Synthesising Chinese flutes using Csound

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This paper gives brief descriptions of five Chinese flutes: the *paixiao*, *xun*, *koudi*, *xiao* and *dizi*, and short musical excerpts with their notation, idiomatic phrasing and typical ornaments. The source material section describes their spectral characteristics. Following a brief description of the previous wavetable synthesis design, an expressive new Csound additive synthesis design used to model the instruments is described. Chinese notation is a convenient Csound pitch input method using Ling Lun's tuning. Finally, several excerpts from compositions illustrate applications of the designs.

1. INTRODUCTION

Chinese flutes include a range of colourful instruments with distinctive characters. They are often decorated with ancient Chinese poems and carved dragon heads. As a flute player, I became fascinated with the Chinese flutes after moving to Hong Kong in 1994. I collected as many as possible and studied with a local teacher, Chan Chun Nin. I soon became interested in synthesising the flutes using Csound so I could use them in my computer music compositions.

Previous work on computer modelling has primarily focused on simulating Western instruments. Researchers have also explored the acoustics of the Japanese *shakuhachi*, the Asian free reed instruments (Cottingham 2004) and large Chinese bells (Braun 2003). Few researchers, apart from Tsai (2003, 2004), have devoted much attention to Chinese flutes, and he focused mainly on the *dizi*. We previously modelled the Chinese flutes using a wavetable model similar to the one we used for Western wind instruments in *Cooking with Csound* (Horner and Ayers 2002).

This research describes a new Csound additive synthesis design for the *paixiao*, *xun*, *koudi*, *xiao* and *dizi* (see figure 1) which captures more of the expressive characteristics of each instrument. The Chinese flutes are diatonic, and each type of flute comes in many sizes because each instrument plays in only one or two keys. D major is one of the most popular keys. Good players can get chromatic pitches by tricky fingering or blowing. A special benefit of the computer instruments is their ease in producing uncharacteristic microtones which I used in three compositions.

2. CHINESE FLUTES, NOTATION AND EXPRESSION

The Chinese flutes are made from bamboo, clay, wood, stone and crane bone. Among these, the *dizi* and *xiao* are used in the Chinese orchestra and for solos and small ensembles, the *paixiao* and the *xun* are ancient instruments and the *koudi* is a small bamboo instrument which can play exciting bird-like melodies. Chinese performers add ornaments according to their taste and the mood of the music, and can add different ornaments to different performances of the same piece. This section describes the instruments and their expressive techniques.

2.1. The *paixiao*

The *paixiao* is a panpipe that evolved from Ling Lun's method of tuning individual end-blown bamboo *lü* pipes using successive perfect fifths (Partch 1974). A thirteen-pipe bamboo *paixiao* discovered in Zheng Hou Yi's tomb dates back to about 433 B.C.E (Hubei Provincial Museum 1989). The *paixiao* commonly has a single row of sixteen or twenty-two bamboo tubes, often partially enclosed by a wooden case which holds them together. The blowing ends have angled edges. Because the tubes of the *paixiao* are stopped, the frequency is an octave lower than if the tubes were open (Helmholtz 1954), allowing the performer to hold a smaller instrument.

The twenty-two-pipe *paixiao* has a diatonic playing range of three octaves (the sixteen-pipe *paixiao*'s range is two octaves). Pentatonic scales are easier to play on a pentatonic *paixiao*, so some have fewer pipes. Since changing notes requires moving the embouchure from pipe to pipe, the player must either blow across all the intervening tubes in a scalar glissando or move away from the instrument to skip from one pitch to another. It is easier to synthesise rapid passages with a computer than play them on an acoustic instrument.

Figure 2 (sound example 1; all sound examples are included on the *Organised Sound* **10**(3) CD) shows a spectrogram analysis of the first phrase of *A Descending Phoenix* (Qian Zhaoxi 1989). A typical glissando ascends to the sustained tones, and the pitch bends down and then back up about 2/3 of a semitone

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Figure 1. Chinese flutes (*paixiao*, *xun*, *koudi*, *xiao and dizi*).

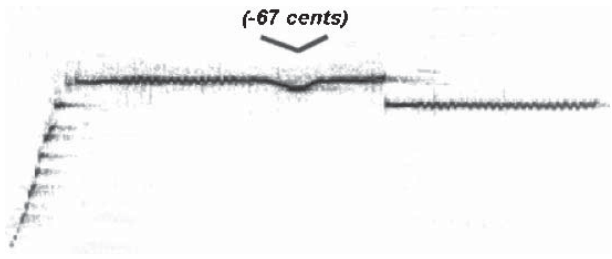


Figure 2. First phrase of original *paixiao* performance of Qian Zhaoxi: *Descending Phoenix.*

(about 67 cents). The second phrase echoes the first, with the opening glissando an octave shorter and a pitch bend of only 1/3 of a semitone (about 33 cents). Players bend the pitch down by angling the instrument away from them, sending the air stream deeper into the tube, and move the instrument back toward them to restore the original pitch. The amount of the inflection varies, but is usually less than a semitone. Experienced performers can play chromatic tones using this technique, but it is difficult to achieve accurately.

2.2. The *xun*

The *xun* is an egg-shaped ocarina believed to be at least 7,000 years old, usually made of clay, but a few

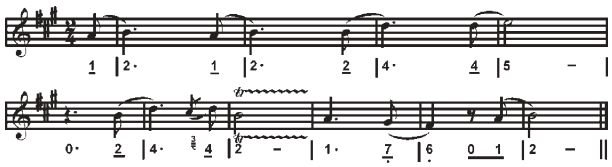


Figure 3. *Xun* solo, Zhao Liang Shan: *Ai Ying.*

are carved of wood, stone, ivory or bone. Instruments have up to nine finger holes, including the two thumb holes on the back, producing about an octave range. Inconsistency in the number and placement of the finger holes causes variation in the intonation. Professional *xun* players control the intonation of the diatonic pitches and play chromatic pitches by varying their embouchures, but it is difficult to change quickly between chromatic pitches. Portamento up to a minor third is characteristic of *xun* playing technique.

The *xun* excerpt from *Ai Ying* (Zhou Liang Shan 1991) in figure 3 (sound example 2) illustrates Chinese cipher notation with corresponding Western notation. Pitch 1 is the tonic in A major. A dot below a number means that the pitch is in the lower octave, no dot means that the pitch is in the middle octave, and a dot above a number means that the pitch is in the higher octave. For flutes with extended ranges, extra dots indicate pitches that are in higher octaves.

A number usually represents one beat, and a dash after a note lengthens the note by one beat. The beat is usually a quarter note, but the time signatures work as they do in Western music, so eighth note beats are also possible. The line under the numbers is similar to the Western beam but with no stems connected to the notes. Two eighth notes grouped together on a beat have a single line under the numbers. Four sixteenth notes have a double line under the numbers. Tuplets have tuplet numbers under the lines, but only triplets are used frequently. Dots after numbers and ties work the same as in Western music. A 0 on all or part of a beat means a rest. The notation usually does not indicate slurs, but performers may slur the notes according to their taste, as shown in the figure.

2.3. The *koudi*

The *koudi* is a recently created folk instrument that can imitate bird songs. The small bamboo tube is one to four inches long, open at both ends, with a blowhole in the middle and up to two small finger holes on each side of the blowhole. Its tone sounds high, bright and dramatic, like a cross between a piccolo and a whistle.

The *koudi* playing range is about an octave. Pitch bend is very characteristic of *koudi* playing technique because the performer must partially cover varying amounts of the open end holes on the short bamboo

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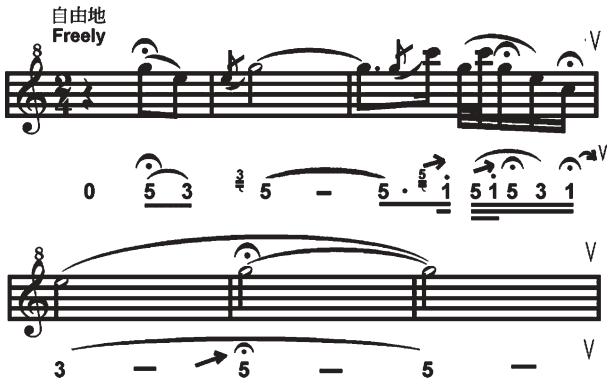


Figure 4. *Koudi* solo with portamento, Du Chong: *Morning in Miao Mountain.*

pipe to play the lower pitches. Moving from one of these pitches to another requires sliding the finger across the open hole to another position, resulting in pitches that slide across large intervals. Figure 4 (sound example 3) shows a small excerpt including portamento and grace notes from the beginning of the *koudi* solo, *Morning in Miao Mountain* (Du Chong 1989), which is based on a folk tune of the Miao tribe. A later section of this piece features trills and energetic figures representing birds.

2.4. The *xiao*

The *xiao* performer blows across a small notch at the edge of an open tube or node in the bamboo, depending on the style. The size and shape of the notch varies, and some of the instrument's length is usually decorative. The most common type has five finger holes on the top and a thumb hole on the back.

The grace notes shown in *Autumn Reflection at the Dressing Table* (see figure 5, sound example 4, 1990) are typical of Chinese ornamentation. Grace notes placed *after* the notes that they ornament seem to sigh as they escape from the ends of phrases, usually from a tonic to the fourth pitch.

2.5. The *dizi*

The *dizi* is a Chinese transverse flute, usually made of bamboo, with a membrane (see figure 6) over one hole that produces a bright buzzing tone rich in upper
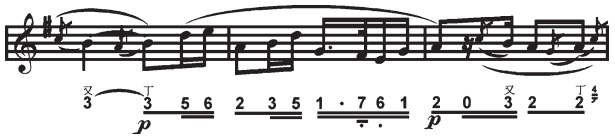


Figure 5. Grace notes in *Autumn Reflection at the Dressing Table*.



Figure 6. *Dizi* membrane.
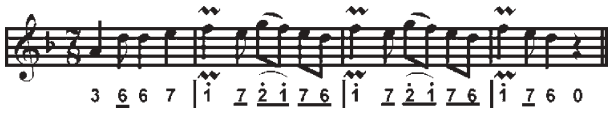


Figure 7. *Dizi* solo with trills, Shi Jia Huan: *Pamir Spring.*

partials. The practical range of the *dizi* is about two octaves, but lower *dizis* have larger ranges than higher ones.

Figure 7 (sound example 5) shows an excerpt from the beginning of *Pamir Spring* (Shi Jia Huan 1990), which uses a *dizi* in the key of F major to play in D minor by using pitch 6 as the tonic. Although the pitches normally consist of the integers 1 to 7, Chinese music occasionally uses chromatically altered pitches. Performers partially cover a tone hole to play chromatic pitches, so the intonation is less accurate than for the pitches of the major scale. For example, the unusual chromatic tone of 5♯ changes the scale of *Pamir Spring* into a harmonic minor scale (see figure 8, sound example 6), which with the 7/8 metre in the beginning is characteristic of Islamic music in western China but unusual in typical Han Chinese music.

Our Chinese friends find our synthesised individual Chinese tones indistinguishable from the originals,

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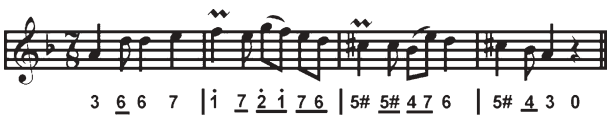


Figure 8. *Dizi* solo with chromatic pitch 5♯, Shi Jia Huan: *Pamir Spring.*

but they have always been able to tell that the musical excerpts testing the tones were synthesised. After studying Chinese musical expression, we wanted to synthesise the ornaments to make the musical examples sound more convincing.

3. THE SOURCE MATERIAL

Chan Chun Nin recorded two or three tones without vibrato for each pitch on the flutes in each key. Figure 9 shows the spectral plots of representative tones. The spectra show quite a bit of instability. The tones have large slow fluctuations and small fast fluctuations in the noise in the amplitudes of the harmonics. Two notes per octave produced a fairly realistic-sounding range of up to a perfect fifth above and below each of the modelled tones. Some of the flutes, such as the *xiao* and *koudi*, can produce realistic-sounding tones much higher than the normal playing range if the highest original tone has very few significant harmonics, but synthesised tones much lower than the lowest original tone sound dull.

The closed tubes of the *paixiao* reinforce the odd harmonics, but the perceived timbre is closer to that of the Western flute than to the clarinet. The A4 *paixiao* tone is more stable than the other flute tones. *Paixiao* tones lower than C3 sound more like foghorns, and tones above D7 sound like whistles.

The fundamental is much weaker than the second harmonic in the C4 *xiao* tone. The spectra of higher *xiao* tones, such as D5, contain primarily a fundamental with a small amount of colouring from the other harmonics, whose amplitudes are less than ten per cent of the fundamental.

The *xun* has an egg-shaped resonating cavity rather than a resonating tube. Its tone is mellow and its higher range is clear. The other spectra are similar to the C4 *xun* tone, with a prominent fundamental and a few weak harmonics.

The spectra of the *koudi* tones are similar to D6, with a strong fundamental and small variations on the other harmonics. The *koudi* spectra, with extreme amplitude fluctuations in the fundamental, are the most unstable of any of the studied instruments.

After testing the spectra of tones from many *dizis*, nine tones from five instruments produced a range

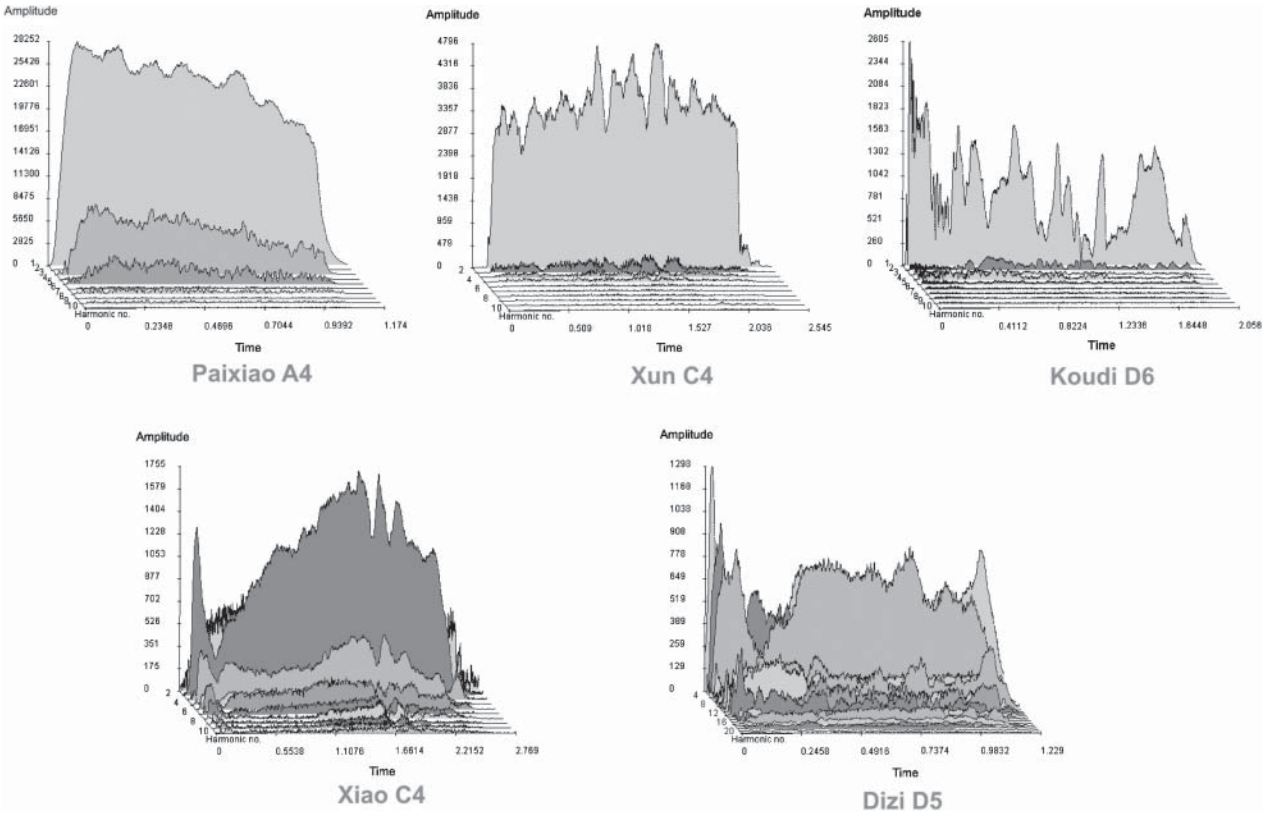


Figure 9. Chinese flute spectra.

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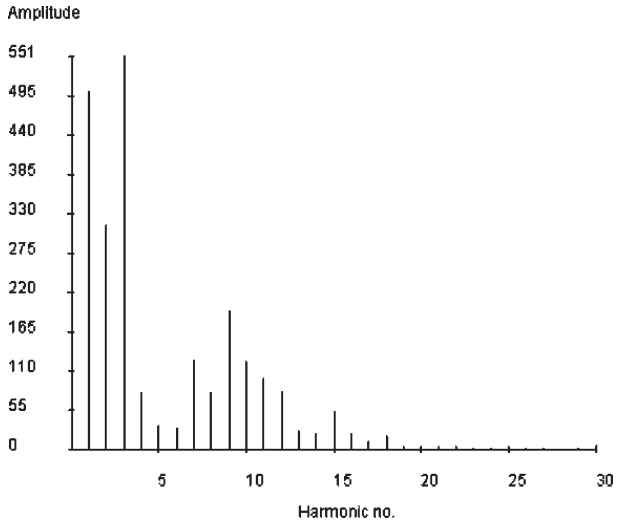


Figure 10. Average amplitude of *dizi* D5 tone.

from D3 to D8. The fundamental is prominent throughout the *dizi*'s range. The higher harmonics gradually roll off in higher-range tones, which are still fairly bright. The lowest tone sounds rather muddy, but the strong absolute formant centred at 5,300 Hz (see figure 10) gives all of the tones their characteristic *dizi* timbre.

4. SYNTHESISING THE EXAMPLES

4.1. The wavetable synthesis model

Our first Chinese wind instrument designs used the same wavetable designs we were developing for the Western wind instruments (Horner and Ayers 2002; see also Horner and Ayers 1998a, b; Horner, Ayers and Law 1999; Ayers 2003; Ayers and Horner 2004a, b). We modelled the original tones as exactly as possible, cross-fading amplitude envelopes for multiple wavetables on each tone. Similar to sampling, the resulting tones sounded too consistent and lacked the expressive variation of live performance. In addition, this complex design would have been difficult for others to use. We simplified the design to a generalised amplitude envelope with random variation. As the tone was too static using a single wavetable, we used group wavetable synthesis. Because the fundamental is the most important harmonic in the tone, we treated it alone as the first group. We used one group for the second and third harmonics, and another group for all the higher harmonics. The three groups varied independently of each other in a more dynamic spectrum, but the harmonics in each group all varied together, making the timbres sound slightly synthesised.

4.2. The additive synthesis model

Figure 11 compares the time-varying spectra of additive synthesis and wavetable-synthesised *dizi* D5 tones. While the wavetable synthesis design produces acceptable matches for Chinese flutes, the additive synthesis method is much more effective at simulating the subtle nuances of the Chinese instruments. The amplitudes of the harmonics in the original spectra of many of these instruments are extremely unstable. Comparing the spectra of multiple recordings of the same tones suggested that finding their average spectra and then randomly varying the amplitudes of the harmonics would better simulate their timbres. A large variation in the spectral amplitudes makes the tones sound more lifelike, and also helps to make

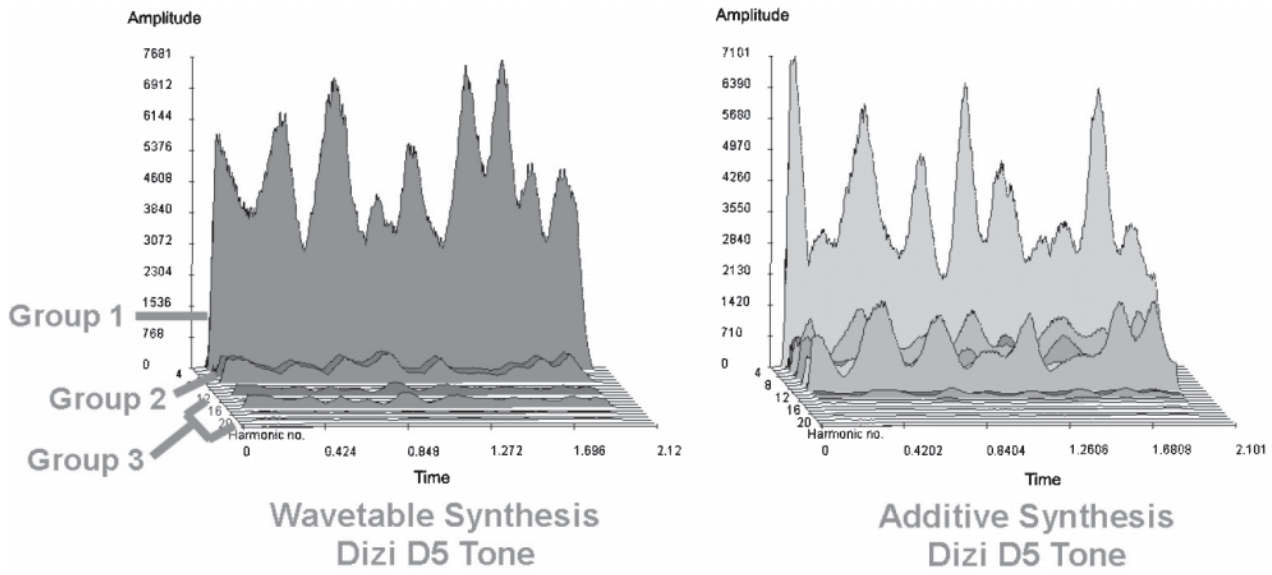


Figure 11. Comparing wavetable and additive synthesis *dizi* D5 tones.

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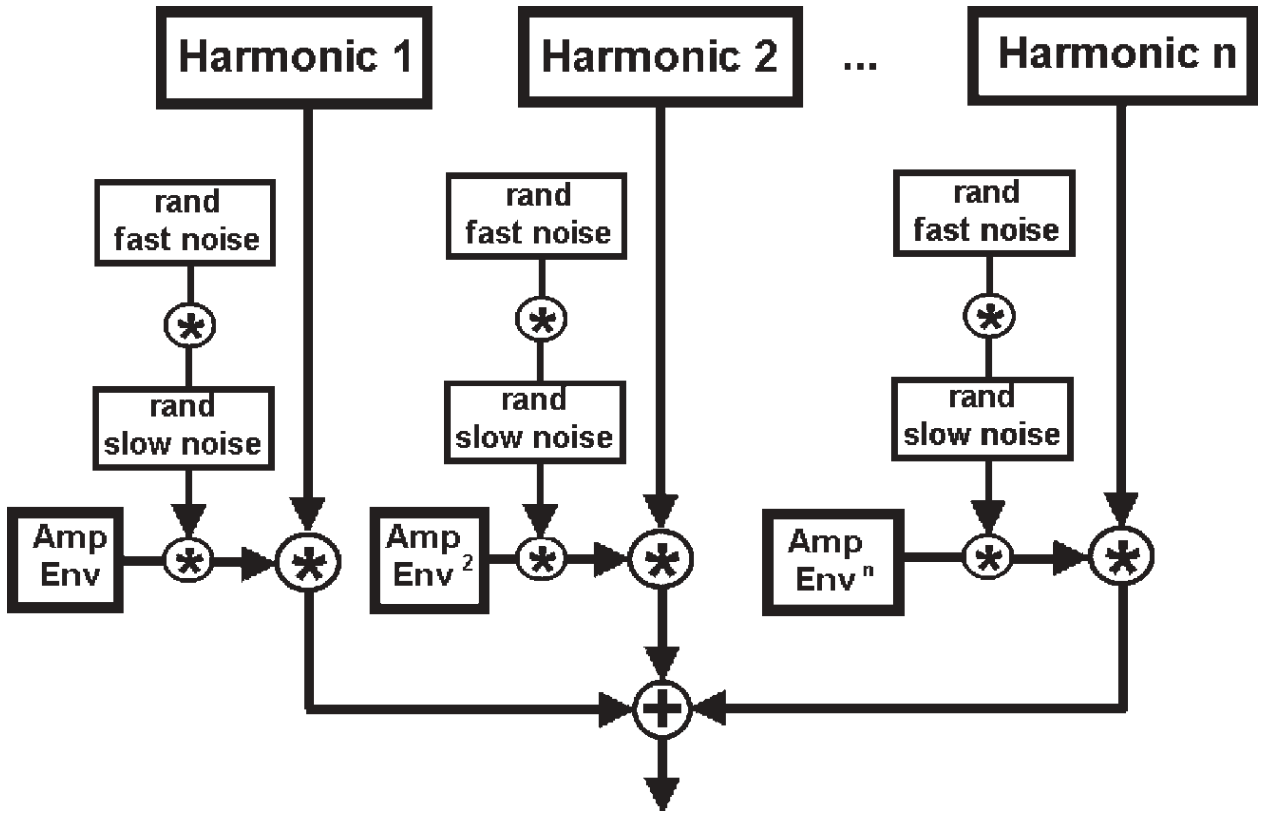


Figure 12. Additive synthesis block diagram.

each tone unique, a feature missing from the preliminary wavetable design, where each tone was so like the original that the effect was similar to sampling.

4.2.1. The harmonic code blocks

The additive synthesis design uses up to thirty harmonic sine waves to model the tone (see figure 12). Each code block produces one harmonic in the spectrum with slight random inharmonicity, vibrato, amplitude interpolation, slow and fast amplitude noise and breath noise. Each harmonic uses the same overall amplitude envelope on the spectral average for that harmonic. However, to make the overall tone brighter as it gets louder and less bright as it decays, the attack and decay times increase as the harmonics get higher. To do this, each harmonic's amplitude envelope results from multiplying the previous harmonic's amplitude envelope by the original amplitude envelope. Slow harmonic amplitude noise varies the overall amplitude slightly to simulate gradual random increases and decreases in breath pressure. Fast harmonic amplitude noise is essentially jitter. The design adds a variable amplitude/frequency modulation vibrato over the whole tone. A ten per cent random variation on the original frequency of the tone, the vibrato rate, and the vibrato depth make the time-varying FM vibrato sound more realistic. Finally, at the end of the code block, the signal accumulates the harmonic. The additive synthesis design avoids aliasing by multiplying the number of harmonics by the frequency of the note and comparing the result to the sampling rate; the design decreases the number of harmonics if necessary.

4.2.2. Breath noise

Breath noise makes the flutes sound more realistic. The breath frequency depends on the tube length producing the pitch. For example, multiplying the frequency of pitch 1 by 0.75 produces the frequency of low 5, the tone produced by the closed *dizi* tube. Overblowing on the tube produces octaves, but the breath frequency depends on the fundamental tube length, which remains the same, so the breath frequencies for middle 5 and low 5 are the same. This rule does not apply to the *paixiao*, since the *paixiao* uses different tubes to produce octaves, or to the *xun*, which does not overblow.

Each harmonic receives a very small amount of filtered breath noise. The centre frequency for the breath noise filter for the harmonic is the breath noise frequency multiplied by the harmonic number. The same amplitude envelope scales the breath noise and the corresponding harmonic for the tone. Attenuating the amplitude of the accumulated breath noise keeps the breath effect subtle.

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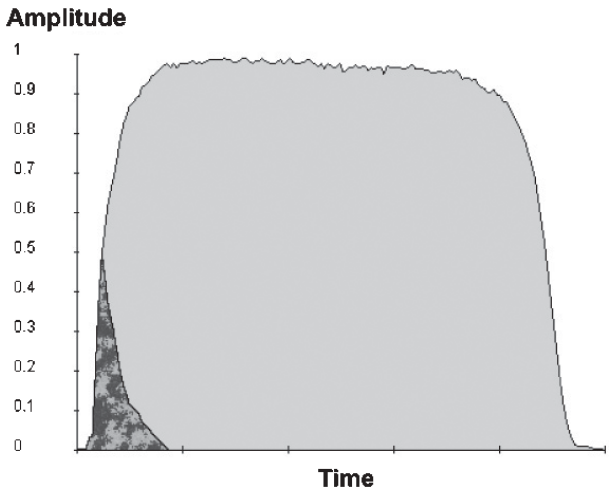


Figure 13. Amplitude envelope with attack noise.

4.2.3. Articulation

Pronouncing the syllable 'tu' produces a hard attack on the flute. A burst of noise at the beginning of the tone approximates this effect. A simple amplitude envelope cross-fades the noise to zero against the attack of the note (see figure 13).

4.2.4. Spectral interpolation

The design interpolates parameters to eliminate the range breaks between the spectra of modelled tones by finding the weighted average amplitude for each of the harmonics. The design first finds the frequency of the original tone closest to the tone to be synthesised. The design determines if the frequency of the tone to be synthesised is higher or lower than the original tone, and finds the frequency of the original tone on the other side of the tone to be synthesised. It calculates the proportional weight of the synthesised tone's spectrum from the weighted average between the spectra of the original tone and the tone on the other side of the synthesised tone. It uses the cents differences between the frequency of the tone to be synthesised and the two original tones because frequency is logarithmic. The synthesised spectrum comes from the proportional weight of each of the original tones' spectra, scaling the amplitudes for each of the harmonics, producing a smooth spectral interpolation not only for single tones, but during the transitions in the slurs and trills as well. The musical examples are both expressive and realistic.

4.3. Synthesising the ornaments

This section describes ornaments that Chinese performers add according to their taste and the mood of the music. They can add different ornaments to different performances of the same piece. The design is successful with long and short tones, slurs, grace notes and trills.

4.3.1. Slurs

A line segment connecting the note parameters most closely models the slur effect on many of the instruments. However, the pitch does not slide between the tones on multiple pipe instruments such as the *paixiao* as it does on single pipe instruments, and overlapping best simulates the *paixiao* slurs when the tones are long enough that the decay of one tone can overlap the attack of the following tone. Connecting the frequencies of two notes with a line segment and morphing the transition using parameter interpolation (Rodet and Lefèvre 1997) more closely models the slurs on the single pipe instruments.

The wavetable synthesis instrument cross-fades two unison signals to use their correct wavetables. The additive synthesis instrument uses a frequency and amplitude line segment with a variable number of notes for each of the harmonics of a single signal. The line segment method models grace notes as other slurred notes. Advancing the starting time of the grace note when it precedes the main note places the main note on the beat. As the grace note is lighter than the main pitch, it receives less amplitude.

4.3.2. Pitch bend

The pitch bend effect slows down the slides between the pitches of the slur design. Figure 14 shows spectrograms of the original and synthesised versions of the *koudi* solo, *Morning in Miao Mountain* (sound example 3, Du Chong 1989). The pitches last longer in the synthesised version because the reverb is heavier. Figure 2 shows a spectrogram analysis of the first phrase of *A Descending Phoenix* (sound example 1, Qian Zhaoxi 1989). This phrase has a pitch bend down and then back up of about 2/3 of a semitone (about 67 cents). The design allows entering the amount of

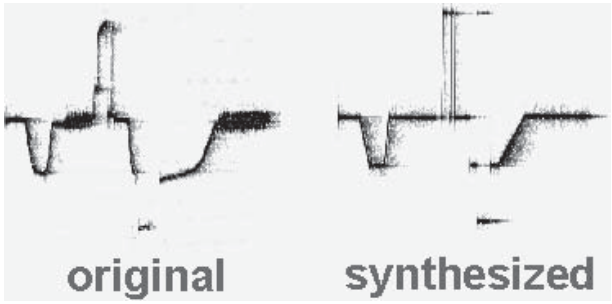


Figure 14. Original and synthesised *koudi* performance of Du Chong: *Morning in Miao Mountain.*

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pitch-bend in cents to permit the expressiveness of this effect.

4.3.3. Trills

How can trilled phrases slur varying numbers of notes? In Csound, slurred groups of different numbers of notes need different numbers of input parameters. A repeating function controlling the frequency of a single tone produces smoother trilled notes than overlapping tones does. Our previous work used amplitude and frequency modulation functions to cross-fade the trills in the wavetable instrument designs (Ayers 2003, 2004; Ayers and Horner 2004a, b).

The frequency modulator repeats a function that approximates the frequency change for one average trill cycle as shown in figure 15. The function oscillates between the frequency of the lower note and the frequency of the higher note, using a phase shift of 180°. To give each note in the trill the correct spectrum, the same function with a phase of 0° modulates the difference between the harmonic amplitudes of the lower and higher notes. The cycles begin with a twenty per cent overshooting of the required frequency. Separate parameters change the trill amplitude as for a single sustained tone. A line segment with random variation controls an initial, middle and final trill rate, and the times required to change among the trill rates. Adding random jitter on the average tone varies each cycle. One of the notes may be a little louder or softer than the other.

4.3.4. Combining grace notes with trills

Zhonghua Liuban (Lu 1996, 2000, 2002; sound example 7) is a slow, legato, *jiangnan sizhu* piece (Witzleben 1995) combining trills with one or more grace notes in various combinations before and after

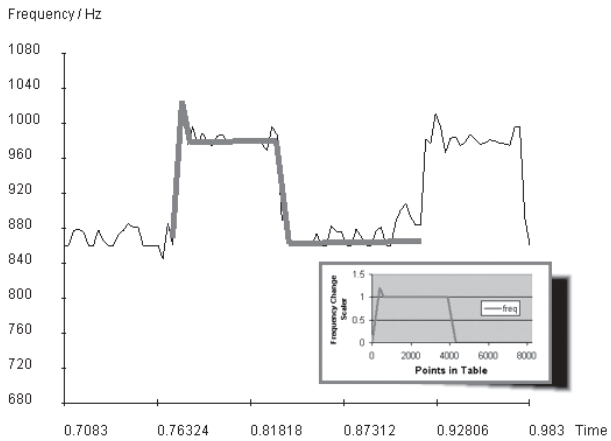


Figure 15. Averaging one cycle of the trill for a frequency function.

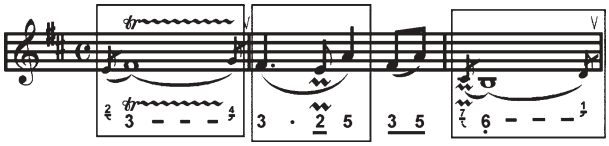


Figure 16. Grace note and trill combinations in *Zhonghua Liuban.*

the note. Figure 16 shows the notation for the first phrase of the piece, which includes three combinations of grace notes and trills. Two of these examples have a grace note escaping from the main note.

In order to connect the grace notes with the trills, line segments set the frequency and all the harmonic amplitudes. A delay on the frequency and amplitude modulators begins the modulation at the same time as the note requiring the trill occurs in the line segment to ensure that the trill begins on the desired note and not on any random note that may be occurring by the time the trill note occurs. Finally, all the modulators add to their corresponding signals.

4.4. Csound pitch input and tuning

This section describes the Csound pitch input method and tuning. It is easy to input the pitch from Chinese numerical notation. The tuning in Chinese music depends on the instrument, but most flutes are tuned using successive fifths. Csound function tables make it easy to change between tuning systems.

The Csound scores contain two parameter fields for pitch. The first field handles the pitch numbers, and the second controls the octave. The octave is set by multiplying the pitch by another power of 2 for each higher octave, so the original octave is 1, the next octave is 2 and the next octave is 4. The excerpt shown in table 1 from the Csound score for the *Pamir Spring* example (1990, last two measures of figure 8, sound example 6) illustrates the pitch input method.

Some flutes originally had a more or less equal spacing between the tone holes, making a comfortable placement of the musician's fingers on the instrument, but producing more widely-spaced pitches as the tube gets shorter. Most of the flutes now use Ling Lun's string of perfect 5ths (later called Pythagorean tuning in Greece). Although electronic tuners make it possible to tune instruments in Western tuning, Ling Lun's tuning sounds better in traditional melodies. Function table 10 sets Ling Lun's tuning. The input pitches normally consist of the integers 1 to 7, and the input method is more intuitive if chromatic pitches occur between the integers. For example, the input for pitch 5♯ (used in *Pamir Spring*, see figure 8) would be 5.5. As the indexes to function table 10 must be integers, function table 9 provides the conversion. Csound then reads the pair of numbers occurring at

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Table 1. Excerpt from Csound score for *Pamir Spring* example.

```
;-------------------------------------------------------------------------------------------------------------------------------------------------
; Csound score
; function table for pitch to choose ratios
f9 0 16384 -17 0 0 105 1 205 2 305 3 405 5 505 6 555 7 605 8

; function table for Ling Lun's tuning ratios
f10 0 64 -2 1 1 9 8 81 64 4 3 3 2 128 81 27 16 243 128
;-------------------------------------------------------------------------------------------------------------------------------------------------
; tempo statement
t0.0 258.1 7.0 304.17 8.0 312.13 10.0 325.67 11.0 334.43 13.0 348.97 15.0 360.4 15.0 358.7 . . . 254.87 362.9
;-------------------------------------------------------------------------------------------------------------------------------------------------
; set global variables in i1

;p1     p2      p3      p4          p5          
;       start   dur     gifreq      giattn      
i1      0       1       588.6       1           ; global tuning frequency is D5
;-------------------------------------------------------------------------------------------------------------------------------------------------
;bar 26 ----------------------------------------------------------------------------------------------------------------------------------------
; trill
;p1     p2      p3      p4      p5      p6      p7      p8      . . .   p13     p14     . . .
;       start   dur     amp     amp2    ptch1   octv1   tr      . . .   ptch2   octv2   . . .
i27     174     2       10739   10629   5.5     1       2       . . .   6       1       . . .

;p1     p2      p3      p4      . . .   p8      p9      . . .
;       start   dur     amp     . . .   pitch   oct     . . .
i25     176     1       6931    . . .   5.5     1       . . .

; 2-note slur
;p1     p2      p3      p4      p5      p6      p7      p8      . . .   p13     p14     . . .
;       start   dur     amp     amp2    ptch1   octv1   vib     . . .   ptch2   octv2   . . .
i27     177     2       8121    7846    4       1       0.020   . . .   7       1       . . .

;p1     p2      p3      p4      . . .   p8      p9      . . .
;       start   dur     amp     . . .   pitch   oct     . . .
i25     179     2       7070    . . .   6       1       . . .

;bar 27 ----------------------------------------------------------------------------------------------------------------------------------------
; trill
;p1     p2      p3      p4      p5      p6      p7      p8      . . .   p13     p14     . . .
;       start   dur     amp     amp2    ptch1   octv1   tr      . . .   ptch2   octv2   . . .
i27     181     2       10466   9887    5.5     1       2       . . .   6       1       . . .

;p1     p2      p3      p4      . . .   p8      p9      . . .
;       start   dur     amp     . . .   pitch   oct     . . .
i25     183     1       6472    . . .   4       1       . . .
i25     184     2       8058    . . .   3       1       . . .
;-------------------------------------------------------------------------------------------------------------------------------------------------
```

the indexed position and the following position in function table 10 as the numerator and denominator of the frequency ratio for the tone.

A global tuning frequency in a Csound note statement can tune all the instruments in the orchestra to the tonic key. As the frequency value is initialised at the start of the note, the note duration is irrelevant as long as it is greater than 0. In the orchestra, instrument 1 reads the global frequency and attenuation values from the score. Another note statement with a new global tuning frequency or attenuation can reset the values at any start time, making it possible to change the key in the middle of a piece. A few simple lines of code in the instrument designs use the global frequency to set the frequency for the individual notes, as shown in table 2.

A short utility program writes the tempo statement with subtle beat scaling to give the beat a more human feeling. The Csound score shows the beginning of the tempo statement.

5. APPLICATIONS

A special benefit of the virtual Chinese computer instruments is their ease in producing the microtones which I use in my compositions. For example, *Why Ask Questions?* used the *dizi* and *xiao*, along with *erhu* (two-string fiddle), *pipa* (pear-shaped plucked-string

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Table 2. Global tuning frequency code.

```
;-------------------------------------------------------------------------------------------------------------------------
; Csound orchestra
instr 1
gifreq          =       p4                              ; set global tuning frequency
giattn          =       p5                              ; set global attenuation scaling

endin
;-------------------------------------------------------------------------------------------------------------------------
instr 25
. . .
ipitch          =       p8
ioct            =       p9

ipitchtable     =       9                               ; table of indexes for table 10
iratiotable     =       10                              ; table of frequency ratios

iprange         table   ipitch*100, ipitchtable         ; pitch range of note
inum            table   (iprange*2), iratiotable        ; numerator of note
iden            table   (iprange*2)+1, iratiotable      ; denominator of note
ifreq           =       inum/iden * gifreq              ; ratio x global freq

ifreq           =       (ioct = 0 ? ifreq/2 : ifreq * ioct)   ; prevent division by zero
. . .
;-------------------------------------------------------------------------------------------------------------------------
```

instrument) and gong designs. I composed the microtonal piece algorithmically, then processed Chinese voice samples and the computer instrument designs. In *Yazi's Dream,* synthesised trills on the *dizi* represent the bird fantasies of Yazi, my first cat. In the 'Looking at Birds' section, *dizi* fantasy birds dialogue with recorded bird sounds. Joining sliding trills to other *dizi* notes produces bird melody fragments. Figure 17 (sound example 8) shows a 12-second example of legato and staccato tones, sliding trills and pitch bend from the *dizi* part for this section. Sound example 9 shows the same example with the dialogue among the *dizi* trill melody fragments and real bird and cat sounds. The dialogue between the dizi and the real birds and cat returns at the end of the piece.

Ghost Shadow in Fragile Light uses a computer-generated tape to create a ghost environment around the five live performers: the Chinese flutes (*dizi*, *xiao*, *xun* and *paixiao*), along with the *erhu*, *pipa*, *zheng* (plucked zither) and *yangqin* (similar to hammer dulcimer). Virtual instruments form an orchestra from shadows of the live instruments, along with *bawu* (single free reed), sampled Chinese percussion instruments (*boling*, *muyu*, *qing*, *xing*, *luo* and *drum*), Woodstock gamelan (a microtonal tubular percussion instrument) and Western wind instruments. The live performers play mostly in a tuning close to their normal tuning, with a few unusual inflections. The virtual shadow surrounds them with a microtonal environment. In addition, some fragile sounds on the tape, such as a bowed crystal glass, create a strange illumination which surrounds both the live and ghost orchestras.

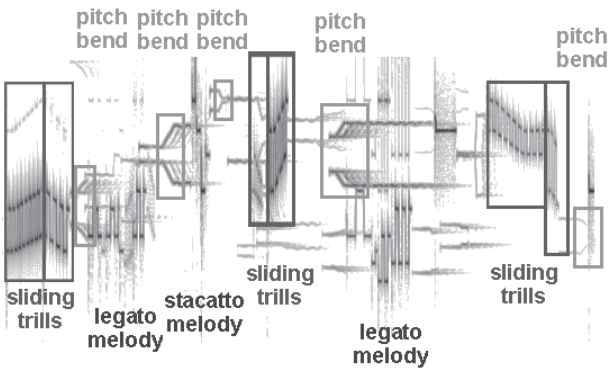


Figure 17. *Dizi* bird melody fragments from *Yazi's Dream*, 'Looking at Birds'.

The piece has three movements. Chinese musical ornaments inspired some of the sounds traded between the live performers and the tape in the first movement. The *pipa*, *paixiao* and *xun* have short solos, the *erhu* plays an ascending sliding trill, and the other live instruments appear sporadically. The movement includes tremolo of the live *xun*, *erhu*, *pipa* and *zheng* accompanied by the taped *qing*, drum and vocal fry. Descending scales interlock live performers and taped sounds. The Chinese percussion instruments and Woodstock gamelan provide rhythmic punctuation figures throughout the movement. Sound example 10 is a synthesised demo of an excerpt from the end of the movement (see the spectrogram in figure 18). Musical elements visible on the graphs include the ghost *xun* framing the live *xun* trill with impossible sliding trills. The *erhu* is the only instrument which performs the ascending sliding trill live. Adding different spectral data to the Chinese additive

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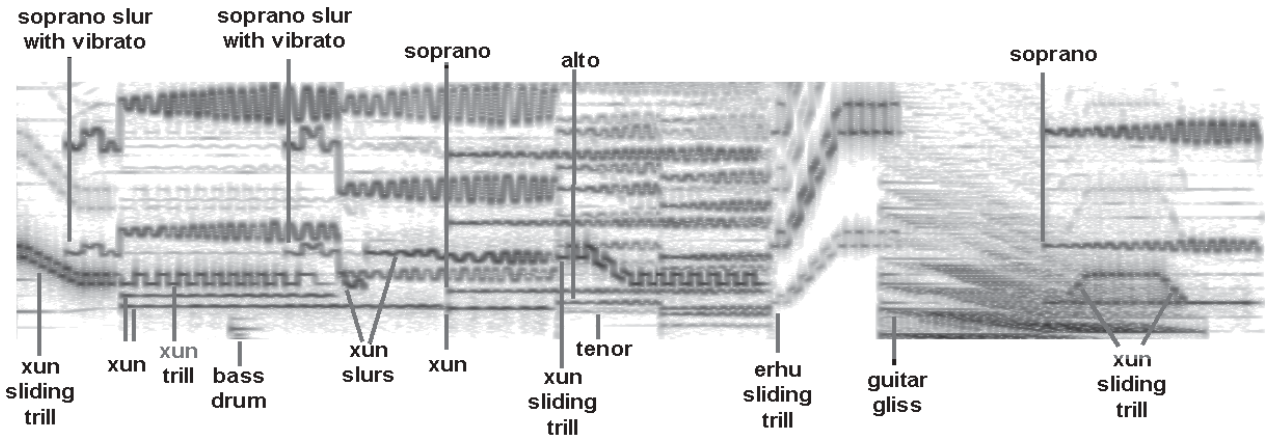


Figure 18. End of *Ghost Shadow in Fragile Light*, part 1.

synthesis instrument template produces the Western instruments and the shadow voices, which appear as zig-zag lines in the spectrogram because of their large vibratos. The final *xun* sliding tremolo oscillates within an interval that increases from unison to a perfect fifth and returns to unison. Several Western instruments, including a bass clarinet drone with phasing and sampled guitar glissandi, colour the shadows.

The bowed glass and crystal flutter (filtered noise) sounds suggest an intense eerie light framing the second movement, and some of the melodic fragments from the first movement break up and evolve into other fragments. Sound example 11 is an excerpt from the middle of this movement that demonstrates some of the expressive qualities of the designs (see the spectrogram in figure 19). Some of the live instruments can bend the pitch a small amount, but the *erhu* is the only one that can play the long sliding trill which begins the excerpt. The ghost clarinet echoes with a larger sliding trill. After some scattered instrumental fragments, a crystal flutter leads to a live *xiao* trill accompanying a clarinet sliding tremolo that oscillates within an interval that increases from unison to a minor third and returns to unison. The clarinet and flute timbre tremolo and live *erhu* semitone trill accompany a *yangqin* arch phrase, which the *pipa* repeats under its sequence. Bass clarinet phasing gives a subtle background aura. The clarinet concludes the excerpt with a dramatic octave portamento drop.

The third movement features the synthesised Woodstock gamelan, whose ghost shifts among several strange tunings, while the ghostly voices return to fly around. By the end of this movement, the ever-changing shadow affects the live performers, who have a few microtones added to their scale. Throughout much of the movement, the ghost guitar, gamelan and muyu take a lively Indonesian character, with various instruments taking turns interlocking with the triplet melody fragments and the duple gamelan-like layers.

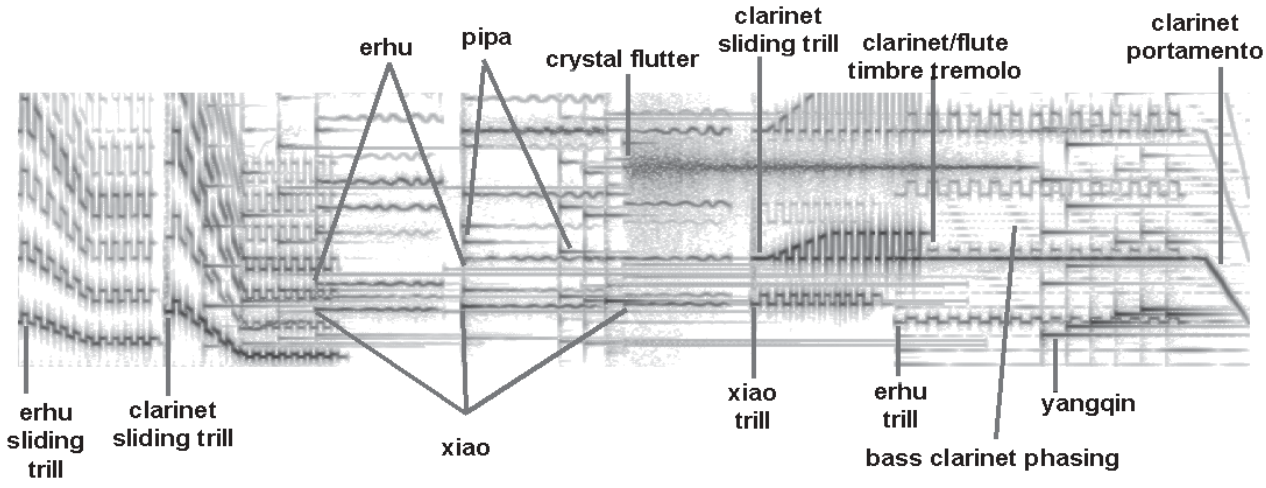


Figure 19. Middle of *Ghost Shadow in Fragile Light*, part 2.

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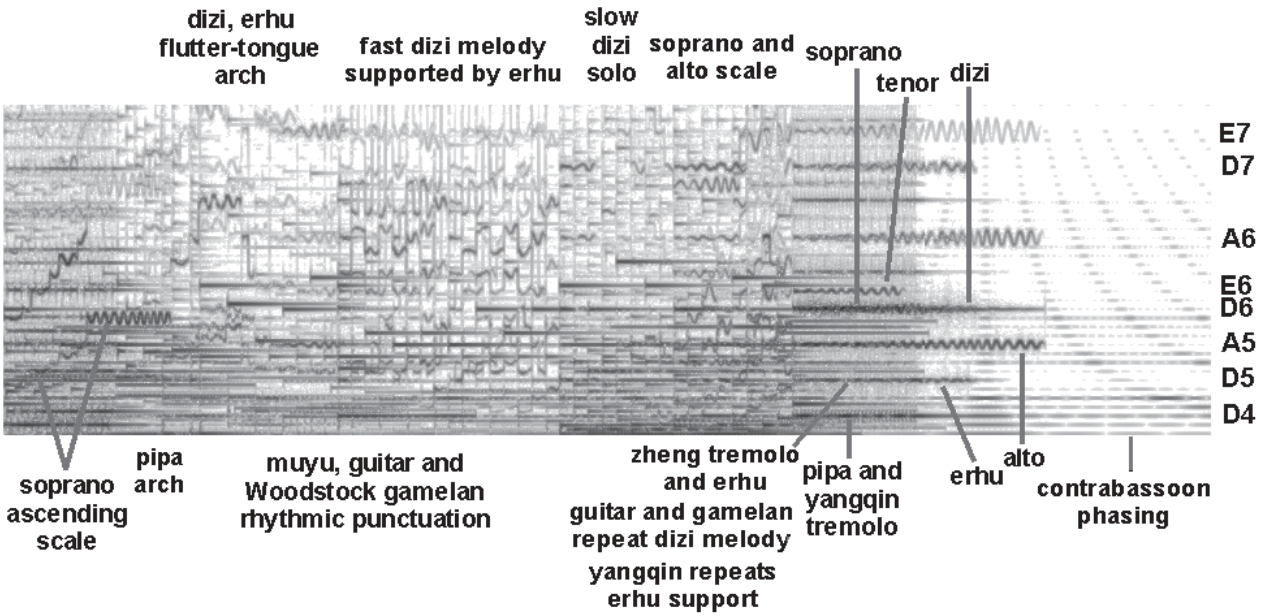


Figure 20. End of *Ghost Shadow in Fragile Light*, part 3.

The movement ends with the shadow voices flying upward while the ghost guitar, gamelan and muyu accompany the live *dizi* and *erhu* (sound example 12, figure 20). Finally the phasing on the contrabassoon drone, nearly inaudible throughout the movement, emerges briefly and disperses as the darkness dissipates.

4. CONCLUSION AND FUTURE WORK

Composers are experimenting with extended techniques for live Chinese instruments, though the physical characteristics of the instruments limit what they can produce. For example, the ranges of individual *xun* and *koudi* instruments are limited to approximately an octave, and attempting to overblow high harmonics to expand the range of the *dizi* shatters the fragile membrane. Computer designs can use tones from several like instruments to produce synthesised super-ranges.

Some instruments can produce a few multiphonics by a combination of cross-fingering and overblowing, but this kind of effect is very limited. Future work includes branching out to study multiphonics, vocal sounds combined with instrumental sounds, such as humming while playing, and will report the results for the free reed and double reed instruments, including the *suona* technique called *kaxiao*, which uses vocal sounds with a special metal 'reed' within the mouth. Modelling such timbral effects from real instruments can extend the timbral palette available to computer music composers. The timbres of multiphonics and vocal and instrumental combinations can apply to any pitches and sounds, especially those which do not exist on acoustic instruments. A field of infinite possibility remains open.

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PIECES MODELLED AND CORRESPONDING CD RECORDINGS

(The following list gives recordings of the pieces we modelled. Recorded versions of these well-known pieces may differ from the versions in this paper.)

paixiao: A Descending Phoenix

Qian Zhaoxi. 1989. *New Voice of Huaxia: Dizi Solo by Zhan Yong-Ming*, with Folk Music Ensemble of the China Broadcasting Corporation. China Record Corporation, Beijing, CRD89/044.

xun: Ai Ying

1991. *A New Fascinating Soul of the Pottery Xun*. Performed by Zhao Liang Shan with Zhong yang yin yue xue yuan min zu yue dui, cond. Peng Xiancheng. China Record, CCD-91-113.

koudi: Morning in the Miao Mountain

Du Chong. 1989. *Chinese Wind Instrument Music*, Vol. 1. Performed by Du Chong with the Chinese Orchestra of Shanghai Music Conservatory, cond. Xia Fei-yun. Hong Kong: Hugo Productions (HK) Ltd.

xiao: Autumn Recollection at the Dressing Table

1990. *Chinese Tung-Hsiao*. Performed by Tong Ku-Chiun. Taiwan, Taipei: Wind Records Co., Ltd., TCD1007.

dizi: *Pamir Spring*

1990, *Carefree Flutes.* Performed by Shi Jia Huan with the Chinese Chamber Ensemble, cond. Gu Feng Yu. Taipei: Sunrise Records Ltd., 8524

1995. *Ten Chinese Dizi Classics*. Performed by Yu Xunfa. Shanghai, Hanzhou: HNH International, Middle Kingdom, 8.828008.

dizi: *Zhonghua Liuban*

1996. *Glad Tidings.* Performed by Lu Chun-ling with the Shanghai Chinese Orchestra, cond. Xia Fei-yun. Hong Kong: Hugo Productions (HK) Ltd., HRP7148-2.

2000. *The Magic Flutist Lu Chun Ling and The Music of Silk & Bamboo*, performed by Lu Chun-ling with the Harmonious Music Ensemble, cond. Chai Man Cheng. Dun Huang Music Ltd.

2002. *Eight Masterpieces of Jiangnan Folk Music*, performed by Lu Chun-ling with The Chinese Folk Music Ensemble, Starlight Music International Ltd., DDD-31119.

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