Experimental Evaluation of Tactile Patterns over Frictional Surface on Mobile Phones

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ABSTRACT

Tactile displays[1] have been widely used in information transfer through various tactile patterns on mobile devices. The fundamental consideration in designing tactile interactions is intuitive tactile feedback patterns that convey information. This study investigates the user perception of various tactile stimuli patterns over frictional surface on mobile phones in terms of strong feedback. We designed 36 different tactile patterns with a combination of different signal lengths (w1 = 0.2-3.2 mm) and intervals (w2 = 0.2-3.2 mm) of frictional feedbacks. These parameters covered most cases in the tactile pattern design for a mobile phone. Using these stimuli, we presented 666 pairs of comparisons to 50 participants who would distinguish whether the stimuli in each pair were similar or different. The results indicated the dense patterns in which smaller values of w1 and w2 conveyed stronger tactile feedback and quick distinguish time to users. Meanwhile, the denser tactile patterns had significant differences, which suggests that users can easily distinguish different strong tactile patterns even when these patterns appeared simultaneously. The results of this study can be used as a reference to design tactons, obtain non-visual information, or encode tactile language.

Author Keywords

Haptics, tactile feedback, frictional surface, tactile interface, user study

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INTRODUCTION

In modern mobile devices, tactile feedback can provide unintrusive, non-visual information that supplies potentially meaningful cues through tactile encoding with different patterns. This feedback is widely studied in emotional and affective communication, non-visual information transfer, virtual reality, telepresence, teleoperation, and soldiers communication in battle field [1-5].

The challenge in designing tactile interface is how to define a set of patterns will be either easily distinguishable or salient in combination. The main trend study on tactile interactions on mobile phones involves using vibrotactile technology that operates waveform, frequency, amplification, rhythm encoding, or temporal properties of a vibration signal to convey tactile information; however, this technology generally requires high cognitive processing in interpretation [3], and vibrotactile feedback is abstract and text message content is difficult to convey [6]. The mechanical-needle actuated systems simulate dot matrix printer technologies and Braille systems to convey text information, but they are rarely used in mobile devices because of their large components and high cost [7].

Frictional-surface tactile displays present a potential alternative for useful tactile interaction on mobile devices [8]. These devices vary the coefficient of friction as the user's fingertip moves across the display, thereby providing a unique sensation of bumps and textures on a flat glass surface; this technology is easy to deploy into existing mobile phones [9]. However, to the best of our knowledge, the tactile patterns and user experience of the new frictional feedback over a glass touch surface have not been studied in depth. The aspects that need further investigation are how to design distinguishable tactile patterns and what parameters convey high sensation strength and quick distinguish time. We also want to know how fast and how accurately these stimuli could be distinguished from one another. These factors are crucial to design an effective tactile interface [10].

To achieve the aforementioned purpose, this paper describes an initial study of 36 different tactile patterns with combinations of different signal lengths (w1 = 0.2-3.2 mm) and intervals (w2 = 0.2-3.2 mm) of frictional feedbacks. The selected parameters covered most cases of pattern design on a mobile phone screen. With the assistance of 50 experiment participants, we evaluated the patterns based on 666 pairs of comparisons with the 36 tactile patterns; the participants had to indicate whether the stimuli were the same or either one was stronger.

This study makes the following two contributions:

1) It presents an experimental evaluation of distinguishable sensation strength of 36 tactile patterns. These patterns were designed with different signal lengths and interval parameters that covered most cases of pattern design.

2) The results of the experiment show that the dense patterns with smaller values of w1 and w2 convey stronger tactile feedback to users. In addition, the denser tactile patterns were salient and had significant differences, thereby suggesting that users could distinguish different strong tactile patterns even when these patterns appeared simultaneously.

BACKGROUND

Tactile displays

The most predominant tactile display on a mobile phone is the vibrotactile type, which motors the entire device in the user's hand. This display can generate varying frequencies and amplify vibrations to supply different patterns of haptic feedback. Although studies have reported different patterns to convey notification messages or icons [10-12], the vibrotactile feedback is abstract and encounters difficulty in conveying the content of text messages [13].

Another type of display inspired by dot-matrix printer technologies and Braille systems have been proposed; this type includes mechanical needles actuated by electromagnetic, shape memory alloys, piezo-electric crystals, voice coil motor, pneumatic systems, and heat pump systems with Peltier modules [7]. These techniques provide great diversity of user interface to convey text messages, but they are rarely used in mobile devices because of their large components or high cost.

Different from the aforementioned types of display, electrostatic friction, such as TeslaTouch [14] and TPad [9], has been proposed to control electrostatic friction between an instrumented touch surface and the user's fingers. This surface haptic technology varies the coefficient of friction as the user's fingertip moves across the display, giving the sensation of bumps and textures on a flat glass surface. This type of technique provides distinct advantages. For example, it can be easily implemented and deployed to mobile phones, e.g., using piezoelectric sensor on the TPad phone project [9]. Moreover, using the controlled level of friction can generate various strengths and feedback experiences, which can be used to encode text information. Thus, in the present study, we choose the frictional tactile technique.

Tactile patterns

The main trends in designing tactile patterns are operating frequency, amplification, waveform, rhythm encoding, or temporal properties of a vibration signal [6, 15]. Each of these parameters can be used as one or combined as multi-dimensions to convey information. In general, recognizing tactile messages requires high cognitive processing to interpret and users must follow the exact sequence of signals [3, 16, 17]. Thus, the reading accuracy was usually low. Owing to the low-bandwidth channel for information transfer and limited perception accuracy of tactile sensation, investigating the stronger feedback patterns with significant distinguishability is one of the fundamental topics in tactile interaction.

Study [6] proposed to combine 50, 100, and 200 Hz frequencies and 52, 80, and 237 um amplitudes to represent 9 different patterns, and showed 73% of correct identification. Study [11] reported the use of rhythm in which 20 ms of vibration represented dots and 100 ms represented dashes to simulate the Morse code and then encode the dots and dashes to six-dot Braille code to convey text information. The study with trained participants showed 89% accuracy of recognition. Study [1] proposed a combination of friction-based burst length, continuity, and direction sensation to design tactile patterns; the experiment showed 87% distinguishing rate.

Study [18] compared different approaches of representing tactile information that indicated the recognition rates of 94% for waveform, 81% for frequency, and 61% for amplitude modulation, indicating that a more effective way to create tactile patterns using the texture parameter is to employ different waveforms to represent roughness.

To the best of our knowledge, no previous study has experimentally evaluated the patterns on frictional surfaces, such as TPad. This paper presents a study to identify the pattern features, and to determine how the combination of different signal lengths and interval parameters to represent roughness on frictional surfaces that affect subjective sensation in terms of strength.

EXPERIMENT

Device setup

The experiment used a TPad phone[2] to display variable frictions on a touch screen. This device provides dynamic frictions on different locations on the touch screen by using an air-squeeze-film technique [8]. The device provides API to dynamic change surface frictions while the user moves a finger on the screen. In the experiment, the screen size was 4.7 inches and the display resolution was 720 × 1280 pixels.

In software, the device adopted a gray-scale map to present the strength of friction, i.e., black indicates the strongest friction, white represents the smoothest, and others indicate the strengths between them.

The experiment adopted pair comparison method [1, 19], in which users are only required to compare two patterns at a time. The screen is divided into two regions displaying a pair of tactile patterns that enable users to perceive and distinguish differences in feedback strength. The strengths of all 36 patterns were then derived from aggregated comparison results of the individual pairs.

Participants

A total of 50 (25 female, 25 male) university students with an average age of 20.8 participated in the experiment. Each student was paid 60 yuan for participating in the study.

Stimuli

The patterns were designed in vertical stripes on the TPad phone screen where users moved their finger across the lines to sense the friction feedback switching back and forth. Studies showed that shape stimuli, such as sine, triangle, square, or sawtooth were indistinguishable to users, but the varying frequencies of feedback stimuli are strong [10]. The reason is that moving one's finger provides constant and consistent feedback that is perceived easily. Thus, in this situation, the stripe width (w1) and space between stripes (w2) were two crucial factors in design (see Fig. 1).

We designed the experiment w1/w2 starting with 0.2 mm because study [20] reported that larger than 0.2 mm (3 pixel) texture was rough and likely be perceived. On the other hand, while the stripe width increases to 3.2 mm (40 pixels), only 9 stripes can be shown on the screen, and the finger needs to move a long distance to perceive a switching feedback. Thus, we set the maximum width of the stripes.

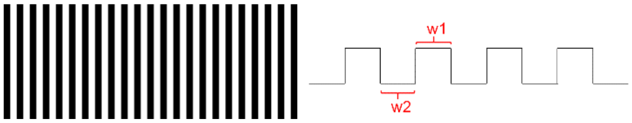

Figure 1: Left: The tactile pattern in black-white image; Right: w1 represents white width (light friction), w2 represents space between stripes (strong friction).

Consequently, we assigned 6 parameters of w1/w2: 0.2, 0.8, 1.4, 2.0, 2.6, and 3.2 mm. By combining these parameters, we can obtain 6 x 6 = 36 patterns (P1-P36) in order, which are **P1-P6**: 0.2/0.2, 0.2/0.8, 0.2/1.4, 0.2/2.0, 0.2/2.6, 0.2/3.2; **P7-P12**: 0.8/0.2, 0.8/0.8, 0.8/1.4, 0.8/2.0, 0.8/2.6, 0.8/3.2; **P13-P18**:1.4/0.2, 1.4/0.8, 1.4/1.4, 1.4/2.0, 1.4/2.6, 1.4/3.2; **P19-P24**: 2.0/0.2, 2.0/0.8, 2.0/1.4, 2.0/2.0, 2.0/2.6, 2.0/3.2; **P25-P30**: 2.6/0.2, 2.6/0.8, 2.6/1.4, 2.6/2.0, 2.6/2.6, 2.6/3.2; **P31-P36**: 3.2/0.2, 3.2/0.8, 3.2/1.4, 3.2/2.0, 3.2/2.6, 3.2/3.2.

Procedure and tasks

The experimenter first demonstrated the TPad Phone to participants, and allowed them to sense the friction switching while the finger moves on screen. Then, the 36 patterns were shown to participants, and they were allowed to touch and sense the differences. Thereafter, the participants were invited to sit in front of a table, put on a sound isolating earphones to prevent auditory noise, and to use their index finger to sense the pairs of tactile patterns on the TPad phone in a portrait mode.

The TPad phone displayed a pair of tactile patterns at the same time on the left and right regions of the screen, but the screen did not show the pattern images to participants. There was no finger's moving speed control during the experiment, participants tried ordinary smartphone usage style to perceive the tactile patterns. After sensing the two sides of patterns, the participants distinguished which side had a stronger or similar feedback by pushing a corresponding button on a tablet PC for recording (see Fig. 2).

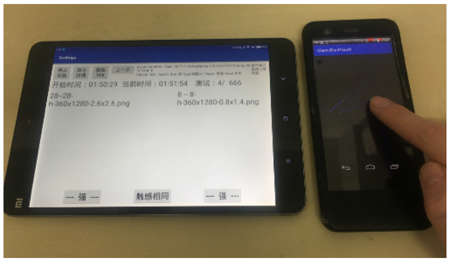

Figure 2: The experiment task and TPad phone.

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[2] http://www.thetpadphone.com/

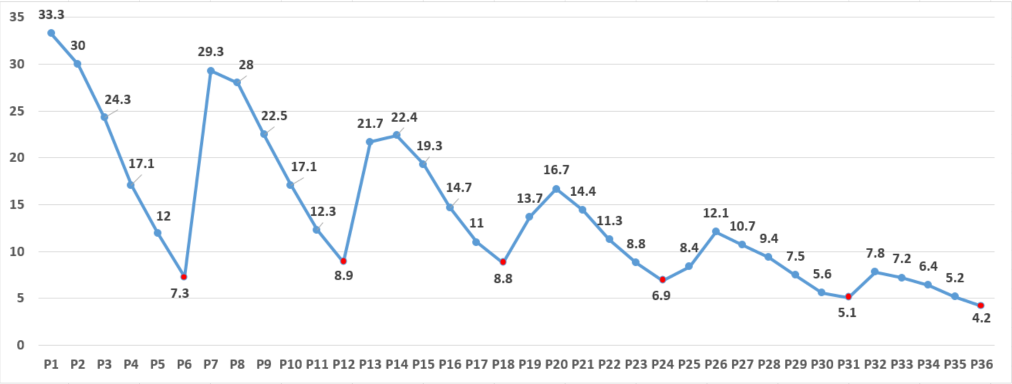

Figure 3: The feedback strength of tactile patterns.

RESULTS

A voting method was adopted to estimate the tactile feedback strength, that if a pattern gave stronger sensation compared to another the pattern strength plus one. The overall result was shown in Fig. 3, a number of common trends can also be observed. The pattern P1 (0.2/0.2) obtained the largest value of 33.3, but the P36 (3.2/3.2) showed the lowest value of 4.2. This result means that the pattern P1 (0.2/0.2) was the strongest tactile pattern among all the patterns, but P36 (3.2/3.2) had the weakest feedback. The strength value of other tactile patterns were between the two extreme values.

The strengths of patterns drop while increasing w1 or w2, means that the dense patterns conveyed a strong sensation. The strengths difference become less at P25 and following patterns.

We classified the results into groups using hierarchical clustering method based on dissimilarity matrix by squared Euclidean distance. This method is recommended for clustering ordinal data [21]. Table 1 shows the various clustering results, this can be used for further study the distinguishability of different patterns and convey code information.

Table 1: Classifying the 36 tactile patterns into various cluster using hierarchical clustering method.

2 Clusters	3 Clusters	4 Clusters
P1	P1	P1
P2-36	P2,7,8	P2,7,8
	P3-6,9-36	P3,9,13,14
		P4-6,10-12,15-36
5 Clusters	**6 Clusters**	
P1	P1	
P2,7,8	P2,7,8	
P3	P3	
P4-6,10-12,15-36	P4,10,15,20	
P9,13,14	P5,6,11,12,16-19,21-36	
	P9,13,14	

DISCUSSION

From the Fig. 3, we observed that the strengths of patterns increase while decreasing w1 or w2, meanwhile, the greater differences between w1 and w2 values decreased the perceived roughness strengths. For example, the P6, P12, P18, P24, and P31 (0.2/3.2, 0.8/3.2, 1.4/3.2, 2.0/3.2, and 3.2/0.2) patterns obtained the smallest perceived roughness compared with the other patterns. These results indicate that the constant and consistent feedback that is perceived easily and offer larger strength.

Participants seemed to experience increased difficulty in isolating the mid-range stimuli but performed significantly better for the extremes of the set. Therefore, this condition implied that in designing tactile information, the dense patterns with larger strength value could be perceived and distinguished more easily by users. In addition, when using the different patterns to represent different codes to transfer information, such as alphabet and notification messages, using larger difference strength patterns is more effective, and tactile feedbacks may be more significant.

Though we did not present the distinguish time, during the experiment we observed that the dense patterns obtained shorter time for users to make identify, e.g., 0.2/0.2, 0.2/0.8, and 0.8/0.2, were quickly distinguished by the participants. The fast distinguish time above 1-3 s, where the patterns with less strength different like to generate inaccurate results and took about 2-5 s to make distinctions.

Limitations

We did not take the finger's moving speed and reaction time into consideration in the current experiment. Thus, further work should examine the finger's moving speed, time performance, and error rates required for the user to distinguish tactile patterns.

Though we suggested varying frequencies (w1/w2) of feedback stimuli are stronger than those gradual changing ones, such as such as sine, triangle, square, or sawtooth, they still convey distinct sensations. Our result could give a baseline that to compare the new pattern design.

The present study was based on the frictional surface over glass touch screen, i.e. TPad Phone, further experiment should be conducted to study the applicable to any other tactile presentation systems, such as TeslaTouch [14].

CONCLUSION

This study investigated the user sensation of various tactile stimuli patterns over frictional surface on mobile phones. The experiment of 36 different tactile patterns showed that the dense patterns with quick feedback switching tactile feedback conveyed stronger sensation to users. The patterns with large strengths were salient and can be easily distinguished from others. The implications of this study can be used to design a tactile interface, obtain non-visual information, or encode tactile language. In the future, we will conduct an experiment to learn the distinguishability of different patterns and test the recognition of 3, 4, 5 or more patterns to convey code information.

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