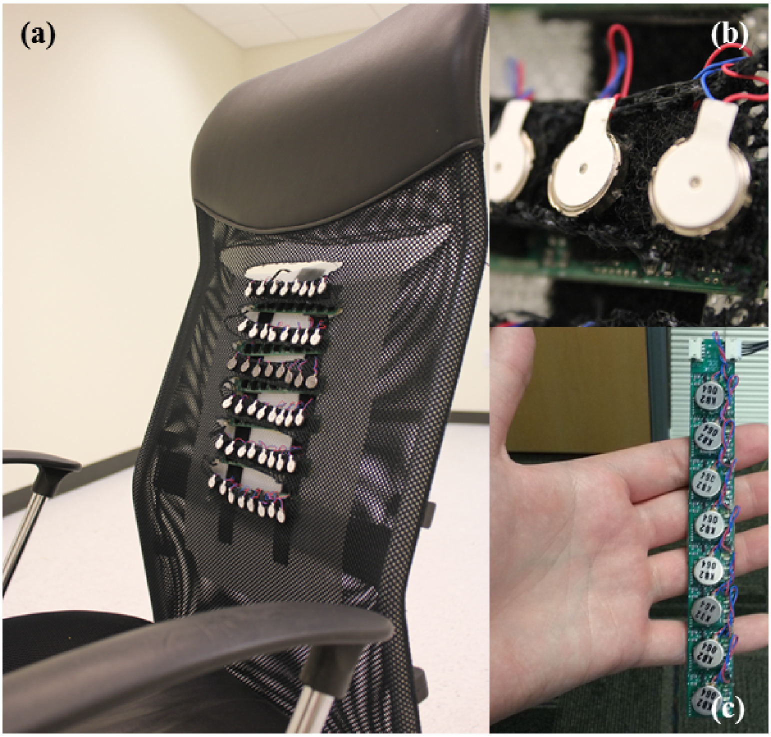


Fig. 1. Haptic Face Display (a) Tactor strips are embedded on the back of an ergonomic mesh chair to explore passive display of symbolic vibration patterns; (b) Close-up of vibration motors and how they attach to a chair; (c) Close-up of a tactor strip

The tactor strips are an extension of our previous work on developing vibrotactile belts [11-12]. As previously described, each tactor strip consists of a linear array of eccentric rotating mass vibration motors and an I^2C extender. Each tactor unit of the tactor strip consists of a 3 V DC pancake vibration motor and an ATTINY88 microcontroller for processing communication and pattern commands with independent timing from the control module. The addition of the I^2C extender removes bus capacitance, which allows us to approach the bus address device limit of 128. The tactor is implemented on a printed circuit board to maximize flexibility in spacing (as small as 18 mm apart) and placement of vibration motors. The design of the tactor strip is innovative by offering a completely modular solution, not only when combined to create large two-dimensional displays, but also at the level of individual tactor modules. Each tactor unit can be detached from the strip and extended out for larger spacing or reused as a standalone tactor module. The front and back of a tactor strip's circuit design for PCB manufacturing is depicted in Fig. 2. This design is intended to support ease of implementation and rapid prototyping, and has since been shared with the community as a *haptic construction kit*[1].

---

[1] `http://hapticconstructionkit.com`

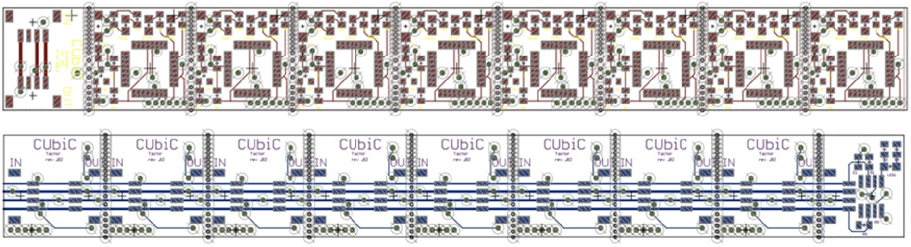


Fig. 2. Front (top) and back (bottom) of circuit design for tactor strip of Haptic Face Display

3.2 Firmware Design

Both the control module and tactor unit firmware has been shared with the community via github[2]. The control module firmware can be loaded using the popular Arduino IDE. Once connected, the firmware hosts a test mode where new vibrotactile patterns may be designed and actuated. Actuation scripts can be developed using drivers in both C and Python, which can also be found on github. The tactor unit firmware is lower level Atmel C designed for compilation via the open source AVR GCC.

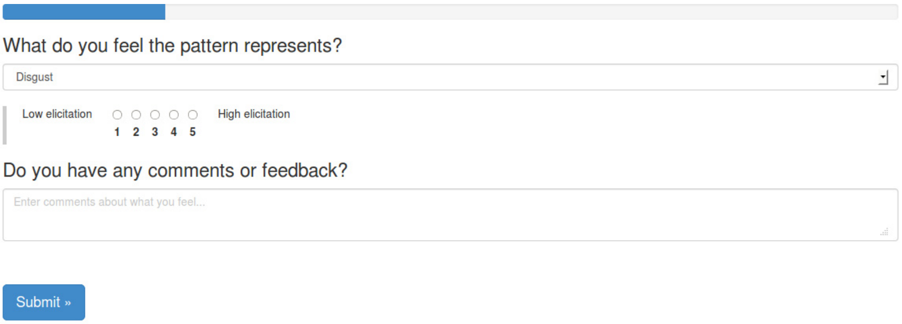
4 Experiment

We conducted an Institutional Review Board-approved experiment to identify which of the six basic emotions are elicited using a large set of vibrotactile patterns inspired by existing vibrotactile designs for affective haptics [10]; existing designs that have been explored for possible use in a variety of other applications such as navigation [13]; common wisdoms/sayings such as “a chill down the spine”; and our own results from our previous work and pilot tests with the HFD. Identification of vibrotactile patterns that naturally evoke emotions will support the development of intuitive and easy-to-use social aids for individuals who are blind. The experiment involved 20 participants (10 males and 10 females) recruited from graduate students at Arizona State University. The age range of participants was 18 to 26 years old. Participants had no known visual or tactile impairments. The HFD described in Section 3, Fig. 1(a), was used during the study. Custom software was designed to fully automate the experimental procedure.

During the study, each participant sat in the HFD chair in front of a laptop while listening to white noise through headphones so that vibrations could not be heard. Each participant used the laptop to step through the study’s forced-choice procedure using a custom software application created using the Python programming language, the Bootstrap GUI framework, and the serial interface to the HFD. The software presents 54 vibrotactile patterns in a random order. After feeling each pattern, participants select the emotion elicited (‘happy’, ‘sad’, ‘surprise’, ‘anger’, ‘disgust’, ‘fear’ or ‘neutral’), intensity of elicitation (rated using a 5-point Likert scale from “Low”-1 to

---

[2] `https://github.com/Haptic-Construction-Kit`



What do you feel the pattern represents?

Disgust

Low elicitation ○ ○ ○ ○ ○ High elicitation
1 2 3 4 5

Do you have any comments or feedback?

Enter comments about what you feel...

Fig. 3. Screenshot of software for prompting participants and collecting responses

"High"-5 elicitation) and provide further description through an open-ended comment box. Participants also have the option of selecting 'none at all' if no emotion was elicited. Fig. 3 depicts a screenshot of the software, which is implemented as a form in a web browser. The vibrotactile patterns are depicted in Fig. 4-19, and run from left to right. The basis of these patterns is 16 shapes each with 3 timing variations for 48 patterns. Timing variations include pulse widths of 250 ms, 500 ms and 1000 ms; gap width was kept constant at 50 ms. Six saltation [14] versions of the following patterns were also included in the pattern set: Snake (Horizontal), Snake (Vertical), Spiral (In), Spiral (Out), Spine (Up) and Spine (Down).

Certain shapes were more likely to elicit specific emotions compared to others. The following results are averaged across gender, vibration duration (three variations) and with/without saltation.

- Shoulder Tap (Fig. 8), elicited anger with a 22.4% consensus.
- Six Motor Burst (Fig. 9), elicited anger with a 26% consensus.
- Snake (Fig. 10-11), regardless of directionality, elicited happiness with a 28.1% consensus.
- Spine (Fig. 12-13), regardless of directionality, elicited happiness with a 27.2%.
- Spiral (Fig. 14-15), regardless of directionality, elicited neutrality with a 22.9% consensus.
- Wave (Fig. 16-19), regardless of directionality, elicited anger with a 20.9% consensus.

Considering duration variations, patterns of 1000 ms pulse width elicited sadness with 131.6% greater frequency compared to 250 ms; whereas shorter pulse widths were more likely to elicit positive emotions. Patterns of 250 ms pulse width were 103.6% and 23.7% more likely to elicit surprise and happiness, respectively, compared to 500 ms and 1000 ms pulse widths. Considering with/without saltation, those patterns utilizing saltation elicited anger or disgust 59.4% and 18.7% more often, respectively. Patterns without saltation elicited surprise or neutrality 36.5% and 19.2% more often, respectively.

The consensus results indicate that certain spatiotemporal vibrotactile patterns can elicit emotions without any training or paired stimulus. While consensus among participants regarding emotions elicited by different shapes may seem low (20-30%), it is important to note that participants are not given any guidance on which of the eight responses (happy, sad, surprise, anger, fear, disgust, neutral, no emotion) is correct or most correct. The study is designed such that there is no correct or most correct response; the response depends entirely on each user and the emotions elicited by the stimuli. The consensus results found demonstrate convergence on the perception of specific patterns and how they naturally elicit emotions. This information is useful when designing social assistive aids in such a way that enhances naturalness and reduces training times; for example, the proposed Snake pattern seems best for conveying happiness; the Six Motor Burst or a saltation design may be used to convey anger; and the Spiral pattern may be used to convey neutrality. Longer durations may be used to convey sadness whereas shorter durations may be used to convey happiness and excitement.

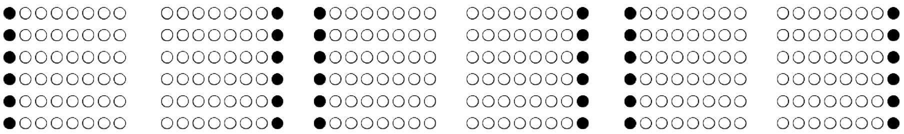


Fig. 4. Alternate (Left, Right)

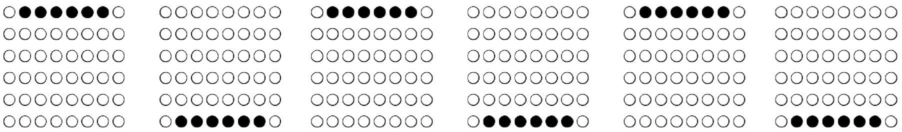


Fig. 5. Alternate (Top, Bottom)

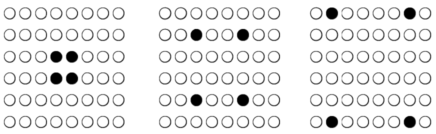


Fig. 6. Explode

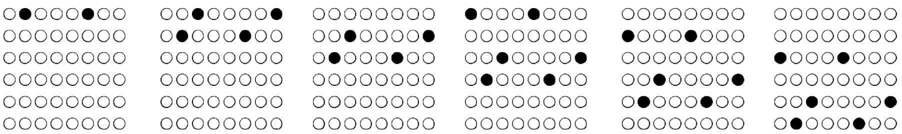


Fig. 7. Rain

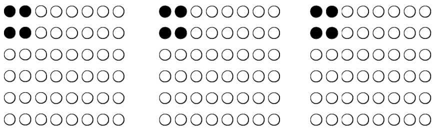


Fig. 8. Shoulder Tap

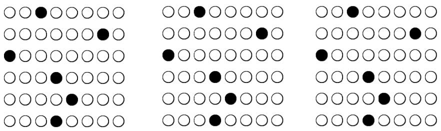


Fig. 9. Six Motor Burst

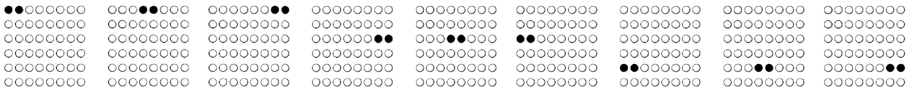


Fig. 10. Snake (Horizontal)

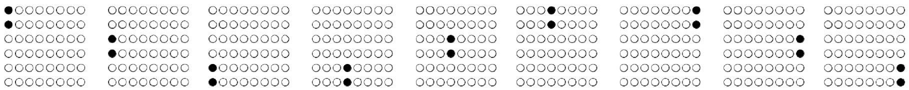


Fig. 11. Snake (Vertical)

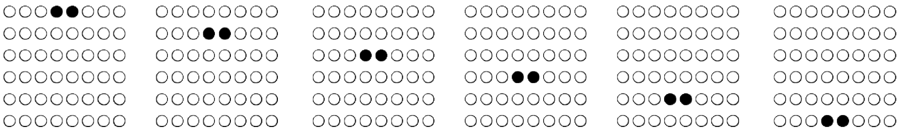


Fig. 12. Spine (Down)

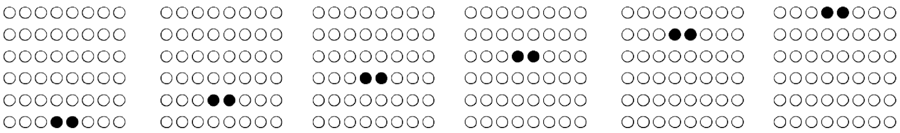


Fig. 13. Spine (Up)

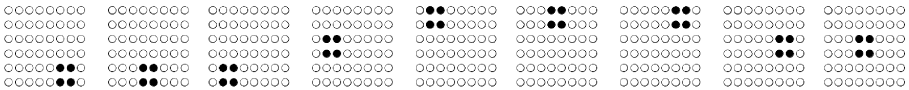


Fig. 14. Spiral (In)

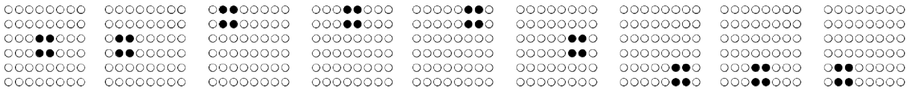


Fig. 15. Spiral (Out)

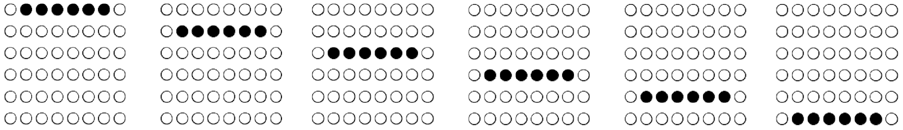


Fig. 16. Wave (Down)

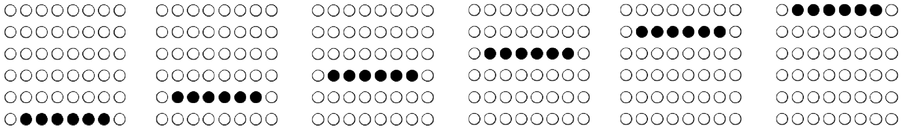


Fig. 17. Wave (Up)

Fig. 18. Wave (Left)

Fig. 19. Wave (Right)

5 Conclusion and Future Work

We have introduced a novel haptic display, called the Haptic Face Display (HFD), which serves as a versatile research platform to explore affective haptics among other applications in passive or active interaction styles. In this work, we have used the HFD to explore natural emotional responses to spatiotemporal vibrotactile patterns for eventual use in assistive social aids for individuals who are blind. As part of future work, we are using the HFD to explore different levels of mediation including semi-symbolic, semi-literal and literal haptic representations of emotions and facial expressions. We are also extending the design presented here to support multimodal presentation of emotions using other modalities of touch such as light to hard pressure and temperature variations.

Acknowledgements. We would like to thank the National Science Foundation and Arizona State University for their funding support. This material is partially based upon work supported by the National Science Foundation under Grant Nos. 1069125 and 1116360.

References

1. Knapp, M.L.: Nonverbal Communication in Human Interaction. Harcourt College Pub. (1996)
2. Krishna, S., Colbry, D., Black, J., Balasubramanian, V., Panchanathan, S.: A Systematic Requirements Analysis and Development of an Assistive Device to Enhance the Social Interaction of People Who are Blind or Visually Impaired. In: Proceedings of the Workshop on Computer Vision Applications for the Visually Impaired (CVAVI 2008), ECCV (2008)
3. McDaniel, T., Krishna, S., Balasubramanian, V., Colbry, D., Panchanathan, S.: Using a Haptic Belt to Convey Non-Verbal Communication Cues during Social Interactions to Individuals who are Blind. In: Proceedings of the IEEE International Workshop on Haptic Audio Visual Environments and Games, pp. 13–18 (2008)
4. McDaniel, T.L., Krishna, S., Colbry, D., Panchanathan, S.: Using Tactile Rhythm to Convey Interpersonal Distances to Individuals who are Blind. In: Proceedings of the CHI 2009 Extended Abstracts on Human Factors in Computing Systems, pp. 4669–4674 (2009)
5. Krishna, S., Bala, S., McDaniel, T., McGuire, S., Panchanathan, S.: VibroGlove: An Assistive Technology Aid for Conveying Facial Expressions. In: Proceedings of the CHI 2010 Extended Abstracts on Human Factors in Computing Systems, pp. 3637–3642 (2010)
6. Krishna, S., Bala, S., Panchanathan, S.: Exploring the Dorsal Surface of the Fingers for Visio-Haptic Sensory Substitution. In: Proceedings of the IEEE International Symposium on Haptic Audio-Visual Environments and Games (HAVE), pp. 1–6 (2010)
7. Liu, L., Li, H.: Manifold of Facial Expressions for Tactile Perception. In: Proceedings of the IEEE 9th Workshop on Multimedia Signal Processing, pp. 239–242 (2007)
8. Tsetserukou, D., Neviarouskaya, A.: iFeel_IM!: Augmenting Emotions during Online Communication. IEEE Computer Graphics and Applications 30(5), 72–80 (2010)
9. Lemmens, P., Crompvoets, F., Brokken, D., van den Eerenbeemd, J., De Vries, G.-J.: A Body-Conforming Tactile Jacket to Enrich Movie Viewing. In: Proceedings of the Third Joint EuroHaptics Conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, pp. 7–12 (2009)
10. Benali-Khoudja, M., Hafez, M., Sautour, A., Jumpertz, S.: Towards a New Tactile Language to Communicate Emotions. In: Proceedings of the IEEE International Conference Mechatronics and Automation, pp. 286–291 (2005)
11. Edwards, N., Rosenthal, J., Moberly, D., Lindsay, J., Blair, K., Krishna, S., McDaniel, T., Panchanathan, S.: A Pragmatic Approach to the Design and Implementation of a Vibrotactile Belt and its Applications. In: Proceedings of the IEEE International Workshop on Haptic Audio Visual Environments and Games, pp. 13–18 (2009)
12. Rosenthal, J., Edwards, N., Villanueva, D., Krishna, S., McDaniel, T., Panchanathan, S.: Design, Implementation, and Case Study of a Pragmatic Vibrotactile Belt. IEEE Transactions on Instrumentation and Measurement 60(1), 114–125 (2011)
13. Piateski, E., Jones, L.: Vibrotactile Pattern Recognition on the Arm and Torso. In: Proceedings of the First Joint Eurohaptics Conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, pp. 90–95 (2005)
14. Geldard, F.A., Sherrick, C.E.: The Cutaneous 'Rabbit': A Perceptual Illusion. Science 178(4057), 178–179 (1972)