Visual Vibrations to Simulate Taps on Different Materials

Taku Hachisu[1], Gabriel Cirio[2], Maud Marchal[2],
Anatole Lécuyer[2], Hiroyuki Kajimoto[1]

[1]The University of Electro-Communications
1-5-1 Chofugaoka, Chofu, Tokyo 182-8585, Japan
[2]INRIA Rennes
Campus de Beaulieu, F-35042 Rennes Cedex, France
{hachisu, kajimoto}@kaji-lab.jp
{gabriel.cirio, maud.marchal, anatole.lecuyer}@inria.fr

Abstract. This paper presents a haptic visualization technique for conveying material type through visual feedback, expressed as visible decaying sinusoidal vibration resulting from tapping an object. The technique employs cartoon-inspired visual effects and modulates the scale of the vibration to comply with visual perception. The results of a user study show that participants could successfully perceive three types of material (rubber, wood, and aluminum) using our novel visual effect.

Keywords: cursor, visual simulation of haptics, vibration, material.

1   Introduction

Using haptic visualization (HV) techniques are more practical to convey haptic events in virtual environments than using complex mechanical devices in terms of cost. However, HV are limited in terms of frequency bandwidth because of limitations imposed by the visual display and perception. Whereas vibration around 500Hz can be haptically perceived [1], the maximum frequency perceivable for vision is less than 50Hz [2].

In this paper, we present a novel HV technique to provide higher frequency of haptic cues. We focus on the vibration resulting from tapping an object, which is an initial haptic cue for grasping the properties of the object [3, 4]. We describe our HV method, which employs a decaying sinusoid model and a cartoonified rendering method that modulates the model to fit the display and visual perception. The results of a user study show that participants could successfully three types of materials (rubber, wood, and aluminum) assigned to virtual objects.

2   Related Work

Pseudo-haptics is a type of visuo-haptic illusion that is especially accompanied by motion [5]. For instance, when moving a PC mouse on a smooth surface, if the velocity of
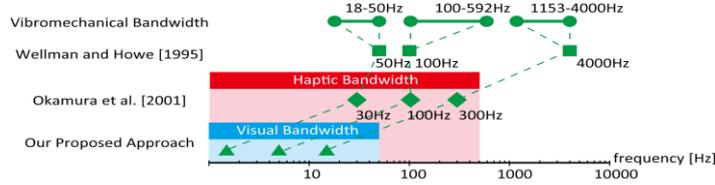
Fig. 1. Frequency of vibration resulting from tapping (i.e., vibromechanical bandwidth), frequency of presenting the vibration, and haptic and visual bandwidths for vibration.

the cursor on the monitor slows down in comparison with that of the mouse, the user feels as if the mouse has become heavier. Interestingly, pseudo-haptics induce actual kinesthetic sensations [6] while other HVs do not always induce haptic sensations. Besides pseudo-haptics, various HV techniques have been developed by modulating the trajectory [7], movement and size [8] of a visual representations provides haptic cues.

With the vibrations resulting from contact, we can both identify the material and estimate the stiffness of the object [3, 4]. However, to the best of the authors' knowledge, no attempt has been made to simulate the vibrations in a HV context. As described in the previous section, it is difficult to visually simulate the vibrations because of the limitations imposed by the visual display and perception.

On the other hand, representing the vibrations with a conventional force feedback display was also challenging since it requires high frequency (vibration) as well as low frequency (force). To cope with this difficulty, Wellman et al. [3] mounted a vibrator on the haptic display. Then, Okamura et al. [4] provided the both by modifying the vibratory parameters to fit the bandwidth of the haptic display. The both studies simulated the vibrations resulting from tapping, by employing the following decaying sinusoid:

$$Q(t) = A(v)\exp(-Bt)\sin(2\pi ft) \tag{1}$$

Vibration Q is determined by the amplitude A as a function of the impact velocity v, the decay rate of sinusoid B, and the frequency f. These parameters are dependent on the type of material. **Fig. 1** illustrates the frequency of vibromechanical bandwidth, represented vibrations ([3, 4] and our approach), and the haptic and visual bandwidths.

Okamura et al. [3] demonstrated that it was possible to simulate the material with a vibration model that was designed based on haptic perception and display, which is different from the actual physical phenomenon. Hashimoto et al. [9] implemented a similar concept for a haptically achieved "slow-motion" effect. While these studies focus on scaling along the temporal axis, attempts have also been made to exaggerate haptic reactions, in a process called cartoon-inspired haptic rendering [10]. These authors modulated the vibrations of the impact, which, although not same as reality, appeared to enhance the interaction experience.

3   Visually Simulating Material Vibration

This section describes an implementation of visual vibrations of collision on a two-dimensional monitor. Since the frequency, duration and amplitude of the real vibrations
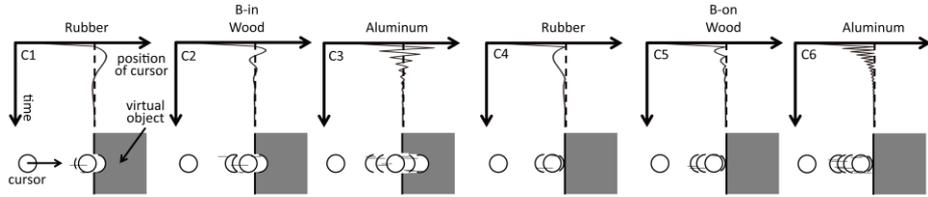
Fig. 2. Illustration of the visual vibration to simulate tapping on different materials (rubber, wood, and aluminum) in two different conditions: B-in (left) and B-On condition (right).

cannot be visually perceived by users or be displayed on the monitor, we present the following HV method inspired by [3, 9, 10]. The frequency range problem is resolved by scaling down f and B to a visually perceptible range. The amplitude range problem is resolved by amplifying the amplitude.

First, the algorithm defines the position of a virtual object and then draws it on the monitor. The cursor is also drawn according to the user's manipulation using the mouse. When the edge of the cursor touches the surface of the object, the algorithm detects a collision. Upon detection of the collision, the algorithm obtains the velocity of the cursor. Next, the algorithm begins vibrating the cursor according to Eq. 1. We implemented two vibrating modes; 1) B-in mode set the initial collision position as the center of vibration, as shown in the left panels of **Fig. 2**. Thus, the cursor penetrates the object; 2) B-on mode vibrates the cursor but does not penetrate the surface of the virtual object, as shown in the right panels of **Fig. 2**. Thus, the frequency of the cursor appears to be doubled. We expect that the two modes will enable users to understand the elasticity of the contacting object: a hard object is hard to deform, while a soft object easily deforms so that the position of the cursor moves forward. In summary, our algorithm expresses the material properties using four parameters while there are other possibilities, such as vibrating the object.

We selected three sets of material parameters corresponding to rubber, wood, and aluminum, taken from [4]. We modified the parameters to enable all the participants to see the vibration, as listed in **Table 1**. These parameters were determined by haptic experts (the authors) through a preliminary test that, in practice, led to the linear down-scaling of [4]. Concerning A and B, we knew that the users could notice a visual difference between the three materials. Concerning f, we set the highest frequency as 15 Hz, which is the fastest vibration that the LCD can support and that the users were able to perceive stably. For each material parameter, we prepared two vibrating conditions (B-in and B-on). Thus, we had six conditions.

4 Experiment

4.1 Setup and Procedure

The goal of the experiment was to assess whether participants could interpret our method as intended. We used a 20-inch liquid crystal display (LCD) with resolution
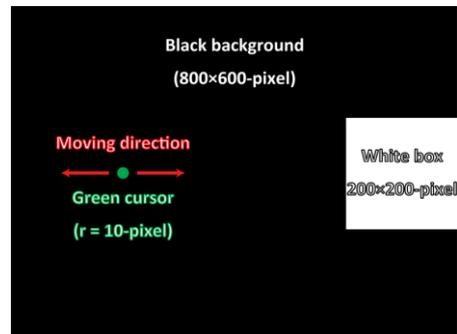
Fig. 3. Screen shown to participants during the experiment.

800×600, refresh rate 60 Hz, and a three-button infrared mouse. The green mouse cursor and the white virtual object was displayed as shown in **Fig. 3**. The cursor could only be moved horizontally by sliding the mouse horizontally. We used the six sets of parameters (**Table 1**). Twelve participants (10 males and 2 females, 22-29 years) were recruited. Participants were divided into two groups (G1 and G2).

The experiment comprised two successive tests (material identification and realism rating). Because participants were given only three alternatives in the identification test, it is possible that they could have guessed the correct answer without actually feeling the realism. Thus, the objective of the realism rating test was to quantitatively evaluate the realism of the vibratory parameters. After the identification test, the same participants conducted the realism rating test.

In the identification test, participants sat in front of the LCD on the table with their dominant hand on the mouse. Before each trial, participants were asked to set the mouse on the start line marked on the table. The cursor was placed 400 pixels away from the white box. To begin a trial, participants pressed the space bar on the keyboard. During the trials, participants were asked to tap the box with the cursor, and identify the material. Participants were allowed to tap the box as many as they wanted within five seconds for each trial. After each trial, the names of the three materials (rubber, wood, aluminum) appeared on the screen to remind participants of the options, while the cursor and box disappeared. The participants were then asked to use the keyboard to select the material of the box. G1 first performed the trials in the B-in condition, and then in the B-on condition. Before the trials, participants first performed six training trials. They then carried out 24 trials, followed by the same procedure in the B-on condition. Thus, each participant performed a total of 60 trials. G2 performed the trials in reverse order. For each trial, the material of the box was randomly set.

In the realism rating test. The six condition numbers and evaluation scores were displayed at the top of the screen, and the current vibratory condition was marked. Participants were asked to imagine that the box was made of rubber and to tap the box with the cursor. They were then asked to rate the realism of the six conditions on a seven-grade scale (1: definitely not rubber, 7: really made of rubber). During the evaluation, participants were allowed to switch to the other conditions, thereby allowing them to evaluate one condition against another. There was no time limit and they could tap the box as many as they wanted. After evaluating all six conditions for rubber, participants

were asked to imagine that the box was made of wood and then aluminum while they repeated the same procedure. Participants were unaware of the correct answers until end of the experiment.

4.2 Results and Discussion

The correct answer rates for all six conditions are given in **Table 1**. The chance level of the correct answers was 33.3%. We performed a chi-squared goodness-of-fit test of the correct and found that participants produced significantly more correct answers, i.e., overall percent correct = 62.2% > 33.3% ($\chi^2(1) = 215.3$, p < 0.001), which means that the visual vibration enabled participants to identify the material of the box.

Table 2 shows the medians and inter-quartile ranges of the scores for each condition and result of a Steel-Dwass test. The result indicates that the B-on condition increased the score for the realism of wood (C4 and C5) and aluminum (C5 and C6). Similarly, the B-in condition increased the score for the realism of rubber (C1 and C2).

According to questionnaire after the experiment, a realistic perception was not reported by five participants. By carefully reading the questionnaires, we could categorize them into two groups: 1) not feeling realistic at all, and 2) not feeling realistic, but understandable. The former means participants did not understand what the visual vibration was intended to provide. Meanwhile, the latter means they did not feel that the object was realistic, but something that conveyed the essence of reality. In other word, our method was not realistic, but conceivable. Thus, the interpretation of the visual vibration relies on participants' subjective impressions. For the application of our method, we assume that users correctly understand what the designer means by visual vibration after an introduction comprising a brief explanation of haptics or the enrichment of context. In particular, designing context is important because the participant's impression is easily affected by their interpretation of the situation, just as the same pseudo-haptic feedback can be interpreted as friction or weight [5].

Table 1. The six sets of parameters and correct answer rate in the experiment.

No.	Material	A (s)	B (s⁻¹)	f (Hz)	Vibrating	Correct answer rate
C1	Rubber	0.015	6.0	1.5	B-in	79.2%
C2	Wood	0.009	8.0	5.0	B-in	61.5%
C3	Aluminum	0.020	9.0	15.0	B-in	68.8%
C4	Rubber	0.015	6.0	1.5	B-on	40.6%
C5	Wood	0.009	8.0	5.0	B-on	53.1%
C6	Aluminum	0.020	9.0	15.0	B-on	69.8%

Table 2. Result of realism rating test): the medians (inter-quartile ranges) of the scores for each condition (shaded cells represent the correct material for each condition).

	C1	C2	C3	C4	C5	C6	Steel-Dwass Test (p < 0.05)
Rubber	4 (3.25)	4 (4.25)	1 (0)	3 (2)	2 (1.5)	1 (0)	C1, C2 > C3, C6; C4 > C3
Wood	1 (0)	1 (2.25)	1 (1.25)	6 (1)	5 (2)	1 (1.25)	C4 > C1, C2, C3, C6; C5 > C1, C3, C5
Aluminum	1 (0)	1 (1)	4 (3.25)	1.5 (2.25)	3 (1)	6 (1)	C3 > C1; C5 > C1, C2; C6 > C1, C2, C4

5   Conclusion

This paper presented a HV technique, which employs modified decaying sinusoidal vibrations resulting from tapping an object to comply with visual perception. The results of a user study showed that participants could successfully discern three types of materials (rubber, wood, and aluminum) assigned to virtual objects. However, the implementation can be improved by refining parameters, vibrating objects (not cursor) and using a higher refresh rate display such as cathode-ray tube display, which expand the expression of our method.

We applied this technique to a music video game, and simulated virtual chromatic percussion instruments (xylophone and glockenspiel) using visual and tactile vibrations [11]. Users could feel the material of different instruments haptically as well as aurally. The King-Kong Effect [12] is another application, in which visual and tactile vibrations are applied to walking in virtual environments. The visual vibration is presented by vibrating a virtual camera that provided a first person view to a user in front of a monitor, and improved the sensation of walking. It means that our method can be applied to convey the surface properties of the ground.

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