HyperPuja: A Tibetan Singing Bowl Controller

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ABSTRACT

HyperPuja is a novel controller that closely mimicks the behavior of a Tibetan Singing Bowl rubbed with a "puja" stick. Our design hides the electronics from the performer to maintain the original look and feel of the instrument and the performance. This is achieved by using wireless technology to keep the stick un-tethered as well as burying the electronics inside the the core of the stick. The measured parameters closely resemble the input parameters of a related physical synthesis model allowing for convenient mapping of sensor parameters to synthesis input. The new controller allows for flexible choice of sound synthesis while fully maintaining the characteristics of the physical interaction of the original instrument.

1. INTRODUCTION

In this paper we describe a new controller based on an instrument called the Tibetan singing bowl. These bowls have received increased attention in the Computer Music community in recent years [22, 15, 8, 23, 17, 3, 18, 19] for their intriguing sound and performance style.

Tibetan singing bowls are metallic or glass bowls in shapes varying from that of a spherical segment to an almost cylindrical shape. The bowls can be made to ring by striking. The sound of a bowl when struck is related to bell sounds [13]. The sound mainly depends on the shape, material and size of the bowl and the hardness of the striker.

However the more characteristic performance type is based on a rubbing interaction. The bowl is rubbed with a wooden stick called "puja", which may or may not be wrapped in a thin sheet of leather. The performer rubs with the stick around the outer rim of the bowl at various speeds and tangential forces that, if performed correctly, create a sustained ringing sound.

In recent years, research on Tibetan bowls has focused on two main aspects. One is the use of real and virtual bowls in performance through novel interfaces. Atau Tanaka [18] used an array of acoustic Tibetan bowls, which he played while controlling additional electronically created or modified sounds through electromyogram and position sensing technology developed by him and Benjamin Knapp [19]. The technology was used in two ways: The first was used to electronically augment the original sound through the control of the measured gestures. The second does not use original sound, but rather the gestures create independent sound articulations.

Carr Wilkerson and co-workers [22, 23, 17] used the Mutha Rubboard Controller to play physical models of the Tibetan singing bowl. The Mutha Rubboard Controller is a controller motivated by washboard playing as present in Zydeco music. A capacitive sensing technique was used to determine the position of the key. This was used as a contact free excitation mode for the virtual bowl. The performer would use circular up-down hand motions in front of his body to feed energy into the synthesis algorithm.

Research in controllers for musical expression has seen an increased development in theoretical foundations and guiding principles [2; 4; 5; 11; 21, for example]. The mapping problem, that is the relation of control-device output to synthesis algorithm input, has seen both theoretical and experimental advances [9; 10; 14, for example].

The type of friction behavior that is responsible for the oscillatory action of the rubbing stick on a Tibetan bowl is known as stick-slip friction [1], a mechanism also reponsible for the dynamic function of string instrument bows. Bowed string controllers are under ongoing development. One line of research augments the violin bow and maintains the original bow action [24, 20] whereas another line includes haptic feedback in the controller design [12].

In the remainder of the paper we describe the design of a new controller for Tibetan singing bowls by implementing an electronic sensor version of the "puja" stick that we call the "HyperPuja".

2. HARDWARE IMPLEMENTATION OF THE BOWL CONTROLLER

In designing the first prototype of the HyperPuja stick, there were several priorities established from the onset. Because the most immediate goal of this research is to allow the performance of the Tibetan bowl physical model using traditional playing technique, we wanted to maintain the ergonomics of the stick above all. Therefore, we wanted to make a system of sensors that was both as small and as light as possible. We also aimed to maintain the natural wireless feature of both the bowl and the stick, and so it was decided that the data transmission would be performed using an RF module.

In this work, we also sought to integrate as much of the electronics within the structure of the HyperPuja stick as possible, so that in all ways the stick would give the appearance and feel of that of its traditional counterpart. Therefore, a design was desired that allowed the various components of the electronics system to be placed almost entirely inside the stick itself.

Because we wanted to create an interface that could not only be used as a means of controlling a physical model, but could also offer the player the use of the acoustic sound of the bowl (so that, for instance, a player might be able to play a duet between real and virtual bowls), another priority of the interface design was that the bowl itself remain as untouched by technology as possible.

With the above priorities in mind, we sought to create a prototype of the HyperPuja interface that would be capable of measuring data relating to the velocity of the moving stick around the bowl, the pressure between the stick and the bowl, and the acceleration of the stick along its trajectory. The first two types of measurements are of obvious interest for this project, as they relate directly to parameters of the basic physical model of the Tibetan bowl. Though acceleration measurement is not crucial to the control of the model, we included it in our design specification for possible use in extended performance control.

The acceleration measurement was performed quite simply using a commercial 2-axis accelerometer.

In order to measure velocity, we began by placing magnets, which are the only visible components of the sensing system associated with the controller, on the inside of the singing bowl . These were temporarily affixed to the side of the bowl using a small amount of easily-removable putty. Two Hall effect sensors were then employed to detect the presence of the magnetic field produced by the magnets. The rate of the appearance of the peaks in the Hall sensor data is then taken to reflect the velocity of the stick in its trajectory around the bowl.

Building the pressure sensor for the HyperPuja was a challenge, as we wanted the model to be able to respond to continuous pressure changes between the stick and the bowl occurring at any contact point on the traditional playing area of a rubbing stick. This criteria concerning area, as well as the added constraints of working with a curved surface and our initial priorities demanding simplicity in hardware, made the common use of devices such as FSRs unfeasible here.

Through experimentation, a novel pressure sensor was designed. Conductive rubber, which responds to changes in pressure with a decrease in the resistance measured between the planar surfaces at the points directly above and below the point of contact, was ultimately used. The pressure sensor was comprised of three layers of material wrapped around the stick: a thin piece of copper foil carefully adhered directly to the stick, a sheet of conductive rubber (0.5mm think) placed around the first layer of copper, and a piece of finely woven copper fabric secured over the rubber. By this construction, the conductive rubber is held in place simply by the sleeve of copper fabric and a final piece of chamois placed over the entire assembly that closely resembles the leather found on many traditional rubbing sticks. The changes in resistance that occur as a result of pressure fluctuations are measured by making contacts to the two pieces of copper material.

We began the construction of the HyperPuja stick by first hollowing out the middle volume of a traditional rubbing stick. This process left a 0.9” diameter cavity in which to place our electronics. The electronics board that houses the accelerometer, Hall sensors, microcontroller, wireless transmitter, and the battery were all placed inside the barrel of the stick. The electronics board is powered by a 3V camera-style battery that has a lifetime of over 30 hours in this system. The microcontroller used for the HyperPuja is a PIC16LF877, which possesses an internal 10-bit A/D converter. The signals from the Hall sensors and the pressure sensor are sent to inputs here. The accelerometer (ADXL202) outputs two digital signals, which are routed to two other input pins of the PIC. The data stream for all of the sensors is transmitted with a wireless transmitter using a serial protocol that is received remotely. This data stream for all the sensors is then sent using the wireless transmitter with a serial protocol. This data is then collected by a receiver on a remote board that connects to the serial input of the Windows machine used for our experiments. The electronics inside the HyperPuja stick can be seen in Figure 1.

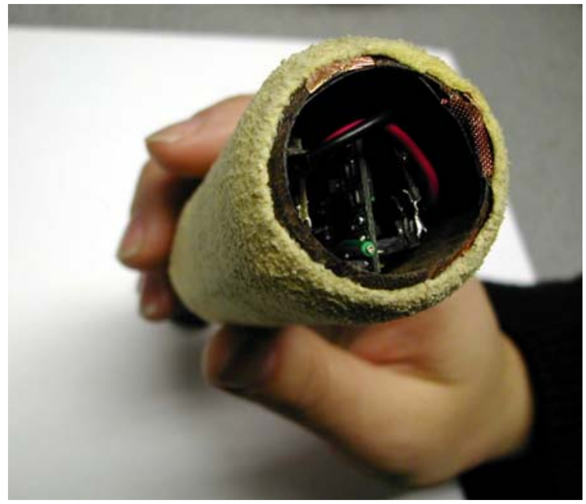

Figure 1: The electronics inside the HyperPuja stick.

The complete design can be seen in Figure 2. Here, the magnets used for the velocity measurement, the only apparent component of the sensing system, may be seen inside the bowl.

Figure 2: The HyperPuja stick with a Tibetan singing bowl. The magnet for the hall effect sensors can be seen inside the bowl.

2.1 Sensor Data and Synthesis Model Parameter Visualization

The HyperPuja data is displayed using a C++ stripchart application. For the first experiment using the HyperPuja to control the physical model of the Tibetan bowl, we established a C++ software link between this GUI and the tcl/tk GUI displaying the input parameters of the physical model. This method of interfacing between the controller and the model was chosen because it offered a test setup that facilitated control of the model with the HyperPuja and also allowed immediate experimentation with un-mapped parameters using the computer mouse.

The whole setup in performance is depicted in Figure 3. The first working prototype of this interface allows a performer to control each of the "bow pressure", "bow velocity", and "integration" parameters of the synthesis model with the pressure, hall effect, and acceleration sensors in the HyperPuja stick, respectively.

Figure 3: The HyperPuja stick in performance. The laptop screen shows the sensor data display on the left and the sound synthesis GUI on the right.

3. PLAYING THE STICK

These initial experiments with the current implementation of both hardware and software are very encouraging, as with limited practice a player is able to create a convincing performance using the HyperPuja of what sounds and looks much like a traditional Tibetan singing bowl. Often during various practice sessions, casual observers remained unaware that the sound they were hearing was not being generated by the acoustic bowl. From the perspective of the performer, the HyperPuja stick was found to have a comparable "feel", both in terms of weight and the perceived friction produced between it and the bowl, to a traditional rubbing stick.

In playing the model, it is apparent that the nature of the sound produced is the product of the unique evolution of the current performance. That is, the sound builds and progresses in such a way that is strongly influenced by time and reflects the history of the interaction between the stick and the bowl. This behavior reflects the non-linearity of the friction mechanism [1]. This characteristic of the interaction, which is of course also shared by a real Tibetan bowl performance, greatly contributes to the overall experience of playing the HyperPuja, as there is an inherent sense of exploration and discovery in the process of playing. From this initial aesthetic observation, it would seem that some of the challenging and engaging performance characteristics of the traditional instrument are maintained by this controller. The desirability of such traits in new controllers is discussed in [9].

4. ACOUSTICS AND SYNTHESIS OF TIBETAN SINGING BOWL

The Tibetan singing bowl has received modeling attention in recent years [8, 23, 17, 3] based on banded waveguide synthesis which was earlier introduced for struck and bowed bar percussion instruments [7]. In the following we will repeat the essential features of the acoustic properties and the synthesis algorithm as it was used in conjunction with the controller.

Courtesy James F. O'Brien

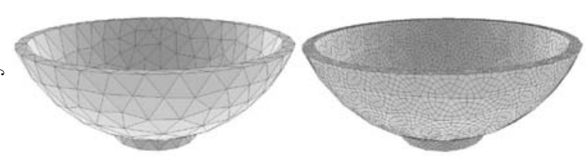

Figure 4: Mesh of simulated bowl.

For this discussion we'll assume a Tibetan singing bowl that is geometrically close to a spherical segment. A discretized mesh version of the bowl can be seen in Figure 4). Depending on the rubbing velocity and initial state of the bow (i.e. certain modes may be already ringing), various frequencies can be made to oscillate. Behavior is comparable to rubbing or bowing a wine glass [8, 15] in terms of dynamic envelope, mode locking, mode duplication and related phenomena as a result of the non-linear interaction of the stick-slip-based rubbing.

Courtesy James F. O'Brien

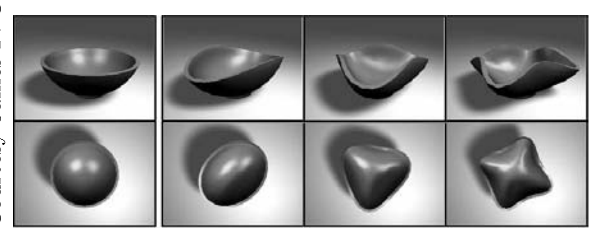

Figure 5: Simulated mode shapes of the bowl.

If struck, the bowl will show a modal response of circularly symmetric form. The first few modal shapes are depicted in Figure 5 with exaggerated amplitudes. These shapes will oscillate around the circular rest position in a manner comparable to circular flexing motion of the wine glass depicted in Figure 6. The circularly repeating pattern is depicted in Figure 7.

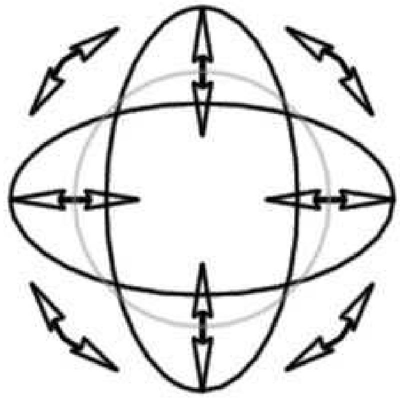

Figure 6: The wavetrain closure on the rim of a wine glass and corresponding flexual waves as seen from the top (after [13]).

Figure 7: Path of circular mode on bowl (used with permission from [6]).

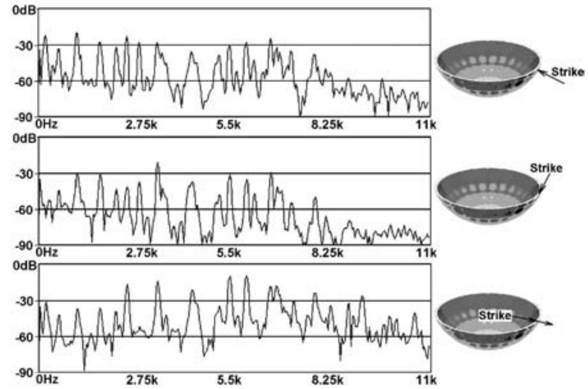

Figure 8: Spectra of different excitations (used with permission from [6]).

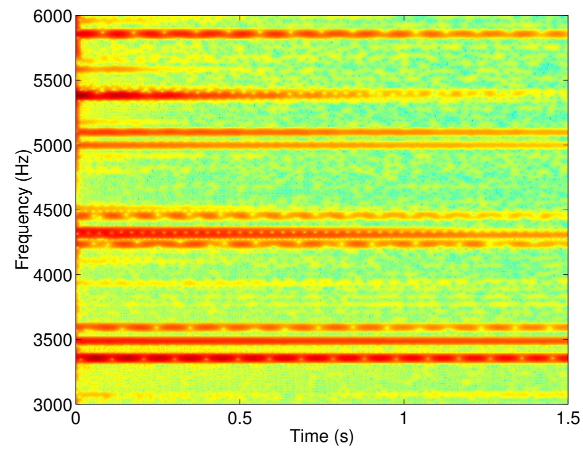

Figure 9: Beating upper partials in spectrogram of a recorded Tibetan bowl.

The measured spectra of the struck bowl can be seen in Figure 8 for various impact positions. As can be seen, there are a number of higher modes that lie close together yielding audible beating. The beating can be seen more clearly in Figure 9.

4.1 Beating Banded Waveguides

The beating modes combined with the very weak damping poses the main challange for modeling the dynamics using banded waveguides (as depicted in Figure 10.)

For two neighboring banded wavepaths whose center frequencies get close, the respective frequency-bands start to overlap strongly. This means that energy will contribute to traveling waves in both bands simultaneously. To guarantee stability within the frequency region the sum gain of both waveguides can not exceed unity as both are summed together for interaction or feedback. More specifically the gain of the respective banded wavepaths can be calculated from the maximum of the overlapping bandpass filter amplitude characteristics. This maximum has to be tuned to the desired gain, and the respective gain of the bandpasses is adjusted by the weight of the overlap. The resulting simulation of an isolated beating mode pair can be seen in Figure 11. The relative ratio between the modes is 1 : 1.05.

The beating modes following this construct, combined with plain modes then yields the complete simulation of the Tibetan bowl, which can be achieved with less than 20 banded wavepaths including beating mode-pairs.

4.2 Synthesis Parameters and Mapping

The complete synthesis model takes radial stick force and rubbing velocity as input. In addition an integration factor is included in the friction model that allows for artificial mode coupling. These are then mapped to sensor outputs. The sensors provide a measure of the radial stick force. In the first version, the sensor data was experimentally scaled and offset to achieve a playable region comparable to the subjective playable region of an actual bowl performance. The velocity is calculated from the time differential between peaks in the hall sensor output. Velocity is maintained throughout one rotation limiting the velocity responsiveness to slowly varying changes relative to average rubbing speeds. These are at about one revolution per 1 second. This value is use to control the rubbing velocity parameter of the model and corresponds to a physically accurate mapping. We have attempted to utilize the free sensor data of the accelerometer to control the integration value of the model. The integration value itself has no known physical interpretation and hence this mapping is quite arbitrary. In simulations that are meant to reproduce original bowl performance, this last mapping is usually disabled.

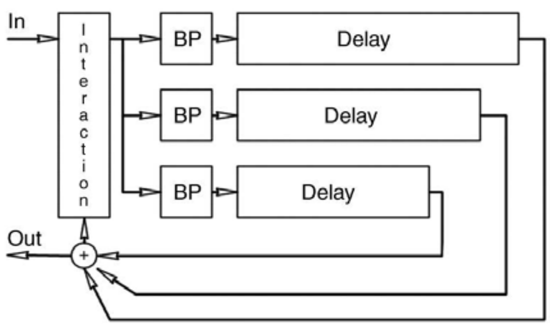

Figure 10: A complete banded waveguide system.

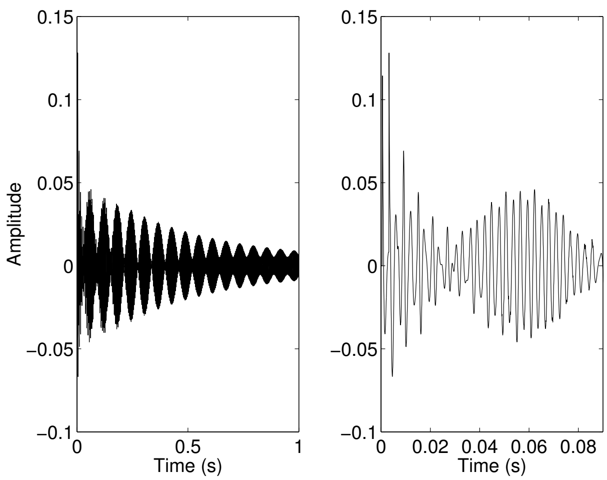

Figure 11: Left: Evolution of an isolated simulation of a beating mode pair. Right: Initial transient and the first beating period.

5. CONCLUSION

The HyperPuja provides a first controller design that maintains the physicality of the actual rubbing interaction and measures relevant physical parameters for the rubbing motion to be mapped to synthesis algorithms. Previous work either uses frictionless gesture [22] or EMG and position sensing technology [19] that each don't directly map to the original interaction type. While Tanaka and Knapp maintain the physicality of the rubbing gesture in performance, the sensed parameters don't have a physically close correspondence, which affects the mapping to parameters of physical models of the bowl. We see the maintenance of the original physical interaction and the sensing of the interaction-relevant parameters as a significant design advantage, because questions of force-feedback and responsiveness, engagement and intimacy, as well as performance familiarity and analogy are answered by maintaining the physical characteristics of the original behavior. At the same time the interaction gesture is decoupled from the physically sounding body. The interaction can now be performed on non-sounding objects and can be extended to arbitrary sound synthesis and manipulation algorithms. This design also hides technology and makes it unencumbering allowing the performer to focus purely on the physical interaction.

In future work, we will continue to extend the integration of the HyperPuja stick and the physical model of the Tibetan singing bowl. In particular the coupling of gesture and sensor data to synthesis model parameters will be investigated in more detail, also including a more direct unification of the data visualization and a more streamlined performance system. The modeling itself may need improved accuracy in the description of the friction coupling, and so related work in this area will be utilized [16].

We will also experiment with a version of the HyperPuja stick that includes a pressure sensor covering only part of the length of the playing surface, so as to provide a player with the performance option to excite the bowl acoustically using the hard wood surface. Maintaining the acoustic capabilities of the bowl itself and allowing the player to have the tactile feedback of the bowl's vibrations (transmitted to the hand and felt through the stick), while also providing the sound of a virtual bowl could produce a unique electro-acoustic performance experience.

In the next version, we will also experiment with additional sensing techniques for extended performance. For instance, it may prove interesting to measure the proximity of the stick to the bowl as well, or exploit different kinds of tilt of the bow stick using perhaps another accelerometer.

We will investigate the possibilities of using and perhaps making alternate kinds of bowls that will provide different form factors for playing and may be useful for exploring the limits of the physical model. In fact, we look forward to exploring the performance possibilities of bowing (rubbing with the HyperPuja stick) completely different kinds of structures and eliciting quite different sounds from the physical and non-physical synthesis models. Examples of this type include performance of the glass harmonica [8], the musical saw [15] and other friction based sound sources.

6. ACKNOWLEDGMENTS

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