DEPTHROW: A PHYSICS-BASED AUDIO GAME

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ABSTRACT

We present an interactive audio game designed around the auditory perception of distance and the use of physics-based models for simulations of the dynamics, the sound source, and the acoustical environment. The game consists in throwing a virtual sounding object inside a virtual open-ended tube which is inclined. The task is to keep the object inside the tube, in other words the user should adjust the initial velocity applied to the object such that the latter does not fall out at the far end of the tube. The position of the object inside the tube is provided by continuous audio feedback. User performance is closely related to its ability to perceive the dynamic distance of the object in the virtual tube. Therefore, this game represents a potential tool for exploring the usability of auditory distance information in interaction design.

1. ARCHITECTURE OF THE INTERFACE

The game prototype has been developed as a complex Max/MSP[1] patch where three interacting physics-based models enable to simulate, respectively, the dynamics of the environment (an inclined plane), the sound source (a rolling ball), and to render the acoustical properties of the environment (an open-ended tube).

The action of throwing is performed using a Wii Remote[2] which provides, among other things, a 3D accelerometer, a vibration actuator, several buttons, and Bluetooth connectivity.

The three physics-based models are connected in a top-down chain structure. Figure 1 shows the main Max/MSP patch. The throwing force applied to the virtual ball is captured (gesture mapping) by means of the accelerometer and provides the input to the computation (integration) of the initial velocity with which the ball is getting thrown inside the inclined tube. Then the initial velocity provides the input to the simulation of the inclined plane. The resulting velocity of the ball moving along the inclined plane drives the real-time synthesis of a rolling sound, which constitutes the audio input to a spatialization process (simulation of a tube), while the distance currently covered controls the distance parameter of the spatialization model. The latter conveys auditory information about the relative position of the sound source inside the virtual tube.

The vibration actuator is exploited for providing tactile feedback: for example when the object comes back to the user's hand, or when the ball falls over.

[1] `http://www.cycling74.com/products/maxmsp`

[2] The handed wireless controller for Nintendo's Wii console. Thanks to Masayuki Akamatsu for his [aka.wiiremote] Max object (available at `http://www.iamas.ac.jp/~aka/max/`).

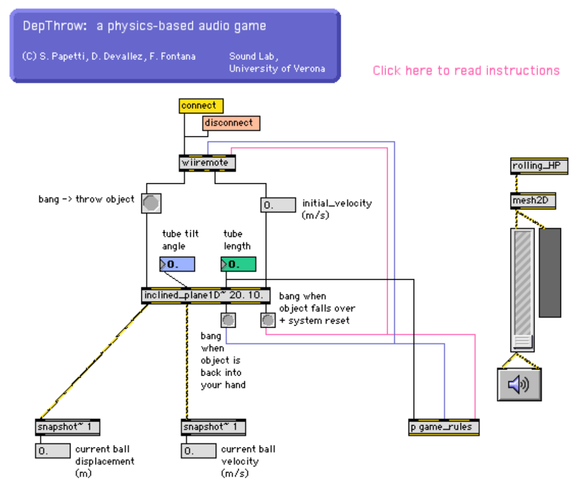

Figure 1: The main Max/MSP patch

2. PHYSICS-BASED MODELS

2.1. Inclined plane

The first (topmost) model is a simplified simulation of the dynamics of an inclined plane. It is currently possible to set the length, tilt-angle and friction of the plane. The model takes as input the initial velocity of an object moving upward along the plane, and returns its current displacement and velocity. As for the implementation, we wanted these quantities to be returned as signals (in contrast to controls) in order to allow high- (in fact, audio-) rate control of the following models. For this reason, we discarded premade dynamics libraries such as *pmpd* [3], and decided to develop our own dynamics simulation as a Max/MSP external object.

2.2. Rolling sound model

The sound source is represented by a rolling sound model [1] which was originally developed and implemented during the EU-funded project *SOb* [2] (The Sounding Object), and further developed for the EU-funded project *CLOSED*[4] (Closing the Loop Of Sound Evaluation and Design).

The rolling model combines different underlying components: the heart of the model is a physics-based impact model [3], which

[3] `http://drpichon.free.fr/pmpd/`

[4] `http://closed.ircam.fr`

is driven by two pseudo-physical models that simulate respectively, the geometry of the contacting surfaces (which controls the temporal pattern of micro-impacts), and the ball's asymmetries (which superimpose a modulation of the impact force).

As for the contact interaction between the rolling ball and the plane surface, only normal impacts are taken into account, discarding friction components (which are comparatively small). The non-linear impact model adopted complies with the modular structure "resonator-interactor-resonator", hence representing the impact interaction between two resonating objects. In this case the resonators are a ball (*object1*) and a tube (*object2*). They are modeled through the modal synthesis [4] technique, which describes a vibrating object by means of its resonating modes (i.e., the frequency, decay time and modal weights of each mode). For simplicity, in our case, only *object2* resonates while *object1* is considered as a point mass, and therefore does not have any resonating mode.

The shape of the plane surface is simulated by a band-pass filtered noise signal. This serves as input for a specifically designed filter, which in turn calculates the trajectory of (the center of) a ball rolling on such surface. Given a surface, the trajectory depends on the ball's diameter. Again, for simplicity, the possible bouncing of the ball is not taken into account.

2.3. Sound spatialization

In recent years, research on the Digital Waveguide Mesh (DWM) has enabled to use discrete-time simulations of acoustic propagation as a model for real-world acoustical spaces [5]. Fontana and Rocchesso [6] have recently demonstrated the effectiveness of a DWM modeling a rectangular parallelepiped to provide auditory distance cues. Our sound spatialization model consists of a two-dimensional rectangular DWM. Each internal junction is connected to four other junctions via waveguides, thus providing acoustic wave transmission. Besides, reflections at the mesh boundaries are modeled by Digital Waveguide Filters, whose coefficients have been tuned to model specific reflective properties of surfaces. This structure, modeling a tubular environment in 2D, allows to render dynamic variations of the sound source position, and consequently provides a tool for interactive manipulation of sound sources along the depth dimension.

3. GOALS AND ISSUES

Besides investigating whether the game is entertaining, user performance allows to evaluate the playability of the game which is the result of a perception-compliant mapping of user gesture (the act of throwing the virtual object), i.e. the mapping of the acceleration signals sensed by the Wii Remote onto the control parameters of the dynamics environment (inclined plane) and the rolling model. This adequate mapping is achieved through the iterative development and informal evaluation of the prototype.

Another issue of this gaming application is the perception of the far end of the virtual tube to avoid the object falling over. Human ability to perceive distance is relatively weak in comparison with the perception of direction [7]. The most problematic issue during listening experiments on distance perception is the difficulty of humans to separate the distance cues from the spectral characteristics of the sound source itself. Therefore, users may need some *a priori* information about the sound source, or a preliminary phase of training. Moreover, many studies agree on the systematic deviation of the perceived distance of the sound source from its physical distance, and on a high response variability across listeners. In particular, distance perception is very poor without reverberation. However, a recent study [8] has shown that distance accuracy improves with experience in reverberant environments. This result suggests that user performance may improve with training. User testing should be carried out to validate this assumption.

Of interest for the present work are the studies by Yao and Hayward [9] and Rath and Rocchesso [10]. In [9] the authors studied the cues exploited by users to locate the position of a virtual rolling or sliding ball inside a tube, and showed the relatively good ability of users to guess the length of the tube just by tilting it and perceiving (from auditory and/or haptic cues) the virtual object's dynamics. A physics-based model of rolling sound was also used in [10] as a continuous auditory feedback for balancing a ball along a tiltable track. To evaluate the interface, subjects had to move a virtual ball until a specific position on the track. Even without any visual display, all subjects managed to solve the task, which means that people were able to locate the virtual ball with the only auditory feedback.

4. REFERENCES

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