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Lightness Influence on Virtual Haptic Roughness Perception

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Abstract

It is very natural for us to interact with computers using multimodal interfaces, as we do in real life. Haptic (tactile) human-computer interaction (HCI) is considered to be a promising approach among them with its unique bi-directional nature. To investigate lightness influence on virtual haptic roughness perception of textured surfaces, the authors conducted some experiments, via a PHANToM force feedback device. It is better to use a high level of lightness when perceiving haptic textured surfaces because we have found that (1) the percentage of correct answers of virtual haptic roughness judgment was higher when the haptic textured surfaces had a higher lightness. Furthermore, a left-right haptic textured surfaces layout is recommended over an up-down layout when using PHANToM because we found that (2) participants tended to perceive the lower haptic textured surface as rougher when judging the roughness of two textured surfaces with an up-down layout interface. We also found that (3) different roughness was perceived for textured surfaces with sinusoidal grating numbers of 25, 28, 32 and 35 per 300 mm.

Keywords

Multimodal Interface, HCI, Lightness, Haptic Perception, Virtual Roughness, Textured Surface

1. Introduction

It is very natural for us to interact with computers using multimodal interfaces, as we do in real life: we see with our eyes, hear with our ears, touch with our hands, taste with our tongues, and smell with our noses. Haptic (tactile) human-computer interaction (HCI) is considered to be a promising approach with its unique bi-directional nature compared with mainstream visual and auditory interfaces [1][2][4].

However, when we introduce haptic interface into current computer interfaces, researches should be done to make it clear how cross-modal interfaces interact, or how factors in different interfaces interact. Do they contribute to, or on the contrary, impair the resultant effectiveness?

As an important visual factor of visual information, color's influence has been studied in many researches [10][11][12][13]. Luo and Imamiya [13] have found that color does have an influence on haptic perception, and that Yellow (1, 1, 0) (RGB (Red, Green, Blue) value) has the lowest error rate among Red (1, 0, 0), Orange (1, 0.65, 0), Yellow (1, 1, 0), Green (0, 1, 0), Blue (0, 0, 1), Violet (0.93, 0.51, 0.93) and NoColor (0.3, 0.3 0.31). It is very easy to ask whether lightness influences haptic perception as well, since high lightness looks brighter, and seems easier to perceive, or what lightness value should be set when we perceive haptic textured surfaces in order to have a high percentage of correct answers. To answer these kinds of questions, we conducted some experiments to verify the lightness influence on haptic perception of virtual roughness, via a PHANToM force feedback device.

2. General Methods

(1) Apparatus

The hardware setup in our experiment, as shown in Fig. 1, is composed of a PHANToM (Model: Premium EW) force feedback device from SensAble Technologies, a dual Pentium III PC operating on a Windows 2000 Professional platform, and a set of headphones. This model of PHANToM has a workspace of 19.5cm × 27.0cm × 37.5cm. The Reachin 3.0 API [8] for PHANToM, from Reachin Technologies AB, was used to program the haptic interaction experimental environment. The programming languages used for creating the 3D experimental environment are C++ (Borland C++ Builder 5.0), VRML (The Virtual Reality Modeling Language) and Python. Participants in our study can manipulate a virtual haptic textured surface under a half-mirror that reflected the monitor via PHANToM by holding a stylus.

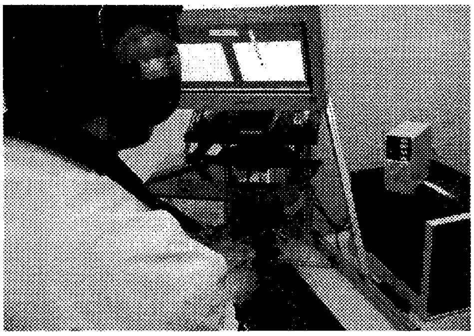

Fig. 1. The Hardware Setup for the Experiment

(2) Lightness Stimuli

In a HLS (hue, lightness, saturation) color system, a high level of lightness will make a certain color with the same hue value look brighter. As mentioned above, Luo and Imamiya found that Yellow (RGB value (1, 1, 0), HLS value (60, 0.5, 1) [3]) had the lowest error rate [13]. As an example, yellow (hue 60, saturation 1) with different lightness was selected in our experiment to examine the lightness influence on percentage of correct answers of haptic perception.

To make it easy to detect the lightness influence, different values 0.2 (L0.2), 0.5 (L0.5), and 0.8 (L0.8), with a relatively large difference, were chosen in our experiment. Values 0, 0.1, and 0.9, 1 were avoided because they make the yellow interface look almost completely black or white and do not look yellow any more. Only the RGB color system is supported by

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PHANToM, so HLS values (60, 0.2, 1), (60, 0.5, 1), and (60, 0.8, 1) were changed into RGB values (0.4, 0.4, 0), (1, 1, 0), and (1, 1, 0.6) [3] respectively in our experiment.

(3) Virtual Haptic Roughness Stimuli

The haptic stimulus used in our experiment is a one-dimensional sinusoidal grating superimposed on an underlying box. The sinusoidal grating is described by $z=A\sin(2\pi x(t)/L)+A$ (Fig. 2), where $(x(t), y(t), z(t))$ is the 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 surface of the underlying box.

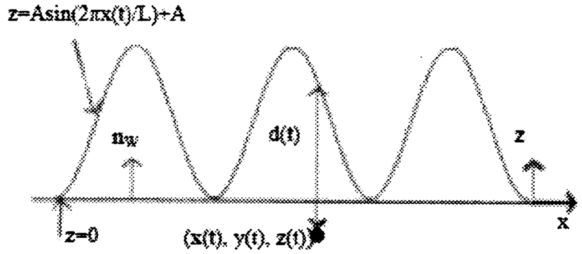

Fig. 2. An Illustration of the Textured Surface and Its Associated Variables

We use the first method $F_1(t)$ from Choi and Tan for texture rendering [9]. The force F(t) generated can be calculated as:

$$F(t)=Kd(t)n_w,$$

$$d(t)=\begin{cases} 0, & z(t)<0 \\ z(t)-A\sin(2\pi x(t)/L)-A, & z(t)\geq 0 \end{cases}$$

where K is the stiffness of the surface, and d(t) is the penetration depth of the stylus into the textured surface at time t.

McGee et al. conducted some experiments [5][6][7] on perceiving virtual haptic roughness, and they found that the frequency of the texture (sinusoidal gratings on a box with a length of 300mm) had an effect on perception of roughness (the proportion of times that texture was rated as rougher than each of the others) [6]. Further result can also be concluded from their experiments [6] that frequency range with grating numbers from 25 to 35 on a 300 mm-long box is the most monotonic scope where perceived roughness rises with the rising of grating numbers. So in our experiment, 25 (F25, 25 sinusoidal gratings per 300 mm), 28 (F28), 32 (F32) and 35 (F35) were selected as haptic roughness stimuli. Grating number difference of different roughness stimuli in McGee's study [6] was 5, however ours was 3 or 4 because we thought that in this state the roughness difference was harder to perceive and lightness influence easier to find. In our experiment, A was set up as 0.5 mm as in McGee's study [6].

(4) Participants

Twenty participants, 14 males and 6 females, aged 21 to 56, all full-time students, took part in our experiment. All of these participants had normal color vision.

(5) Experiment Procedure

All our haptic textured surfaces had a certain frequency (F25, F28, F32, or F35) and a certain lightness (L0.2, L0.5, or L0.8). There were totally 12 (4*3) kinds of textures used in our experiment. Participants were asked to judge which one was perceived as rougher, or whether they were the same from two textures with a left-right layout interface (Fig. 3). If we do not consider the order of the two textured surfaces, there were 78 (${}_2C_{12}$+12) pairs for participants to judge, and usually 20 minutes were needed including some training time before the experiment began. The sequence of the 78 pairs of textured surfaces was randomly decided before the experiment. Participants interacted with PHANToM by holding a stylus to scrape on virtual haptic textured surfaces with headphones to avoid the sound hint from PHANToM.

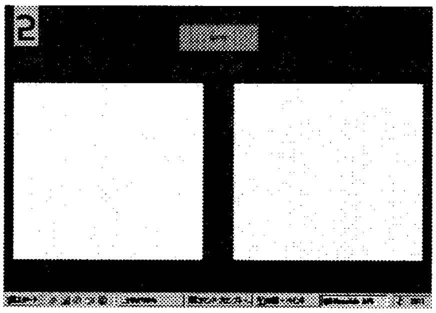

Fig. 3. Experiment Interface

3. Results and Conclusions

We scored the judgment as correct when the textured surface with more sinusoidal gratings was judged to be rougher, or two textured surfaces of a pair with the same gratings were judged to be the same roughness. Fig. 4 is the percentage of correct answers for all the participants.

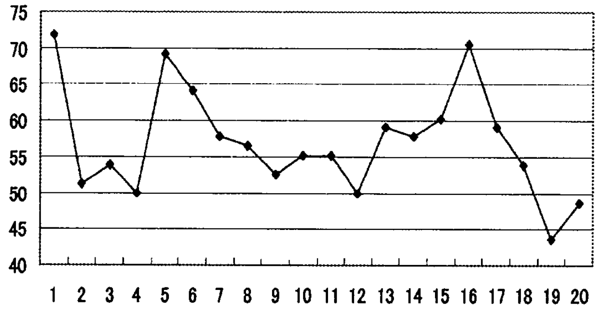

Fig. 4. Percentage of Correct Answers (Vertical Axis) for Participant (Horizontal Axis)

We drew the following three conclusions from our experiments:

(1) The percentage of correct answers of roughness judgment was higher when the haptic textured surface had a higher lightness.

Fig. 5 is the percentage of correct answers for L0.2 (when both of the textured surfaces of a pair had a lightness value 0.2), L0.5 (when both of the textured surfaces of a pair had a lightness value 0.5), and L0.8 (when both of the textured surfaces of a pair had a lightness value 0.8).

The mean percentages of correct answers for L0.2, L0.5, and L0.8 are 45.3%, 54.7%, and 56.8%, respectively. The roughness judgment percentage of correct answers is higher when the textured surface is with a higher lightness for L0.2, L0.5, and L0.8. The difference in mean percentage of correct answers between L0.2 and L0.8 showed significance (t=|-

$2.80|>t_{0.05}(19)=2.10$) (Fig. 6). However, an analysis of variance (ANOVA) did not reveal significance ($F=2.92<F_{0.05}(2, 57)=3.17$) and there was no significance in the differences in mean percentages of correct answers between L0.2 and L0.5 ($t=|-1.61|< t_{0.05}(19)=2.10$), and between L0.5 and L0.8 ($t=|-0.47|< t_{0.05}(19)=2.10$).

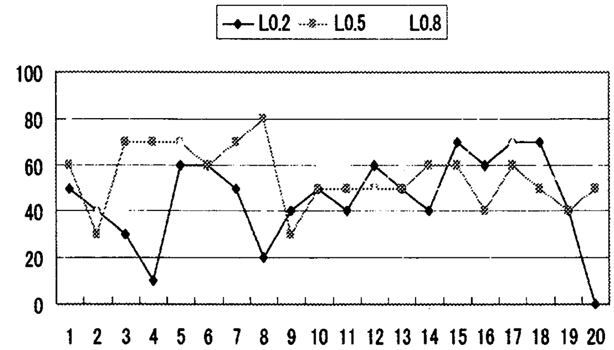

Fig. 5. Percentage of Correct Answers (Vertical Axis) for L0.2, L05, and L0.8 (Horizontal Axis: Participant)

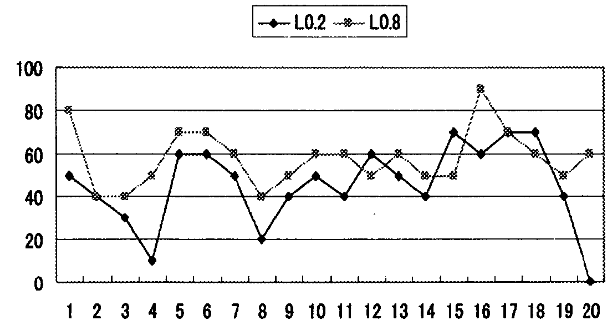

Fig. 6. Percentage of Correct Answers (Vertical Axis) for L0.2 and L0.8 (Horizontal Axis: Participant)

(2) Participants tended to perceive the lower haptic textured surface as rougher when judging the roughness of two textured surfaces with an up-down layout interface.

Before we began our experiment, other 15 participants had participated in the same experiment with an up-down layout interface of textured surfaces (Fig. 7). We found that participants tended to select the lower textured surface as rougher, even when that was not always the case. Fig. 8 shows that most of the participants perceived the lower textured surface as rougher more frequently than the upper one ($t=|-5.75|>t_{0.01}(14)=3.01$). By contrast, there is no significant trend favoring the left or right panels in the left-right layout interface used in our experiment ($t=1.86<t_{0.05}(19)=2.10$) (Fig. 9).

(3) Different roughness was perceived for textured surfaces with sinusoidal grating numbers of 25, 28, 32, and 35 per 300 mm.

We calculated a roughness score for F25, F28, F32, and F35 by adding 1 point to them if they were perceived rougher in a pair and 0.5 points to each of a pair if they were perceived as the same roughness. The roughness score tells us whether participants can really distinguish among them or not. Fig. 10 and Fig. 11 show that textured surfaces with sinusoidal grating numbers of 25, 28, 32, and 35 per 300 mm were perceived as having different roughness ($F=271.75>F_{0.01}(3, 76)=4.07$, F25 vs F28: $t=|-11.40|>t_{0.01}(19)= 2.88$, F28 vs F32: $t=|-8.18|>t_{0.01}(19)=2.88$, F32 vs F35: $t=|-7.15|> t_{0.01}(19)=2.88$).

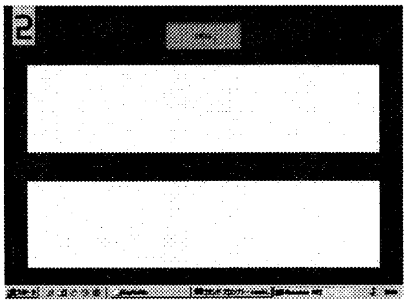

Fig. 7. An Up-Down Layout Interface

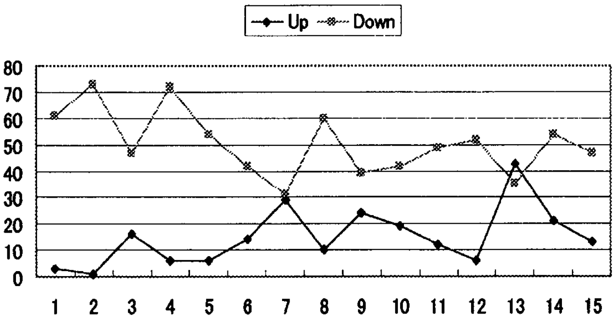

Fig. 8. Selected Times (Vertical Axis) with a Up-Down Layout Interface for Participants (Horizontal Axis)

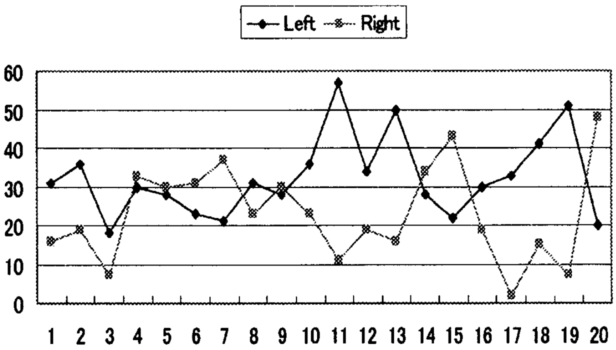

Fig. 9. Selected Times (Vertical Axis) with a Left-Right Layout Interface for Participants (Horizontal Axis)

4. Discussion and Future Work

In our experiments, to examine how lightness influences virtual haptic roughness perception of textured surfaces, one value for hue (60) and three for lightness (0.2, 0.5, and 0.8) were used. It is better to use a high level of lightness when perceiving haptic textured surfaces because we found that (1) the percentage of correct answers of roughness judgment was higher when the haptic textured surface had a higher lightness. But why did it happen? Is it just because a textured surface under a high level of lightness looks brighter and seems easier to be perceive? And, what if more lightness values or more hue values are used? The complete relationship between the percentage of correct answers of haptic perception and the lightness is still unknown and needs further research.

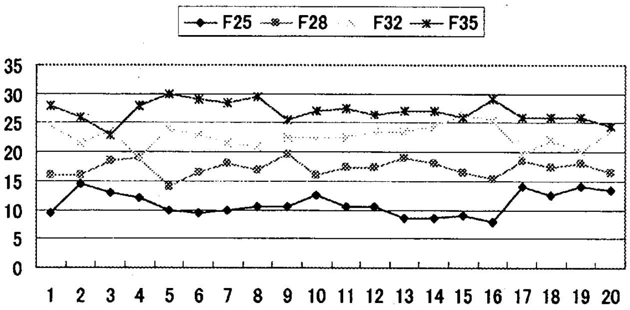

Fig. 10. Roughness Score (Vertical Axis) for Participants (Horizontal Axis)

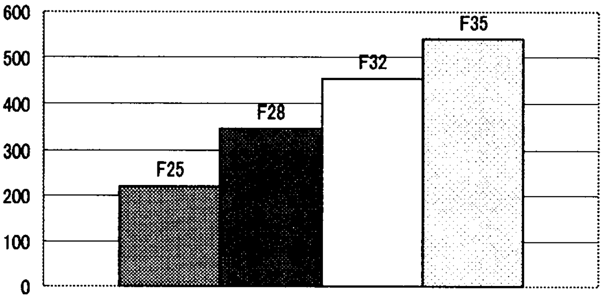

Fig. 11. Total Roughness Score (Vertical Axis) for F25, F28, F32, and F35

Furthermore, a left-right haptic textured surfaces layout is recommended over an up-down layout when using PHANToM because we found that (2) participants tended to perceive the lower haptic textured surface as rougher when judging the roughness of two textured surfaces with an up-down layout interface. This might be a mechanical problem in PHANToM, because participants scraped on different textured surfaces with a different stylus angle. The problem is how to distinguish it. When we used a left-right layout interface in our experiment, there was no significance in the mean selected times difference any more. However, it should still be noticed that some participants (for example, participant 11, participant 13, and participant 19) tended to perceive the left textured surfaces as rougher, while others (for example, participant 15, and participant 20) tended to perceive the right ones as rougher (Fig. 9). In fact, the order of the two textured surfaces in each pair was randomly decided before the experiment began, so there should be no significant difference between the two positions.

As for conclusion (3), different roughness was perceived for textured surfaces with sinusoidal grating numbers of 25, 28, 32, and 35 per 300 mm, future work may be done to find to what extent human beings will perceive textured surfaces with different sinusoidal grating numbers as different roughness.

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