THE DISPLACED BOW AND APHISMS: ABSTRACT PHYSICALLY INFORMED SYNTHESIS METHODS FOR COMPOSITION AND INTERACTIVE PERFORMANCE

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ABSTRACT

Physical Modeling has been around for a while and has been used for musical compositions and interactive performance. This paper explores new ways of looking at physical or physically informed synthesis methods in the light of recent developments in the field. In particular, *Banded Waveguide Synthesis* [1] offers an intersection between spectral modeling and physical modeling that can be abstracted and seen as controlled compositional devices. Also, physical input usually drives interactive performances, which makes physical modeling an appealling synthesis method as the parameters are of this physical nature. This paper explores how abstractions of the synthesis algorithms formed by physical models can yield new and surprising results for composition and performance. The *Displaced Bow* is introduced as an algorithm for creating richly textured spectra.

1. INTRODUCTION

In an abstract and technical sense composition and musical performance can be seen as the task of deciding how to fill and change the spectral content over time. Without constraints there are infinitely many (in the continuous sense) or at least a very large number of variable (in the discreet sense) to pick from.

Synthesis algorithms can be seen as a way to reduce the number of parameters. Then the question remains, how those reduced parameters control the much larger set of parameters. For the composer and improviser it is also of interest, if this particular form of control is desirable. This desirability is obviously subjective, but certain observations can be made. For one the control the composer is seeking may be different to the control an interactive performer is seeking due to the nature of the tasks. For example, real-time performance is essential to live performance, whereas merely desirable to the composer (see also Loy's critique of Music N with regards to the relation of computation time to compositional convenience [2, p. 331]). Also the performer may worry about the physical way in which the sound is controlled.

At the same time there are attribute which both composition and interactive performance share. To illustrate this, a variation and an extention of Perry Cook's *Principles for Designing Computer Music Controllers* [3] may be helpful. His principle "Programability is a curse" relates to the parameter mapping problem mentioned before. Too much required control can be a problem, hence the modified principle"Too many parameters may be a curse".

The interplay between control and intend on the one side and instrument and synthesis method on the other side are related to by two complemetary Cook principles, namely "new algorithms suggest new controllers" and "new controllers suggest new algorithms". This should probably be modified to "new algorithms suggest new compositions/performances" and "new compositions/performances suggest new algorithms". Neither of those may seem surprising. If an algorithm is seen as a musical instrument, then the first principle corresponds to musical instruments suggesting (through it's characteristics) uses in composition and performance. The second corresponds to the choice of the composer and performer in expressing the artistic intent. This intent may result in picking an existing instrument, lead to particular use of that existing instrument or may ask for new instruments (following Edgar Varese's often cited remark "We need new instruments very badly." [4, p. 294]).

The "success" of a new synthesis algorithm then can be seen as either a offering controls that are close to the expressive intent of the artist (and possibly keeping this intent transparent to the audience) or if the result of the algorithm is deemed desirable in use by the artist and in performance to the audience. An evaluation of success is highly subjective and the purpose of this paper is not to make a determination in that respect. Rather the purpose is to illustrate how the properties of algorithms affect composition and interactive performance. The argument centers around the point that abstracting physical or physically informed algorithms retains properties that are desirable.

To facilitate this discussion I would like to suggest a number of categories and dichotomies:

- Predictability/Unpredictability
- Familiarity/Novelty
- Robustness & Stability/Fragility
- Flexibility/Rigidity
- Simplicity/Complexity
- Efficiency
- Expressiveness
- Fidelity
- Causality & Correlation/Detachment

All of these categories relate to the control of the algorithm and the subjective perception of the result of the control. Depending on the intent of the artist, closeness of a synthesis algorithm to one or the other end of a dichotomy or to a category may be desirable.

2. BANDED WAVEGUIDE SYNTHESIS AS AN APHISM

Next Banded Waveguides will be discussed in the above mentioned context. First the method will be briefly reviewed and then the parameters and their properties will be discussed. Then abstract manipulation of these parameters will be discussed as well as non-physical extensions. Finally, these manipulations are evaluated with respect to the categories of control and subjective perception.

2.1. Banded Waveguide Synthesis

Banded Waveguide Synthesis is a physical modeling synthesis technique originally developed for the synthesis of bowed bar percussion instruments [1], though it has sence been realized that the synthesis method for musical instruments where vibrating elastic solids are responsible for the sound generation [5]. Drums [6], cymbals [7] glass harmonicas [8, 9], tibetan prayer bowls [8, 10] and the musical saw [9] have been modeled using this method.

The algoritm itself is widely available through the Synthesis ToolKit (STK) by Perry Cook and Gary Scavone [11], PeRColate by Dan Trueman and R. Luke DuBois [12] for MAX/MSP and Olaf Matthes for PureData [13].

Here only the basic intuition will be repeated and the reader is directed to the above references for further details.

The basic structure of the Banded Waveguide Synthesis method can be seen in figure 1. It consists of a number of delay-lines. A number of bandpass-filters (labeled **BP** in figure 1) and an interaction unit which takes an input parameter. The signal coming out of the interaction unit is separated into frequency bands through the bandpass filters, then delayed and then combined again in a summation operation and fed back into the interaction unit. This structure can be seen as spectrally decomposed form of the classical Karplus-Strong algorithm depicted in figure 2, where the lowpass filter is replaced by gains in the bandpass filters of figure1.

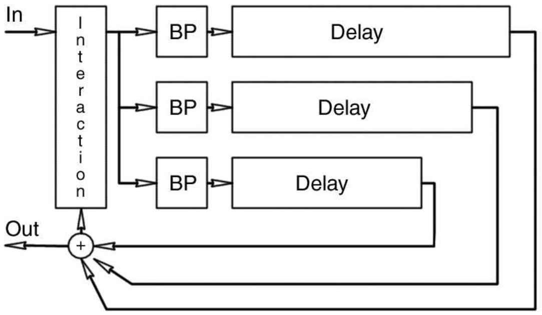

Figure 1: *The Basic Banded Waveguide Structure.*

Figure 2: *The Karplus-Strong Algorithm.*

2.2. Banded Waveguide Synthesis Parameter Space

Banded Waveguides as abstract entities (i.e. in the absence of a physical interpretation) retain a number of parameters for control. These are:

- Number of bandpass/delay pairs.
- Length of delay lines.
- Frequency of bandpass filters.
- Content and parameters of the “interaction module”

The first three categories correspond to spectral content. In fact in the physical interpretation the frequenct of the bandpass filter and the frequency of one resonance of the comb-filter associated with the delay-line following the bandpass filter are set to be the same. Hence, the delay-line and bandpass filter is seen as a conceptual unit block (as seen in figure 3) that defines a *spectral unit* contribution.

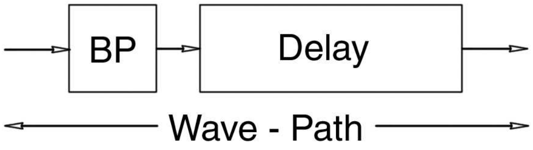

Figure 3: *The "Spectral" unit of Banded Waveguide Synthesis. In the physical interpretation it is called a Banded Wavepath.*

Following this unification leaves three parameter types. Number of spectral units, frequencies, and choice of interaction module. Hence a Banded Waveguide is in this sense really a spectral synthesis method. There are two main advantages over standard spectral synthesis:

- The ability to use physical or physically informed interaction methods on non-physical spectral content.
- The manipulation of spectral content through mode-frequency bending, automatially retaining continuity and the ability to physically (or in another physically informed, hence controlled fashion) interact with it.

The spectral content can be choosen by allocation of spectral units, but the underlaying structure retains it's physical and algorithmic properties even in the abstract application. This means that a wide variety of spectral content, even in the absence of a corresponding physical instrument or sound generation mechanism can now be physically interacted with. For example novel spectral content can now be "bowed" by a bowing interaction method as driving input.

On the other hand, the spectral content can be choosen physically or otherwise, but the interaction method can be abstracted maintaining simple stability conditions. Usually starting from a physical interaction method and abstracting it can be helpful.

2.3. Properties and Stability Conditions

The overall stability of a Banded Waveguide is characterized by the loop-gain of the complete structure. This can best be understood at the point right after the summation operation in Figure 1. If the total accumulated gain of all samples through the structure is less or equal than 1 at that point, the total energy within the structure in the absence of external input will remain the same or decrease. This is true independent of the presence or absence of an interaction model. Any insertion of a block still has to maintain that condition. So including an interaction model, in order for it to be stable it has to have a maximum gain of 1. Any interaction model which satisfies this condition will result in stable simulation.

3. NON-PHYSICAL INTERACTIONS

3.1. The Displaced Bow: Integrated Bow Interaction

A particular type of non-physical interaction was discovered by accident when Banded Waveguides were developed by the author. An uninitialized variable led to the bow velocity that is usually fed into a bowing algorithm to be accumulated (or "integrated") over time. The resulting sound was surprisingly rich and expressive. The name *Displaced Bow* comes from the fact that integration of velocity is displacement. This is a non-physical interaction model, because it is doesn't make physical sense to drive a model that requires velocity as input with displacement.

Examples of musical performances using integration on a bowing mechanism of various Banded Waveguide Models can be heard in the sound example accompanying this paper. The example was computed in real-time using a graphical user interface using TCL/Tk as provided by the STK software bundle. First one strike on each Banded Waveguide model can be heard followed with short physical bowing interactions. The models are based on physical parameters measured from a uniform wooden bar, an aluminum vibraphone bar, a wine glass, and a tibetan prayer bowl (see [1, 8] for details). Thereafter non-physical integrated bowing is performed. Main varying parameters are bowing velocity and force. The pitch is changed at times as well as the underlaying banded waveguide model to illustrate the change in sound creation. Integrated bowing creates a rich and variable spectrum with modes fading in and out, bend their frequency and interact with each other, though the transition between the various stages is well-behaved. There are no clicks or mechanic transitions. The spectral content is guided by the modal structure of the underlying Banded Waveguide model.

3.2. Arbitrary Non-Linearities: "Spectral Waveshaping"

The Displaced Bow is only one example of abstract manipulation that is possible for interaction models. The non-linearity of an excitation model (like the action of a bow, the behavior of a reed and so forth) can be altered. It can also be replaced by any other non-linearity that satisfies the stability condition mentioned before. As an example the bow-nonlinearity as depicted in figure 4 was replaced by an alternative function which was calculated from an exponentially dropping sinusoid that is bound by a gain of 1 as can be seen in figure 5. This table was chosen without any physical motivation and the bow interaction structure is kept for convenience only. The result a much more aggressive interaction model can be heard in the second sound example.

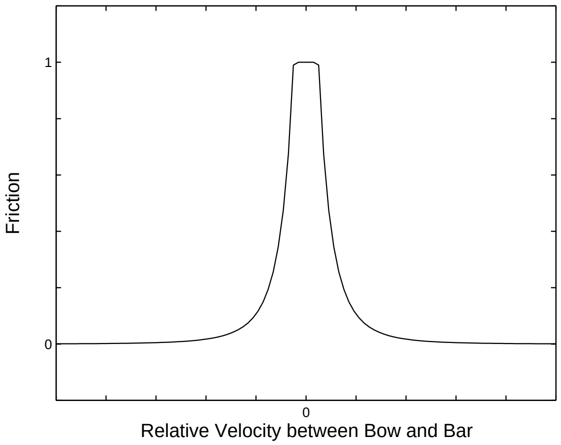

Figure 4: *The standard friction table used in the bowing algorithm of both the standard and displaced bow.*

Standard wooden bars, vibraphone bars, glass harmonicas and tibetan bowls are excited with the model. There are now multiple regions of excitation. The final part of the example is including the integration factor of the Displaced Bow. The texture is rougher than that of the generic Displaced Bow.

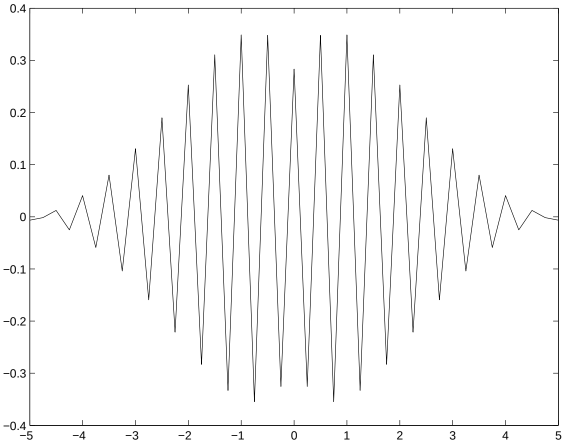

Figure 5: *The abstract interaction table used in the bowing algorithm instead of a physically motived one.*

This approach has resemblance of a method called “waveshaping” for waveform manipulation. In this method the waveform itself is fed into a possibly non-linear function to manipulate the timbre. The new approach does not directly manipulate the waveform, but rather shapes the spectral decomposition of the waveform. The advantage is that spectral control is retained while keeping the flexibility of waveshaping, hence the name *Spectral Waveshaping*.

4. DISCUSSION AND CONCLUSIONS

In the introduction of this paper, a number of categories were introduced, which relate to control of algorithms and the subjective perception of the results. The advantage of abstract physically informed synthesis methods (APhISMs) is that efficiency, fidelity and causality are inherent to the method. In addition by using expressive physical interactions (like bowing) as starting points, expressive non-physical ones can be intuitively abstracted. With regards to to dichotomies of (un)predictability, familiarity/novelty, rigidity/flexibility and simplicity/complexity, APhISMs relate these dichotomies to the categories physical/abstract. This is beneficial for various reasons. Familiarity in traditional forms of music expressions through physical instruments can be used to guide the exploration of the unfamiliar. The Displaced Bow is a surprising example of an abstraction that yields rich and expressive new sound but retains desirable properties, of stability, causality, fidelity, efficiency and control over spectral content. Spectral content and textural features can be controlled separately in a seamless and interactive fashion, which makes this approach very suitable for real-time performance. Physical parameters of traditional or novel musical instruments map directly to parameters of the algorithm and hence this approach does not have an inherent mapping problem.

In this paper just a few possible abstractions were discussed to illustrate the idea. Following this idea a wide variety of manipulations remain to be explored through artistic application and technical analysis.

5. REFERENCES

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