Real-Time Beat-Synchronous Audio Effects

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ABSTRACT

We present a new group of audio effects that use beat tracking, the detection of beats in an audio signal, to relate effect parameters to the beats in an input signal. Conventional audio effects are augmented so that their operation is related to the output of a beat tracking system. We present a tempo-synchronous delay effect and a set of beat synchronous low frequency oscillator effects including tremolo, vibrato and auto-wah. All effects are implemented in real-time as VST plug-ins to allow for their use in live performance.

Keywords

Audio Effects, Beat Tracking, Real-Time, VST plug-in

1. INTRODUCTION

For the recording engineer and performing musician, audio effects are standard tools. They can be used to add interesting new textures and sounds to music. Musicians control audio effects by setting parameters, such as the rate in Hz of a low frequency oscillator (LFO). While these parameters allow complete control over the effect, they can be restrictive when the desired result is related to the input signal upon which it is acting. An example is the setting of a delay effect in such a way that it delays the signal by a number of beats. Two problems arise in this situation. First, the delay time (in milliseconds), must be calculated as a function of the length of a single beat, which in a real-time performance environment is a complex and non-intuitive process. Second, the parameter must be adjusted if the tempo of the performance varies, which is highly likely given imperfect human timing and tempo variation used to create musical expression.

Currently there exist two possible solutions to these problems. The musician can synchronise the tempo of their performance to an external source, such as a click track, to ensure that the tempo does not vary and hence that the effect stays related to the tempo throughout the piece. This is an undesirable solution as it removes all possibility for tempo variation leaving a piece less expressive and somewhat 'mechanical'. Another solution is to use commercially available 'tap-tempo' pedals. These allow the musician to 'tap' the tempo of the performance into the pedal with their foot. The resulting temporal information can then be used to relate parameter values to the tempo of the input. This solution is effective as it allows the musician to indicate changes in tempo during the performance but using such pedals requires constant attention to possible changes in tempo and this can detract from the musician's ability to play their instrument.

In this paper, we describe a new group of audio effects that employ the automatic detection of beats in a musical signal (beat tracking) to relate effect parameters to beats in the input signal. This is an intuitive interface for the creation of such effects, places no extra restrictions on the musician and can automatically adapt to changes in the input signal. For a description of the beat tracking system, see [3].

Figure 1: A Beat-Synchronous Tremolo effect implemented as a VST plug-in. The rate is controlled by the number of *cycles per beat* (CPB).

2. METHOD

2.1 Audio Effects

Previous work on signal dependent audio effects includes compressors and noise gates that vary the output level of the audio signal depending on the input level [1] and the work presented in [2] where features such as pitch are extracted from input signals and used to control effect processing. All effects described in this paper were designed to be causal and implemented in real-time as VST plug-ins (see Figure 1). These audio effects fall into two categories.

2.1.1 Tempo-Synchronous Delay Effects

Tempo-synchronous delay effects augment conventional

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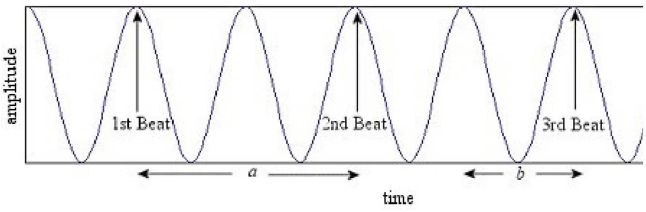

Figure 2: The LFO for a beat-synchronous effect set to operate at 2 *cycles per beat*. The length a is the beat period. The cycle length $b = a/2$.

delay effects by allowing the delay time to be set as a number of beats rather than a number of milliseconds. Tempo-synchronous refers to the fact that only the time between beats is used, whereas beat-synchronous effects also make use of beat alignment.

The delay time is found by multiplying the number of beats by which the user wishes to delay the signal by the time between successive beats, or beat period, provided by the beat tracker. A change in tempo will result in a change in the length of the delay line. At these points, phase mismatches can occur in the delayed audio as non-consecutive sections of audio are output consecutively. This problem is overcome using a crossfade technique to smoothly make the transition from one section of audio to another.

2.1.2 Beat-Synchronous LFO-based Effects

Many audio effects, such as tremolo or vibrato, use a low frequency oscillator (LFO) as part of the effect processing. Beat-Synchronous LFO-based effects synchronise the rate of the LFO to the beats in the audio signal. The cycle length of the oscillator is related to the beat period by a user defined number of *cycles per beat* (CPB). The phase of the oscillator must also be controlled so that the oscillator reaches its maximum (or minimum, depending on the waveform) on the beat (see Figure 2). This is achieved by starting the LFO cycle on a beat and ensuring that the cycle ends at the next beat.

The above algorithm for synchronising a LFO with beats in an audio signal must be adapted for implementation in a real-time system. The real-time beat tracker uses a 1.5 second analysis window. Based upon this window, predictions are made of beat locations in the next 1.5 second window. In the space between the last beat of one window and the first beat of the next, there is no way to know exactly when to end the cycle (as a new set of beat predictions has yet to be made). Without a solution, phase mismatches occur at the first beat of each frame. Therefore, cycles that finish early or late are automatically adjusted after the first beat so that they finish exactly on the second beat. See [4] for more details.

Four different types of LFO-based effects were adapted in this way: a tremolo, auto-wah, vibrato and a flanger. The first two effects used a LFO where the rate was one or more cycles per beat while the latter two effects used LFO cycles that were one or more beats in length.

3. RESULTS

Assessing the performance of the effects is a difficult task due to the subjective nature of using the audio effects and the dependency on the performance of the beat tracker. It is interesting to note that because many beat tracker 'errors' are related to the beat in some way, the effects perform better than beat tracking results may suggest. For example, the tempo-synchronous delay effect makes no use of beat alignment information and therefore performs correctly even if beats are tracked on the offbeat. Offbeat errors also cause no loss in performance for beat-synchronous LFO waveforms with an even number of cycles per beat as the resulting waveform is identical to the waveform that would be produced during correct beat tracking. Tracking beats at half or double the correct tempo does produce incorrect performance but these errors are subtle as the effect is still related to the signal tempo. For more results see [4].

The audio effects described allow musicians to create a time-based effect and use it regardless of tempo. Using the delay effect, it is possible to delay a signal by a single beat, which, if used on an arpeggio, will cause each note to fall on and harmonise with the next. This 'semantic' effect can be represented using the parameters of a tempo-synchronous delay effect in a way that it cannot on a conventional delay effect.

An example in commercial music of an audio effect used in a way where it is synchronised with the tempo of the performance is the introduction to the song *How Soon Is Now* by *The Smiths* (1985). The song features a guitar with a tremolo where the rate is set at 2 cycles per beat of the song. In this example, the tremolo would have likely been set to a pre-determined tempo. The advantage of using a beat-synchronous tremolo effect is that this result is easy to obtain and can be replicated at any tempo without altering effect parameters.

Interesting rhythmic effects can also be achieved using LFO-based beat-synchronous effects. For example, if the rate is set to 3 cycles per beat, it can give a 'triplet' feel to each note.

4. CONCLUSION

We have developed methods to adapt several different conventional audio effects using a beat tracker. Conventional audio effects are restrictive to musicians when the aim is to synchronise the operation of the effect with the tempo of the input signal. By employing beat tracking, we present effects that overcome these problems, providing a simple and intuitive interface for creating temporally relevant effects that adapt to changes in tempo.

5. REFERENCES

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