WAVELET ANALYSIS OF THE ULTRAWIDEBAND SIGNALS

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Abstract

The results of the wavelet analysis application to the ultrawideband (UWB) signal investigation are introduced. The continuous wavelet transform, the analytic wavelet transform, the discrete wavelet transform, the wavelet packets, the stationary wavelet transform and the Kravchenko-Rvachev analytic wavelets based on the atomic functions have been used to the analysis of the UWB signals and processes.

Keywords: Ultrawideband signals and processes, wavelet analysis, UWB signal detection, quality functional, expansion entropy.

1. INTRODUCTION

The application of the new UWB signal types such as pulse, direct-chaotic, non-linear and fractal UWB signals requires the usage of the new modern mathematical methods of the digital processing [1].

The wavelet analysis including, in particular, the continuous wavelet transform, the analytic wavelet transform, the discrete wavelet transform, the stationary wavelet transform and other was found to be useful for the description of the UWB signal and processes [2, 3]. Therefore, development is appears to be useful, modern and important today.

2. WAVELET ANALYSIS OF THE PULSE UWB SIGNALS

The wavelet analysis was shown to be effective for the UWB signal describing. Many real wavelets from present ones were found to be the UWB signals by the definition. Moreover, real or imaginary parts of the complex analytical wavelets were shown to be the UWB signals too. Therefore, the wavelet basis was appears to be the UWB signal own basis [2, 3].

2.1. DISCRETE WAVELET TRANSFORM APPLICATION

The discrete wavelet transform (DWT), the wavelet packets (WP) and the stationary wavelet transform (SWT) for the UWB signal detection problem versus the additive weakly correlated Gaussian noise background were applied [2-4]. It was shown that DWT, WP and SWT are appeared to be more effective in many cases of UWB signal analysis than methods based on the Fourier analysis have been.

To describe numerically each wavelet from the existing ones, the set of the characteristics was proposed [4]. This idea was based on the fact that all wavelets can be considered as the frequency filters. Because of that the proposed characteristics were constructed on the basis of existing ones for the frequency filters [5].

Let's consider this wavelets and signals characteristic more detail. In this set γ_1 is the relative location of the Fourier spectrum maximum; γ_2 is the relative location of the first null of the Fourier spectrum; γ_3 and γ_4 are the Fourier spectrum width on the level 3 dB and 6 dB responsively; γ_5 is the information losses (in dB), observed when the frequency components with $f \notin \left[0, \tilde{\nu}\right]$, where $\tilde{\nu}$ is the first null being right-hand from the general Fourier spectrum maximum, have been deleted; γ_6 is the information losses (in dB), observed when the frequency components with $f \notin \left[f_{\min}, f_{\max}\right]$, where $f_{\min}$ and $f_{\max}$ are defined at that level when the Fourier spectrum decreases e times relatively its general maximum, have been deleted; γ_7 is the coherent amplification; γ_8 is the equivalent noisy band; γ_9 is the maximal level of the side maxima.

The characteristics of model UWB signals reconstructed on the additive noise background were estimated. The optimal wavelet basis choice procedure based on the DWT spectrum entropy estimation was proposed [4].

2.2. Continuous wavelet transform application

The continuous wavelet transform (CWT) for the UWB signal models analyzing were used. There are both the analytical results [6] as the numerical ones [3, 4]. The results of the model UWB signal analysis with specially constructed format were represented. This format covers the CWT spectral density function (SDF), the CWT SDF sceleton, CWT SDF energoram, the SDF of the short-time Fourier transform (STFT), the STFT SDF sceleton and the STFT energogram. An example is shown at Fig. 1.

The quality functional as the possible way of the optimal wavelet basis choice for each UWB signal during the CWT application was successfully constructed [6, 7]. The quality functional is given by

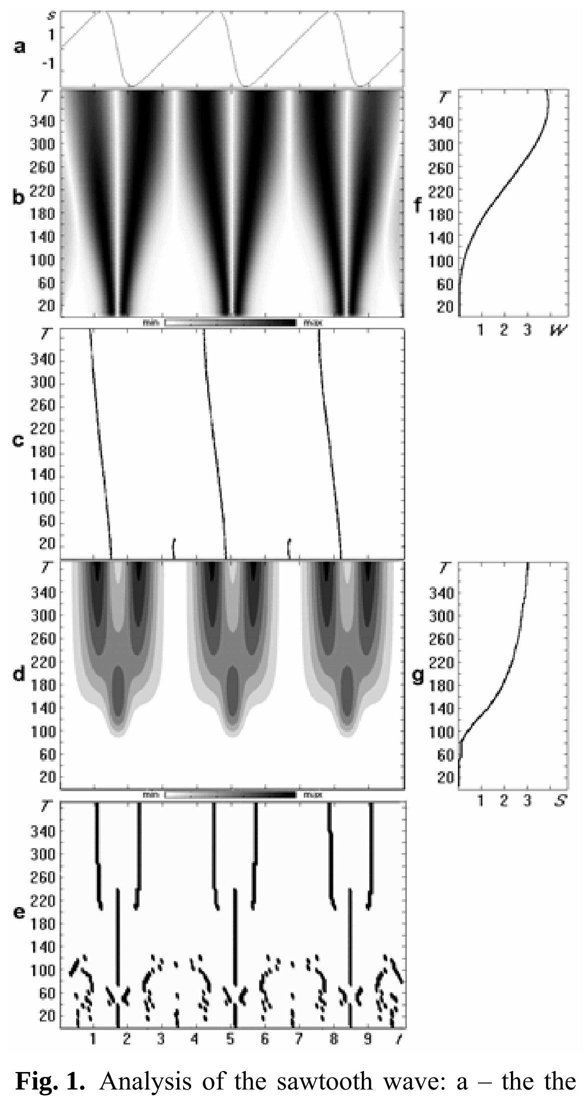

Fig. 1. Analysis of the sawtooth wave: a – the the sowtooth wave in time domain, b – the CWT SDF with mexh wavelet, c – the CWT SDF sceleton, d – the STFT SDF, e – the STFT SDF sceleton, f – the CWT SDF energogram, g – the STFT SDF energogram.

$$J(f_1, f_2) = \sum_{i=1}^{10} \left(\frac{\gamma_i(f_1) - \gamma_i(f_2)}{\gamma_i(f_2)} \right)^2 ,$$

$$\gamma_{10}(f_{1,2}) \equiv \mu(f_{1,2}) ,$$

where f_1 is the used wavelet function $\psi(t)$, f_2 is the analyzed signal $s(t)$, $\gamma_i(f)$ are the parameters proposed above for the describing of both the wavelets and UWB signals. The minimal value of the given functional $J(f_1, f_2)$ corresponds to the optimal basis selection. Such optimal bases for each UWB signal model from the proposed set were shown in [6].

2.3. Analytic wavelet transform application

The analytical wavelet transform (AWT) for the UWB signal describing were successfully used. Both the analytical results and the numerical ones of the AWT application to the UWB signal models analyzing were obtained [6].

In addition to many analytical wavelets, the new Kravchenko-Rvachev analytic wavelets based on the atomic functions for the UWB signal analysis with AWT were applied [8].

Using the quality functional listed above, for each UWB signal model the optimal analytic wavelet basis was chosen.

3. Wavelet analysis of the non-linear UWB signals

The UWB signal is called as the non-linear UWB (NLUWB) signal, if it has being a finite solution of the non-linear differential equation [1].

As the NLUWB signal models, for example, the soliton of envelope, some periods of the sawtooth wave and the first derivative of the blast wave, kink and antikink can be considered.

The calculation results of the discussed above set of parameters being good for the describing both the wavelets and the UWB signals were shown in [7, 9]. In that papers there are many results of NLUWB signal analysis based on both the wavelet analysis and the short-time Fourier transform. Wavelet analysis is presented by the CWT. The example of such analysis is given at the fig. 1.

4. Wavelet analysis of the fractal UWB signals

The fractal ultrawideband (FUWB) signal is the signal which has the fractional dimension and the property of the self-similarity or self-affinity. Many simple numerical and analytical FUWB signal models in time-domain were proposed [10, 11].

It was found (see, for example, [12]), that, on hand, many different wavelet functions such as Daubechie's wavelets, symlets, coiflets, biortogonal wavelets are self-similar and have fractal dimension. Other hand, that wavelet functions are appeared to be the UWB signals [2, 4, 6]. Thus, they can be used as good numerical FUWB signal models.

Analytical FUWB signals are based on the well-known fractal functions (see, for example, [12]) which were some modified. These analytical models are based on the Weierstrass', Riman's and Riman-Weierstrass' functions.

The Fourier analysis of the FUWB signal models described above was performed. As it was assumed the Fourier spectrum of FUWB signal model is appeared to be fractal. Fractal structure of that spectrum leads to the increasing of wideband index μ comparing with μ for non-fractal UWB signal model with same parameters. Moreover, such Fourier spectrum decreases more slowly with the frequency increasing than one for non-fractal UWB signal decreases. Because of that reasons, we believe that Fourier analysis is not sufficiently good for the FUWB signal describing. Wavelet analysis was appeared to be very useful for the FUWB signal investigation.

Different types of wavelet analysis such as continuous wavelet transform (CWT), discrete wavelet transform (DWT), wavelet packets (WP) and stationary wavelet transform (SWT) were used. All considered wavelet spectra in particular continuous wavelet spectra have a fractal structure and depend on both investigated signal and applied wavelet. The numerical characteristics for FUWB signal models were calculated and discussed [10].

Unfortunately, CWT is not so good to recover a signal from wavelet spectrum. One side, not all wavelets have inverse wavelet transform. Other side, if such transform is present, needed calculations are very difficult. Because of that the DWT, WP and SWT were believed to be more useful for FUWB signals. Before DWT is performed, there is a problem of the best analyzing wavelet selection for each signal. The condition of Shannon's entropy minimization was choused. It was found that the best analyzing wavelets for our FUWB signal models are Daubechie's wavelets db9 and db5.

The wavelet analysis is proposed to apply for detection of FUWB signals against an interference background. The method described in [2, 4] was used. Obtained results were compared with ones for non-fractal UWB signals. WP was appeared to be the best in this case. SWT got worse results. This can be explained by non-stationarity of FUWB signals.

5. Conclusions

- The DWT, the CWT and the AWT to the describing of the pulse, non-linear and fractal UWB signals have been successfully applied.
- The problem of the pulse and fractal UWB signal detection against an interference background with the wavelet analysis application has been resolved.
- The numerical characteristic set and the quality functional which are used for the optimal wavelet basis choice have been proposed.
- The class of the Kravchenko-Rvachev analytic wavelets based on the atomic functions have been introduced.

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