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A New Processing Algorithm For the Time-Frequency Mathematical Morphology Operators Method

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Abstract – The method uses the ridges extraction method from the time-frequency distribution based on mathematical morphology operators (TF-MO). The TF-MO method for signals with highly non-linear IF corrupted by Gaussian white noise is not very adapted for IF estimation. In this paper is presented a new improved technique for IF estimation based on TF-MO method.

Keywords: Instantaneous frequency, time-frequency distribution, complex argument, mathematical morphology, signal analysis, image analysis.

I. INTRODUCTION

In signal processing the decision (detection, denoising, estimation, recognition or classification) is a basic problem. Knowing that the real environments are generally highly non-stationary, it is necessary to use a method able to provide suggestive information about the signal structure. A potential solution is based on time-frequency representations that provide a good concentration around the law of the IF and realize a diffusion of the perturbation noise in the time-frequency plane.

The TF-MO estimation method [2] is based on the conjoint use of two very modern theories, that of time-frequency distributions and that of mathematical morphology. This strategy permits the enhancement of the set of signal processing methods with the aid of some methods developed in the context of image processing.

In [1] it has been showed that for signals with a time-frequency structure not so complicated, the performances of the TF-MO method are good. Unfortunately for signal with swift transitions over a short duration of time and SNR high enough, the accuracy of the IF estimation in the TF-MO method is poorer. In this case the bias in the TF-MO method is significant and dominates the estimation error, the IF estimator cannot accurately follow the rapid transitions in the IF.

For signals with highly non-linear IF the performance can be improved by applying the morphological operators on multiples segments of the signal component.

The paper is organized as follow. The improved TF-MO method is illustrated in section II. In section III some simulation results are depicted. Section IV will close this communication.

II. TIME-FREQUENCY MORPHOLOGICAL OPERATORS METHOD

The estimation method based on time-frequency and image processing techniques has been introduced in [2]. The quality of estimating the IF depends on the time-frequency distribution and on its ridges projection mechanism. The TF-MO method proposes a time-frequency representation based on cooperation of linear and bilinear distributions: the Gabor and the Wigner-Ville distributions. It is known [3] that the Gabor representation has a good localization and free interference terms properties. Unfortunately, the linear distributions, except the Discrete Wavelet transform, correlate the zero mean white input noise, as shown in [4]. The WVD is a spectral-temporal density of energy that does not correlates the input noise, thus having a higher spreading effect of the noise power in the time-frequency plane [2]. The WVD has also a good time-frequency concentration.

To combine these useful advantages, the time-frequency distribution is calculated according to the following algorithm [2]:

1) Calculate the Gabor transform for the signal s, $G(t,\omega)$.

2) Filter the image obtained with a hard-thresholding filter:

$$Y(t,\omega)=\begin{cases}1, & if\ |G(t,\omega)|\geq tr\\ 0, & if\ |G(t,\omega)|<tr\end{cases} \quad (1)$$

where tr is the threshold used.

3) Calculate the WVD for the signal s, $WV(t,\omega)$.

4) Multiply the modulus of the $Y(t,\omega)$ distribution with the $WV(t,\omega)$ distribution.

In step 2) the proposed threshold value is:

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$$tr = \frac{\max_{(t,\omega)}\{|G(t,\omega)|\}}{5} \quad (2)$$

This operation decreases the amount of noise that perturbs the ridges of $G(t,\omega)$ and brings to zero the values in the rest of the time-frequency plane. The effect of the multiplication in step 4) is the reduction of the interference terms of the WVD and the very good localization of the ridges of the resulting ditribution.

To estimate the ridges of the obtained distribution, some mathematical morphology operators are used, the above resulting distribution being regarded as an image. This mechanism is applied through the following steps [2]:

1) Convert the image obtained in step 4) (in the procedure described earlier) in binary form.

2) Apply the dilation operator on the image in 1).

3) Computation of the skeleton of the last image, an estimation of the IF of the signal being obtained. This image represents the result of the TF-MO method.

The conversion in binary form realizes a denoising of the time-frequency distribution. The role of the dilation operator is to compensate the connectivity loss, produced by the preceding steps. The skeleton produces the ridges estimation.

III. THE NEW SIGNAL PROCESSING ALGORITHM

Instead of applying the TF-MO method on the entire signal, we break the signal processing with this method on multiples segments of the signal component. Each signal segment is oversampled.

For each signal segment is obtained an image representing the estimation of the IF on that signal interval. The final image (the estimation of the IF of the entire signal) is constructed by merging all segments' IF images.

The new signal processing procedure is done according to the following algorithm (Fig. 1):

1) Take *M* samples from the original signal, obtaining a segment.
2) Oversample the signal segment by 2.
3) Apply TF-MO method, obtaining the estimation of the IF of the segment.
4) Repeat the steps from 1) to 3) for the next segments, each one containing *M* samples. Two consecutive segments contain *l* overlapping samples.
5) Merging all the segments' IF images, the estimation of the IF of the entire signal is obtained.

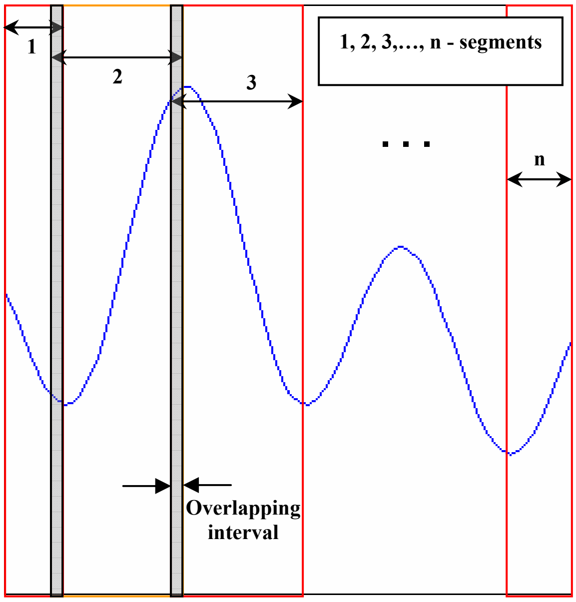

Fig. 1. The new signal processing procedure applied to the signal which IF is represented in blue.

IV. RESULTS

For all the following examples the STFT transform calculation is done according to

$$STFT_s(n,k) = FT_m\{s(n\Delta t + m\Delta\tau)w(m)\}$$

with Δt= 2/*N* and N=128 samples. The sampling rate is Δτ = 1/16. The window of the form $w(m) = \exp\left(-(m\Delta\tau / T)^4\right)$ is used with 2*T*= 1/2.

The WV distribution is calculated according to

$$WV(n,k) = FT_m\left\{ s\left(n\Delta t + m\frac{\Delta\tau}{2}\right)s^*\left(n\Delta t - m\frac{\Delta\tau}{2}\right)\times \atop \times w_c(m) \right\}$$

with $w_c(m) = \exp\left(-(m\Delta\tau / 2 / T)^4\right)$.

The conversion in binary form is done with the following parameters: low-threshold=128 and high-threshold=255. The dilation factor is 2 and the skeleton operator used is the minimal skeleton.

Example 1: Consider a noisy monocomponent signal with highly non-linear IF:

$$s(t) = \exp\{j(3\cos(\pi t) - \cos(3\pi t)/2 + \cos(5\pi t)/1.5))\} + n(t) \quad (3)$$

within the interval [-1, 1] where *n(t)* is a Gaussian white noise.

The IF is estimated for various values of the SNR, based on the TF-MO method and improved TF-MO method. Fig. 2, represents the estimated IF with the TF-MO method, for SNR=30dB along with the real IF law. Mean squared errors of the IF estimation calculated in 128 realizations for SNR values within the interval [3dB, 30dB], based on TF-MO method is showed in Fig. 3.

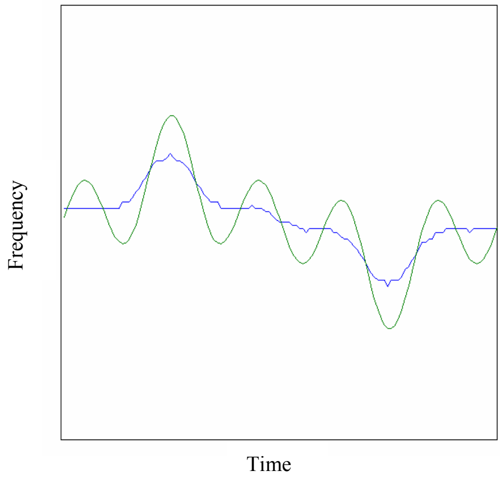

Fig. 2. IF estimation based on TF-MO method for SNR=30dB

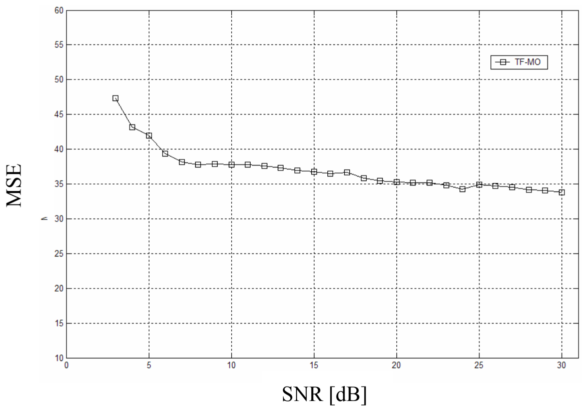

Fig. 3. Mean squared error of the IF estimation for SNR between [3dB, 30dB] based on TF-MO method

Analyzing Fig. 2, it can be observed that the TF-MO method is not able to track the rapid variations of the IF. This incapability is observed in Fig. 3 like a polarization of the estimator. Fig. 4, represents the estimated IF with the improved TF-MO, for SNR=30dB along with the real IF law.

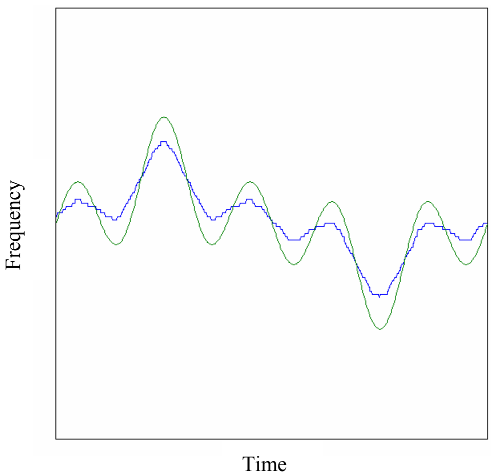

Fig. 4. IF estimation based on improved TF-MO method for SNR=30dB

Fig. 4 illustrates a better tracking capability in comparison with the experiment illustrated in Fig. 2. The IF estimator based on the improved TF-MO method follows more accurately the rapid transitions in the IF.

In the next table is presented a comparison of the values of the mean squared error (MSE) of the IF estimation for SNR=30dB for the TF-MO method and the improved TF-MO method.

Table 1.

SNR [dB]	MSE TF-MO method	MSE Improved TF-MO method
30	33.80	18.69

From these numerical results, it can be noticed an improvement in the IF estimation of about 44.7 percent.

Example 2: Consider now a noisy monocomponent signal with an IF with reduced nonlinearity:

$$s(t) = \exp\{j(5\pi t^3 - 9.5\pi t)\} + n(t) \qquad (4)$$

within the interval [-1, 1] where *n(t)* is a Gaussian white noise.

The IF is estimated for various values of the SNR, based on the TF-MO method and improved TF-MO method. Fig. 5, represents the mean squared errors of the IF estimation calculated in 128 realizations for SNR values within the interval [3dB, 30dB], based on TF-MO method.

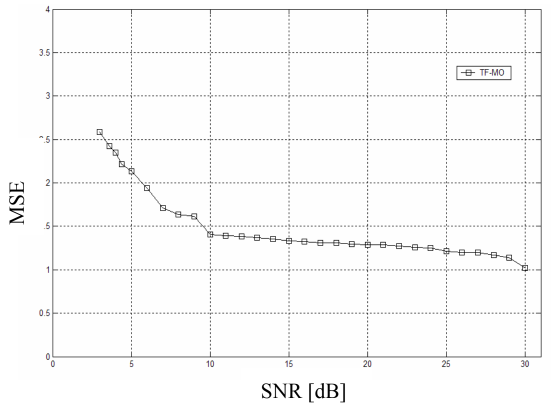

Fig. 5. Mean squared error of the IF estimation for SNR between [3dB, 30dB] based on TF-MO method

Fig. 6 represents the estimated IF with the TF-MO method, for SNR=30dB along with the real IF law.

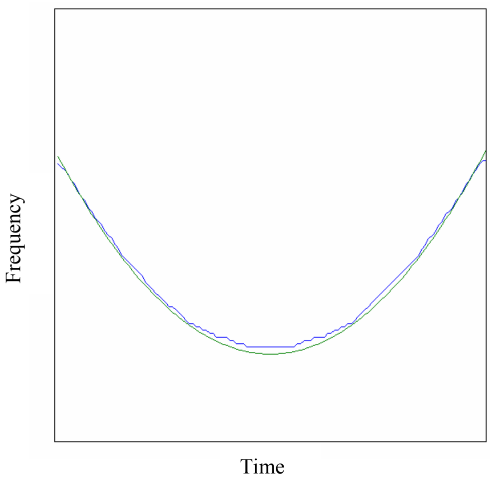

Fig. 6. IF estimation based on TF-MO method for SNR=30dB

The estimated IF with the improved TF-MO, for SNR=30dB along with the real IF law is showed in Fig. 7.

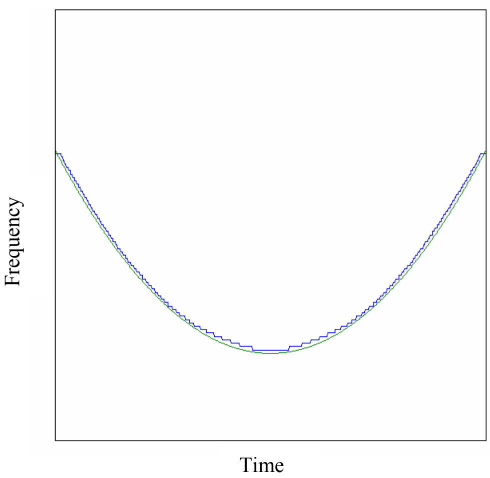

Fig. 7. IF estimation based on improved TF-MO method for SNR=30dB

In the next table is presented a comparison of the values of the mean squared error (MSE) of the IF estimation for SNR=30dB for the TF-MO method and the improved TF-MO method.

Table 2.

SNR [dB]	MSE TF-MO method	MSE Improved TF-MO method
30	1.096	1.085

From these numerical results, it can be noticed that the improvement in the IF estimation is not important in this second example, thus for signals with an IF structure not so complicated, the use of the improved TF-MO method is not justified.

IV. CONCLUSION

In this paper, it has been analyzed the performances of the IF estimation for the new improved TF-MO method, for the signals with highly non-linear IF.
Using this technique of signal processing the IF estimation results are considerably better than in the classical TF-MO processing method.
Further research could be directed toward the optimization of this TF-MO technique.

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