A meta-wind-instrument physical model,
and a meta-controller for real time performance control

Perry R. Cook

Stanford CCRMA, Stanford, CA, 94305
PRC@CCRMA.STANFORD.EDU

ABSTRACT

A waveguide instrument has been constructed which simulates the main acoustical mechanisms of the wind instrument family, allowing one instrument to function as flute, recorder, clarinet, saxaphone, trumpet, trombone, and other instruments which are hybrids of the various wind instrument sub-families. Multiple voices of the instrument can be run in real-time on a Motorola DSP 56001 signal processing chip, under control from a NeXT scorefile, mouse control with graphical feedback on the NeXT computer screen, or via MIDI. The instrument is controlled by parameters affecting reed stiffness, mass-spring-damper control of the reed/lip oscillator, length of the bore and of secondary delay paths, state of tone/register holes, jet length, and breath pressure. Lower level control allows direct access to control coefficients, allowing hybrid instrument settings to be defined.

A special MIDI controller has been constructed for controlling this instrument as well as more conventional MIDI synthesizer instruments. The controller allows a musician to play in the paradigms of most wind instruments, but provides all of these modes and others simultaneously. Controls include linear slide control like that of the trombone, valve control like that of other brass instruments, fingering control like that of the woodwinds, breath pressure, lip tension, bite pressure, and rotational position (simliar to rotating the flute or head to change embouchure). A new rotational control is mounted in the mouthpiece which varies playing position from recorder-like (end blown) to flute-like (edge blown). The controller allows a performer to effectively use much more of the real time control bandwidth available in the mouth and hands.

1. SIMPLE WAVEGUIDE INSTRUMENTS FOR REAL-TIME SYNTHESIS

Synthesis of musical sounds by physical modeling is becoming more feasible due to two components: computing equipment is growing increasingly powerful and inexpensive, and more efficient algorithms for computing the physical solutions are emerging [Smith87]. Once the basic physics of an instrument or instrument family are understood, a computational model can be derived, and that model can be simplified for more efficient computation. Optimization often takes advantage of the ideosyncracies of specialized DSP hardware. Figures 1-3 show three simplified physical models, based loosely on the physics of brass instruments, jet-reed instruments, and cane reed instruments. Non-linearities are modeled as polynomials for efficient DSP calculation.

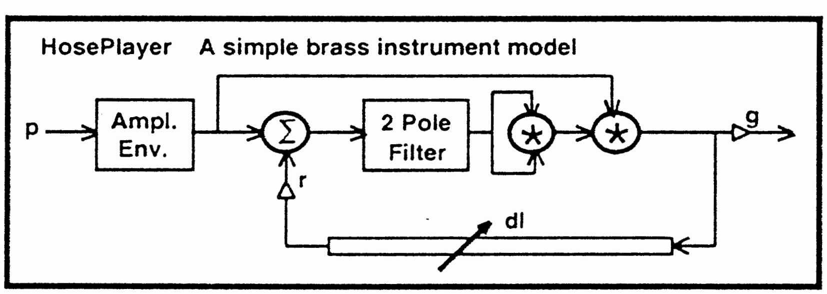

Figure 1. A simple physical brass wind instrument model for DSP implementation.

The brass instrument model shown in Figure 1 uses a second-order digital filter to model the mass-spring-damper oscillator system of the lip [Cook91]. This filter solves for the position of the lip as a function of the differential pressure applied by the mouth and bore. The pressure input to the bore is found by squaring the lip position, and multiplying by the input breath pressure. The bore is modeled by a delay line of length *dl*, and an asymptotic envelope generator provides smoothing of the instantaneous breath input pressure *p*. The variable *g* is an output scaling parameter, and *r* is the net reflection gain. The instrument as shown requires a total of 7 multiplies and 3 adds per sample computation. As with all instrument models in this paper, memory useage is dominated by the delay line length(s).

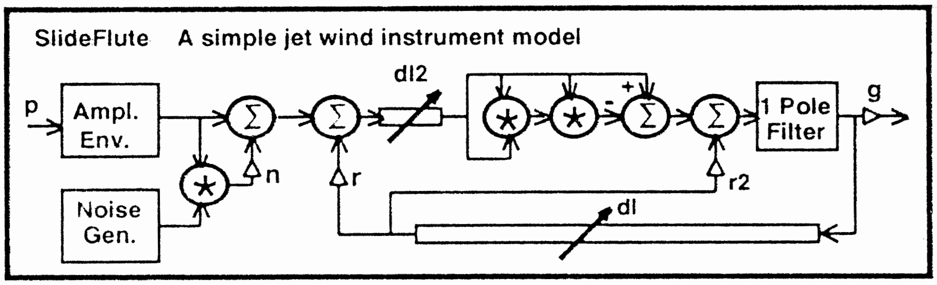

Figure 2. A simple physical jet-reed wind instrument model for DSP implementation.

The jet-reed instrument model shown in Figure 2 approximates the sigmoidal non-linearity of the jet using the polynomial $x - x^3$. The second delay line of length *dl2* models the propagation time of the jet reed, as discussed by Fletcher [Fletcher91] and implemented by Karjalain and others [Karjalain91]. A 1-pole filter models the low-pass reflection function at the end of the instrument. The variable *n* determines the amount of random noise mixed into the breath pressure excitation function. The variables *dl*, *r*, *g*, and *p* perform the same functions as in the brass instrument model. The instrument as shown requires a total of 9 multiplies and 6 adds per sample computation.

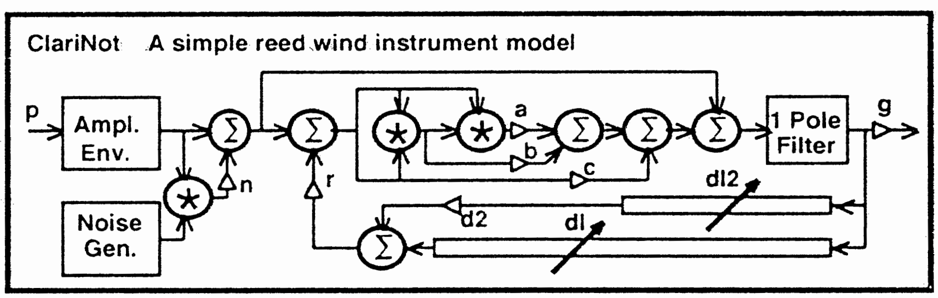

Figure 3. A simple physical reed wind instrument model for DSP implementation.

The reed instrument model shown in Figure 3 allows the use of an arbitrary polynomial of the form: $ax^3 + bx^2 + cx$ for the non-linearity of the reed. The second delay line models the reflection effects of a register hole, supressing the fundamental and emphasizing a particular harmonic determined by the length variable *dl2*. A 1-pole filter models the low-pass reflection function at the end of the instrument. The variables *dl*, *r*, *g*, *n*, and *p* perform the same functions as in the brass instrument model. The instrument as shown requires a total of 12 multiplies and 8 adds per sample computation.

2. WHIRLWIND: A META-WIND INSTRUMENT PHYSICAL MODEL

Figure 4 shows the result of combining the models of Figures 1-3, yielding a model which can simulate simple reed, jet, and lip excitation models. Pitch control paradigms of tube length, register hole, jet length, and embouchure are available. The instrument requires a total of 20 multiplies and 17 adds per sample computation.

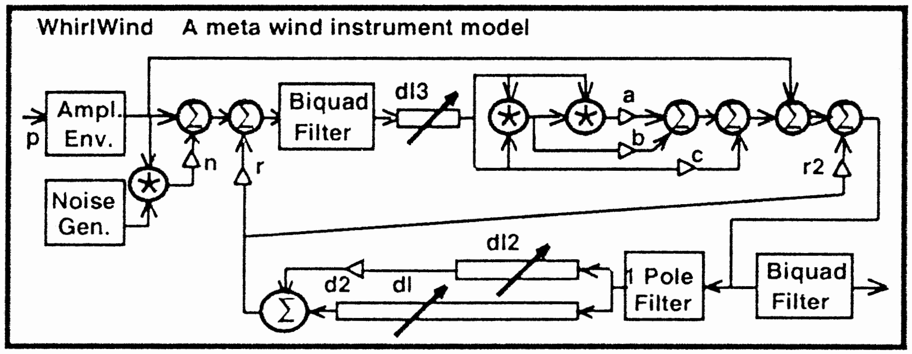

Figure 4. WhirlWind: the Meta-Wind Instrument Physical Model.

3. HIRN: A NEW REAL-TIME SYNTHESIZER CONTROLLER

Based on the premise that wind players have much unused control bandwidth available while playing their instruments, a Meta-Wind Instrument Controller was designed and constructed. Called HIRN, this controller exploits the common control modes found in the wind instrument family, and adds many more degrees of control freedom. Figure 5 shows the HIRN Meta-Wind Instrument Controller. Signals detected in the instrument mouthpiece include breath pressure, bite tension, lip tension as estimated by measuring the myoelectric activity of the upper lip [Knapp90], and a pitch detector so the player can sing or buzz the lips directly into the instrument mouthpiece. Fingering control is provided via 8 buttons, controlled by four fingers on the right hand, and three fingers and thumb on the left hand. The right hand can be slid linearly along the axis of the instrument, as well as radially rotated. The left hand can be rotated radially. Finally, the head of the instrument can be rotated to vary the playing style from end blown as in a clarinet or soprano saxaphone, to edge blown as in a flute. Optional continuous and switch foot controllers can be added to the HIRN controls.

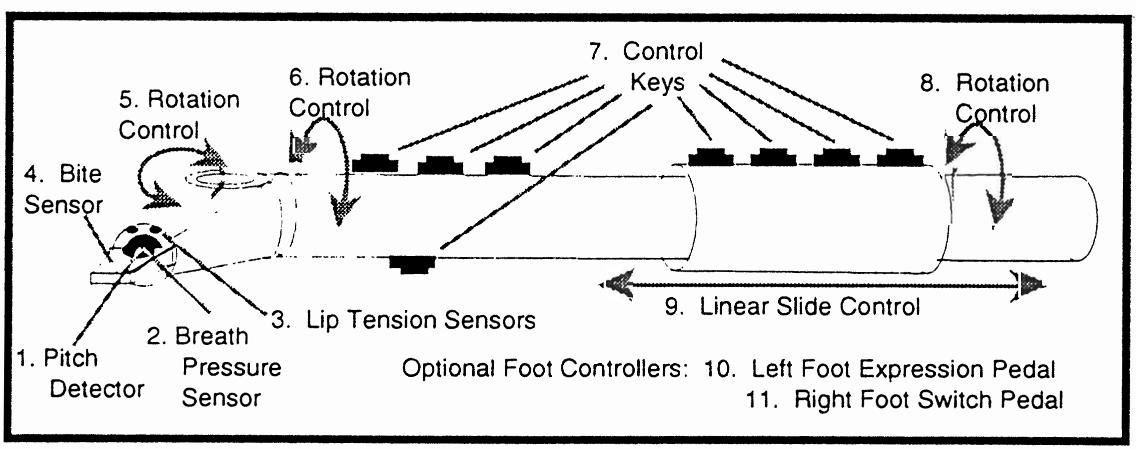

Figure 5. The HIRN Meta-Wind Instrument Controller.

4. SUGGESTED MAPPINGS OF HIRN CONTROLS FOR STANDARD MIDI AND WHIRLWIND CONTROL

	Control type	Standard MIDI Control Function	WhirlWind Control Function
1.	Mouthpiece Pitch Detector:	Note # with pitch bend	N/A
2.	Breath Pressure Sensor:	Aftertouch / Breath Controller	Breath Pressure
3.	Lip Tension Sensor:	Note # (with 7.) (Brass Mode)	Lip Tension
4.	Bite Pressure Sensor:	Note # (with 7.) (Wood Mode)	Reed/Lip polynomial
5.	Head Rotation Control:	Cross Fading MIDI Volume Chs.1<-->2 and 3<-->4	Feed-Forward Delay Line (Clar. to Flute)
6.	Left Hand Rotation Control:	Cross Fading MIDI Volume Chs.1&2<-->3&4	Flute Embouchure Control
7.	Control Keys:	Note # Select: Penny WhistleFingering (Wood) Three Keys as Valves (Brass)	Two implemented as Register Holes
8.	Linear Slide Control:	Pitch Bend	Delay Line Length
9.	Right Hand Rotation Control:	Modulation Wheel	Noise Volume
10.	Left Foot Expression Pedal:	Global Volume Chs. 1, 2, 3, & 4	Output Volume
11.	Right Foot Switch Pedal:	Sustain	Sustain (Breath Pressure)

5. INTERPOLATIONS IN TIMBRAL AND PHYSICAL MODEL SPACE

For MIDI control, the left hand and head rotation controls allow two degrees of movement, controlling a total of four MIDI channel volumes. This simple control scheme has proven quite effective for elementary timbral manipulation. Adding the right hand rotation control would allow for arbitrary movement through a three-dimensional timbral space like that proposed by Grey [Grey75].

A more difficult, but more motivating task is mapping the controls of the HIRN controller to the control parameters of a physical synthesis algorithm like the WhirlWind instrument model. In this case, some of the mappings, like breath pressure and linear slide control, are obvious. The mapping of the head rotation control to the feed-forward delay line gain allows the model to vary quite smoothly from flute-like to clarinet-like. Control of the non-linear polynomial coefficients using linear and Lagrange interpolations has been implemented, and higher-order schemes like those proposed by Bowler et.al. [Bowler90], or neural net schemes like those proposed by Lee and Wessel [Lee92] [Wessel91] could be used to provide smooth interpolation of model parameters.

6. REFERENCES

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