

ARTIFICIAL INTELLIGENCE BASED MODELING OF MUSICAL INSTRUMENTS

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ABSTRACT

In this paper, a novel research tool, which allows real-time implementation and evaluation of sound synthesis of musical instrument, is described. The tool is a PC-based application and allows the user to evaluate the effects of parameter changes on the sound quality in an intuitive manner. Tuning makes use of a Genetic Algorithm (GA) technique. Flute and plucked string modeling examples are used to illustrate the capabilities of the tool.

1. INTRODUCTION

Over the last decade, sound synthesis, especially physical modeling of musical instruments, has emerged as an important research field in computer music. Physical modeling, which refers to the computational simulation of the acoustics of musical instruments, is the most promising sound synthesis technique at present [1].

Two major problems in computer modeling of musical instruments are: (1) the difficulty in producing realistic sound and (2) the challenge of finding the optimal parameters of the computer model in order to produce the desired sound. This paper is concerned with finding a solution to the above problems.

The work presents the development of a software environment for the study and exploration of computer modeling of plucked, bowed and blown musical instruments, with particular interest in wind instruments, such as flute and organ pipe, using digital waveguide models [1][2]. The user-friendly, PC-based research tool offers the user the possibility to explore the inter-relationship between the instrument sound and the model parameters. An important requirement is to allow the user to evaluate the instrument model quickly in real-time for an immediate assessment of the effects of parameter changes on sound quality. The tool also allows accurate tuning of the model parameters based on recordings of real instruments using an intelligent algorithm.

2. SOUND SYNTHESIS SYSTEM

The sound synthesis system is based on a multimedia computer. The computer should be capable of sustaining sound synthesis in real-time. In the current system, the computer is a PC (Pentium II 450 MHz) running under Windows NT 4.0 operating system. The interaction is done by the use of the mouse and keyboard. Later MIDI control will be added to allow performance with various MIDI controllers such as keyboards and electronic wind controller (Yamaha WX11).

3. SYSTEM SOFTWARE

For this research tool, two software libraries have been developed using Visual C++ 6.0. The first library is a set of Audio Elements, the second library is made of Control Elements, and each of them is associated with an audio element. The tools developed make extensive use of these libraries. Each consists of a Sound Engine for sound synthesis and a Control Engine to give the user full access to the instrument model.

3.1. Audio Library and Sound Engine

The audio library consists of Digital Signal Processing (DSP) building blocks commonly found in audio including noise generators (white, pink, etc.) multi-segment envelope generators (classic attack-decay-sustain-release) frequency selective filters (e.g. low-pass, high-pass, band-pass, stop-band and DC killer). The audio library also contains interpolating (linear and higher order Allpass and Lagrange filters [3]) and polynomials. The Sound Engine is a real-time thread that implements the model of the musical instrument. It can sustain real-time sound synthesis giving the user immediate results of the capabilities of the model. The Sound Engine has also a real-time input that can be used as an excitation signal for the model. Finally it can generate WAV and AIFF files that can be used by any standard sound editing software.

3.2. Control Library and Control Engine

Each audio element of the audio library has its associated control element. This makes use of the Windows graphic objects such as sliders and other custom controls. The Graphic User Interface (GUI) shows the shape of the musical instrument to be modeled can be visualized. Each part of the instrument model has associated control elements, which give the user access to sliders to freely adjust the model parameters.

3.3. Intelligent Optimiser

To accurately tune the model an intelligent algorithm has been used. Following the guidelines from [4] we have added a feature to allow tuning from real recording of organ pipe and flute instruments.

The population is first randomly initialised and then evolves towards better solutions through a selection process, i.e. the selection of the best individuals based on their fitness score, a mutation process introducing some innovation into the population and recombination process for the next population. The fitness value is determined by the similarity of the harmonics peaks of the sound generated by the model to those of the recording of the acoustic instrument.

4. APPLICATION EXAMPLES

At present, two models of musical instruments have been implemented using the sound synthesis system and these are described below.

4.1. Flute Model

A flute model based on Cook's air-jet pipe model [5] and Välimäki's improved flute model [6] has been implemented. This model consists of an excitation, a non-linear and a linear part. The excitation, modeling the action of the musician on the instrument, uses filtered noise with an envelope generator. The non-linear interaction between the air-jet and the tube resonator is modeled by polynomial. The linear part, the resonator, is built using a network of multi-section tube and tone holes junctions. A dedicated GUI called the Pipe Modeler was developed for this flute model.

4.1.1. Pipe Modeler GUI

The Pipe Modeler is a multi property page application dialog based application. It consists of the Excitation, the Non-linear, the Linear, the Waveform, the Spectrum, the Output and the File pages.

4.1.2. Excitation Page

The excitation of the flute model uses a low pass filtered noise generator with an Attack-Decay-Sustain-Release (ADSR) amplitude envelope generator. The control elements for the noise generator, the digital filter and ADSR envelope generator have

been developed. The user can adjust the noise level, cutoff frequency of low-pass filter, and time constants of the ADSR envelope (in ms). Various ADSR envelope characteristics can be used to emulate a variety of the flute features from a pulse to very slow raising blowing characteristics.

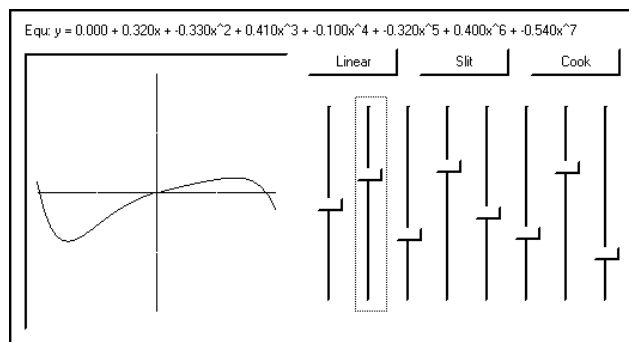


Figure 1. Control element of the polynomial.

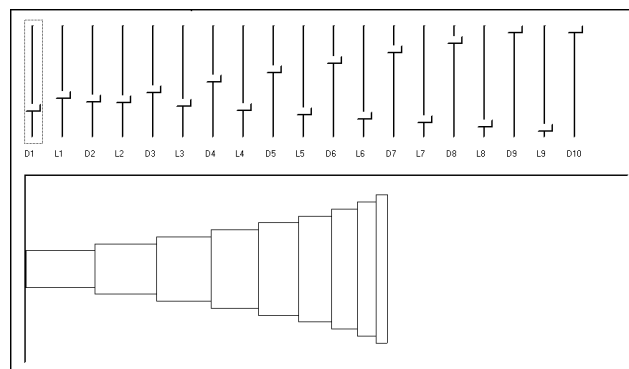


Figure 2. Control element of the multi-sections tube

4.1.3. Non-linear Page

The main element of the non-linear page is the polynomial transfer function, which is used to model the air-jet of the flute. The user can use the sliders to adjust the corresponding polynomial coefficients. The polynomial curve is automatically updated. Figure 1 shows the control element for the polynomial function. Presets can be assigned to three buttons (for example: linear, slit and Cook characteristic [5]).

4.1.4. Linear Page

With the linear page, the user can easily edit the shape of the pipe resonator of the model. In the Pipe Modeler, the pipe is made of several subsections of cylindrical tubes and tone hole junctions. For each subsection the diameter and the length can be adjusted, allowing the user to experiment with the shape of the tube. An example of control element for the multi-section tube is shown in Figure 2.

4.1.5. Waveform Page

The waveform page gives a time domain representation of the sound produced by the model. Any part of the produced sound can be zoomed. The attack and sustain parts of the produced sound are interesting. Visual clues about the quality of the sound can be obtained from inspection of the waveform of the produced sound.

4.1.6. Spectrum Page

A frequency representation of the produced sound is shown in the spectrum page of the tool. The user can choose between a linear and logarithmic scale. Visual clues about the tone color of the sound can also be obtained from inspection of the spectrum. The spectrum is also used by the Genetic Optimizer to calculate the fitness function.

4.1.7. Output Page

The output page gives the opportunity to the user to specify which signals of the model to be used and mixed and by which amount to produce the final sound output. This feature has also been found useful during the testing of the different audio elements of the model. The same way, the real-time input can be injected in any part of the model. Figure 3.a shows the waveform of synthesized flute sound and Figure 3.b. its 3D spectrum.

4.1.8. File Page

The File page is concerned with disk operations to save and load configuration files. After experimenting with the model, the user can save the configuration of the Pipe Modeler that gives the best results. Finally, the File page allows selecting the WAV file template (acoustic recording) used for the calculation of the fitness value for the Genetic Optimiser.

4.3. Plucked String Model

The plucked string model we used is a simple computational technique for modeling plucked string sounds based on refinements of the Karplus-Strong (KS) algorithm [7]. The model has been improved over the original version using a 3rd order Lagrange interpolator fractional delay filter to fine-tune the pitch and a low-pass filter (also called loop filter) to model the frequency-dependent damping of the string as described in [8]. The model is runs at a sampling rate of 44.1 kHz and is excited (pluck action of the musician) using various filtered bursts of noise to obtain different tone color plucked string sound. This plucked string model, despite its simplicity, produces realistic and high quality sounds. The waveform of synthesized plucked string tone and its 3D spectrum are shown in Figure 4.a and 4.b. respectively. The plucked string model will be demonstrated at the conference.

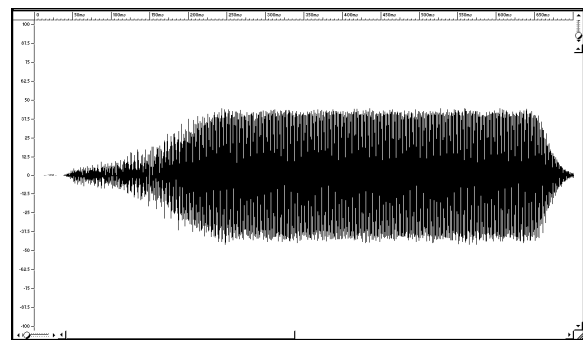


Figure 3.a. Flute synthesised tone.

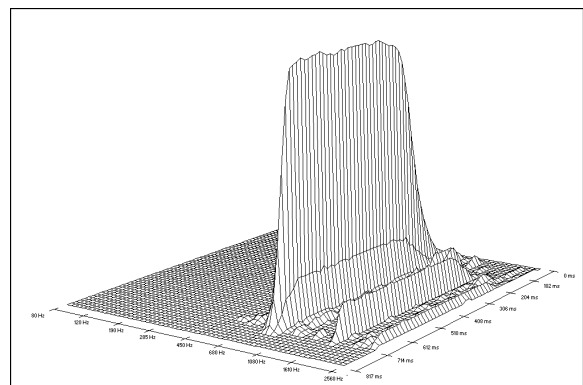


Figure 3.b. 3D Spectrum of the flute synthesised tone.

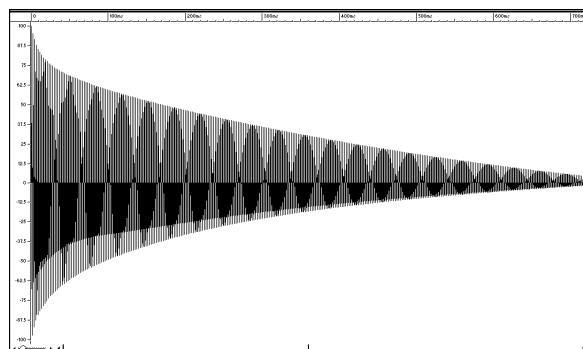


Figure 4.a. Plucked String synthesised tone.

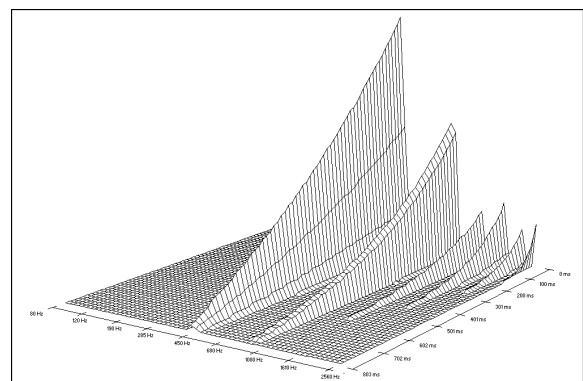


Figure 4.b. 3D spectrum of the plucked string synthesised tone.

5. CONCLUSIONS AND FUTURE WORK

In this work, a computer-based environment for real-time implementation and evaluation of sound synthesis of musical instruments has been presented. The main motivation behind it is to develop a flexible environment that allows the user to experiment with the instrument models, using the real-time capabilities to listen to the sound produced. We have illustrated the potential of the sound synthesis environment by examples including flute and plucked string modeling.

In future, the library of audio elements for the sound engine and their associated control elements will be extended. Other sound synthesis techniques such as additive and Frequency Modulation (FM) will also be added. Control issues will also be considered using an electronic wind controller. Finally, the real-time input feature will allow real excitation signals to be used to drive the models.

This will provide the basis for an advanced investigation into Artificial Intelligence (AI) based modeling of audio expertise that will help to improve the modeling of musical instruments and control of the sound synthesis.

6. REFERENCES

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