Gestural Sounds by Means of Wave Terrain Synthesis

Anderson Mills and Rodolfo Coelho de Souza
The University of Texas at Austin

Abstract
Wave terrain synthesis can be used as an efficient tool for generating sound objects with time varying spectra to create a musical gesture. To accomplish this goal some changes need to be made to Mitsuhashi’s original approach to wave terrain synthesis. These changes include less limited terrain functions, complex orbital paths, windowing corrections, and displacement of a pair of orbits defining a stereo sound. An example of a CSound implementation is given.

1 INTRODUCTION
The technique of sound generation by means of two variable functions, also known as wave terrain synthesis, is a field that has not yet been explored to its full musical potential. The technique was devised by Mitsuhashi (Mitsuhashi 1982) as an alternative to Chowning’s method of FM synthesis (Chowning 1973), considering the goal of hardware implementation, but the technique has also been implemented in software as demonstrated by Borgonovo (Borgonovo and Haus 1986), Nelson (Nelson 1998), and Pinkston (Pinkston 1999). The primary goal of Mitsuhashi’s research was to emulate natural sounds or other standard synthesis techniques. Though wave terrain synthesis is a versatile tool that can produce results equivalent to many other synthesis techniques, like FM, AM and wave shaping, it attracted our attention because of the unique results which it can generate.

Roads (Roads 1996) summarizes the technique describing its two basic elements: the choice of a three-dimensional table that can be visualized as a topographic terrain representing amplitudes built by vector product of two-variable functions and a table look up procedure following a chosen path or orbit. These orbits determine the character of the resulting sound object, particularly its development over time and the creation of distinctive shapes outside
of the framework of traditionally conceived musical sounds. This implies the generation of gestural sound objects by direct digital synthesis rather than by the musique concrete technique of distortion of recorded sounds.

A gesture is defined by Hatten (Hatten 1999) as movement that may be interpreted as significant. As the musical meaning does not point to external references but to relations inside the musical discourse, Smalley (Smalley 1986) emphasizes the importance of spectro-morphological design to control spectral and dynamic shaping of sound objects to create real and imagined motions without the need for spatial movement. The idiomatic procedures of wave terrain synthesis allow and almost imply the generation of many kinds of directional or moving sounds. Therefore, wave terrain synthesis can be considered a gestural synthesis technique by its nature.

2 TERRAIN

Because Mitsuhashi uses tables that wrap beginning to end, he proposes many restrictions for the functions that can be used to build the terrain. He recommends that the functions and their first-order partial derivatives in space should be continuous in the area of definition. He also specifies that the values of the functions on the boundaries should be zero and have the same partial derivative in space on the two boundaries. He is concerned that the result should provide smooth waveforms even when a jump occurs from one boundary to another. Borgonovo and Haus followed the path recommended by Mitsuhashi. Their implementation is on a Fairlight platform and experiments with three new functions following the principles suggested by Mitsuhashi as well as his original two.

As Roads points out, these restrictions are necessary if the terrain table is to be used to generate predictable waveforms, particularly when using periodic orbits that extend beyond a single table. When the aim of the technique is to produce more complex output (which happens simply by using time-varying orbits), Pinkston's alternative implementation implies that many of these restrictions might be relaxed and the terrain table may be filled with more complex functions or data. Nevertheless the restriction that the boundary values should have a constant value (not necessarily 0 but also 1 or any other) is convenient for assuring continuity of the waveform when a complex orbit wraps around the table.
For this implementation the terrain is described by the vector product of the function \( \sin(x^4) \) in both \( x \) and \( y \) axis. This function is chosen because it has a varying spectral density that depends upon the value of the independent variable. Any terrain space defined will therefore be “quietest” nearest the origin and “noisiest” farthest from the origin. An orbit moving through these areas allows the variation of spectra in time. The next section will show how appropriate orbits create the gestural movement previously mentioned. Note that because \( \sin(x^4) \) is a function defined for all \( x \), there is no wrapping of the table as in Mitsuhashi’s implementation.

### 3 ORBITS

The orbits researched by Mitsuhashi and Boronovo were chosen to create a direct relation with the fundamental frequency of the resulting sound. They describe simple trajectories over the terrain table which are a combination of a linear and a periodic term. Though the implementation listed below is capable of reproducing their results, the gestural aspect of wave terrain synthesis is achieved by summing both a slow and fast periodic orbit. A lunar orbit around the sun proves to be a useful model for visualizing this summation. Such an orbit describes a compound path formed by a larger circular or elliptical path, usually in slower, sub-audio rate, and a local smaller and faster circular orbit. We extend this local orbit to rectangular motion to correct for the deviation in the frequency content caused by circular motion in a rectilinear terrain table. In this approach, the small fast orbit is related to the perception of the fundamental frequency while the large slow orbit is related to the evolution of the changes of the harmonic spectra. In our implementation a slow orbit which passes through different areas of the terrain causes the gestural changes we have described.

### 4 WINDOWING

Some experiments were done with different small orbit shapes, and it was found that rectangular orbits with linear paths over a known function on each side allow the best control of the harmonic content over time. Unfortunately rectangular orbits lead to a problem due to the change of directions on each corner of the rectangle causing discontinuities in the wave shape’s first order partial derivative in time. These cusps on the wave shape have the effect of adding a band of non-harmonic high partials (a parasitic buzz). To avoid this
artifact without resorting to filters a windowing function is applied to each side of the rectangular orbit that reduced the amplitude at the corners of the small orbit and eliminated the cusps. This windowing solution controls the problem introducing a form of amplitude modulation.

5 SPATIAL LOCALIZATION

Another effect that is implemented in this approach to wave terrain synthesis is spatial movement through the use of displaced slow orbits without the use of specific panning controls. Two different techniques prove significant: slow orbit time displacement and slow orbit terrain-space displacement. The idea is to provide each stereo channel with a slightly displaced orbit from the same terrain table. As our CSound implementation uses phasor functions accessing the terrain table to act as oscillators, a small time difference between the phasors of the two stereo channels can generate significant changes in sound localization as the orbits cross different parts of the terrain. The second approach uses a small spatial offset between the slow orbits. The difference in spectral content between the stereo channels due to spatial displacement is similar to the effect created by time displacement, though as the spatial offset becomes larger, the two stereo channels become dissociated. It is interesting to note that small differences in the visual field create a sense of visual depth and spatial perspective and small differences in the aural field create a sense of aural depth and physical space.

6 SUMMARY

We have shown several new aspects to wave terrain synthesis here including less limited terrain functions, more complex orbits (and windowing corrections of undesired artifacts caused by rectangular orbits), and stereo movement created by slightly displaced orbits. Our research shows that there is much more ground to explore in wave terrain synthesis and its potential application to music composition.

7 AN EXAMPLE OF CSOUND IMPLEMENTATION OF A WAVE TERRAIN GESTURAL SOUND

; terrain.orc

    sr = 44100
kr     =     44100
ksmps  =     1
nchnls =     2

; for this implementation krate must equal arate

instr  1

; initialization
idur    =     p3     ;duration
iamp    =     p4     ;amplitude
ifsarfn =     p5     ;fast orbit aspect ratio function (x/y)
ifsfqfn =     p6     ;fast orbit frequency function
ifsdsfn =     p7     ;fast orbit distance function

(ixlslfn =     p8     ;slow orbit left x function
iylslfn =     p9     ;slow orbit left y function
ixrslfn =     p10    ;slow orbit right x function
iyrsln =     p11    ;slow orbit right y function
ixangfn =     p12    ;wave terrain x function
iyangfn =     p13    ;wave terrain y function
iwinfn  =     p14    ;window function
isquafn =     p15    ;square function (must be -1 to 1 to 1 to -1)

; constants
ixmode   =     1     ;tables go from 0 to 1
inoff    =     0     ;no offset to the tables
iwrap    =     1     ;wrap the tables as necessary
isine    =     1     ;function 1 contains a sine
iquawv   =     0.25   ;quarter offset
ihalfwv  =     0.5    ;half wave offset
i3quawv  =     0.75   ;three quarter offset
ipi      =     3.14159265359  ;pi
ifour    =     4      ;there are four sides to a rectangle
irise    =     0.01   ;rise time
idecay   =     irise  ;decay time

; performance - a ramp at the audio rate that goes from 0 to 1
aramp line  0.0, idur, 1.0
kramp  line  0.0, idur, 1.0

; start looking up from tables - slow orbits
axlslo  tablei  aramp, ixlsln, ixmode
aylslo  tablei  aramp, iylsln, ixmode
axrslo  tablei  aramp, ixrsln, ixmode
ayrslo  tablei  aramp, iyrsln, ixmode

; the fast orbit
; the aspect ratio function for the fast orbit
kasrfas  tablei  kramp, ifsarfn, ixmode
; the frequency function for the fast orbit
kfrqfas  tablei  kramp, ifsfqfn, ixmode
; the distance function for the fast orbit
adstfas  tablei  aramp, ifsdsfn, ixmode

; a phasor that changes rate according to aspect ratio
; pass from 0 to 0.25 in kxunit, then 0.25 to 0.5 in kyunit and repeat

kfasorb    phasor kfrqfas
kunit = 2 * kasrfas + 2
kyunit = 1 / kunit
kxunit = kasrfas / kunit

if  kfasorb < kxunit  goto undera
if  kfasorb < ihalfwv  goto underb
if  kfasorb < (ihalfwv + kxunit)  goto underc
    goto underd
undera:  avarphs = iquawv * kfasorb / kxunit
    goto done
underb:  avarphs = iquawv * (kfasorb - kxunit) / (ihalfwv - kxunit) + iquawv
    goto done
underc:  avarphs = iquawv * (kfasorb - ihalfwv) / (kxunit + ihalfwv
    goto done
underd:  avarphs = iquawv * (kfasorb - ihalfwv - kxunit) / (ihalfwv - kxunit) + 3iquawv
    goto done

done:

; now the window function (four times each period at kfrqfas)
awindex    =  avarphs * ifour
awin  tablei  awindex, iwinfn, ixmode, inoff, iwrap
; the x and y fast portion of the indexes into the terrain
axfas tablei avarphs, isquafn, ixmode, iquawv, iwrap
; offset by a quarter to make equiv to cos
axfas = axfas*adstfas
ayfas tablei avarphs, isquafn, ixmode, inoff, iwrap
ayfas = ayfas*adstfas/kasrfas

; calculate the indexes into the terrain
alxin = axslos+axfas
alyin = aylslo+ayfas
arxin = axrslo+axfas
aryin = ayrlos+ayfas

; pick the point in the terrain
axangfc tablei aramp, ixangfn, ixmode
; get the angular factor for x
ayangfc tablei aramp, iyangfn, ixmode
; get the angular factor for y
alxout = sin(alxins+alxin*alxin*alxin*alxin*axangfc)
; sin (x^4*factor)
alyout = sin(alyins+alyin*alyin*alyin*alyin*ayangfc)
arxout = sin(arxins+arxin*arxin*arxin*arxin*axangfc)
aryout = sin(aryins+aryin*aryin*aryin*aryin*ayangfc)

; stereo output for this instrument
; amplitude gate
acompgt linen iamp, irise, idur, idecay
alout = alxouts+alyouts+acompgt+awin
arout = arxouts+aryouts+acompgt+awin
outs alout, arout
endin

;=================================================================
; terrain.sco

; functions
; aspect ratio function
;f start size gen p1
f05  0.0  8193  7  1.0  8193  1.0
; fast orbit radius function
:f  start  size  gen  p1
f10  0.0  8193  -7  0.08  8193  0.08
f11  0.0  8193  7   0   8193  1.0
; fast orbit frequency function
:f  start  size  gen  p1
f20  0.0  8193  -7  50   8193  50
f22  0.0  8193  -7  200  8193  200
; slow orbit functions
:f  start  size  gen  p1
f32  0.0  8193  -19 1   0.4  315  0.5
f33  0.0  8193  -19 1   0.4  225  0.5
f34  0.0  8193  -19 1.01 0.4  317  0.45
f35  0.0  8193  -19 1.01 0.4  227  0.5
; angular factor functions
:f  start  size  gen  p1
f70  0.0  8193  -7  60.0  8193  60.0
f71  0.0  8193  -7  60.0  8193  30.0
; square function
:f  start  size  gen  p1
f98  0.0  8192  7   -1.0 2048 -1.0 2048  1.0
     2048  1.0 2048 -1.0
; Hamming window function
:f  start  size  gen  p1
f99  0.0  8192  20  1
; tempo
 t0  60
; performance
;ins  start  dur  amp  fsarfn  fsfqn  fsdfsfn
i01  0.0  6.0  20000 5   22  10
;xlsln  ylsln  xlsln  yrsln  xangfn  yangfn  winfn  squafn
32 33 34 35 70 70 99 98
;ins  start  dur  amp  fsarfn  fsfqn  fsdfsfn
i01  6.0  12.0 20000 5   20  11
;xlsln  ylsln  xlsln  yrsln  xangfn  yangfn  winfn  squafn
32 33 34 35 71 71 99 98
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