PITCH BENDS AND TONGUING ARTICULATION IN CLARINET PHYSICAL MODELING SYNTHESIS

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ABSTRACT

A physical modeling approach is used to investigate playing effects in woodwind instruments. This builds upon prior work concerning both empirical studies of the acoustics of the clarinet and extensive development of computer simulations of musical instrument systems. Specifically, explicit implementations of two performance gestures for the clarinet are given and demonstrated: tonguing and pitch bending. Physical modeling for the clarinet is briefly reviewed. Following this we show how both tonguing and pitch bending map to changes in the clarinet physical model itself and in the control parameter data. To our knowledge, tonguing in particular is one effect that has not been widely discussed in the literature, at least in the exact form we present. Finally, some possible future research directions are indicated.

Index Terms— music, modeling, signal synthesis

1. INTRODUCTION

Physical modeling for musical instruments has been an active area of research for more than two decades [1, 2, 3]. The widespread availability of cheap computing power has greatly facilitated this research. It is hoped that physical modeling will not only lead to better synthesizers for musical sound but to new musical representations which are not only trenchant but compact [4, 5].

Accurate and efficient computer simulations of the systems underlying musical instruments can provide a special insight into the subtleties of performance. The ability to replicate complicated gestures and effects in the context of physical modeling allows a researcher some claim to understanding their origins. Certain musical gestures may have fairly obvious physical correlates, such as vibrato (frequency modulation) on a violin being related to a small periodic adjustment of finger placement by the player. However, in other cases they may depend upon the physics in a sufficiently opaque manner that modeling becomes one of the only methods to get at what is really going on.

In previous papers [6, 7] we have studied physical models of woodwind instruments. A running collaboration with professors and graduate students at the Eastman School of Music has allowed us to solicit feedback and opinions from musical professionals. This has been helpful in revealing the deficiencies of various synthesis models and exposing us to the salience of playing effects that were absent in our work. Two such effects, *tonguing* and *pitch bending* are the topic of this paper. Tonguing is consistently referred to by players as an essential component of clarinet technique, especially if one is to achieve good articulation. Pitch bending is a more exotic performance gesture in which a player can “bend” the pitch of a note down (within about a semitone) while continuously producing a tone. To the best of our knowledge these effects have not been widely studied, at least in the explicit manner we attempt to present.

Below, we show how tonguing and pitch bends are incorporated into previous versions of our physical model simulations. First, the dynamical model and relevant details of the computer implementation are reviewed. The effects are discussed in our specific physical modeling context and are mapped to both components of the clarinet physical model and to the control parameters. Synthesis results are presented and we lastly give some closing remarks.

2. PHYSICAL MODEL

The well known McIntyre-Schumacher-Woodhouse (MSW) model [8, 9] (see also [10]) and specific variants of clarinet physical models [11, 12, 13] consists in the combination of a nonlinear exciter and a passive resonator. In the clarinet, these two systems are, respectively, the reed-mouthpiece assembly and the bore. Roughly, the effective length of the bore (controlled by fingering keys and tone holes) selects the pitch while the reed acts as a negative resistance oscillator. Energy is provided by the breath or blowing pressure of the player. The relevant variables are the acoustic variables just inside the mouthpiece of the instrument, the acoustic pressure p_b and the volume velocity u. The pressure p_b and u are related to one another by both a convolution with the bore impulse response h and the nonlinear pressure-flow relation g [14, 15] of the reed. The discrete form of these equations (which we implement) can be written as follows. Let U_n be a state vector consisting of past values of u.

$$U_n = \begin{bmatrix} u[n] \\ u[n-1] \\ \vdots \\ u[n-L+1] \end{bmatrix} \tag{1}$$

Then the model update can be written.

$$p_b[n] = h_i^T U_{n-1} \tag{2}$$

$$u[n] = g(p_m - h_i^T U_{n-1}) \tag{3}$$

where

$$g(\Delta p) = U_M \frac{3\sqrt{3}}{2} \left(1 - \frac{\Delta p}{p_{ext}}\right) \left(\frac{\Delta p}{p_{ext}}\right)^{1/2} \tag{4}$$

$$\Delta p = p_m - p_b \tag{5}$$

If our goal is to *resynthesize* [16, 17] a piece of music then relevant control parameters can be computed from a source recording. The parameters needed are the blowing pressure $p_b[n]$ and the note onsets and pitches (which determine an appropriate h_i at any instant of time). As discussed previously, the envelope of a signal often provides an adequate estimate of p_m (scaled by an appropriate constant). The envelope can be calculated as shown in (6) with filter coefficients h_{lp} computed from a standard filter design algorithm.

$$\operatorname{env} p = h_{lp} * |p| \tag{6}$$

It is noted that the impulse responses h_i used in our model are derived from detailed acoustic measurements [7] of the clarinet by the method described in [18]. We have also constructed physical models incorporating dynamical reed nonlinearities and practical features such as radiation effects [6]. The pitch bending and tonguing effects discussed below are accomplished in changes to the linear subsystem (2) and to the blowing pressure control parameter data and thus may be realized in a model with or without reed dynamics.

The physical model itself runs in MATLAB and consists of a combination of routines in the MATLAB language and C++ code using the MEX API. Computation time is typically at a ratio of $7/1$ compared with synthesized audio time. While definitely not real time this is practical for experimental investigations.

2.1. PITCH BENDING AND TONGUING

Additional terms can be introduced into the physical model presented above for the purpose of producing a richer set of output signals.

Pitch bending is incorporated as follows, a second order system is combined in parallel in Eq. (2). This is meant to represent an effective contribution of the player's vocal tract [19, 20, 21]. The right hand side of (2) then becomes,

$$h_i^T U_{n-1} + 2a[n]\cos(\phi[n])p_b[n-1] - a^2[n]p_b[n-2] \tag{7}$$

The extra terms represent an IIR second order system. The poles are parameterized by magnitude a (for stability $a \in (0, 1)$) and phase ϕ, each of which may vary with time. The vocal tract system of an actual player will, admittedly, possess a more complicated structure. However, we feel that this prescription captures part of the generally agreed upon picture of vocal tract and instrument interaction: that is, a resosant impedance response connected in series with the reponse of the instrument bore [21].

Here, a and ϕ become new control parameters for the physical model and completely determined the system which we have added in parallel. Note that we can recover (2) by setting a to zero. The value of ϕ localizes the system in frequency. In the following section we will demonstrate how a choice of these parameters can lead to a characteristic bent note. The pitch bend itself is accomplished through variation of ϕ.

Unlike pitch bending, the effects of tonguing are not manifested by an immediate change to the equations of motion. Instead, tonguing is represented by qualitative changes to existing control parameters, namely the blowing pressure. Clarinet graduate students queried on the issue of articulation responded by saying that the presence of the tongue at the reed opening is used to interrupt the flow of the players blowing pressure. For a good technique the blowing pressure and tongue operate independently of one another and during articulated passages the goal of the player is to maintain a *constant* blowing pressure while using the tongue to control the beginnings and ends of notes. In physical modeling terms this can be expressed by selectively introducing discontinuous jumps in the blowing pressure at note onsets. These jumps correspond to the fact that, for articulated notes, once a player removes his or her tongue from the reed opening the blowing pressure is already equal to some finite value. For resynthesis from a source recording this is a refinement of blowing pressure estimation by the envelope detection method presented above. In certain cases, the envelope detection method may result in a disparity between the source and the resynthesis (especially at attack transients, for example, a resynthesized note may begin too late). This is not entirely surprising considering that, by its very nature, the envelope detector will tend to smooth out rapid or discontinuous structures. In a more complete parameter estimation system notes would be classified as tongued or not tongued and an appropriate discontinuity would be introduced into the envelope at each point (by for example, pointwise addition of a step-like function to the blowing pressure data). Outside of the resynthesis application, the same reasoning could be used in the creation purely synthetic blowing pressure waveforms to reflect tonguing.

For the purposes of this paper we show examples of single notes, with tonguing discontinuities following an exponential distribution type function. The variables C and λ are free parameters attached to the articulation of notes while τ is meant to represent the location in time of a particular note onset.

$$T(n) = \begin{cases} Ce^{-\lambda(n-\tau)}, n-\tau \geq 0 \\ 0, \text{otherwise} \end{cases} \tag{8}$$

Likewise, similar sets of functions could be associated with the decays of notes to represent abrupt stoppages in the blowing pressure.

3. SYNTHESIS RESULTS

Synthesis examples are presented in this section. In Fig. 1 the tonguing parameter is used to achieve two different types of attack. In cases where control parameter is generated without reference to a specific performance (for instance, working just from the score) some of the typical musical accents could be mapped to different values of the tonguing parameter. Results for pitch bending are given in Fig. 2. This shows a detail of the spectrogram around the second partial of the synthetic bent note. For this particular case ϕ varies linearly over the duration of the note at a rate of ≈ 3 radians per second. Although the pitch change is certainly audible, at typical frame sizes (here frame size $N = 8192$ samples at 44100Hz sampling rate) the effect is not convincingly demonstrated with a full spectrogram. Audio samples, however, will be made available upon request.

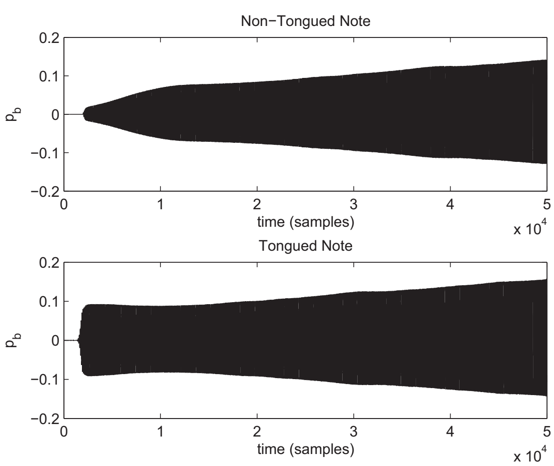

Fig. 1. Demonstration of the effect of tonguing parameter. Two qualitatively different note attacks obtainable with the same underlying envelope/blowing pressure data.

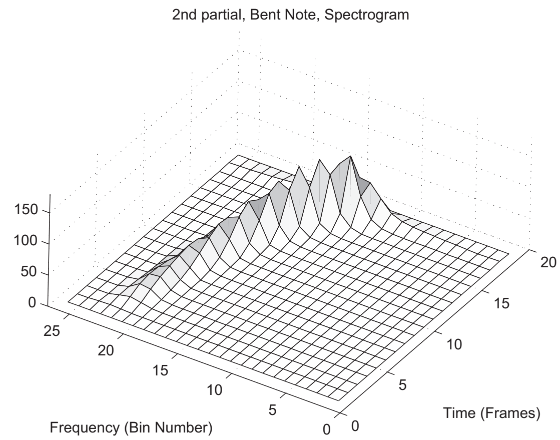

Fig. 2. Detail of spectrogram around second partial of synthesized bent note showing deviation of pitch with parameter ϕ.

4. CONCLUSION

Two gestural playing effects have been explicitly introduced into a standard clarinet physical model and demonstrated: tonguing and pitch bending. This supplements an existing system for the synthesis and representation of woodwind musical audio. A longstanding goal of physical modeling research has been the creation of new musical representations based upon control parameter data. In the context of the physical model described above we see that any solo clarinet performance would be situated in an essentially five-dimensional dimensional parameter space (fingering, blowing pressure, embochoure, tonguing events, and vocal tract configuration). Future work will involve using these more elaborate clarinet models in tandem with new parameter estimation routines to incrementally improve the quality of synthesized sounds obtained by physical modeling. In particular, it is our intent to use the tonguing presented here as an essential component of informed parameterizations of articulated passages.

5. REFERENCES

[1] V. Valimaki, J. Pakarinen, C. Erkut, and M. Karjalainen, "Discrete-time modelling of musical instruments," *Reports on Progress in Physics*, vol. 69, no. 1, pp. 1–78, 2006.

[2] V. Valimaki, R. Rabenstein, D. Rocchesso, X. Serra, and J. O. Smith, "Signal processing for sound synthesis: computer-generated sounds for all," *IEEE Signal Processing Magazine*, vol. 24, no. 2, pp. 8–10, 2007.

[3] J. O. Smith, "Physical modeling using digital waveguides," *Computer Music Journal*, vol. 16, no. 4, pp. 74–87, 1992.

[4] B. Vercoe, W. G. Gardner, and E. D. Scheirer, "Structured audio: Creation, transmission, and rendering of parametric sound descriptions," *Proc. IEEE*, vol. 86, no. 5, pp. 922–940, 1998.

[5] G. De Poli, A. Piccialli, and C. Roads, Eds., *Representations of Musical Signals*, The MIT Press, Cambridge, Massachusetts, 1991.

[6] M. Sterling, X. Dong, and M. Bocko, "Representation of solo clarinet music by physical modeling synthesis," in *Proc. IEEE Intl. Conf. Acoustics Speech and Sig. Proc. 2008 ICASSP 2008, Las Vegas, NV*, 2008.

[7] X. Dong, *Musical sound synthesis and a new music representation based on empirical physical modeling of musical instruments*, Ph.D. thesis, Univ. of Rochester, Rochester, august 2007.

[8] M. E. McIntyre, R. T. Schumacher, and J. Woodhouse, "On the oscillations of musical instruments," *J. Acoust. Soc. Am.*, vol. 74, no. 5, pp. 462–470, 1983.

[9] R. T. Schumacher, "Ab initio calculations of the oscillations of a clarinet," *Acustica*, vol. 48, no. 2, pp. 71–85, 1981.

[10] S. D. Sommerfeldt and W. J. Strong, "Simulation of a player-clarinet system," *J. Acoust. Soc. Am.*, vol. 83, no. 5, pp. 1908–1918, 1988.

[11] B. Gazengel, J. Gilbert, and N. Amir, "Time domain simulation of single reed wind instruments. from the measured input impedance to the synthesis signal. where are the traps?," *Acta Acust.*, vol. 3, pp. 445–472, 1995.

[12] M. van Walstijn and D. M. Campbell, "Discrete-time modeling of woodwind instrument bores using wave variables," *J. Acoust. Soc. Am.*, vol. 113, no. 1, pp. 575–585, 2003.

[13] P. Guillemain, J. Kergomard, and T. Voinier, "Real-time synthesis of clarinet-like instruments using digital impedance models," *J. Acoust. Soc. Am.*, vol. 118, no. 1, pp. 483–494, 2005.

[14] J. Dalmont, J. Gilbert, and S. Ollivier, "Nonlinear characteristics of single-reed instruments: Quasistatic volume flow and reed opening measurements," *J. Acoust. Soc. Am.*, vol. 114, no. 4, pp. 2253–2262, 2003.

[15] A. Almeida, C. Vergez, and R. Causse, "Quasistatic nonlinear characteristics of double reed instruments," *J. Acoust. Soc. Am.*, vol. 121, no. 1, pp. 536–546, 2007.

[16] M. van Walstijn and G. De Sanctis, "Towards physics-based re-syntheis of woodwind tones," in *Proc. International Congress on Acoustics 2007, Madrid, Spain*, 2007.

[17] P. Brossier, M. Sandler, and M. Plumbley, "Matching live sources with physical models," in *Proc. of the 6th Int. Conference on Digital Audio Effects (DAFx-03), London, UK, September 8-11*, 2003.

[18] A. H. Benade and M. I. Ibisi, "Survey of impedance methods and a new piezo-disk-driven impedance head for air columns," *J. Acoust. Soc. Am.*, vol. 81, no. 4, pp. 1152–1167, 1987.

[19] J. Backus, "The effect of the player's vocal tract on woodwind instrument tone," *J. Acoust. Soc. Am.*, vol. 78, no. 1, pp. 17–20, 1985.

[20] A. H. Benade, "Interactions between the player's windway and the air column of a musical instrument," *Cleveland Clinic Quarterly*, vol. 53, no. 1, pp. 27–32, 1986.

[21] C. Fritz and J. Wolfe, "How do clarinet players adjust the resonances of their vocal tracts for different playing effects?," *J. Acoust. Soc. Am.*, vol. 118, no. 5, pp. 3306–3315, 2005.