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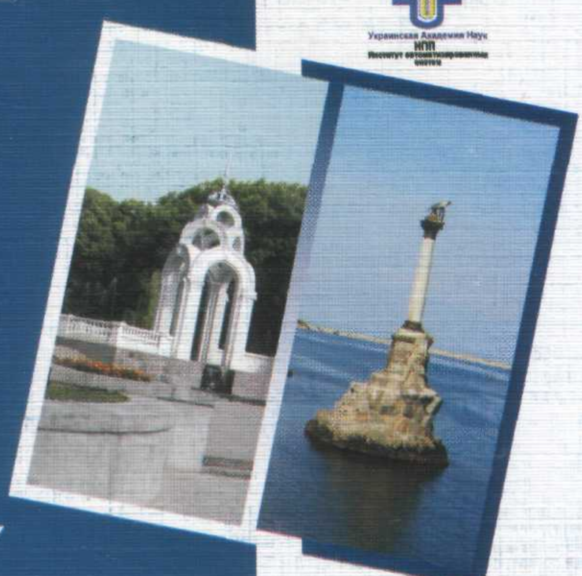

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SYSTEM SPECTRAL ANALYSIS OF THE SIGNALS

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Abstract

The new complex signal analysis method called as system spectral analysis and based on the simultaneous application of the set of linear and non-linear integral transforms is proposed. The abilities of the system spectral analysis at the sample of investigation of the unique natural phenomenon well known as the rogue wave are shown.

Keywords: Digital signal processing, wavelet transforms, Gabor transform, short-time Fourier transform, Cohen class non-linear transforms.

1. INTRODUCTION

The creation and the more frequent usage of new signal types, such as ultra-short [1], direct-chaotic [2], fractal ultrawideband (UWB) [3], fractal [4] ones, in different branches of science and engineering calls for the development of new mathematical methods of signal analysis allowing to detect and to describe the features of such signals at higher level comparing with traditional Fourier transform.

Different types of wavelet transform [5], atomic functions [6], adaptive Fourier transform [7], non-linear transforms from Cohen's class, in particular, Wigner and Choi-Williams transforms [8] were made a good showing during the analysis of such signals [9, 10].

Nevertheless, each transform from that has both the unique properties and some disadvantages. Therefore, the creation of new complex method of signal analysis, in which the disadvantages of ones transforms will be compensated by the advantages of other transforms, is appeared to be advisable and topical.

2. SYSTEM SPECTRAL ANALYSIS BASES

The proposition of creation of the new method based on the simultaneous usage of many transform set and called as the system spectral analysis seems to be modern and useful.

This set covers two different groups of continuous transforms – linear and non-linear transforms. In first group there are the continuous wavelet transform (CWT), the analytical wavelet transform (AWT), the Gabor transform (GT), the adaptive Fourier transform (AFT) and the short-time Fourier transform (STFT). Second group includes the Fourier spectrogram, the Wigner transform, the Choi-Williams transform and the Born-Jordan transform.

The continuous wavelet transform is given by

$$Wf(T,\tau) = |kT|^{-1/2} \int_{-\infty}^{\infty} f(t)\psi\left(\frac{t-\tau}{kT}\right)dt\,,$$

where $f(t)$ is the analyzed signal, $\psi(t)$ is the analyzing real wavelet, τ is the time-shift variable, T is time-scale variable, connected with ordinary scale variable a [1] by the relation $a = kT$, where k is the factor, determined for each wavelet $\psi(t)$.

The analytical wavelet transform is given by

$$\dot{W}f(T,\tau) = |kT|^{-1/2} \int_{-\infty}^{\infty} f(t)\psi^*\left(\frac{t-\tau}{kT}\right)dt\,,$$

where $\psi^*(t)$ is the complex conjugation of wavelet function $\psi(t)$.

The Gabor transform is given by

$$\dot{G}f(T,\tau) = \frac{1}{(\pi\sigma^2)^{1/4}} \int_{-\infty}^{\infty} f(t) \times$$
$$\times\exp\left(-\frac{(t-\tau)^2}{2\sigma^2}\right)\exp\left(-i2\pi\frac{t}{T}\right)dt,$$

where σ is the half-width of the Gauss spectral window.

The adaptive Fourier transform is given by

$$\dot{A}_\nu f(T,\tau) = \frac{1}{\sqrt{T}} \int_{-\infty}^{\infty} f(t) \times$$
$$\times g\left(\frac{t-\tau}{T}\right)\exp\left[-i\pi\nu\left(\frac{t-\tau}{T}\right)\right]dt,$$

where $g(t)$ is the window function, ν is positive coefficient which is equal to number of the harmonic function periods covered in the window $g(t)$.

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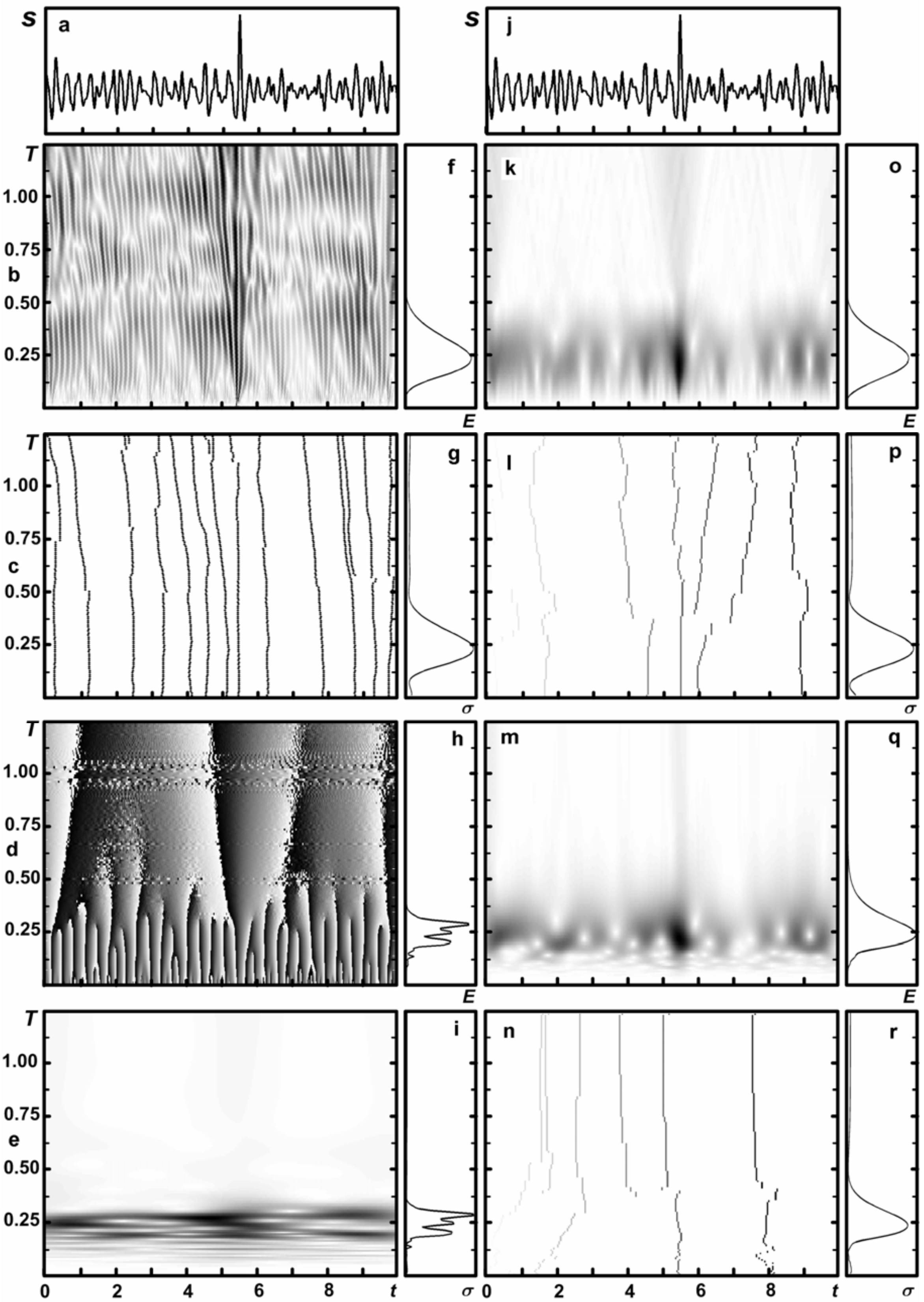

Fig. 1. The results of the rogue wave analysis: a, j – signal in time domain, b –CWT spectrum with gaus1 wavelet, c – sceleton of CWT spectrum, d – phase of complex coefficients of AWT with cgau1 wavelet, e – GT FSD module, f – CWT energogram, g – dispersion of CWT coefficients, h – GT energogram, i – dispersion of GT FSD module, k – AFT FSD module, l – AFT sceleton, m – STFT FSD module, n – STFT skeleton, o – AFT energogram, p – dispersion of AFT FSD module, q – STFT energogram, r – dispersion of AFT FSD module.

The short-time Fourier transform is given by

$$\dot{S}f(T,\tau)=\int_{-\infty}^{\infty} f(t)g(t-\tau)\exp\left(-i2\pi\frac{t}{T}\right)dt\,.$$

The Fourier spectrogram is given by

$$P_S f(\omega,\tau)=\left|\dot{S}f(\omega,\tau)\right|^2=$$
$$=\left|\int_{-\infty}^{\infty} f(t)g(t-\tau)\exp(-i\omega t)dt\right|^2.$$

The Wigner transform is given by

$$P_V f(\omega,\tau)=\int_{-\infty}^{\infty} f\left(\tau+\frac{t}{2}\right)f^*\left(\tau-\frac{t}{2}\right)\exp(-i\omega t)dt.$$

The Choi-Williams transform is given by

$$P_{CW} f(\omega,\tau)=\sqrt{\frac{\gamma}{4\pi}}\int_{-\infty}^{\infty}\frac{\exp(-i\omega t)}{|t|}\times$$
$$\times\int_{-\infty}^{\infty}\exp\left(-\frac{(u-\tau)^2\gamma}{4t^2}\right)f\left(u+\frac{t}{2}\right)f^*\left(u-\frac{t}{2}\right)dudt,$$

where γ is positive coefficient driving by level of the cross-terms.

The Born-Jordan transform is given by

$$P_{BJ} f(\omega,\tau)=\int_{-\infty}^{\infty}\frac{1}{|t|}\int_{\tau-|t|/2}^{\tau+|t|/2} f\left(s+\frac{t}{2}\right)\times$$
$$\times f^*\left(s-\frac{t}{2}\right)ds\exp(-i\omega t)dt.$$

For each signal the spectral density function (FSD), its ridges ore sceleton, the energogram, the dispersion of module of the spectral density function coefficients for linear transforms and the mean-square deviation of module of the spectral density function coefficients for non-linear transforms for each used transform were calculated. The results in specially constructed data formats were shown. That formats are useful for the comparing of results given by different transforms.

For the system spectral analysis performing the system of computer mathematics (SCM) MATLAB 7 including packages Wavelet Toolbox, Time-Frequency Toolbox and some original software for MATLAB was used.

3. ROGUE WAVE ANALYSYS

The abilities of the new analysis method are demonstrated by the example of investigation (Fig. 1) of the unique registration of the rogue wave which has the height being equal to the 26 m and was registered by equipment in Northern Sea near the Norway at the first day of New Year (1 January 1995).

This wave is appeared to be deadly danger for the big sea and ocean ships. The nature of the rogue wave is most likely to be non-linear. This wave is probably to be the distant "relative" of the solitones and shock waves. The rogue wave is probably can be considered as the UWB process with wideband index $\mu\sim 1,3-1,5$.

CONCLUSIONS

- The system spectral analysis as a new complex method of signal analysis was created and applied for the rogue wave analysis.
- The main peculiarity of the system spectral analysis is the compensation of disadvantages of ones transforms by the advantages of other transforms.
- The system spectral analysis combines the linear and the non-linear methods of signal analysis.
- The simultaneous usage of linear and non-linear transforms allows processing the signals at background of as Gaussian as non-Gaussian noises.
- The special data format for the representation of the system spectral analysis of signals was constructed.

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