Lecture 8: Physics-based Sound Synthesis

Introduction

Topic of this lecture was synthesis of sound based on physics. The lecture covered several approaches to perform physical modeling such as the Karplus Strong algorithm, digital waveguide method and functional transformation method. Besides covering those methods, it went over the necessary physical background to perform them. Through this diary I will give a brief overview of the lecture's contents and provide an implementation example of the Karplus Strong algorithm.

Methodology Overview

Karplus Strong Algorithm

Karplus Strong algorithm is one of the first physical models. It consists of a delay line (of varying length which has an impact on pitch) and an averaging filter. When a noise is passed through the aforementioned structure, it gets transformed into a very harmonic signal which resembles the sound of a string being plucked. Karplus Strong algorithm can also be further generalized by replacing the averaging filter by an arbitrary filter of choice in order to model variety of different physical effects such as dispersion, damping, reflections, etc.

Digital Waveguide Method

The idea for development of digital waveguides stems from the wave propagation in various elastic bodies, air columns or waveguides. This behaviour can be modeled using a bi-directional delay line. The procedure involves solving a wave equation of the traveling wave, modeling it in discrete domain and adapting it so that it resembles real oscillations using digital filters. Digital waveguide synthesis is mostly used for modeling different string and wind instruments. The method starts by solving a wave equation in terms of travelling waves obtaining

$$y(x,t) = y_l(x+ct) + y_r(x-ct)$$

. Thereafter, the solution is sampled in time and space and a discrete-time realization is obtained:

$$y[m,k] = y_l[m+k] + y_r[m-k]$$

where the output is the superposition (sum) of the signals propagating in the opposite directions. Boundary conditions caused by mechanical fixing in the physical world is modeled using various digital filters on both ends of delay lines, e.g. we can use simple filter for lossless reflection or more complex filters to achieve elastic bearing, coupling to the soundboard, etc.

Functional Transformation Method

This method takes a different approach compared to the digital waveguide method. Instead of modeling the behaviour using delay lines, first we want to describe the vibrations by using partial differential equations which contain the necessary information, we can then transform them into transfer functions and convert them into discrete-time models. The transfer functions are put into parallel and reflect each of the modes physical characteristics, outputs of each transfer function is summed to obtain the final output. Functional transformation models can be utilized to model various string excitations, e.g. by plucking in a guitar, by bow in a violin or by hammer in a piano.

Conclusion

This lecture provided some interesting techniques to perform physical modeling. Karplus Strong algorithm was especially interesting as I was not previously aware that such simple and computationally efficient technique can model such convincing replica of string plucking.