Exploring Affective Communication Through Variable-Friction Surface Haptics

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ABSTRACT

This paper explores the use of variable friction surface haptics enabled by the TPad Tablet to support affective communication between pairs of users. We introduce three haptic applications for the TPad Tablet (text messaging, image sharing, and virtual touch) and evaluate the applications with 24 users, including intimate couples and strangers. Participants used haptics to communicate literal texture, denote action within a scene, convey emotional information, highlight content, express and engage in physical playfulness, and to provide one's partner with an experience or sensation. We conclude that users readily associate haptics with emotional expression and that the intimacy of touch in the contexts we study is best suited for communications with close social partners.

Author Keywords

Surface Haptics; Touchscreen; Variable Friction; Tablet; Communication

ACM Classification Keywords

H.5.2. Information interfaces and presentation: Input devices and strategies, Haptic I/O

INTRODUCTION

Human touch conveys many social messages, including level of intimacy, hostility, and affiliation [9]. Physical touch is a crucial aspect of most human relationships [16]. While haptic interfaces have been shown to convey emotional information [3,8,33], the potential for surface haptic technologies to support person-to-person affective communication has yet to be explored. Different than vibration feedback that is common in mobile devices and force feedback that is common in graspable devices such as joysticks, surface haptic technologies provide force feedback directly to the fingertip in form factors that are increasingly appropriate for mobile devices [1,24,1]. This paper explores variable-friction technology for direct person-to-person communication and seeks insights into designing surface haptics for communication. While this technology has been used to improve navigation tasks on touch screens (e.g., [18]), the present study is the first known to explore haptic communication between two people using connected variable-friction tablet displays.

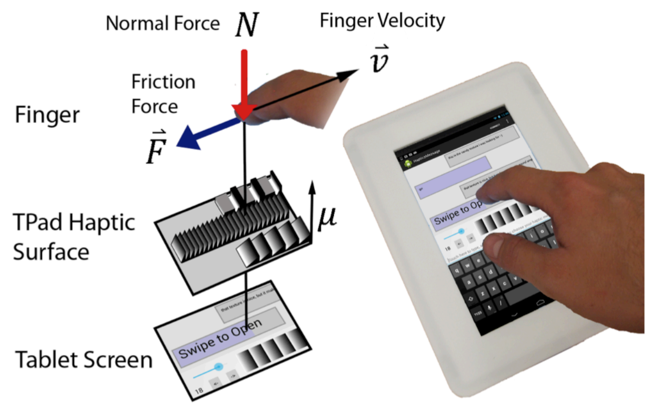

Figure 1: The TPad Tablet is a hand-held device with a variable-friction haptic surface. When the user swipes to open a text message, for example, the friction coefficient is varied, resulting in a pattern of forces felt by the fingertip.

Beyond application context, we also seek to explore how intimate communication, with its concerns of privacy, expression, and co-presence, might be better supported through touch. A brainstorming session of experts outside of the research team coupled with idea evaluation by the research team yielded three application ideas that were prototyped. These include *haptic text messaging* (Fig. 1) that enables users to embed haptic patterns within traditional text messages, *haptic image sharing* where users annotate and exchange images with a range of haptic textures, and *haptic virtual touch* where users move their fingers on their personal displays while seeing and feeling their partner's touch simultaneously.

The technology used in this study is a TPad Tablet (tactile pattern display) which is a self-contained, handheld device incorporating a haptic surface above a touchscreen tablet (Fig. 1) [24,25]. The feeling of a variable-friction TPad surface is not simply that of vibration. Rather, the coefficient of friction, and therefore the resistance force can be varied as the fingertip slides across the screen, creating perceptions of shape and texture. This means, for example, that the device can visually and haptically display a slider that resists and then releases as it unlocks, or a textured button that grabs the finger to confirm that it is currently selected [18,21,1].

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We evaluated the three applications with 24 users, including couples in a long-term relationship and stranger pairs. We allowed for open-ended exploration of the applications so that users controlled the haptic experience. Observations and user feedback provided insights into expectations about with whom and under which circumstances communication involving surface haptics is appropriate and meaningful.

RELATED WORK

As is noted by Picard [28], there is a need for systems that better support person-to-person affective communication. We examine how applications might be designed with variable friction surface haptics to address this need, drawing from the literature on technology supported affective communication, person-to-person haptic interaction, and emotional information in haptics.

Technology for Affective Communication & Intimacy

This paper focuses on haptics for affective communication, and we consider intimacy to play an important role in this design space. While it is difficult to define intimacy, the literature describes intimate communications as information poor but rich in emotion and meaning, seemingly ambiguous (particularly to outsiders), involving a sense of presence in absence, often private and created in ways that can be hidden from others, and involving reciprocity [1,22,29]. Kieldskov et al. [15] used cultural probes to better understand how technology could support intimacy. They suggest that intimate acts require support for privacy, enable communication of emotion, particularly in unspoken ways, transmit a feeling of presence in absence, and play with ambiguity and incompleteness.

Mobile phones, through the use of voice, SMS, and e-mail, help people who are separated geographically establish a sense of awareness and connection, which may reduce loneliness [13]. A number of research prototypes explore supporting intimate connections through technology, and while space precludes a full treatment of this work, we mention several examples. One notable example is the Virtual Intimate Object [14], where couples may express intimacy in a rich manner through a simple and purposefully minimalistic interface. LumiTouch [8] involves digitally augmented picture frames that transmit touch from one frame to light in the other frame, providing an ambient display that communicates emotional content. Cubble [17], designed to support couples in long distance relationships, allows sharing of simple messages through color signals, vibrations, and thermal feedback. Cubble also involves touch and light-based interaction over mobile devices, which is similar to the haptic virtual touch application we present here as well as smartphone applications such as Pair and FeelMe. Unique to our haptic virtual touch application is an exploration of how to design the subtleties of joint touch through variable friction.

Person-to-Person Haptic Interaction

Much related work involves the development of haptic interfaces to support interaction between two people. InTouch [4] is an early haptic-only system that allows distributed users to interact with a set of rollers using their hands. This allows users to passively feel their partner's manipulation of the device, providing the sense of joint interaction with a shared physical object. Similarly, HandJive involves joysticks to support playful interaction among dyads [12]. Other haptic systems use stroking (e.g., [10]) or a hug (e.g., [23]) to support physical closeness. While most systems examine the haptic channel alone, ComTouch [7] explores verbal and haptic channels in combination by converting hand pressure on a handheld phone-like device into vibrational intensity between users in real-time.

Haptic Interaction and Emotional Information

Several studies have sought to understand whether specific emotions map to certain haptic patterns or textures. A notable example is work by Smith and MacLean [33], which examines how dyads (intimate pairs and strangers) communicate specific emotional states (angry, delighted, relaxed, unhappy) through a haptic interface of simple knobs. They focus on synchronous, bidirectional dyadic interaction and conclude that emotion can be communicated through their prototype interface. Other related work examines how well users are able to differentiate friction-based haptic stimuli and measures the emotional responses to such stimuli [32], suggesting that even simple haptic stimulation can carry emotional information. Our approach builds on these findings and explores emotional expression within the context of specific applications.

Considerable research also investigates the idea of haptic icons or hapticons [5,6,11,19,20,30], which are patterns of programmed force, friction, or vibration that can be used to communicate a basic idea similar to traditional graphical icons. Building on this research, we design and present users with haptic patterns as part of a text messaging application. In contrast to studies that distinguish unique tactile feelings and attempt to map emotions onto such patterns, Wang and Quek [35] argue that touch interaction needs to be coupled with other communication channels to clarify its meaning. They also suggest the use of touch as an immediate channel by not assigning any symbolic meaning to touch interactions. Our research also avoids assigning specific symbolic meanings or affective qualities to haptic interactions; instead, we seek to understand ambiguities in haptic interaction within the context of social relationships and established practices with social applications (e.g., text messaging). Furthermore, we explore whether such symbolic systems should be pre-determined or develop organically among people depending on their relationship.

SYSTEM IMPLEMENTATION

The devices used in this study are two internet-connected second-generation TPad Tablets as shown in Figure 1. Inside the device is a Google Nexus 7™ tablet, an

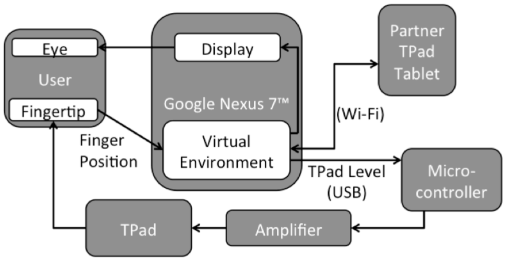


Figure 2: System diagram of TPad Tablet.

overlaying glass sheet with piezoelectric actuators (TPad), a printed circuit board, and a lithium polymer battery. A system diagram is shown in Figure 2. Finger position is sensed at approximately 60 Hz, and for the direct touch application, it is immediately sent via Wi-Fi to the partner tablet. Finger position is also used to update the virtual environment and generate friction-level commands. These are sent via USB at 1000Hz to a microcontroller which sends a pulse-width-modulated signal to actuate the piezos. Full instructions for building and programming an open-hardware TPad Tablet are available free for research and other non-commercial use at http://tpadtablet.org [24].

The friction reduction effect of the TPad haptic surface is generated through high frequency (~35 kHz) and low amplitude (~1μm) out-of-plane oscillating motion. Higher amplitude oscillation corresponds to a lower value of friction coefficient μ, allowing modulation between low (full oscillation) and high (no oscillation) friction [1]. Referring to Figure 1, the resistance force F is modeled as equal to the normal force N times the coefficient of friction in the direction opposite to the finger velocity: $F = -N\mu\frac{\vec{v}}{|v|}$.

This effect is very distinct both physically and perceptually from vibratory actuation. When the fingertip passes over real-world textures and features, mechanoreceptors in the finger body and in the skin of the fingertip respond to vibration, force, and skin-stretch. While high-bandwidth vibration alone is sufficient to stimulate some textures, it cannot apply shear force to the finger or stretch the skin. With variable friction, controlled forces stretch the skin and react against the finger while retaining the ability to create vibration through amplitude modulation of friction level.

APPLICATION DESIGN

Brainstorming and Ideation

As part of our exploration, we first conducted a brainstorming session with nine experts in the fields of communication, design, and human-computer interaction around the themes of privacy, emotional expression, and co-presence in dyadic communication, all of which are central to technology designed for intimacy support [15]. The participants were given a brief overview and demonstration of the technology and were asked to first generate situations where the themes are important and then generate ideas of ways to use the technology to support them. The session was video recorded and moderated by two researchers, and all sketches were collected. Four

Figure 3: Sketches from brainstorming session describe using friction to indicate sarcasm within a text message (left) and enhance images for low-vision users (right).

researchers analyzed and discussed a total of 24 application ideas. Several ideas generated by participants included: using surface friction to indicate the tone of a news story, sarcasm within a text message, and important parts of a message; adding haptics to an image to support interaction with children, low-vision users, and artistic expression; and sharing and entering passwords haptically to enhance privacy. Example sketches generated during the brainstorming session are presented in Figure 3.

Applications

The research team rated ideas based on their relevance to affective communication, technical feasibility, amount of discussion and interest the idea generated during the brainstorming session, and relevance of surface haptics to the application idea. Similar ideas were grouped and merged together. Three final ideas were selected for prototyping and evaluation, each with a distinct use of surface haptic feedback across different modes of person-to-person communication.

Haptic Text Messaging

This application involves embedding haptic information within the context of mobile text messaging, similar to [27,30]. Users type a message as they would in a traditional text messaging application but also may choose to add one of 24 unique friction patterns (see Fig. 1). A visual representation of the friction pattern (white for low friction, black for high) is shown above the keyboard where users may touch to preview the feeling as well. After a message is sent, the recipient swipes across to open it and reveal the text, feeling the embedded tactile pattern as they move. The patterns were created as sets or families, inspired by past haptic communication studies [20,32] and mathematical

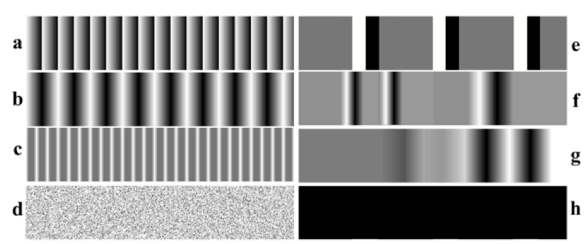


Figure 4: Representative haptic patterns in text messaging app: (a) sawtooth pattern, (b) triangle pattern, (c) low friction triangle, (d) white noise, (e) alternative direction, (f) rhythmic bumps, (g) crescendo, and (h) default blank pattern.

variation (see Fig 4). Within families, patterns vary by spatial frequency (4a, 4b, 4d), magnitude (4c), rhythm (4e, 4f), and increasing or decreasing magnitude or frequency across space (4g). These patterns are not meant to define a surface haptic vocabulary or complete set, nor is it tested as such, but are provided to gain insights, such as: What types of messages, if any, make sense to augment with haptics? Do users attempt to convey affect with haptics, and how do they interpret received haptic messages? Is a preset vocabulary wanted or needed?

Haptic Image Sharing

The second application enables users to "paint" friction patterns as an additional layer above an image. Users select an image from a collection of 10 photos, including works of art, landscapes, and animals. They then select from a palette of simple color-coded textures, painting them to a semi-transparent overlay on top of the image. The color hue corresponds to the waveform: red is a 100Hz square wave, yellow is a 70Hz sinusoid, green is a 30Hz sawtooth wave, blue is a 20Hz sinusoid, and cyan is a constant friction level. The value of the color corresponds to the magnitude of the effect, with five levels varying from full power to 20% of full power. Users may resize the brush stroke and apply an eraser to the image. Figure 5 illustrates the sequence of authoring a haptic image. This application allows us to pose questions about which types of photos and what elements within the photos are interesting to annotate with haptics. Do people annotate images based on a literal texture (e.g., rocks have a rough texture) or use texture in other ways relating to affective communication?

Haptic Virtual Touch

The third application examines expressivity in communication and co-presence by enabling remote users to draw on the TPad Tablet with their finger and feel a tactile pattern when their finger intersects with their partner's finger. When a user touches the screen, an image of a fingerprint appears on their screen and on their partner's screen (Fig. 6). Moving on the screen creates a colored trail that is visible on both screens. Users have access to sliders that adjust how quickly their trail fades and the diameter of the trail. Two methods of rendering haptic "touches" were explored: (1) a force-based physical rendering of a fingertip-shaped three-dimensional object, designed for realism, and (2) a texture-based target. For the 3D rendering, the fingertip was modeled as a 120x200 pixel hemispheroid (Fig. 7a1), and the resistance force was modeled as proportional to the instantaneous slope in the direction of travel (Fig. 7a2). In this way, as users move up the virtual slope (z increasing), they experience a resistance force. As they travel down the virtual slope, they experience a reduction in resistance. The second rendering of touch was texture-based, varying friction level as a 100 Hz sine wave that increases in magnitude as the radial distance, R, between the fingers decreases (Fig 7b). The maximum radius at which the effect is displayed, Rmax, was set to be proportional to the partner's radius.

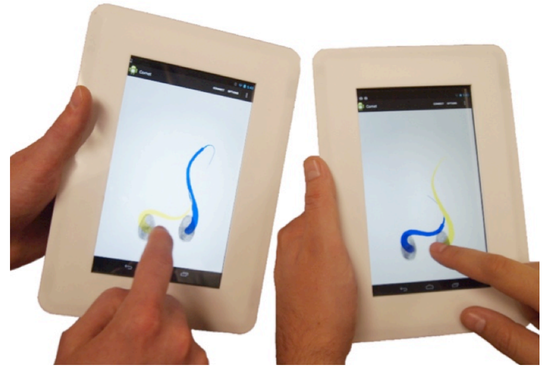
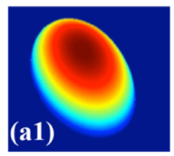


Figure 6: Haptic Virtual Touch allows users to see and feel where their partner is touching the screen. When users touch virtually, they feel a haptic rendering of their partner's finger.



(a1)

(a2) $$TPaD\ Level = 0.5 - A * \frac{z - zlast}{mag(\Delta R)}$$

(b) $$TPaD\ Level = 0.5 + \frac{Rmax - R}{2 * Rmax} * \sin(2\pi * 100t)$$

Figure 7: a1, a2. Visual representation of 3D haptic rendering of fingertip and related function for TPad level approximating (a) directional derivative, (b) texture based touch rendering.

While related work investigates how haptic feedback may increase perceived virtual presence [31] and coordination in group work [6], our aim is to understand how familiar and unfamiliar pairs react to another person's touch as it is conveyed through surface haptics and whether this yields an interesting and intimate form of co-present touch [26]. We want to observe whether couples or strangers would engage in touching behavior across the TPads or whether they would try to avoid collisions. We also examine whether a more realistic rendering aids interaction and the sense of co-presence or connection with one's partner.

Figure 5: Haptic Image Sharing allows users to select an image to customize, select from a palette of friction patterns, draw a texture overlay in "edit" mode, and explore the image in "feel" mode.

EVALUATION

We conducted a laboratory study with 24 participants, including six participant pairs (n=12; 6 male; mean age=38.0, SD=10.9) who were in an intimate relationship (dating one year or more) and six pairs (n=12; 6 male; mean age=31.1, SD=8.2) who had not met prior to the study. We recruited male-female stranger pairs who were close in age but were unable to control for gender or age gaps in partner pairs. No participants had used a TPad prior to the study. Participant pairs used each application in the same laboratory space but were unable to see or hear each other during the task. While using each application, participants wore noise-reducing headphones to avoid hearing sounds created by the TPad or comments by their partner.

Participants first experienced a brief training period that introduced them to the TPad and different surface haptic textures. The order of applications was varied among participant pairs. When presented with an application, participants received brief instructions and a written prompt to guide their interaction. We crafted the prompts to be open-ended and flexible to accommodate diverse interests and relationships. After using each application, the pair individually filled out a questionnaire to evaluate that particular application's usability and appeal. Participants rated their agreement with statements on a five-point (zero neutral) Likert scale. At the end of the study, each pair sat face-to-face and discussed their experience with two researchers. The discussion sessions were video recorded, transcribed, and analyzed.

Results

We first describe the high-level themes that emerged from the laboratory study, and then we present application-specific results. Participants viewed surface haptics as a way of communicating emotional information. Within a messaging context, S5M (stranger pair 5, male) said, "The strongest ones [haptic patterns] definitely can convey emotion." S4M said of the haptic image application, "What I was trying to convey is the emotion behind that scene." Participants often associated the strongest haptic patterns with strong emotions such as anger, and we elaborate this point below. Only one participant (C2F2; couple pair 2, female) mentioned that, to her, haptics did not have an emotional connection. Rather, she viewed the interaction as increasing expression more broadly.

Surface haptics were not wanted in isolation; participants described haptics as another dimension for communication and indicated that haptics should be used as a supplement to voice, text, and image-based communication. By studying haptic interaction in context of specific applications and existing social relationships, we better understand how one might design affective haptic experiences. For example, C2F1 called the haptic feedback "weird, creepy, and unsettling" when she touched things and did not expect a texture or did not expect it to feel the way it did.

Participants described the applications as "playful" and "fun" and rated them correspondingly (see Fig. 8; no sig. differences between couples vs. strangers for these data, so we report overall means). C1M2 said his favorite part was "being synchronized with your partner, being able to play with each other..." His partner said, "The whole textural sense was very novel… Discovering the feedback and the touch was fun." S3F commented, "I just thought it was a fun way to communicate." C6M "had fun playing with the texture." Users were neutral about whether the applications helped them understand their partner better, likely resulting from the short time using the technology together. This result and the lower rating of text messaging for self-expression are likely due to users needing to develop a shared haptic language, which we describe below.

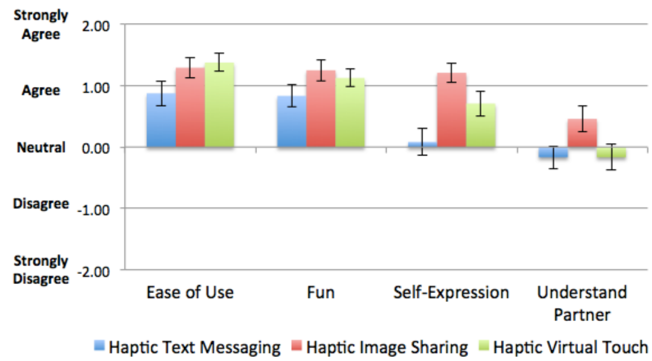


Figure 8: Likert ratings by app with mean and SE.

We analyzed Likert scale ratings for preferred communication partner across applications (Fig 9) using a mixed-effects statistical model to account for between and within-subject factors. The independent variables included were preferred communication partner, application, and the interaction between them. Because observations were not independent, subjects nested within partner type (couple/stranger) were modeled as a random effect. Participants viewed the applications to be most appropriate for interaction with a significant other or close friend (see Fig. 9), and this was significantly different from their preference for using applications with strangers and acquaintances ($F(3,253)=30.62$, $p< .0001$). To compare differences across levels we used Tukey's HSD, which revealed that ratings for spouse/sig. other and close friends were not different ($F(1,253)=0.30$, $p<0.59$), but ratings for close friends versus acquaintances and strangers versus acquaintances are both significant ($F(1,253)=12.8$, $p<0.0004$; $F(1,253)=18.8$, $p<0.0001$). C5M said, "Touching is like a personal thing, so this is not the kind of thing you

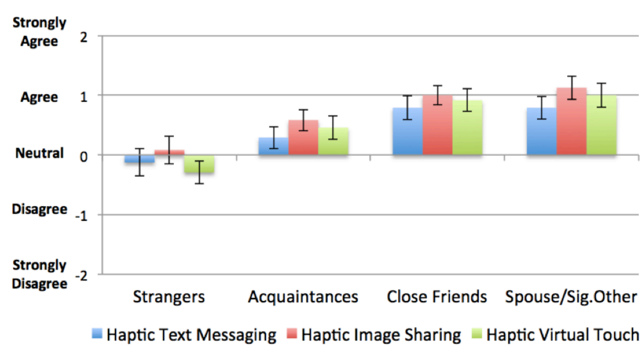


Figure 9: Mean Likert ratings with SE for preferred communication partner for each application.

would use with strangers." Additionally, during the discussions, half of participants (n=12) suggested using various applications with children. S2M explained, "Based on the fact that it's mostly touch, I would see myself using it more with a child because...you have more of an intimate feeling with a child as far as touch goes with hugs and kisses..." This finding supports the playful nature of interaction and the intimacy of haptics.

Haptic Text Messaging

On average participants previewed 11.5 (SD=6.4) different patterns and sent 6.8 (SD=2.5) different patterns to their partner. Users added a pattern to 66% (182/278) of messages they sent; however, follow-up discussion with participants indicated that they would send haptic patterns with messages less frequently if they were using this application outside of the lab. Two participants mentioned that it interrupted the conversation to send a texture with every message. We anticipate use in a field study to be less than that of emoticons, which were found in 4% of text messages [34].

Adding haptics to a message was viewed as only one aspect of a person's communication repertoire, and haptics were seen as a supplement to text, voice, and image-based communication. Users were able to send haptic messages without text, but only two of 278 messages were sent as a haptic pattern without text (see Fig 10, top). Furthermore, users thought that not all messages or words should have a texture or vibration pattern. For example, C3F said, "'Fun' could have a texture, but 'How was your day?' didn't seem to fit with a texture." Our application allowed users to apply a single texture to an entire message, but participants wanted to specify the texture of individual words.

We analyzed the content of participants' text messages and the haptic patterns they associated with various messages. Four primary uses of haptics in a text-messaging context emerged from our analysis of the logfiles and group discussion:

(1) Emotional expression. The majority of participants associated haptic patterns with emotional expression, and four participants compared the idea of haptic messaging to emoticons or emojis. Strong haptic patterns were often associated with anger. C5F said this application "would be great if you were fighting with someone," and that she would use it to "add a layer of expression." S5F said, "If you can't communicate what you're trying to say with words, it would be good to use a strong one to show anger." S5M explained that haptic messaging doesn't make sense "unless you can do something really intense." C3M explained that texture on words makes sense with "a strong emotion, anger... Dragging your finger across would take more effort." C4M said, "The problem with texting… there's implied tones…undertones that are part of the message..." and suggested haptics may help clarify this. S5M echoed this statement and said, "You'd be able to sense tone without using the cap locks button."

(2) Literal representation of texture. Participants applied texture to words in a literal sense. This was part of how participants shared a sensory experience with their partner (see Fig. 10, top). C2F1 explained, "In the context where I was experiencing something and I wanted to share with her multiple aspects of it, I would possibly use haptic feedback in that... 'Here's the sound. Here's what it looks like. Here's what it feels like.' To give her a rich experience." Another participant described using texture to communicate an experience of falling on ice.

(3) Highlighting content or messages. Participants applied haptics to highlight a particular message or content for the recipient. For example, S6M used contrasting haptic patterns to differentiate the punch line of a joke (Fig 10, center), and during the discussion he explained this was his intention. C1M1 wanted to use haptics to highlight important items on a shopping list, and C6M suggested using haptics for emphasis, as "an exclamation point." Five participants mentioned sending haptic messages as a surprise or on special occasions like a birthday [14].

(4) Physical playfulness. Both couples and strangers used haptics to be physically playful with their partner. C1M2 described adding rougher, higher friction patterns to impede his partner from opening the message, and his partner correctly interpreted this as a joke. Figure 10 illustrates a playful exchange between C3 where a series of static-like patterns became "boring" and they broke this trend by introducing a different texture (sawtooth wave) for fun. C2F1 said she would use haptics in a messaging context "to surprise somebody." S5M would use "an intense feeling where someone could get shocked, like a hand buzzer."

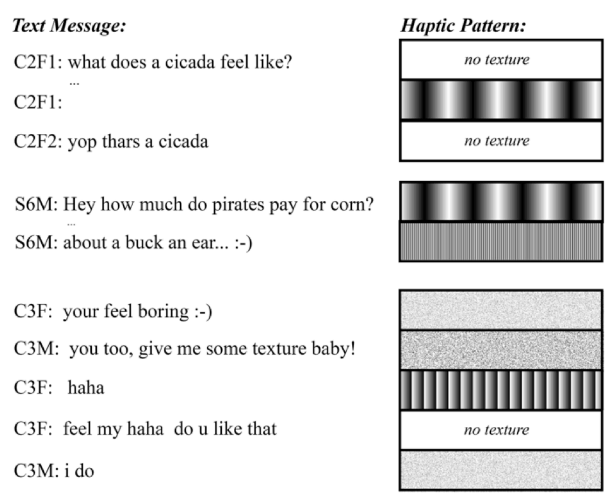


Figure 10: Haptic patterns were used to communicate literal texture (*top*), highlight or make a contrast between different messages such as a joke punch line (*center*), and as part of physical playfulness between pairs (*bottom*).

To understand the relationship between haptics and communicating affect, two researchers independently examined the corpus of text messages and extracted all messages (resolving any differences) that use text to explicitly indicate tone (i.e. with laughter "haha", exclamation points, smiley/frowning faces, and acronyms like "lol"). We found that 15% (42/278) of messages in the corpus included explicit tonal information. Of these messages, 79% (33/42) included a haptic pattern (compared to 66% of messages overall containing haptics), suggesting that users are slightly more inclined to add a haptic pattern when they explicitly indicate tone with textual information.

Overall, participants acknowledged that it would take time to learn to use haptic messaging in an everyday context, as they would need to learn or develop a "haptic vocabulary" and learn to weave it into conversation. Some users wanted a pre-defined vocabulary where others felt strongly it should develop organically between partners. C5M viewed the haptics as "a fancy emoticon" and acknowledged that it takes time to create shared meaning out of ambiguity: "People didn't use colons and parentheses like that [as a smiley face] 20 years ago to express feeling but now they do." Knowing one's partner is a critical piece of establishing this shared haptic language. C5F said, "I would only use [this application] with close friends or family, to add a layer of expressions to what I write." Thinking about learning a haptic vocabulary led participants to comment on exploiting touch for private communication. Two people described using haptics like a secret code to ensure onlookers did not view their message.

Haptic Image Sharing

Overall, the addition of haptics in an image editing and sharing context made sense to participants. When relating haptics to emotional expression, C2F2 said, "Words don't have a feeling but objects do." In general, participants responded favorably to this application and described it as a fun experience. C2F2 said, "I can see it being like a meme online... I can see it going viral." S4F said, "I think it was cool how it made the different images come alive, like the rocks 'cause you had feeling around the rocks. Then the water had this novel touch on it." We were surprised by the amount of thought many participants put into designing haptic images. We learned during the discussion that participants selected images they thought their partner would enjoy and/or images that had what they perceived to be varied or high contrasting textures. Participants selected images of a waterfall (n=6), a lion (n=4), sunset (n=3), field of flowers and mountains (n=3), puppy (n=2), cat (n=2), explosion (n=2), and impressionist painting (n=2). An image of rocks and an image of a still life painting were never selected. C5F said about selecting an image, "I thought it would have to be something I can imagine putting textures to… [It] would be too abstract for me to choose a painting…. Whereas with water, you can kind of feel, it's moist and soft." On average, participants added 4.7

Figure 11: Participants used haptics for literal texture (feeling of animal's tongue, fur), experiential/sensory information (intensity of an explosion), and hidden messages ("bliss" written over a waterfall). Color-coded textures are overlaid.

different textures to their image (SD=2.09), with one participant adding nine different textures to a single image. Participants who selected a landscape-type image tended to add more textures (mean=5.5; SD=2.0) than participants who selected an image of an animal (mean=3.0; SD=1.1), indicating that images with greater variation in textures led participants to apply more varied haptic feelings.

Analysis of the images participants selected and their application of texture revealed three primary uses of haptics in this context:

(1) Literal texture of an object or scene. As we observed in the text messaging application, participants applied various haptic patterns to convey the literal feeling of objects or a scene. For example, C2F1 selected an image of a dog (Fig. 11, left). She explained, "I made the nose and tongue...a color that kind of stuck to your fingers a little bit... Then I tried to pick one that gave a little bit of resistance and vibration for the fur of the body that was a little coarse..." As she described this during the discussion session, her partner said he noticed those differences in texture. Another participant (C3M) commented, "I liked the [texture] that I used for the water because it felt almost like your finger was wet when you tried to drag it across [the surface]."

(2) Texture as action or sensation. Participants also used haptics to create an interactive experience or tactile sensation based on the image content. C2F2 said, "The yellow color felt most like a waterfall..." She went on to explain that the yellow "rumbled" like a waterfall. Two other participants also used the yellow texture (70Hz sine wave) for the waterfall. S6F selected a cat photo and explained, "I was thinking of the feelings [textures] as the cat's purring, so I tried to map the intensity of the feeling to the places cats tend to like to be scratched." C4M selected an image of an explosion. He said, "I associated the explosion with the haptic… I figured there would be a concentrated center with a loud energy and then it would dissipate as it went out, so I really thought about painting that out with different sensory kinds of frequencies..."

(3) Hidden messages. Participants also applied haptics to an image in the form of a hidden message. For example, one participant drew a peace sign over a lion's face. Another wrote the word bliss in multiple layers over a waterfall (Fig. 11, right). When participants exchanged haptic images, we encouraged them to first explore the image in the haptic "feel" mode and then look at the visual of the haptic layer. Participants described exploring hidden messages as a game and tried to guess the message.

Participant couples reported feeling significantly more connected with their partners while using this application than strangers reported (F(1,22)=7.40, p=.0125); however, no differences in connectedness were found for haptic text messaging (F(1,22)=0.24, p=.627) or haptic virtual touch (F(1,22)=0.303, p=.588). We suspect that this difference is for two reasons. First, the task involved creating a haptic image for one's partner. This required thinking about what one's partner would enjoy and understand, which is a more difficult task for strangers than intimate couples. Second, as we found through our analysis, this application allowed for creative expression, providing opportunities for a person to demonstrate their understanding of their partner through the selection of an image and the way in which they add haptic patterns to it. We observed this connectedness between couples play out in interesting ways. For example, C1M2 said he "went with a Snoop Lion," which was an image of a lion with facial hair like the music artist. His partner laughed upon receiving this image and said, "Yeah, I got it completely." Other couples described selecting an image that they knew their partner would enjoy (e.g., a puppy dog or sunset). Relatedly, six participants mentioned using this application as a way to understand how other people think. C5M said, "It's a different vehicle for expressing feelings or sensations…meaning you want to attribute."

Haptic Virtual Touch

Overall, participants seemed to enjoy using this application. S5M said, "I thought it was fun. I liked it." C5F said, "It was playful, funny" to cross paths with her partner and that it "made me smile." We aimed to understand differences in interaction between pairs of couples and strangers, exploring whether a haptic virtual touch application might provide a sense of co-presence and intimacy between couples or possible discomfort between strangers [33].

Analysis of log files indicated how often and for how long participants touched virtually (Table 3). This data has high individual variation with no significant difference between couples and strangers. We highlight pairs who touched the most in Table 3 and understand their actions through observation and discussion data. Interestingly, most pairs turned this application into a game, and in some cases this lead to a high number of overlapping touches. C2F1 said, "We chased each other around for a while and touched finger tips a little bit. One of us would leave our finger still while the other would circle it." C6M told his partner, "I made a circle at one point, really fast, and I was wondering

	Times crossed	Time touching		Times crossed	Time touching
C1	22	0.77%	S1	**86**	**1.78%**
C2	**134**	**2.38%**	S2	35	0.81%
C3	2	0.06%	S3	19	0.41%
C4	10	0.10%	S4	27	0.41%
C5	34	0.59%	S5	9	0.07%
C6	**94**	**1.78%**	S6	**248**	**3.83%**
	49.3 (53.7)	***1.06 (0.94)***		***70.6 (90.9)***	***1.22 (1.41)***

Table 3: Number of times pair crossed finger paths and percent time spent touching partner virtually. Means (SD) reported.

if you would do something inside it." S1F commented, "It was fun... It was like cat and mouse with your fingers." S6 mimicked each other's movements, and S6F said that they touched "most when playing hide-and-seek." In contrast, pairs with lower numbers of intersecting touches (C3, C4, S5) focused on turn taking, which requires consideration of protocols to manage transitions [6]. A couple participants wanted haptic virtual touch to be embedded within shared tasks (e.g., document editing) to be more meaningful.

While there was no difference in Likert ratings for whether this application made strangers vs. couples uncomfortable (F(1,22)=0.712, p=.408), several users described haptic virtual touch as an intimate experience that conveys a sense of touching one's partner. C5M said, "You're replicating the other person's moves, so you're kind of touching the other person," to which his wife replied, "which is nice because I know you, you're my spouse." His wife said she would not use it with a stranger because "it feels kind of intimate… You're kind of touching the other person…" Although, she said she might use the application with far away relatives because "it is a nice way to make contact." P1M explained "I could see this with a significant other… Though it's cyber it's a little closer to hand holding… I can see that almost in a way being 'footsies.'" S5M said he would use the application for "flirting." C2F2 explained, "It would be really creepy to do with a stranger, but then I could see it would really be a big thing to have total strangers connecting like that." In this sense, the intimacy of virtual touch may provide a novel social experience for strangers.

Other participants did not perceive the experience to be too intimate to perform with a stranger. When asked what she thought of the haptics when a finger overlap occurred, S5F said she "felt it but didn't really think of it." S3M said, "When my lines crisscrossed with hers, I felt her finger moving so that was kind of neat." His partner (S3F) responded, "That was kind of cool... Then we tried to do follow the leader." S6F said touching fingers was "a good sensation," and it "takes on different meanings when you're doing it with someone you don't know."

We also examined the subtleties in designing the haptic experience for a virtual touch application. For this application, we tested two variations of the haptics experienced when participants' fingers overlapped. Six participant pairs (three stranger pairs and three couples) received a 3D rendered version (Fig. 7a) of haptics and six participant pairs received a textured version (Fig. 7b), as described in the application section. Five of 12 people who used the 3D version said that they did not notice the haptics when their fingers intersected, indicating that the haptics were too subtle to feel or notice during the interaction. Two of the 12 participants who used the textured version said they did not notice the haptics. Furthermore, this application has a heavy visual component, and participant comments indicated that they focused on the visuals instead of the haptics. C4M said, "You're paying so much attention to what you're seeing that you don't notice the haptic[s]." The experience also varied by person with some people wanting stronger haptics and others calling the experience "sensory overload."

DISCUSSION

The present study provides insights into the use of surface haptics for communication, both in terms of designing better applications for affective communication as well as understanding haptic languages. Prior work indicates that haptics can convey emotional information [3,8,33], and we found that users associated haptics with emotional expression in multiple different contexts. Haptics are seen as only one facet of a communication experience, and users wanted texture to supplement existing forms of voice, text, and image-based communication. Past studies identified haptics as appropriate for interaction with close social partners [33], which we found as well, but this intimate and playful interaction may generalize to parent-child dyads.

For text-based communications, haptics provide another way of communicating affective information [27,30]. We observed the use of haptics for communicating emotion, conveying literal texture, highlighting information, and physical playfulness. Adding haptic patterns to individual words may be more meaningful than adding a pattern to an entire message, and we expect haptic messages would be used sparingly as a way of emphasizing or elaborating a particular communication. When defining a haptic language, users wanted established haptic mappings with flexibility to create an evolving haptic language unique to different social partners.

We found that adding haptics to an image sharing application engaged and made sense to users. Naturally, images that had a diversity of textures and action in the scene encouraged users to more fully exploit the palette of haptic textures as a way to make the image "come alive." Users explored and noted the differences between various intensities of a single texture and the contrasts between multiple textures. This use case is promising, and further exploration is needed into defining a range of textures that work well for various categories of pictures as well as how the application might engage other populations, such as children and visually impaired people.

The haptic virtual touch application was the most abstract and open-ended of the applications. Based on user feedback and log file data, users tended not to come in close proximity to each other for a large majority of the time. This application encouraged movement, and movement was indicated visually by a trail, which may have detracted from noticing the haptic experience of direct touch. One question we posed was whether the 3D rendering added realism and connection. Unfortunately, the 3D rendering was not noticed by almost half of participants, and we attribute this to both the rendering itself and the context in which it was presented. That is, the alternate "texture target" 100Hz sine wave went unnoticed by people as well. However, in the image sharing application, participants articulated subtle differences between haptic patterns, such as a 100Hz square wave or a 70Hz sine wave. In the real world, touch is complex. As variable friction technology improves, we plan to refine the design of virtual touch to enhance the feeling of co-presence.

Examining these use cases outside of the lab is critical. We speculate that virtually touching fingers as implemented here may be too ambiguous or simple without a larger context of a long-distance relationship or additional media (e.g., voice, video). While participants indicated that the applications enhanced self-expression (Fig 8), their ability to understand their partner was not enhanced, and we expect such understandings to develop over time. Future work should examine how haptic languages evolve "in the wild" and how tactile information may be used for emphasis, mimicry, and turn-taking (e.g.,[6]).

CONCLUSION

We presented the design and evaluation of three applications for affective communication involving variable friction surface haptics. Users readily related emotional expression and affect with haptic interaction in multiple contexts. We found that users perceive touch interaction through haptics most suitable for use with close social partners or even their children, although surface haptics present possibilities for new social interactions with strangers. Participants used haptics in varied ways to communicate literal texture, convey emotional information, highlight content, for physical playfulness, and to provide one's partner with an experience or sensation. The rich communication repertoire enabled by variable friction surface haptics makes it a promising platform for exploring affective computing.

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