INFORMATIONALITY OF NOISE-LIKE SIGNALS

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Abstract. With known methods of detecting and extracting a useful signal from a signal-noise mixture, another method of detecting an information signal is proposed - based on the analysis of the energy spectrum of such a mixture. Examples of informational signals were noise-like signals generated by operators. The white noise signal was generated with a computer. The statistical parameters of the signals of the operators and the computer - average value, variance - were commensurate. The analysis of the operators' signals showed that with sufficient duration of these signals, their energy spectrum is similar to flicker noise. The energy spectra of most signals generated by natural dynamic systems are similar to the form of flicker noise. The informativeness of operator signals, white noise, and additive signal-noise mixture was evaluated by the value of entropy, which was determined by the parameter τ of the approximating function of the energy spectrum. At the same time, the amount of information in white noise is zero, and the amount of information in noisy signals of operators is greater, the smaller the value of τ is.

Key words: Energy spectrum of signals, noise-like signals, amount of information, flicker noise.

1. Introduction

Real signals generated by the dynamic systems (biological, geological, electrical, etc.) are similar in form to the noise. The level of such signals is situated near the level of the measuring equipment's noises. This creates problems in detecting and analyzing them.

The noise-like signal can contain some information, or information may be absent in such a signal. How find out whether useful information is present or not in this noise-like signal? “The useful information” means the information about the processes that happen in the environment and are presented in signals. We assume that useful information is absent in the white noise (the only information that can be received during the measurement of parameters of white noise – the power using Nyquist’s formula – is the information about the temperature).

2. Drawbacks

There are different ways of detecting and extracting useful signals from the mixture of signal-noise: usage of optimal filters [1], algorithm Viterby [2], and cross-correlation [3]. The methods above are effective for the extraction of determined signals from the mixture of signal-noise. In [4] there is presented the method of detection of signals of unknown form hidden in any noise. The method is based on the decomposition of signal-noise mixture by range and time. It is necessary for the preliminary processing of the signal by ranking while this method is used.

3. Goal

The work aims to check the possibility of isolating signals of natural origin with a form similar to noise, against the background of interference in the form of white noise, urgent in technology [1- 3,5], in research [4], medicine [6] and develop a simpler method of signal detection from the mixture of signal-noise by its energy spectrum analyze.

4. Generation of noise-like signals and their energy spectrum

Noise-like signals can be obtained in different ways: experimental (electroencephalogram, electrocardiogram, fluctuations of voltage, current, electrical resistance, etc.) or with the help of a computer model. Here, an example of natural signals was signals generated by operators. The white noise signals were computer-generated. Both types of signals (computer-generated and operator-generated) are in the form of time series of the same length and approximately the same amplitude, average value, and standard variance. Operators generated signals in three ways: 1) drawing a noise-like signal on the plane with the subsequent digitization and conversion into a time series; 2) generation of random numbers in a given range with their simultaneous recording; 3) generation of random numbers by randomly pressing keys on a computer keyboard without visual fixation of the generated numbers.

The signal difference score was the energy spectrum $S(f)$, where f is the frequency.

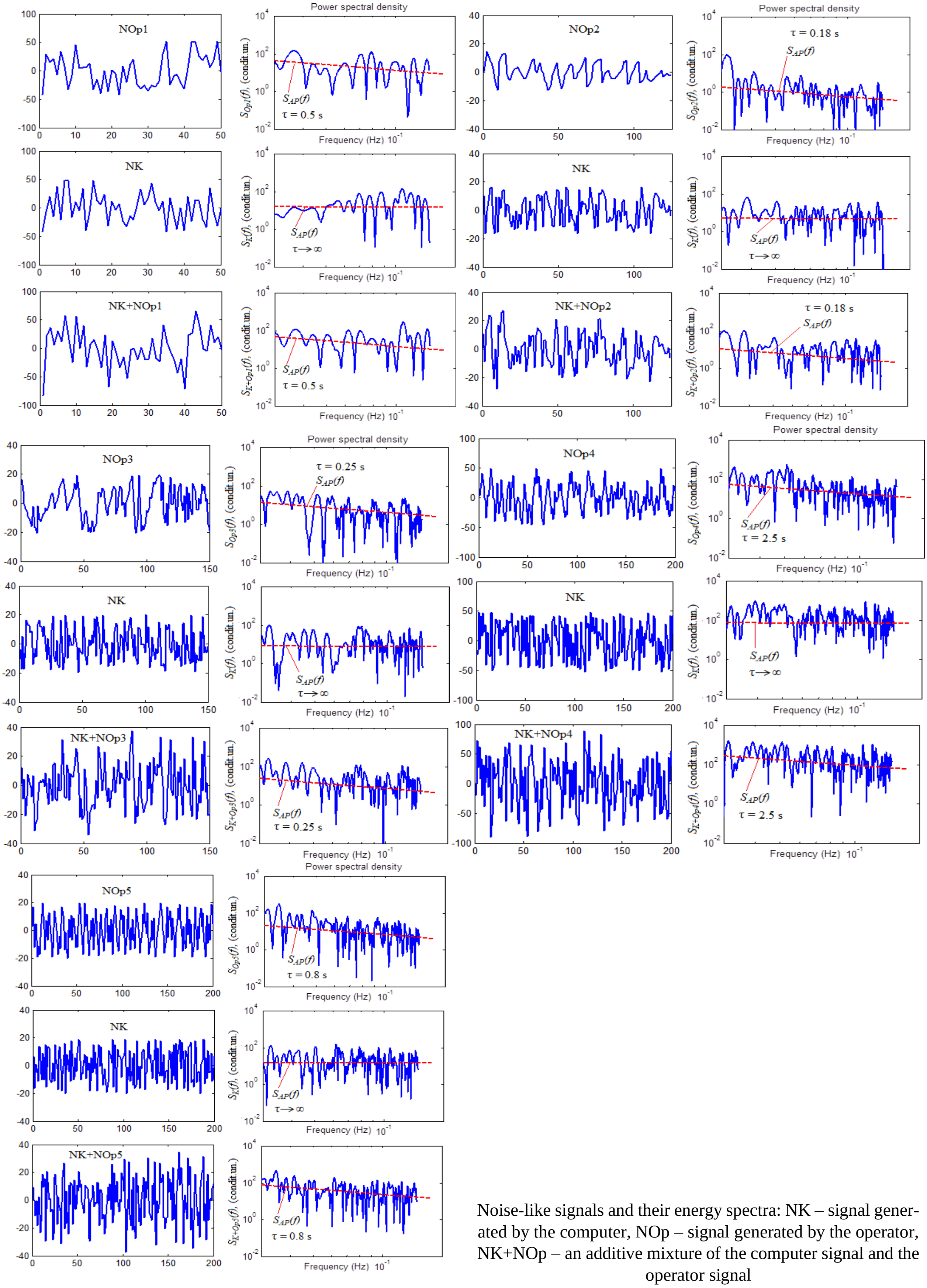
Analysis of the energy spectra of the investigated signals demonstrated that noise-like signals generated by computers according to normal and uniform distribution laws are inherent in an energy spectrum similar to white noise. Mostly, signals generated by operators were similar to a uniform one.

The energy spectrum of noise-like signals generated by operators is:

1) similar to white noise in most cases with a short signal length (≤ 50 numbers) and the generation of noise-like signals by the second and third methods;

2) similar to flicker noise (FN) when generating signals by the first method, the 2nd method (with a signal length of 150-200 numbers), and the 3-rd method with a signal length > 200 numbers.

$$S_{AP}(f) = \frac{\exp(f \cdot \tau)}{\exp(f \cdot \tau) - 1} \cdot S_0$$



Noise-like signals and their energy spectra: NK – signal generated by the computer, NOp – signal generated by the operator, NK+NOp – an additive mixture of the computer signal and the operator signal

The energy spectrum of the additive mixture of the signal generated by the computer and the signals generated by the operators in the 1st and 2nd ways with a time series length of 200 numbers was determined. Therefore, with the enough length of time series of noise-like signals of the operators the energy spectrum of these signals is ‘colored’ and like the FN.

The energy spectra of the investigated signals “Fig.1” were approximated by the dependence [7]:

$$S_{AP}(f) = \frac{\exp(f \cdot \tau)}{\exp(f \cdot \tau) - 1} \cdot S_0 , \qquad (1)$$

where the value of S_0 (minimum value of the energy spectrum) and τ (relaxation time) were determined according to the method [8]. For computer-generated white noise signals, $\tau \to \infty$.

Analysis of energy spectrums in Fig.1 demonstrates that the mixture of NK+NOp of noise-like signals of operators and the computer-generated noise (white noise) is satisfactorily approximated by the dependence $S_{AP}(f)$ (1) with the same value of τ parameter as for the operators’ signals NOp. The energy spectrum of an additive mixture of white noise and ‘colored’ noise is characterized by the value of τ parameter of colored’ noise approximating dependence $S_{AP}(f)$. The results of the investigation of real signals demonstrate that their energy spectrum is ‘colored’ and similar to the energy spectrum of flicker-noise of the biological systems [9-10], in medicine [11-13], geology [14], and others [15]. It can be approximated by the dependence $S_{AP}(f)$.

Analysis of energy spectrums in Fig.1. demonstrates that being externally similar $S_{OP}(f)$ to FN they differ by the value of parameter τ of the approximating curve $S_{AP}(f)$. This can signify that the value of parameter τ is individual for each real signal and using τ value it becomes possible to distinguish one real signal from another one.

5. Determination of the quantity of information in noise-like signals

To compare the informational saturation of generated signals, it is possible to apply the quantitative assessment of the information. For today, the calculation of the quantity of information contained in the continuous signals (noise-like signals can be treated as continuous random signals) is carried out using differential entropy $H(x)$ and distribution of density of continuous signals probability:

$$H(x) = -\int_{-\infty}^{\infty} p(x) \log p(x)\, dx , \qquad (2)$$

where $p(x)$ is the density of distribution of the probability of values of the continuous signal. The distribution law of continuous signals sometimes is unknown in real conditions. Sometimes, its determination needs additional investigations conjugated with time and resources. Often the spectral distribution of random signals and information quality included in these signals and dependent on spectrum are known [16].

The computed entropy of noise-like signals generated by the computer and operators was considered the spectral distribution of the signal [8]:

$$H(\tau) = \int_{-\infty}^{\infty} P_H \log \frac{1}{P_H} df =$$

$$= \int_{-\infty}^{\infty} \frac{\exp(f \cdot \tau) - 1}{\exp(f \cdot \tau)} \log \frac{\exp(f \cdot \tau)}{\exp(f \cdot \tau) - 1} df \qquad (3)$$

From (2), the continuous random variable x with the normal distribution law is characterized by the maximal differential entropy: $H_{\max}(x) = \log \sqrt{2\pi e \sigma^2}$,

where σ^2 is the dispersion of the random variable. For instance, white noise and useful signals with the normal distribution law and the same dispersion are inherent in the same differential entropy. While computation of the differential entropy by formula (3) the quantity of qualitative information that is in white noise and useful signal are different. As well known, the energy spectrum of white noise does not change within the whole frequency band. Systems in the balanced state are characterized by such an energy spectrum of fluctuations [17]. From the equation for $S_{AP}(f)$ (1) the balanced state of the system $S_{AP}(f) = S_0 = const$ is under condition $\tau \to \infty$. From (3) the differential entropy of such signal $H(\tau) = 0$. So, white noise does not include any qualitative information.

The evaluation of the information based on the density of distribution of continuous random signals (2) can be applied for the analysis of communication channels where the ratio of signal/noise is important. The evaluation of the information by equation (3) can be used for the evaluating quantity of information in the signal source. The latter in the noise-like signals generated by operators and computed by (3) is inversely proportional to τ. For instance, the quantity of information in the signal NOp4 within the frequency band 0 … 10^3 Hz for τ = 2.5 s is ≈ 0.1 bit, and in the signal NOp2 for τ = 0.18 s is ≈ 1.5 bit.

6. Conclusions

The analysis of the investigated signals demonstrated that for sufficient signal duration, the energy spectrum of signals generated by operators is similar to FN. Most signals generated by natural dynamic systems are characterized by a spectrum similar to FN. With the external similarity of the energy spectrum of the operators' signals to the FN, they differ in the value of τ parameter of the approximating curve. This producesgives the reasons for the hypothesis that each real system "produces noise" in its way. The degree of "coloring" can be estimated by τ parameter, the certain for each system. If the considered hypothesis turns out to be correct, the system can be identified by the value of τ parameter. By latter, it can be determined the amount of information in a pseudorandom signal: the smaller τ, the more information is in the studied signal.

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8. Mutual claims of authors

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