Short Overview of Methods of Sound Synthesis

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Abstract
Many methods of sound synthesis were developed in the 20th century. Some of them have stayed in the phase of scientific experiment, others have been applied in practice and have won a stable position in the field of electroacoustic music. Synthesized sounds are also used in research in the area of acoustics (psychoacoustics, electroacoustics etc.) Today the methods of additive and subtractive synthesis, modulation synthesis, mathematical modelling and syntheses, which use process of sound sampling are considered to be the classical ones. In the following paper the comparison of those methods as to their technical aspects, synthesis algorithms, suitability for imitation of acoustical instruments or for searching new sound colours is given.

Introduction

The history of synthetic generating of sound using electronic circuits begins in the 1920s. The development of electronics has brought about improving conditions for creation of new musical instruments, which were gradually implemented in the instrumentation of the electroacoustic, experimental and especially popular music.. The synthesizers (as we call instruments for synthetic sound generating) massively expanded in 1960s and 1970s.

Methods of Sound Synthesis

● Additive synthesis

The additive synthesis applies so called Fourier's principle, i. e. constructs a complex waveform by summing of harmonic (sine) waves. Additive synthesizer contents series of harmonic generators and controlled amplifiers. The sound variability of this synthesis is large, if a great number of the harmonic oscillators is used. By using of simple setting of a ratio of harmonics - static, but very rich spectral sounds can be created. Digital technology enabled to construct stable sine generators, which in addition content separate envelope generators for controlling of amplitudes of harmonics in the course of time. Setting of individual envelope generators is too hard and long, so a lot of instruments use so-called macro commands to simplify programming. Thanks to individual access to individual harmonic components it is possible to simulate for example sharp band-pass or band-reject filters etc. It is also possible to change parameters (cross-fade) from one setting to another and create the *morphing* effect.

One of the advantages of the additive synthesis is its large variability and in case of great amount of harmonics possibility of modelling arbitrary spectrum of sounds. The principles of these synthesis are also used in the process of so called sound re-synthesis of acoustical instruments. Recorded sound is first frequency-analysed and spectrum is found. The amplitudes of individual harmonics are counted by the Fourier's methods and found spectrum is an envelope-curve of the harmonics. Next, reverse process of the re-synthesis is made by summing of all set harmonics. The disadvantage of the additive synthesis is the possibility to model only discrete spectras, which are represented in time by periodical waveforms. Non-discrete spectra, as for example noises, is not possible to generate.

The typical sound characteristics of the additive synthesis are "coldness" and static-sounding, which are not problem in organ-type of sounds (where are static-sounding typical). If it is not possible to modulate individual amplitudes of harmonics, the sound becomes cold and banal. The additive synthesis is often a component of a more complicated system, for example in combination with other synthesis like sampling or subtractive synthesis, where the filtration of additive spectra is very common.

Advantages: objective, almost didactical access to the synthesis of sounds based on the Fourier's principle, creating of rich spectra if many harmonics are used, the possibility of cross-fading from one setting to another at some instruments with additive synthesis.

● Subtractive synthesis

This method of synthesis is based on the filtration of signal with rich spectrum, with many harmonics, mostly with saw or pulse waveform. This method reached its greatest development in the 60s and 70s so-called analog synthesizers. These instruments, built by using of the analogue electronical circuits, copy by their structure the basic principle of sound generating by acoustical music instruments. As it is possible to model acoustical an instrument by linking excitator-oscillator-resonator, we can simulate the sound of this instrument with electronics based on physical, respective electroacoustical analogies. Here we can speak about so-called "physical modelling", which is the term used at the end of 20th century for virtual acoustic synthesis, which should be better called "mathematical modelling".

An instrument with subtractive synthesis uses most often RC voltage-controlled generator as oscillator. The waveform is either saw-wave, whose spectrum contents all harmonics with amplitude falling down proportionally to its number, or rectangular waveform with variable mark-to-space ratio (pulse width). The signal from oscillator next goes into a voltage controlled filter, of different types: low-pass, hi-pass or band-pass with the possibility of emphasizing the frequencies next to cut-off frequency (*resonance*, *emphasis*). This circuit filters (subtracts - see the name of the synthesis) a certain part of the signal spectrum from the oscillator to gain the required sound. The filtration process can be controlled during the time by using a low frequency oscillator (*LFO*) and an envelope generator (*EG*) and demanded modulation of sound timbre can be created. The last circuit in the signal way is a voltage controlled amplifier. Also this circuit can be modulated by a controlled signal from *LFO* and *EG* to get an amplitude modulation.

Also after introducing a digital control and microprocessors these so-called A/D instruments were manufactured till the end of the 1980s. One of the advantages of instruments with the subtractive synthesis is an easy and well-arranged adjusting of parameters, especially if the control knobs and buttons are adjusted in the same order as the final sound is produced. It is possible to simulate some acoustical instruments quite successfully. The disadvantage of the subtractive synthesis is limited sound possibilities, which are given by the spectrum of primary signal from oscillator and by the sound characteristics of filters. The subtractive synthesis itself is a linear process (like additive synthesis) and its sound possibilities can be expanded by using some non-linear circuit, e.g. by ring modulator for metal-sounding spectrum. This circuit makes the non-linear summing of two input signals and there are subtractive and additive tones in the spectrum.

● Frequency modulation synthesis (FM)

The principle of frequency modulation as a special type of non-linear summing, has been already known since the beginning of the history of radiocommunication, but it was applied in the area of music electronics in the 80s thanks to LSI circuits. FM synthesizers YAMAHA were the most famous and most successful.

FM synthesizers use simple sine oscillators, connected to structures, called algorithms. There are 32 algorithms and each consists of 6 oscillators. These are called operators and exist in two mutations: either as a *carrier* or as a *modulator*. By a simple combination of a *modulator* and a *carrier* basic building stone of FM synthesis is laid. The sound possibilities of this simple structure, which is controlled by 3 basic parameters (frequency of modulator, frequency of *carrier* and modulation index), are wide. Frequencies of the *modulato*r and also of the *carrier* oscillator are situated in the audible range and by their ratio either periodic waveform (rational ratio) or non-periodic, metal-sounding spectra (irrational ratio) can be made. In spectrum it means creating of side bands and the primary *carrier* frequency can be removed in case of the certain setting. There is a closed feedback loop in some algorithms. *Carrier* oscillators are modulated by themselves and interesting and often unexpected sounds are generated. Each operator has its own envelope generator. The envelope of a *carrier* oscillator influences the volume, the envelope of the *modulator* influences the timbre of the sound. FM synthesis is fully digital.

The advantage of FM synthesis is rich sound possibilities, reached by relatively simple means. The strength of the FM synthesis is percussive waveforms with bell-sounding character, various effects, noises etc. Disadvantage is that it is not possible to programme systematically more difficult FM sounds without perfect knowledge of this synthesis. FM synthesis is a non-linear process, which has no equivalent in acoustical instruments. Another disadvantage is certain digital "coolness" of FM sound. In relation to the subtractive synthesis, it is given by the absence of filtration in "pure" FM synthesis.

● Sampling methods

Principle of sampling is nothing else but taking off, recording and playing back of arbitrary audio signal from an input of sampler, as we call the device for sampling. Conversion of an analogue signal to digital form is made by an A/D converter. This consists of a *sample & hold* circuit, which measures levels from an incoming signal in regular time intervals (so-called discretization in time) and of *quantizer*, which appropriates the right PCM code according to amplitude intervals to the samples.. The waveform of sound is this way converted to the series of numbers, which are memorized for further processing.

Recorded samples of an input signal is just "freezing" of the real sound, which can be reproduced again any time in the same form. That is suitable for example in video and film post-production for playing back sound effects etc. If a sampler is to become a musical instrument, it is necessary to work with samples further. For convincing sounding of an acoustical instruments more tones in the range of origin instrument must be sampled. Otherwise the transposition of formant areas of original spectrum creates an unwanted effect. Very often we sample after minor or major 3rd (i.e. 4 or 3 tones in one octave range). Sampler can calculate missing steps in tone scale by transposing the recorded sounds, which is not so audible in this range.

One of the advantages of sampling is the possibility to simulate sounds of acoustical instruments. It is not a real simulation in fact because the sampler reproduces memorized signals of various really existing acoustical (or non-acoustical) instruments. Thanks to processing of samplers and parameters of synthesis (filtration, envelopes etc.) the static character of recorded real sound can be removed. For better sounding simulations it is necessary to sample wide range of sounds, miscellaneous playing techniques, tonal mutations and so on. By combining of this material can we come just near to the sound of a real instrument but it can't be replaced.

● Other methods of synthesis

There are many other types of sound synthesis, which have been more or less commercially successful. Most of them use some variations of principles known from other syntheses. By their hybrid combining new syntheses have evolved.. The most important methods will be concisely described.

One of them is LA synthesis, found by the Roland company. Linear arithmetic, as the Roland Corporation named this synthesis, combines principles of the subtractive synthesis with sampling. LA synthesis works with short sound samples of acoustical instruments and uses the fact, that for their convincing imitation just few tens of milliseconds of starting sound transient, which a human ear is most sensitive to is enough. The main body of sound is generated by an analogue, digitally controlled oscillator with a saw or pulse wave.

Related or derivated methods of other techniques are for example wavetable synthesis (short sound samples and their controlled playback), vector synthesis, granular synthesis etc.

Separate chapter is a group of virtual syntheses, methods based on the principle of mathematical modelling. These methods have two basic tendencies: first is the simulation of classical instruments with possibility to make mutations and to construct virtual, non-existing types. In this area, YAMAHA's synthesizers are well known and important. They are not so commercially successful, but are important mile stone in the history of music electronics. More attractive and also more successful orientation is modeling of analogue synthesizer structure. There are being manufactured many instruments these days.

Conclusion

All above described methods of sound synthesis are mostly implemented in hardware form, i.e. in real electronic musical instruments. Modern computer technology offers colossal possibilities in education as well as in practical electroacoustical composition. Most of existing methods can be realized by programming and more, these algorithms can be combined to get new structures and hybrid mutations of well known methods. From the economical, ergonomical and educational point of view it is hard to exceed the hardware realization of this complex system. Studio of elektroacoustical music in the past contended many various instruments, with demands on space and certain unreliability. Today the same and much more can be realized with just one powerful computer workstation and proper software. Respect to classical electronic instruments is not lowered, rather on the contrary.

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