Abstract
Previous research has successfully modeled individual tones, but performing them musically has proven more difficult. Musical expression requires variation and connection of the tones. An especially difficult problem is connection of the tones in timbre tremolos. Flutter tonguing is a technique that many wind instrument players use to produce a characteristic buzzing timbre. This project extends the method that we used to model trills to make realistic timbre tremolos and flutter tonguing effects. We used one function table for frequency modulation and another for amplitude modulation. The flutter tongue and most of the tremolos sound realistic enough to fool listeners into believing that humans played our synthesized examples. The method also successfully creates interesting new timbral possibilities.

1 Introduction:
This project extends our previous work using frequency modulation with a function table to make realistic timbre tremolos and flutter tongue effects. After studying the musical characteristics of timbre tremolos and flutter-tongued wind instrument tones, we found that the frequency/amplitude modulation function table method was the method of choice for the synthesized examples.

If we treat a tremolo as a single tone instead of as many individual tones, we have more convenient control over its musical effect. Several score parameters can easily control the tremolo rate in a line segment. For example, our design controls an initial, middle and final tremolo rate, and the time required to change from the first tremolo rate to the second. Other parameters control the amplitude envelope of the tremolo as for a single sustained tone. The flexibility is especially useful, and much easier than typing many notes and trying to manually adjust their start times, durations and amplitudes to get a naturally-varying rate and amplitude quality.

Our new method extends the trill design to alternate between two different timbres. It is also possible to slide from one basic pitch or pair of pitches to another (see Figure 1). We also found that this method can simulate realistic flutter tonguing when the parameters are set to suitable values.

| Table 1. Example of Timbre Tremolo with Parallel Portamento Tones |
|-----------------|-----------------|-----------------|
| **Timbre**     | **Frequency**   |                  |
| Tone 1          | flute           | C4              |
| Tone 2          | clarinet        | D4              |
|                 |                 | A4              |

2 Background:
Much previous research modeled the spectra of single wind instrument tones (such as Risset and Mathews 1969; Morrill 1977; Horner and Beauchamp 1995; Horner and Ayers 1998a and 2002). We previously designed wavetable synthesis models (i.e., group additive synthesis models) of many wind instrument tones that are easy to use and sound like the original individual tones (Horner and Ayers, 1998; Horner, Ayers and Law, 1999). But musicians don’t always play isolated tones in “musical” performances! Rodet and Lefèvre (1997) connected the frequencies of two notes with a line segment and morphed the transition using parameter interpolation to give a smooth slur. We used our previous synthesis design to slur varying numbers of notes in trills for the Chinese *dizi* (Ayers, 2003). Since wavetable
synthesis is straightforward and matching works well for isolated wind instrument tones, we will focus our discussion on modeling timbre tremolos and flutter-tongued tones.

3 Synthesizing Trills and Tremolos:
Tremolos are similar to trills, but have a larger frequency change. If two notes are close to the original note modeled, their spectra may be similar enough to use the same wavetable. But if two notes alternate by leap, the spectrum of one of the notes may be very different from that of the original note, causing its timbre to be distorted, and it may sound synthetic.

We created a hybrid instrument which cross-fades two unison signals sharing one frequency line segment and phase, but using their correct wavetables (Ayers 2003) (see Figure 1). A repeating amplitude envelope function cross-fades the two signals as with overlapped notes, but it is smoother because the frequency change in the transition more closely resembles one on a real wind instrument, and using the same phase (and the other frequency parameters, such as noise and vibrato) also makes the cross-fading itself less noticeable. We increased the noise in the cross-fade as the amplitude decreases, so that the maximum amount of noise is in the middle of the cross fade, at the point of minimum amplitude.

4 Timbre Tremolos:
Timbre tremolos can give very interesting, even unrealistic, effects. For example, we can alternate a clarinet with a flute. While using separate wavetables to handle the alternating note timbres in the tremolos, we can use a single frequency envelope to slide the timbre tremolo from a starting pitch to a final pitch (see Figure 2), or one of the pitches can have a portamento and the other can remain constant (see Figure 3 and Table 2).

5 Tremolo Frequency Modulator:
Averaging one cycle provides a good shape for a tremolo frequency function. The function oscillates between the frequency of the lower note and the frequency of the higher note. The
higher note begins with a slight overshooting of the required frequency, perhaps 20% (see Figure 4). As a refinement, we use random variation on the trill rate. The function does not need to model pitch variation of the average tone, change of speed or jitter, so it can represent one average cycle of the trill, and adjusting the parameters randomly within their typical ranges can vary each cycle.

We stored the new tremolo shape in a function table. An amplitude modulator uses the function to alternately fade the amplitudes of the two signals in and out (see Figure 6).

### Figure 4. Trill Cycle Frequency Function

![Figure 4. Trill Cycle Frequency Function](image)

### 6 Tremolo Amplitude Modulator:

What is the optimal shape for the tremolo amplitude function? In our previous research (Ayers 2003), we found that the amplitude decreases in the transitions between the trilled notes. We found the tremolo has similar changes in amplitude during the note transitions. The most important amplitude changes occur at the same time as the most important frequency changes, but we cannot use the same function to control both the frequency and amplitude because the amplitude peak is in the middle of the cycle, and the frequency peak is at the beginning, so we take the average amplitude of a tremolo cycle for a separate function (see Figure 5). In addition, the cycles have slight amplitude spikes during the transitions between the notes.

We found that a simple amplitude envelope would suffice, though the minimum amplitude is about 20% of the total amplitude, rather than 0% (see Figure 9).

### Figure 5. Tremolo Cycle Amplitude Function

![Figure 5. Tremolo Cycle Amplitude Function](image)

7 Flutter Tongue

Wind players use several types of flutter tonguing. Some performers roll the “rrrr” at the front of the tongue and others gargle in the back of the throat. It is even possible to roll the flutter from the front of the tongue to the back of the throat. It is also possible to flutter with and without a vowel sound which can further complicate the timbre.

On examination of recorded flutter-tongued tones, we found a basic amplitude modulation at approximately 20 Hertz (see Figure 7).

### Figure 7. Two Amplitude Modulations of a Flutter-Tongued Dizi Tone

![Figure 7. Two Amplitude Modulations of a Flutter-Tongued Dizi Tone](image)

The next step was finding a function that best represents the average amplitude envelope of the individual modulations (see Figure 8)

### Figure 8 Dizi Average Amplitude Modulation

![Figure 8 Dizi Average Amplitude Modulation](image)
8 Conclusion:
After comparing the results, we concluded that the function table method works better than the overlapping or line segment methods for modeling tremolos and flutter tongue effects, and the new method is easier to use. We used one function table for frequency modulation and another for amplitude modulation. Our method is highly successful and the trills sound realistic enough to fool listeners into believing that humans played our synthesized examples.

9 Acknowledgements:
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10 References: