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Virtual Reality Instruments capable of changing Dimensions in Real-time

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Abstract

In this paper it is described how an immersive and interactive application is created by implementing physical models of a flute and a drum with the capability of changing dimensions in real-time. A flute-like controller is able to measure how hard a person blows into the instrument and lets the user control different tones using buttons connected into a sensor box.

A mallet is tracked using color tracking in order to measure when the mallet hits the virtual drum, and how hard.

Virtual models of both instruments are also developed and implemented in 3D stereo using Virtools [1]. The virtual flute is experienced as an extension of the physical instrument using a magnetic tracker system, which maps the movements of the user to the position and rotation of the virtual flute. The virtual drum is experienced as hovering in the air ready for the mallet to hit it. Both instruments are capable of changing size and shape to match the sound synthesis models.

To further immerse the user, a visual feedback of the sound is produced. Lights and particles are altered in intensity and color to visualize changes in amplitude and frequency.

1. Introduction

Physical models of musical instruments have been developed for at least two decades, mainly for acoustics or engineering applications. The possibility of using physical models in creative ways has not been fully investigated yet. Being introduced to waveguides and modal synthesis, the fact that a physical model of a non existing instrument could be built, was one of the major motivations for this project.

Daniel Truman and Perry Cook have developed an interface to control a virtual violin [2]. What characterizes the interface in the sound independence of strings and the body, although the timbre of the instruments is still the one of a traditional violin?

Some of Daniel Trueman's thoughts behind this project, which were very inspirational, were:

"What would it mean to draw the bow across the string and hear sounds that are not acoustically motivated by the induced oscillations? What kind of music would we make with such a violin and what aesthetic tendencies would this violin have? What possible forms could this violin assume?" [3]

Sound can be created without being limited by e.g. material and form, which makes it possible to play sound, which can not be played on an ordinary physical instrument. The possibility of building extreme instruments such as a two kilometer long didgeridoo or a tiny five centimeter long saxophone seems to be an interesting thought for the future of advanced synthesis techniques. Many creative aspects can also be found for a variety of different artists and perhaps in the field of education.

Wouldn't it be an interesting thought to develop an instrument capable of changing size and shape in real-time?

Being able to use the VR facilities present at Aalborg University, such as a virtual reality CAVE and augmented reality with head mounted displays, led to the possibilities of combining a physical model capable of changing size in real-time with a VR environment as a user interface, which seemed to be obvious but also quite interesting.

This project has both pedagogical and artistic applications. Teaching students about sound waves is normally done by traditional lectures with textbooks, images and diagrams.

By using physical models combined with virtual or augmented reality, it is now possible to develop a platform where a user has the possibility of playing an instrument with different materials, shapes and dimensions. The user will now be able to both see and hear the output and in real-time change the dimensions of the instrument played.

It is interesting to understand if the learning process of playing a musical instrument is enhanced by such a VR environment and visual feedback, where the sense of “being there” and “doing it” is strongly enhanced.

A second application has mostly artistic purposes. Here, the possibility of changing the length and width of an instrument while playing it creates not only the possibility of exploring new sounds but also the possibility for lots of interesting new audio-visual effects for an artist.

A similar project, coupling physical modeling with virtual reality is the virtual air guitar made by Matti Karjalainen and Teemu Mäki-Patola [4]. The project is developed for a virtual reality CAVE. Two data gloves are used for precise tracking and interaction of the hands. The tracking of the left hand is particularly interesting in relation to our project as it is controlling the length of the vibrating string.

The physical model of the guitar is based on the extended Karplus Strong algorithm [5] with an applied distortion to simulate a rock guitar.

Another project from the same research group is the virtual xylophone[4]. This project is also developed for a VR CAVE. The user wears a pair of data gloves, and virtual mallets are placed in his hands. A tracking system allows the user to play on a virtual xylophone. An interesting consideration from this work is that the authors conclude the following from this research:

“…people prefer a real mallet over a virtual one when hitting virtual objects. The use of a physical mallet results also in better temporal accuracy while playing a virtual percussive instrument.”[6]

Hence, tactile interface for controlling the output seems to be an important feature of a virtual space experience.

2. Concept and Idea

The idea of creating an application that augments the experience of instruments synthesized by physical modeling opens up for different approaches. Therefore it was decided to implement the application for two very different instruments, which are created with two different approaches to physical modeling; a flute and a drum.

It seems natural to visualize the dimensions used in the physical model synthesis in order to give the user an understanding of what he is controlling. The visual feedback therefore provides information on the size and shape of the instruments played.

According to T. Azuma [7] the four key elements of experiencing virtual reality are the following:

– A virtual world
– Immersion
– Sensory feedback
– Interactivity

Looking at these four key elements, it can be argued that virtual reality is the right media for this application. The key elements are explored by trying to implement them as much as possible in the development of the application.

In order to enhance immersion, 3D models of the instruments are developed for a VR environment.

The flute is implemented in 3D stereo so it appears as a virtual extension of the physical instrument. The user can hold an actual physical instrument in his hands and at the same time control a virtual instrument extended from it. In the case of the drum, the instrument remains stationary. The main challenge is to let the drum come out of the screen also using 3D stereo, providing the user with something to hit, with a physical mallet.

From the original idea many other questions arose. How can the user interact with the virtual 3D stereo model of the flute? In order to make the 3D model of the flute interactive, and have the view change according to the position of the user, a magnetic tracking system is introduced. This tracking system is able to track the physical flute, in such a way that the visualization of the flute (the virtual flute) will always follow the translation and rotation of the physical flute.

In the case of the drum, the question was what kind of tracking should be used for the physical mallet and how is it possible to determine when the user is hitting the virtual drum and with what velocity.

The next issue is how to provide the user with the ability to alter the dimensions of the instruments.

Since the hands are already occupied by playing the instruments, it was decided to control the size of the instruments with the foot. The foot is often used in traditional instruments to give the user control of additional features, such as a volume pedal for an organ or a wah-wah pedal for a guitar. In this case the foot is moved back and forth and from side to side to control the physical models and thereby the virtual instruments. The foot is tracked in real-time using color tracking.

The last question is what kind of visual feedback of the actual sound produced can add to the immersiveness of the application. In order to enhance the learning experience, we decided to visualize properties like amplitude and frequency of the sound waves produced.

Several other projects have visualized properties like frequency and amplitude. The ReacTable [8] is a very nice example of how a waveform and its amplitude could be visualized in a very understandable way. Also The Virtual Membrane [9] visualizes a waveform of a membrane in a very understandable and educational way.

In our case the visualization is made simply by manipulating particles flying from the instruments with data from the sound produced.

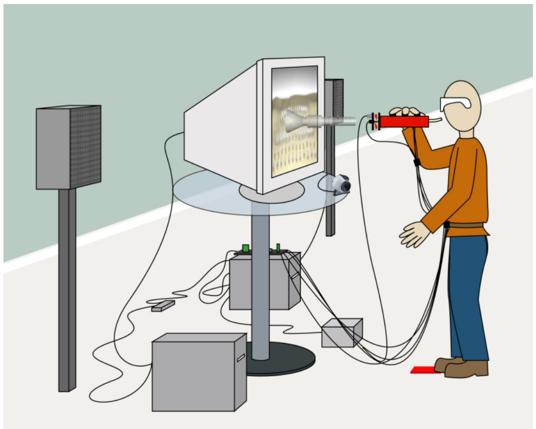


Figure 1. Setup of the virtual reality flute. A physical interface controls the flute physical model together with its visualization.

3. The Virtual Flute

3.1 Sound synthesis

The physical model of the flute is build by using digital waveguides. The model is based on Perry Cook's original flute model [10], with the addition of all-pass filters to simulate the effect of changing the width of the instrument.

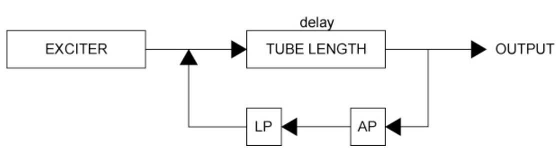


Figure 2. Block diagram of the flute physical model, based on digital waveguides. LP represents the low-pass filter simulating losses, while AP represents the all pass filters used to simulate changes in dimensions of the instrument.

The model has been implemented as a Max/MSP [11] object. The following different input parameters of the model can be controlled in real-time by the user; the excitation (input pressure), the length and width of the flute, represented by the dimensions of the digital waveguide and the coefficients of the all pass filters respectively. Extra inputs for the object are created for controlling the filter coefficients, which are used for experimenting with the quality of the sound.

When designing a physical model like this the accuracy/responsiveness tradeoff must be considered. In [12] Dinesh K. Pai argues that there is a tradeoff between accuracy and responsiveness when dealing with models. Because this application demands interactivity for the user to feel immersed, the responsiveness is much more important than accuracy. Therefore the model is merely an approximation of a flute because it must be able to run real-time, keeping the computation low.

3.2 The physical instrument

An interface was needed to give the user a way of playing the virtual flute. The device had to give the user a feeling of being in control as if he was playing an ordinary instrument. A tangible interface was thought up to simulate a real flute. Three push-buttons are attached using a Teleo sensor interface [13] with four inlets capable of reading 0-5V in 1024 steps.

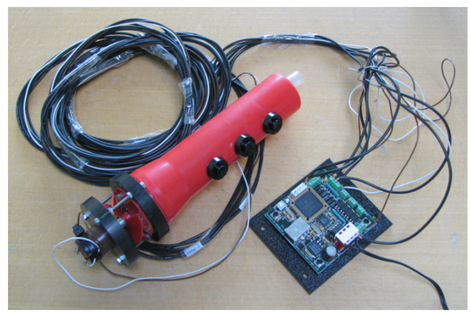


Figure 3. The flute interface

To track how much the user blows into the physical device a small dynamo motor was tested to be sensitive enough to create usable data. When blowing at a small fan attached to the motor, the fan rotates and creates voltage data. Sending the data from the dynamo into the computer through the fourth inlet of the interface the exciter of the physical model is controlled by how hard the user blows.

The device actually works quite well although there is still room for improvement. The flute has a lot of wires and is a bit heavy. The fan doesn't stop exactly when the user stops blowing, and it requires lots of breath to get started.

Using a wireless interface such as the Kroonde Gamma interface [14] would get rid of wires and help with the weight. Replacing the fan with a bend strip sensor would give a more realistic excitation and also help a lot with the weight. Gary Scavone and Andrey da Silva [15] argues that combining a pressure sensor, as from a midi saxophone, with a small microphone would make the device able to give the user the possibility to vary his expression making the flute much more life like and thus more immersive to play.

To make the device look and act more like a real flute, the three push buttons could be replaced with holes with tiny infrared sensors applied to each of them. A finger interrupting the infrared beam could then act as a trigger.

4. The virtual drum

4.1 Sound synthesis

The physical model of the drum was developed by creating a 2D digital waveguide mesh [16].

Like the virtual flute, the virtual drum works in real-time under the Max/MSP platform. The control parameters of the drum are the amplitude of the excitation mechanism, the tension of the drum and the size of the drum.

The player, by varying these parameters, is able to change the size of the instrument in real-time. Given the high computational cost of the waveguide mesh, typically meshes of 8x8 respond efficiently in real-time. For higher mesh dimensions some latency is perceived by the user.

4.2 The Mallet

The physical device used for the virtual drum is simpler than for the flute. A stick with a red object attached to the tip works as a mallet. By performing a color tracking of the tip, its position and velocity can be determined. When the mallet crosses a predetermined threshold, the sound is activated and the velocity at that point is then mapped directly to the excitation of the physical model.

A problem is that a quite high amount of latency is perceived due to the latency of the webcam used for the color tracking.

A possible solution to this problem could be to use a CCD camera, as done in Leonello Tarabella's "Imaginary Piano" [17].

A further development of the instrument could also be to increase the number of drums and mallets in order to mimic a real drum-set or take it even further.

5. 3D stereo vision and latency

As a first solution, we implemented the 3D visualization in Jitter, the image processing and visualization library available with Max/MSP.

As argued in [18] where an experiment was conducted on the effects of latency in virtual environments; *"participants in the low latency condition had a higher self-reported sense of presence"*. The latency in this approach was so high that it severely lowered the feeling of being immersed. This made us choose a different visualization environment.

Rendering the 3D stereo has been done by manipulating the graphics in 3D in Virtools[1] by retrieving data from Max/MSP about the dimensions of the instruments and data from the magnetic tracker about the translation and rotation of the flute. It is then hardware rendered through an NVIDIA Quadro FX graphics card creating the 3D stereo using shutter glasses [19]. This second solution provided very little perceived latency for the users in regards to the visual rendering, which gave them a much better overall experience.

6. Tracking

The Polhemus ISOTRAK magnetic tracking system [20] is used to determine the position and rotation of the physical flute. This is then fed into Virtools and applied to the positioning and rotation of the virtual flute making it seem as if it were attached directly to the physical one.

7. Visual feedback

The goal of the visual feedback was to provide the user with information about what sounds were produced, while helping to engage and immerse the user in the installation. A simple setup is made where particles flow from the instruments in different ways according to the characteristics of the sound. The amount of particles, the color and the size are mapped to the frequency and amplitude of the sound.

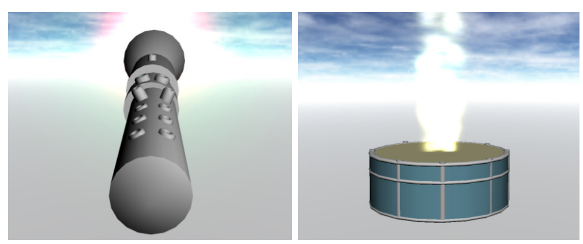


Figure 4. Visualization of the virtual flute and the virtual drum

To take the idea of the sound education situation a little further, the visual feedback could be made more entertaining (i.e., for younger children). An example was made where small characters carry out the behavior, by being the elements of the visualization of the sound waves produced. The amplitude is mapped to the height of the jumps, and the frequency is mapped to the speed of the jumps. Thereby the children could learn about the behavior of sound and by the same time feel entertained.

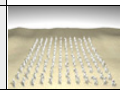
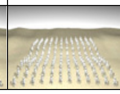
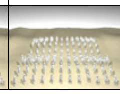
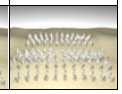
Amp.	Zero	Low	Med.	High
Wave				

Figure 5. Characters jumping in different heights.

8. The prototype

The virtual flute and virtual drum have been demonstrated to the Danish minister of education during the opening of Aalborg University in Copenhagen on September 1st.

Figure 6. Demonstration of the flute during the opening of Aalborg University Copenhagen on Sept. 1st 2005.

The application is ready to be implemented in a CAVE running the Virtools Development Pack together with the VR Pack [1]. For the prototype the application was implemented using computer monitors which of course reduced the immersion of the application drastically because the field of view was decreased [21]. However the feeling of actually playing these very flexible instruments was still there.

The instruments work quite well and users understand the principle of changing their dimensions in order to change the sound. However, if the instruments, especially the flute, were to be mastered to actually play a piece of music the user would probably have to spend a lot of time exploring the combination of the tone configuration and the dimension/sound change. Especially if the instruments were further developed; the flute given extended room for expression and the drum extended to a whole drum set or more, all giving the user extended possibilities.

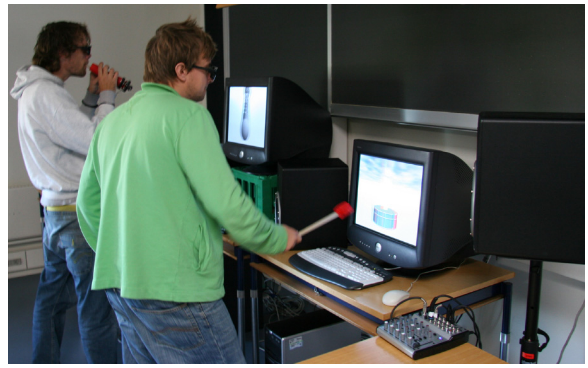


Figure 7. Flute and Drum setup.

9. Virtual reality musical instruments as enactive interfaces

Like traditional musical instruments, virtual reality musical instruments belong to the category of enactive interfaces. Both the traditional and virtual enhanced counterparts of the instruments we developed respond directly and intuitively to the gestures of the performer, and are easy to learn how to play.

In a traditional flute and in our virtual reality one, it is easy to reproduce simple notes. However, the virtual flute has limited playability possibilities compared to a real one in regards to expression. For this reason, the virtual flute is appealing as a new musical instrument, especially considering its extensions through visualization. However, we doubt that in the current state it is an instrument which would encourage people to practice for an extended amount of time, as is the case with traditional flutes.

The same observation is true also for the virtual drum. In this virtual reality instrument, the main limitation compared to its traditional counterpart is the significant latency, which prevents skilled player to perform multiple fast strokes.

The enactive approach to interface design assumes that a continuous sensorimotor engagement between the player and the instrument exists. We feel that our instruments provide an initial step to such engagement in virtual reality, especially considering their multimodality, but they can still be improved to cope with some of the limitations mentioned above.

10. Future perspectives

Creative use of physical models is still an interesting field of research. This can be very useful for electronic musicians and composers as new instruments with interesting effects and interesting possibilities for expression emerge.

When a composer of electronic music is performing his work, the audience could be engaged more in the work and process with some of the visualizations and control parameters in an entertaining way.

The fact that the system is using a multiple control of different parameters at the same time could be used to advance the possibilities of playing a virtual instrument.

The combination of virtual reality and physical model synthesis is also an interesting field with lots of possibilities for further research. The fact that physical modeling uses physical parameters as input makes it possible to create very realistic and exciting experiences if combined with virtual or augmented reality.

The possibilities of edutainment with a system like this could be interesting for later research. It would be interesting to test if in fact the augmented experience would be able to make for instance children learn the relationship between an instrument and its sound faster.

11. Further developments

As further developments on this project, we are interested in extending the physical modeling synthesis to 3D sound. In this way, the user could possibly navigate inside the flute while playing it.

By using 3D sound the user will be able to become even more immersed in the system, and the experience of playing a realistic physical model of a flute with specific physical dimensions could become complete. We are currently investigating the possibilities to implement the flute physical model in the 8-channel cube loudspeakers setup of the CAVE in Aalborg. Another aspect which is interesting and relevant for further development is the visual feedback.

Currently, the frequency and amplitude of the sound are mapped to the visuals. It would be interesting also to visualize other parameters of the sound, such as width changes and inharmonicity.

One could also take a closer look at the visual or haptic feedback and provide the user with more control in regards to tones. The visual feedback could display information about how close or whether or not the user was hitting a clear note. “The FM Theremin” created in [9] also uses a vertical piano keyboard as a guide telling the user when they hit pure notes and which.

In other words, it would be nice to have as much control and visual feedback as possible, so if any small detail in the sound would change, it would affect the visual feedback.

Testing the system with several different technical solutions like for instance trying the system in augmented reality using a head mounted display could be interesting.

12. References

[1] http://www.virtools.com

[2] Daniel Trueman and Perry Cook, BoSSA – The Deconstructed Violin Reconstructed, Princeton University, 1999 .

[3] Daniel Trueman, Reinventing the Violin, Chapter 3: The Infinite Virtual Violin, PhD dissertation, Princeton University, 1999.

[4] Matti Karjalainen and Teemu Mäki-Patola, Physics based modelling of musical instruments for interactive virtual reality, in Proc. Int. Workshop on Multimedia Signal Processing (MMSP04), Siena, Italy, Sept. 29 - Oct. 1, 2004.

[5] Jaffe, D. A., and J. O. Smith. 1983. ³Extensions of the Karplus-Strong Plucked-String Algorithm.² Computer Music Journal 7(2):76-87.

[6] Teemu Mäki-Patola, User interface comparison for virtual drums, Proceedings of the International Conference on New Interfaces for Musical Expression (NIME05). Vancouver, Canada, May 2005.

[7] Ronald T. Azuma, A survey of augmented reality, Presence: Teleoperators and Virtual Environments 6, 4 (August 1997).

[8] Martin Kaltenbrunner, Günter Geiger, Sergi Jordà, Dynamic Patches for Live Musical Performance, Proceedings of International Conference on New Interfaces for Musical Expression. Hamamatsu, Japan, 2004.

[9] Teemu Mäki-Patola, Juha Laitinen, Aki Kanerva, Tapio Takala, Experiments with Virtual Reality Instruments, Proceedings of the International Conference on New Interfaces for Musical Expression (NIME05). Vancouver, Canada, May 2005.

[10] Perry Cook, Integration of Physical Modelling for Synthesis and Animation, ICMC, Banff, Canada, Sept. 1995

[11] http://www.cycling74.com

[12] Dinesh K. Pai, Multisensory Interaction: Real and Virtual, in proceedings of the International Symposium on Robotics Research, Siena, Italy, October 19-22, 2003.

[13] http://www.makingthings.com

[14] http://www.cycling74.com/products/kroonde.html

[15] Gary P. Scavone, Andrey da Silva, Frequency Content of Breath Pressure and Implications for Use in Control, NIME Vancouver, 2005

[16] Van Duyne, S. A. and J. O. Smith (1993b), Physical modeling with the 2-D digital waveguide mesh. In Proceedings 1993 International Computer Music Conference, Tokyo, pp. 40-47. Computer Music Association.

[17] Leonello Tarabella, The Imaginary Piano, http://cnuce.isti.cnr.it/tarabella/

[18] Michael Meehan, Sharif Razzaque, Mary C. Whitton, Frederick P. Brooks Jr. Effect of Latency on Presence in Stressful Virtual Environments, proceedings of IEEE Virtual Reality 2003 (Los Angeles, CA, March 2003), 141-148, IEEE Computer Society.

[19] NVidia, Technical Brief, 3D Stereo, Consumer Stereoscopic, 3D Solution, NVIDIA Corporation 2003, http://www.nvidia.com

[20] http://www.inition.co.uk/inition/product_mocaptrack_polhemus_isotrak.php

[21] P.J. Costello, Health and Safety Issues associated with Virtual Reality - A Review of Current Literature, July 23rd, 1997