Combining granular synthesis with frequency modulation.

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Abstract

Both granular synthesis and frequency modulation are well-established synthesis techniques that are very flexible. This paper will investigate different ways of combining the two techniques. It will describe the rules of spectra that emerge when combining, compare it to similar synthesis techniques and suggest some aesthetic perspectives on the matter.

Keywords

Granular synthesis, frequency modulation, partikkel, csound, sound synthesis

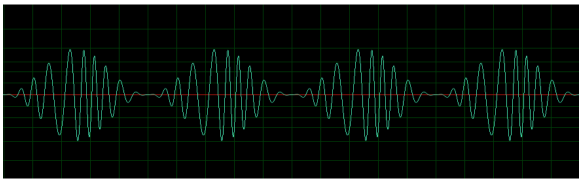

Fig 1:Grain Pitch modulation

1 Introduction

1.1 Method

Working on this subject, We´ve been using csound for implementing and generating sound, and reviewing graphical analysis of the sounds generated. We have been working systematic trying to find similarities and differences between regular FM, granular synthesis (GS), and FM in GS. For the purpose of this project, we have been using sinusoidal grains.

1.2 Granular synthesis

The idea of granular synthesis can be traced back to Gabor's theory of acoustical quantum in 1947 [7]. Thinking of sound as particles as a philosophical and a musical point of view can be very interesting, and has led to the development of granular synthesis, or particle synthesis. Granular synthesis means synthesizing sound based on adding thousands of sonically grains into larger acoustical events. Sound as particles has been used in applications like independent time and pitch scaling, formant modification, analog synth modeling, clouds of sound, granular delays and reverbs, etc [3]. Examples of granular synthesis parameters are density, grain pitch, grain duration, grain envelope, the global arrangement of the grains, and of course the content of the grains (which can be a synthetic waveform or sampled sound). Granular synthesis gives the musician vast expressive possibilities [10].

1.3 FM synthesis

Frequency modulation has been a known method of coding audio into radio signal since the beginning of commercial radio. In 1964 that John Chowning discovered the implication of frequency modulation of audio working on synthesis of brass instrument at Stanford [2]. He discovered that modulating the frequency resulted in sideband emerging from the carrier frequency. Yamaha later implemented the technique in the hugely successful DX7.

If we consider FM synthesis using sinusoidal carrier and modulation oscillator, the spectral components present in a FM sound can be mathematically stated as in figure 2.

$$f_n = f_c \pm n f_m$$

Fig 2:The spectral components present in a FM sound where n is an integer, fc is the carrier frequency and fm is the modulation frequency.

The intensity of the sidebands can be calculated with Bessel functions. When a sideband passes 0 Hz or the nyquist frequency, it is mirrored and 180 degrees phase shifted. The modulation frequency is usually a product of a modulation ratio and the carrier frequency, while the modulation amplitude is the product of a modulation index and the carrier frequency, which sets the sidebands in a constant relation to the carrier frequency [9].

FM in GS is earlier mentioned in Jones and Parks (1988) as a method to increase the range of possibilities available to the composer or researcher using granular synthesis [8].

2 Combining the two techniques

2.1 FM of GS parameters

In granular synthesis the pitch interpretation of the sound is dependent on the grain rate. If the grain rate is within the audible range, the pitch is given by the grain rate[1]. If the grain rate is sub audio, the pitch of the source waveform within the grain defines the pitch of the generated sound. We can do both FM of the grain rate, and FM of the pitch within the grain. We´ve looked at different variants and investigated the differences in spectrum.

The grain pitch affects the spectrum of a GS tone with high grain rate. When the grain rate is low the spectrum might be affected by the grain rate. So there are two parameters that oppose each other. But seen as one, the two parameters controlling pitch and timbre are grain rate and grain pitch, and that's why we have tried to modulate the two.

If we look at regular FM synthesis, the perceived pitch is dependent on the modulation ratio. If the FM ratio is 0.5 the pitch is interpret as one octave below the carrier. The distance between the frequency components of the spectrum is an important part of determining the perceived pitch. If a tone is generated with FM ratio at 7/8, the timbre will be inharmonic resulting in a diffuse fundamental pitch. As shown above in both FM and GS we have many different factors contributing to the perceived pitch.

To sum up we have two different ways of combining FM with GS:

- Frequency modulation of the pitch within the grain
- Frequency modulation of the grain rate

3 Frequency modulation of the pitch within the grain

Grain pitch modulation is easily done in csound using the partikkel opcode [1]. The particle opcode has an a-rate input that alters the pitch of the grain, implemented as phase modulation, directly modifying the reading position of the source waveform. This input can be fed with any audio signal, for our experiments, we have used a sine wave signal. A modulation oscillator can be set up as in regular FM synthesis using the parameters FM ratio and FM index, although the calculation of modulation index is done somewhat differently than in regular FM [4].

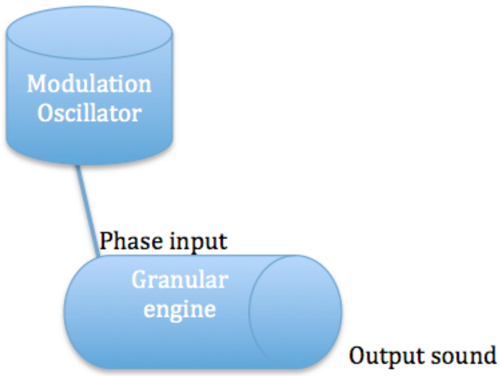

Fig 3: Grain pitch FM

3.1 Grain pitch modulation with modulation frequencies below 30 Hz

If we modulate the frequency at a rate below 30 Hz in a regular FM synthesis setup, the result is vibrato. The same thing happens in grain pitch modulation with grain rates below 30 Hz. With high grain rates the situation is somewhat different, as the grain pitch will affect the timbre. This means that a modulation frequency below 30 Hz applied to grain pitch modulation using high grain rates will lead to periodic spectral sweeps similar to filter sweeps.

There is an interesting transition area (approx. 20 – 50 Hz) both for grain rate and modulation frequency. In this area we move from a pitch perception defined by the grain pitch to the grain rate, similarly we move from vibrato to FM. We also note significant interaction between these parameters (grain rate and modulation frequency), so the situation is somewhat complex. Further exploration of this area might prove fruitful.

3.2 Grain pitch modulation with modulation frequencies above 30 hz compared to regular FM synthesis.

Since the grain rate constitutes the perceived pitch at high grain rates, it might be convenient to calculate the modulation frequency as a relation between the grain rate and the modulation ratio. Calculating modulation frequency based on a fixed pitch within the grain gives rather arbitrary spectrum. But with modulation frequency

[1]With some exceptions. For instance if the phase or the reading position of the grain source is modulated, the pitch may be defined by the pitch of the content in the grains. Another exception is if the grain stream is asynchronous. Then the result will be noisy dependent on the random range of the grain distribution.

calculated based on the grain rate, a constant relation between the fundamental pitch and the timbre is obtained.

The spectral behavior in grain pitch modulation is similar to regular FM. It might be relevant to compare grain pitch modulation with regular FM using a non-sinusoidal carrier wave. In that example all the harmonics get sidebands, resulting in very dense spectra's. The same thing happens in grain pitch modulation. There are three major differences in the spectral behavior. First of all the FM index is behaving differently. In grain pitch modulation the strength of the sidebands is weaker than those in regular FM.

Secondly simple FM ratios behave differently. The spectra of a regular FM tone will only contain even harmonics if the modulation ratio is two. But in grain pitch modulation with integer FM ratios, for instance 2, the sidebands line up with every other harmonics of the grain rate resulting in both odd and even harmonics (se figure 4). This is not the case though with complex FM ratios. FM ratio at for instance 0,5 will cause the sidebands from the frequency modulation to line up between the harmonics of the grain rate resulting in a drop in the perceived pitch (se figure 4). In some cases complex FM ratios might give inharmonic spectra, although the spectral behavior is different than in regular FM because of the dominant harmonics of the grain rate, which are still present.

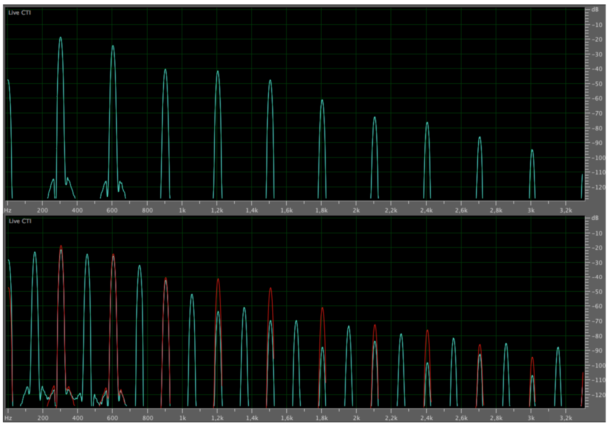

Fig 4: Grain rate at 300 Hz, grain pitch at 300 Hz. Shows the difference between grain rates at 3 and at 0,5.

The third difference is that in grain pitch modulation sidebands will also emerge from a sub harmonic tone at 0 hz, which is a sub harmonic from the grain rate in the GS. It is not audible, but the sideband might be. This results in a much fatter tone than in regular FM.

To understand the effect of the grain pitch that are modulated, we must look at FOF synthesis, a variant of particle synthesis. FOF synthesis is a formant synthesis where the grain rate gives the fundamental pitch and the grain controls formant frequency. The shape of the formant is given by the grain shape and duration. The same thing happens in grain pitch modulation, only with a much wider peak in the spectrum. It's so wide that it's perhaps not correct to call it a formant. This enables us to shift the spectral energy of the FM synthesis upwards.

If one uses Gaussian grain envelope and the grains don't overlap, the result is similar to amplitude modulation. One very important difference is that the phase of the wave inside the grains are resetting for each grain. That's means that if the grain frequency is not in an integer ration to the grain size, the wave cycles inside the grains will be cut short, resulting in a spectrum with a lot more components than in the case of integer ratios. So for cleaner sound one need the grain frequency to be an integer of the grain size, which limits the number of available grain frequencies. The way to solve this is to use two grain streams, each containing grain pitches at integer ratio to the grain rate, and then crossfade between them.

3.3 Similarities and differences between grain pitch modulation and regular granular synthesis using FM synthesized sound as wave source.

It might be useful to compare grain pitch modulation with regular granular synthesis using an FM synthesized sound as source for the grains. The major difference is the continuity of the phase in the FM synthesized source wave, whereas the phase will be reset for each new grain when doing FM on the pitch within the grain. In other respects, grain pitch modulation is comparable to combining FM with AM.

4 Frequency modulation of the grain rate

Since the perceived pitch is given by the grain rate with grain rates above 30 hz, its interesting to experiment with modulation of the grain rate, using a regular sine modulator. The modulation frequency can be calculated the same way as in grain pitch modulation. When the grain rate is modulated, it should be updated at audio rate. Ideally the grain rate and the modulation wave should be an a-rate variable. This is possible with the partikkel opcode [5].

4.1 Grain rate modulation with modulation frequencies below 30 hz

If we use modulation frequency below 30 hz we will get vibrato, just like in grain pitch modulation with low grain rates. But also here there are some interesting transition areas to explore in both grain rate and modulation frequency.

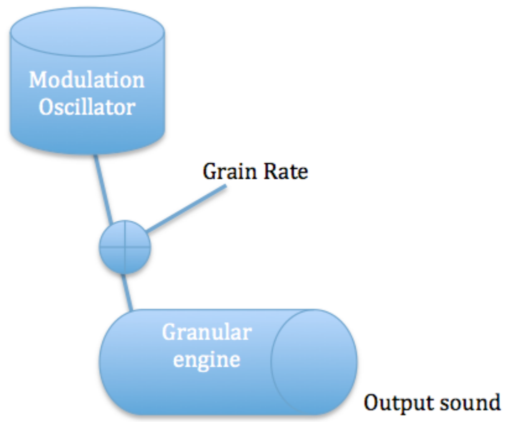

Fig 5: Grain rate modulation

4.2 Grain rate modulation with modulation frequencies above 30 hz compared to grain pitch modulation

This implementation gives similar spectral behavior as grain pitch modulation, except when the modulation index is above 1. The way we have used modulation index here, we have calculated it with a reference to the grain rate. In this respect, the modulation index is a measure of grain displacement within 1/grain rate seconds. If the modulation index exceeds one, the modulation wave leads to a negative grain rate. This allows extra grains to be generated, as the grain rate is mirrored around 0 Hz. This leads to an alteration of the perceived pitch.

Just as in grain pitch modulation, we already have harmonics from the granular synthesis before we start modulating the grain rate. This results in a perceived pitch that never can be higher than the fundamental of the grain rate. But in grain rate modulation the timbre don't get brighter with integer FM ratios above 1. This can be explained by looking at the grain rate as a sampling frequency. The modulation can only occur within the sampling frequency. According to the nyquist sampling theorem the highest frequency representable is ½ the sample rate. So the timbre of a tone with FM ratio at 0.4 is the same as the timbre of a tone with FM ratio at 0.6.

Of course even though the relation of the harmonics are similar in the two variants, the differences in the strength of the content result in sounds that have different tonal quality. That goes for grain pitch modulation versus regular FM synthesis as well.

5 Grain rate and grain pitch modulation

The two techniques described above can also be combined. This can be seen as two modulators in parallel. If one use grain pitch modulation ratio at ½ and grain rate modulation ratio at 1/3 one get a perceived pitch equivalent to modulation ratio at 1/6 [6]. Of course there are some differences in the strength of the sidebands leading to slightly different sounding timbres.

6 Other considerations

Because of incomplete wave cycles inside the grains, the spectra stretch further up in the frequency range than in regular FM. This results in a lot of aliasing. A suggested solution to this distortion is to use higher sample rates, or to implement the suggested solution containing two grain generators described earlier in this paper.

6.1 What Granular synthesis brings to FM

FM synthesis is a very flexible synthesis technique with a wide range of different sounding spectra. It has defined an entire decade of contemporary music via its widespread commercial use in Yamaha synthesizers. When combined with granular synthesis there are new unheard sounds and possibilities. Now you can create a Chowning brass sound, with overlapping grains, or with steeper grain envelopes. It is possible to make bells with grains panned in all directions and much more. Thinking of the sound as particles instead of as waves results in new ideas and alters the way we are creativ.

6.2 What FM brings to granular synthesis

To get a synth inside your granular engine enables us even more control compared to using a prerecorded sample as source inside the grains. One very interesting thing is the shift of the spectra when the carrier pitch within the grain is altered. For instance, for making new aggressive bass sounds one could control the center pitch inside the grain with an ADSR envelope. One could also make edgy sweep pads with a LFO on the center frequency.

7 Conclusion

We have investigated two different ways to combine FM synthesis with granular synthesis, compared them, and presented our results. The two are grain rate modulation and grain pitch modulation. They behave similar to regular FM, but there are some differences in the strength of the sidebands, and in the spectra due to harmonics from the grain rate. We have also suggested some aesthetic perspectives on the combination of the two techniques.

8 Acknowledgements

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