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A Visual and Haptic Multimodal Roughness Rendering with a Matrix of Regular Dots: Towards Digitalization of Psychological Haptic Attributes

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Abstract

It is very natural for us to interact with computers using multimodal interfaces, including haptic interface, as we do in real life. Haptics are considered a promising approach to human-computer interfaces, particularly because of their unique bi-directional nature. In this paper, we discuss physical and psychological haptic attributes, and digitalization of psychological haptic attributes in a virtual reality world. Then we present a visual and haptic multimodal haptic rendering of roughness, one of the most prominent perceptual attributes of texture, using a matrix of regular dots. With dots of radius 1 mm spaced 5 mm, 10 mm, or 15 mm apart, we find that participants perceive a surface as rougher when the distance between dots is smaller. With dots spaced 5 mm apart and of radius 0.5 mm, 1 mm, or 1.5 mm, we find that participants perceived a surface rougher when the dot radius is larger. Our findings can be used for haptic stimuli in future research and in applications, such as telemedicine.

Keywords: psychological haptic attributes, roughness, multimodal interface, virtual reality

1. Introduction

It is very natural for us to interact with computers using multimodal interfaces, just as we use multiple modalities in real life. Haptic (tactile) human-computer interaction is considered to be a promising approach to multimodal interfaces, particularly with its unique bi-directional nature. Haptics is a technology that creates a sense of touch in a multimodal media. The availability of force feedback haptics requires the formation of haptic virtual objects.

A haptic surface has its own texture attributes. These include physical attributes, such as temperature, hardness, and friction, and psychological attributes, such as roughness, smoothness, and stickiness. To render psychological haptic attributes in a virtual reality world, research needs to be done to clarify how users perceive psychological haptic attributes.

Roughness is regarded as one of texture's most prominent haptic attributes [5]. Although the precise physical determinants of roughness are not entirely clear [7], a texture composed of a primitive pattern that is repeated, which is not based exactly on reality, is sufficient to convey the sensation of texture and roughness [15]. Many real or virtual haptic roughness renderings have been proposed, including virtual sandpaper [4], grooved surfaces [7] [18], rock simulation [1] [20], and vibration-based roughness [8] [6].

A one-dimensional sinusoidal wave is often used in multimodal human-computer interfaces as a haptic roughness stimulus for interaction research of visual and haptic information, or auditory and haptic information [19] [17] [12] [13] [14] [9] [10] [11] [3] [2]. It is based on a model where a function (regular sinusoidal wave) is used to approximate to a textured surface [15]. In the structured approach, the spatial structure of texture is emphasized. The sinusoidal wave is described by $z = A\sin(2\pi x(t)/L) + A$ (Figure 1), where $(x(t), y(t), z(t))$ is the

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coordinate of the stylus at time t, A and L are the amplitude and the spatial wavelength, respectively, and n_w is the normal vector of the underlying surface.

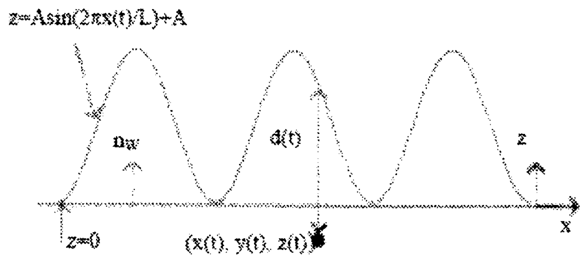

Figure 1. An illustration of the textured surface and its associated variables

However, the sinusoidal wave-based haptic roughness rendering is only a one-dimensional haptic textured surface: users can only haptically feel the stimuli from left to right and right to left. We think it is more natural to feel a two-dimensional textured surface with haptic and visual stimuli, as we do in real life. So we suggested a visual and haptic multimodal two-dimensional roughness rendering, with a matrix of regular dots for the haptic stimulus.

2. A Visual and Haptic Multimodal Roughness Rendering with Matrix of Regular Dots

The hardware setup for our rendering is shown in Figure 2. It is composed of a PHANToM Premium EW force feedback device from SenseAble Technologies, a dual-Pentium III computer operating on a Windows 2000 Professional platform, and a set of headphones. The PHANToM Premium EW has a workspace of 19.5 cm x 27.0 cm x 37.5 cm. The Reachin 3.0 API [16] for PHANToM (Reachin Technologies AB) was used to program the haptic interaction experimental environment. The programming languages used for creating the three-dimensional experimental environment were C++ (Borland C++ Builder 5.0), VRML (The Virtual Reality Modeling Language) and Python. Through PHANToM, participants in the study used a stylus to manipulate a virtual haptic textured surface under a half-mirror that reflected the monitor.

Figure 2. The hardware setup for the virtual roughness rendering

Because there is still debate over the actual parameters that determine roughness, participants' perception of virtual roughness is an increasingly important issue in virtual haptic interaction. To examine how users perceive haptic roughness rendered with our matrix of regular dots (Figure 3), we conducted two cognitive experiments. We hypothesized that a relationship exists between dot distance, dot radius and perceived roughness. We did not assume, however, that this relationship is necessarily a simple monotonic one. In our first experiment, we invested the relationship between perceived roughness and dot distance under an experiment environment with dots of radius 1 mm with 5mm, 10mm, or 15mm between the dots. In our second experiment, we invested the relationship between perceived roughness and dot radius under an experiment environment with dots of radius 0.5mm, 1mm, or 1.5mm, with 5 mm between the dots. Ura pair-wised comparison (a modification of Scheffe pair-wised comparison) was used for analysis. One merit of the Ura method is that it works with fewer participants (5 in our experiments). ANOVA showed statistical significance in both experiments at a significance level of 0.01 (F=292.0000 in the first experiment and F=1862.0000 in the second experiment). Participants perceived a surface as rougher when the distance between the dots was smaller (first experiment, Figure 4, Yardstick(0.05) = 0.280688), and participants perceived a surface rougher when the dot radius was larger (second experiment, Figure 5, Yardstick(0.05) = 0.150034).

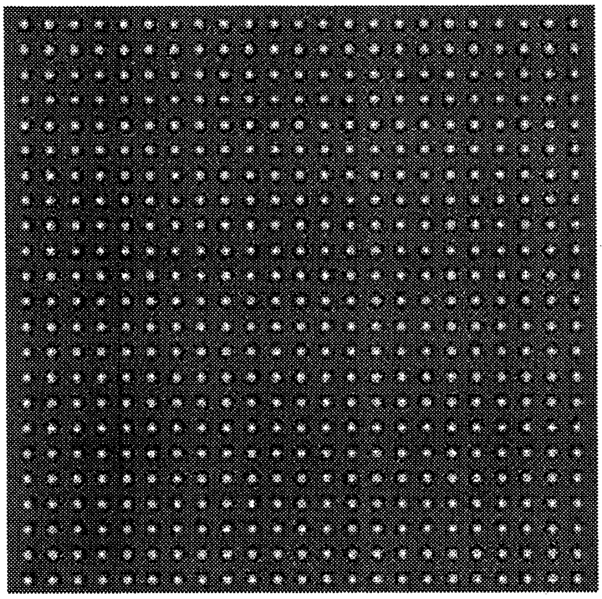

Figure 3. Sample rendering of a matrix of regular dots

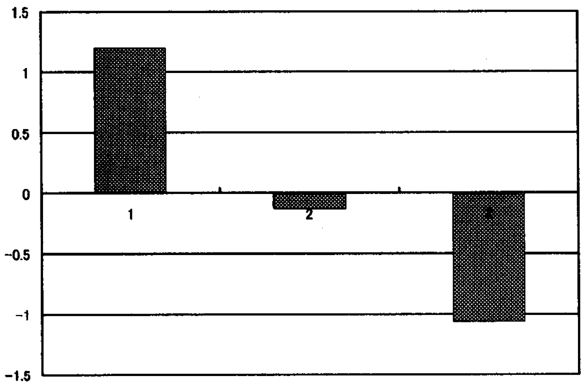

Figure 4. Roughness value (vertical axis) for distance 5 mm (1), 10 mm (2) and 15 mm (3)

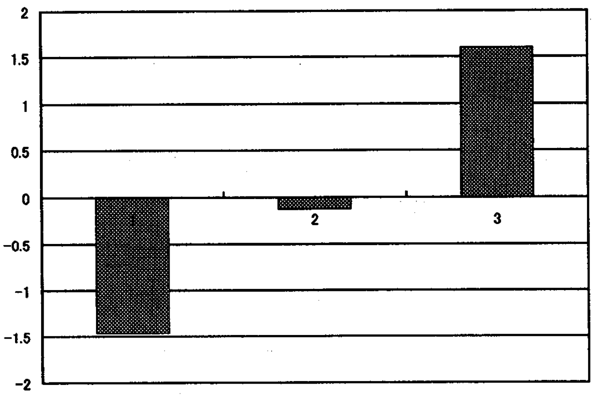

Figure 5. Roughness value (vertical axis) for radius 0.5 mm (1), 1 mm (2) and 1.5 mm (3)

3. Discussion and Future Work

In this paper, we have discussed physical and psychological haptic attributes and analyzed variations in roughness rendering. We created a multimodal visual and haptic roughness rendering and examined relationship between perceived roughness and dot distance and radius. We hope that our findings can be used for haptic stimuli in future research, as well as applications, such as telemedicine.

An important area for future research is to examine how visual and haptic stimuli interact in multimodal interfaces.

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