Towards Pleasant Touch: Vibrotactile Grids for Social Touch Interactions

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Figure 1. A calming stroke on the arm conveys emotions in human-to-human interactions.

Abstract

In this paper, we realize a wearable tactile device that delivers smooth pleasant strokes, those resemble of caressing and calming sensations, on the forearm. In Study 1, we develop a psychophysical model of continuous illusory motion on a discrete vibrotactile array. We use this model to generate a variety of tactile strokes that vary in frequency (quality), amplitude (strength) and duration (speed), and test them on a hedonic scale of pleasant-unpleasant in Study 2. Our results show that low frequency (<40 Hz) strokes at low amplitude (light touch) are felt pleasant, while high frequency strokes are unpleasant. High amplitude strokes are biased towards unpleasantness. Our results are useful for artificial means to enhance social presence among individuals in virtual and augmented settings.

Author Keywords

Social touch, vibrotactile illusions, pleasant touch, vibrotactile grid displays, wearable.

ACM Classification Keywords

H.5.2 [Information Interfaces and Presentation]: Haptic I/O.

Introduction

Touch is a primary source for non-verbal interactions and critical for interpersonal communication [1]. Due to its discriminative and affective roles, human touch
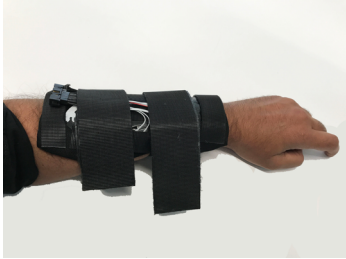
Figure 2. The wearable vibrotactile grid mounted on the forearm.

mediates both physical and emotional states among individuals, and therefore plays an important role in social etiquettes, social presence and social development [10]. Our research explores artificial means to engage users through their skin, and establish social connections between individuals that are physically apart.

Recent research has shown successful communication of emotions through touch. Individuals characterized as *strangers* conveyed emotions of anger, fear, disgust, love, gratitude and sympathy while touched on the participants' arm [5]. Particularly, participants preferred touch gestures over facial or body actions for conveying love and sympathy [1]. These gestures are characterized by light patting, rubbing and pleasant stroking sensations on the arm [5].

The goal of the present work is to develop a wearable haptic device that renders pleasant moving tactile strokes, resembles to that of soft calming and caressing sensations, on the hairy skin of the forearm. We realized the system with a linear array of vibrotactile actuators mounted on the dorsal forearm, Figure 2, and utilized a tactile illusion in somatosensory motion, namely apparent tactile motion [8]. This illusion creates a smooth continuous moving stroke on a discrete grid of vibrotactile actuators.

In this paper, we explore broad frequency and amplitude of vibrotactile stimulations that render smooth continuous strokes and determine optimal parameters for pleasant sensations on the forearm. In the first psychophysical study, we determine parameters to control the continuity of the illusory motion when varied in stimulation frequency, amplitude

and duration. This allows us to control stroking motion that varies in quality, strength and speed (semantic properties). In the second study, we asked another set of participants to subjectively rate a range of vibrotactile strokes on the pleasant-unpleasant scale.

The organization of the paper is as follow: we first reviewed background related to CT afferents and tactile cues in social context. Then we present our approach for creating pleasant tactile strokes and two accompanying studies. Finally, we conclude the paper with general discussion and future work.

Background

Recent research using microneurography and cortical images has shown evidence of pleasant touch highly correlated with the activation of C-tactile (CT) afferents [10]. CT afferents are a distinct type of unmyelinated, low-threshold mechanoreceptor units exist in the hairy but not glabrous skin of humans and other mammals. CT units responded most vigorously with gentle and soft brush stroking, at brushing velocities of 1-10 cm/s [9]. Similar pleasant strokes are also evoked on the glabrous skin of palm and sole, and the hairy skin of forearm and calf [4]. The hedonic attributes of tactile strokes are that low forces are more pleasant; pleasantness-to-touch decreases from calf to forearm to thigh to hand to forehead; and textured surfaces are less pleasant.

During human-to-human interactions, as in [1, 5], "stroking" gestures are mainly used to convey emotions of *love*, *sadness* and *sympathy*. Other emotions, such as *anger*, *fear*, *disgust* and *gratitude* are conveyed by pats, taps, squeezes, and hand/arm movements. There are many prior efforts to simulate affective touch using
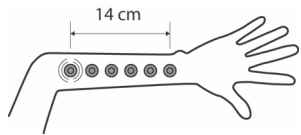
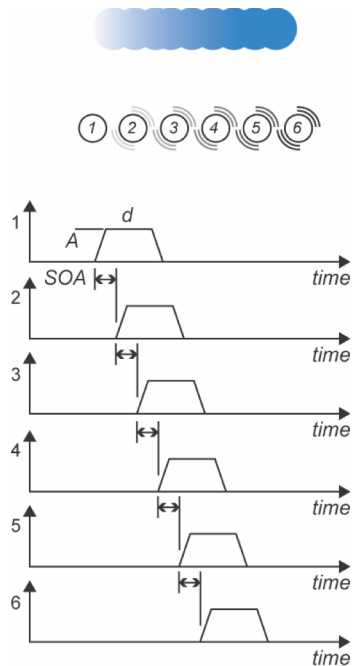**Figure 3.** Location of vibrotactile actuators on the dorsal forearm.

Figure 4. Apparent Tactile Motion is evoked by sequentially setting actuators with a controlled delay, SOA.

haptic feedback technologies and many wearable devices have been realized to create social events like hugs, handshake, taps, etc. [3].

For example, Huisman and colleagues developed a touch-sensitive vibrotactile arm sleeve (TaSST) [6], that enable two people to communicate different types of touches over a distance. The system had 4x3 compartments for sensors and actuators. Six gestures were created, they were simple - poke and hit; protracted - press and squeeze; dynamic - rub and stroke. More recently, Huisman et al. [7] used an array of vibrotactile actuators (fixed frequencies) to modulate stroking sensations using the *Tactile Brush* algorithm [8]. The Tactile Brush algorithm utilizes psychophysics of sensory illusions in touch, namely Apparent Tactile Motion, to create smooth continuous illusory motion on the skin's surface (Figure 3). Very recently, Culbertson et al. rendered pleasurable strokes using an array of indenters on the forearm [2].

In the present paper, we first re-establish the psychophysical model of apparent tactile motion on the forearm using a broad vibrotactile stimulus set (study 1), and then use this new model to generate a variety of strokes to access subjective pleasantness of each stoke (study 2).

Our Approach

As discussed earlier, our approach is to use an array of vibrotactile grid that simulates smooth pleasant motion on the dorsal forearm. Figure 3 shows layout of vibration points in the array and its location on the forearm. By sequentially modulating the vibrations with a set SOA (stimulus onset asynchrony), as shown in Figure 4, a user feels continuous motion across the

array [8]. It is known that vibration frequency, amplitude and duration effect the quality of illusion, and we first determine the optimal SOA that results in most continuous motion as a function of stimulus frequency, amplitude and duration.

Common Apparatus and Procedures
Six voice-coil vibrotactile tactors (model: TEAX13C02, Tectonic Elements, UK) are arranged equidistantly inside the padded shin guard. The actuators are covered with speaker cloth and mounted on the forearm using Velcro straps. Figure 4 shows the apparatus mounted on a user's forearm. The actuators are computer controlled using an audio interface (Motu, UltraLite-mk3 Hybrid, USA) and powered with a set of audio amplifiers (MAX98306). Tactile stimuli are generated as audio streams and played through an experiment interface developed in java-script.

All participants were employees and had no known sensory impairments. Participants sat in front of the computer screen and filled a participant log form before a study session. Before the studies, participants tested and familiarized with the type of patterns by playing "training trials" as many times. The actuator array was mounted on the left forearm such that the tactile motion was produced at the centerline of the dorsal forearm, and the arm was rested on the table, Figure 2. During the studies, participants wore headphones that played pink noise to mask the ambient noise.

Study 1: Continuous Motion on Vibrotactile Grids
The purpose of study 1 is to determine the optimal SOA between successive stimulations that generates a smooth continuous motion on the dorsal forearm.
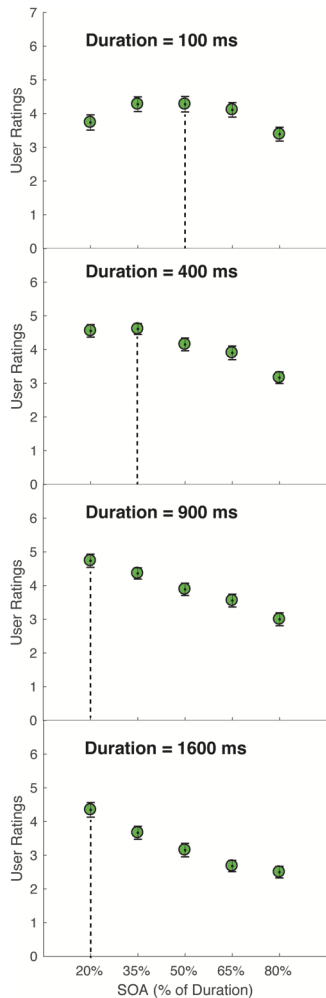
Figure 5: Subjective ratings of continuity as a function of SOA at four durations of Study 1. Error bars are the standard errors.

Before the experiments, a pilot study estimated driving voltages at absolute threshold levels (SL).

METHODS

The stimulus set consisted of 3 frequencies (20, 70 and 250 Hz) at 2 amplitudes levels (15 and 30 dB SL) and 4 durations (100, 400, 900, 1600 ms). Each stimulus was tested with 5 SOA levels uniformly between 20-80% of the test duration. Each stimuli was tested twice in a random order.

Six participants (5 males, 24-60 years old) took part in the study. In each trial, participants felt a pattern of straight line motion from elbow to wrist, as shown in Figure 3. The pattern was presented twice with a gap of 1 sec. Participants' task was to rate the continuity of motion on the scale of 1-7, where 7 was when the line motion was felt continuous. Participants were asked not worry about the quality of vibrations rather focus on the continuity and smoothness of the motion. Once participants rated the pattern by clicking one of the numbered button, a new trial would start. Each participant completed a 240 trial session that was divided into 4 blocks of 60 trials, with sufficient rest in between blocks. The whole session took less than 1 hour.

RESULTS

Subjective ratings of two repetitions for each stimulus type is averaged and analyzed in a repeated-measure ANOVA test. The test shows significant effect of frequency (p=0.01) and SOA (p=0.03) and no effect of amplitude (p=0.05) and duration (p=0.4) on the continuity ratings. Interactions between frequency-SOA, frequency-duration, duration-SOA and frequency-

duration-SOA are significant (p<0.05), indicating mixed trends of frequency, duration and SOA.

The results are generalized by combining frequency and amplitude, and shown in Figure 5. Vertical dash-lines indicate SOA values achieving highest rating at each duration. These optimal SOA values (in milliseconds) are plotted against the stimulus duration and regressed with a straight line, shown in Figure 6. The first order psychophysical model for apparent tactile motion is:

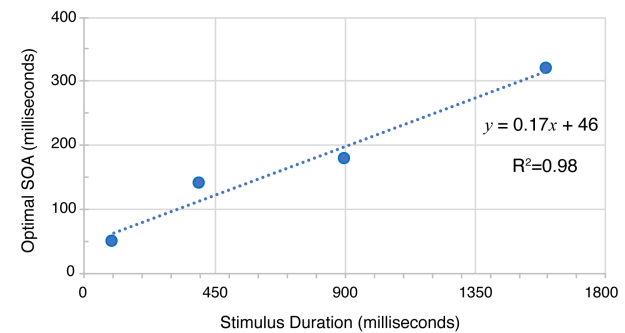$$SOA_O = 0.169 \times d + 46 \qquad (1)$$

Figure 6: Optimal SOA's (dash-lines of Fig. 5) plotted against the stimulus duration. Also, shown the best straight line fit.

Study 2: Pleasant Strokes on Vibrotactile Grid
In study 2, we use the model determined in study 1 (Eq. 1) and generate a variety of moving tactile strokes that vary in frequency, amplitude and speed. Duration of tactile stroke is $d+5 \times SOA$ (Figure 3). We test these strokes on a pleasant-unpleasant scale to determine the hedonic value of vibrotactile stimuli.
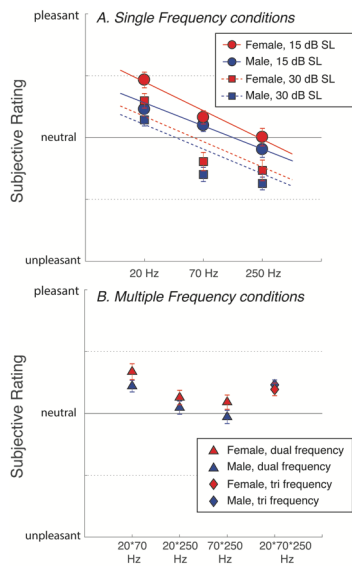
Figure 7: Subjective ratings on pleasantness-unpleasantness scale as a function of stroke frequency and amplitude. Error bars are the standard errors. **A.** single frequency strokes, straight lines are best fits. **B.** multiple frequency strokes.

METHODS

21 participants (11 males, avg. 37 years old) took part in the study. In each trial, participants felt a straight-line motion from elbow to wrist. This pattern was presented twice with a gap of ~1 sec. Participants' task was to rate the pattern on a pleasantness scale from -7 to +7, where +7 being "pleasant" and -7 being "unpleasant". 0 being neutral. Participants were instructed not to associate patterns to any real or physical sensation, rather rate the pattern if they felt as pleasant or unpleasant.

Tactile strokes either had one frequency or multiple frequencies (multiple sinusoids added together). Test frequencies were 20, 70 and 250 Hz. 3 single-frequency strokes were tested at two amplitudes (15 and 30 dB SL), 3 double-frequency waveforms ([20•70 Hz], [20•250 Hz], [70•250 Hz]) at roughly 20 dB SL, and 1 triple-frequency waveform [20•70•250 Hz] at 25 dB SL. All strokes were tested in 5 durations (200, 450, 700, 950, 1200 ms) corresponding to tactile stroking speed of 23, 13, 9, 7, and 5.7 cm/s. 50 strokes were divided into 2 blocks of 25 trials, with a rest period in between, that lasted roughly 15 minutes.

RESULTS

Subjective ratings are averaged and analyzed using two repeated measure ANOVA tests. The first test examines effects of stroke (10 levels) and speeds (5 levels) as within subject factor and gender (2 levels) as between subject factor. The test shows significant effect of stroke ($p<0.01$) only. Another test examines single frequency strokes, with frequency (3), amplitude (2) and speed (5) as within subject and gender (2) as between subject factor, reveals significant effect of frequency ($p<0.01$), amplitude ($p<0.01$) and their

interaction ($p<0.01$). No significant effects of stroke speed and any other interactions are observed. Therefore, we average the data for all speeds and recompile it in Figure 7; panel A for single frequency, and panel B for multiple frequency cases.

Figure 7A shows that participants rated low frequency (20 Hz) strokes along the pleasant scale and high frequency (250 Hz) strokes along the unpleasant scale. Subjective pleasantness decreased as the stimulus frequency increased ($p<0.05$). Pleasant ratings at 20 Hz strokes was significant higher than the neutral 0 ($p<0.01$). Higher amplitude strokes were rated less pleasant than low amplitude strokes ($p<0.01$). Figure 7B shows that participants rated pleasant to low- and mid-frequencies strokes ([20•70 Hz]) but high frequency reduced pleasantness. Triple frequency strokes were also rated pleasant ($p<0.05$). This could be because high-frequency was perceived relatively lower than the combined influence of low- and mid-frequency components.

Overall, females were generally more generous in rating pleasantness than male participants, but the differences are not significant ($p=0.27$). Participants commented that low-frequency strokes were smooth and felt like massaging, while high frequency strokes were creepy and artificial. They also mentioned that tactile strokes will be more relevant with context and complained about busy and open testing area.

Concluding Remarks and Future Work

The paper presents a technique to create smooth tactile strokes on the forearm using a static vibrotactile grid. Smooth continuous motion is rendered on the discrete grid using a vibrotactile illusion called apparent tactile

motion. In two studies, we first explored the broad vibrotactile space of frequency, amplitude and duration to create smooth continuous motion and then tested it in a pleasant-unpleasant subjective scale. Our results show that low-frequency strokes are more pleasant and felt 'organic', while high-frequency strokes are smooth and continuous, but not pleasant.

Study 1 provides a psychophysical model for generating tactile illusory strokes that varied in frequency (quality), amplitude (strength) and duration (speed). Eq. 1 is a generalize model and a high-order model could be obtained for precision, however, in our experience the loose model was sufficient due to poor processing capabilities of the skin.

The present work can be used to generate a variety of tactile strokes and synchronize them with visuals and other contextual cues in human-to-human interactions. Current work is a first step to deliver predefined tactile patterns from a device to a human. Our future work includes exploration of real time human-to-human communication system, that senses real time interactions of one user and delivers them to the second user, who are physically apart.

Acknowledgements

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