FIFTH INTERNATIONAL CONGRESS ON SOUND AND VIBRATION
DECEMBER 15-18, 1997
ADELAIDE, SOUTH AUSTRALIA

THE EVOLUTION OF PARTIALS IN POLYPHONIC PIANO SOUNDS

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The aim of this paper is to present a study of the evolution of partials in polyphonic piano sounds. The identification of polyphonic sounds usually takes place in the frequency domain and works on a small number of partials, but a common problem in most of the identification methods is octave errors. In this paper, the authors consider the identification of polyphonic piano sound signals, that is, several notes played simultaneously on the same keyboard instrument. The evolution in time and frequency of the partials and the distribution of their energy are interesting to investigate in order to use them to identify the notes. For example, the amplitude of the partials could be used to distinguish the case of overlapping repeated notes. Thus the case of a note (N1) played two times with a short delay between the notes [N1+short delay+N1] is difficult to separate from the case [N1 long+short delay+N2], when note N2 is played during N1's decay.

In order to treat these and similar difficult situations, this paper presents a study of the evolution of the partials of different piano notes, which can be used when deriving general identification methods for polyphonic piano signals.

INTRODUCTION

The identification of polyphonic piano sounds is a problem recognized as being very difficult to solve especially owing to the fact that the signals studied are non-stationary and that possible interactions between partials belonging to different notes can occur. No ideal time-frequency transform for this kind of problem has been discovered and the Short Time Fourier Transform continues to be used frequently.

The identification method for polyphonic piano sounds (several notes played simultaneously on the same piano) that we have developed [Rossi and Girolami, 1996] uses spectral information but this information does not help distinguish easily, for example, long notes from the same note played several times successively. In order to detect the notes' onsets, a study of the evolution of the notes' partials' in monophonic and polyphonic piano sounds was thus carried out.

1 - MONOPHONIC SOUNDS

Monophonic sounds present, a priori, fewer difficulties of identification than polyphonic sounds. Nevertheless, the multiplicity of ways of playing, even in the case of a single note played once, makes it difficult to distinguish some ambiguous cases.

1.1 - SIGNAL AMPLITUDE

A first possible use of the information from the temporal domain is the detection of notes' onsets from the evolution of the signal amplitude. Figure 1 presents the evolution of the signal amplitude in the case of a long note C_1 and also in the case of this note played twice successively with variable delays between the onsets. The hammer velocity is 72 (MIDI notation) for repeated notes and 68 for the isolated note.

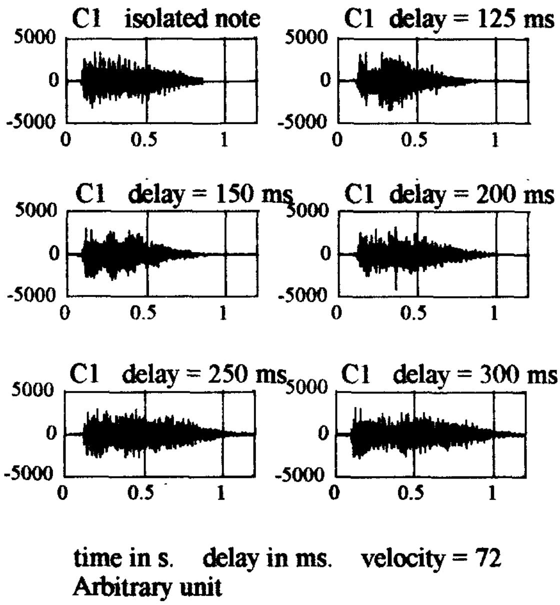

Figure 1: Temporal signal of note C_1 played twice successively with various delays. The second onset is not clearly visible in the different figures.

In this figure, we can see that the second onset is not easily visible in every case, for example when the delay is 200 ms and 250 ms. The smooth onset of note C_1, which is a characteristic of lower notes [Blackham, 1965] makes the detection of notes' onsets from the evolution of the signal amplitude difficult.

1.2 - SIGNAL ENERGY

Logically, it could be expected that, if a note is played twice successively, there would be two increases in the energy in the signal, so, we studied the temporal evolution of the signal energy for various notes: isolated notes, repeated notes, long notes. To determine the temporal evolution of the notes' energy, separated frames 20 ms long were used. Then, the energy contained in each frame was computed using the formula:

$$\varepsilon_m = \sum_n (x(n).h(m-n))^2$$

where:

$X(n)_{n=1,N}$: sampled data,

$$h(n) = \begin{cases} 1 & 0 \le n \le N \\ 0 & elsewhere \end{cases}$$

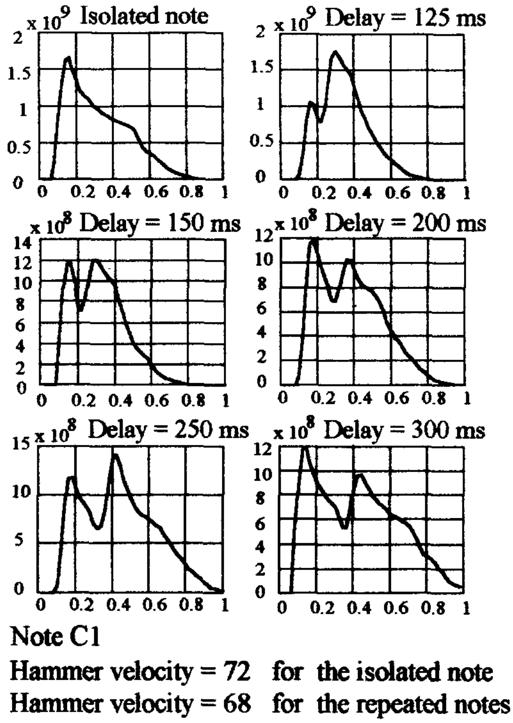

Figure 2: Temporal evolution of the energy of note C_1 played twice successively with various delays.

The temporal evolution of the energy of note C_1 is shown in figure 2 for the same cases as those presented previously in figure 1. Note onsets are easily visible in this figure, but three points must be observed: first, the energy of the second onset is not systematically of the same amplitude as the first one, although the hammer velocity is the same for the two onsets. There is an increase in energy but its level depends on the delay between the two onsets. Secondly, after the second onset, the shape of the energy curve is not always the same as in the case of the isolated note. Because the energy distribution of a note is linked to the energy of its partials, these observations show it is necessary to study the temporal evolution of the amplitude of note's partials even in the simple case of repeated notes. This study will be presented in the following subsection (1.3). The third point is a question. Each new onset is associated with a more or less significant increase in energy, but is it the only situation where an increase in energy can be found? No, as we shall now see. The first part of figure 3 presents the evolution of several long notes from octave five.

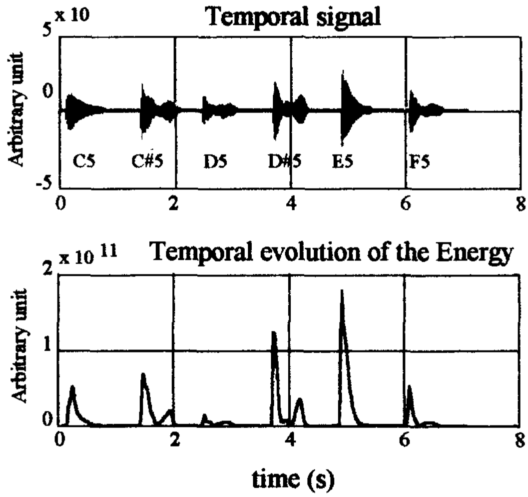

Figure 3: Temporal evolution of the energy of long notes with beats.

The notes shown in this figure are C5, C#5, D5, D#5, E5 and F5 all played with the same velocity, 104. In these long notes, beats (due mainly to the contributions of the three strings) are present and produce very significant variations in the notes' amplitude. The evolution of the energy presented in the lower part of this figure shows that the level of the energy of some notes' onsets is lower than that of the beats of some other notes. Consider, for example, D_5 and $D\#_5$. The energy associated with the beats of $D\#_5$ is higher than the energy of the onset of note D_5. If one doesn't know the fact that, for a given note, beats occur, it will thus be difficult to distinguish the case of a long note with beats from the case of repeated note.

1.3 - THE EVOLUTION OF THE AMPLITUDE OF NOTES' PARTIALS

The evolution of the partials' amplitudes is obtained in the following way: the spectrum of the sampled signal (with a sampling rate equal to 22050 Hz) is computed by using an FFT on 32768 points. The partial to study is isolated by weighing the spectrum with a gaussian band-pass filter and an inverse FFT is carried out to obtain its temporal evolution. Figure 4 presents, for note C_3, the evolution of the amplitude of partial #8, and the energy associated with this note.

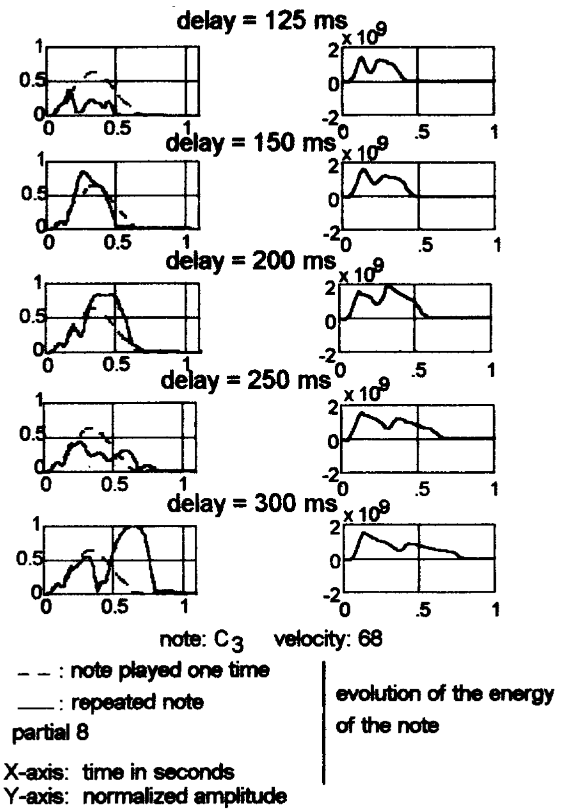

Figure 4: Temporal evolution of partial #8 of note C_3 and the energy associated with this note in the case of repetition of the note.

This figure shows that the global energy increases for each new onset, but also shows that for a given partial, the evolution of the amplitude can be very different, and depends on the delay between the first and the second onset. This fact is due to the difference of phases between the already existing partial, and the new excitation; for a partial with a frequency of 1000 Hz, a difference of 0.5 ms in the delay will give a phase opposition instead of the same phase. In other words, the presence of a second onset of the same note does not systematically mean that the amplitude of a given partial will increase (at least at the time of the onset).

The computation of a signal's energy when a note is played can be carried out by adding the square moduli of the signal's components. If, for two successive onsets, the amplitude of note partials are different, then the level of the global energy of the signal will be different for the two onsets. Moreover, the evolution of the partials' amplitude depends on the delay between the first and the second onset and produces a different shape of the energy evolution in each new onset, which was observed in figure 2.

2 - POLYPHONIC SOUNDS

The study of the temporal evolution of the amplitude of notes' partials in a polyphonic context is interesting to investigate in order to estimate the results of interactions between partials pertaining to different notes. A simple case of partial interaction occurs when two notes sharing the same partials are played one after the other with the two notes simultaneously present for a certain length of time. To illustrate this case, an example with notes C_1 and A_1 played with a delay of 125 ms and 300 ms is considered in figure 5, which shows the temporal evolution of partials #9 and #10 of note C_1. These partials have FFT bin numbers 437 and 486 (32768 points FFT, a sampling frequency of 22050 Hz) while the closest partials of note A_1 have bin number 407 (partial #5) and bin number 489 (partial #6). The frequency difference between bin numbers 407 and 437 is about 20 Hz while the difference between bin numbers 486 and 489 is about 2 Hz. From figure 5 we can see that when the partials of the two notes have close bin numbers the perturbations on the amplitude can be very important.

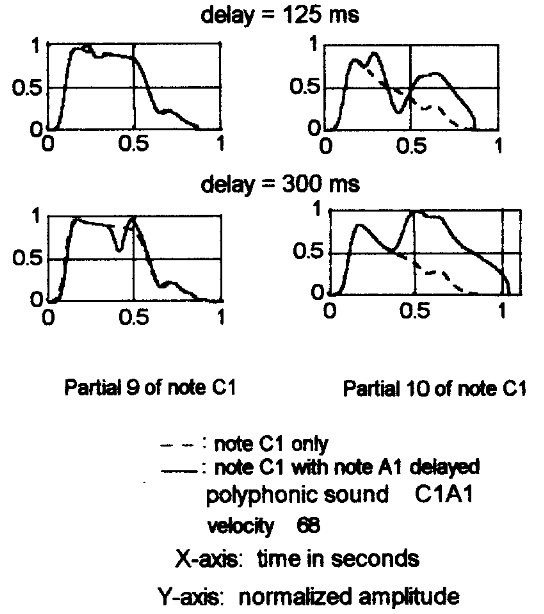

Figure 5: Temporal evolution of partial #9 and #10 of note C1 when notes C_1 and A_1 are played with a delay of 125 and 300 ms.

The figure also shows that even a remote partial can consequently modify the evolution of the amplitude of another one.

CONCLUSION

This study of the evolution of partials in monophonic and polyphonic piano sounds has shown that the perturbations in the temporal evolution of the amplitude of partials, due to interactions of different note partials, can be significant. The differences in phase at the time of a second onset determine if the interaction is constructive (with an increase of amplitude) or destructive (with a diminution of amplitude) and in a general way, the evolution of the amplitude of the partials of these sounds is very different from that of isolated sounds. This shows that the energy of a note is not a very good criterium for detecting notes' onsets.

REFERENCES

Blackham E. D., (1965) "The physics of the piano", Scientific American, pp. 88-99.
Rossi L. and Girolami G. (1996) " A novel approach for identifying polyphonic piano signals ", J.A.S.A., vol. 100, No. 4, Pt. 2, Oct. 1996, pp.2842.