Creating Mediated Touch Gestures with Vibrotactile Stimuli for Smart Phones*

Qianhui Wei
Eindhoven University of Technology
Department of Industrial Design
5612 AZ Eindhoven, Netherlands
q.wei@tue.nl

Min Li
NXP Semiconductors
Interleuvenlaan 80, Leuven, Belgium
min.li@nxp.com

Jun Hu
Eindhoven University of Technology
Department of Industrial Design
5612 AZ Eindhoven, Netherlands
j.hu@tue.nl

Loe Feijs
Eindhoven University of Technology
Department of Industrial Design
5612 AZ Eindhoven, Netherlands
L.M.G.Feijs@tue.nl

ABSTRACT

Mediated touch gestures are essential for delivering information in social networking. This study presents a method to create mediated touch gestures with vibrotactile stimuli for smart phones and explores the effectiveness of applying mediated touch gestures with vibrotactile stimuli when sending text and stickers in instant messaging applications. We developed a preliminary prototype to record vibration signals of touch gestures. The envelopes of the recorded signals are approximated by piecewise linear functions and then translated to MIDI parameters for generating vibrotactile stimuli. We applied mediated touch gestures in instant messaging applications as haptic icons. A user study showed that gesture traits and the contact time affected the sensation of haptic icons. The enhancement effect of touch gestures was influenced by the contact time.

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KEYWORDS

Touch gestures; Mediated social touch; Vibrotactile stimuli; Instant messaging applications; Touchscreens; Smart phones

INTRODUCTION

Touch is our primary non-verbal communication channel for conveying physical and emotional expressions [1]. Mediated social touch is a popular research field in the digital age. Tactile and kinesthetic interfaces were designed and developed for haptic communication between people who are physically apart, and may thus provide mediated social touch, with both physical and emotional performance [1, 2].

Researchers have developed different systems for the mediated representation of specific touch events between communication partners and developed a touch vocabulary to define touch behavior [1, 3]. Devices and prototypes were designed to mediate touch gestures. A tactile device was created in [4], which can be squeezed or touched with the finger by one user, another user felt corresponding vibrotactile stimulation on the other device with four vibrating actuators. Wearable systems were developed to sense and record the force or deformation of skin during the contact interaction [5–7].

A lot of wearables were designed to present mediated social touch. Some wearables are designed for arms [8–11] and hands [6] to sense social touch. Others are developed for body especially those for feeling of being hugged [12, 13]. Also, robots were developed to display mediated social touch in context like videoconference in office [14] or to maintain intimacy in long distance relationships [15]. In addition, efforts were made to present mediated social touch on mobile phones [16, 17].

From research results, we can see that as for presenting mediated touch gestures, most researchers focused on developing devices and prototypes such as wearables. Some consider adding extra devices to present mediated touch gestures on mobile phones. A prototype was attached to mobile phones to display cheek touch [16]. An inflatable surface was added to mobile phones to present emotional touch [17]. However, adding extra devices to a mobile phone is not an optimal way to apply mediated touch for the market. Instead, we use an embedded LRA motor without adding any extra devices on a smart phone. A flat plate is used to collect signals from touch gestures to extract related parameters, since the vibrotactile stimuli will be presented through the phone`s flat touchscreen.

This study mainly focuses on presenting mediated touch with vibrotactile stimuli on touchscreens. We present a method to record touch signals and present touch gestures with vibrotactile stimuli generated through mediating the envelope of the recorded signals. We apply mediated touch gestures with vibrotactile stimuli in an instant messaging application on smart phones in the form of haptic icons and evaluate the application for the effectiveness of the mediated social touch.

Table 1: Characteristics of touch gestures

Touch gestures	*Contact time*	*Gestures traits*
Stroke	Long	Dynamic
Hit	Short	Dynamic
Knock	Short	Dynamic
Hug	Long	Static

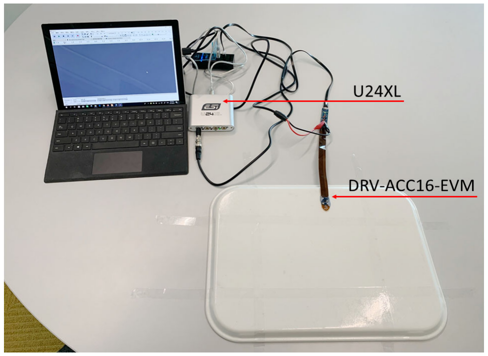


Figure 1: Recording setup

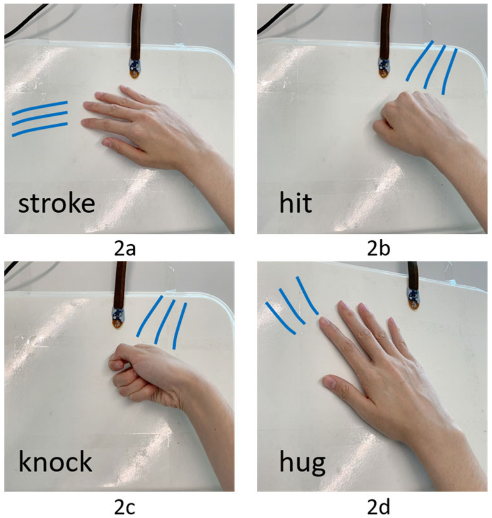


Figure 2: Performing touch gestures on a flat plate

DESIGN AND APPLICATION

Recording method

As Fig. 1 shows, an accelerometer (DRV-ACC16-EVM, with three axes), an audio input device (U24XL) and a hollow flat plate were employed to acquire vibration signals of touch gestures. The hollow flat plate was fixed to the table with transparent adhesive tape so it would not move when performing touch gestures on it. The small accelerometer board was attached to the surface of the hollow flat plate. We connected the audio input device as an input to the Z axis test points on the measurement board. The audio input device was connected to Audacity on a computer to display and record the vibration signals of the touch gestures on the plate. The average vibration on Z axis was recorded as audio with a sample frequency of f=44100Hz.

We chose four typical touch gestures, namely 'stroke', 'hit', 'knock' and 'hug' (Table 1), two of which have a long contact time between communicating partners while the other two have a short contact time. According to Freeman and Roth [18], 'stroke', 'hit' and 'knock' are dynamic gestures since they are related to the hand movement and can be represented by a sequence of images while 'hug' is a relatively static gesture since the hand configuration and pose can be represented by a single image.

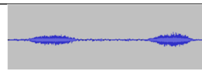
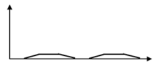
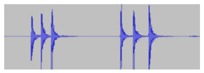
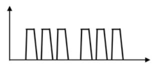
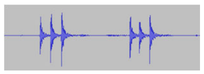
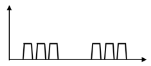
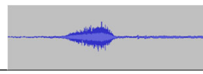
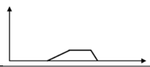
Fig. 2a shows the gesture 'stroke' – sliding one hand from left to right on the flat plate with a gentle force to simulate stroking. Fig. 2b shows 'hit' – hitting the flat plate with a strong force to simulate hitting. Fig. 2c shows 'knock' – tapping the flat plate with a medium force as knocking a door. Fig 2d shows 'hug' – using one hand to move a small distance on the flat plate with a strong force to simulate a small displacement between the hand and the object being hugged.

Vibrations of each touch gesture were recorded several times and we selected the most stable sample of signals (see Table 2) for the next analysis.

Displaying method

In order to simulate force change of touch gestures, we mimicked the envelopes of the recorded signals by piecewise liner functions (Table 2) and translated them to MIDI parameters (Table 3). We applied the Sound Library in Processing 3 to generate vibrotactile stimuli. An envelope controls how a note begins and ends through four parameters, namely attack time, sustain time, sustain level and release time [19]. According to [19], attack time refers to how long it takes for the volume of the note to go from zero to its peak , which means the amplitude of signals in this stage increases from zero to sustain level (peak volume of the sound during its duration), representing an increase of force from zero to the peak of touch gestures. Sustain time refers to the amount of time the note plays. It represents the time of peak force of touch gestures. Release time refers to the length of time it takes for the level to decay from the sustain level to zero, which means amplitude of signals in this stage decreases from the peak to zero which simulate the stage that force decreases. Envelopes of the recorded signals in this study are shown in Table 2. Table 3 shows specific patterns of mediated vibrotactile stimuli in haptic icons and Fig. 3 shows the basic

Table 2: Recorded signals and mediated envelope of touch gestures

Touch gestures	*Recorded signals*	*Mediated envelope*
Stroke		
Hit		
Knock		
Hug		

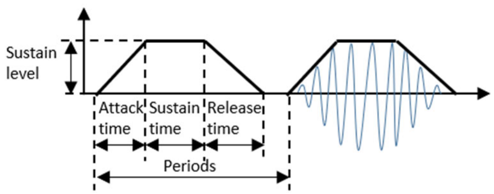


Figure 3: The basic piecewise liner function of the envelope and the waveform of mediated audio signals

Table 4: Overview of haptic icons (1)

Task	*Visual information*	*Haptic icons*
Text with haptic icons	'Let me stroke your hair.'	
	'Hit you!'	
	'Knock knock.'	
	'Let me hug you.'	

piecewise liner function of the envelope [20] and the waveform of mediated audio signals. We used the MIDI note number to represent the frequency of the signals. MIDI notes can be converted into frequencies with the following formula [21, 22]:

$$MIDI\ note\ number = 69\ + 12\ log_2\left(\frac{f}{440}\right)$$

For stroking, a low amplitude and a high frequency were chosen to display a gentle force since the perceived intensity decreases as frequency increases when it is over mid and high-frequency [23]. For hugging, a low value near resonant frequency of the actuator in our experiment was applied to display a strong force. A middle frequency which can make the feeling of hitting clearer was set for knocking and hitting. Amplitude of hitting is the highest, so the perceived intensity is high, which shows a sense of strong force according to [23]. Attack time, sustain time, sustain level and release time [19] were set and adjusted according to the mediated envelope of the recorded signals. Frequency and numbers of envelopes were set and adjusted according to the typical gestures.

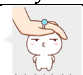
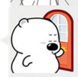
Table 3: Recorded signals and mediated envelope of touch gestures

Touch gestures	Attack time(s)	Sustain time(s)	Sustain level	Release time(s)	Note number	Frequency (Hz)	Period (s)	Envelope number
Stroke	1.0	1.0	0.3	1.0	65	350	2.6	4
Hit	0.01	0.1	1.0	0.03	57	220	0.2	8
Knock	0.005	0.01	0.5	0.005	57	220	0.27	3
Hug	1.5	1.0	0.5	0.5	50	147	-	1

Prototype

The experiment device is an LG V30 smart phone containing an embedded Linear Resonant Actuator (LRA) vibration motor which can convert audio signals into vibrotactile stimuli. Audio signals were firstly generated with the Sound Library in Processing 3, using the parameters of recorded vibration signals (Table 3). Then, the LRA motor converted audio signals into vibrotactile stimuli with preprogrammed audio signals. A prototype of an instant messaging application was developed using Android Studio with those testing vibrotactile stimuli. Since our research is to evaluate the effectiveness of applying mediated touch gestures with vibrotactile stimuli when sending text and stickers in instant messaging applications, we only provided interfaces with a virtual communication context in which the virtual sender has already sent information with haptic icons to the receiver. Participants will act as the receiver to sense these haptic icons on the touchscreen. In Fig. 4 (left), the virtual chatting partner sent four haptic icons which display different virtual touch gestures. The virtual chatting partner sent text (Fig. 4 center) and stickers (Fig. 4 right) to express touch gestures with haptic icons. Detailed information about haptic icons are in Table 4 and Table 5. In visual information, dialog boxes of stickers are from WeChat.

Table 5: Overview of haptic icons (2)

Task	*Visual information*	*Haptic icons*
Stickers with haptic icons		
		
		
		

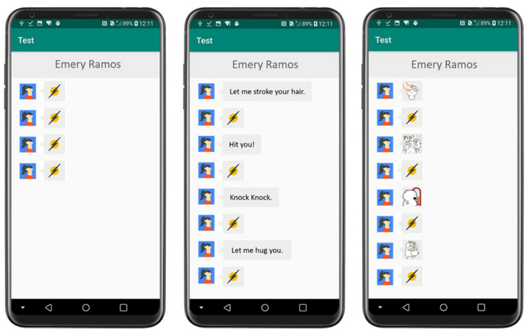


Figure 4: Application interface. Haptic icons only (left); Text with haptic icons (center); Stickers with haptic icons (right).

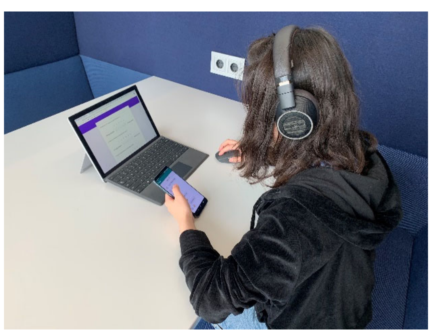


Figure 5: Test settings.

USER STUDY

Research questions

This user study investigates these questions. The first question is if only haptic icons could express touch gestures. The second question is if haptic icons displaying touch gestures could enhance the touch effect of text. The third question is if haptic icons displaying touch gestures could enhance the touch effect of stickers.

Participants

16 participants (4 males and 12 females) aged from 25 to 30 participated in the experiment, all participants have no constraints of sensing touch according to their own report.

Instrument

A questionnaire was created to collect data from participants. There were three parts aiming at three tasks in the questionnaire. The main questions in the questionnaire were constructed with a 5-point Likert scale that ranged from 1 (strongly disagree) to 5 (strongly agree). In the first part, questions were as follows: 'Haptic icon 1 feels like stroking.', 'Haptic icon 2 feels like hitting.', 'Haptic icon 3 feels like knocking.', 'Haptic icon 4 feels like hugging.'. In the second part, questions were 'This haptic icon enhance the effect of text.'. In the third part, questions were 'This haptic icon enhance the touch effect of stickers.'.

Procedure

Participants were asked to wear headphones (Fig.5), playing white noise which has no rhythm or pitch, to block out the sound of vibration from the experiment device and other environmental sounds which may affect perception of vibrotactile stimuli.

In the first task (Fig.4 left), participants pressed and felt the sensation of each haptic icon, filled out the first part of the questionnaire. In the second task (Fig.4 center), participants read the text, pressed the haptic icon and felt the vibrotactile stimuli, then filled out the second part of the questionnaire. In the third task (Fig.4 right), participants read the sticker, pressed the haptic icon and felt the vibrotactile stimuli, then filled out the third part of the questionnaire. The questionnaire was presented on a computer. The experimenter explained how to perform tasks before each task. The order of the last two tasks were counterbalanced between participants.

RESULTS AND DISCUSSION

Fig. 6, Fig. 7 and Fig. 8 show the descriptive statistics of three tasks and we also conducted paired-sample t tests for evaluation. In the first task, the significant effect can be found in pairs of 'hit-

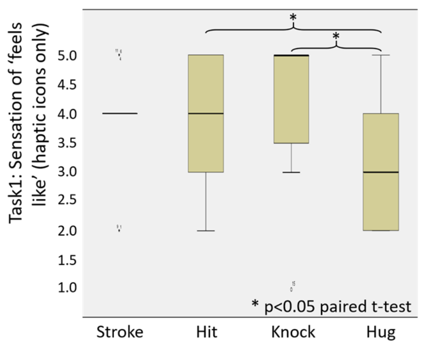


Figure 6: Results of task 1 (haptic icons only)

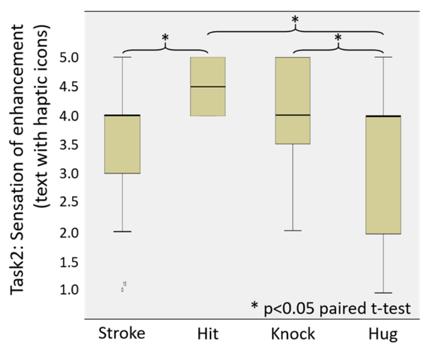


Figure 7: Results of task 2 (text with haptic icons)

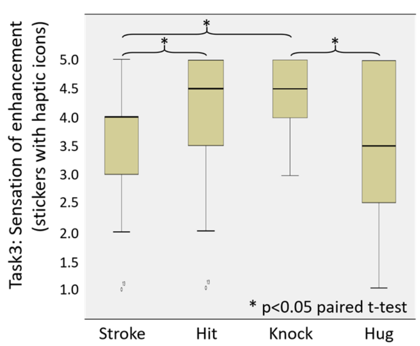


Figure 8: Results of task 3 (stickers with haptic icons)

hug', t(15) = 2.423, p<0.05 and 'knock-hug', t(15) = 3.651, p<0.05. There is no significant effect in other pairs. Fig. 6 also shows that 'hit' and 'knock' got a higher grade in representation of touch gestures while 'hug' got a relatively lower grade. The results are mainly due to the reason that 'hug' is a relative static touch gesture. Touch dictionary [24] defines 'hug' as 'squeeze the haptic creature tightly in your arms', in the recording stage of this study, we mediated 'hug' as a small movement with strong force to simulate a small displacement between the hand and the object being hugged, which is a little abstract since performing relatively static gestures on a flat plate is not easy. Also, the contact time of touch gestures affects the expressive effect of haptic icons. In the second task, significant effect can be found in pairs of 'stroke-hit', t(15) = -3.656, p<0.05, 'hit-hug', t(15) = 5.000, p<0.05 and 'knock-hug', t(15) = 2.448, p<0.05. In the third task, significant effect can be found in the pairs of 'stroke-hit', t(15) = -2.522, p<0.05, 'stroke-knock', t(15) = -4.038, p<0.05 and 'knock-hug', t(15) = 2.908, p<0.05. There is no significant effect in other pairs in the second or the third task. Considering the results in Fig. 7 and Fig. 8, we can see that touch gestures which have a short contact time as 'hit' and 'knock' got relatively higher grades while the other two which have a long contact time as 'stroke' and 'hug' got relatively lower grades when enhancing the touch effect of a text and stickers. Results show that the enhancement effect from haptic icons of text or stickers is influenced by the contact time of touch gestures.

CONCLUSIONS AND FUTURE WORK

This paper presents a method to generate touch gestures with vibrotactile stimuli for smart phones. We recorded and translated vibration signals for generating vibrotactile stimuli. We applied the vibrotactile stimuli in an instant messaging application acting as haptic icons. Results showed that dynamic mediated touch gestures with vibrotactile stimuli on touchscreens could represent touch gestures well, while for relatively static touch gestures, it is not easy to do so with haptic icons only. The enhancement effect of touch gestures which have a short contact time from haptic icons of text or stickers is better than those which have a long contact time.

There are some limitations and challenges in this study. Firstly, for touch gestures, we only considered the contact time and gesture traits as two dimensions. We need to consider more dimensions of touch gestures for smart phones. Meanwhile, we only considered four touch gestures in this study. We need to mimic more touch gestures for the future research. Secondly, for recording methods, we performed touch gestures according to the researcher`s experience when recording vibration signals. However, different people may have different ways of performing touch gestures. Thus, we need to ask more participants to perform touch gestures for recording vibration signals. We should analyze and extract common factors from recorded vibration signals to make haptic touch gestures understandable for more people. Then, for the application of haptic icons, we provided fixed haptic icons in this study. In the future, we will consider self-generating haptic icons and allow users to customize haptic icons, and to make mediated touch gestures more personalized.

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