ENHANCED METHOD OF INTERFERENCE REDUCTION IN SMOOTHED PSEUDO WIGNER-VILLE DISTRIBUTION

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Abstract: This article deals with Wigner-Ville distribution as an approach to analyze non-stationary or transient signals. Problematic of interference presence is mentioned and new enhanced interference reduction method is described. Multiple Smoothed Pseudo Wigner-Ville Distributions and their differences are used to select appropriate energies from smoothed time-frequency representations. This method can be partially parallelized and its good results are demonstrated on typical benchmark signals: echo-location chirp of a brown bat, multiple Gaussian atoms and parabolic chirp with Gaussian atom.

Keywords: Smoothed Pseudo Wigner-Ville distribution, reduced interferences, signal processing

1 INTRODUCTION

In practical applications non-stationary or transient components are often present in signals. Analysis of these data by traditional methods (for example Short Time Fourier Transform or Wavelet Transform) is difficult. Good quality of results, especially time-frequency resolution, often depend on correct settings of transformation parameters (width and type of used window, choice of mother wavelet etc.) and in general there is a trade off between good time and frequency resolution leading to a problematical general analysis of signals. In more complex methods a priori knowledge about signal is often needed.

2 WIGNER-VILLE DISTRIBUTION AND INTERFERENCES

Wigner-Ville distribution (WVD) is one of the time-frequency (TF) analysis tools with high quality resolution (for monocomponent linear chirp signal exhibits ideal TF representation) and has no parameters in basic form [1]. In addition WVD has many positive mathematical properties [2].

However great properties are balanced by presence of interferences, which are inevitable part of the distribution and cause problematic interpretation of resulted TF representation [3]. Sufficiently fast and general cross term reduction is still not a resolved problem.

Typical non-stationary testing signal is Brown bat echo-location chirp, see figure 1. From only time or spectrum approach the signal is hardly analyzable. WVD produces TF representation of the signal with great resolution but including interferences.

2.1 EXISTING METHODS OF INTERFERENCE REDUCTION

First methods of WVD interference attenuation were analyzed thirty years ago [4] and now there exists many methods of crossterm reduction [5]. Generally all methods tries to reduce or remove interferences, preserve autoterm clarity and keep maximum of distribution properties. Computer calculation cost is also nowadays concern, because best developed algorithms are iterative and very computationally demanding [6].

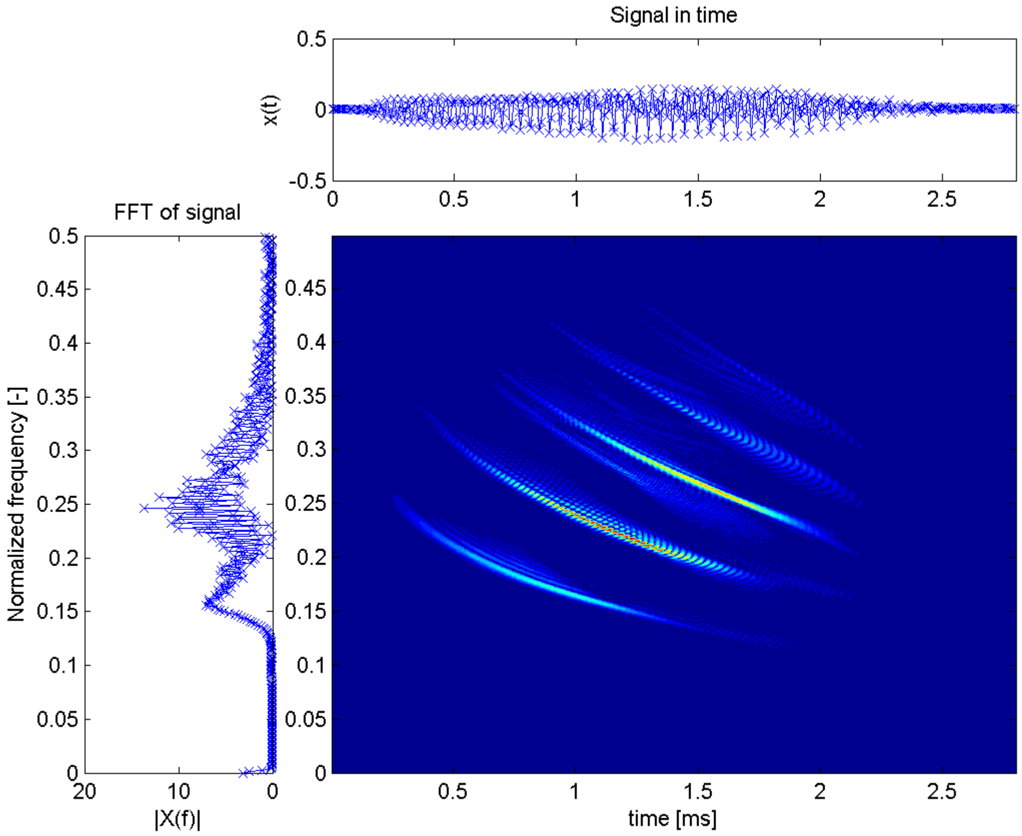

Figure 1: Brown bat echo-location chirp in time (top), its power spectrum (left) and WVD.

3 SMOOTHED PSEUDO WIGNER-VILLE DISTRIBUTION

For practical use, windowing is needed to be implemented in WVD. One of the WVD variants, called Smoothed Pseudo Wigner-Ville distribution (SPWVD) enables independent windowing (smoothing) in time and frequency [7]:

$$SPWVD(t,\omega) = \int h(\tau) \int g(\varepsilon - t) s(t - \frac{1}{2}\tau) s^*(t + \frac{1}{2}\tau) e^{-j\omega\tau} \, \mathrm{d}\tau \qquad (1)$$

Where $g(t)$, $h(\tau)$ are time and frequency smoothing windows and $s(t)$, $s^*(t)$ are analytic signal and its complex conjugate. It is necessary to note, that the use of analytic signal on the input of SPWVD is crucial for obtaining usable results [8]. Analytic signal is derived from actual signal $x(t)$ by Hilbert transform. Selectable width of filtering windows influence interferences and autoterm clarity.

Interferences contain inner oscillations with higher frequencies than actual real signal oscillations, thus they are smoothed more rapidly than a real signal amplitude is degraded. This fact will be used in new proposed algorithm and is exploited in some other existing methods: non-linear filtering [9] or adaptive optimal kernel [10]. Wider smoothing of signal by SPWVD results in less interferences, however the cost is TF resolution degradation, both is clearly visible on figure 2.

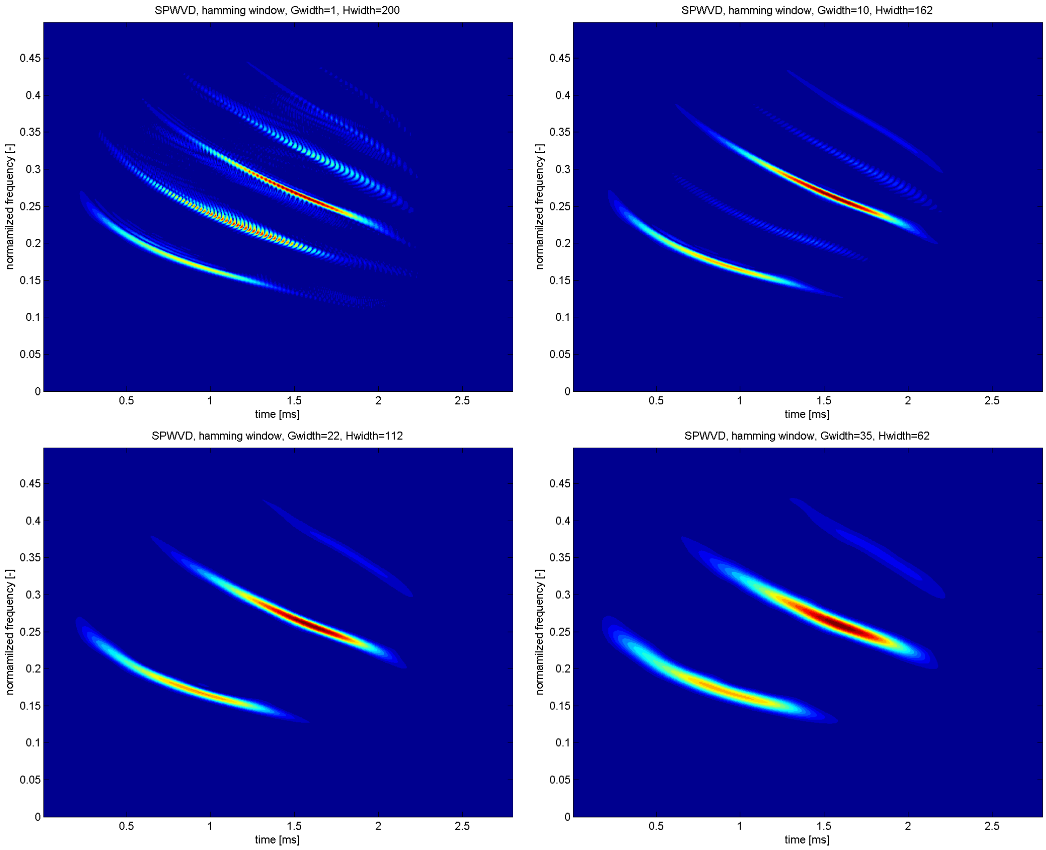

Figure 2: Four differently smoothed SPWVD. From left to to right bottom with increasing time and frequency filtration.

4 NEW METHOD

In my previous work [11], I suggested an algorithm of comparing more outputs of SPWVD for identification of interferences. Subsequently a method of linear extrapolation of smoothed distributions was tested to estimate energy without interferences. On simulated data, method showed decent results, however algorithm was very sensitive to choice of extrapolated data and needed high number of compared SPWVD resulting to unusability in general practice.

New proposed algorithm focus on finding minimal TF point difference between SPWVDs with various widths of smoothing windows. In case of an interference, the minimal difference between consecutive SPWVDs occurs when the interference is smoothed out. While autoterm (useful signal) is in concern, with growing filtering the signal decrease more rapidly resulting in finding minimal difference at the beginning before actual reduction of useful signal.

Finally if cross term overlays autoterm, minimal difference corresponds to the smoothing point when interference is reduced, however autoterm is not. Amplitude of every point in TF plane corresponding to a minimal difference is used as the estimated one.

Algorithm shows to be very robust. It exhibits good results with as few as four different smoothing windows (four SPWVDs). It is not signal dependent and calculations of SPWVDs can be parallelized. For maximal universality the smoothing time and frequency windows width is dependent on number of SPWVDs R and length od data N as follows:

$$\begin{aligned} \forall i \in \{R,\ldots,1\} : F_{smooth} &= \left\lfloor \frac{iN}{2R} \right\rfloor \\ \forall i \in \{1,\ldots,R\} : T_{smooth} &= \left\lfloor \frac{iN}{8R} \right\rfloor \end{aligned} \tag{2}$$

Fact that only small number of SPWVDs is needed for good cross term reduction is clearly visible on figure 3. Results of combination of 4 and 16 SPWVDs are well matching each other, in conclusion four distributions are enough for reliable outcome.

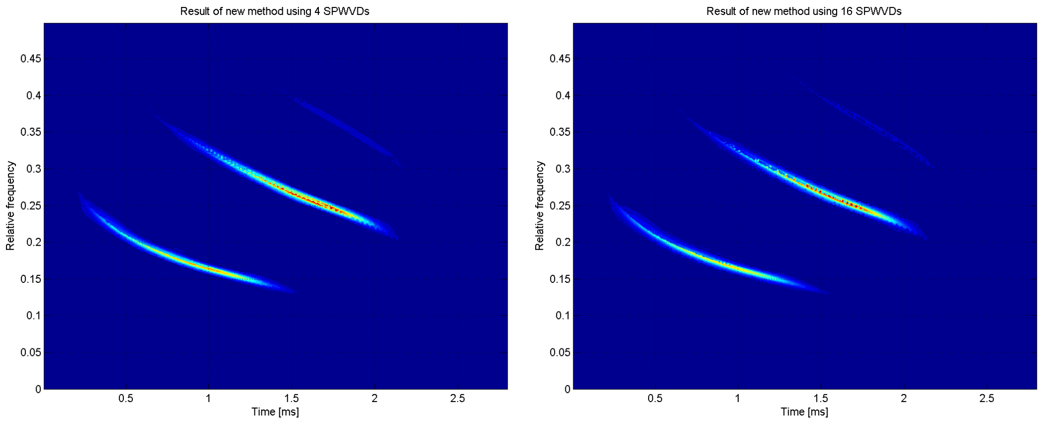

Figure 3: Result of reduced interference method created from 4 (left) and 16 (right) SPWVDs.

Same algorithm exceedingly attenuates inner and outer interferences in case of parabolic chirp with gaussian atom. Moreover one of the most problematic schemes (autoterm masked by interference) is also well resolved. Figure 4 illustrates this general usability of method by results of mentioned tested signals.

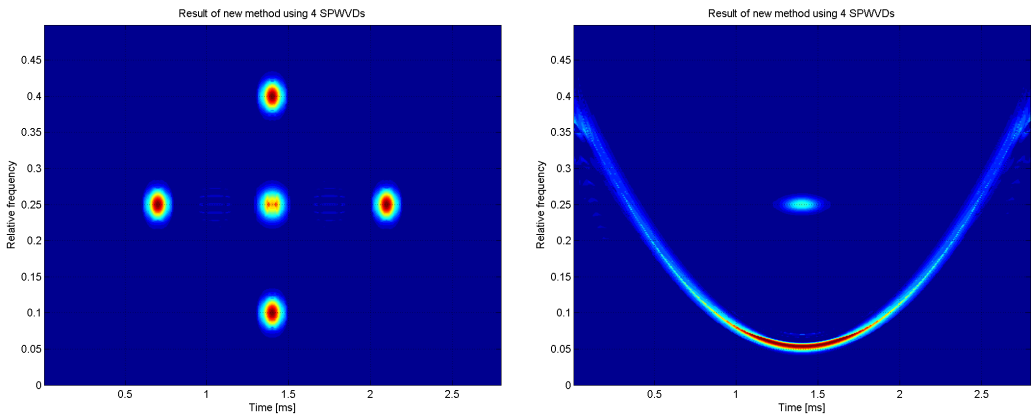

Figure 4: Results of reduced interference method created from four SPWVDs. On left: five gaussian TF atoms, on right: parabolic chirp with gaussian atom.

5 CONCLUSION

New enhanced method of interference reduction was presented . Selection of minimal time-frequency change between multiple Smoothed Pseudo Wigner-Ville Distributions provide good interference reduction and only partial degradation of resolution. In spite of need of more SPWVDs, they can be calculated in parallel and in addition even four differently smoothed distributions generate good results. Huge advantage of algorithm is its universality considering that it can be used for all variety of multicomponent or transient signals as was showed in this paper.

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