New information technologies in the estimation of stationary modes of the third type systems

V V Grigorenko¹, Yu V Bashkatova², L S Shakirova², A A Egorov¹ and N B Nazina¹

¹BI HE “Surgut State University”, 1, Lenin St., Surgut, 628400, Russia
²FSI FRC Federal Scientific Research Institute for System Analysis of the Russian Academy of Sciences, 36, Nakhimovsky Prospekt, Moscow, 117218, Russia

Email: grigv_84@mail.ru

Abstract. More than 70 years ago, W. Weaver introduced the classification of all systems of nature. A special place in this classification was allocated to the third type systems, which (as was proved over the past 20 years) do not possess statistical stability. For such systems, it is proposed to construct pairwise comparison matrices of samples that demonstrate the lack of their homogeneity. In this regard, new invariants and new models are introduced to describe the stationary modes of the third type systems and their kinematics (motion) in state phase space. The parameters of the pseudo-attractors are calculated.

1. Introduction

In 1948, W. Weaver divided all systems of nature into three types [1]. Nowadays, it is obvious that the first type systems are described in the framework of functional analysis (deterministic systems), the second type systems are stochastic systems, however there are neither mathematical tools nor models for describing of the third type systems (TTS [1]) [2-5]. Moreover, there is no description of their special properties, which they undeniably have [5-9].

These special properties of the TTS (complexity) are based on the lack of statistical stability of any samples of the components of the state vector of any biosystem \( x = x(t) = (x_1, x_2, \ldots, x_m)^T \), where \( x_i(t) \) represents the parameters of the biosystem. This was first proved in the form of the Eskov-Zinchenko effect (EZE) in biomechanics [5-10], and then for other biosystems [11-16]. The EZE extends not only to samples of tremorograms (TMG), teppinggrams (TPG), electromyograms (EMG), RR intervals (RR) and other parameters of the human body, but also to their spectral densities of signals (SDS), autocorrelations \( A(t) \) and other characteristics \( x_i(t) \).

A logical question arises about the existence of other invariants in the description of the TTS - complexity. If all characteristics of a biosystem are continuously and randomly changing in an unchanged state, how one shall describe stationary modes of the TTS? The answer to this question is given by the new theory of chaos and self-organization (TCS), which introduces new invariants for the vector \( x(t) \) of the TTS [5-13].

2. Statistical instability of samples of the TTS parameters

Let us note once again that the EZE was first proved in biomechanics in the study of tremorograms (TMG) and teppinggrams (TPG) in the same research subject (with many repeated registrations of TMG
and TPG) or in the same group of subjects (more precisely, in many repeated measurements). For the group, this means a loss of sample homogeneity, since the number of pairs k of TMG samples in pairwise comparison matrices of samples always turns out to be small.

For example, a pairwise comparison matrix of a group of subjects (out of 15 people) is presented in the paper. Elements of this matrix (see table 1) represent the Newman–Keuls test p for pairwise comparison of TMG samples. If p > 0.05, then this compared pair of TMG can be attributed to one (same) sampled population [11-16].

Table 1. The pairwise comparison matrix of samples of tremorograms of a group of subjects (number of repetitions N = 15), the Newman–Keuls test was used (p-value p < 0.05, number of matches k1=7).

|   | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   | 11   | 12   | 13   | 14   | 15   |
|---|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 1 | 0.42 | 0.72 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2 | 0.42 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3 | 0.72 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 5 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 6 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.28 | 0.00 | 0.00 | 0.00 | 0.00 |
| 7 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.08 | 0.00 | 0.00 | 0.02 |
| 8 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.26 | 0.00 | 0.00 | 0.00 | 0.00 |
| 9 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.26 | 0.00 | 0.00 | 0.00 |
| 10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.26 | 0.00 | 0.00 |
| 11 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.26 | 0.00 |
| 12 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 13 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 14 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 15 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

From table 1, it follows that the number k1=7 of such pairs is extremely small. This means that the compared TMG samples do not match statistically (almost all of them are different). It should be noted that if we take samples of the same subject (when repeating the tests), the result is similar, i.e. k ≤ 5% of all 105 different comparison pairs in such pairwise comparison matrices of TMG samples. This proves the loss of homogeneity of TMG samples (similarly for TPG) and the lack of statistical stability of TMG and TPG.

It shall be underlined that a similar picture of statistical instability is observed for many other parameters of the human body. This applies to the parameters of the cardiovascular system - CVS (16 parameters 16 xi(t) were examined), EMG, EEG as well as their (samples) SDS and A(t). In all cases, the EZE is obtained and this means the completion of the further application of stochastic methods in the estimation of the third type systems. In this case, the question is how to estimate the stationary modes (SM) of the TTS and their changes.

3. Second-type uncertainty in the TCS

It shall be underlined that the mentioned EZE is now characterized in the new TCS as the second-type uncertainty. In this case, the SM in terms of the TCS cannot be characterized as the SM in terms of stochastics, since all statistical functions f(x) of the samples xi(t), their SDS, A(t) are continuously and randomly changing. In the framework of the TCS, it is necessary to introduce other invariants [10-15].
In the TCS, this is performed as an analog of the Heisenberg uncertainty principle, when the phase coordinates xi(t) and their speed xi2=dxi/dt are introduced as inequations. For example, for a new state vector of a biomechanical system, we introduce restrictions in the form Zmin≤Δxi·Δxi2≤Zmax, where Zmin and Zmax are some constants for a given subject (or the group of subjects) [2-5]. It should be noted that Zmax (TCS) has the meaning of a pseudo-attractor (PA) area. By a PA in the TCS [2-5] there is meant a certain limited region of the state phase space of the vector x=x(t)=(xi, x2)T, inside which the vector x(t) moves randomly.

It should be noted that the PA (its area and the coordinates of its center xi) is the invariants at SM for the given TOS and represents the model behavior of the TTS. As an example, table 2 is presented, where the values of the area S for the PA of the same subject are given (calculation for TMG). In table 2, there are presented the average values of the area <S1> of the PA without load (F1=0) and the average value of the area <S2> of the PA with load on the finger in F2=3H.

**Table 2.** The values of the areas S of the pseudo-attractors of tremorograms samples of the same subject.

|       | S1*10^6 y.e., without load | S2*10^6 y.e., with load F3=3 H |
|-------|-----------------------------|--------------------------------|
| 1     | 5.78                        | 3.55                           |
| 2     | 2.29                        | 3.87                           |
| 3     | 1.42                        | 5.74                           |
| 4     | 3.89                        | 2.92                           |
| 5     | 1.61                        | 6.82                           |
| 6     | 3.03                        | 5.71                           |
| 7     | 3.86                        | 3.67                           |
| 9     | 1.69                        | 4.77                           |
| 10    | 1.77                        | 6.78                           |
| 11    | 6.27                        | 7.24                           |
| 12    | 1.92                        | 5.06                           |
| 13    | 2.02                        | 5.28                           |
| 14    | 3.42                        | 2.91                           |
| 15    | 3.98                        | 6.24                           |
| <S>   | 2.27                        | 3.36                           |

The Wilcoxon test, significance of differences in functions f(x) =p=0.01.

Obviously, the average values <S1> and <S2> of the PA areas for the same subject differ significantly in different physical states. At any moment, <S2> > <S1> for different subjects. As a result, there was proved that the area of the PA for TMG (and for other parameters of the body) is an invariant for a given physical state of the subject. Moreover, all its statistical characteristics are continuously and randomly changing. The parameters of pseudo-attractors, which implement the uncertainty principle for the TTS-complexity, are proposed to be calculated.

It should be noted that two types of uncertainties were introduced in the new theory of chaos and self-organization, which is being developed. The second type of uncertainty, which is most commonly encountered in biomechanics, is presented above. It is an analog of the Heisenberg uncertainty principle in quantum mechanics and imposes restrictions on any coordinate xi(t), that correspond to the state of the biomedical system [11-16], the second coordinate is the rate of change of points xi(t), i.e. xi(t), t.e. x2=dxi(t)/dt. These two coordinates form a two-dimensional state phase space of the state vector of the biosystem x=x(t)=(xi, x2)T.

Any state of the studied biosystem in such two-dimensional state phase space of the state vector x(t) describes a certain trajectory. We have now proved in the TCS that such phase trajectory cannot be described within the framework of stochastics. The samples of this coordinate xi(t) itself and its rate of change x2(t) cannot demonstrate the stability of the statistical distribution functions f(x), the stability of
the spectral densities of signals (SDS), autocorrelation A(t) or fractal dimensions. All characteristics are continuously and randomly changing [11-16]. This constitutes the basis of the TCS.

In this case, the statistical chaos of any parameters of the organism xi(t) in the form of the Eskov-Zinchenko effect is not the dynamic chaos of Lorentz. Let us remind that there is a mixing effect in the deterministic chaos of Lorentz, i.e. there is the invariance of measures within the Lorentz attractor. At the same time, the Lyapunov constants are positive in the chaos of Lorentz and, as a rule, there is the tendency of the correlation functions A(t) to zero. For the statistical chaos in the form of the Eskov-Zinchenko effect, the same cannot be observed. The Lyapunov constants randomly change sign, there is no mixing effect, autocorrelation functions do not tend to zero.

In the TCS, it was proved that the chaos of the third type systems (biomedical systems) is not the chaos of Lorentz. This requires other approaches and other models for describing the statistical instability of the TTS. However, in addition to the second-type uncertainty (it is global and covers any parameters of the body functions xi(t)), there is the first-type uncertainty. As it was shown earlier, statistics can show statistical stability when comparing samples (samples match statistically, \( p \leq 0.05 \), number of matches \( k_3 = 25 \)).

Table 3. The pairwise comparison matrix of the EEG of the same healthy person (number of repetitions \( N = 15 \)) during the relaxation period in the Fz-Ref lead, the Wilcoxon test was used (critical p-value \( p \leq 0.05 \), number of matches \( k_3 = 25 \)).

|     | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  | 13  | 14  | 15  |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1   | 0.00| 0.00| 0.03| **0.29**| **0.65**| 0.00| 0.01| 0.00| 0.00| 0.00| **0.71**| **0.19**| **0.64**| 0.00| 0.00|
| 2   | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| **0.12**| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| 3   | 0.03| 0.00| 0.15| **0.15**| **0.19**| **0.11**| 0.00| 0.00| 0.00| 0.00| **0.02**| **0.79**| 0.00| **0.88**| 0.00| 0.00|
| 4   | 0.29| 0.00| 0.15| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| **0.40**| **0.07**| **0.48**| 0.00| 0.00|
| 5   | 0.65| 0.00| 0.19| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| **0.10**| **0.31**| 0.00| **0.38**| 0.00| 0.00|
| 6   | 0.00| 0.00| 0.11| 0.00| 0.65| 0.00| 0.02| 0.00| **0.22**| **0.34**| 0.00| **0.68**| 0.00| 0.00| 0.00| 0.00|
| 7   | 0.01| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| **0.22**| 0.00| 0.00| 0.00| 0.00|
| 8   | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.02| 0.00| **0.82**| 0.01| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| 9   | 0.00| 0.12| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| 10  | 0.00| 0.00| 0.02| 0.00| 0.10| 0.22| 0.00| 0.01| 0.00| 0.00| 0.00| **0.07**| 0.00| 0.00| 0.00| 0.00|
| 11  | 0.71| 0.00| 0.79| 0.40| 0.31| 0.34| 0.00| 0.00| 0.00| 0.00| 0.00| **0.78**| 0.00| 0.00| 0.00| 0.00|
| 12  | 0.19| 0.00| 0.00| 0.07| 0.00| 0.00| 0.22| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| 13  | 0.64| 0.00| 0.88| 0.48| 0.38| 0.68| 0.00| 0.00| 0.00| 0.00| 0.00| 0.07| 0.78| 0.00| 0.00| 0.00|
| 14  | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| 15  | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
Thus, we have established that our brain also works erratically. At the same time, the living brain is in continuous reverberation, its biopotentials $x_\mathbb{E}$ show the absence of rest, i.e. $dx_\mathbb{E}/dt \neq 0$ in a continuous way. If $dx_\mathbb{E}/dt = 0$, then this means brain death (this is one of the methods for identifying the physiological death of a person). If multiple reverberations are introduced into an artificial neural network and random values of attributes are set randomly on each setting of such neural network, then a ranking of samples of $x_i$ parameters of the human body will be received after 1000 iterations.

As a result, we not only eliminate the first-type uncertainty, i.e. we prove that the samples differ, but we can also solve the problems of system synthesis, i.e. find order parameters. In this case, the doctor receives information about which signs are main and which are secondary. The quality of diagnosis and treatment is significantly improved. Thus, new methods for disclosing uncertainties of the first and second types have been developed in the TCS at present. As a result, stationary modes in the chaotic dynamics of real biosystems can be identified.

4. Conclusion

Within the framework of the new theory of chaos and self-organization, the Eskov-Zinchenko effect is now rigorously proven. The effect appears in the absence of statistical stability of the samples not only in biomechanics, but also in other divisions of biology, medicine, and psychology. Statistical instability is now proved not only for samples of TMG, TPG, the parameters of the cardiovascular system, but also for the parameters of the spectral density of such signals and for their autocorrelation $A(t)$.

Simultaneously with the EZE, second-type uncertainty, which is demonstrated by all TTS-complexity (in the representations of W. Weaver), is being proved. In this case, there arises the problem of choosing homogeneous groups and developing new invariants that go beyond stochastics. The parameters of pseudo-attractors are proposed to be such invariants.

It was found that the area of the PA and the coordinates of their centers remain statistically unchanged, when the physiological state of the biosystem remains unchanged. When this state changes, the area of the PA changes (see table 2). The calculation of new invariants shall provide a real identification of the stationary modes of the TTS or their change, which is difficult to perform within the framework of stochastics.

References

[1] Weaver W 1948 Science and Complexity Rokfeller Foundation New York City American Scientist 36 536-44
[2] Betelin V B, Eskov V M, Galkin V A and Gavrilenko T V 2017 Stochastic volatility in the dynamics of complex homeostatic systems Doklady mathematics 95(1) 92-4
[3] Eskov V V, Gavrilenko T V, Eskov V M and Vokhmina Y V 2017 Phenomenon of statistical instability of the third type systems – complexity Technical physics 62(11) 1611-6
[4] Eskov V M, Kulaev S V, Popov Y M and Filatova O E 2006 Computer technologies in stability measurements on stationary states in dynamic biological systems Measurement techniques 49(1) 59-65
[5] Eskov V M, Eskov V V and Filatova O E 2011 Characteristic features of measurements and modeling for biosystems in phase spaces of states Measurement techniques 53(12) 1404-10
[6] Eskov V M, Gavrilenko T V, Kozlova V V and Filatov M A 2012 Measurement of the dynamic parameters of microchaos in the behavior of living biosystems Measurement techniques 55(9) 1096-101
[7] Eskov V M, Gavrilenko T V, Vokhmina Y V, Zimin M I and Filatov M A 2014 Measurement of chaotic dynamics for two types of tapping as voluntary movements Measurement techniques 57(6) 720-4
[8] Eskov V M, Eskov V V, Vochmina J V and Gavrilenko T V 2016 The evolution of the chaotic dynamics of collective modes as a method for the behavioral description of living systems Moscow university physics bulletin 71(2) 143-54
[9] Filatova D Yu, Bashkatova Yu V, Melnikova E G and Shakirova L S 2020 Homogeneity of the parameters of the cardiointervals in school children after north-south travel Human ecology 1 6-10

[10] Filatova O E 1997 Standardizing measurements of the parameters of mathematical models of neural networks Measurement techniques 40(1) 55-9

[11] Filatova O E, Gudkov A B, Eskov V V and Chempalova L S 2020 The concept of uniformity of a group in human ecology Human ecology 2 40-4

[12] Zilov V G, Eskov V M, Khadartsev A A and Eskov V V 2017 Experimental verification of the Bernstein effect “Repetition without Repetition” Bulletin of experimental biology and medicine 163(1) 1-5

[13] Zilov V G, Khadartsev A A, Eskov V V and Eskov V M 2017 Experimental study of statistical stability of cardiointerval samples Bulletin of experimental biology and medicine 164(2) 115-7

[14] Zilov V G, Khadartsev A A, Ilyashenko L K, Eskov V V and Minenko I A 2018 Experimental analysis of the chaotic dynamics of muscle biopotentials under various static loads Bulletin of experimental biology and medicine 165(4) 415-8

[15] Zilov V G, Khadartsev A A, Eskov V M and Ilyashenko L K 2019 New effect in physiology of human nervous muscle system Bulletin of experimental biology and medicine 167(4) 419-23

[16] Zilov V G, Khadartsev A A, Eskov V V, Ilyashenko L K and Kitanina K Yu 2019 Examination of statistical instability of electroencephalograms Bulletin of experimental biology and medicine 168(7) 5-9