SMOOTHED QUADRATIC TIME-FREQUENCY DISTRIBUTIONS USING IMAGE SEGMENTATION TECHNIQUES

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Abstract: This paper deals with the topic of realization of smoothed quadratic time-frequency distributions. New crossterm reduction method based on image segmentation techniques is proposed and applied on the set of test signals. The results are discussed and compared with existing directional smoothing method.

Keywords: spectral analysis, Wigner distribution, image processing

1 INTRODUCTION

Quadratic Time-Frequency Distributions (QTFD) offer much better resolution properties in both time and frequency axis in comparison with short term Fourier transform. Almost per-sample accurate time resoulution together with significantly smoother frequency resolution makes QTFDs attractive for use as a key spectral analysis tool. However, the quadtratic properties of the local autocorrelation function used in the calculation of these distributions introduce the occurrence of undesirable crossterm components in resulting time-frequency distribution [1]. This can be problematic especially in cases where the character of the analyzed signal is not known beforehand.

There is a number of methods that are promised to eliminate or reduce the effect of crossterm components. These methods are solely based on two-dimensional filtering. In this paper, a new method of finding the optimal crossterm-suppressing filter kernel is introduced. Finally, the results of application of this approach on the set of test signals is discussed and compared with Adaptive Directional TFD method (ADTFD) [5].

2 METHOD PROPOSAL

2.1 Ambiguity domain filtering

Sussman's ambiguity function $A(\theta,\tau)$, in which θ denotes the Doppler shift and τ is the time lag, can be defined by two consecutive Fourier transforms of the existing Wigner distribution [2] $W(t,f)$:

$$A(\theta,\tau) = \mathcal{F}_t \mathcal{F}_f^- \{W(t,f)\} \tag{1}$$

where $\mathcal{F}^-$ denotes the inverse Fourier transform.

The main reason for utilization of ambiguity function in crossterm filtering is more distinctive separation of autoterms and crossterms of initial QTFD, in which autoterms are located in the center of the ambiguity function matrix (matrix of values obtained by eq. 1) [4].

Depending on the given filtering method, the kernel mask is chosen in a way, that (ideally) only autoterms are left unaffected. Inverse transform of Hadamard product (element-wise multiplication) of the ambiguity function matrix and the matrix of filter kernel back to the time-frequency domain yields the final smoothed QTFD.

2.2 Finding the optimal kernel shape

As mentioned before, in ambiguity domain the autoterms are located around the center of ambiguity function matrix with crossterms situated by sides symmetrically with the origin. That being said, we can assume that the biggest concentration of spectral energy will be located in these regions while the amount of energy in the rest of the matrix will be less significant. If we consider the data of normalized ambiguity function matrix as the image data, we can utilize the region growing algorithm for image segmentation. This algorithm is based on comparing pixel's intensity with threshold parameter value [3]. The seed point (i.e. the initial pixel) of the algorithm is obviously set in the center of the matrix to select the autoterm area.

The binary mask yielded by region growing algorithm is then processed with simple two-dimensional averaging filter to smooth out the transients of area edges thus preventing the occurrence of noise in resulting spectrogram.

Filtering efficiency can be affected directly by preprocessing of ambiguity matrix using ordinary image processing algorithms. For example, enhancing the contrast or utilizing image sharpening algorithms, such as unsharp masking [6], can result in better separation of cross and autoterm components.

A big advantage seems to be lower computational cost in comparison with other adaptive methods that rely mostly on performing multiple computational heavy operations such as convolutions in order to find the best kernel parameters.

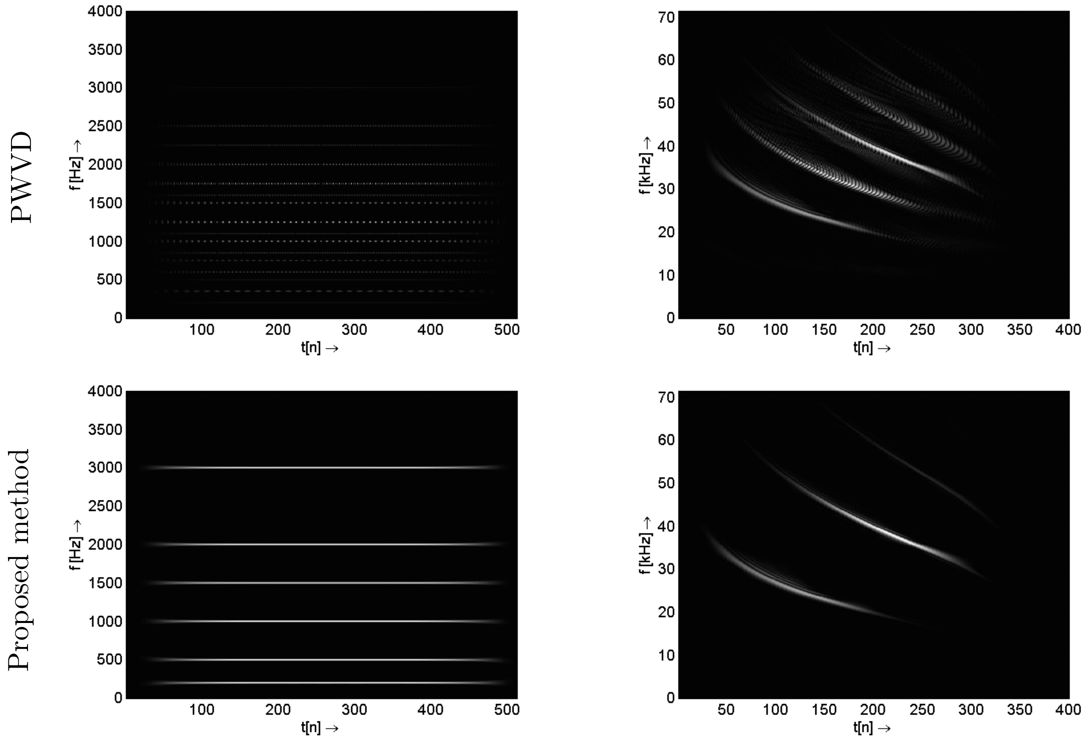
3 RESULTS

Proposed method was implemented using Matlab environment with pseudo Wigner-Ville distribution (PWVD) [1] as the initial QTFD. Additionally, ADTFD method based on directional filtering in time-frequency plane was implemented for results comparison [5].

The set of test signals consisted of:

- **Synthetic signals (512 samples sampled at 8.0 kHz)**:
  1. multicomponent stationary harmonic signal. ($f_1 = 200$ Hz, $f_2 = 500$ Hz, $f_3 = 1000$ Hz, $f_4 = 1500$ Hz $f_5 = 2000$ Hz, $f_6 = 3000$ Hz),
  2. combination of stationary and FM signal ($f_1 = 700$ Hz, $f_c = 3000$ Hz, $f_m = 12$ Hz),
  3. two near-frequency lineary modulated signals ($f_{10} = 800$ Hz, $f_{11} = 1800$ Hz, $f_{20} = 1000$ Hz, $f_{21} = 2000$ Hz).
- **Real world signals (400 samples sampled at 142.0 kHz)**:
  4. Big brown bat's echolocation signal (three non-linear chirps with frequency descending from approx. 65, 60 and 40 kHz).

The resulting PVWD spectrograms of signal 1 and 4, as well as their smoothed versions obtained by presented method, can be observed in figure 1.



(a) Spectrograms of signal 1

(b) Spectrograms of signal 4

Figure 1: Spectrograms obtained by application of PWVD and the proposed method on signal 1 (multicomponent harmonic signal) and 4 (bat's echolocation signal).

The method yields results comparable with ADTFD and even outperforms it in some cases. In multicomponent harmonic signal, the ADTFD spectrogram shows significantly less crossterm reduction even with bigger kernell sizes. In the bat signal, proposed method eliminates crossterms completely thus giving better result in comparison with ADTFD. On the other hand, use of the ADTFD results in better reduction of "self crossterms" created near areas where autoterm components are curved.

When applied on signals with near-located spectral components, the noticeable lack of separation in the ambiguity domain results, depending on threshold settings, in significant resolution loss or imperceptible crossterms reduction.

4 CONCLUSION

Proposed method seems to give promising results when applied on the most of the signals from the test data set. In signals that are composed of two near-frequency harmonic components, method fails to deliver satisfying results.

There is a corellation between analyzed signal character and ideal segmentation algorithm threshold parameter as well as ideal contrast adjustement amount. For fully adaptive solution, these parameters should be also adapted automatically. Overall, however, the method produces results with good ratio between resolution and crossterm suppression.

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