TBone: An Interactive WaveGuide Brass Instrument Synthesis Workbench for the NeXT Machine

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Abstract

A system for interactive experimentation with waveguide brass instrument synthesis has been constructed on the NeXT machine. Controls affecting individual tubing section length, slide position (in the trombone case), and valve positions determine the overall length of the cylindrical part of the horn. Controls affecting bell flare type and amount determine the characteristics of the bell. A mouthpiece editor allows adjustment of the shape and length. Spectral displays show the response of the horn as affected by changes in physical control parameters. A lip editor controls mass, spring constant, and damping of the lip oscillator. Performance controls allow sweeping of the lip oscillator, breath pressure, slide position, and valve position individually or together. Remarkably convincing brass instrument synthesis is accomplished by setting the variables to physically reasonable values.

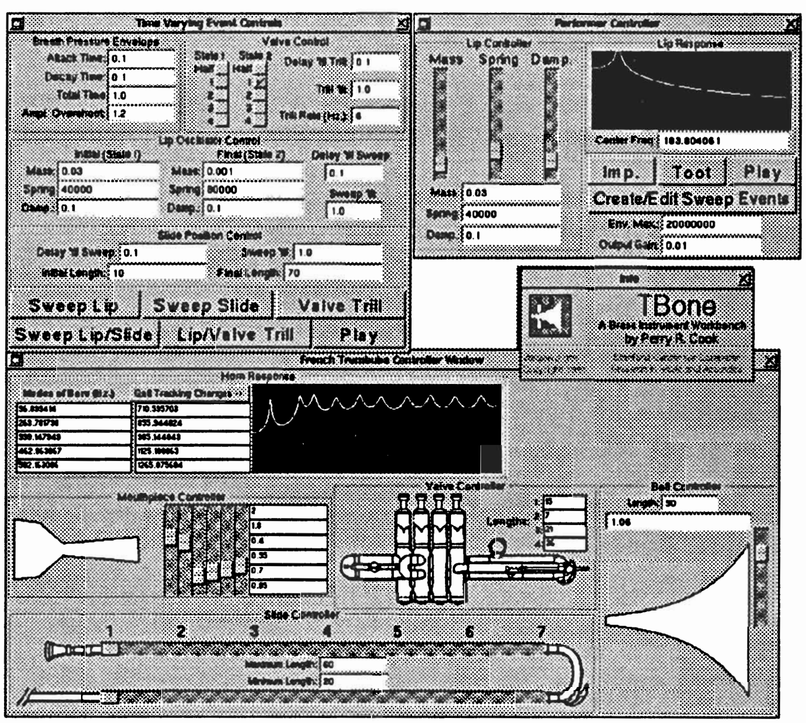

Figure 1: TBone windows provide controllers for the horn, the player, and time varying synthesis.

1 The Instrument

The instrument is composed of a mouthpiece of arbitrary shape, four cylindrical tubing sections switched by valves, a cylindrical tubing section of continuously variable length (trombone slide), and an exponentially flaring bell.

The section of brass instruments which begins at the mouthpiece leadpipe and extends through the network of valves and tuning slides is essentially a cylindrical bore. The freely moving slide and tuning slides of the trombone and valved instruments would not work correctly if the tubing were not cylindrical. These cylindrical sections are well modeled using simple delay line pairs (waveguides) [1]. In the TBone simulator, there are 5 sets of delay-line pairs active at all times, representing a continuously varying slide and four valves. Using these elements, an arbitrary brass instrument can be built. Editors control the length and range of the trombone slide element, and the length of each of the four valve controlled tubing sections. Fractional sample lengths are modeled by using longer delay lines than necessary, and interpolating the contents to the appropriate fractional location. The valves are modeled as four-way scattering junctions, allowing fractional valve positions to be simulated.

The mouthpiece can have arbitrary shape, and is modeled using one scattering junction per spatial sample. The bell is modeled as an exponentially flaring acoustic tube, using one scattering junction per spatial sample. A simple low-pass filter is used to model the reflection characteristics at the end of the bell.

2 The Performer

The performer is composed of a mass-spring oscillator modeling the lip, controls affecting the breath pressure envelope, and controls affecting valve and slide movements. To efficiently model the lip, a number of assumptions are made. The primary oscillation is assumed to take place in the upper lip, which is modeled as a simple mass-spring-damper oscillator. Figure 1 shows the lip oscillator and equivalent model.

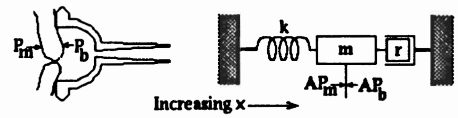

Figure 1: A drawing of the lips as placed on the mouthpiece, and a simplified physical model of the upper lip.

The force equation governing the simplified lip oscillator position x is:

$$f = (P_m - P_b)A - kx - r\dot{x} = m\ddot{x} \qquad (1)$$

Where P_m and P_b are the mouth and bore pressures acting on the lip. A is the area, k is the spring constant, r is the damping coefficient, and m is the mass of the lip. For a simple discrete time simulation, the velocity and acceleration components, $\dot{x}$ and $\ddot{x}$ are replaced with their finite difference approximations.

$$\dot{x} \approx \frac{x(t) - x(t-T)}{T} \qquad (2)$$

and

$$\ddot{x} \approx \frac{x(t+T) - 2x(t) + x(t-T)}{T^2} \qquad (3)$$

Substitution and algebraic manipulation yields a second order recursive digital filter, which when run at the sampling rate approximates the position of the lip as a function of the net force acting on the lip.

$$\frac{X}{F} = \frac{T^2 Z^{-1}}{m - (2m - Tr + T^2 k)Z^{-1} + (m - Tr)Z^{-2}} \qquad (4)$$

As the sampling period approaches zero, the digital filter approximation to the continuous time differential equation becomes more accurate. Once the lip position is calculated, it is used to look up a reflection/transmission coefficient from a table. This table is similar to those used for massless reed simulations in the models of the clarinet and saxophone[2][3[4]. The lip position is limited at each extreme (closed, or open to the point that it hits the mouthpiece cup) by limiting the position state variable to the minimum or maximum value.

3 Synthesis Examples

Synthesized tones of great variety, both realistic and fantastic, can be produced rapidly with the simulator. Graphical interaction along with fast auditory feedback encourage experimentation and new sounds. To briefly explore the synthesis capabilities of the system, two synthesis examples will be presented here. The first synthesis example is that of a crescendo and decrescendo. Since the lip oscillator is non-linear, the system behaves quite differently in different regions of excitation amplitude. Figure 2 shows the amplitude envelope and the pitch trajectory of the synthesized tone. The measured pitch varied from 230 to 236 Hz. (45 cents), with the tone flattening at both the softest and loudest points.

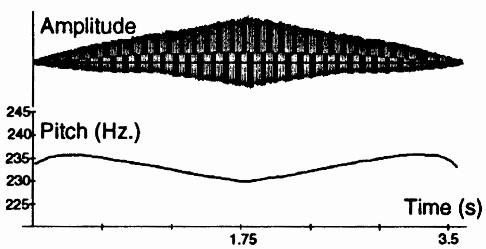

Figure 2: Amplitude envelope and the pitch trajectory of a tone synthesized with linearly increasing then decreasing breath pressure.

The second example is that of a sweep of the lip simulator parameters of mass and spring constant. The lip oscillator was initially configured for a resonance frequency of 183 Hz., then was swept over one second to a final resonance frequency of 714 Hz. The resulting synthesis exhibited an upward sweep in frequency, but since only certain modes are reinforced by the horn simulation, only certain frequencies were favored. The waterfall spectrum plot of Figure 3 shows the spectral evolution of this synthesized tone.

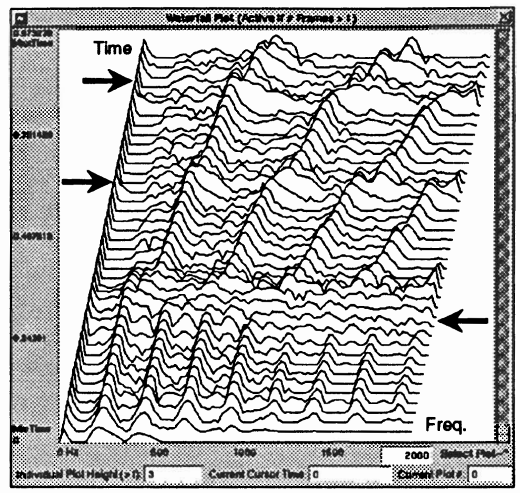

Figure 3: Time varying spectral plot of TBone synthesis performed while sweeping the lip oscillator from 183 to 714 Hz. The arrows show where transitions from one mode of oscillation to another occurred.

References

[1] J. O. Smith, "Musical Applications of Digital Waveguides." Stanford University Center For Computer Research in Music and Acoustics, Report No. STAN-M-39, 1987.

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[4] S. Z. Hirschman, "Digital Waveguide Modeling and Simulation of Reed Woodwind Instruments." Engineer Thesis, Stanford University Department of Electrical Engineering, 1991.