28th INTERNATIONAL SCIENTIFIC SYMPOSIUM
METROLOGY AND METROLOGY ASSURANCE 2018

ANALYSIS OF FRACTAL NOISE INDICATORS IN MEASURING SYSTEMS OF TECHNICAL OBJECTS

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Abstract: The indicators and characteristics of the estimation of the noise fractality and interference in systems for measuring the characteristics and condition of technical objects are considered. A reasoned choice of indicators used in prospect for the implementation of the fractality estimation method is carried out.

Keywords: fractal of the noise, fractality index, statistical characteristics

Introduction

Nonlinear systems with dynamic chaos describe the phenomena in various fields of science and technology. Conducted researches showed, that the importance and urgency of the task of increasing the efficiency, accuracy and reliability of the work of computerized measurement systems, control and diagnostics of characteristics and condition of technical objects requires the development of devices for suppressing fractal noise and interference operating in a realistic interference environment and being one of the main sources of error.

In this case, one of the solved tasks is the choice of indicators and characteristics of the estimation of the noise and interference fractality, which in the prospect will be input in the corresponding technical systems.

Analysis of the literature [1-6] showed that at present one of the most common indicators of fractality assessment is the Hurst index. However, from a set scientific works [2-5] it is known that this indicator has a set of weakness. The most critical weakness is a low accuracy of estimates.

Consequently, actually the task of research and choice estimation method noise fractality of in systems for measuring characteristics and condition of technical objects is presented.

1. Research and classification of noise fractality estimation and methods in characteristics measuring systems and technical objects conditions

Properties of random signals are describing with probability distribution functions, correlation-spectral functions and with fractal characteristics [5]. Integral probability distribution and probability density functions are general for static characteristic signals calculation. Static characteristics of random signals (table. 1) including: mathematical awaiting (first-order initial moment), dispersion (midpoint initial moment), autocorrelation function (ACF), reciprocally-correlative function (RCF) and covariance functions, spectral density functions [1, 5].

Besides listed random signals characteristics in table 1, central third-order moment have to used too, on the basis of which the asymmetry coefficient of distribution law and central fourth-order moment can be estimated, on the basis of which distribution curve smoothness (excess coefficient) have to estimated [5].

Conducted researches demonstrated: quality of signals, formed by nonlinear systems with chaotic dynamics, estimated through entropy and fractal characteristics [1-6].

Between those indexes most famous are Shannon and Kolmogorova entropies, Hausdorff and Herse indexes.

Literature analysis demonstrated, Shannon entropy is information measure, which needed for system location in some state determination, j:

$$S(\delta) = -\sum_{j=0}^{N(\delta)} P_j \ell n P_j \ , \qquad (1)$$

where P_j – system probability to receive j state. Shannon entropy is a particular case of generalized entropy, which uses in fractal theory [1]…

One more indicative – Kolmogorov entropy, which is most important characteristic of chaotic motion in phase area with random dimension, have such definition [1]:

$$K_2 = -\ell im \ \ell im \ \ell n \left[\frac{C_n(\ell)}{C_n(\ell)} \right], \qquad (2)$$

where $C_n(\ell)$ – generalized correlative integral. Evaluating with formula (1) gives lower limit of

Table 1. General static characteristics of random signals

№	Name of characteristic	Formula
1	Distribution function	$P(X,t)=P\{x(t)\le X\}$
2	Probability density	$p(x)=\frac{dP(x)}{dx}$
3	First-order initial moment v	$m_v=\int_{-\infty}^{+\infty}x^v p(x)dx$
4	Mathematical awaiting	$m_1=x=\int_{-\infty}^{+\infty}xp(x)dx$
5	Midpoint initial moment v	$\mu_v=\int_{-\infty}^{+\infty}(x-m_1)^v p(x)dx$
6	Dispersion	$D=\int_{-\infty}^{+\infty}(x-m_1)^2 p(x)dx$
7	Normalized to energy E autocorrelation function	$R_x(\tau)=\frac{1}{E}\int_{-\infty}^{+\infty}x(t)x(t-\tau)dt$
8	Normalized to energy E_x and E_y reciprocally-correlative function	$R_{xy}(\tau)=\frac{1}{\sqrt{E_xE_y}}\int_{-\infty}^{+\infty}x(t)y(t-\tau)dt$

Kolmogorov entropy.

From science sources is known [1-6], that Mandelbrot introduced «fractal» definition, Mandelbrot wrote number of works about fractal geometry phenomenons from many humanity activity areas. Fractal nature of signals, generated by chaotic dynamic, estimated through fractal dimension (Hausdorff – Besicovitch dimension).

$$D=-\ell im\frac{\ell nN(h)}{\ell nh}, \quad (2)$$

where h – cell size, on which the object is divided; $N(h)$ – count of cells.

Hurst wrote about development methods of fractality estimating in his works. He offered new method of normalized swing for fractal processes characteristic, which using for signals analysis, those signals were by non-linear systems with chaotic dynamic and fractal processes formulated. By formulated time series Hurst index can be estimated [1]:

$$H=-\ell im\frac{\ell n\left(R/\sigma\right)}{\ell n\left(\tau/2\right)}, \quad (3)$$

where R – signal swing; σ – root-mean-square divergence; τ – observation interval. Actually Hurst showed, that normalized swing of most time series is described by empirical ratio $R/\sigma=\left(\tau/2\right)^H$, where H – Hurst index.

Worth noting, that the offered indexes have the row of disadvantages, the most essential of them are: – large (in the number of cases up to 0,4) deviation from average value of indexes of fractal dimension and Hurst index, and high computational complexity, which need development of separate realization algorithms. Those disadvantages practical excluding the using of offered indexes in the real-time systems.

Therefore, in order to increase the accuracy, as well as increase the identification speed, along with the considered indexes, to evaluate the noise fractality in the characteristics change systems and technical objects states, the lecture suggests the use of the Minkowski index and BDS-test characteristics.

Researches show, that Minkowski index is the one of methods of fractal dimension setting of limited set in metrical area, which defined as follows [1]:

$$D=\ell im_{\varepsilon\to 0}\frac{\ell nN(\varepsilon)}{-\ell n\varepsilon}, \quad (4)$$

where *N(ε)* – minimal count of diameter ε sets, which can cover the original set.

Minkowski dimension, information and correlation dimensions, considered as particular case of contiguous spectrum of generalized dimensions α-order, which defined as follows:

$$D = \ell im_{\varepsilon \to 0} \frac{\frac{1}{1-\alpha} \ell og\left(\sum_i p_i^{\alpha} \right)}{-\ell og \frac{1}{\varepsilon}}, \qquad (5)$$

Worth noting, this index is not enough accurate in high-dimensional systems. However, in the number of practical cases this accuracy is enough for abnormal system technical condition signaling.

At the same time for increasing of estimate precision noise fractality in characteristics, measuring systems and technical objects states is the use of BDS-test characteristic values suggested [6].

The analysis, shows, that BDS-tests, proposed as result of finance markets analysis by economists B. Brock, W. Dechert and J. Scheinkman in 1987 [6], which are effective methods of dependencies detection in time series in the context of nonlinear analysis. Their goal is, to recognize the data I.I.D. and any kind of dependence – check zero-hypothesis H_0 for independence and identical distribution values of time series $\vec{\xi} = (\xi_1, \xi_2, ..., \xi_N)$, with the significance criterion usage. According to this criterion for hypothesis acceptance H_0 it's necessary to choose critical area G_α, satisfying this condition $P(g \in G) = \alpha$, where $g(\xi_1, \xi_2, ..., \xi_N)$ – observation statistic, and α – settable significance level.

Further development this direction got in works [2-4], where experimentally determined boundary conditions of system responses, which using this index.

Results of researches planned to be used in further development of fractal noises estimation method in characteristics measuring systems and technical objects states, and in data security systems.

Conclusion

In this way, in the lecture were conducted researches and presented classification of the general fractal noises estimating indexes in the characteristics measure systems and technical objects states. In this work shown advantages and of the most common indexes and characteristics of measuring, proposed the defects elimination way through complex usage of Minkowski index and BDS-test characteristic values. Their complex usage will increase estimation speed with considering the necessary object identification speed.

Literature

[1] **Peters E.** *Fraktalnyj analiz finansovyh rynkov. Primenenie teorii haosa v investiciyah i ekonomike* / E. Peters // M.: «Internet-trejding», 2004. – 304 s.

[2] **Semenov S.G.** *Metod identifikacii telekommunikacionnogo trafika na osnove BDS-testirovaniya* / S.G. Semenov, O.A. Smirnov, Ye.V. Meleshko // Informacijni tehnologiyi v navigaciyi i upravlinni: stan ta perspektivi rozvitku: mat. nauk.-tehn. konf. – K: DP «CNDI NiU». – 2010. – S. 27.

[3] **Semenov S.G.** *Sravnitelnye issledovaniya metodov identifikacii trafika v telekommunikacionnyh setyah dlya povysheniya operativnosti peredachi dannyh* / S.G. Semenov, Ye.V. Meleshko // Prikladnaya radioelektronika. – H.:HNURE. – 2010. Tom 9, №3. – S. 444-448

[4] **Semenov S.G.** *Metod strukturnoj identifikacii informacionnyh potokov v telekommunikacionnyh setyah na osnove BDS-testirovaniya* / S.G. Semenov, O.O. Kuznecov, S.M. Simonenko, Ye.V. Meleshko // Nauka i tehnika Povitryanih Sil Zbrojnih Sil Ukrayini. – H.: HU PS. – 2010.– Vip. 2(4). – S. 131-136

[5] **Semenov S.G.** *Rozrobka zagalnoyi strukturi identifikacijnih vimiriv z vikoristannyam okremih imovirnisno-chasovih harakteristik signaliv* / S.G. Semenov, O.V. Petrov, S.O. Yengalichev // Sistemi ozbroyennya i vijskova tehnika. – H.:HU PS. – 2011. – Vip. 1(25). – S. 146-149

[6] **Brock W.** *A test for independence based on correlation dimension* / W. Brock, W. Dechert, J. Scheinkman and B. LeBaron // Econometric Reviews 15: 197-235, 1996

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