Virtual Chromatic Percussions Simulated by Pseudo-Haptic and Vibrotactile Feedback

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ABSTRACT

Musical video games that allow users to play expensive musical instruments in a virtual environment constitute one of the most popular genres in the field of video games. Recent developments in motion input technology have enabled users to play the instruments intuitively and immersively. However, output technology, in particular haptic feedback, is not as advanced as input technology. We believe that providing a haptic sensation enriches the content of musical video games since the results of the motion input are fed back. To enrich the haptic sensation, we propose a system for playing virtual chromatic percussion, where the haptic feedback changes according to the instrument, as well as the acoustic feedback. In this paper, we propose a system describing a novel stick type controller and pseudo-haptic feedback to enrich the haptic sensation of the content. We also present an application that provides a virtual environment for playing two chromatic percussion instruments, namely the xylophone and glockenspiel.

Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – Haptic I/O, Input devices and strategies, User-centered design.

General Terms

Design, Human Factors.

Keywords

Haptic illusion, haptic sensation, material, musical video game, vibration.

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1. INTRODUCTION

Playing a musical instrument is one of the most popular forms of entertainment. Anyone can do it regardless of experience, as it is possible to create clear and beautiful sounds, synchronize with other instruments, and express sounds as one feels fit. The variety of content in music video games allows users to experience this by providing an accessible and inexpensive virtual environment in which to play musical instruments.

Several interfaces for virtual musical instruments have been developed. Kanebako et al. proposed the Mountain Guitar, which enables musical expression through sensor technology, allowing the user to play by making guitar playing motions [3]. Nintendo released Wii Music, in which the user can easily play various instruments by making certain gestures through the Wii Remote and its motion sensors [6]. One of Nintendo's aims was to allow less experienced users to play musical instruments easily by expressing their musicality through body movement. From these works, it is clear that the input technology of the interfaces for the musical instruments has shown good progress.

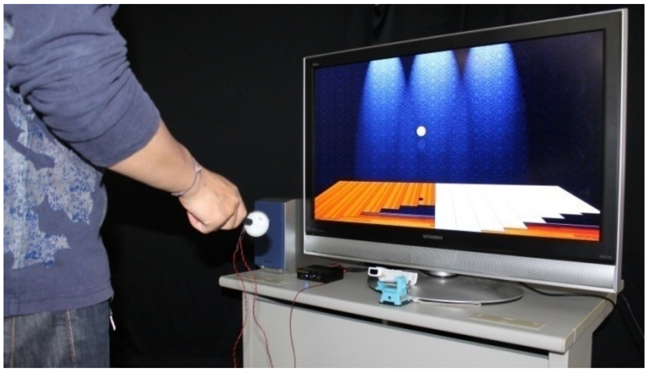

Figure 1. Virtual xylophone and glockenspiel.

However, output technology has not progressed as well. Although audio output has advanced in terms of surround sound, haptic feedback is still rudimentary. For instance, the Wii Remote has only a vibration motor as a haptic stimulator, which provides simple vibration that is insufficient feedback for complex motion input. Take, for example, real chromatic percussion instruments, such as the xylophone or glockenspiel. The difference in feedback

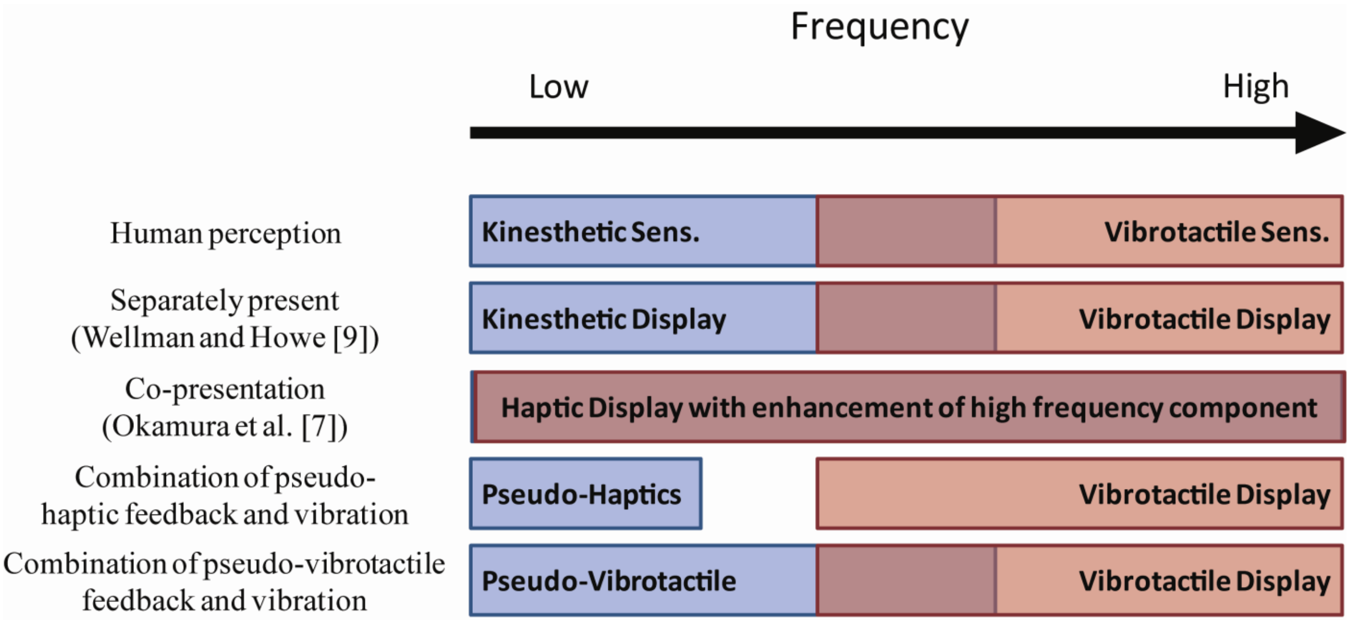

Figure 2. Haptic human perception and display.

resulting from striking is not only the sound, but also haptic feedback due to the construction materials—usually wood and metal. We believe that the user experience can be enriched by adding haptic feedback, since the results of motion input are fed back. In addition, various works in the research field reported that haptic feedback improved the experience of the video game content [4][8].

In this study we had three aims. First, to develop a richer haptic sensation capability than simple vibration output from a vibration motor. Second, to use inexpensive hardware rather than conventional (and expensive) active-force feedback devices. Third, to avoid interference with the user's motion input; a simple structure, such as the Wii Remote, is preferable because it is easy to manipulate by the user.

In this paper, we propose a novel music video game system to provide rich haptic sensation. We simulate two chromatic percussion instruments made of different materials, namely a xylophone (wood) and a glockenspiel (metal), to demonstrate the efficacy of our proposal.

First we review related works on haptic simulation based on our analysis of haptic sensation resulting from playing chromatic percussion. Next we describe our current system structure including the prototype of our proposal controller. Finally, we present an application that provides a virtual environment for playing two chromatic percussion instruments (Figure 1).

2. RELATED WORKS

2.1 Haptic Simulation of Tapping an Object

When tapping the surface of a hard object, we can discern the material using haptic cues without visual or acoustic ones. The haptic sensation consists of a kinesthetic sensation (i.e., a reactive force from the surface of the object) and a vibrotactile sensation (i.e., cutaneous mechanical deformations and vibrations).

Various methods have been proposed to present kinesthetic and vibrotactile sensations. Wellman and Howe proposed mounting a vibrator on a kinesthetic display [9]. Okamura et al. presented both kinesthetic and vibrotactile stimuli solely through a conventional active-force feedback device [7]. For vibrotactile stimuli, they employed vibration models, with the parameter of the vibration adjusted to fit the bandwidth of the actuators. The following equation shows Okamura's model of a decaying sinusoidal waveform:

$$Q(t) = A(v)e^{-Bt}\sin(2\pi ft) \qquad (1)$$

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, where A, B, and f are dependent on the type of material. They simulated three materials (rubber, wood, and aluminum) using their vibration model, and demonstrated that users could successfully discern the materials.

2.2 Pseudo-Haptic Feedback

Although a vibrotactile stimulus can be provided through a reasonably small actuator such as a voice-coil, kinesthetic stimulus as mentioned above is generally provided through more expensive devices such as an active-force feedback device.

Pseudo-haptic feedback [5] is one of the most practical methods for providing haptic feedback, in that visual cues create the haptic sensations without any physical haptic stimulus. For example, when moving a PC mouse on a smooth surface, if the velocity of the cursor on a PC monitor slows down compared to the velocity of the mouse, it feels as if the mouse has become heavy or the friction of the surface has increased. Various kinesthetic sensations can be generated with pseudo-haptic feedback, such as the stiffness of a virtual spring, the texture of an image, or the mass of a virtual object.

To produce the haptic sensation of chromatic percussion, it would be possible to provide a reactive force by stopping the cursor at the collision point. However, contrary to actual force feedback, the sensation generated by the conventional pseudo-haptic phenomenon has a limited frequency component, making it difficult to connect smoothly to the vibrotactile sensation (Figure 2).

To solve this problem, we propose expanding pseudo-haptics by adding high frequency visual cues. As the real amplitude of the oscillations is in the scale of microns, we increase the oscillation amplitude. Gleeson et al. proposed a cartoon-inspired oscillation model of the impact, which was not realistic but seemed to enhance the interaction experience [1]. By applying Gleeson's model to Okamura's model to fit the material parameter to the bandwidth of the conventional Liquid Crystal Display (LCD), a visually oscillating and bouncing mouse cursor creates a pseudo-vibrotactile sensation. The concise algorithm is described in Section 3.2.1. Although the vibration is not realistic, because the parameter changes significantly to convert the haptic modality to a visual one, the user experience appeared to be enriched.

3. SYSTEM STRUCTURE

3.1 Prototype Hardware

3.1.1 System configuration

Our proposal is implemented on a system consisting of a PC, a PC monitor, an audio amplifier, an audio speaker, a stick type controller, and an Infrared (IR) position sensor (Wii Remote) as shown in Figure 3.

The user receives two haptic cues: from the monitor, i.e., pseudo-haptic feedback induced by visual stimulus [2]; and from the controller equipped with a vibrotactile actuator [10].

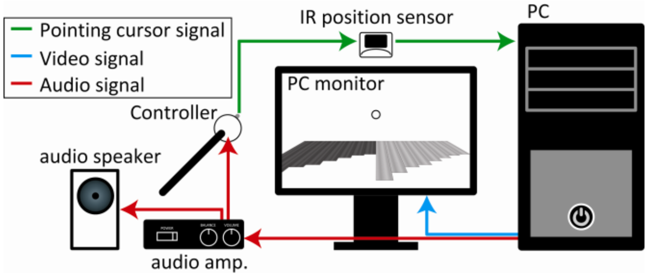

Figure 3. System configuration.

3.1.2 Stick Type Controller

Our proposed controller and the internal configuration are shown in Figure 4 and Figure 5. The current prototype is made of Acrylonitrile Butadiene Styrene (ABS) resin and includes a voice-coil type vibrotactile actuator [10] and an IR Light-Emitting Diode (IR LED). The length of the controller is 200 mm, and its weight 80 g.

The actuator has the ability to output a high-bandwidth vibrotactile stimulus controlled by the audio signal, which achieves our first aim of providing a richer haptic sensation than that provided by a vibration motor. The details of the specifications of the actuator can be found in [10].

The position of the IR LED is captured by the IR position sensor on the Wii Remote. The PC receives this from the Wii Remote through the Bluetooth module and displays it as a cursor on the PC monitor.

The controller configuration is so simple that it does not interfere with the user's motion input. Production of such technology would not be expensive if it was in bulk (as in the case of the Wii Remote).

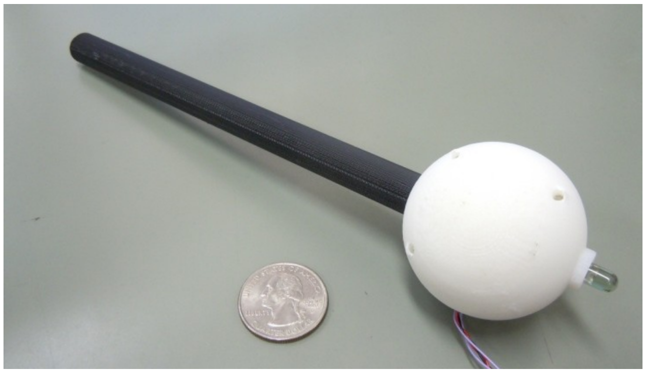

Figure 4. The prototype controller.

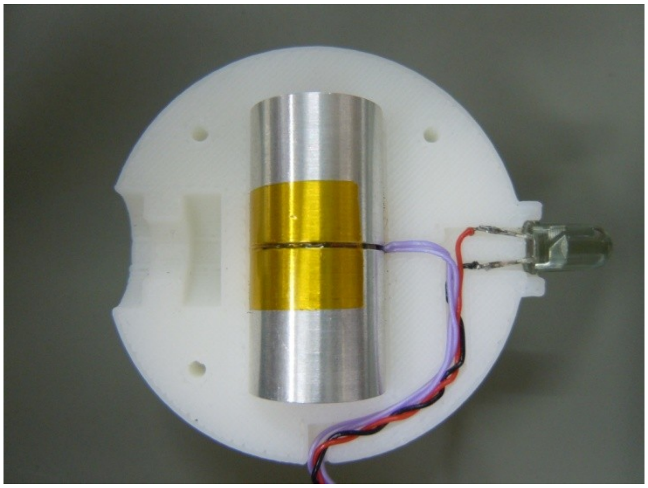

Figure 5. The internal configuration of the head of the controller, which comprises a voice-coil type vibrotactile actuator and IR LED.

3.2 Prototype Algorithm

In this section, we describe how to compute the behavior of the mouse cursor and the vibration from the actuator, and the auditory sound from the audio speaker, when simulating the material vibration resulting from beating.

First, our algorithm defines the position of the plates, and the material and musical scales thereof. The algorithm then determines the collision when the edge of the cursor comes into contact with the surface of the plate. Finally, it computes and outputs the video and two audio signals at the moment of collision as outlined below.

3.2.1 Visual Vibration

Figure 6 illustrates our algorithm for visual vibration. At the moment of collision, the algorithm obtains the velocity of the cursor v. Then the cursor begins to oscillate according to Equation 1. The cursor oscillates, bouncing off the surface of a virtual object with amplitude A as a function of the cursor impact velocity v after the collision. The algorithm oscillates the cursor and decays its oscillation according to the frequency f and decay rate of sinusoid B.

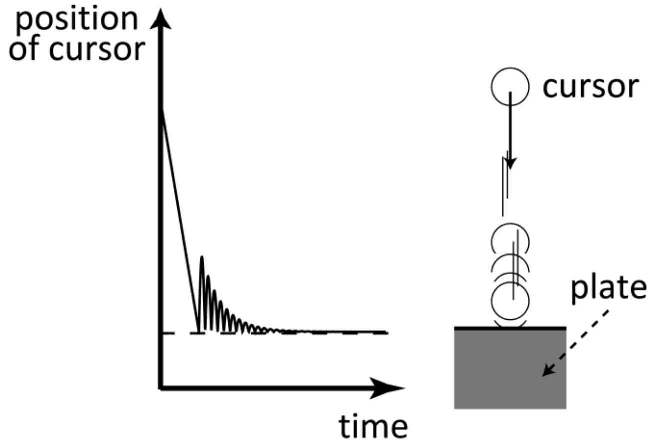

Figure 6. Illustration of visual vibration.

3.2.2 Tactile Vibration and Auditory Sound

At the moment of collision, the algorithm computes and outputs two audio signals: a vibrotactile signal and an acoustic signal.

The vibrotactile signal is for the actuator on the controller, and is computed by Equation 1 using the position and velocity data, i.e., the three parameters A, B, and f for the material vibration and the impact velocity v.

The acoustic signal is for the audio speaker, and is computed from the impact position and impact velocity. The position data is used to simulate the tone and musical scale of the acoustic sound, while the velocity data is used to determine the loudness of the sound. In the algorithm, both data are mapped to the Musical Instrument Digital Interface (MIDI) protocol, which produces the xylophone and the glockenspiel sounds.

The algorithm outputs both signals, converting the digital signal to an analog one through a stereo channel audio jack on the PC.

4. DEMONSTRATION

In this section, we present an example application. Our current setup is shown in Figure 7. As shown in Figure 8, the PC monitor displays a xylophone (the wooden plates on the left of Figure 8), a glockenspiel (the metal plates on the right of Figure 8), and a white sphere cursor as the head of the mallet. The cursor moves in only two dimensions, i.e., horizontally and vertically. The shadow of the cursor on the xylophone or the glockenspiel helps the user know exactly where the cursor is.

We assigned one octave (i.e., C, D, E, F, G, A, B, and C) to each chromatic percussion instrument. The three parameters in Equation 1 for the visual vibration and audio signal for the actuator on the controller are shown in Table 1. Note that the amplitude functions of the actuator are ratios rather than physical quantities. Currently, they are adjusted according to the user's sense by a rotary switch on the audio amplifier. These numerical values were determined by taking the values from Okamura's paper [7] and fitting these to the bandwidth of the LCD and the actuator.

We demonstrated the application system during a laboratory open day and the reactions of the participants appeared to be positive (Figure 9).

Seeing two parameters, with different values for the visual vibration and actuator, would lead to an unnatural sensation. For example, it is possible for the cursor to still be vibrating even though the vibration from the actuator has decayed. Contrary to expectations, the sensation seems to enrich the experience rather than feel unnatural. Although future quantitative evaluation is necessary, the exaggerated visual vibration seems to involve perceptual augmentation for haptic sensations.

Table 1. Parameters for visual vibration and the actuator. Starred (*) values represent the amplitude functions A for the actuator as ratios and not as physical quantities.

	For visual vibration		For the actuator	
	Wood	Metal	Wood	Metal
A (s)	0.009	0.020	1.0*	2.0*
B (s^{-1})	8.0	9.0	80.0	90.0
f (Hz)	5.0	15.0	100	300

Figure 7. The current setup.

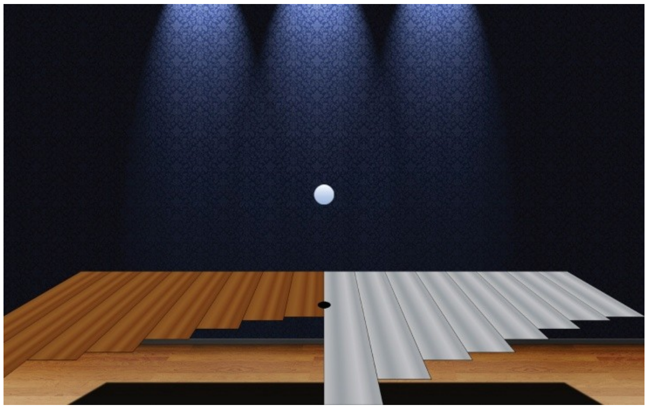

Figure 8. Screen shot of the PC monitor for demonstration: the PC monitor display a xylophone (left), a glockenspiel (right) and a white sphere cursor as the head of the mallet (center).

5. CONCLUSION

In this paper, we proposed a system for a musical video game utilizing a novel stick type controller and pseudo-haptic feedback to enrich the user's haptic experience. Our system was able to provide a rich haptic sensation, but remained inexpensive. The system did not interfere with the user's motion input. We also developed an application system to provide a virtual environment for playing two chromatic percussion instruments with different haptic and acoustic feedback characteristics. Our controller is made of ABS resin: the material for the controller is important as it affects the specifications, such as vibration transmissibility. In future work we plan to develop prototypes using alternative materials, and to evaluate and compare them with the ABS resin model.

In the future, we plan to study the effects of visual vibration that seems to involve perceptual augmentation for haptic sensation. Furthermore, we plan to simulate other chromatic percussion instruments besides the xylophone and glockenspiel and carry out user studies.

Figure 9. Users' reactions at the laboratory open day.

6. REFERENCES

[1] Gleeson, B. and Johnson, D.E. 2010. Expressive haptic rendering with cartoon-inspired effects. In *Proceedings of 2010 IEEE Haptics Symposium* (Boston, USA, March 25-26, 2010). Haptics '10. 191-194.

[2] Hachisu, T., Cirio, G., Marchal, M., Lécuyer, A., and Kajimoto, H. 2011. Pseudo-haptic feedback augmented with visual and tactile vibrations. In *Proceedings of 2011 IEEE International Symposium on VR Innovation* (Singapore, March 19-20, 2011). ISVRI '11. 327-328.

[3] Kanebako, J., Gibson, J., and Mignonneau, L. 2007. Mountain guitar: a musical instrument for everyone. In *Proceedings of the 7th International Conference on New Interfaces for Musical Expression* (New York, USA, June 6-10, 2007). NIME '07. ACM, New York, NY, 396-397. DOI= http://doi.acm.org/10.1145/1279740.1279833.

[4] Koga, D., and Itagaki, T. 2002. Virtual Chanbara. In *Proceedings of ACM SIGGRAPH 2002 Conference Abstracts and Applications* (New York, USA, July 21-26, 2002). SIGGRAPH '02. ACM New York, NY, 83. DOI=http://doi.acm.org/10.1145/1242073.1242118.

[5] Lécuyer, A. 2009. Simulating haptic feedback using vision: a survey of research and applications of pseudo-haptic feedback. *Presence*. 18, 1 (February 2009), 39-53.

[6] Nintendo. 2008. Wii Music. http://www.wiimusic.com/.

[7] Okamura, A.M., Cutkosky, M.R., and Dennerlein, J.T. 2001. Reality-based models for vibration feedback in virtual environments. *IEEE-ASME T Mech*. 6, 3 (September 2001), 245-252.

[8] Ooshima, S., Hashimoto, Y., Ando, H., Watanabe, J., and Kajimoto, H. 2008. Simultaneous presentation of tactile and auditory motion on the abdomen to realize the experience of "being cut by a sword". In *Proceedings of the 6th International Conference on Haptics* (Madrid, Spain, June 10-13, 2008). EuroHaptics '08. 681-686.

[9] Wellman, P. and Howe, R.D. 1995. Towards realistic display in virtual environments. In *Proceedings of the ASME Dynamic System and Control Division*. 57, 2 (San Francisco, USA, November 12-17, 1995), 713-718.

[10] Yao, H.-Y. and Hayward, V. 2010. Design and analysis of a recoil-type vibrotactile transducer. *J. Acoust. Soc. Am.* 128, 2 (June. 2010), 619-627.