DIGITAL WAVEGUIDE MODELLING OF REED WOODWINDS: AN INTERACTIVE DEVELOPMENT

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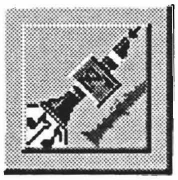
ABSTRACT

The digital waveguide filter has proven to be extremely effective for modelling wave propagation in musical instruments. It can be easily connected to independent models of reed mechanisms and bell shaping functions. In addition, the waveguide can be adapted to simulate arbitrary bore shapes and tone hole lattices. The WGF was used as the basis for an interactive modelling environment for a generic cylindrical cane reed-type instrument on the NeXT computer. The user has direct access to parameters defining the reed, the bell, the waveguide length, and the attack envelope. The program offers both reed lookup table and dynamic reed models for reed implementation, and a number of filter types for bell implementation. In addition, a single tone hole, implemented as a two-port scattering junction with "diameter" and placement defined by the user, is included. The ouptut of the simulation is a NeXT soundfile, which can be played and analyzed using a variety of tools on the NeXT computer. In addition, a spectrum panel allows the user to generate and analyze the impulse response of the instrument. Studies performed with this simulation include: implementation of a register hole; influence of attack on steady-state mode excitation; single vs. double reed behavior; influence of bell and cutoff frequency on tone; and influence of reed resonance on tone and stability.



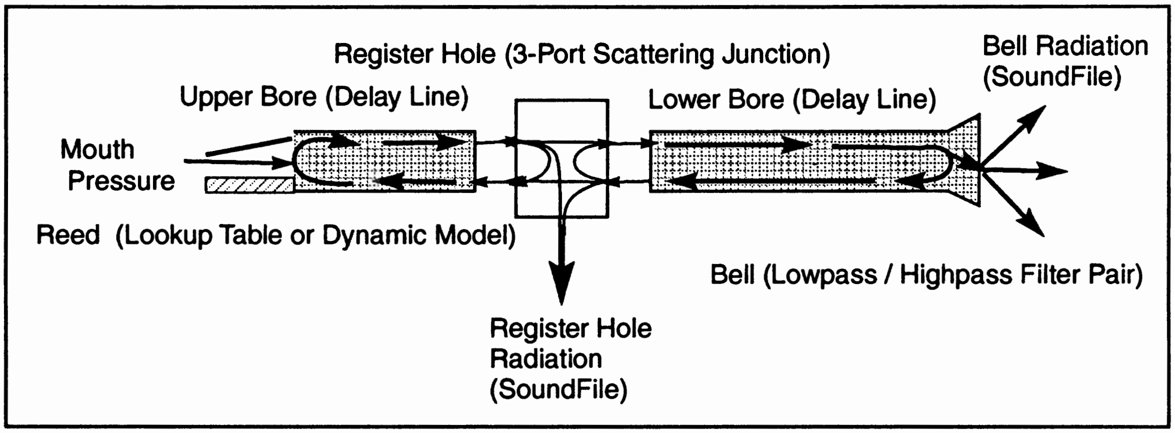
INTRODUCTION

As the field of digitally produced sound, and its associated computer technology develops, so does the potential for creating realistic real-time computer simulations that model acoustic instruments. Simulation has long been a tool for acoustical analysis; in the field of physical modelling, it is rapidly becoming a viable and exciting resource for musical performance.

The primary source of musical sound in an acoustic instrument is the propagation of waves through the instrument medium and the subsequent pressure radiation to the outside air. A good model of the instrument must therefore duplicate the wave behavior, as well as the nonlinear relationships between the medium and its excitation mechanism. Julius Smith has demonstrated that the waveguide digital filter, an offshoot of the normalized ladder/lattice filter, is an ideal structure for this task [1]. The waveguide filter is essentially a two-way delay line interspersed with partially reflective ''scattering'' junctions which operate on the oncoming wavefronts. Such a filter implements the wave propagation equations exactly. Just as a tonehole or bore diameter change will create an acoustic barrier within an instrument, allowing only part of the wave to penetrate while reflecting the rest, so can the associated changes in impedance be used to calculate the filter reflection coefficients which will result in similar scattering of the propagated, simulated wavefronts. The waveguide section is extremely modular, and can easily be connected to models of excitation and terminating impedance.

This paper, a summary of a more complete report available in reference [2], discusses the implementation of Smith's clarinet model [3] in an interactive environment on the NeXT computer. The clarinet model in its basic form is particularly elegant and efficient, as its cylindrical bore reduces much of the waveguide to a simple delay line. Inelaborate as it is, it provides a powerful demonstration of the principles of wave propagation, and of the essential coupling between reed and air column, as well as being a potentially rich source of musical sound. The simulation, dubbed the "ClariNeXT Workbench", was designed as an evolutionary, interactive workbench both for exploring acoustical behavior and for evaluating the musical potential, with respect to a real-time digital instrument, of various refinements to the basic model.

THE CLARINEXT MODELLING WORKBENCH



The clarinet simulation was developed in Objective C on the NeXT computer, using the NeXT Interface Builder application to provide the graphical user interface. It was designed to run with the 22050 Hz sampling rate used by the NeXT sound processing software. The simulation contained the following component models:

Cylindrical Bore Sections: modelled by pure delay lines, sized according to the pitch designated by the user;

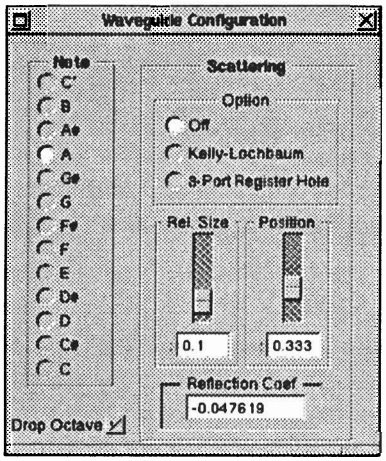
Register hole: modelled as a 3-port scattering junction at a user-defined location along the bore. A modified 2-port scattering junction was also provided to allow a crude source of bore perturbation;

Reed: modelled as a time-varying reflection coefficient based on either 1) Smith's static reed look-up table [3] or 2) a 2nd order dynamic model with user-definable damping ratio and resonant frequency. Additional enhancements to the reed model included a provision for any level in the elasticity of collision against the lay and a scalable "Bernoulli"-like force;

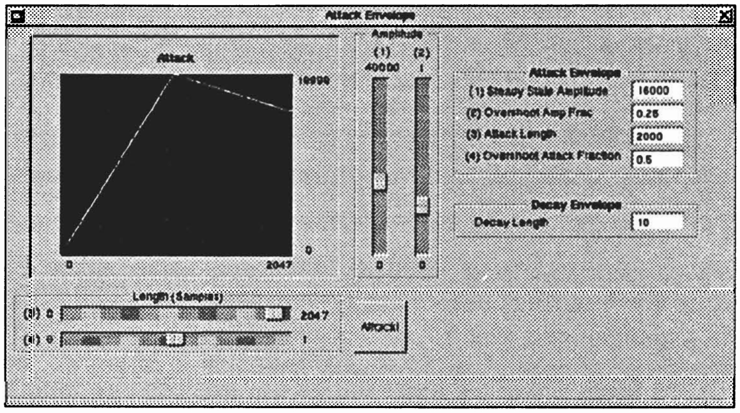
Bell: modelled as a lowpass (reflection) / highpass (transmission) filter pair. For the reflection filter, the user could select among a simple averager and 2nd, 4th, and 6th order Butterworth filters with a variety of cutoff frequencies. A simple one-pole filter was used for transmission. In addition, the reflection portion of the simulation was reconfigured to allow true complementary transmission;

Inputs: simulation driven by a 4-segment user-defined pressure envelope with optional vibrato and noise. The simulation operates purely on pressure wave propagation; flow is never explicitly calculated;

Outputs: Pressure output at the bell and register hole, as well as the reed tip displacement, were written to NeXT Soundfiles. In addition, an impulse response panel was available so that the user could obtain a spectrogram of the bore resonances.



Rel. Size: 0.1
Position: 0.333
Reflection Coef: -0.047619



Attack Envelope

(1) Steady State Amplitude: 16000
(2) Overshoot Amp Frac: 0.25
(3) Attack Length: 2000
(4) Overshoot Attack Fraction: 0.5

Decay Envelope

Decay Length: 10

RESULTS

The simulation successfully achieved a clarinet-like tone that could be modified by user inputs, and matched in behavior many of the experimental and theoretical predictions in the literature. Particularly noteworthy was the addition of the register hole scattering junction, which cleanly elicited the desired register shift of a twelfth. Other realistic behavior included:

Generation of harmonics with input amplitude, and subsequent timbre/volume dependency;

Existence of a threshold blowing pressure and the ratio of nonbeating to beating regime;

Sensitivity of steady-state mode to initial attack profile in marginally mode-stable cases, such as when steady-state attack pressure was below threshold. In extreme cases, with very high initial attack overshoot with respect to the steady-state input pressure, a "wind pluck" could be achieved, where the mode is first excited strongly, and then dies away in transient form as its support vanishes. In general, sensitivity to attack envelope was somewhat less than anticipated;

Effect of bell cutoff frequency on timbre. Adjusting the bell filter cutoff frequency provided a convenient means of modifying instrument tone. However, the bell in this simple form could not provide any of the midrange harmonic boosting that was demonstrated experimentally;

Instrument "squeaking" in the presence of reed dynamics and a low blowing pressure. Although squeaking has been attributed to various causes - usually reed resonance excitation - in the past, the most easily obtained "squeak" was actually a third register shift which occurred near threshold blowing pressure. This was consistent with the admonishments of reed teachers in this author's experience to avoid squeaking by providing "sufficient support". Although added (and somewhat excessive) damping would suppress the squeak, simply raising the input pressure was the more musically meaningful way to solve the problem. Reed resonance squeaks similar to those reported in the literature were also obtained, by lowering the reed damping below the normal level.

From a musical standpoint, the addition of the register hole and the adjustable cutoff frequency showed much potential. The scattering junction bore perturbations did not reproduce the expected acoustical results, but did produce some interesting multiphonic sounds which could be useful. The reed dynamics did not seem to contribute much musically, at least with this simple model. The "Bernoulli" force did have some aural effects on tone, but could be precalculated in the look-up table the same result. Especially given the dearth of current understanding of how reeds really operate (a situation which Hirschberg is trying to correct, in, for example, [4]), the inclusion of reed dynamic computations in a real-time model seems wasteful at this point. However, with the development of a more complex, less modally stable bore with a tonehole lattice, the sensitivity of the results to currently discardable second order factors would probably be greatly increased.

Although the simulation itself did not run in real-time - a typical one second run took about five seconds to complete - it was still very fast, especially considering the number of output files it wrote to and the amount of testing required because of the many options offered in the user interface. It is conceivable that a real-time runtime ratio could be obtained on a dedicated version of the instrument with streamlined options, even without using the NeXT DSP. For the workbench environment, a real-time ratio is not required. However, the combination of the high running speed and the convenient user interface allowed for a considerable amount of intuitive experimentation and parameteric study which would have been impossible in a less responsive environment.

REFERENCES

1) Smith, J. O, "Music Applications of Digital Waveguides," Stanford University Music Department Technical Report STAN-M-39, Stanford, California: 1987.

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3) Smith, J. O., "Efficient Simulation of the Reed-Bore and Bow-String Mechanisms", *Proceedings of the 1986 International Computer Music Conference.* Computer Music Association, 1986.

4) Hirschberg, A., R. W. A. van de Laar, et. al., "A Quasi-stationary Model of Air Flow in the Reed Channel of Single-Reed Woodwind Instruments," *Acustica*, vol. 70, pp. 146-154, 1990.