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Abstract. **Several time-frequency methods including the most recent ones are compared. Their performances are exemplified on a selected segment of depth EEG recordings.**

INTRODUCTION

Epileptic seizures, observed by means of surface or depth Electroencephalography (EEG and SEEG respectively), lead to complex, non linear and non stationary mixture of signals. The analysis of these signals is aimed at providing a better identification and understanding of the functional behaviour of the brain structures involved and their inter-relations [1]. One of the most appealing frameworks to perform such a task is represented by Time-Frequency approaches as soon as a clear view of the potential biases they convey is known.

METHODS

A number of methods have been already developed to represent the time-frequency patterns of nonstationary signals. The spectrogram and the Wigner-Ville Distribution (WVD) are the most widely used approaches. These two distributions belong to Cohen's class which is defined by [2]:

$$T_x(t,f;\varphi) = \iiint e^{j2\pi\upsilon(s-t)}\varphi(\tau,\upsilon)x(s+\frac{\tau}{2})x^*(s-\frac{\tau}{2})e^{-j2\pi ft}\,d\upsilon\,ds\,d\tau$$

where $x(s)$ is the signal, $x^*(s)$ is its complex conjugate and $\varphi(\tau,\upsilon)$ is a kernel function. The range of integration is $(-\infty,+\infty)$. This class includes all time-frequency shift-invariant, quadratic distributions. Each distribution of this class is uniquely determined by the kernel function. The WVD, $W_x(t,f)$, is obtained using $\varphi(\tau,\upsilon)=1$ [3]. This distribution has a perfect resolution but it suffers from undesirable interference cross terms due to the inherent quadratic structure of such transformations. A smoothing operation (i.e. lowpass filtering) may attenuate the interference terms because they are oscillatory [3]. Unfortunately this attenuation of interference terms leads to a lower time-frequency resolution.

Each distribution of Cohen's class can be derived from the WVD via a two-dimensional convolution with a kernel function [3]:

$$T_x(t,f;\varphi) = \iiint W_x(s,\eta)\,\Phi(t-s,f-\eta)\,ds\,d\eta$$

where $\Phi(t,f)$ is the two-dimensional inverse Fourier transform of $\varphi(\tau,\upsilon)$. It is clear that this convolution will result in a smoothing of the WVD only if the kernel $\Phi(t,f)$ is sufficiently smooth.

For the spectrogram, i.e. the squared magnitude of the short-time Fourier transform using the window $h(t)$, the smoothing kernel is the WVD of the short-time window: $\Phi(t,f) = W_h(t,f)$. This kernel results in substantial interference attenuation but also in poor time-frequency resolution. In addition, there is an inherent tradeoff between time and frequency resolution. This tradeoff is removed by the Smoothed Pseudo Wigner-Ville Distribution (SPWVD) defined by a separable smoothing kernel [4]: $\Phi(t,f) = g(t)H(f)$, where $g(t)$ is a window whose effective length determines the time resolution and $H(f)$ is the Fourier transform of $h(t)$, the window whose effective length determines the frequency resolution.

The recent distributions belonging to this class feature a WVD smoothing which is more sophisticated; they attempt to attenuate the interference terms while preserving simultaneously a high time-frequency resolution. The Choi-Williams Distribution (CWD [5]) has an exponential kernel in the plane (τ,υ): $\varphi(\tau,\upsilon) = \exp\{-(2\pi\tau\upsilon)^2/\sigma\}$, where σ is a scale factor which can control the smoothing operation.

For the Cone-Shaped Kernel Distribution (or Zhao-Atlas-Marks Distribution, ZAMD [6]) the kernel is: $\varphi(\tau,\upsilon) = q(\tau)|\tau|\,\mathrm{sinc}\{2\pi\tau\upsilon/a\}$, where a has the same role as σ in the Choi-Williams Distribution. For the Bessel Distribution (BD [7]) the kernel is: $\varphi(\tau,\upsilon) = J_1(2\pi\alpha\tau\upsilon)/\pi\alpha\tau\upsilon$, where J_1 is the first kind Bessel function of order one and α is a scaling factor. The Bessel distribution preserves the time and frequency support properties when $\alpha \le 0.5$.

In addition to the distributions of Cohen's class, another important quadratic time-frequency representation is the scalogram, i.e. the squared magnitude of the time-frequency version of the wavelet transform. Scalogram is defined as [8]:

$$SCAL_x(t,f;\gamma) = \left|WT_x(t,f;\gamma)\right|^2 = \left|\int x(s)\sqrt{f/f_0}\,\gamma^*(\frac{f}{f_0}(s-t))\,ds\right|^2$$

where $\gamma(t)$ (the "analyzing wavelet") is a real or a complex bandpass function centered around $t=0$ in the time domain. f_0 is the center frequency of $\gamma(t)$. Scalogram belongs to the affine class, i.e. the class of quadratic time-frequency distributions that preserve time scalings and time shifts. Any distribution of this class can be derived from the WVD by means of an affine transformation [3]:

$$T_x(t,f;\Phi) = \iint \Phi(f(s-t),\frac{\xi}{f})W_x(t,f)\,ds\,d\xi$$

where $\Phi(\alpha,\beta)$ is a kernel function. The scalogram's kernel is the WVD of the analyzing wavelet [3]: $\Phi(\alpha,\beta) = W_h(\frac{\alpha}{f_0},\beta f_0)$.

RESULTS

The time-frequency representations mentioned previously were applied to SEEG signals. The whole data set comprises more than 60 sensors distributed over 5 needle electrodes. The sampling rate was equal to 200 Hz. The

patient was suffering from a temporal epilepsy and 5 seizures were recorded through long-term monitoring. Each seizure depicted true varying patterns including multiple, stable or fast changing oscillatory, as well as spike-like sequences. Figure *a* shows this selected segment from ictal phase of one seizure. This segment contains a particular pattern, a parabolic signature, in the time-frequency plane. A representation of the spectrogram, the SPWVD, the CWD, the ZAMD, the BD and the scalogram [1] for this segment is given in figures *b-g*. This pattern is shown clearly in all of these time-frequency representations, but for the SPWVD, due to possibility of controlling the time and frequency resolution independently, a more accurate resolution is obtained in addition with more attenuated interference terms. Other SEEG segments have been processed and simulation experiments have been conducted. They allow to gain deeper insights into the potential drawbacks of these methods according to the signal contents and also the cautions to be taken when interpreting epileptic seizure.

<div align="center">REFERENCES</div>

[1] L. Senhadji et al., "Wavelet Analysis of EEG for Three Dimensional Mapping of Epileptic Events ", Annals of Biomedical Engineering, Vol. 23, N° 5, pp.543-553, 1995.

[2] L. Cohen, "Time-Frequency Distributions - A Review", Proc. IEEE, vol. 77, pp. 941-981, 1989.

[3] F. Hlawatsch & G. E. Boudreaux-Bartels, "Linear and Quadratic Time-Frequency Signal Representations", IEEE Sig. Proc. Magazine, pp. 21-67, Apr. 1992.

[4] P. Flandrin, "Temps-Fréquence", Ed. HERMES, Paris,1994.

[5] H. Choi & W. Williams, "Improved Time-Frequency Representation of Multicomponent Signals Using Exponential Kernels", IEEE Trans. on ASSP, vol. 37, pp. 862-871, June 1989.

[6] Y. Zhao, L. E. Atlas, & R. J. Marks, "The Use of Cone-Shaped Kernels for Generalized Time-Frequency Representations of Nonstationary Signals", IEEE Trans. on ASSP, vol. 38, pp. 1084-1091, July 1990.

[7] Z. Guo, L. G. Durand & H. C. Lee, "The Time-Frequency Distribution of Nonstationary Signals Based on a Bessel Kernel", IEEE Trans. on Sig. Proc., vol. 42, pp. 1700-1707, July 1994.

[8] O. Rioul & M. Vetterli, "Wavelet and Signal Processing", IEEE Sig. Proc. Magazine, pp. 14-38, Oct. 1991.

Figures a-g. a. Original signal, b. Spectrogram, c. Smoothed Pseudo Wigner-Ville Distribution, d. Choi-Williams Distribution, e. Z.A.M. Distribution, f. Bessel Distribution, g. Scalogram. The horizontal axis represents the time (15 seconds). The vertical axis in the first figure is the amplitude and in the others the frequency varying from 0 to 50 Hz.