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Improving the quality of signals using an adaptive filter

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Abstract. Nowadays, in the automation of technological processes, many digital devices are used in all areas of the industry, especially in the mining sector. With the high accuracy of digital devices, they are still affected by noise and interference, which can lead to a measurement device error. Therefore, many filters are used in the industry. The purpose of using filters is to reduce the amount of interference that affects. The article outlines an algorithm for forming noise affecting precision indicators of automation of technological processes using adaptive filters, which allows measuring instruments to reduce errors. Such a type of noise reproduces a useful signal specter and limits the possibilities of its debugging.

1 Introduction

One of the methods to reliably shield information that is used in the technological process is interfering that makes it difficult to receive and decrypt a useful signal. In this case, several noise interference generators are extensively used, which cover the signal, making it problematic for an unauthorized device to identify it and isolate it in the receiving device. Simultaneously, in circumstances of a priori uncertainty about the characteristics of the signal, generators of various noise-like signals are often used, releasing an interference signal of sufficiently high power and wide frequency band, which affect the signal quality. In this favor, it seems appropriate to progress an algorithm for producing signal-like interference, which could create interference with the lowest probable power and amplitude-frequency response repeating the signal range. This increases signal quality and data processing [1,2].

2 Materials and methods

The synthesis of the algorithm for creating signal-like interference (Fig. 1) is based on the scheme of the classical Wiener filter. The most important difference between the depicted algorithm for generating signal-like interference is the forced "mixing" of white noise with a useful signal. With the purpose of form, a signal-like interference, it is essential to reform the weighting coefficients into an adaptive filter 2, at the input of which “white noise” acts. Thus,

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a signal-like interference is produced at the output of such an adaptive filter 2, which is principally an adaptive signal model.

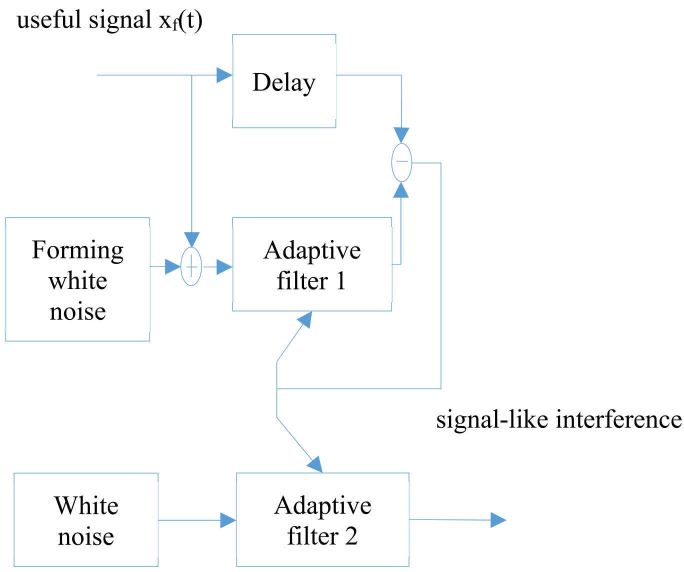

Fig. 1. Structure diagram of a noise generator.

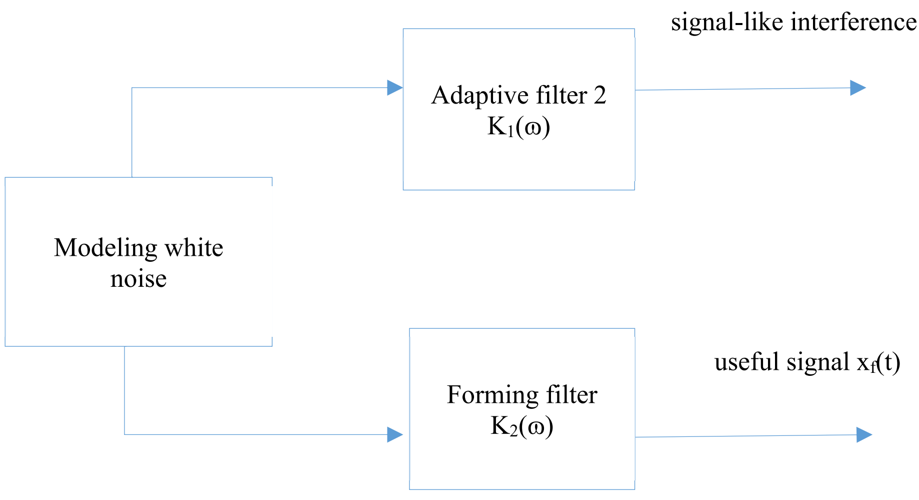

Fig. 2. Structure diagram of the model tolerability valuation mean.

Let's use the spectral densities formulas [3-5]:

$$\overline{\varepsilon^2(t)}_{\text{n}} = \overline{\left[\frac{s(t)}{\sqrt{P_S}} - \frac{x_f(t)}{\sqrt{P_x}}\right]^2} = \frac{\overline{s^2(t)}}{P_b} + \frac{\overline{x_f{}^2(t)}}{P_x} - 2\frac{\overline{s(t)x_f(t)}}{\sqrt{P_b}\sqrt{P_x}} = $$
$$= 1 + 1 - \frac{2R_{AB}(0)}{\sqrt{P_b}\sqrt{P_x}} = 2\left[1 - \frac{1}{2\pi\sqrt{P_b P_x}}\int_{-\infty}^{\infty} S_\varepsilon(\omega) K_1(j\omega) K_2(j\omega) d\omega\right], \quad (1)$$

where R_{AB} - the related function of noise and a useful signal, $K_2(j\omega)$ - transmission coefficient of the reality filter, S_ε - the spectral power density of the forming white noise. Permitting for that for static input signals, the spectral densities contained within in expression (1), there are non-negative and actual functions [6-8], then the transmission coefficient of the adaptive filter is also non-negative and real. Then the transmission coefficient of the establishing filter $K_2(j\omega)$. It can be presumed to be equal to the square derivation of the relation of the spectral density of the useful signal to the spectral density of the forming white noise.

$$\overline{\varepsilon^2(t)}_{\text{n}} = 2\left[1 - \frac{1}{2\pi\sqrt{P_S}\sqrt{P_x}} \times \int_{-\infty}^{\infty} \sqrt{S_\varepsilon(\varpi)} \frac{S_b(\omega)}{S_b(\omega)+S_g(\omega)} \sqrt{S_b(\varpi)} d\omega. \right. \quad (2)$$

Let a continuous Gaussian-Markov procedure [2] with spectral density act as a useful signal

$$S_b(\omega) = \frac{A_0^2 2\alpha}{\alpha^2+\omega^2}. \quad (3)$$

Then the optimal transfer function of the adaptive filter 1 is characterized by

$$K_1(\omega) = \frac{2\alpha r}{\omega^2+\alpha^2+2\alpha r}, \quad (4)$$

where r - the ratio of the power of the Markov procedure and the making white noise.

Changing spectral densities into expression (4), we gain the adequacy of the Markov procedure model:

$$\overline{\varepsilon^2(t)}_{\text{norm}} = 2\left[1 - \frac{1}{2\pi\sqrt{P_S}\sqrt{P_x}} \int_{-\infty}^{\infty} \frac{2\alpha r}{\omega^2+\alpha^2+2\alpha r} \times \sqrt{\frac{A_0^2 2\alpha}{\omega^2+\alpha^2}} d\omega \right. \quad (5)$$

First, let's find the power of the Markov process model:

$$P_s = \frac{1}{2\pi}\int_{-\infty}^{\infty} |K_1(\omega)|^2 d\omega = \frac{1}{2\pi}\int_{-\infty}^{\infty} \left(\frac{2\alpha r}{\omega^2+\alpha^2+2\alpha r}\right)^2 d\omega = \frac{\alpha r^2}{(2\alpha r+\alpha^2)^{\frac{3}{2}}} \quad (6)$$

Then we calculate the integral in the expression (7):

$$J = \int_{-\infty}^{\infty} \frac{2\alpha r}{\omega^2+\alpha^2+2\alpha r} \sqrt{\frac{A_0^2 2\alpha}{\alpha^2+\omega^2}} d\omega = \frac{2\alpha r A_0\sqrt{2\alpha}}{2\sqrt{2\alpha r+\alpha^2}\sqrt{2\alpha r}} \times \ln\left[\left|\frac{\sqrt{2\alpha r+\alpha^2}\sqrt{\omega^2+\alpha^2}+\omega\sqrt{2\alpha r}}{\sqrt{2\alpha r+\alpha^2}\sqrt{\omega^2+\alpha^2}-\omega\sqrt{2\alpha r}}\right|\right]_{-\infty}^{\infty} =$$

$$\frac{\alpha\sqrt{r}A_0}{\sqrt{2\alpha r+\alpha^2}} \ln\left[\left[\frac{\sqrt{2r+\alpha}+\sqrt{2r}}{\sqrt{2r+\alpha}-\sqrt{2r}}\right]^2\right]. \quad (7)$$

Replacing expressions (5), (6) into (7) we change to:

$$\overline{\varepsilon^2(t)}_{\text{n}} = 2\left[1 - \frac{(2\alpha r+\alpha^2)^{\frac{1}{4}}}{2\pi\sqrt{r}} \ln\left[\left[\frac{\sqrt{2r+\alpha}+\sqrt{2r}}{\sqrt{2r+\alpha}-\sqrt{2r}}\right]^2\right]\right]. \quad (8)$$

We find the minimum of expression (8), differentiating it by the parameter r and associating the resultant expression to zero,

$$\frac{\alpha^{\frac{1}{4}}}{2\pi r^{\frac{3}{2}}(2r+\alpha)^{\frac{5}{4}}}\left[\ln\frac{\left(1+\sqrt{1+\frac{\alpha}{2r}}\right)^2}{\left(1-\sqrt{1+\frac{\alpha}{2r}}\right)^2} \times (r+\alpha)\sqrt{2r+\alpha} - 8\sqrt{2}r^{\frac{3}{2}} - 4\alpha\sqrt{2r}\right] = 0. \quad (9)$$

Explaining the obtained expression by numerical methods, we control the optimal signal-to-noise ratio r, at which point the signal model is most suitable:

$$r_{\text{on}} \approx 2{,}86\alpha = 2{,}86 \cdot 2\pi\frac{\Delta f}{f_S} \quad (10)$$

where Δf - signal bandwidth in Hz, f_s - sampling frequency in Hz.

Thus, the ideal parameter for the construction of an adaptive model of a useful signal is the ratio of the power of the useful signal and the producing white noise r (Figure 3).

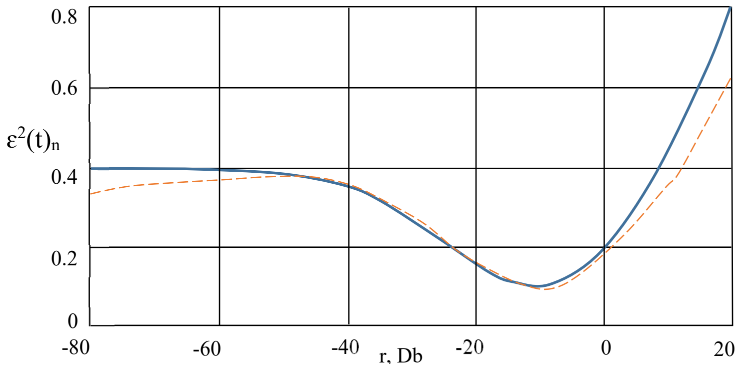

Fig. 3. Requirement of $\varepsilon^2(t)_n$ on q for the Markov procedure at α=0.1: theoretical (solid) and simulated (dotted).

3 Results and discussion

The error estimation device allows to act out the operation of an adaptive auto compensator both under the conditions of associated nosiness at both inputs of the compensator, and with their restricted decorrelation. Noise decorrelation is approved by a decorrelator made in the form of a non-recursive filter. The decorrelator is functionally compulsory to create conditions close to the concrete operation of auto compensators [9]. A signal is directed to the input of the device for approximating the dispersion of the filtering error, to which the produced interference is mixed. The combination enters one input of the auto compensators, and on the other there is interference partly decor associated with interference in the main channel. The error variance is used to estimate the operation of the auto compensators. For ease of presentation, the error variance is defined as

$$\delta^2 = \frac{\delta_1^2}{1+\delta_1^2} \tag{11}$$

where δ_1^2 - the standard deviance of the useful signal from its assessment at the output of the automatic transmission is normalized to the power of the useful signal [10,11].
With the benefit of the developed software “Adaptive jamming System”, dependences of the dispersion of the useful signal filtering error on the signal-to-noise power relation were attained when a Gaussian-Markov process was used as a useful message, white noise, a Gaussian-Markov process and adaptive signal-like interference with different coefficients of mutual correlation of nosiness in channels were used as interference (r).

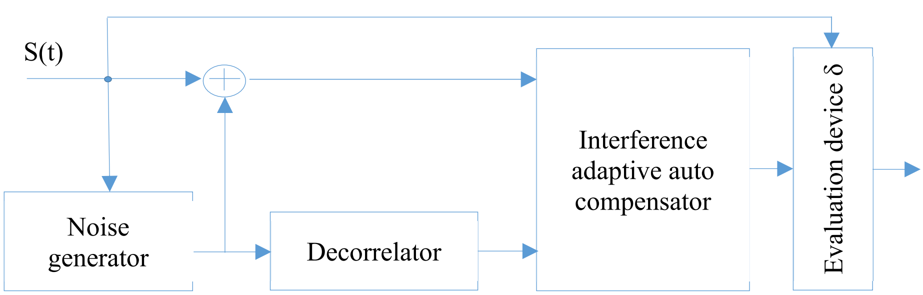

Fig. 4. Block diagram of the device for establishing the estimation of the modification of the filtration error.

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The imitation parameters are shown in Table 1, the signal and nosiness parameters are shown in Table. 2. The imitation results are shown in Fig. 5-8. The measurement of signal strength and nosiness was carried out in the Nyquist band.

Table 1. Simulation parameters.

Parameter	Value
Sampling rate (f_S), Hz	200000
Sample size for evaluation δ^2	131072
The number of samples to average δ^2	20
Number of automatic transmission weight coefficients	2048
Automatic transmission adaptation coefficient	0.01
Automatic transmission adaptation algorithm	the least squares method

Table 2. Message and interference parameters.

Type	Parameters
The Markov procedure	band width = 3354 Hz
Adaptive interference	length of the adaptive model $L = 128$;
	the coefficient of adaptation $M = 0{,}01$;
	s/w ratio $r_o = -6$dB;
	The adaptation algorithm- is the least squares method [2]

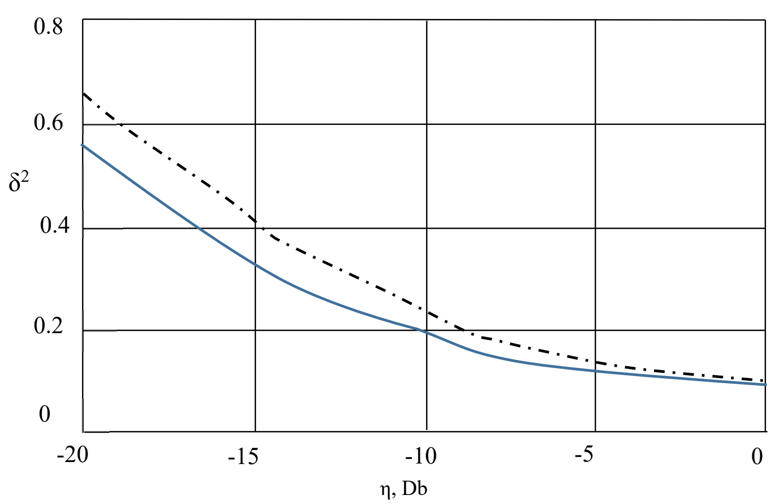

Fig. 5. Necessity of the standardized dispersion of the filtering error on the signal-to-noise power ratio under the situations of adaptive interference (solid), Markov interference (dashed) and white noise (dotted) with a cross-correlation coefficient of interference $R = 1$.

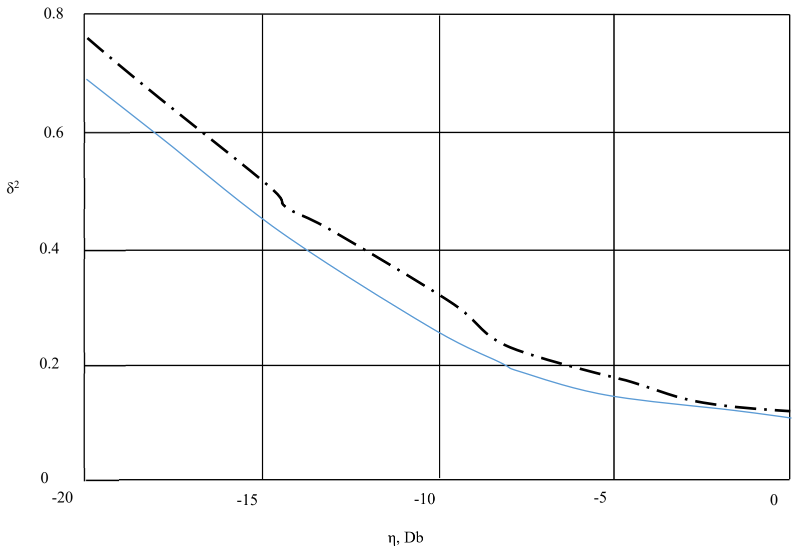

Fig. 6. The necessity of the normalized dispersion of the filtering error on the signal-to-noise power ratio under the situations of adaptive interference (solid) and Markov nosiness (dashed) with a cross-correlation coefficient of interference $R = 0{,}99$.

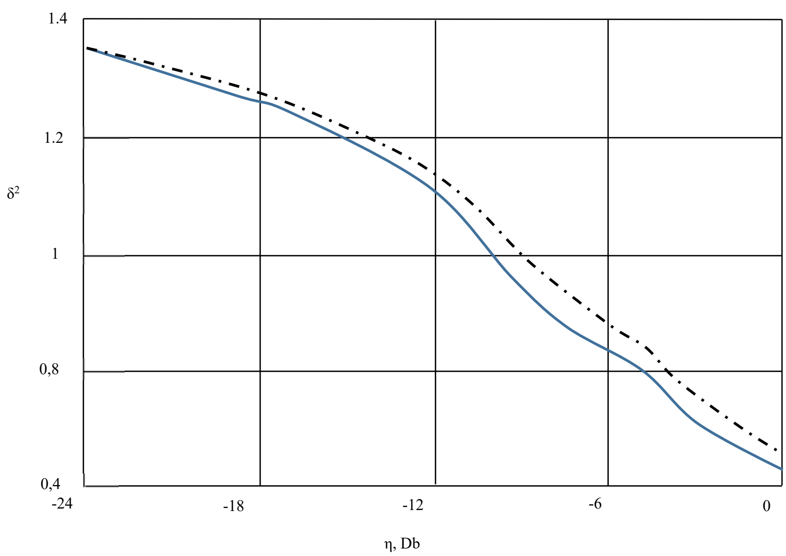

Fig. 7. Necessity of the normalized dispersion of the filtering error on the signal-to-noise power ratio under the situations of adaptive interference (solid) and Markov interference (dashed) with the interference cross-correlation coefficient $R = 0{,}88$.

The analysis of figures 5-8 specifies the high competence of the adaptive interference preparation.

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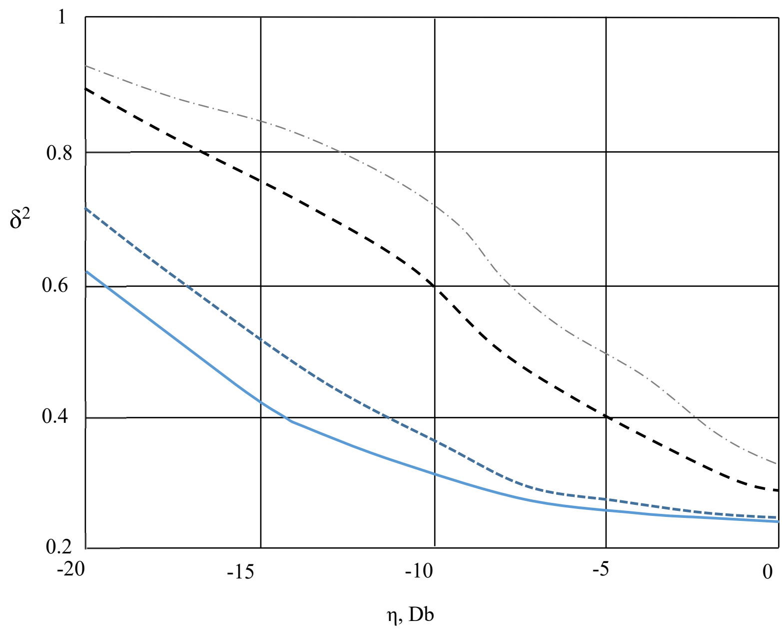

Fig. 8. Dependence of the normalized dispersion of the filtering error on the ratio of the signal interference power under the conditions of adaptive interference with the interference cross-correlation coefficient R=1 (solid), R=0.99 (dotted), R=0.95 (dotted), R=0.88 (dashed).

4 Conclusion

The algorithm for establishment an adaptive model of a useful signal permits to gain signal-like nosiness with expressively higher productivity than broadband noise and with a slight loss of Markov interference. In particular, with a solo correlation coefficient of interference in channels and a signal-to-noise power ratio of 15 dB, the dispersion of the filtering error for white noise is 0.022, for Markov interference - 0.44, whereas for signal-like interference - 0.37, which allows signal-like interference to “cover” the useful signal at lower levels compared to broadband interference. To confirm the dispersion of the 0.41 filtering error when using signal-like interference, the power investments compared to white noise is more than 21 dB, and the loss to Markov interference is only 3 dB.

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