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SOME METHODS OF DESCRIBING ECHOLOCATION CALLS OF BATS USING COHEN'S CLASS AND WAVELET ALGORITHMS

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In this paper some digital signal processing algorithms, that are used for describing bats' echolocation calls of two different species of bats *(Myotis daubentoni, Nyctulus noctula)* are presented. Analyzed algorithms are dedicated to calculate time frequency (TF) representation of digital signals. Spectrogram of the bat sonar call gives us information about many important features of the signal like type of frequency modulation which is one of the most important signal parameter. Comparative analysis of the algorithms mentioned in this paper suggests that we can select the best suitable method of analysis of bat's sonar signals.

Keywords: bat, echolocation calls, time-frequency decompositions.

1. Introduction to bats calls analysis

In accordance with information provided in papers [4, 7, 11] one of the main problem of bats' sonar signals analysis are time frequency decompositions of the signal, in fact that types of frequency modulations used by bats are very complicated functions and differ each other between species. The problem of determining frequency modulation function is very complex due to Gabor–Heisenberg uncertainty principle. On the other hand, frequency modulations are used to compensate Doppler effect in accordance with [7] and vertical angle estimation in 3D space tracking presented in paper [7]. More effective method of digital signal processing may have significant influence on the development of automatic bats species recognition.

2. Materials and methods

2.1. Bat's signal database

The database consisting of the recordings of various bats species was used to the analysis. Data were registered in the period 11.04–20.07.2007 in four various places.

Time-Expansion meter (Pettersen D240x) was applied to the registration of recordings. All the signals were presented in digital form 44.1 kHz sampling frequency and 16 bit resolution. Due to the signal acquisition method the maximum frequency range is shifted from 22.050 kHz to 220.5 kHz.

2.2. Methods of signal processing

From among various methods of digital signal processing the following algorithms were selected and compared:

- STFT – Short Time Fourier Transform [2],
- WV – Wigner – Ville distribution [4],
- PWV – Pseudo Wigner – Ville distribution [2, 4],
- SPWV – Smoothed Pseudo Wigner – Ville distribution [2, 4],
- SPAW – Smoothed Pseudo Affine Wigner – Ville distribution [6],
- DFLA – D – Flandrin distribution [2, 6].

Calculations were made in the computational environment Matlab 2007R with TFTB (Time Frequency Toolbox) installed [2, 3]. Based on the comparative analysis STFT, WV, PWV algorithms were chosen because of the smallest mean squared error (see Fig. 1, Fig. 2). The main goal was estimation of parameters of modulation function (A, B for linear and C, k for exponential modulation). In accordance with information provided in paper [11], we can assume that signal of *Myotis daubentoni* bat has close to linear frequency modulation given by Eq. (1)

$$f(t) = A \cdot t + B \tag{1}$$

and *Nyctulus noctula* bat has close to exponential frequency modulation given by Eq. (2).

$$f(t) = C \cdot e^{-kt}. \tag{2}$$

It is important to notice that both bats have downsweep frequency modulation due to we can sort in descend order the obtained points of time-frequency representation. It must also be stressed that in case of all kinds of transforms signal windowing was on an arbitrary basis with the use of Hamming window and 4096 pint of FFT was applied to the calculations.

2.3. Computational speed examination

To examine a computational speed of the algorithms from Sec. 2.2 time of calculation was compared. We used PC Intel Pentium T7200 Core2Duo 2 GHz processor with 1 GB RAM installed. All calculation were made in Matlab 2007R environment.

3. Results of analysys

In Figs. 1 and 2, the results of comparative analysis of the algorithms from Sec. 2.2 are presented. The approximation of linear modulation function (LMF) is presented in

Fig. 1 and power modulated function (PFM) in Fig. 2. In the Tables 1 and 2, the results of estimation of frequency modulation function are shown. It is an important detail that the number of analyzed signals of bats was ten in both cases.

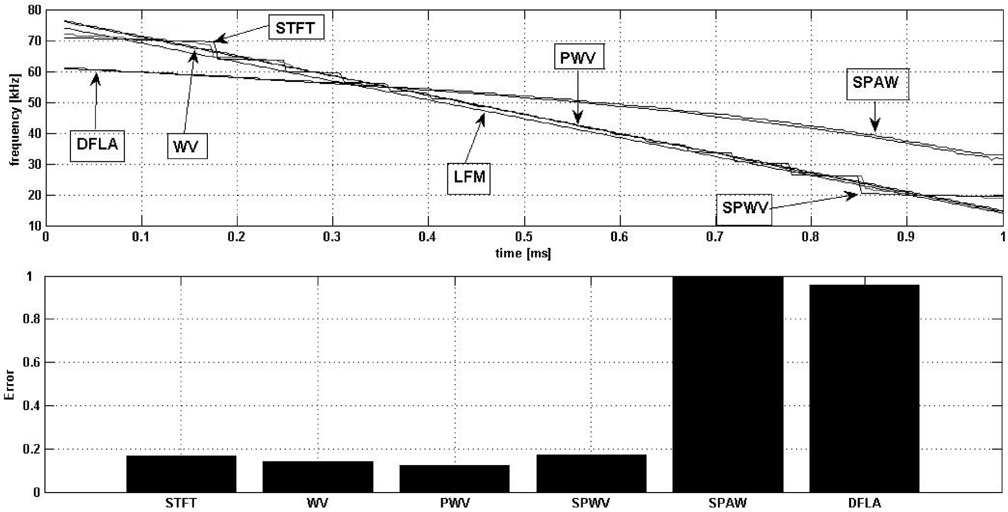

Fig. 1. Linear function approximation [8] and error of the approximation.

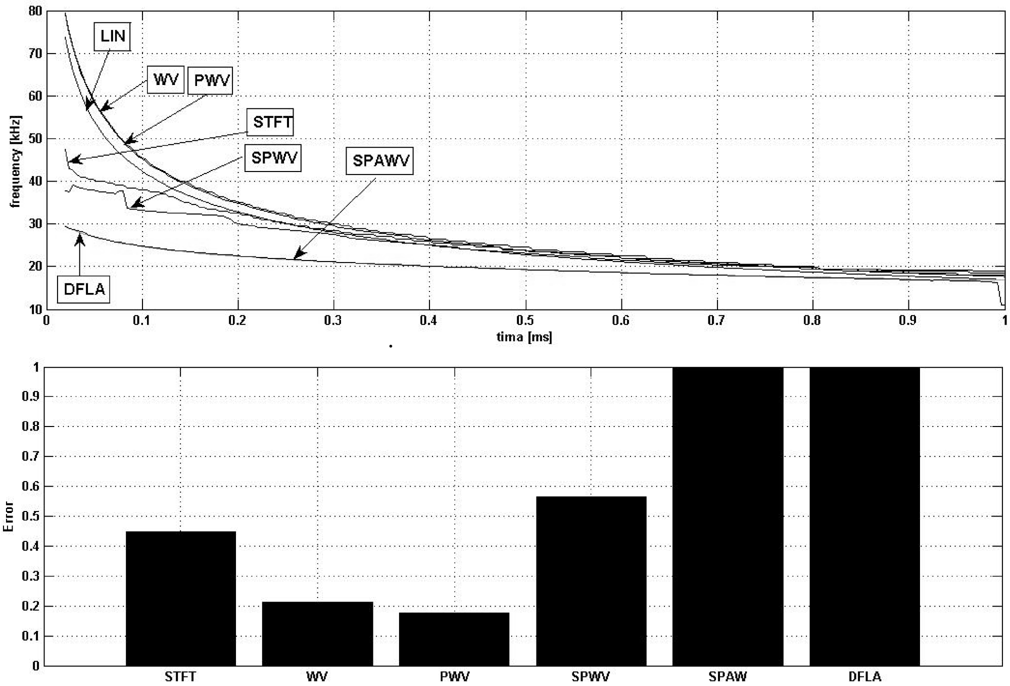

Fig. 2. Power function approximation [8] and error of the approximation.

Table 1. Estimation of frequency modulation function parameters for *Myotis daubentoni* bat.

Algorithm	mean(A) [kHz/ms]	std(A) [kHz/ms]	mean(B) [kHz]	std(B) [kHz]
STFT	−9.97	5.01	63.09	12.09
WV	−10.27	3.55	60.12	8.53
PWV	−25.29	7.52	61.32	8.81

Table 2. Estimation of frequency modulation function parameters for *Nyctulus noctula* bat.

Algorithm	mean(k) [1/ms]	std(k) [1/ms]	mean(C) [kHz]	std(C) [kHz]
STFS	−0.08	0.04	37.16	9.61
WV	−0.08	0.03	36.22	8.86
PWV	−0.18	0.08	35.91	8.24

The computational speed analysis results are presented in graphical form in the Fig. 3.

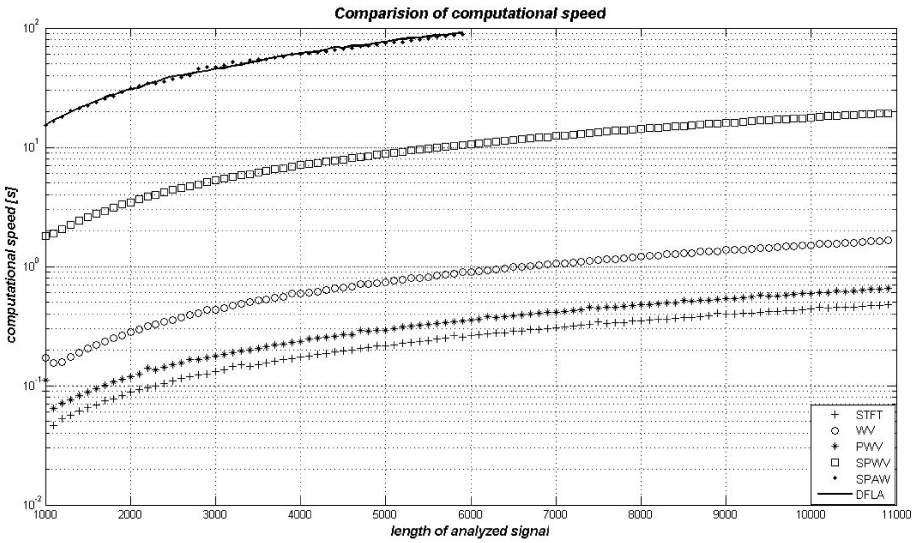

Fig. 3. Computational speed vs. number of samples of analyzed signal.

4. Discussion

On the ground of performed studies and the obtained results, the matter of processing of bio-echolocation signals can be regarded as a problem which is complicated in the area of method selection and calculation complexity. On the basis of Fig. 3 it is possible to conclude that it is hardly recommended to use DSP processor in such calculation due to very long time of calculation. Analysis of obtained results leads us to a conclusion that we can analyze signals which length is lower than $10k$ samples (40 ms for 250 kHz sampling frequency) in a few seconds.

In the Tables 1 and 2 the analysis of capabilities of mathematical description of frequency modulation function of actual echolocation signals of various bat species was shown. The analysis of the results suggests that parameters of the frequency modulation function differ each other between presented algorithms. The Wigner-Ville distribution minimizes the standard deviation (std) of parameters A, B for the *Myotis daubentoni* bat. High value of std(C) is a result of intra species differences and different strategies of navigation in obstacle field for *Nyctulus noctula* bat. The attempts to mathematically model bats' signals by means of advanced of digital signal processing can contribute to development of non-invasive, automatic species recognition and classification of individual features (species, sex, age) of bats.

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