UDC 004.5:331.4 **doi: 10.32620/reks.2021.4.01**

V. MYGAL[1], G. MYGAL[1], S. MYGAL[2]

[1] ***National Aerospace University "Kharkiv Aviation Institute", Ukraine***
[2] ***Ukrainian National Forestry University, Ukraine***

TRANSDISCIPLINARY CONVERGENT APPROACH - HUMAN FACTOR

The article is devoted to the systemic problems of the study of the human factor, which are associated with the cognitive aspects of human-computer interaction. The rapid development of mathematical modeling has created systemic problems of safety, control and forecasting of the functioning of dynamic transport systems in difficult conditions. The accumulation of latent contradictions and interdisciplinary conflict are the main reasons for the systemic complexity of the problems of education and science, which have increased the importance of the human factor. The main goal of the work is to further develop a convergent approach to studying the problems of the safety of the human factor on a transdisciplinary basis. The key reason for systemic security problems and the manifestation of the human factor is self-organized criticality, the manifestation of which in information transmission lines causes nonlinearity and instability of fractal signals of various natures. The work establishes a connection between the transitional functional states of a person with the individuality of his cognitive activity. A toolkit for identifying induced spatial and temporal inhomogeneities of information transmission media, which generate hidden spatio-temporal relationships at different scale levels, is proposed. These interconnections are determined by the individuality of the cognitive graphic images of fractal and multifractal signals of various natures. The creation of a knowledge base of cognitive graphic images of the dynamic structure of fractal and multifractal signals of various nature will allow finding solutions not yet available to the brain and computer separately. The application of the transdisciplinary convergent approach and tools based on it to electrophysiological signals of a human operator demonstrates advantages and new possibilities. In particular, revealing hidden spatio-temporal relationships that determine the manifestation of human factor in difficult conditions. The innovative potential of the convergent approach to training and forecasting activities of operators (pilot, dispatcher, etc.) is being discussed.

Keywords: *human factor; human-computer interaction; cognitive ergonomics; cognitive graphics; system dynamics; convergent approach; 3D modeling.*

Introduction

Motivation. Intensive human activity has created extreme environmental conditions that have led to global challenges of the 21st century. The COVID-19 pandemic has exacerbated the systemic problems associated with the phenomenon of the human factor (HRP). These problems affect safety (biological, physical, and informational), as well as the sustainability of vehicle management and critical infrastructure [1, 2]. Despite the advances in post-industrial technologies (nanotechnology, artificial intelligence, etc.), the digitalization of the economy, science, and education has increased the cost of new disasters (pandemics, earthquakes, tsunamis, etc.). The accumulation of latent contradictions and interdisciplinary conflict is the main reason for the systemic complexity of the problems of education and science.

Ergonomic aspects of the problem of the human factor are analyzed and discussed in [3]. It highlights advances in research and development, design, operation, and analysis of transport systems and their complementary infrastructures. Particular attention is paid to case researches on road and rail, air and sea transportation. The analysis of accidents and intelligent control of vehicles and problems related to the human factor and safety is given. Intelligent technologies and automation in transport are considered, as well as ergonomic aspects of the design of transport systems that are focused on the user. However, in our opinion, not enough attention has been paid to model-based design methods, as well as modeling methods and cognitive aspects of the problematics.

The review [4] analyzes the current state of human factor/ergonomics research related to the context of Industry 4.0 in manufacturing. On its basis, the characteristics of the maturity model at the organizational level

ISSN 1814-4225 (print)
ISSN 2663-2012 (online)

are formed to optimize the overall productivity of the socio-technical labor system in the context of rapid technological development. This system is of particular interest to the manufacturing industries.

The analysis of the program of The International Conference on Applied Human Factors and Ergonomics (AHFE 2022, New York, USA, 2022), which includes more than 20 Affiliated Conferences [5], also testifies to the unsolved problems of the human factor. Of particular interest are identifying the reasons for the unreliability of a human operator of ergatic systems, modeling the state and behavior of a person and the human factor, ergonomic and sustainable design of human-machine systems, as well as Human Factors in Training, Education, and Learning Sciences, Neuroergonomics & Cognitive Engineering.

In the context of the rapid integration of information and post-industrial technologies, cognitive problems of information interaction at school, university and production have become relevant. This increased the importance of interdisciplinary and polydisciplinary sciences (biophyschemistry, cyberphysics, cognitive ergonomics, human factor engineering, etc.) [6]. However, they are characterized by difficulties, problems, and contradictions. The key ones are:

- the difficulties in assessing the degree of systemic diversity in information sources;
- the problems of forecasting risks based on mathematical models;
- the contradiction between the growing number of information sources and the systemic complexity of studying their interaction.

This increases the systemic complexity, which limits the further development of the multidisciplinary sciences. In particular, the complexity of ergonomic studies of the phenomenon of the human factor is increasing. The development of methods of cognitive ergonomics, neuroergonomics, etc. limits the variety of methods, terms, parameters, and analysis criteria.

Objectives. The solution of real problems of complex technical systems' safety and their stability requires the development of transdisciplinarity of education and science. The “World Declaration on Higher Education for the 21st Century: Approaches and Practical Measures” contains recommendations - to encourage the transdisciplinarity of educational programs (Article 5 and Article 6 of the Declaration) [7].

The main goal of the report Advancing Research in Science and Engineering ("ARISE-2") is in American science to carry out "the transition from interdisciplinarity to transdisciplinarity" [8]. ARISE 2 recommendations were used in China in the preparation and implementation of State programs for the development of science and technology (Program "973") [9].

The main goal of the work is the further development of a convergent approach to studying the problems of the safety of the human factor on a transdisciplinary basis.

1. Systemic problems of digitalization

Matematization of disciplines and their differentiation. In extreme environmental and economic conditions, security has become too dependent on IT, digitalization, and Industry 4.0. Their rapid development has created systemic problems and contradictions that are associated with the cognitive and ergonomic aspects of human interaction with a computer [10]. Natural principles are widely applied [11]. In the 21st century, the increase in the possibilities of computational experiments and mathematical models is accompanied by the mathematization of disciplines, as well as their further differentiation. All this gives impetus to the accelerated development of artificial intelligence, cognitive computing, machine, and deep learning, with the mutual enrichment of which latent contradictions arose [12]. The rapid development of mathematical modeling is accompanied by a decrease in the volume of fundamental disciplines and experimental research. At the same time, the exponential growth of computational capabilities (Moore's law 1965 [13]) contributed to an increase in the systemic complexity of technologies, and neuroergonomic studies established the influence of the human factor on the selection of relevant information [14]. Therefore, it is sometimes difficult for experts to understand each other, and it is difficult for teachers of special and natural science disciplines not to take into account the cognitive aspects of the perception of information by the new generation.

Problems of stability of complex dynamic systems - cognitive aspects. Integration of informational and postindustrial technologies revealed cognitive problems [2]. They increased the significance of the ergonomic laws of mutual adaptation and transformation [15]. The cognitive aspects of digitalization limit forecasting capabilities:

- safety (biological, physical and informational);
- activities of a human operator of complex dynamic systems in unpredictable conditions;
- environmental disasters (earthquakes, tsunamis, the effects of magnetic storms, etc.).

External influence on a complex dynamic system (a person, information transmission medium, etc.) causes the self-organization of its subsystems to counteract a state change (Le Chatelier-Brown principle) [16]. Self-organized objects of various natures in extreme conditions approach the bifurcation point, at which the phenomenon of self-organized criticality occurs [17]. This leads to a dynamic similarity of characteristics of objects of different nature, which is naturally associated with fractality and nonlinearity of processes. This is confirmed by the results of a comprehensive study of the functional state of a person, nanostructures, and nanomaterials. However, mathematical models do not take into account the processes that are caused by self-organized criticality. This creates hidden systemic problems of the stability of self-organized objects in difficult conditions, which are caused by the human factor. From his point of view, the connection between the following problems is of interest:

- variety and nonlinearity of fractal signals, which limit the possibilities of cognitive computing and artificial intelligence;
- increasing variety of parameters and indicators;
- latent cognitive distortions due to the influence of fatigue and stress.

The consequence of these problems is the complexity of predicting the operator's activities in unforeseen conditions.

Complexity of transients. Fractality and nonlinearity of electrophysiological signals determine the complexity of transient processes [18]. Their features are due to the self-organization of the body's subsystems to counteract external and internal influences [13]. The systemic complexity of the dynamics of competing processes is hidden in the induced asymmetry of excitation (self-excitation) and inhibition [19]. Physical analogues of these processes in electrodynamics and mechanics of continuous media are induction, self-induction, and mutual induction. Inhomogeneities of information transmission media (defects, fluctuations, etc.) of different scales are sources of fields (physical, biological, and information). Their interaction causes anomalies of properties (characteristics, parameters), which indicate the ordering of the structure of these fields. Therefore, the self-organized criticality of environments increases the systemic complexity of the dynamic structure of time series (information flows) of various nature. All this creates cognitive problems (perception, distortion, etc.) that are difficult to identify in real-time [20]. This leads to the manifestation of the human factor in difficult conditions.

Knowledge fragmentation and G. Miller's law. The differentiation of disciplines has increased the fragmentation of knowledge and decreased the motivation to teach the pragmatic generation. The complexity of the variety of information processing methods and ways of displaying it increases. A person can simultaneously take into account seven plus or minus two different sources of information (H. Miller's law) [21]. Their attitude, 7-2 / 7 + 2 = 5/9 reflects cognitive personality (cognitive style). This is due to the functional asymmetry of the cerebral hemispheres, discovered by R. Sperry (Nobel laureate 1981). Unfortunately, the digitalization of education contributes to the development of functional asymmetry and complex systems thinking [22]. The consequence of the fragmentation of knowledge and different definitions of the measure of information [23] (according to Wiener, Shennon, Kolmogorov, etc.) is:

- a variety of concepts, indicators, models and patterns, as well as the difference in their semantic definitions in different subject areas;
- cognitive distortions of information when exposed to stress factors of the environment and activity;
- selection by the operator in emergency situations of irrelevant sources of information.

The human factor and ergonomic problems of digitalization. Ergonomics does not yet take into account the "clip" perception and thinking, which is characteristic not only of the new generation. The dominance of fragmented perception does not allow analyzing information in a holistic manner, which reduces the ability to analyze information, the effectiveness of learning, and assimilation of knowledge. Such perception and thinking is a protective reaction of the brain in the process of adaptation to the increasing complexity of information and post-industrial technologies.

The main reasons that lead to the manifestation of the human factor in transport include:

- the complexity of implementing functional diagnostics methods online;
- insufficient sensitivity of parameters and indicators to transient states, which is important for the admission of operators (pilots, etc.) to work;
- limited opportunities for individualization of education today.

Existing approaches to intelligent decision support do not allow analyzing a large number of backbone factors in real time. The principles of maximization in evolutionary biology are important for their study [24].

2. Hidden Causes of Cognitive Problems

Influence of medium inhomogeneities. At the most fundamental level, physics, chemistry and biology present us with the world of structures [25]. The transformation of the dynamic structure of atoms and molecules into static graphic images (spectra, diagrams, etc.) simplified their identification and classification. This allows us to assume that information about the influence of medium inhomogeneities is hidden in small distortions of the information flow structure. In a self-organized environment, spatial inhomogeneities (force field gradients) generate temporary inhomogeneities, and temporary inhomogeneities induce spatial inhomogeneities. Their interconnection distorts the dynamic structure of the temporal signal (information flow).

ISSN 1814-4225 (print)
ISSN 2663-2012 (online)

Spatio-temporal relationships. The development of technology and applied sciences is constantly running into various physical limits (the uncertainty principle, etc.). Therefore, the real structure of self-organized media for information transmission is determined by the interconnections of spatial and temporal inhomogeneities (Fig. 1). External influence induces latent spatio-temporal relationships in the environment, which distort the fine (informational) structure of the information flow (electrophysiological signal, etc.) [26]. Consequently, only visualization of dynamic and stationary fields of inhomogeneities in the same space makes it possible to realize the complementarity of dynamic and statistical research methods.

Distortion of information flows. When analyzing the spatial inhomogeneities of the medium, the Boltzmann entropy is used, and the temporal inhomogeneities use the Kolmogorov entropy. Medium inhomogeneities distort information flows due to the following phenomena:

- induction, self-induction and mutual induction in electromagnetic continuous media;
- transfer (direct and conjugate) - particles, energy, charges, momentum and information;
- magnetohydrodynamics and electrohydrodynamics, as well as morphic effects that are caused by the superposition of symmetries of external and internal fields. These phenomena generate counter streams, the change of which under the influence (information attack, etc.) induces anisotropy and asymmetry in the information transmission medium. Therefore, the results of modeling the relationship between stationary and dynamic fields of different nature using the Maxwell and Navier-Stokes equations are ambiguous and contradictory. Spatial and temporal inhomogeneities of systems are revealed by statistical and deterministic methods.

The hidden structure of induced relationships - Digitalization challenges. Features of the functioning of physical and biological systems are determined by dynamic and static complexity (Fig. 2).

It follows from the analysis of the figure that the cognitive aspects are due to the complexity of assessing the order / disorder, simplicity / complexity, etc. Functional asymmetry of the brain is associated with the individuality of complex-system thinking [22].

The manifestation of the hidden structure of interconnections in dynamic systems of different nature leads to an increase in errors and the realization of risks, in other words, to the manifestation of the human factor. The combination of cognitive load and cognitive diversity creates systemic problems that require cognitive flexibility to address. The application of the ergonomic laws of mutual adaptation and transformation limits the hidden structure of interconnections in a dynamic system, which complicates:

- selection of up-to-date sources of information;
- identification and classification of states;
- decision making in real time.

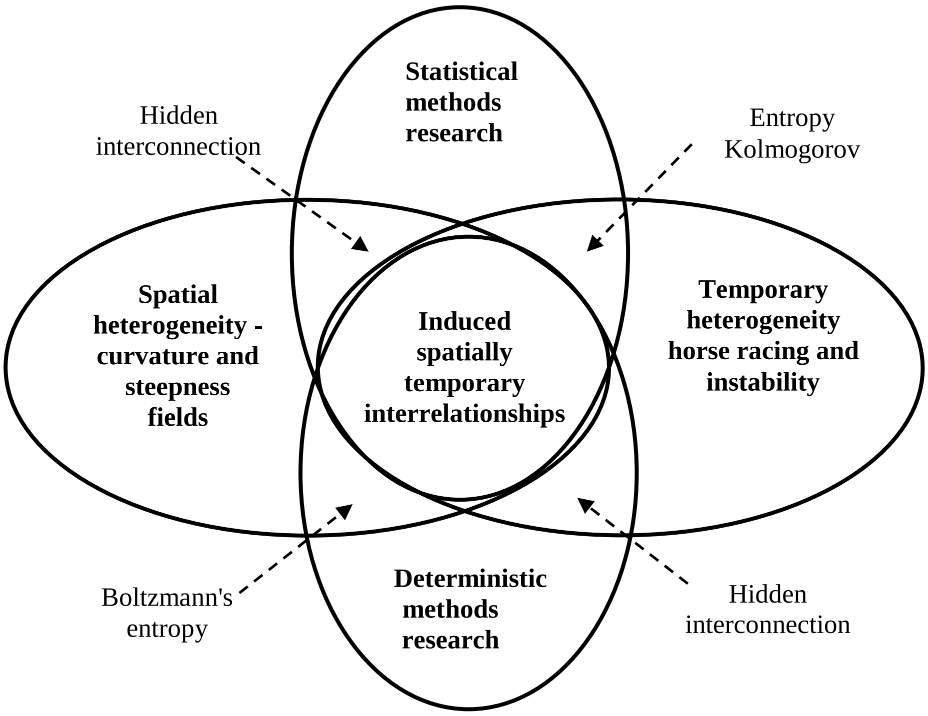

Fig. 1. Interrelation of heterogeneities and complementary ethods of their study

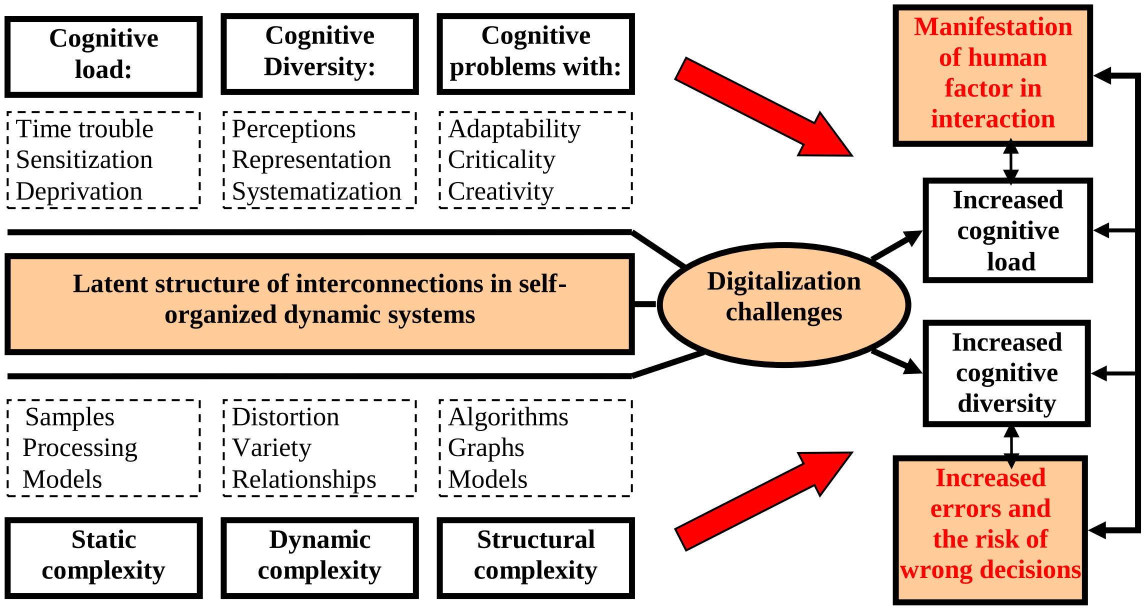

Fig. 2. The relationship between cognitive aspects and complexity

The study of the functioning of a self-organized dynamic system based on the principles of system dynamics limits the complexity of the models and the variety of tools for their analysis [27, 28].

Individuality of cognitive activity. Controlling a complex dynamic system (reactor, aircraft, etc.) in unforeseen conditions is extremely difficult. Fractality and nonlinearity of information flows of different nature (time series) are hidden in different types of complexity (structural, dynamic, static, etc.). It determines the individuality of cognitive activity. Cognitive diversity increases the cognitive load, which leads to the manifestation of the human factor in the interaction.

3. Transdisciplinarity of problems of science

Transdisciplinarity and biomimetics. The terms that are used in biology, natural history, engineering, etc., differ depending on the field of science. The emergence of the international standard “ISO 18458 Biomimetics. Terminology, concepts and methodology” allowed to standardize terminology. The standard aims to find a common language for scientists and engineers. Biomimetics contributed to the development of functional materials science, nanotechnology, biotechnology [29]. In addition, the principles of biomimetics underlie biodesign as well as:

- nonequilibrium thermodynamics of open systems, discovered by I. Prigogine (Nobel laureate 1977);
- synergetics of G. Haken [30];
- nano-bio-information technologies (NBIT) [31];
- modeling dynamic and stochastic fractals and multifractals.

All of them contributed to the development of academic science and post-industrial technologies. When creating artificial intelligence, all sciences faced the problem of systemic complexity. There are also computability limits, which follow from K. Gödel's completeness theorem [32]. These insurmountable mathematical problems limit the possibilities of system dynamics [27]. It is used to model the cause-and-effect relationships of complex systems and processes, feedback loops, response delays in information transmission lines.

Transdisciplinarity and Cognitive Computing Issues. In the current state of cognitive computing, the base solution can act as an assistant or virtual advisor. However, information transmission media contain spatial inhomogeneities that give rise to temporal inhomogeneities. They determine the asymmetry and symmetry of the bonds, which are shown in Fig. 3.

This limits the possibilities of machine learning and deep learning, since the training algorithms use linear models [12]. From the analysis of interdisciplinary relationships in Fig. 3 it follows that genetically inherited information is concentrated in the range of 1-100 nm (DNA size is 100 nm).

The production of new knowledge. Transdisciplinarity is usually defined by the inclusion of non-academic stakeholders in the knowledge production process. Transdisciplinarity is a promising concept, but its ability to effectively tackle the world's most pressing problems still needs improvement [33]. While exploring

ISSN 1814-4225 (print)
ISSN 2663-2012 (online)

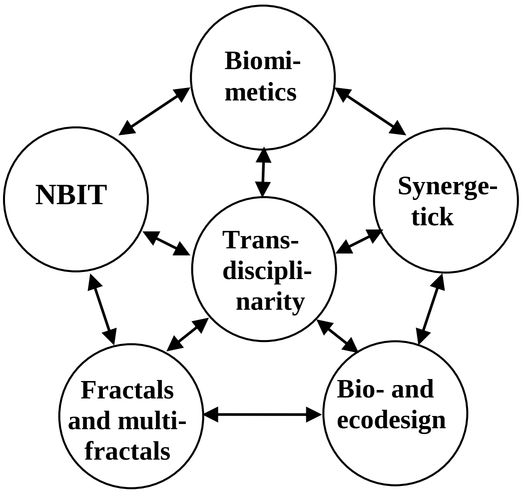

Fig. 3. Interdisciplinary and transdisciplinary relationships

multiple levels and perspectives on reality, transdisciplinary work provides an intriguing potential to spur scientific research [34].

Side effects of digitalization. Unforeseen side effects threaten not only stable structures, but also self-organized dynamic systems [2, 30, 31]. Therefore, to study the problems of the human factor, transdisciplinary methods of knowledge integration are needed. The connection between the extreme principles of dynamics and the principles of biomimicry is characteristic of self-organizing dynamic systems of animate and inanimate nature [31]. The analysis of the induced complexity of real objects (viruses, information attacks, etc.) can be carried out using the extreme principles of natural science (principle of least action, Fermat's principle of least time, Huygens-Fresnel principle, etc.). Their complementarity makes it possible to estimate the contribution to the complexity of the spatial and temporal fields of inhomogeneities. It also simplifies the identification of the individuality of the functioning of objects of different nature.

Overcoming mathematical limitations. Geometry has always played the role of a “generator of revolutionary ideas” in natural sciences, and the development of applied sciences has stimulated the success of analog and mathematical modeling. Some of the mathematical limitations were partially overcome by the following ideas:

- N. Wiener's cybernetics about the most general form of signal organization (its structure) as its spatio-temporal, which also underlie synergetics and cognitive psychology;
- Packard [35] on the reconstruction of a model from a one-dimensional measured signal (1980), which Takens formalized in the form of a theorem on embedding a time series in Rп [36];
- spatio-temporal parametrization of the cyber-physical approach [37].

The further development of these ideas was limited by non-linearity, uncertainty and instability of signals of various nature.

Transdisciplinarity of the phenomenon of the human factor. To study the individuality of the functioning of dynamic systems, the most important principles are: 1 – nonlinearity, 2 – stability, 3 – openness, 4 – dynamic hierarchy, 5 – observability. Any boundary of the integrity of the research object assumes non-linear effects. Therefore, nonlinearity is clearly manifested near the boundaries of the existence of the system, because collective actions are not reduced to a simple sum of individual independent actions. This is the psychological complexity and nonlinearity of the tasks being solved. On the one hand, human relationships themselves are extremely non-linear. On the other hand, there are boundaries of feelings, emotions, passions, near which behavior becomes unpredictable. To study the phenomenon of the human factor, it is important to identify transitional states to functional breakdown.

4. Cognitive visualization of dynamic processes and their 3D models

Complementarity of extreme principles. The creation of natural and artificial 3D structures with unique temporal and other characteristics contributed to the emergence of new ideas. In particular, the ideas of the NBIT gave impetus to the development of 3D modeling, 3D diagnostics, 3D design, and 3D technologies. Visualization of dynamic processes of different nature in one space can be realized on the basis of extreme principles of physics [38-41], which have a geometric interpretation, namely:

- complementarity of Hamilton's principle of least action and A. Hertz's principle of least curvature and distance;

- the principle of least Jacobi action, which displays a geodesic curve;

- the energy interpretation of the Gauss principle of least action is related to the theorem of E. Noether.

The complementarity of the principles of least action made it possible to implement parametric visualization of time series of various nature.

Parametric visualization. In the space of dynamic events (state-speed-acceleration), the individuality of the functioning of dynamic systems of various nature is manifested [39]. In particular, the measured time series (electrophysiological signal, detector response, etc.) is transformed into a topological 3D model, the orthogonal projections of which are individual graphic images - signatures of the 1st and 2nd order. Their configurations reflect the natural decomposition of the signal into mutually conjugated components (phases, subsets, extrema, etc.). This determines the complementarity of deterministic and statistical methods for studying time series of different nature (responses of sensors, detectors, spectrometers, electrophysiological signals, etc.).

Dynamic natural fractals. Further researches of fractal electrophysiological signals made it possible to establish for the first time that the relationship between the configurations of the 1st and 2nd order signatures is of a topological nature. It turned out that natural fractals exhibit topological or statistical self-similarity, that is, self-affinity [43]. To identify the structure of the microcycle of multifractal formation, we have developed a new technology (know-how). It is based on the self-consistency of the particular with the whole, which is characteristic of multifractal time series. A microcycle is a display of two configurations of Sierpinski fractals. The first is formed by exposure, and the second by counteraction. The same microcycle is formed by the fractal and antifractal "Koch snowflake", the structure of which is a Star of David [44, 45]. The microcycle structure for the state of local dynamic balance also looks like a Star of David. The use of a microcycle made it possible to reconstruct the topological 3D model from the measured electrophysiological signal and compare it with known methods (see Fig. 4).

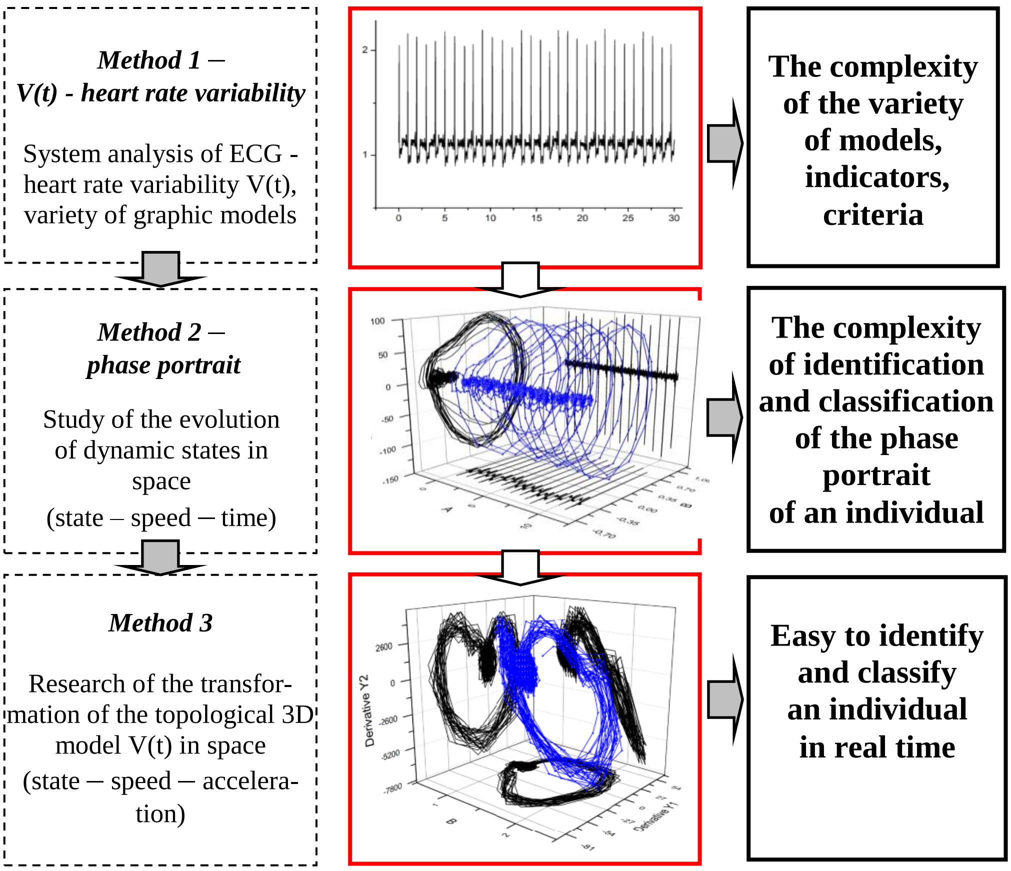

Fig. 4. Transformation of the time series X (t) (ECG) into a topological 3D model

ISSN 1814-4225 (print)
ISSN 2663-2012 (online)

From the comparison of the three methods, it follows that the parametric 3D models of the functioning of a dynamic system has a great heuristic and cognitive value. Thus, the phase portrait (method 2) as a sequence of dynamic states is a simplified model of the 1st order signature (model 3). The area of the signature is proportional to the power of a subset of microstates, the natural logarithm of which is proportional to the Boltzmann entropy [42]. This simplifies the analysis of the spatio-temporal ordering of mutually conjugated signal components.

The polydisciplinarity and complementarity of the extreme principles of dynamics and biomimetics makes it possible to model the functioning of self-organized dynamic systems of different nature in difficult conditions.

Distortions of the structure of the 3D model. In works [46, 47, 49, 51] attention is paid to local distortions of the structure of the fractal signal and the power of their conjugate components.

Analysis of their structure by complementary deterministic and statistical research methods made it possible to identify:

- attractors and instabilities in functional (reasonable) materials and in electrophysiological signals of a person taken from the database "Physionet";
- cognitive aspects of the operator's interaction with the information field [46];
- technological and genetic inheritance, which is hidden in the information complexity of fractal signals [43, 45].

The application of other extreme principles of natural science (Fermat, Huygens, etc.) in the analysis of the signatures of fractal signals and the nature of their rearrangement makes it possible to apply fundamental conservation laws and entropy criteria of reversibility, stability, etc.

3D - visualization of dynamic states and events. The distribution of local distortions in a fractal signal contains information about the processes of mutual adaptation and transformation. On the basis of a systemic generalization of topological 3D models of time series (signals) of various nature, characteristic features of the structure of transient states have been established for the first time. Therefore, the key to solving urgent problems of the safety of the functioning of a complex dynamic system is to visualize the nature of the restructuring of the fine (informational) structure of interconnections in the dynamics of signals of various nature. The restructuring of the signal can be visualized using a convergent approach. Therefore, the quantitative indicators given in [47] demonstrate the advantages of the developed approach. Multifractal electrophysiological signals (ECG, EEG, EOG, etc.) contain unique information.

5. The cognitive relevance of the converged approach

Spatio-temporal decomposition of the time series. The natural decomposition of the configuration of the second-order spatio-temporal signatures into mutually conjugated signal components simplifies the analysis of the energy and information features of the structure of the cycle of functioning. This is because:

- morphologically different dynamic systems functionally obey the same extreme principles of physics (biophysics) and the principles of biomimicry;
- different dynamical systems operate according to the same laws of thermodynamics;
- dynamic processes of different scales are subject to the principle of detailed balance.

The evolution of signature configurations has cognitive significance. Visualization of the nature of the restructuring of the spatio-temporal ordering of the structure of the time series made it possible to:

- assess the imbalance of dynamic and energetic mutually conjugated components;
- use in the analysis the fundamental conservation laws and criteria of thermodynamic stability;
- analyze the structure of functioning in real time.

All this indicates that the individuality of the functioning of a complex dynamic system is multifacetedly displayed in the space of dynamic events. Therefore, the space of dynamic events is polydisciplinary and corresponds to the definition of cognitive space [48].

Overcoming cognitive complexity. The measure of the complexity of dynamical systems is the topological entropy, which expresses the degree of chaos of its trajectories [47]. It was established for the first time that in the space of dynamic events, the nature of the change in the orthogonal projections of the 3D model reflects the distortions of the structure of internal relationships. Individuality is characteristic of different time series (responses of sensors and detectors), as well as electrophysiological signals of a person.

Thus, by the nature of the rearrangement of their configurations in the package of fractal signal signatures, one can estimate the topological entropy. In fact, the transformation of the scalar information flow into a 3D model stimulates the active work of both hemispheres of the brain. Therefore, the use of such models allows:

- increase the motivation of learning by visualizing 3D models of signals of various nature;
- synthesize new knowledge while integrating sciences;
- to reduce the influence of "glare" perception and thinking on the development of education and science.

The cognitive value of 3D models can be increased with original digital filters. With their help, the configurations of signatures can be transformed into the corresponding structural patterns in which there are no individual features.

The innovative potential of the converged approach. Different methods of analysis (deterministic, statistical, fractal, structural-functional, etc.) can be applied to signatures and patterns. Application of conservation laws, thermodynamic criteria of stability, reversibility, etc. provides new opportunities for the study of cognitive aspects in interdisciplinary sciences (ergonomics, human factor engineering). These are new opportunities for improving the efficiency of various types of online diagnostics and predictive analytics, for which it is important to study the cognitive aspects of human-computer interaction. In general, cognitive 3D models and signatures based on them have cognitive value for ergonomics / human factors and ecodesign. The innovative potential of the convergent toolkit approach on a transdisciplinary basis is enormous. The unification of cognitive graphics simplifies human-computer interaction in teaching, design and modeling [49]. The modeling of natural processes given in [50] illustrates the high innovative potential of the approach. For engineers, a convergent toolkit on a transdisciplinary basis is of interest. In particular, the proposed cognitive graphics tools simplify human-computer interaction in teaching, design and modeling.

Benefits of a converged approach. Within the framework of the transdisciplinary convergent approach, it is possible to identify and classify the transition states of self-organizing systems. For example, a three-dimensional model of solar activity based on statistical data on sunspots for 300 years has a multifractal structure [52]. It turned out that the configuration of the 3D model of the structure of the spectrum of an absolute black body does not depend on temperature. Cognitive 3D models of digitized electrophysiological signals of an operator (pilot, dispatcher, etc.) are relevant for online diagnostics. Their use on complex dynamic simulators will reduce the influence of the human factor.

Conclusions

The digitalization of science and education has created systemic problems that have increased the cost of man-made disasters. The transdisciplinary convergent approach to the reconstruction of a topological 3D model of the functioning of a dynamic system from a measured fractal electrophysiological signal revealed:

- the complexity of the transient states of the operator (pilot, dispatcher, etc.) for online diagnostics;
- latent structure of interconnections of subsystems of the human body, the individuality of which is determined by external and internal factors;
- the possibility of visual analytics in real time, which is extremely necessary for the selection, admission and monitoring of the dispatcher (pilot, etc.).

Overcoming the cognitive complexity of time series (electrophysiological signals of a person, signals of objects of various natures) should begin with the formation of convergent (critical) thinking in teaching based on the extreme principles of natural science and the principles of biomimicry. New opportunities are provided by the combination of dynamic and statistical research methods in the space of dynamic events. Thus, the cognitive value of topological 3D models of the functioning of subsystems of the human body and their signatures is due to the fact that:

- the configurations of the signatures of electrophysiological signals reflect the spatio-temporal decomposition of the cycle of functioning into mutually conjugated components (phases, sets, extrema);
- when analyzing adaptation to external influences, ergonomic laws of mutual adaptation and transformation, as well as fundamental conservation laws, are applied.

The advantage of the transdisciplinary convergent approach is the ability to visualize data in the cognitive space, which allows:

- by means of entropy-fractal analysis to reveal the relevant relationships, characteristic scales and times;
- to ensure the complementarity of the results of deterministic and statistical analysis of the functioning of the dynamic system in real time;
- to visualize spatio-temporal signatures of transient functional states in real time.

The application of a convergent approach and tools on a transdisciplinary basis to human electrophysiological signals (EEG, EOG, rheograms, etc.) demonstrate the advantages and new possibilities for revealing hidden spatio-temporal relationships that determine the manifestation of the human factor in unforeseen conditions.

References (GOST 7.1:2006)

1. Mygal, G. The viability of dynamic systems in difficult conditions: cognitive aspects [Text] / G. Mygal, V. Mygal // 2020 IEEE 11th International Conference on Dependable Systems, Services and Technologies (DESSERT), 2020. – P. 224-229. DOI: 10.1109/DESSERT50317.2020.9125063.

2. Mygal, V. Problems of Digitized Information Flow Analysis: Cognitive Aspects [Text] / V. Mygal, G. Mygal // Information & Security: An International Journal. – 2019. – Vol. 43, No. 2. – P. 134-144. DOI: 10.11610/isij.4312.

3. Stanton, N. Advances in Human Factors of Transportation [Text] / Neville Stanton // Proceedings

ISSN 1814-4225 (print)
ISSN 2663-2012 (online)

of the AHFE 2019 International Conference on Human Factors in Transportation, July 24-28, 2019. – Washington D.C., USA, Springer, 2020. – Vol. 964. – 834 p. DOI: 10.1007/978-3-030-20503-4.

4. *Human factors and ergonomics in manufacturing in the industry 4.0 context – A scoping review [Text] / A. Reiman, J. Kaivo-oja, E. Parviainen, Esa-Pekka Takala, Th. Lauraeus // Technology in Society. – 2021. – Vol. 65. Article No. 101572. DOI: 10.1016/j.techsoc.2021.101572.*

5. *AHFE 2022 - 13th International Conference on Applied Human Factors and Ergonomics. July 24-28, 2022 [Electronic resource]. - Sheraton New York Times Square, USA. – Access mode: https://2022.ahfe.org/index.html. – 10.08.2021.*

6. *Designing for People: An introduction to human factors engineering [Text] / J. D. Lee, C. D. Wickens, Y. Liu, L. N. Boyle. – Charleston, SC : CreateSpace, 2017. – 692 p.*

7. *Transdisciplinarity: stimulating synergies, integrating knowledge [Text] // International Symposium on Transdisciplinarity, UNESCO, Division of Philosophy and Ethics. Val-d'Oise, France, 1998. – P. 37-38.*

8. *Advancing Research in Science and Engineering. Investing in Early-Career Scientists and High-Risk, High-Reward Research [Text]. – American academy of arts and sciences. Cambridge, Massachusetts, 2008. – 55 p. ISBN: 0-87724-071-X.*

9. *Мокий, М. С. Трансдисциплинарность в высшем образовании: экспертные оценки, проблемы и практические решения [Електронний ресурс] / М. С. Мокий, В. С. Мокий // Современные проблемы науки и образования. – 2014. – 16 с. – Режим доступу: https://ssrn.com/abstract=2550155. – 12.05.2021.*

10. *Мигаль Г. В. Когнітивні та ергономічні аспекти взаємодії людини з комп'ютером [Text] / Г. В. Мигаль, В. П. Мигаль // Радіоелектронні і комп'ютерні системи. – 2020. – №. 1(93). – С. 90-102. DOI: 10.32620/reks.2020.1.09.*

11. *Scott, A. Basic nature [Text] / A. Scott, J. Scott. – Blackwell Publishers, 1991. – 192 p. ISBN 10: 0631173625.*

12. *Russel, J. S. Artificial Intelligence: a modern approach [Text] / J. Russel, S. Norvig. – Prentice Hall, New Jersey, 2003. – 946 p. ISBN 0-13-103805-2/*

13. *Moore, G. W. K. No Exponential is Forever: But Forever Can Be Delayed! [Text] / G. W. K.Moore // Computer Science: Proc. International Solid-State Circuits Conference. Digest of Technical Papers, 2003. – 19 p.*

14. *Fedota, J. Neuroergonomics and human error [Text] / J. Fedota, R. Parasuraman // Theoretical Issues in Ergonomics Science. – 2010. – Vol. 11, Iss. 5. – P. 402-421. DOI: 10.1080/14639220902853104.*

15. *Venda, V. F. Dynamics in Ergonomics, Psychology, and Decisions: Introduction to Ergodynamics [Text] / V. F. Venda, Y. V. Venda. – Norwood, NJ : Ablex, 1999. – 503 p.*

16. *Evans, D. J. Fluctuation theorem for Hamiltonian systems: Le Chatelier's principle [Text] / D. J. Evans, D. J. Searles and E. Mittag // Phys. Rev. – 2001. – Vol. 63, Iss. 5. DOI: 10.1103/PhysRevE.63.051105.*

17. *Bak, P. Self-organized criticality [Text] / P. Bak, C. Tang, K. Wiesenfeld // Physical review. E, Statistical physics, plasmas, fluids, and related interdisciplinary topics (PHYS REV A). – 1988. –Vol. 38, Iss. 1. – P. 364-374. DOI: 10.1103/PhysRevA.38.364.*

18. *Mygal, V. P. Convergent Approach to Identification of Transient States of a Dynamic System [Text] / V. P. Mygal, G. V. Mygal // Journal of Nano-Electron. Phys. – 2020. – Vol. 12, Iss. 6. – Article No. 06018. DOI: 10.21272/jnep.12(6).06018.*

19. *Haken, H. Synergetics as a bridge between the natural and social sciences [Text] / H. Haken. – London : Evolution, Order and Complexity, 1996. – 296 p.*

20. *Mygal, V. Intelligent Decision Support - Cognitive Aspects [Text] / V. Mygal, G. Mygal, O. Illiashenko // Digital Transformation, Cyber Security and Resilience of Modern Societies. – Cham : Springer, 2021. – P. 395–411. – (Studies in Big Data; Vol. 84. – ISSN 21976503). DOI: 10.1007/978-3-030-65722-2_25.*

21. *Miller, George A. The Psychology of Communication [Text] / George A. Miller. – New York : Basic Books, 1967. – 197 p. DOI: 10.1002/hrm.3930060308.*

22. *Mainzer, K. Thinking in Complexity: The Complex Dynamics of Matter, Mind, and Mankind [Text] / K. Mainzer. – Springer-Verlag Berlin Heidelberg, 1994. – 327 p. DOI: 10.1007/978-3-662-03014-1.*

23. *Встовский, Г. В. Элементы информационной физики [Text] / Г. В. Встовский. – М. : МГИУ, 2002. – 260 р.*

24. *Edwards, A. W. F. Maximization principles in evolutionary biology. Philosophy of Biology [Text] / A. W. F. Edwards. – Elsevier B.V., 2007. – P. 335-347.*

25. *French, Steven. The Structure of the World: Metaphysics and Representation [Text] / Steven French. – Oxford University Press, 2014. – 390 p. DOI: 10.1093/acprof:oso/9780199684847.001.0001.*

26. *Kadomtsev, B. B. Dynamics and information [Text] / B. B. Kadomtsev // Phys. Usp. – 1994. – Vol. 37, Iss. 5. – P. 425–499. DOI: 10.1070%2FPU1994v037n05ABEH000109.*

27. *Forrester, J. W. System dynamics - a personal view of the first fifty years [Text] / J. W. Forrester // System Dynamics Review. – 2007. – Vol. 23, Iss. 2-3. – P. 345-358. DOI: 10.1002/sdr.382.*

28. *Schwaninger, M. System dynamics and cybernetics: A synergetic pair [Text] / M. Schwaninger,*

J. P. Ríos // System Dynamics Review. – 2008. – V. 24 – No. 2. – P. 145-174. DOI: 10.1002/sdr.400.

29. Passino, K. M. Biomimicry for Optimization, Control, and Automation [Text] / K. M. Passino // Springer-Verlag London. – 2005. – 957 p. DOI: 10.1007/b138169.

30. Хакен, Г. Тайны природы. Синергетика: учение о взаимодействии [Текст] / Г. Хакен. – М.– Ижевск : Ин-т компьютер. исслед., 2003. – 350 с.

31. Roco, M. C. Converging Technologies for Improving Human Performance: Nanotechnology, Biotechnology, Information Technology and Cognitive Science [Text] / M. C. Roco, W. S. Bainbridge // Journal of Nanoparticle Research. – 2002. – Vol. 4, Iss. 4. – P. 281–295. DOI: 10.1023/A:1021152023349.

32. Gödel, K. Die Vollständigkeit der Axiome des logischen Funktionenkalküls [Text] / K. Gödel // Monatshefte für Mathematik und Physik. – 1930. – Vol. 37. Part 2. – P. 349-360. DOI: 10.1007/BF01696781.

33. Rigolot, Cyrille. Transdisciplinarity as a discipline and a way of being: complementarities and creative tensions [Text] / Cyrille Rigolot // Humanities and Social Sciences Communications. – 2020. – Vol. 7. Article No. 100. DOI: 10.1057/s41599-020-00598-5

34. Bernstein, J. H. Transdisciplinarity: A Review of Its Origins, Development, and Current Issues [Text] / J. H. Bernstein // Journal of Research Practice. – 2015. – Vol. 11, Iss. 1. – Article R1. – 20 p.

35. Geometry from a time series [Text] / N. Packard, J. Crutchfield, J. Farmer, R. Shaw // Phys. Rev. Lett. – 1980. – Vol. 45, Iss. 9. – P. 712-716. DOI: 10.1103/PhysRevLett.45.712.

36. Takens, F. Nonlinear dynamics and turbulence [Text] / F. Takens. – N.Y, Pitman, 1983. – P. 314-333.

37. Mygal, V. P. Cyber physical approach to study the functioning of dynamic systems [Text] / V. P. Mygal, G. V. Mygal // Electrical and computer systems. – 2016. – № 22 (98). – P. 354-358.

38. Katzav, J. Dispositions and the Principle of Least Action [Text] / J. Katzav // Analysis. – 2004. – Vol. 64, No. 3. – P. 206-214.

39. Georgiev, Georgi Yordanov. A Quantitative Measure, Mechanism and Attractor for Self-Organization in Networked Complex Systems [Text] / Georgi Yordanov Georgiev // Self-Organizing Systems. IWSOS 2012. Lecture Notes in Computer Science. – 2012. – Vol. 7166. – P. 90–95. DOI: 10.1007/978-3-642-28583-7_9.

40. Stöltzner, M. The principle of least action as the logical empiricist's Shibboleth [Text] / M. Stöltzner // Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics. – 2003. – Vol. 34, Iss. 2. – P. 285-318. DOI: 10.1016/S1355-2198(03)00002-9.

41. Terekhovich, V. Metaphysics of the Principle of Least Action [Text] / V. Terekhovich // Studies in History and Philosophy of Science. Part B: Studies in History and Philosophy of Modern Physics. – 2018. – Vol. 62. – P. 189-201. DOI: 10.1016/j.shpsb.2017.09.004.

42. An interdisciplinary approach to study individuality in biological and physical systems functioning [Text] / V. P. Mygal, A. V. But, G. V. Mygal, I. A. Klimenko // Scientific Reports. – 2016. – Vol. 6. – P. 387–391. Article No. 29512. DOI: 10.1038/srep29512.

43. Встовский, Г. В. Введение в мультифрактальную параметризацию структур материалов [Текст] : монография / Г. В. Встовский, А. Г. Колмаков, И. Ж Бунин. – М.-Ижевск, 2001. – 116 с.

44. Чумак, О. Энтропии и фракталы в анализе данных [Текст] / О. Чумак. – R&C Dynamics, 2012. – 82 с. DOI: 10.13140/2.1.4739.6800.

45. Mandelbrot, B. B. Self-affine fractal sets [Text] / B. B. Mandelbrot // Fractals in physics. – M. : Mir, 1988. – 672 p.

46. Mygal, V. P. Influence of radiation heat transfer dynamics on crystal growth [Text] / V. P. Mygal, I. A. Klymenko, G. V. Mygal // Functional Materials. – 2018. – Vol. 25, Iss. 3. – P. 574-580. DOI: 10.15407/fm25.03.574.

47. Mygal, V. P. Individuality of photoresponse dynamics of semiconductor sensors [Text / V. P. Mygal, I. A. Klymenko, G. V. Mygal // Functional Materials. – 2017. – Vol. 24, Iss. 2. – P. 212-218. DOI: 10.15407/fm24.02.212.

48. Newby, G. B. Cognitive space and information space [Text] / G. B. Newby // Journal of the American Society for Information Science and Technology. – 2001. – Vol. 52, Iss. 12. – P. 1026-1048. DOI: 10.1002/asi.1172.

49. Mygal, S. Design of Galicia: formation, development, national component [Text] / S. Mygal, O. Borysenko // The European Journal of Humanities and Social Sciences, Premier Publishing s.r.o. Vienna. – 2019. – Iss. 2. – P. 20-23.

50. Mygal, V. P. Visualization of Signal Structure Showing Element Functioning in Complex Dynamic Systems – Cognitive Aspects [Text] / V. P. Mygal, G. V. Mygal, L. M. Balabanova // Journal of Nano- and Electronic Physics. – 2019. – Vol. 11, No. 2. – Article No. 02013. DOI: 10.21272/jnep.11(2).02013.

51. Lee, J. D. Designing for People: An introduction to human factors engineering [Text] / J. D. Lee, C. D. Wickens, Y. Liu, L. N. Boyle. – 3nd Edition. Charleston, SC: CreateSpace. – 2017. ISBN 9781539808008.

52. Mygal, V. 3D-Modeling of the Dynamics of Real Processes of Different Nature [Text] / V. Mygal, I. Klymenko, G. Mygal // Integrated Computer Technologies in Mechanical Engineering. Lecture Notes in Networks and Systems. – 2020. – Vol. 188. – P. 633-

ISSN 1814-4225 (print)
ISSN 2663-2012 (online)

643. Springer, Cham. DOI: 10.1007/978-3-030-66717-7_54.

References (BSI)

1. Mygal, G., Mygal, V. The viability of dynamic systems in difficult conditions: cognitive aspects. *2020 IEEE 11th International Conference on Dependable Systems, Services and Technologies (DESSERT)*, 2020, pp. 224-229. DOI: 10.1109/DESSERT50317.2020.9125063.
2. Mygal, V., Mygal G. Problems of Digitized Information Flow Analysis: Cognitive Aspects. *Information & Security: An International Journal*, 2019, vol. 43, no. 2, pp. 134-144. DOI: 10.11610/isij.4312.
3. Stanton, N. Advances in Human Factors of Transportation. *Proceedings of the AHFE 2019 International Conference on Human Factors in Transportation*, July 24-28, 2019, Washington D.C., USA, Springer, vol. 964. 834 p. DOI: 10.1007/978-3-030-20503-4.
4. Reiman, A., Kaivo-oja, J., Parviainen E., Takala Esa-Pekka, Lauraeus, Th. Human factors and ergonomics in manufacturing in the industry 4.0 context – A scoping review. *Technology in Society*, 2021, vol. 65, article no. 101572. DOI: 10.1016/j.techsoc.2021.101572
5. *AHFE 2022 - 13th International Conference on Applied Human Factors and Ergonomics*. July 24-28, 2022 - Sheraton New York Times Square, USA. Avalible at: https://2022.ahfe.org/index.html. (accessed 10.08.2021)
6. Lee, J. D., Wickens, C. D., Liu, Y., Boyle, L. N. *Designing for People: An introduction to human factors engineering.* Charleston, SC, CreateSpace, 2017. 692 p.
7. Transdisciplinarity: stimulating synergies, integrating knowledge. *International Symposium on Transdisciplinarity, UNESCO, Division of Philosophy and Ethics*. Val-d'Oise, France, 1998, pp. 37-38.
8. *Advancing Research in Science and Engineering. Investing in Early-Career Scientists and High-Risk, High-Reward Research.* American academy of arts and sciences, Cambridge, Massachusetts, 2008. 55 p. ISBN: 0-87724-071-X.
9. Mokiy, M. S., Mokiy, V. S. Transdistsiplinarnost' v vysshem obrazovanii: ekspertnye otsenki, problemy i prakticheskie resheniya [Transdisciplinarity in Higher Education: Expert Assessments, Problems and Practical Solutions]. *Sovremennye problemy nauki i obrazovaniya – Modern problems of science and education*, 2014. 16 p. Availible at: https://ssrn.com/abstract=2550155. (accessed 12.05.2021).
10. Mygal, V. P., Mygal, G. V. Kohnityvni ta erhonomichni aspekty vzayemodiyi lyudyny z komp"yuterom [Cognitive and ergonomics aspects human interactions with a computer]. *Radioelektronni i komp'uterni sistemi – Radioelectronic and computer systems*, 2020, no. 1(93), pp. 90-102. DOI: 10.32620/reks.2020.1.09.
11. Scott, A., Scott, J. *Basic nature*. Blackwell Publishers, 1991. 192 p. ISBN 10: 0631173625.
12. Russel, J. S., Norvig S. *Artificial Intelligence: a modern approach.* Prentice Hall, New Jersey, 2003. 946 p. ISBN 0-13-103805-2.
13. Moore, G. W. K. *No Exponential is Forever: But Forever Can Be Delayed*! Computer Science, In Proc. International Solid-State Circuits Conference, 2003. 19 p.
14. Fedota, J., Parasuraman, R. Neuroergonomics and human error. *Theoretical Issues in Ergonomics Science*, 2010, vol. 11, iss. 5, pp. 402-421. DOI: 10.1080/14639220902853104.
15. Venda, V. F., Venda, Y. V. *Dynamics in Ergonomics, Psychology, and Decisions: Introduction to Ergodynamics*. Norwood, NJ, Ablex, 1999. 503 p.
16. Evans, D. J., Searles, D. J. and Mittag, E. Fluctuation theorem for Hamiltonian systems: Le Chatelier's principle. *Phys. Rev*., 2001, vol. 63, iss. 5. DOI: 10.1103/PhysRevE.63.051105.
17. Bak, P., Tang, C., Wiesenfeld, K. Self-organized criticality. *Physical review. E, Statistical physics, plasmas, fluids, and related interdisciplinary topics (PHYS REV A)*, 1988, vol. 38, iss. 1, pp. 364-374. DOI: 10.1103/PhysRevA.38.364.
18. Mygal, V. P., Mygal, G. V. Convergent Approach to Identification of Transient States of a Dynamic System. *Journal of Nano-Electron. Phys*., 2020, vol. 12, iss. 6, article no. 06018. DOI: 10.21272/jnep.12(6).06018.
19. Haken, H. *Synergetics as a bridge between the natural and social sciences*. London, Evolution, Order and Complexity, 1996. 296 p.
20. Mygal, V., Mygal, G., Illiashenko, O. Intelligent Decision Support – Cognitive Aspects. *Digital Transformation, Cyber Security and Resilience of Modern Societies.* Cham, Springer, 2021, pp. 395–411. (Studies in Big Data; vol. 84). DOI: 10.1007/978-3-030-65722-2_25.
21. Miller, G. A. *The Psychology of Communication*. New York, Basic Books, 1967. 197 p. DOI: 10.1002/hrm.3930060308.
22. Mainzer, K. *Thinking in Complexity: The Complex Dynamics of Matter, Mind, and Mankind.* Springer-Verlag Berlin Heidelberg, 1994. 327 p. DOI: 10.1007/978-3-662-03014-1.
23. Vstovsky, G. V. *Elementy informatsionnoi fiziki* [Elements of information physics]. Moscow, Moscow State University, 2002. 260 p.

24. Edwards, A. W. F. *Maximization principles in evolutionary biology. Philosophy of Biology*. Elsevier B.V., 2007, pp. 335-347.

25. French, S. The Structure of the World: Metaphysics and Representation. *Oxford University Press*, 2014. 390 p. DOI: 10.1093/acprof:oso/9780199684847.001.0001.

26. Kadomtsev, B. B. Dynamics and information. *Phys. Usp.* 1994, vol. 37, iss. 5, pp. 425-499. DOI: 10.1070%2FPU1994v037n05ABEH000109.

27. Forrester, J. W. System dynamics - a personal view of the first fifty years. *System Dynamics Review*, 2007, vol. 23, iss. 2-3, pp. 345-358. DOI: 10.1002/sdr.382.

28. Schwaninger, M., Ríos, J. P. System dynamics and cybernetics: A synergetic pair. *System Dynamics Review*, 2008, vol. 24, no. 2, pp. 145-174. DOI: 10.1002/sdr.400.

29. Passino, K. M. *Biomimicry for Optimization, Control, and Automation*. Springer-Verlag London, 2005. 957 p. DOI: 10.1007/b138169.

30. Haken, G. *Tainy prirody. Sinergetika: uchenie o vzaimodeistvii* [Secrets of nature. Synergetics: the doctrine of interaction]. Izhevsk, In-t komp'yuter. issled., 2003. 350 p.

31. Roco, M. C., Bainbridge, W. S. Converging Technologies for Improving Human Performance: Nanotechnology, Biotechnology, Information Technology and Cognitive Science. *Journal of Nanoparticle Research*, 2002, vol. 4, iss. 4., pp. 281-295. DOI: 10.1023/A:1021152023349.

32. Gödel, K. Die Vollständigkeit der Axiome des logischen Funktionenkalküls, *Monatshefte für Mathematik und Physik*, 1930, vol. 37, part 2. pp. 349-360. DOI: 10.1007/BF01696781.

33. Rigolot, Cyrille. Transdisciplinarity as a discipline and a way of being: complementarities and creative tensions, *Humanities and Social Sciences Communications*, vol. 7, Article No. 100. DOI: 10.1057/s41599-020-00598-5.

34. Bernstein, J. H. Transdisciplinarity: A Review of Its Origins, Development, and Current. *Issues Journal of Research Practice*, 2015, vol. 11, iss. 1, article R1. 20 p.

35. Packard, N., Crutchfield., J, Farmer, J., Shaw, R. Geometry from a time series. *Phys. Rev. Lett*., 1980, vol. 45, iss. 9, pp. 712-716. DOI: 10.1103/PhysRevLett.45.712.

36. Takens, F. *Nonlinear dynamics and turbulence*. N.Y, Pitman, 1983, pp. 314-333.

37. Mygal, V. P., Mygal, G. V. Cyber physical approach to study the functioning of dynamic systems. *Electrical and computer systems*, 2016, no. 22 (98), p. 354-358.

38. Katzav, J. Dispositions and the Principle of Least Action. *Analysis*, 2004, vol. 64, iss. 3, pp. 206-214.

39. Georgiev, Georgi Yordanov. A Quantitative Measure, Mechanism and Attractor for Self-Organization in Networked Complex Systems. *Self-Organizing Systems. IWSOS 2012. Lecture Notes in Computer Science*, 2012, vol. 7166, pp. 90-95. DOI: 10.1007/978-3-642-28583-7_9.

40. Stölzner, M. The principle of least action as the logical empiricist's Shibboleth. *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics*, 2003, vol. 34, iss.2, pp. 285-318. DOI: 10.1016/S1355-2198(03)00002-9.

41. Terekhovich, V. Metaphysics of the Principle of Least Action. *Studies in History and Philosophy of Science. Part B: Studies in History and Philosophy of Modern Physics*, 2018, vol. 62, pp. 189-201. DOI: 10.1016/j.shpsb.2017.09.004.

42. Mygal, V. P., But, A. V., Mygal, G. V., Klimenko, I. A. An interdisciplinary approach to study individuality in biological and physical systems functioning. *Scientific Reports*, 2016, vol. 6, pp. 387–391. DOI: 10.1038/srep29512.

43. Vstovsky, G. V., Kolmakov, A. G., Bunin, I. Zh. *Vvedenie v mul'tifraktal'nuyu parametrizatsiyu struktur materialov* [Introduction to multifractal parametrization of material structures]. Izhevsk: Research Center "Regular and Chaotic Dynamics", 2001. 116 p.

44. Chumak, O. *Entropii i fraktaly v analize dannykh* [Entropy and fractals in data analysis]. R&C Dynamics, 2012. 82 p. DOI: 10.13140/2.1.4739.6800.

45. Mandelbrot, B. B. *Self-affine fractal sets. Fractals in physics*. Moscow, Mir Publ., 1988. 672 p.

46. Mygal, V. P., Klymenko, I. A., Mygal, G. V Influence of radiation heat transfer dynamics on crystal growth. *Functional Materials*, 2018, vol. 25, iss. 3, pp. 574-580. DOI: 10.15407/fm25.03.574.

47. Mygal, V. P., Klymenko, I. A., Mygal, G. V. Individuality of photoresponse dynamics of semiconductor sensors. *Functional Materials*, 2017, vol. 24, iss. 2, pp. 212-218. DOI: 10.15407/fm24.02.212.

48. Newby, G. B. The Strong Cognitive Stance as a Conceptual Basis for the Role of Information in Informatics and Information System Design. Cognitive space and information space. *Journal of the American Society for Information Science and Technology*, 2001, vol. 52, iss. 12, pp. 1026-1048. DOI: 10.1002/asi.1172.

49. Mygal, S., Borysenko, O. Design of Galicia: formation, development, national component. *The European Journal of Humanities and Social Sciences*, Premier Publishing s.r.o. Vienna, 2019, iss. 2, pp. 20-23.

50. Mygal, V. P., Mygal, G. V., Balabanova, L. M. Visualization of Signal Structure Showing Element

Functioning in Complex Dynamic Systems – Cognitive Aspects. *Journal of Nano- and Electronic Physics,* 2019, vol. 11, no. 2, article no. 02013. DOI: 10.21272/jnep.11(2).02013.

51. Lee, J. D., Wickens, C. D., Liu, Y., Boyle, L. N. *Designing for People: An introduction to human factors engineering*. Charleston, SC: CreateSpace, 2017. ISBN 9781539808008.

52. Mygal, V., Klymenko, I., Mygal, G. 3D-Modeling of the Dynamics of Real Processes of Different Nature. *Integrated Computer Technologies in Mechanical Engineering. Lecture Notes in Networks and Systems*, 2020, vol. 188, pp. 633-643. Springer, Cham. DOI: 10.1007/978-3-030-66717-7_54.

Надійшла до редакції 19.08.2021, розглянута на редколегії 26.11.2021

ТРАНСДИСЦИПЛІНАРНІСТЬ КОНВЕРГЕНТНОГО ПІДХОДУ – ЛЮДСЬКИЙ ЧИННИК

В. П. Мигаль, Г. В. Мигаль, С. П. Мигаль

Стаття присвячена системним проблемам вивчення людського чинника, які пов'язані з когнітивними аспектами взаємодії людини з комп'ютером. Стрімкий розвиток математичного моделювання створив системні проблеми безпеки, управління і прогнозування функціонування транспортних динамічних систем в складних умовах. Накопичення прихованих протиріч і міждисциплінарна конфліктність є основними причинами системної складності проблем освіти і науки, які збільшили значущість людського чинника. **Мета роботи –** подальший розвиток конвергентного підходу до дослідження проблем людського чинника на трансдисциплінарній основі. Ключовою причиною системних проблем безпеки і прояву людського чинника є самоорганізована критичність, прояв якої в лініях передачі інформації обумовлює нелінійність і нестійкість фрактальних сигналів різної природи. В роботі встановлено зв'язок перехідних функціональних станів людини з індивідуальністю його когнітивної діяльності. Запропоновано інструментарій для виявлення індукованих просторових і часових неоднорідностей середовища передачі інформації, які породжують приховані просторово-часові взаємозв'язки на різних масштабних рівнях. Ці взаємозв'язки визначають індивідуальність когнітивних графічних образів фрактальних і мультифрактальних сигналів різної природи. Створення бази знань когнітивних графічних образів динамічної структури фрактальних і мультифрактальних сигналів різної природи дозволить знаходити рішення, які поки не доступні мозку і комп'ютеру окремо. Застосування трансдисциплінарного конвергентного підходу та інструментарію на його основі до електрофізіологічних сигналів людини-оператора демонструє переваги і нові можливості. Зокрема, виявлення прихованих просторово-часових взаємозв'язків, які визначають прояв людського чинника в складних умовах. Обговорюється інноваційний потенціал конвергентного походу до навчання і прогнозування діяльності людини (пілота, диспетчера та ін.).

Ключові слова: людський чинник; людино-комп'ютерна взаємодія; когнітивна ергономіка; когнітивна графіка; системна динаміка; конвергентний підхід; 3D-моделювання.

ТРАНСДИСЦИПЛИНАРНОСТЬ КОНВЕРГЕНТНОГО ПОДХОДА – ЧЕЛОВЕЧЕСКИЙ ФАКТОР

В. П. Мигаль, Г. В. Мигаль, С. П. Мигаль

Статья посвящена системным проблемам изучения человеческого фактора, которые связаны с когнитивными аспектами взаимодействия человека с компьютером. Стремительное развитие математического моделирования создало системные проблемы безопасности, управления и прогнозирования функционирования транспортных динамических систем в сложных условиях. Накопление скрытых противоречий и междисциплинарная конфликтность являются основными причинами системной сложности проблем образования и науки, которые увеличили значимость человеческого фактора. **Цель работы** – дальнейшее развитие конвергентного подхода к иследованию проблем человеческого фактора на трансдисциплинарной основе. Ключевой причиной системных проблем безопасности и проявления человеческого фактора является самоорганизованная критичность, проявление которой в линиях передачи информации обусловливает нелинейность и неустойчивость фрактальных сигналов различной природы. В работе установлена связь переходных функциональных состояний человека с индивидуальностью его когнитивной деятельности. Предложен инструментарий для выявления индуцированных пространственных и временных неоднородностей сред передачи информации, которые порождают скрытые пространственно-временные взаимосвязи на разных масштабных уровнях. Эти взаимосвязи определяют индивидуальность когнитивных графических образов фрактальных и мультифрактальных сигналов различной природы. Создание базы знаний когнитивных графических образов динамической структуры фрактальных и мультифрактальных сигналов различной природы позволит находить решения, которые пока не доступны мозгу и компьютеру в отдельности. Применение трансдисциплинарного конвергентного подхода и инструментария на его основе к электрофизиологическим сигналам человека-оператора демонстрирует преимущества и новые возможности. В частности, выявление скрытых пространственно-временных взаимосвязей, которые определяют проявление человеческого фактора в сложных условиях. Ообсуждается инновационный потенциал конвергентного похода к обучению и прогнозированию деятельности человека (пилота, диспетчера и др.).

Ключевые слова: человеческий фактор; человеко-компьютерное взаемодействие; когнитивная эргономика; когнитивная графика; системная динамика; конвергентний подход; 3D-моделирование.

Мигаль Валерій Павлович – д-р техн. наук, проф., проф. кафедри фізики, Національний аерокосмічний університет ім. М. Є. Жуковського «Харківський авіаційний інститут», Харків, Україна.

Мигаль Галина Валеріївна – д-р техн. наук, доц., проф. кафедри автомобілів та транспортної інфраструктури, Національний аерокосмічний університет ім. М. Є. Жуковського «Харківський авіаційний інститут», Харків, Україна.

Мигаль Станіслав Павлович – канд. архітектури, проф., проф. каф. дизайну, Національний лісотехнічний університет, Львів, Україна.

Valeriy Mygal – Doctor of Technical Sciences, Professor, Department of Physics, National Aerospace University “Kharkiv Aviation Institute”, Kharkiv, Ukraine,
e-mail: valeriymygal@gmail.com, ORCID: 0000-0003-3622-5423.

Galyna Mygal – Doctor of Technical Sciences, Assosiate Professor, Department of Automobile and Transport Infrastructure, National Aerospace University “Kharkiv Aviation Institute”, Kharkiv, Ukraine,
e-mail: mygal.galina@gmail.com, ORCID: 0000-0002-9862-9338.

Stanislav Mygal – Candidate of Architecture, Professor, Department of Design, Ukrainian National Forestry University, Lviv, Ukraine,
e-mail: slava.migal@ukr.net, ORCID: 0000-0001-5267-3934.