FROM MATHEMATICAL CONCEPTS TO HANDS-ON INTERACTION: PHYSICAL MODELING AND INTERACTION PARADIGMS OF TABLAS AND SINGING BOWLS

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ABSTRACT

In this paper I discuss recent research in sound synthesis and musical performance. Two fields have developed that are concerned with two separate but connected questions: (1) How can we come up with synthesis algorithms that are based on the physics of musical instruments, which are fast enough to be useful for life performance? (2) How can we build new musical instruments that are engaging, meaningful and "feel right" for the performer, the audience and the composer? In the field that studies the first question, it has been realized quite early, that the fact that the synthesis algorithms are driven by physically meaningful parameters makes them very suitable for use with physical input devices that register related parameters. Similarly it has been realized by instrument designers that it is helpful in leveraging expert skills on existing instruments when designing new ones. This has led to a synergy of algorithm and instrument design, whose cross-relationship are to be discussed in this paper.

1. INTRODUCTION

Traditionally the fields of building new musical instruments and the development of sound synthesis algorithms have been treated quite separately. However in recent years, these fields have come together to form a space of mutual benefit, but also of mutual necessity. The instrument design, to be successful and the synthesis method have to know of each others subleties.

In this paper I want to discuss these connections by the example of two synthesis algorithms and their corresponding instrument designs. In all these cases the the departure point are existing traditional musical instruments. These are the Tibetan singing bowl and the Indian Tabla drums. The reason for these selection is mostly personal. My own work centered around sound synthesis of these instruments which led to collaborations with instrument designers who worked on controller design.

However this approach is by far limited to these cases. In fact the electronic keyboard used by most commercial synthesizers is an example of a "new controller" piano and much attention has been paid to the physical modeling of piano sounds in recent years. See [1] for a recent review of this literature. Also other instruments have been designed following this paradigm. Contemporary examples include the HyperBow, BoSSA and vBow as Violin bow controllers [2, 3, 4] and related synthesis algorithms [5], the Pipe and the ePipe as a wind instrument controllers [6, 7] just to mention a few. For further a history of these instruments refer to this excellent review article [8] and the proceedings of the conferences on New Interfaces for Musical Expression (NIME). Synthesis based on physical modeling of musical instruments have recently been reviewed by [9, 10].

In what follows I will pay most of my attention to concepts and higher level insights. For details I'll provide references to prior publications.

The remainder of the paper is structured as follows. First I will discuss general insights that can be drawn from combining controller and synthesis works. Then I will discuss these concepts with regards to two instruments. First the Tibetan Singing Bowl and then the Indian Tabla drum. These examples will be used to illustrate the given principles that make the joint development meaningful.

2. SYNTHESIS ALGORITHMS AND INSTRUMENT DESIGN

2.1. Physical Modeling Synthesis

The idea of physical modeling synthesis is to come up with ways to simulate the physics a musical instrument. There are various benefits to this approach. If the physics is appropriately captured, the model will behave like the instrument it was modeled after.

This means that dynamic responses to different kinds of excitations are like the ones you would expect from the physical instruments. Using sampling it would require recording for many different excitation types to get a believable response and this is exactly what commercial sampler-synthesizers will do. However this is not very suitable if the relationship between excitation and sound is very rich and complex. This is the case for instance in violin bowing. The bowing is a highly non-linear behavior and it is difficult to capture the subleties of performances by recording.

It also means that we get parameters that have some physical meaning, whether it is bow force and velocities or impact speed and weight of the beater. While these don't directly correspond to musical qualities they directly relate to parameters that performers would control.

Physical modeling is however not a trivial task. We will discuss some subtleties of modeling by looking at the examples.

2.2. Controller Design

The design of a new musical instrument is a formidable task. The feel and playability of the instrument, the way the audience is able to relate to the instrument, the available sensor technology and the social acceptability are but a few things that an instrument builder has to consider (for discussions of these and other problems see [11, 12]

On particular problem that any sensor-based musical instrument faces is the *mapping problem*. The output of the sensors of the instrument have to be related to, that is mapped to, sound generation mechanisms in some way. Many of the above mentioned concerns have a bearing on the mapping problem. How does a mapping affect the playability of an instrument? How does a mapping affect the meaning of instrument gestures to the audience? And of course there are more such questions. Much of this mapping defines the meaning of an instrument.

However the sensor data is usually not just something arbitrary. These values correspond to physical parameters that the sensor picks up and with some characteristic and noise converts into numbers. Many of these numbers still hold a very strong resemblence of the physical parameters.

This suggests a particularly easy solution to the mapping problem. If the synthesis algorithm takes physical values that are sensed by the instrument, then the dynamic behavior, and meaning is already anchored in the physical world, which performers and audiences alike understand quite well. After all we live in it all the time.

As said earlier, it is this easy solution of the mapping problem that motivates the joint development of synthesis algorithms and instrument design. But this joining also puts additional constraints on the approaches on both sides. Even the *"easy" mapping problem* needs to be addressed. We'll see how this worked out in the development of two examples: The Tibetan singing bowl and the Tabla drums.

3. TIBETAN SINGING BOWL

3.1. Physical Modeling Synthesis

The tibetan singing bowl are geometrically close to spherical segments. In typical performance the bowl is rubbed with a wooden stick (sometimes wrapped in a thin sheet of leather) along it's rim. Depending on the rubbing velocity and initial state of the bowl (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 or a glass harmonica. In all these cases the dynamic behavior critically depends on the non-linear interaction of the stick-slip-based rubbing.

If struck, the bowl will show a modal response of circular-symmetric form. These shapes will oscillate around the circular rest position comparable to circular flexing motion of the wine glass.

As a symthesis algorithm I used banded waveguides, as depicted in figure 1 because it allows the efficient modeling of sounds in solids while also allowing both struck and rubbed interactions [13].

As control parameters one is left with tangential pressure on the bowl and velocity of the rubbing stick relative to the bowls static surface, when the model is set for non-linear bowing interaction.

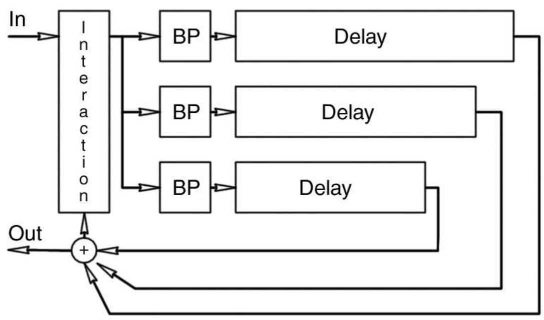


Figure 1: A complete banded waveguide system.

3.2. Musical Controller Design

Now the task is to build a controller device that allows to control the synthesis algorithm in an immediate and meaningful way. Diana Young developed this very neat controller with full awareness of the behavior of the synthesis algorithm [14].

As the bowl is rubbed with a wooden stick that is sometimes called "puja", we coined the controller HyperPuja.

The task was to find a design that would sense the appropriate data for the model, while maintaining the previous performance behavior of the instruments, so that musicians could use their prior skill when playing it.

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".

The data that needed sensing was pressure and velocity. The way Diana Young solved these to problems was twofold. For the pressure sensing she developed an ingenious new sensing mechanism using conductive rubber that can be wrapped around the stick and will give uniform responses independent of the orientation of the stick. To sense velocity she uses hall effect sensors that will sense the change in magnetic field as the stick passes little magnets stuck inside the bowl. All of the electronics is neatly hidden inside the stick and connects to the computer using wireless technology as can be seen in Figure 2. Hence not only superficially does the HyperPuja controller very much look, feel and weight the same as a traditionally leather-wrapped stick. The whole system in action, including sensor data display and the synthesis algorithm can be seen in Figure 3.

To compare this coupled implementation with other controllers that have been developed and used with bowl synthesis highlights the advantage of the tight coupling.

(Draft note: To fill in comparison with Wilkerson's MuthaRub-Board and Atau's EMG sensing technology).

(Draft note: Add remarks about coupling and decoupling in this case)

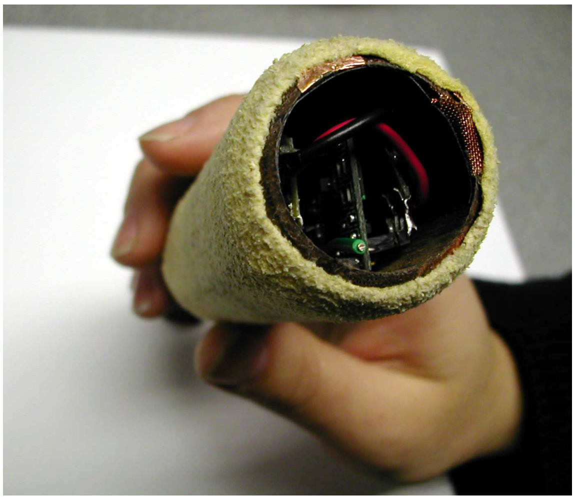


Figure 2: The electronics inside the HyperPuja stick.

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.

4. TABLA DRUMS

4.1. Sound Synthesis

The Tabla is a pair of drums (see Figure 4) with a number of interesting characteristics. The modes of the first four to six partials are harmonic, unlike what one might expect from a circular membrane. To achieve this harmonic tuning, the Tabla drums are manufactured using membranes of non-uniform thickness [15]. There are a number of typical performance strokes to Tablas. One interesting stroke is a modulating form of the "Ga" stroke, which is performed on the larger, right drum, called "bayan." (with foreign language words like these I depend on others, in this case on Ajay Kapur). The palm of the hand resides on the drum. After the drum has been excited with a quick impact with the finger-tips, the player pushes her palm down and towards the center of the drum and hence achieves a characteristic upward pitch-bending sound [15]. The small drum is called "dahina".

Banded Waveguide synthesis can also be used for two-dimensional structures, like membranes. The situation becomes somewhat more complicated in two dimensions but the relationship between physics and mathemtical model

Figure 4: The Indian Tabla Drum consisting of the larger bayan (left) and the smaller dahina (right).

have been worked out starting with seminal work by Keller and Rubinow [16].

They show how paths of rays on the circular membrane can be constructed and related to the membrane's vibrations. Figure 5 gives a glimse at the construction, but will details have to be found in [16, 17].

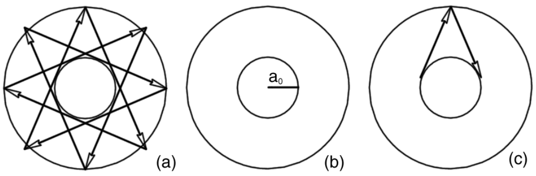


Figure 5: Path construction on the circular domain (compare [16, Fig. 3 and 5]). (a) Closed path touching the interior circular region. (b) A purely circular path. (c) Path containing rays traveling from interior circular region to boundary and back.

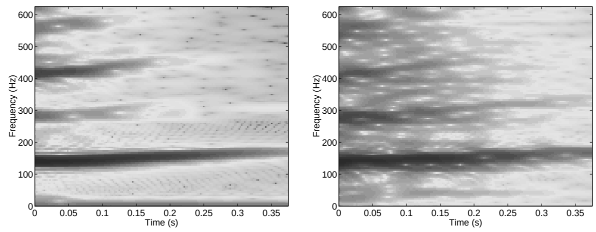
The trajectories which lead to closed paths can be constructed for circular membranes. Also even closed paths in dimensions higher than one are tied to modes using the principle of closed wavetrains [18]. And as the ideal paths are altered by the non-uniform thickness using the principle will give use a corresponding corrected and averaged path. So the path construction is no longer strictly valid, but the modes will be definitely be right.

The results of modal comparison between real drums and propagation simulations can be found in Table 1. The strokes performed are open membrane strokes in the center on both the bayan and the dahina. This was in turn modeled as impulsive excitation.

Using this principle of closed wavetrains we can infer how dynamical interactions of strokes relate to pitch changes through path-length changes. Here we are particularily interested in the "Ga" stroke. In this case, the pitch-bending technique directly corresponds to shortening the physical path of waves traveling on the membrane, which can be directly implemented in a banded waveguide model.

	Bayan		Dahina	
n	measured	simulated	measured	simulated
2	2.00	2.02	2.89	2.87
3	3.01	3.03	4.95	5.01
4	4.01	4.05	6.99	6.73
5	4.69	4.72	8.01	8.00
6	5.63	5.65	9.02	8.70

Table 1: Spectral frequencies of dominant partials of measured and simulated Tablas given as $f_n : f_1$.



(a) Recorded (b) Simulated

Figure 6: Spectrogram showing the upward bending of a modulated *Ga* stroke. The fundamental bends from 136 to 162 Hz (measured) and 134 to 171 Hz (simulated).

The results for the more complicated pitch-bending strokes can be seen in Figure 6. The simulation shows good resemblance and sound comparable to the recorded stroke. It should be noted that the simulation method is robust to the pitch-bending manipulation. In fact, much more extreme bends than the one depicted here are possible. High pitched large-scale bends on our propagational model perceptually closely resemble water-drop sounds, suggesting a much wider range of interesting application for behaviors of this type.

5. CONTROLLER DESIGN

(Draft notes: To add ETabla discussion [19]).

6. CONCLUSIONS

(Draft notes: To add conclusions)

7. REFERENCES

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