Pseudo-Haptic Feedback Augmented with Visual and Tactile Vibrations

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ABSTRACT

Haptic sensations can be induced without requiring haptic devices through pseudo-haptic feedback by the influence of another sensory modality, such as vision. In this paper, we propose two novel approaches that combine pseudo-haptic feedback with visual and tactile vibrations in order to augment the overall haptic sensation. We would like to investigate the integration of pseudo-haptic feedback with vibratory feedback. The first technique enhances pseudo-haptic textures with a stripe pattern that provides a vibrotactile stimulus. The second technique modulates the perceived material stiffness of a virtual object using vibratory models for visual and tactile feedback, introducing novel pseudo-haptic effect based on visual vibrations.

KEYWORDS: Pseudo-haptic, vibrations, virtual environment.
INDEX TERMS: H.5.2 [Information Interfaces and Presentation]: User Interfaces—Haptic I/O, Input devices and strategies, User-centered design

1 INTRODUCTION

Pseudo-haptic feedback is an illusion that uses multi-sensory contradiction, where visual cues create haptic sensations without physical haptic stimulus. Various haptic sensations can be generated with pseudo-haptic feedback [4], such as the stiffness of a virtual spring, the texture of an image or the mass of a virtual object. However, although vibro-tactile feedback is an important factor of haptic perception, as far as authors know, there is no work referring to its integration with pseudo-haptic feedback. We believe the addition of vibro-tactile feedback could strengthen the perception of pseudo-haptic effects, due to the combination of cues from two different modalities (visual and tactile) instead of visual cues alone.

In this paper, we propose two novel approaches that combine pseudo-haptic feedback with visual and tactile vibrations in order to augment the overall haptic sensation. The first technique enhances pseudo-haptic textures with stripe pattern that provides a vibro-tactile stimulus (Figure 1a). The second one modulates the perceived material property of a virtual object using vibratory models for visual and tactile feedback (Figure 1b).

2 RELATED WORK

2.1 Exploring material relief

When exploring the shape of an object with our hand, we experience geometrical cues (e.g., height changes) and force cues (e.g., lateral reactive forces). Robles-De-La-Torre et al. demonstrated that lateral forces have dominance over height changes [6]. Previous work has shown that these lateral force cues could be induced through pseudo-haptic feedback by the sole manipulation of the speed of a mouse cursor used for the exploration (the Speed technique) [3]. The Speed technique generates lateral pseudo-force which results in the perception of the geometric shape (e.g., bumps and holes).

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2.2 Exploring material stiffness

When tapping the surface of a hard object, we perceive kinesthetic cues as well as cutaneous mechanical deformations and vibrations resulting from the contact with the material. Presenting both cues through a haptic device requires very sophisticated devices. Previous work has shown how to generate the kinesthetic cues with pseudo-haptic feedback [4]. Other studies have used reality-based model to combine kinesthetic and vibro-tactile feedback fitted to the bandwidth of the haptic device [5]. The vibrotactile feedback was a decaying sinusoid that could simulate different materials when changing three parameters such as amplitude rate, decay rate and frequency.

3 OUR PROPOSAL

In this section we introduce both of our approaches for augmenting pseudo-haptic feedback, schematized in Figure 1. The first technique simulates a striped pattern with vibro-tactile feedback on top of the Speed technique to provide additional cues of speed modulation and enhance the Speed pseudo-haptic effect (Figure 1a). The second technique simulates the material stiffness of virtual object using vibratory models for tactile and visual feedback, generating a novel pseudo-haptic effect (Figure 1b).

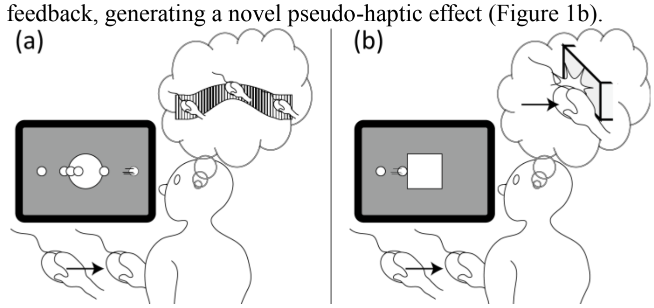

Figure 1. Illustration of our two approaches: (a) Enhancing the pseudo-haptic textures. (b) Modulating the material stiffness of a virtual object.

3.1 Vibro-tactile striped pattern for simulating material relief

The concept is illustrated in Figure 2. A virtual texture (bump or hole) is enhanced with a striped pattern that generates a vibrotactile feedback of constant wavelength λ, following Equation 1.

$$y(t) = A\sin(2\pi \frac{\int_0^t v(\tau)d\tau}{\lambda} + \varphi) \qquad (1)$$

where A stands for the amplitude and φ stands for the phase of sinusoid. The frequency of the vibro-tactile signal depends on v – the velocity of the mouse cursor. As in [3], the Speed technique modulates the speed of the mouse cursor according to the height map of the texture. Hence, when there is a positive slope (going up), the speed of the cursor decreases, which is conveyed to the user through visual cues (the cursor moves slower) and vibro-tactile cues (the frequency decreases). The added tactile modality is expected to strengthen the perception of pseudo-haptic forces, and hence the perception of the slope.

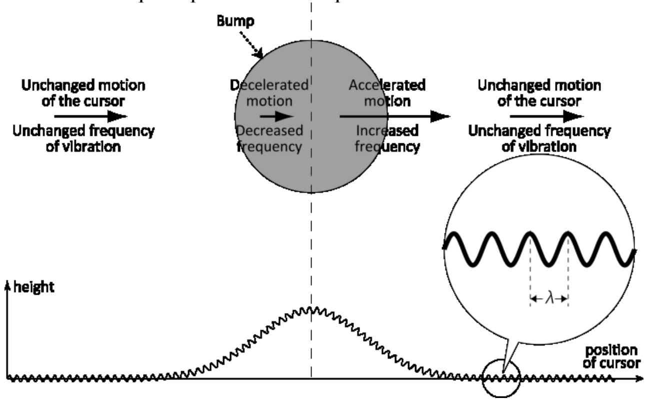

Figure 2. Modification of the cursor speed [3] and the vibratory frequency when passing over a bump

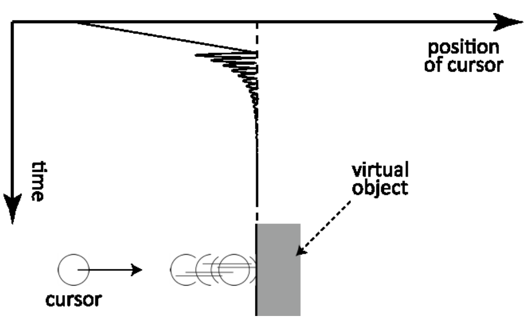

Figure 3. Novel pseudo-haptic effect based on visual vibration

3.2 Visual and tactile vibrations for simulating material stiffness

In order to simulate the stiffness of a material when tapping on it, we combine an existing reality-based vibro-tactile model of the impact with a novel pseudo-haptic effect called visual vibrations. Both models are applied to the cursor at the moment of impact, outputting vibrotactile and visual cues to the user.

3.2.1 Tactile vibrations

In order to generate vibro-tactile feedback, we employed Okamura's decaying sinusoid model [5]:

$$Q(t) = A(v)e^{-Bt}\sin(2\pi ft) \qquad (2)$$

The acceleration of the vibration Q is determined by the amplitude A as a function of the cursor impact velocity v, the decay rate of sinusoid B, and the sinusoid frequency f. A, B and f depend on the type of a material, and numerical values can be found in [5] for materials such as rubber, wood and aluminum.

3.2.2 Visual vibrations

In order to provide pseudo-haptic cues of the impact, the impact vibrations are presented visually to user by applying the signal based on Equation 2 to the mouse cursor. However, since the amplitude of the oscillations is small as in a real-life impact, the resulting cursor displacement might not be perceived by the user. In order to increase the oscillation amplitude when presented through a force feedback device, Gleeson et al. [1] proposed a cartoon-inspired oscillation model of the impact, which is not realistic but seemed to enhance the interaction experience. We apply this model in a pseudo-haptic context to make the cursor visually oscillate. The concept is illustrated in Figure 3. When contacting the surface of a virtual object, the mouse cursor bounces and oscillates, and then the oscillation decays.

4 CURRENT IMPLEMENTATION

These techniques were implemented on a system consisting of a PC, a PC monitor and a tactile display. The tactile display was developed by Hashimoto et al. [2] and includes a PC mouse and an audio-speaker as a tactile vibrator (Figure 4a). The PC receives the mouse event, and sends a waveform signal to the audio-speaker and the visual output to the monitor. A green cursor is controlled through the tactile display. The virtual scene consists of a gray background and a white circle representing either a bump or a hole (Figure 4b) or a white rectangle representing a solid wall on which the user can tap with the cursor.

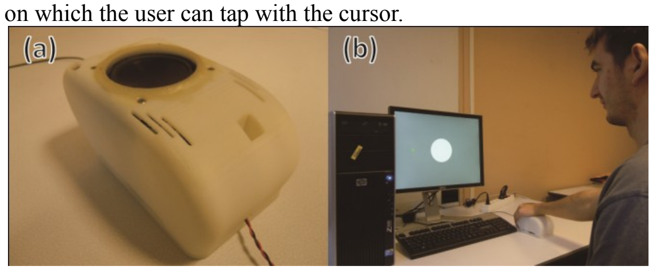

Figure 4. Current implementation: (a) The tactile display [2] and (b) the scene used in first approach.

5 CONCLUSION AND FUTURE WORKS

In this paper, we investigated the use of vibrations for pseudo-haptic feedback effect and presented two novel approaches that augment pseudo-haptic feedback for the exploration of a virtual object. The first technique enhances pseudo-haptic textures with a striped pattern that provides a vibrotactile stimulus, in order to strengthen the Speed technique. The second one introduces a novel pseudo-haptic effect that simulates the material of a virtual object using vibratory models for tactile and visual feedback.

Future work will focus on the evaluation of these techniques with perceptual experiments to assess the effectiveness of the proposed pseudo-haptic effects.

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