Allowable Range of Consistency Between the Visual and Tactile Presentations of a Linear Grating Texture

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Abstract. To impart a tactile sense to the virtual reality experience, a method has been proposed in which the user actually touches an object of the same material as the object in the virtual reality scene. However, in this method, it is necessary to prepare the same number of objects for touching as those that are visually presented. The purpose of this research is to clarify the conditions under which the two modalities are perceived as subjectively matched, thereby reducing the number of tactile textures that must be prepared. In this paper, we studied the range of allowable spatial frequencies of tactile stimuli that a user feels to be consistent with the visual stimuli in the case of line gratings. The results indicate that the discrimination threshold monotonically increases with respect to visual texture width, implying that Weber's law holds true in this range.

Keywords: Cross Modal, Texture Perception, Visual Tactile Sense, Virtual Reality.

1 Introduction

A method of preparing a real object for tactile presentation has been adopted in several studies on virtual reality (VR) systems [1]. This method has the advantage that the sense of touching and stroking an object can be expressed realistically. However, the obvious disadvantage of this method is that the same number of objects that are visually presented in the VR scene must also be prepared for touching, which is quite impractical. Representing several objects using one real object is a conceivable method for solving this problem. In this case, the allowable range of inconsistency between tactile and visual stimuli needs to be obtained.

This research aims to measure the discrimination threshold at which humans perceive the difference between visual and tactile stimuli. The eventual aim is to identify the necessary number and types of tactile textures for VR systems. As a first step, this paper reports an experiment using linear gratings presented both visually and haptically.

2 Related Work

In the study of VR systems, many attempts have been made to use real objects for tactile stimuli. Haptic retargeting [2] manipulates images displayed on the head mounted display so that the same real object can be used to represent multiple objects in the scene. The Magic Table [3] manipulates the rotation angle of the image, presenting a triangle or pentagon table using only a real rectangular table. While these are examples in which multiple shapes or multiple locations of objects are presented by slightly manipulating the visual scene, as far as the authors know, there has been no attempt to represent multiple textures using a combination of multiple visual textures and a smaller number of tactile textures.

In contrast, there have been many studies that measure visual and tactile texture discrimination, at least since the 1960s. Klazkey et al. [4] and Ernst et al. [5] showed that the shape and size of an object are mainly perceived visually. However, Heller [6] showed that texture recognition mainly relies on tactile sense rather than visual sense. Bergmann et al. [7] performed a more detailed verification with 96 textures and concluded that tactile accuracy is good for textures less than 0.1 mm in width, whereas visual accuracy is good for 1-mm wide textures.

While all these research results provide an important factual basis for this research, our setup is different in that visual and tactile images are simultaneously presented.

3 Measurement method

Fig. 1 (a) shows the overall experimental setup.

3.1 Texture

In this experiment, acrylic one-dimensional textures were manufactured using a three-dimensional printer. The blocks were 4 × 4 × 1 cm and the texture widths were in intervals of 1.0 to 3.0 mm in 0.2 mm intervals.

3.2 Experimental device

In this experiment, it is preferable to present the visual and tactile stimuli at the same location. The experimental apparatus is shown in **Fig. 1**(b). It consists of a top board on which a smartphone for presenting images is attached, an acrylic mirror board, an acrylic slide board on which the textures were fixed, a middle board to guide the slide plate, and a bottom plate. By setting the distances from the top plate to the mirror and from the middle plate to the mirror equal, the image of the texture is displayed at the same position as the actual texture (**Fig. 1**(c)).

The slide plate was moved to the left and right to present different textures during experiment. To prevent participants from guessing the type of texture using the parts protruding to the left and right of the slide plate, these parts were covered with a black curtain.

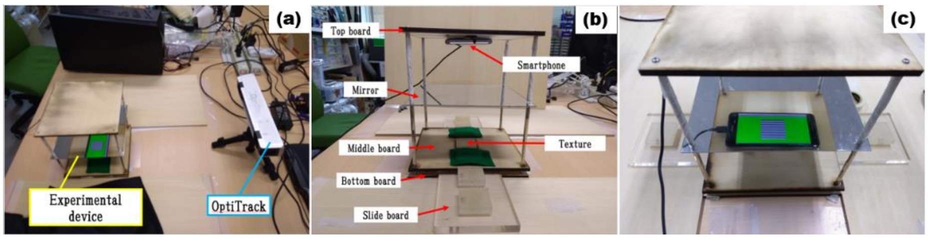

Fig. 1. (a) Overview of the experimental setup. (b) Side view. (c) Presented image.

3.3 Finger position tracking

A three-dimensional tracking system OptiTrack (NaturalPoint, V120: Duo) was used for finger tracking. As shown in **Fig. 2**(a), a retroreflective marker was attached to the finger of the participant and the finger position was reflected on the image.

The texture and finger images were produced by a program using the Unity game engine. The image was designed to be as symbolic as possible to prevent its quality from affecting the result. The unevenness of the texture was represented by a black-and-white striped pattern and the finger position was indicated with a red ball. (**Fig. 2**(b))

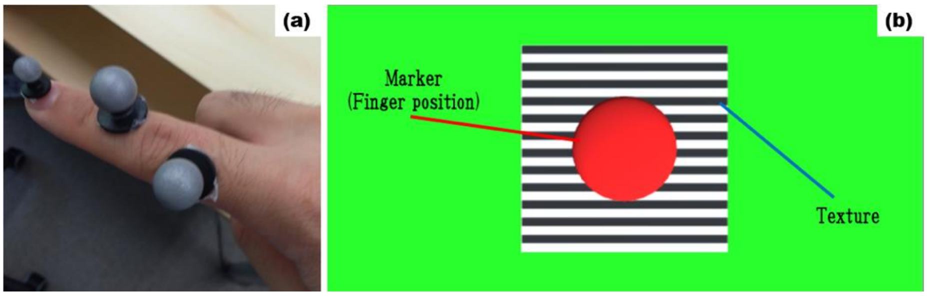

Fig. 2. (a) OptiTrack marker worn on the finger. (b) Image used for the experiment.

4 Experiment

4.1 Purpose

In this experiment, we aimed to measure the discrimination threshold between visual and tactile textures. Specifically, we asked participants to touch the actual texture while looking at the image of the texture and to determine which one was wider.

4.2 Subjects

Six members of the laboratory (two females and four males, one left-handed and five right-handed, 21–24 years old) participated in this study.

4.3 Experimental conditions

Table 1 shows 21 experimental conditions, with three types of visual textures (1.6, 2.0, and 2.4 mm) and seven types of tactile textures (at 0.2 mm intervals) for each visual texture. Ten trials were conducted for each condition, giving a total of 210 trials per person. We presented one set of 70 trials for each visual condition (in order of 1.6, 2.0, and 2.4 mm) with rest periods of more than one day between the sets.

Table 1. Combinations of image and sample texture widths

Image texture width (mm)	Sample texture width (mm)
1.6	1.0, 1.2, 1.4, 1.6, 1.8, 2.0, 2.2
2.0	1.4, 1.6, 1.8, 2.0, 2.2, 2.4, 2.6
2.4	1.8, 2.0, 2.2, 2.4, 2.6, 2.8, 3.0

4.4 Procedure

After explaining the experiment to the participant, the OptiTrack markers were put on the index finger of his/her dominant hand, as shown in **Fig. 2**(a), and the experiment was started.

The participants were asked to touch the actual texture while watching the image reflected in the mirror. We did not specify the direction and speed of the finger, but we asked the participants to keep their fingers moving. Subsequently, they were asked to answer whether the width of the real texture was larger or smaller using a 2AFC (two-alternative forced choice method). The time the participants were allowed touch the texture was not set, and the participants could touch it as much as they liked.

Three sets of 70 trials were conducted for one participant. We asked the participants to close their eyes while we changed the texture.

5 Results

Fig. 3 presents the curves obtained by logistic regression analysis of the averaged data of all participants. **Table 2** summarizes the data on the curves in the figure. The points of subjective equality were calculated as 50% points and the standard deviations are those of the curve fitted by logistic regression analysis.

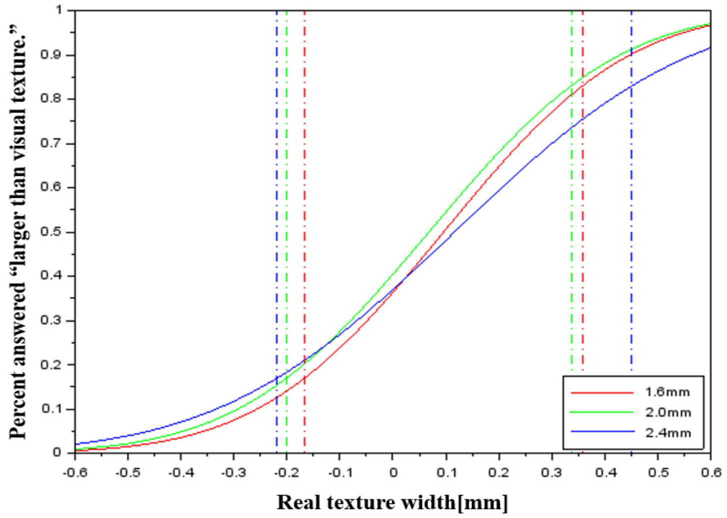

Fig. 3. Logistic regression analysis results of the experimental data. The value on the horizontal axis is the difference between the texture width of the image and the texture width of the actual texture, and the vertical axis shows the percentage of participants who answered that the texture width of the sample was larger than that of the image. The curve is drawn separately for each image condition (1.6 mm (red), 2 mm (green), and 2.4 mm (blue)). The vertical dashed lines indicate 17% and 83% of the curve corresponding to each color.

Table 2. Numerical results of the logistic regression analysis

Image (mm)	*Subjective equivalence point (mm)*	*SD (mm)*	*17% (mm)*	*83% (mm)*
1.6	1.696	0.2744	1.434	1.958
2.0	2.068	0.2811	1.800	2.336
2.4	2.516	0.3505	2.182	2.851

In the results, we observe the trend that the wider visual texture yields larger standard deviations for the tactile texture. This implies that the allowable range of consistency between visual and tactile textures is a function of the spatial frequency of the visual texture and is possibly a monotonically increasing function. In particular, when the visual texture was 2.4-mm wide, the dispersion substantially increased with respect to other conditions.

6 Conclusion

In this research, we conducted an experiment to clarify the human discrimination ability of visual and tactile textures. The results indicate that the discrimination threshold is a monotonically increasing function of visual texture width, implying that the well-known Weber's law holds true in this range. Our future work includes further investigation of one-dimensional textures of different ranges (0–1 mm and 3 mm) and combinations of these different ranges to verify the trends observed in this study. We would also like to obtain general conclusions about texture discrimination ability between visual and tactile displays to design a tactile presentation system in VR space.

Acknowledgments

This research was supported by JSPS KAKENHI Grant Number JP15H05923. We thank Kimberly Moravec, PhD, from Edanz Group (www.edanzediting.com/ac) for editing a draft of this manuscript.

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