Perceived Roughness of Single Sinusoid Compared to Recorded Vibration

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Einleitung

Touch Displays are rapidly emerging apparatus since they are programmable input devices. Apart from their programmability, integrating haptic feedback to touch displays has turned them irreplaceable mediator between users and electronic devices. Thanks to haptic feedback, humans are able to perceive roughness, shapes and their combinations on a haptic touch display [1]–[3].

Recently, many researches have been presented about texture reproduction on a display using a variety of methods [1, 2, 4]. Most of them have aimed to simulate macro surface roughness. Roughness is still the only possible dimension of tactile texture perception to be simulated on a touch display. Although coarse textures can be successfully simulated on a display, there is still difficulty to reproduce fine textures since both types of textures require different rendering approaches for satisfying roughness perception [5]. It is because induced complex vibration when a finger moves over fine textures is not identical to surface roughness as opposed to coarse textures. In the early twentieth century, David Katz asserted [6] that spatial cues developing from the geometrical properties of a surface are only discernible if the texture is not too fine. In case of fine textures, the contribution of spatial cues on texture perception becomes unclear, but vibrotactile encoding ability of sensory receptors take place to perceive them. This famous assertion is known as the duplex theory of tactile texture perception [7]. In the 1970s, important contributions brought a new level of sophistication to the study of texture perception by Susan Lederman [8, 9]. These studies, and subsequent research in Kenneth Johnson's lab [10] - [12] showed that a spatial code is used for texture perception with elements larger than 100/200 mm. Later on, it was presented that spatial cues can contribute to roughness perception if surface bumps are as small as 100 mm [5]. Recently, the final consensus came to the point of that spatial and vibrotactile codes are both necessary and both complete each other for perceiving a texture. The struggle is that actively moving a finger on surfaces with different wavelengths may activate different mechanoreceptors with different selective frequencies [12]. On the other hand, Bensmaia and Hollins asserted that waveform variations on complex vibrotaction can change the perception of texture, and vibrotaction is sufficient itself to perceive fine textures [13].

Recalling the topic of texture reproduction, a landmark research for texture rendering using measurement-based vibrotactile feedback has been introduced by Romano [2] which is a comprehensive method for rendering fine and course textures. In that study, simply, acceleration data in three axes are measured during the relative motion between a texture and contacted accelerometer. Afterward, three axes data are reduced to one-dimensional data in order to be driven on haptic stylus using small voice coil actuator. However, this approach hasn't been applicable for bare finger interactions since smaller haptic actuators which are capable of generating complex vibration haven't been implemented in hand-held devices yet.

As is known, the data-driven approach (playing back recorded vibration) proposes tactile vibration for fine and coarse textures with same complexity resolution. Based on the duplex theory of tactile texture perception, if the datadriven approach is sufficient for rendering fine textures, then it might be over-sophisticated for rendering coarse textures since they only require vibration identical to surface roughness. Besides, there is a risk that measurement based vibration might contain redundant frequency components which are below the human vibration detection threshold. Another fact is that some components which are slightly above the threshold level might not be perceived as well due to the masking effect of more intensive neighboring frequencies [14]. Regarding this issue and that the usefulness of simple and perceptually efficient tactile vibration for handheld touch devices, enough researches haven't been done on reducing the complexity of recorded vibration for different textures [15]. Therefore, our motivation is to investigate simplification possibilities on recorded vibration for different types of textures.

In this study, we expect that simplification approaches might result in different efficiency for fine and coarse textures. For this reason, the textures were selected in varying surface roughness values to be able to observe this difference. To be sure on that the varying spatial sizes of the textures are distinguishable, the subjective roughness evaluation test was conducted before the main investigation. To begin with the main investigation, roughness similarity estimation experiment was conducted by comparing real textures and two different tactile stimuli on a display. The two tactile stimuli consist of recorded vibration and a simplified tactile stimuli which is single sinusoid. After the similarity estimation experiment, the results were analyzed using analysis of variance and multi-dimensional scaling tests.

Experimental Setup

Sample Materials

Our project aims multimodal reproduction of fabric textures on a display in order to increase the efficiency of an online shopping platform in term of customer satisfaction. Thus, six fabric textures have been used in this study which are common industrial and cloth textiles.

As seen in Fig. 1, the textures are sorted from the finest to coarsest surfaces as T1-T6 regarding the subjective roughness evaluation test, respectively. Sample materials have repetitive unevenness and regular surface patterns with different spatial sizes. Besides, the samples are rougher than the glass surface of the display. Apart from that, all textures were firmly wrapped around a wooden piece, 15 cm x 10 cm in size, before they were presented to the participants. The purpose of wrapping is to avoid softness of textures which might interfere with subjective roughness evaluation. A highresolution camera (Sony, Alpha 900) was used to measure the width of spatial bumps on the textures by zooming in so that they can be compared with perceived roughness values. T1 and T2 have the smallest spatial bumps width values (120 mm and 210 mm) while T5 and T6 have the biggest spatial bumps (520 mm and 710 mm). T3 and T4 are varied in between. Based on the visual inspection, T1 and T2 have quite smooth surfaces while T3 and T4 have neither smooth surfaces nor distinct surface bumps. However, T5 and T6 have visible regular bumps on the surfaces. Order of textures regarding the size of spatial bumps was confirmed by subjective roughness evaluation test.

Abbildung 1: Fabric textures are sorted from T1 (finest) to T6 (roughest) based on their spatial density and subjective roughness evaluation test. Types of the fabrics are written as above.

Data Collection Setup

The recorded vibration and single sinusoid were produced based on the measured acceleration data. During the acceleration measurements, three axes 10g accelerometer (Kistler 8692C10M1) was used to collect data via the data acquisition system (Squadriga II) as shown in Fig. 2. Relative motion between the textures and the contacted accelerometer was provided by a rotating drum which is rotated by brushed DC motor. Rotating drum can be easily disassembled to be wrapped around by textures. Acceleration data was measured for 7 seconds while the tangential speed of drum was 15 cm/s. The speed was defined within the range of surface scanning speed on hand-held displays. Before the measurement of each texture, the contact pressure of accelerometer-tip which was measured by the force sensing resistor (FSR402) was calibrated to be 1 N.

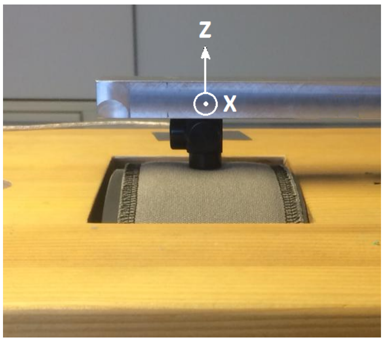

Abbildung 2: Acceleration measurement setup. Rotating drum provides relative motion between texture and contacted accelerometer.

Producing The Tactile Stimuli

To be able to prepare the tactile stimuli, measured accelerations in X and Z axes were taken into account while the data in Y axis was neglected since the relative motion was along the X axis. Afterward, the data in X and Z axes was then compressed by calculating their resultant vector to obtain one-dimensional data. This dimension reduction process doesn't cause textural information loss due to the insensitivity of the human hand to vibration direction.

In order to prepare recorded vibration (S1), 5 second long samples were cut in the middle of one-dimensional data for each texture. Afterwards, low and high pass filters were applied to one-dimensional data to contain frequency components between 20-1000 Hz which are corresponding to tactile cues [2]. The second stimulus is a single tone sine wave (S2) produced by using the most powerful frequency component. Overall RMS levels of S2 was equalized with respect to recorded vibration. Profiles of the two tactile stimuli are plotted for T5 in 3.

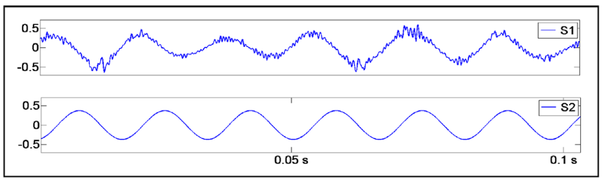

Abbildung 3: The two tactile stimuli signals of T5 are plotted as an example illustration. From top to bottom, recorded vibration (S1) and single sinusoid (S2). The RMS levels of S2 was equalized with respect to recorded vibration (S1).

Physcophysical Experiment Setup

In order to conduct roughness similarity experiment on a haptic display, a hardware was constructed as seen in Fig. 4. A touch display monitor (Gechic HD 1102H) was assembled on top of an electrodynamic shaker (RFT

Messelektronik Type 11076), and the control interface was designed to include play button for driving tactile stimuli and scaling bar. The tactile stimuli were given for 5 seconds when the participants click the play button on the interface. The tactile stimuli were produced via the electrodynamic shaker and stimulated the finger when it slides over the display. While each stimulus was played, associated texture appeared on the display as an image to let participants know which texture they are rating. During the experiment, participants listened to music through a closed dynamic headphone (Sennheiser HDA 200) in order to prevent them hearing the sound of the electrodynamic shaker.

Abbildung 4: The participant is touching haptic display and textures which are under the cover in order to rate the similarity. The user-computer interface, texture cover, tactile display, electro-dynamic shaker, and headphone were placed as in the image.

Before the experiment began, tactile feedback generation system on a display was validated as follows: Intensity level of driven tactile stimuli on the display was set to be similar by tuning the power amplifier according to the intensity level of measured accelerations. Furthermore, the participants were only allowed to move their fingers in the central area of the display where the amplitude of given vibration doesn't vary concretely as on the edges.

Experimental Method

In this study, a similarity estimation experiment has been conducted using continuous equal interval scaling method. The experiments are roughness similarity estimation and subjective roughness evaluation tests. During the similarity estimation experiment, the scanning speed of finger on the textures and display was kept constant at 15 cm/s using visual bar guide on the computer screen in order to be consistent with the acceleration measurements. Indeed, it is known that perceived roughness does not change substantially scanning velocity varies on a texture [16].

In this experiment, fifteen subjects, 12 male and 3 female aged between 20 and 55 years, participated in. They rated the similarity of perceived roughness of tactile stimuli comparing to real textural sensation. Rhormann perception scaling test was applied for roughness similarity estimation experiment. Allowing the participants touching the textures, the similarity of two vibrotactile stimuli were rated using verbal labels. The verbal labels were not at all, little bit, middle, very much and fully placed on the continuous equal interval scale from 0 to 100 with 25 increments. The participants were also allowed to rate anywhere in between two labels. For example, if they felt that the vibration of the given stimuli on the display matches fully with the real texture, they should select fully on the scale which is considered as a score of 100. On the contrary, if they felt the vibration on a display matches little bit with the real texture, they should select little bit which is 25 as a score. The similarity was judged by their own subjective feeling after the experience of stimulation, and the number of trials was not limited.

The experiment consists of two steps which are a training and a main session. At the beginning of the experiment, the participants were trained to teach them how to evaluate the task. They experienced tactile stimuli on the display only for the finest, the mid-coarse, and the coarsest textures to have them familiar to the similarity scaling test. During the texture scanning process and the experiment, subjects were moving their finger at a speed of 15 cm/s on textures and display. The data of the training session were not included for further analysis. On the other hand, the main session aimed to collect the subjective evaluation data with respect to all combinations of tactile stimuli and textures which means 12 stimulation cases by combining the two tactile stimuli (S1-S2) with the six textures (T1-T6). They were driven when the participants play the stimuli after completing the active surface scanning. In the experiment, the participants were not allowed to recognize the textures visually. The experiment including the training session took below 20 minutes for each participant.

Results

Similarity Ratings

Twelve stimuli were rated during the experiment by 15 subjects (2 types of stimuli x 6 textures). The results of both experiments concluded as seen in Fig. 5. Similarity ratings of 12 tactile stimuli were normally distributed while only two of them (S1 of T1 and S2 of T2) had negligible skewed distribution. The average similarity ratings of each type of stimuli and their standard deviations are as follows: S1 is 64.9/16.9 and S2 is 60.1/17.3. These values are close to the resulted realism ratings of driven recorded vibration in the study of Romano et al. [2].

In order to compare types of stimuli with each other for each texture, a one-way ANOVA was performed for 30 values (2 stimuli x 15 participants). For T1, a significant difference was found between S1 and S2 ($F(1,29) = 3.17$, $p = .031$). For T2, T3, T4, T5 and T6, none of the tactile stimuli was found significantly different than each other.

Conclusion

In this work, two types of vibrotactile stimuli have been tested by the psychophysical experiment using the textures with varying surface roughness. The aim was to measure perceived roughness of several tactile stimuli on

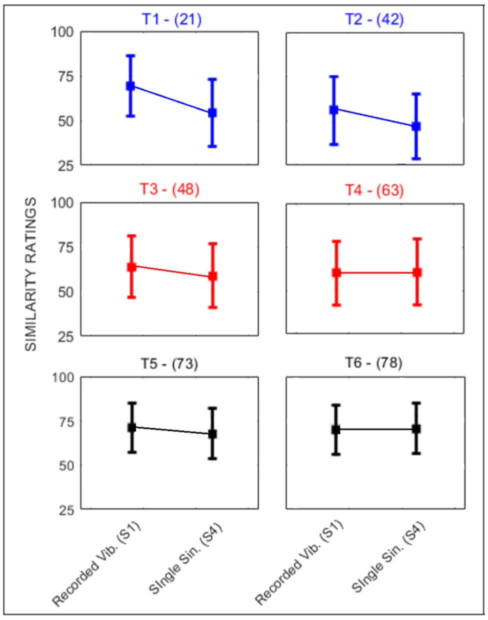

Abbildung 5: Similarity Ratings of two tactile stimuli for six textures were resulted in as above. Besides, subjective perceived roughness values of each texture was given in parenthesis. Only S2 was found to be correlated with the perceived roughness values. R value was calculated as 0.78 for S2.

a display which have been produced with different simplification levels. Thus, the minimum complexity level of tactile vibration could be defined for different surfaces with high perceptual capacity. Although roughness sensation comparison between the real textures and the glass display is not an easy test, the experiment and statistical analyses resulted in meaningfully.

Based on the similarity ratings, single sinusoid stimulus was found as the most similar stimuli for coarse textures. In other words, using a sinusoid resulted in as the most efficient complexity level for representing the coarse fabric textures than driven recorded vibration. Besides, increasing similarity ratings of the single sinusoid is likely due to its emphasized frequency amplitude since its RMS level was increased to be equal with the recorded vibration. Also, one-way ANOVA test showed that single sinusoid was found as the most irrelevant stimuli for the finest textures.

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