Physical Model of a Handpan instrument

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I. Introduction

This current work corresponds to the mini project of the course Modelling Physical Systems of the MSc Sound And Music Computing. The goal of this mini project is to simulate the physics and the sound of a Handpan instrument.
The report starts by describing the Handpan instruments in section II, in the next section it is explained the synthesis method used to model the sound, the Banded Waveguides. In section IV, the implementation process is described.

II. Hand Pan instruments

Handpan is the term given to the musical instruments similar to the trademarked instrument *Hang* [1], which will be the model to follow. Figure 1 displays an image of a Handpan instrument. Handpan are percussive instruments of

Fig. 1. Hang

the idiophone family, which create sound by vibrating the whole instrument. Gentle finger strikes to individual notes allow the instrument to vibrate and produce sound.
The sound of the presented implementation is based in the work of Eyal Alon and Damian T Murphy in [1], in which they recorded an analysed four different Handpand instruments. According to them, the sound of the Handpan is characterized by three partials with an approximated frequency ratio of 1:2:3. The average decay time of the instruments they analyzed was 2.9s with a maximum of 5.9s and a minimum of 0.9s. In the same way, they describe the amplitude modulation that some partials show, which, in average, this rate is 4.44Hz.

In order to simulate this sound, the Banded Waveguides method has been used.

III. Banded Waveguides

The Banded Waveguides method is an extension of the popular Digital Waveguide method [4], used sucessfully to simulate plucked-string instruments. The Bandedd Waveguides, presented in [3], have been proven successful in modelling idiophones instruments, bowed glasses and bowls, and Tabla [**?**].

In this section, the theory of the digital waveguides is first explained followed by the theory of the banded waveguides.

A. Digital Waveguides

Figure shows the basic structure of a Digital Waveguide, which consists on a delay line and a low pass filter. Considering the example of a vibrating string, the delay line represents the string itself and the low pass filter models the losses along the string and the extremities.

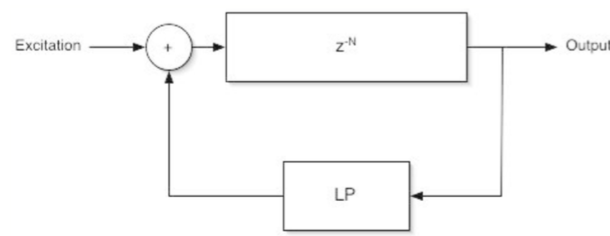

Fig. 2. Model of a vibrating string using Digital Waveguides. Taken from [3]

The equation that describes this method is the following:

$$y[n] = x[n] + \frac{y[n-N] + y[n-N-1]}{2} \quad (1)$$

where $x[n]$ is the exciter signal, $N = f_s/f_0$ is the length of the delay line, f_s is the sampling rate and f_0 is the fundamental frequency of the string.

The exciter signal can be, for example, a short noisy signal, a signal that can represent the movement of the string, such as a triangular function, or a recorded impulse response of a specific guitar. The output sound with this model is highly harmonic, that is the reason why it is well-suited for modelling string instruments. The harmonic content of the Handpan instruments is not as structured as strings. In this case, an extension to the digital waveguides is required.

B. Banded Waveguides

In this method of synthesis, the spectrum of the exciter signal is divided into frequency bands, which contain one resonant mode. For each band, a delay line models the dynamics of the travelling wave and the resonant frequency of the mode [3].

Figure 3 shows the diagram of a Banded Waveguide synthesis system with three modes. The rest of this section gives an overview of the system, it follows closely the article in which the Banded Waveguides were introduced, [3], please refer to it for details.

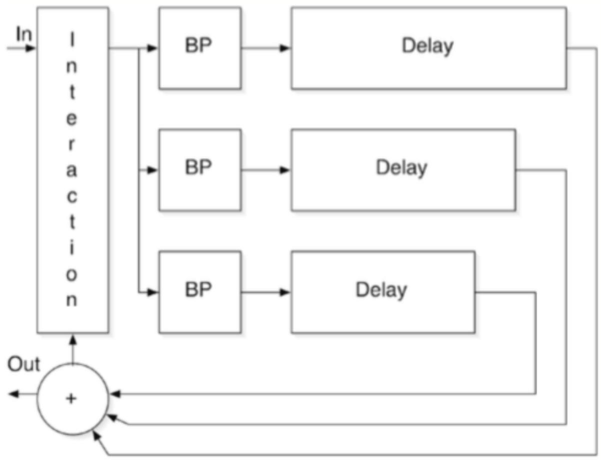

Fig. 3. Diagram of the Banded Waveguides. Taken from [3]

The "interaction" block corresponds to the exciter signal described in the Digital Waveguides section. The "delay" block delays the input signal a certain amount of time, it corresponds to the transfer function:

$$H_d(z) = z^{-d} \tag{2}$$

d is an integer delay-time, corresponding to $d = floor(fs/fm)$. Where fm is the mode-specific frequency.

The "BP" block corresponds to a band pass filtering operation using a second-order filter with the following transfer function:

$$H_d(z) = \frac{1 - z^{-2}}{1 - (2Rcos\theta)z^{-1} + R^2z^{-2}} \tag{3}$$

R^1 and θ define the poles and relate to the bandwidth B, center frequency ψ and gain A_0 as follows:

$$\begin{aligned} R &= exp(-\frac{\pi B}{fs}) \\ \theta &= acos(\frac{2Rcos(\psi)}{1+R^2}) \\ A_0 &= (1-R^2)sin(\theta) \end{aligned} \tag{4}$$

This leads to the following differential equation:

$$y[n] = A_0 * (x[n] - x[n-2] + 2Rcos(\theta)y[n-1] - R^2y[m-2]); \tag{5}$$

With this system, it is possible to implement a physical model of a Handpan instrument, in the following section this process it is described.

[1] In [3], R is defined as $R = 0.99 - B/2$. However, this did not work.

IV. Implementation

One parameter whose formula is not specified in [3] is the one to find the B parameter, the bandwidth for each mode. Since the bandwidth is related to the decay of the mode, the decay times found in [1] are used in conjunction of the following formula to find the values for each B:

$$B = \tau 2\pi f_m \tag{6}$$

Where τ is the decay time in seconds and f_m is the frequency of the mode. This formula has been taken from [2].

This model has been implemented in *MATLAB* and also as a Pure Data [5] external. Matlab has been used to validate the model and the external to develop a real time version of it.

The matlab script can be found in the companion zip file as 'hangphysicalmodel.m'. It allows to be used with different excitation signals such as a noise signal, a cosine impact, a recorded impulse response or the result of convolving the cosine impact and the impulse response. The result is far from the original recording, and the best result is achieved when using the last excitation signal described (listen to file $hangpm_ex1.wav$).

The impulse response has been obtained as the residual component after applying the Harmonic Plus Residual Model [6] to a recording of a Handpan note.

The external implementation is attached as 'bandedwg .c'. It is also attached the Pd patch 'hangphysicalmodel.pd' in order to use it.

References

[1] Eyal Alon and Damian T Murphy. Analysis and resynthesis of the handpan sound. 2015.

[2] Guy D. Moore. Lecture 21: Decay of resonances, 2006.

[3] Georg Essl, Stefania Serafin, Perry R Cook, and Julius O Smith. Theory of banded waveguides. *Computer Music Journal*, 28(1):37–50, 2004.

[4] Kevin Karplus and Alex Strong. Digital synthesis of plucked-string and drum timbres. *Computer Music Journal*, 7(2):43–55, 1983.

[5] Miller Puckette et al. Pure data: another integrated computer music environment. *Proceedings of the Second Intercollege Computer Music Concerts*, pages 37–41, 1996.

[6] Udo Zölzer, Xavier Amatriain, and Daniel Arfib. *DAFX: digital audio effects*, volume 1. Wiley Online Library, 2011.