PROCEEDINGS OF THE INTERNATIONAL DISPLAY WORKSHOPS, VOL.28, 2021

INP1-3
Invited

Differences in Texture Information Processing between Touch and Vision

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Keywords: Tactile, Haptics, Texture perception, 3D print

ABSTRACT

Humans capture the surface textures not only by vision but also by touch. Previous studies revealed detailed mechanism of texture perception in vision, while that in touch remains obscure. To see the limits of haptic texture discrimination, we 3D-printed textured surfaces based on visual images and conducted a discrimination experiment.

1 Introduction

We perceive spatial textures mainly through eyes and hands. In contrast to visual texture perception, computational mechanisms of haptic texture perception remain poorly understood. Most previous tactile texture studies used relatively simple artificial stimuli, such as dots and gratings [1-3], and the limits of haptic discrimination have been investigated mainly by changing the center frequency of the stimuli. Some studies went with common natural surfaces, such as fabric, wood, and metal to study texture perception [4, 5]. With these stimuli, it is difficult to determine which physical quantity contributes to the performance of haptic discrimination because of the complex differences between stimuli. In this study, we try to fill this gap by using high-resolution 3D printing technology, as done by a few recent tactile studies (e.g., [6-8]). Specifically, we mapped the intensity patterns in the images into the height/depth patterns of tangible surface (Fig. 1). By manipulating the image statistics of the visual image for print, we were able to manipulate the surface statistics of the printed surface. Using this powerful methodology, a variety of experimental paradigms developed in vision research that have advanced the understanding of visual texture perception can be applied to tactile research.

Fig. 1 3D-printed stimuli based on visual images

2 Methods

Our tactile stimuli were 3D-printed by taking visual images as height maps.

2.1 Preparation of visual texture images

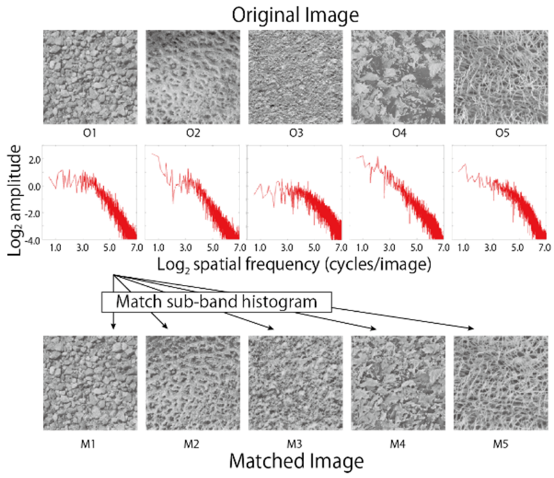

Fig. 2 Height map images for 3D-printed stimuli of original natural scene texture (O1-O5) and subband-matched texture (M1-M5). Red plots are log amplitude spectra of O1-5 images.

We chose natural scene images (i.e., irregular patterns of stones, leaves, actiniae, etc) as our target texture since these images naturally contain complex spatial patterns. Original natural images (O1-O5 in Fig. 2) were chosen from McGill Calibrated Colour Image Database. It is known that natural scene images in general tend to have the amplitude spectrum (i.e., the amplitude of each spatial frequency component in the Fourier spectrum, averaged across orientations) falling with the spatial frequency by a factor of f^{-a} [9]. Amplitude spectra of the chosen images (red lines below O1-O5 in Fig. 2) are similar to each other, although the slope of them differs for some textures. The mean and standard deviation of the image intensity were normalized and equalized across images. Each image had the resolution of 256 × 256 pixels.

Histogram matched images (M1-M5 in Fig. 2) were made by matching the sub-band histograms of original images O1-O5 to O1 image using a texture synthesis algorithm [10]. This synthesis enables us to make textures with an identical amplitude distribution, while keeping the differences of other statistics constant.

2.2 3D printing tactile textures

Tactile stimuli were created using a 3D printer (16 micrometer resolution) (Objet 260 Connex3, Stratasys, USA) with a transparent plastic-like material (VeroClear-RGD810, Objet, USA). Each visual texture images was converted to a 3D model by taking intensity values as a height map. The size of the printed object was 40 × 40 × 10-12 mm. The contrast difference between complete black and complete white in an image was transcribed to a height (thickness of stimuli; black means deep) difference of 2 mm and an average depth of 1 mm.

2.3 Procedures

Groups of ten observers participated. They had never seen the tactile stimuli nor original visual images. Three stimuli of two kinds (A, B, A/B) were set on a linear stage (ERL2, CKD, Japan) before each trial started (Fig. 3, 4). An observer sat at a table and placed the index finger of the right hand on the right edge of the stage. The stage started to move from left to right with a speed of 40 mm/s so that each stimulus swiped the finger for one second. The observer was asked to report which one X was by touching the stimuli A, B, X in order, where X was rotated version of A or B. No feedback as to their response was given to the observer. They performed experiments with eyes open to maintain their arousal level, but they could not see the tactile stimuli, the equipment, nor experimenter, which were occluded by a black curtain.

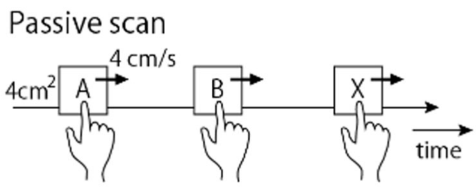

Fig. 3 Time course of the experiment.

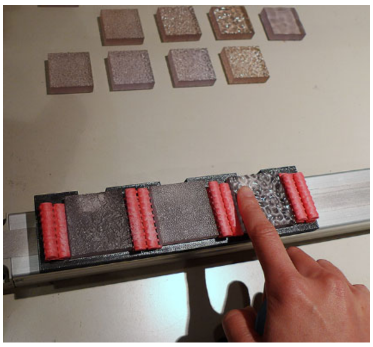

Fig. 4 Experimental setup. The linear stage moved from left to right. The start and end of the stage movement always occurred when the finger was on the cushions (pink in the figure).

3 Results and discussion

The original textures look sufficiently different and the maximum carving depth (2 mm) was well above the haptic detection threshold. However, ten observers barely discriminated some pairs of the stimuli (left confusion matrix in Fig. 5. O1, O2, O4 cannot be discriminated).

This result is counterintuitive given what we know about stimuli with simple statistical structures. Clearly, our 3D printed tactile stimuli contain millimeter-scale differences in the normal and tangential directions (horizontal and vertical), which is well above the level of behavioral threshold differences [11, 12]. Nevertheless, the observer could not discriminate some pairs.

Since the amplitude spectra of natural visual textures are similar to each other (fall by a factor of f^{-a}), we hypothesized that haptic texture discrimination may rely solely on the difference in amplitude spectra, or on the spatial-frequency/orientation subband histograms.

In an additional experiment, we directly tested this hypothesis by matching the subband histogram of each texture using a texture synthesis algorithm [10]. Note that the matched images (M1-M5 in Fig. 2) still looked different from one another, and they were similar to the original images (O1-O5) with regard to global patterning. However, haptic discrimination of these textures was found to be nearly impossible: any two of histogram-matched stimuli appear to be almost identical by touch (right matrix in Fig.5). These findings suggest that haptic texture processing may be qualitatively different from visual texture processing in that it simply relies on the amplitude spectrum.

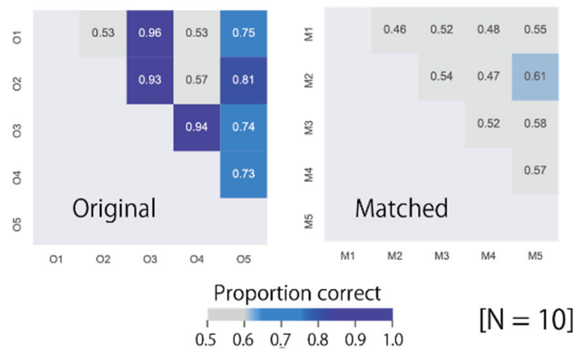

Fig. 5 Results of ABX task. The colour and the number in the cells represent averaged proportion correct. Since the task was 2-AFC, 0.5 (gray) means chance level where observers could not discriminate the paired stimuli, while 1.0 (purple) means observers could discriminate perfectly.

4 Conclusions

To see how well the haptic system can encode complex surface patterns, we conducted a haptic texture discrimination experiment by 3D printing textured surfaces based on visual images of natural scenes such as leaves and stones. The results showed that the "photographic" patterns, which are visually very different, are almost indistinguishable by haptic scan. This suggests that the human sense of touch is good at discriminating differences in simple spatial structures, such as statistics about amplitude spectra, but is relatively insensitive to more complex spatial structures such as correlations of nearby spatial-frequencies/orientations. Although further research is needed to fully understand the spatial statistics associated with the perception of touch, the direct comparison of touch and vision using 3D printing technology is a promising research strategy.

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