USING CONCENTRATED SPECTROGRAM FOR ANALYSIS OF AUDIO ACOUSTIC SIGNALS

KRZYSZTOF CZARNECKI, MAREK MOSZYŃSKI

Gdansk University of Technology, Department of Geoinformatics Systems
11/12 Gabriela Narutowicza Street, 80-233 Gdańsk-Wrzeszcz, Poland
krzycz@eti.pg.gda.pl

The paper presents results of time-frequency analysis of audio acoustic signals using the method of Concentrated Spectrograph also known as "Cross-spectral method" or "Reassignment method". Presented algorithm involves signal's local group delay and channelized instantaneous frequency to relevantly redistribute all Short-time Fourier transform lines in time-frequency plain. The main intention of the paper is to compare various guitar playing techniques including legato, staccato, vibrato, glissando, slide and bending. Additionally, the advantages of concentrated spectrograms especially high energy concentration in comparison with classical spectrogram based directly only on Short-time Fourier transform are presented. Moreover, the vibrato playing technique is considered also for another musical instruments: flute and violin.

INTRODUCTION

The time-frequency (TF) energy distribution referred to as Concentrated Spectrogram is employed to illustrate the analysis of audio acoustic signals and investigate the unique features of various playing techniques. In the paper, zoomed fragments of spectrograms to emphasize some typical details such as local instantaneous frequency evolution, a way of birth and death of partials etc. are especially presented. The similar subject is reported in few papers including [2,4,7].

The proposed method of TF analysis is one of the Gabor transforms that have many advantages. Firstly, they are linear, which simplifies interpretation of the transform and development of analysis systems. Secondly, cells (also referred to as: TF bins, Heisenberg boxes, Gabor atoms etc.) of time-frequency representation (TFR) have the same size in the whole domain (in contrast to scalograms). Specifically for Short-time Fourier transform (STFT), shapes of the cells are determined by a window function. Thirdly, there exists an inverse transformation, that ensures the possibility of the analysed signal reconstruction. Moreover, Gabor transformations do not cause so-called cross-terms - artefacts that are serious problem in many nonlinear transforms [1,2].

The method of calculating the concentrated spectrogram has been introduced by several authors under various names, including the modified moving window method published firstly in [5], the cross-spectral method [6], the time-frequency reassignment [3], method of reassignment, remapping, relocation, replacement, etc. Kodera *et al.* proposed the usage of local group delay (LGD) and channelized instantaneous frequency (CIF) to redistribute energy of STFT in TF plain. In case of discrete signals and its transforms, both LGD and CIF perform new TF coordinates of STFT lines. Similarly to STFT, imaging obtained in this way is subject to the Heisenberg-Gabor uncertainty principle, but new locations are more precise compared to those obtained by classical STFT. It is mainly caused by the reduction of DFT leakage effect for discrete transforms [1,2].

1. CONCENTRATED SPECTROGRAM

Article should The concentrated spectrogram is calculated using the modified moving window method. STFT of the causal time-dependent and discrete-time signal $x[n]$ is obtained using following formula:

$$X[l,k]=\sum x[l+m]h[m]\exp(j2\pi m(k/K-1/2)) \tag{1}$$

where k=0, 1,..., K-1; l=0, 1,..., L-1; n=0, 1,..., N-1; K , L, M , N $\in \mathbf{I}$. M is the width of the window $h[m]$ (single frame) and the obtained transform $X[l,k]$ has size of L x K. L depends on the entire signal length N, and K is the length of the single running DFT.

The next step is calculation of TF coordinates for each STFT line. The new locations are obtained by calculating of local group delay as:

$$T[l,k]=Arg(X[l,k]X^{*}[l,k-1])K/(2\pi F_s) \tag{2}$$

and channelized instantaneous frequency as:

$$F[l,k]=Arg(X[l,k]X^{*}[l-1,k])F_s/(2\pi) \tag{3}$$

where $X^*[l,k]$ is the complex conjugation of $X[l,k]$ and Arg means the principal argument of a complex number, F_s marks sampling rate. The relocated coordinates are obtained by:

$$(t_l,\omega_k)\rightarrow(t_l-T[l,k],F[l,k]) \tag{4}$$

where t_l is delay of l-th frame and ω_k is center frequency of k-th channel.

Simultaneously, the energy of each STFT line is calculated as follows:

$$E[l,k]=|X[l,k]|^2 \tag{5}$$

2. ANALYSIS OF ACOUTIC RECORDS

Spectrograms presented in the paper originate mainly from the sound of acoustic guitar when different playing techniques are applied such us: legato, staccato, bending slide, glissando and vibrato. Moreover, the vibrato technique is presented also for flute and violin [2].

Legato

Legato is a form of a musical articulation, where notes are played fluently and smoothly. A listener should have an impression that sounds are connected. There are various techniques of legato playing on the acoustic guitar, e.g. hammering, pull-off, tapping. On the whole a player can achieve this effect by rapid changes of the strings pressing on the fingerboard and simultaneously by the coherent synchronised strings striking by fingers or by guitar pick. Intervals between the sounds should be as short as possible. The important factor in legato techniques is also proper damping of strings oscillation. The spectrograms of the legato articulation sample are presented in the fig. 1.

Staccato

Staccato, like legato, is a kind of musical articulation. However, as opposed to legato technique, sounds are played clearly separately. Additionally, in staccato technique, duration of sounds is visibly reduced in order to emphasize a distinct changes of pitch. Guitar player can force such effect by sudden suppression of strings vibration by fingers soon after hitting the strings. The separation of sounds is well visible on the spectrogram in the fig. 2, where staccato technique analysed is presented.

Glissando

Glissando is a kind of a smooth transition from one pitch to another playing all sounds between. When playing the guitar, this effect is produced pushing all frets by sliding finger along fingerboard after the single hit in the string. The record spectrogram of such effect is presented in the fig. 2.

Bending

Bending is a kind of guitar lick. However, it can be played also on another string instruments. Banding can be produced by pulling or pushing the string across the fingerboard. Thus player raises the tension in the vibrating string and as a result always raises the pitch of a note. This is clearly visible in the fig. 3, where concentrated and classical spectrograms are compared.

Slide

Smooth transition of pitch obtained by using so-called bottleneck (or another flat and hard items) is referred to as the slide. It is applied by raising and lowering of instantaneous frequency of sound. The bottleneck is fluently moved during the performance along the guitar fingerboard touching the strings. This effect is used mainly as some kind of musical ornament. Slides whose spectrogram is presented in the paper in the fig. 4, were produce using a plastic bottleneck.

Vibrato

Vibrato is a technique of playing musical instruments. For violin, vibrato is created by the rhythmic motion of performer's wrist across the fingerboard. This causes change of the strings tension and, consequently, the modulation of both amplitude and frequency of the sound. Similarly for guitar, the player can produce the vibrato by turns push and pull strings across the fretboard simultaneously pressing the string to the fret. However for flute, the vibrato is obtained due to a proper pulsation of the windstream controlled by player's muscles in the throat and diaphragm. The comparison of vibrato spectrograms are presented in fig. 5 and 6.

CONCLUSION

The presented method of analysis is precise and it can be applied for careful identification of sounds, melody, instruments and various techniques or effects. Characteristic features of various playing techniques and effects contained in the analysed records are clearly visible on presented spectrograms. For staccato musical articulations, energy on the spectrogram is distributed vertically over time-frequency plain in the initial stage of sounds duration, that indicates rapid escalation of sound intensity. Similarly, suppressions of sounds are fairly determined that makes signal emission interruptions. That is in opposed to legato musical articulations, where the signal seems to be continuous. On the other hand, for bending, slide and vibrato effects, the spectrograms present unambiguously modulation depth and deviation of signal instantaneous frequency [2].

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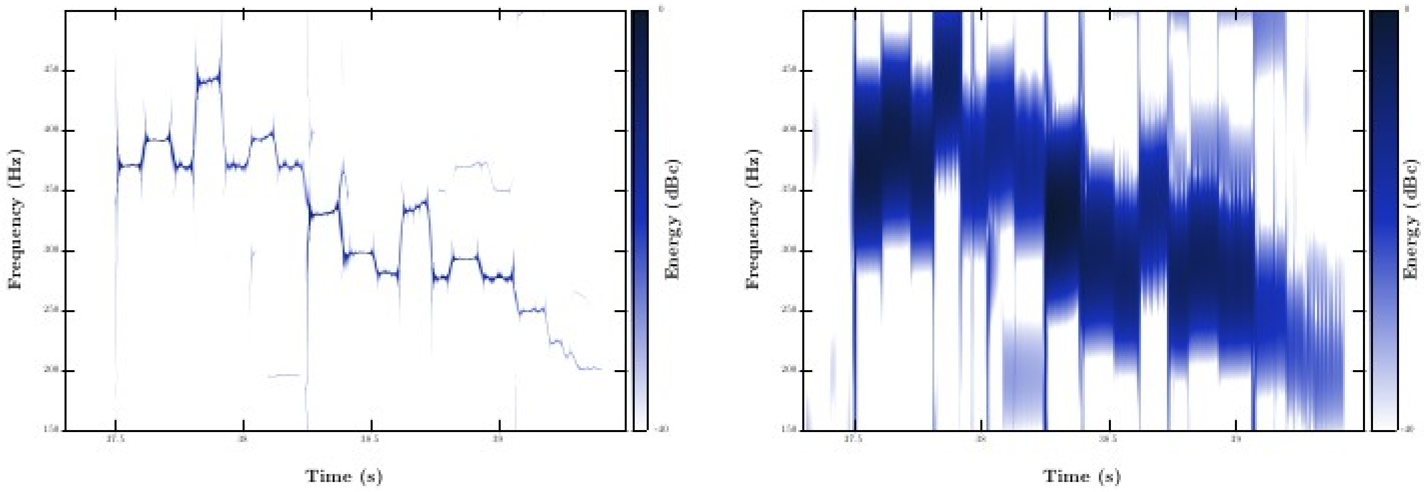

Fig.1. Legato guitar technique spectrograms: concentrated (L) and classical (R)

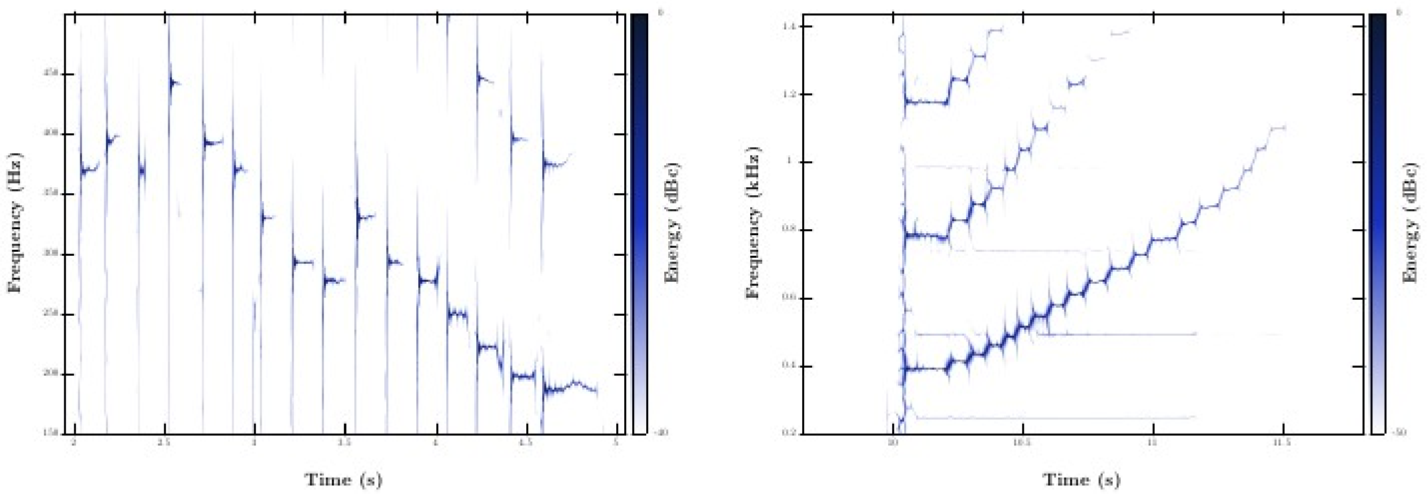

Fig.2. Staccato (L) and glissando (R) guitar techniques concentrated spectrograms

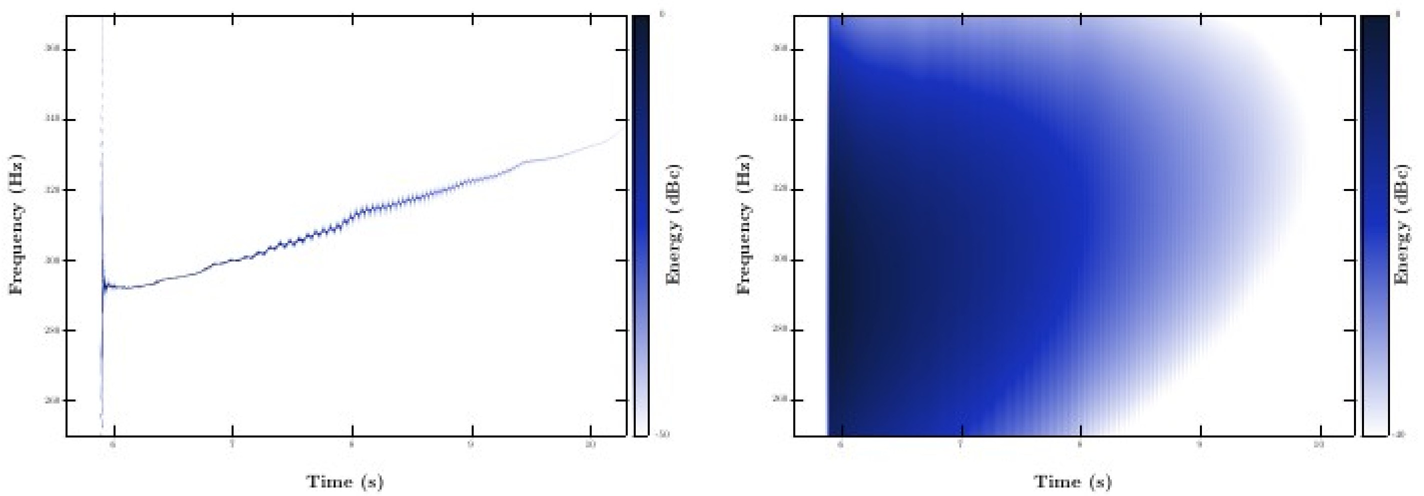

Fig.3. Bending guitar technique concentrated (L) and classical (R) spectrograms

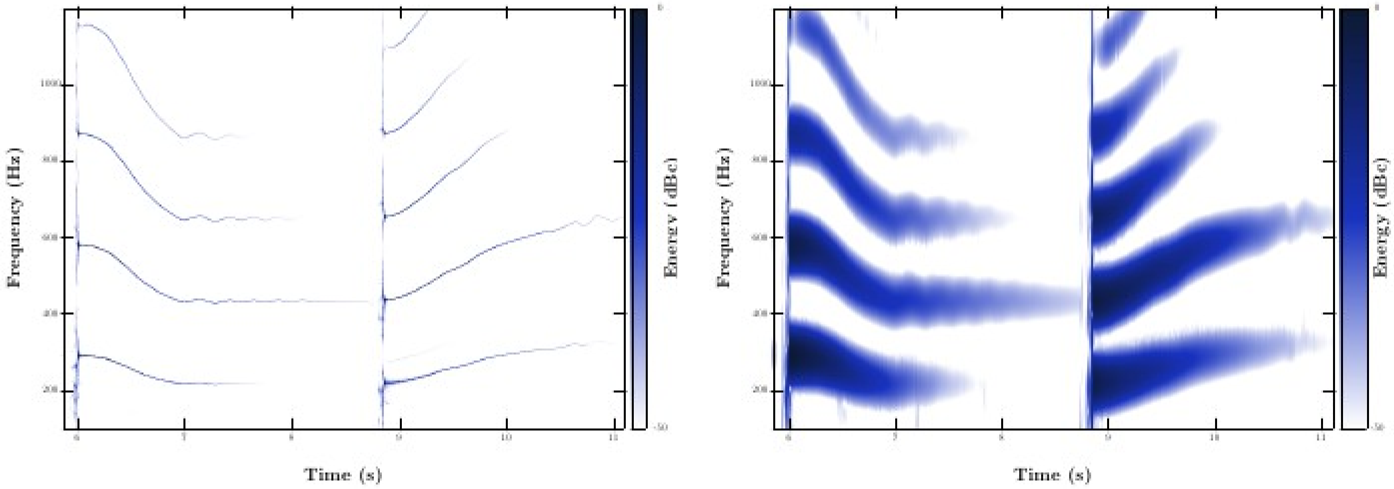

Fig.4. Slide guitar technique spectrograms: concentrated (L) and classical (R)

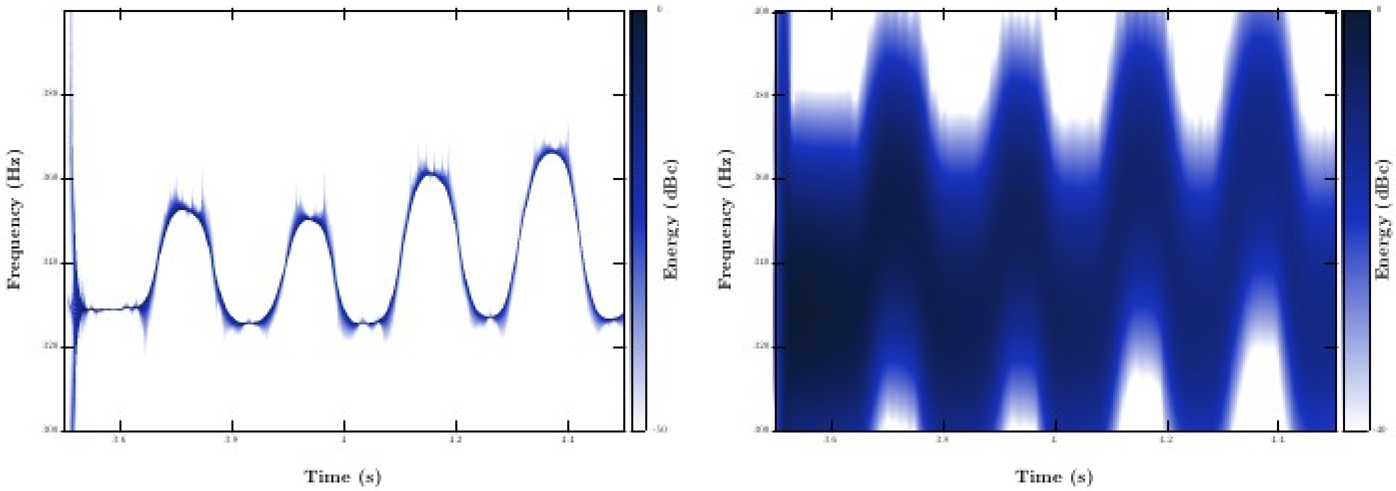

Fig.5. Vibrato guitar technique spectrograms: concentrated (L) and classical (R)

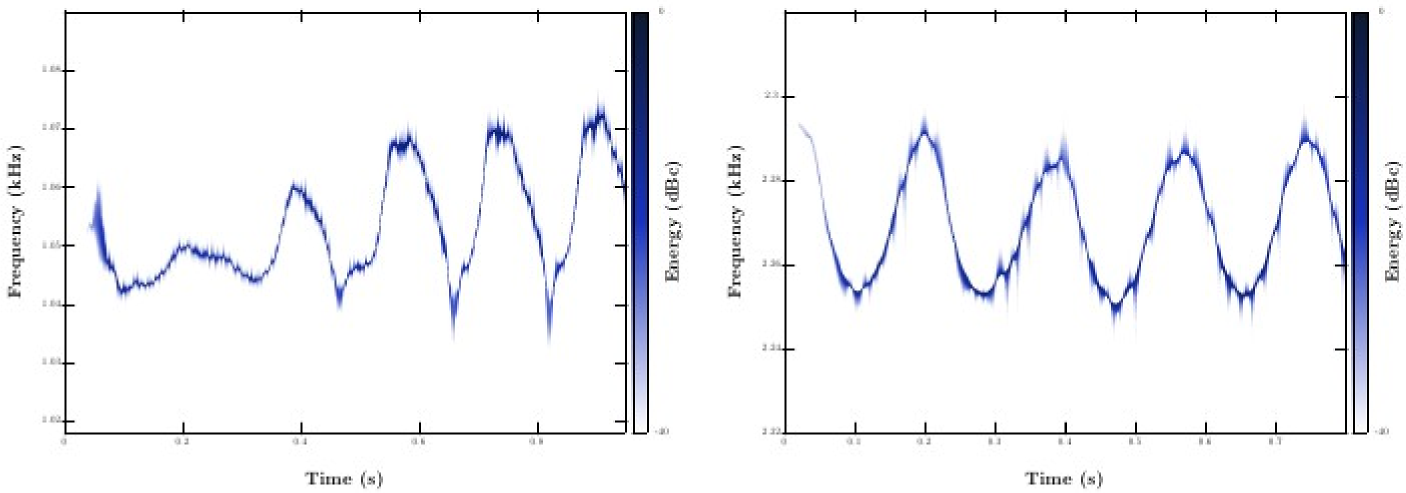

Fig.6. Vibrato flute (L) and violin (R) technique concentrated spectrograms