MAL-d – A Resonator Element Synthesis System

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Abstract

MAL-d sound synthesis system is able to model vibrating systems. It is based on the differential equations of a mechanical mass-spring vibrating system. The oscillator may be set to motion with various excitation signals. System consists of many interconnected oscillators. When the oscillators are excited with continuous audio signals, they may be better called resonators. The continuous excitation causes so-called forced vibrations, which are non-harmonic. The interconnections between the resonators modulate their oscillating frequency, thus making the synthesized audio signal livelier. The results show that the resonator synthesis provides a tool for music creation.

1 Introduction

In the beginning of the year 2003, I started to develop a sound synthesis program for my needs as a computer music composer. Primary requirements were ability to model vibrating objects and simplicity. This led to think about having an array of vibrating elements interconnected to each other in some way. The interconnections are an analogy of real objects consisting of particles that are attached to each other, and, when an object is under vibrating state, the particles push or pull each other that cause tensions that change the vibration conditions of the particles. Therefore, I planned to make the elements in the synthesis system to have modulation inputs and outputs that can be connected to *selected* "neighbor" elements. The topology (selection) of interconnections may be in one dimension (like strings), in two dimensions (plates) or in any number of dimensions (e.g. a cube, a hypercube or, say, a 120-cell). The system should be modular and extensible. The building blocks should be so elementary that you can build various sound synthesis applications from them, which consist of vibrating elements. The starting point was physical modeling, but the developed method did not need to be orthodox because, in music, only the sounding result matters.

2 The Oscillator

The basic part of the system is an oscillator model. The vibration of the oscillator is modeled according to the familiar differential equation of mechanical vibrations: $F = - k y$, where m is the mass, k is the spring constant, and F is the force produced by the displacement (Fletcher and Rossing 2000). Figure 1 below shows the used analogy to basic physical vibration.

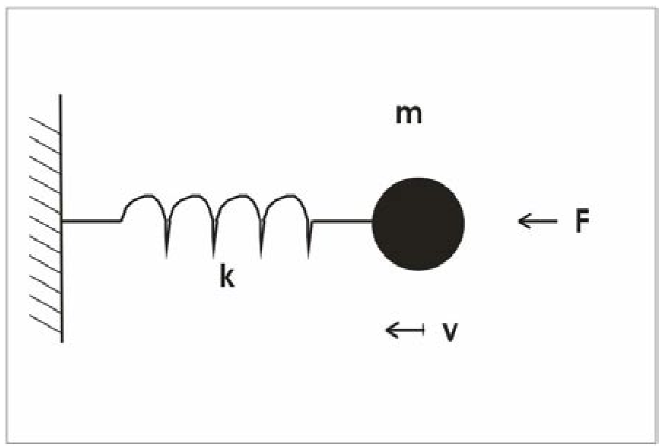

Figure 1. One-dimensional Mass-Spring Vibrating System.

In the figure, v expresses the velocity. The detail implementation algorithm is defined in Appendix 1.

Note that one oscillator is able to produce only one frequency at a time. Therefore, for a spectrum of sound, you need to combine many of these oscillators.

3 The Excitation

Before an oscillator oscillates, it must be set to motion. The signal that sets it to motion – or keeps in motion – is called excitation. The excitation signal can be e.g. an impulse or continuous function like output of other oscillators or white noise.

For percussive effects, an impulse or a short burst of noise is most suitable. This can cause e.g. guitar, xylophone and bell like sounds. - Oscillations without external forces are called *free vibrations*. The vibration is harmonic (sinusoidal, at least with small vibration amplitudes and without damping).

A continuous excitation is suitable for e.g. a weird kind of filtering of a sound signal. One way is to have a deep vibrato control signal connected to modulation inputs of a set of low frequency oscillators, and excite them by a musical signal. The vibrato helps to excite more oscillators, because oscillators are most sensitive to excitation witch their own oscillating frequency. (Vibrato also reduces risk of over excitation that could cause the oscillation increase infinitely.) - Oscillations with external forces are called *forced vibrations*. In this case, the vibration can be non-harmonic.

4 The Modulation

The oscillator elements are interconnected to some other elements with frequency modulation inputs/outputs. These connections can be either bi-directional or unidirectional. At the beginning there was a problem that caused the oscillation to “explode” to chaotic noise if there was even a small amount of modulation, but that was solved by keeping the spring constant *k* and mass *m* unchanged all time and “modulating” the time, instead, what makes it stable – see more in (Vakeva).

The chaotic oscillation was, though, so charming that I used that, too, in my composition *Fether Lyre*.

5 Results

The synthesized sound was quite dull if there was neither modulation nor any other “noise” components, like there is in a real instrument sound. Harmonic series sounds, in same phase, produced a machine-like sound similar to a ramp generator’s sound (which nobody will take for a guitar!). However, when phases of the partials were e.g. randomized, and some inter-modulation added, the sound became lively like a guitar sound – neither dull nor machine-like any more.

Some of the sounds that the synthesis system has produced so far have resembled the following physical instruments:

‘Guitar’	A quite realistic sounding plucked string instrument.
‘Bell’	A struck metal sound.
‘Wood’	A struck wooden object sound.

The synthesis system was also successfully used to various, sound filtering, resonator arrays with continuous excitation.

Listen to the composition *Fether Lyre* and other samples produced by the system at

http://www.karivakeva.com/lyre.htm

Used topologies, so far, are: one-dimensional (line), 120-cell and 600-cell.[1]

6 The Synthesis System

I named the developed sound synthesis system as *MAL-d* (Modular audio laboratory – development environment).

There are auxiliary features in addition to the oscillator elements. For example the following audio functionalities: reverbarator, automatic dynamics compressor, envelope generators, file input/output, variable rate file input, flanger, pitch bending, etc., and non-audio functionality like the120-cell topology methods. Moreover, the system is all the time evolving as I compose (and probably I will never be fully satisfied). Nevertheless, the basic building blocks are capable for many more applications to come.

7 Further work

The experimentation has just begun. There are many possibilities yet to be found. Particularly, I am currently interested in the synthesis of noisy sounds. The damped, noisy, forced vibrations will be studied more in the future.

Appendix

The Differential Equation. The equation (1) below shows the physical law of one-dimensional vibration:

$$F = - k\, y \qquad (1)$$

When we mark acceleration with $\ddot{y}$ we can express the basic law of dynamics as

$$m\, \ddot{y} - F = 0. \qquad (2)$$

Free vibrations. The basic reference model above showed the situation when the motion has been started and there are no resisting (or re-exciting) forces. Then the motion continues as pure harmonic (sinusoidal) motion of constant amplitude that is called free vibration.

Forced vibrations. If there are forces affecting to the oscillating system during its vibration, the motion is not purely harmonic, and what is called forced vibration.

The Difference Equation. For the discrete-time version of the equation, (i.e. the implementation algorithm), we obtain[2] that the displacement force is

[1] A special property of ”boundariless” topologies, like the hypercube and the 120-cell, is that all elements have the same number of neighbors. Therefore, you can apply a similar method to each element.

[2] (To save space, some steps about how we arrive to these final (optimized) equations (3), ..., (6) are left out - as that is not the subject of this paper.)

$$f = - k\, y[\mathrm{n}-1] + e \qquad (3)$$

where *k* is the spring constant, *y*[n-1] is the displacement and *e* is the external excitation force; furthermore, we get the acceleration as

$$a = f / m \qquad (4)$$

where *m* is the mass; also we get the recalculated velocity (in displacement units per sampling interval) to be

$$v[\mathrm{n}] = d\, v[\mathrm{n}-1] + a \qquad (5)$$

where *d* is the damping parameter (value range 0..1, the greater the value, the slower the decay); and, finally, we get the recalculated displacement numerical value to be

$$y[\mathrm{n}] = y[\mathrm{n}-1] + v[\mathrm{n}] \qquad (6)$$

(with the above mentioned assumption that the velocity is expressed in displacement units per unit-time, and the unit-time is set equal to one sample interval, for efficiency of calculation).

The external excitation force *e* is used for setting the vibrator system in motion, and it may be also used during the vibration to restrain the system from moving at its resonance frequency (or to keep the motion alive).

References

Fletcher, N., T. Rossing, “The Physics of Musical Instruments”, Springer-Verlag, New York, USA, 2000.

Vakeva, K., “Safe FM for difference equation vibrator”, unpublished draft at http://www.karivakeva.com/LyrePaper-Draft.pdf.