Rendering by Tuning the Frequency and Amplitude of Single Tone Vibrotactile Feedback

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Abstract

When a finger moves on a surface of a material, textural information is perceived via the sensory receptors. Although the texture rendering is still not very clear phenomenon, it has become a emerging topic in surface haptics recently. However, it is known that even providing a single tone sinusoidal vibration on a tactile display creates considerable haptic feedback. In this study, a new method is proposed for texture rendering using a single tone vibrotactile feedback. Using a magnitude estimation method, the subjects tuned the frequency and intensity of single tone sinusoidal vibration on a tactile display to seek the most similar sensation for the several fabric textures. The results show that one single tone vibrotactile signal can be used to distinguish the textile textures on a tactile surface. Based on the ANOVA tests, using a mean of the defined frequency for each texture has the main contribution to distinguish the textures.

Introduction

In order to percieve the physical information of textures, there must be relative motion between a finger and a surface which is known as active touch [1]. This relative motion stimulates the sensory receptors located under the skin [2, 3, 4] which convey textural information of a material [5]. For this reason, instead of stationary touching, particularly, active touch is required to sense a textural information such as roughness, slipperiness or geometric profile. These vocabularies allowing us to express what we feel are based on study of Okamoto et al. [6]. They identified three main perceptual dimensions: (1) hard/soft, (2) cold/warm and (3) rough/smooth with a sub dimension: slippery/sticky. Among them, only the third dimension describes a textural information of a material. Even though, hard materials have been rendered successfully, rendering a soft texture has not been clarified yet. In this study, only fabric materials are used to understand the limitations of rendering the soft textures.

When active touch takes place, the vibrations are produced due to the interaction between a fingertip and a texture [1, 2, 25] which provides textural information [5, 7]. Neither passive touch nor gliding a pen on a texture are enough to fully experience a texture due to the fact that pressure and induced vibrations are required at the same time [3]. Based on the literature, the process of developing a sense of touch is based on four types of mechanoreceptors which are Merkel's Disks, Ruffini's Cylinders, Meissner's and Pacinian Corpuscles. Merkel's Disks and Ruffini's Cylinders percieve the skin deformations and applied pressure. Meissner's Corpuscles percieve the induced vibrations between 30Hz and 80Hz while Pacinian Corpuscles percieves the vibrations between 250Hz and 350Hz which are the main receptors conveying a textural information [2, 7, 8, 9, 10]. Nevertheless, the association between sense of touch and the way how to manipulate vibrotactile feedback is still partly clear topic.

In the literature, researchers have been working on texture rendering using variety of techniques such as applying electrostatic force [13, 14, 18, 20, 23, 24], electroadhesion [19], ultrasonic vibration [20, 21, 22], pin-array actuation [26] and vibrotactile feedback [11, 12, 15, 16, 17, 25]. These techniques except pin-array actuation and vibrotactile feedback require either high voltage or high mechanical power consumption, while the vibrotactile feedback can be applied easily to current haptic devices with a relatively lower cost. All these techniques have been experimented on tactile displays by using either a single tone input signal or data driven method [15, 16, 18]. Some researches have aimed to analyze how the parameters of a single tone input signal affecting the touch sensation in terms of the third perceptual dimension [4, 12, 13, 23]. However, it does not fully explain the relation between sense of touch and given feedback likely due to the tactile JND of frequency and intensity. Even though the data driven method is based on more realistic rendering technique, it requires a complex control system in order to regulate the frequency contents of an input signal depending on a velocity of moving finger or pen and pressure applied to a surface.

Apart from the variety of significant studies on texture rendering, adjustment method using a simple vibrotactile feedback is proposed in this study. The subjects tuned the frequency and amplitude ratio of the single tone sinusoidal vibrations to seek a most similar touch sensation between a tactile display and a texture. The user interface of the experiment was designed at Matlab Gui toolbox to control two dimensions: (1)Frequency and (2) Amplitude ratio of a single tone sinusoidal vibrotactile feedback. The subjects are allowed to adjust frequency between 50 and 500Hz considering the perceiving range of Meissner's and Pacinian Corpuscles while the amplitude ratio is limited to eight steps. Since the perceived frequency and the velocity of moving finger is tightly coupled to each other, the fingers of the subjects were guided at a constant velocity on the tactile display and textures. The user interface of the experiments were displayed at a tactile display in order to enable the visual feedback and touch gesture. Subjects rated five different fabric textures which are denim, coton, canvas and two different synthetic auto mobile seat textiles which are commonly used at clothe and auto mobile seat industry.

We concluded that even though subjects rated the different fabric textures based on their surface properties by defining several combinations of frequency and amplitude ratio, fine textures are obviously described with higher frequencies and lower amplitude ratios while the course textures are described with lower frequencies and higher amplitude ratios. Consequently, method of tuning the dimensions of a simple vibrotactile feedback can be assumed as a reliable technique to distinguish the unsimilar textures.

Experimental Methods

In this study, vibratory signal refers to a single tone sinusoidal vibrotactile feedback, dimensions refer to frequency and amplitude ratio of vibrotactile signal, assigned vibratory signals refers to the vibrotactile signals for each texture created by using the mean frequency and amplitude ratios defined by the subjects for each texture. The textures, denim, coton, canvas, synthetic automobile seat textiles 1 and 2 as seen in the Fig. 1 are referred as first, second, third, forth and fifth texture from left to right.

Experimental Methods

Participants

20 subjects attended to the experiment. All the subjects are the students of TU Dresden at variety of departments and the one is a secretary personal of our university. The ages of the subjects vary between 24 and 35 except the secretary personal who is 55 years old. The total time of the experiment varied between 10 and 15 minutes. All the subjects were informed about psychophysical experiment procedures clearly.

Experimental Methods

Texture Rendering

Variety of researches have been done concerning the rendering a texture. The existing approaches are based on a pulse train with a slider, data driven using either pen or bare finger and tactile perceptional tests. In this study, magnitude estimation method was proposed to evaluate texture rendering using different aspect. The goal of this experiment is tuning the dimensions of a vibrotactile feedback to seek a most similar tactile sensation for each texture. The subjects were allowed to touch tactile display and textures as much as they desired.

The frequency range was altered between 50 and 500 Hz considering the perceiving range of Meissner's Corpuscles and Pacinian Corpuscles. The frequency is changed with a 20 Hz increment. Amplitude ratios was restricted to eight levels to keep the experiment simple. In order to obtain coherent data, the finger of the subjects were guided with a moving circle. That circle is moving at a constant speed in a desired trajectory. The final decisions of the subjects were recorded by using save button on the tactile display seen in Fig.3.

Figure 1: Textures used at the experiments: From left to right: Denim, coton, canvas and automobile seat textile 1 and 2.

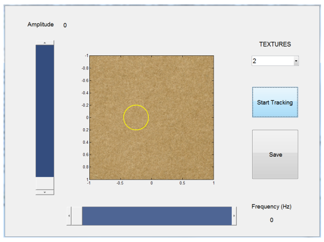

Figure 2: Matlab Gui toolbox used in the first experiment which is displayed at Ipad screen. The yellow circle seen on the texture is used for speed tracking.

Experimental Methods

Experimental Setup

For the experiment, a Gui interfaces was designed at MATLAB because of their different goals. These interfaces were displayed on Ipad screen via the software called Duet Display. Thanks to this software, touch gesture and visual feedback were enabled to control the dimensions by bare fingers. During the experiments, the subjects were listening a white noise to be isolated from the sound of electrodynamic shaker.

Subjects were able to tune the dimensions of vibratory signal by two sliders embedded to X and Y axes of the illustrated textures. The sliders were used to control the frequency and amplitude ratio. Vibrotactile signals fed from sound card of the computer were amplified by the power amplifier(S-100). Through the amplified signals, the electrodynamic shaker excited the tactile display (IPAD) which was fixed on top of the shaker with a strong double side tape.

Experimental Methods

Procedures of Physcophysical Experiments

In the beginning of the experiment, the subjects were trained to keep their fingers moving at a constant speed by using the moving circle. The subjects were allowed to see the textures while they were touching them during the experiments. Moreover, each subject was free to rate

Figure 3: The subject tuning the frequency and amplitude ratio using the experimental setup. The experimental setup includes textures, shaker, amplifier and ipad as seen above.

textures in a random order and as much time they desired during the experiment.

Results

In this section, the results of psychophysical experiment is introduced in this section. The dimensions defined by the subjects for each texture are illustrated in Fig. 4 and 5.

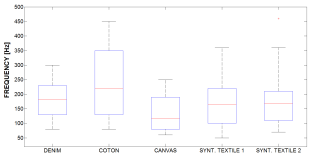

Figure 4: This plot shows defined frequencies for each texture.

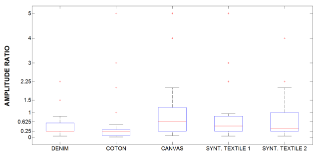

Figure 5: This plot shows the defined amplitude ratios for each texture.

Firstly, the mean frequencies of the textures from left to right as seen in Fig. 1 were found as 183Hz, 231Hz, 140Hz 178Hz and 188Hz, respectively. it is remarkable that the mean frequencies of each texture are quite close to median of the defined frequencies for each texture as seen in Fig. 4. Moreover, The standart deviations of defined frequencies from the first to fifth texture are 69Hz, 113Hz, 63Hz, 79Hz and 107Hz, respectively, as seen in Fig. 4. Regarding the defined frequencies, a one-way analysis of variance (ANOVA) was performed for a total of 100 values (one dimension X five textures) for twenty subjects. This analysis finds a significant relation between the mean and defined frequencies for each texture ($F(1, 99) = 4{,}4E{+}14$, $p = 0.0026$).

Secondly, the mean amplitude ratios for each texture from left to right were founded as 0.58, 0.31, 0.72, 0.6 and 0.66, respectively. The mean amplitude ratios of second, third and forth textures are relatively close to median of each texture as seen in Fig. 5. Considering the average of the amplitude ratios, second texture was rated with lowest amplitude ratio, while the third texture was rated with highest amplitude ratio, as expected. However, the other textures were rated quite similar with each other. Regarding the defined amplitude values, a same ANOVA test was performed for a total of 100 values (one dimension X five textures) for twenty subjects. It does not conclude a significant connection between the mean and defined amplitude ratios fro each texture ($F(1, 99) = 0.26$, $p = 0.899$).

Conclusions

In this paper, a new method of texture rendering is proposed using a single tone vibrotactile signal. Tuning the dimensions to percieve the same tactile sensation on the real textures and the tactile display leads promising results. However, it is concluded that tuning the frequency is more reliable than tuning the amplitude ratio based on the one-way ANOVA tests. On the other hand, using less level of amplitude ratio and finger pressure control can increase the overall reliability of this method.

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