Physically-Based Synthesis Modeling of Xylophones for Auditory-Tactile Virtual Environments

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ABSTRACT

Sound synthesis based on physical modeling is becoming more and more popular for virtual reality applications, particularly simulation of musical instruments. However we obtain not only auditory information but also tactile information when playing different musical instruments, e.g. drum, guitar etc.. In this paper we investigate how to link a physically-inspired digital sound synthesis with a haptic interface and describe the model of a virtual xylophone.

Author Keywords

Musical instruments, virtual reality, digital sound synthesis, haptic feedback.

ACM Classification Keywords

H.5 HCI, H.5.5 Sound and music computing, signal analysis, synthesis, and processing.

INTRODUCTION

A Xylophone is a percussion instrument, which consists of wooden bars. It is probably one of children's first musical instruments. The modeling example in this study is a virtual xylophone. The reason for this selection is that the relationship between physical attributes of the auditory and tactile stimuli and the human perception of these attributes are clearly observable when playing a xylophone.

Block-based physical modeling provides a strategy for realizing complicated models of physical systems with different submodels [1]. Whereas conventional modeling techniques usually allow only a single modeling paradigm to be applied, a BBPM can consist of blocks implemented with different paradigms. A BBPM supports dynamic audio environments and multi paradigm physical modeling [1,2]. It imposes physicality on the audio signals by transforming them to a variable pair of effort and flow. With this dual variable pair, we can define the notions of energy, impedance, and admittance for object blocks, and manage their physically based interaction by using special elements we call nodes [2].

In [3], construction and playing of virtual musical instruments based on BBPM techniques were investigated. For instance, a virtual xylophone that consists of data gloves, a magnetic tracker for head and hands positions, and audiovisual rendering in a cave-like virtual reality (VR) environment has been reported. However the literature data is not available for the application of BBPM techniques on not only haptic input but also haptic feedback generation.

In our previous study [2] we have presented an approach to implement the BBPM for audiotactile virtual environments with two simple case studies. In this study our aims are to develop a virtual interactive xylophone with physically-inspired models and to investigate system properties, like latency and computational load. In the future, we will tackle how to integrate this model within the BBPM framework.

IMPLEMENTATION

Xylophone bars can be classified as one dimensional vibrating systems (Fig. 1). Holz [4] indicates that an "ideal" xylophone wood bar is characterized by a specific value range of density, Young modulus, and damping factors. A number of studies proposed physical models for xylophones [5,6,7]. The Euler–Bernoulli theory has been applied to xylophone bars with some success [6, 7]. In [8], the Euler-Bernoulli theory is improved using the Timoshenko model.

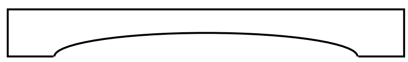

Figure 1. Schematic representation of a xylophone bar.

In this study the Euler-Bernoulli thin bar theory is used to determine the resonance frequencies:

$$\omega_n = 2\pi f_n \approx \frac{\pi^2}{4L^2}\sqrt{\frac{EI}{\rho S}}\,(2n+1)^2$$

where E is Young's modulus, ρ is the density of the material, L is the length of the block, I is the quadratic moment, S is the cross-section area and n is an integer. The approach of additive synthesis [6] is taken as a basis for this study. The analysis results of real recordings are used to determine the amplitude and decay times of the different frequency components.

We have previously applied Pure Data (PD) as the platform for realizing the BBPM environments due to its inherent capabilities of rapid prototyping [2]. DIMPLE, which makes use of the Open Dynamics Engine (ODE) to control the physical interaction between virtual objects, was used to generate the virtual world. DIMPLE was developed by Sinclair [7] to combine a haptic programming library with a physical dynamics engine and to expose its functionality through the Open Sound Control (OSC) protocol. Using OSC messaging, simple 3D objects can be instantiated and constraints on their movement can be specified, allowing the description of physically dynamic mechanisms. It is possible to create the simple objects (e.g. sphere, prism, etc.) and different constraints (e.g. hinge, fixed, etc.) by DIMPLE. Object properties, object movements (position, velocity, acceleration and force) and collision events can be transmitted to PD easily.

Here, we also utilize PD and DIMPLE, but run a physically-inspired sound synthesis model instead of BBPM. A screenshot of the virtual xylophone model is shown in Figure 2. The hit location between the xylophone mallet and a bar and the hit velocity are used as the control parameters of the synthesis model. Note that we need to convert the OSC control stream to an audio stream before applying it to the synthesis model.

A Phantom Omni device is used for users hand tracking and force-feedback generation. It's stylus symbolizes the virtual mallet. It is capable of delivering both steady-state and vibratory forces. The forces are delivered via a pen-like stylus that is held by the user. The position of the user's hand is measured using three digital encoders and three potentiometers (6dof). Digital encoders are mounted on each of 3 DC brushed motors. These motors generate forces in the x, y, and z coordinates.

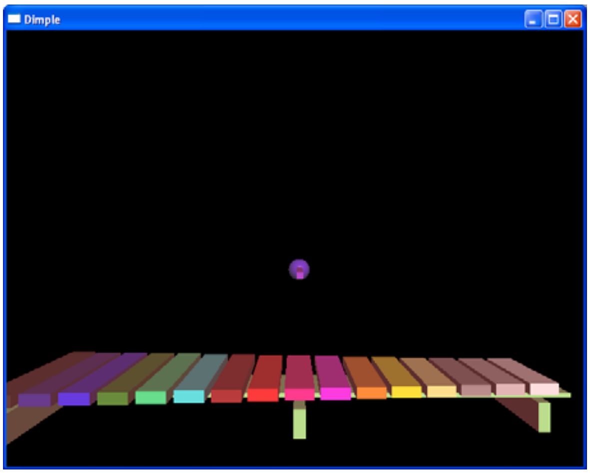

Figure 2. A screenshot of the virtual xylophone graphical representation (Dimple).

EVALUATION OF THE SYSTEM

In multimodal virtual environments, each unimodal information can be delayed with respect to the action of the user. For example, in our system, both auditory and tactile feedback can be delayed with respect to the action. Therefore some sound and vibration measurements were conducted during a user interacted with the virtual xylophone. Measurements results show that the latency between auditory and tactile modalities is approximately 5 ms (Latency for sound: 21 ms, latency for force-feedback: 26 ms.). According to [8], the latency of 5 ms between the modalities is below perception threshold (asynchrony) and tolerable. Some future experiments are planned to evaluate the quality of the system.

CONCLUSIONS

This study shows that simulation of virtual musical instruments may be enhanced by haptic feedback. Sound quality of xylophone bars is one of the important subjects for xylophone developers. The developed virtual xylophone, which includes sound and force feedback, is a valuable tool to conduct evaluation experiments. Next, we plan to reformulate the sound synthesis part within the BBPM framework. Future experiments are planned to investigate the interaction of auditory and tactile information. The system is also useful for collection of psychophysical data.

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