УПРАВЛІННЯ У ТЕХНІЧНИХ СИСТЕМАХ

CONTROL IN TECHNICAL SYSTEMS

УПРАВЛЕНИЕ В ТЕХНИЧЕСКИХ СИСТЕМАХ

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ENTROPY APPROACH IN SYSTEM RESEARCH OF DIFFERENT COMPLEXITY OBJECTS TO ASSESS THEIR CONDITION AND FUNCTIONALITY

Kozulia T. V. – Professor, Dr. Sc., Professor of Software Engineering and Information Technology Management department National Technical University "Kharkiv Polytechnic Institute".

Sviridova A. S. – Master of Software Engineering and Information Technology Management department National Technical University "Kharkiv Polytechnic Institute".

Kozulia M. M. – PhD, Associated Professor of Software Engineering and Information Technology Management department National Technical University "Kharkiv Polytechnic Institute".

ABSTRACT

Context. Consideration of comprehensively studied object in the form "system – environment" to obtain an approximate accurate real situation reflection.

Objective. Search for solutions to problematic research issues based on the entropy approach for systems "object – environment" of different nature and complexity, studying them and obtaining knowledge (stable information) and providing them as a set of complex system tasks modulated by different entropy functions.

Method. The following criteria are used to assess the sustainability of the development of a system object: integrity – the failure of the trajectory of development of the object at a certain forecast time interval from a set of safe states; monotony of growth of indicators of development of object on a certain time interval with the subsequent preservation of them in the set intervals of admissible values; compliance of the development trajectory with the target changes according to the requirements of safety and sustainable development, resistance to disturbance, including asymptotic stability of the program trajectory and structural stability of the system.

In the conditions of nonlinear development of events and spontaneity of processes "object – external systems" at stable structure of system object of research it is expedient to apply the entropic approach and knowledge from the field of the theory of stability developed for technical and cybernetic systems.

Results. The proposed entropy approach to analysis is determined by the fact that the object is characterized from the standpoint of compliance with acceptable regulatory constraints and processes regarding the acceptability of the object of the external environment or the possibility of resolving the situation of coexistence "object – environment".

Within the analysis of a system object, this means that for both stationary and dynamic conditions, their state is described by a certain function, the changes of which indicate the approach to a certain point of homeostatic relations with the environment.

The practical application of the provided methodological proposal for finding solutions in conditions of uncertainty of a certain kind is considered on the example of determining measures to influence the course of positive development of the child's body in the situation of diagnosis of cerebral palsy in the form of information and software application at realization of the appointments of medical character applied to them (factors of influence of emergency).

Conclusions. The proposed entropy approach to the choice of decision-making problems for determining the state and changes as a result of process transformations in system objects of the type "studied system – environment" in conditions of uncertainty does not require additional conditions characteristic of known estimates by criteria in common mathematical means of decision making.

KEYWORDS: entropic approach, entropy-information estimates, software application, complex objects, WindowsForms technology.

ABBREVIATIONS

ApEn is an entropy of approximation;
BESA is a Burg entropy spectral analysis;
BG is a blood glucose;
CESA is a configurational entropy spectral analysis;
CP is a cerebral palsy;

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DM is a decision making;
EEG is an electroencephalogram;
EnDEMO is an ensemble double entropy and multi-purpose optimization;
EP is an episyndrome;
FFA is a frequency floods analysis;
HD is a Halphen distribution;
IGH is an internal gastric hemorrhage;
ME is a maximum entropy;
MSE is a multiscale entropy approach;
PV is a periventricular;
PVI is a periventricular ischemia;
PVL is a periventricular leukomalacia;
RMSE is a root mean square error;
SampEn is a sampling entropy algorithm;
SpecEn is a spectral entropy.

NOMENCLATURE

ξ is a variable of system state information;

$\mathrm{MS}(\xi \mid \eta)$ is a variable of mathematical expectation of conditional entropy;

$\mathrm{M\Delta S}(\xi \mid \eta)$ is a variable of change of conditional entropy at variable ξ;

$\mathrm{N}(\mathrm{Y}_a)$ is variable of the number of the set Y_x elements;

ΔN_i is a variable of changes in the number of elements in the object of the *i*-th type in the total number of changes in the system ΔN;

$S(\xi \mid \eta)$ is a variable of conditional entropy η at $\xi = x$;

$\Delta S(\xi \mid \eta)$ is a variable of changes in conditional entropy η at $\xi = x$;

k is a proportionality coefficient, Boltzmann constant, $k = 1.38\ 10^{-23}$ J / K;

$\Delta\Omega$ – changes in the number of possible microstates (methods) by which you can make a given macroscopic state of the system, identifying the number of system microstates, provided that all microstates are equally likely.

INTRODUCTION

Scientific activity of deep study and knowledge of the world in general is based on the use of achievements of domestic and world science and technology to meet social, economic, cultural and other needs, regulated in Ukraine by the Law of Ukraine "On scientific and scientific-technical activities" of 26.11.2015 № 848-VIII. The difficulty of matching the data obtained by calculations or modeling to the real states of complex systems is that most of the complexity is considered in terms of dimensionality or structural properties of the studied objects. As the experience of modern monitoring (information-analytical) systems related to the study of complex objects, such as different in the hierarchy of ecological systems [1–4], the complexity is generally appropriate to consider with the peculiarities of the interaction of such an object with the environment, which consists of systems set of different nature, in direct or indirect contact with the components and elements of such an object. The study of such system objects is based on the accuracy of their model representation and the clarity of the definition of the target position for structuring as a complex complex of cooperative nature, ie independent functioning systems structurally linked to achieve this goal.

For most of the designed systems in modelling are problematic issues of the cognitive process, which have two directions of scientific research evolution, namely obtaining a result from less to more meaningful, from less to more general knowledge. Establishing a unanimous answer, making a meaningful decision at the maximum breadth of reality is based on the unity of knowledge, due to the unity of the world, to obtain an adequate model of the surrounding reality. Complex system objects and attempts to solve problems require a special interdisciplinary unifying approach, taking into account the only function of the state of any system – the entropy function. The only approach in the systemological analysis of the initial monitoring data and uncertainty about the relationship of such systems with the environment in relation to the interaction between them and changes accordingly properties and state of systems is defined as an entropic approach.

In previous works, the authors of the article, for example [5], proposed a combination of methods of information-entropy type to resolve complex study issues of complex objects, taking into account their interaction with the environment. The research proposes to introduce in quality problems not so much a complex methodological entropy basis for studying complexly structured systems, but to use the so-called entropy measure of conformity on the basis of functions of different entropies and to connect the phenomenological component to the analytical system of state and complexes functionality in the form of knowledge-oriented databases, where the data is existing knowledge and obtained in the research course [6–8].

Thus, the **purpose** of finding solutions to problematic issues in any field of research based on the entropy approach calculations is determined by the need to consider a comprehensive "object – environment" for systems of different nature and complexity, studying them and obtaining knowledge (stable information) should be provided in as a set of problems of a complex system, modulated by different entropy functions.

The paper proposes to consider the application of the entropy approach calculation to modeling states and processes for the system object "system – environment":

1) theoretical substantiation of the system of entropy functions as a methodological basis of knowledge-oriented analysis of monitoring data to find target solutions for the study of system objects taking into account the process phenomena of internal and external nature;

2) testing of the proposed entropy analytics of system analysis for stabilization of the human body state.

Models and methods of complex system research associated with the environment is an article **object**.

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Subject is entropy approach in system research of different complexity objects to assess their condition and functionality

Methodological basis of a comprehensive study of any object as a systemic formation of the type "object – environment – (object – environment) – processes of internal and external nature – (object – environment)^2 – object^3" it is advisable to build on a universal approach that covers all stages of systematic analysis of monitoring data and allows you to state the acquisition of knowledge about the object after the cognitive process.

1 PROBLEM STATEMENT

Within the framework of the analysis of the system object "researched system – environment" the entropic estimation of a condition of the specified components, their mutual influence and processes is offered. This means that for both stationary and dynamic conditions the state is described by an entropy function, changes in which indicate the approach to a certain point of homeostatic relations with the environment ($S_\varepsilon(K)$).The input data are the results of monitoring information regarding the determination of the characteristic parameters of the situation description in the system "object – environment" and "object system – internal object environment" ($C_\varepsilon(K)$) that meet the objectives of environmental research. In any case, the interaction between systems ξ (set X) and η (set Y) regarding the requirements for the space of their existence $X \times Y$ implemented on many possible pairs U at $a \in X$ for those y from Y_a provided $(a, y) \in U$. Then the information entropy from the description of the study object is determined as follows

$$\Delta S(y \mid a) = \log_2 N(Y_a), \tag{1}$$

where $N(Y_a)$ – the number of elements of the set Y_x, that is, those elements that perceive the action and have a reaction to it within the objectives of the study: $a = \overline{1, n}$, $n \in N$

System state information ξ (in x) regarding available information about η (relatively y) is set by the formula

$$I(x : y) = \Delta S(y) - \Delta S(y \mid x). \tag{2}$$

If there is data for the system object from different monitoring media sources, which consists of unrelated or weakly related information (indicators, factors, measurement parameters, etc.), subject to certain probabilistic laws, in practice it is advisable to introduce a probabilistic approach. Within its limits mixing of probabilities and frequencies is allowed at considerable on time and volume of supervision; formation of mathematical expectation for entropy $MS_W(y \mid x)$ and information $MI_W(x : y)$, the value of which can take an excellent value (in the combinatorial approach, it is always a positive value, which should be when you imagine the amount of information). According to A. N. Kolmogorov [25], the true measure of the amount of information is the average value $I_W(x, y)$, characterizing the tightness of the connection between the systems ξ and η, state parameters x, y symmetrically: $S_W(x \mid x) = 0$, $I_W(x : x) = S_W(x)$, $I_W(x, y) = MI_W(x : y) = MI_W(y : x)$ despite the fact that $S_W(y \mid x)$ and $I_W(x : y)$ are functions from x. For system analysis, values are introduced in accordance with the following accepted definitions.

The amount of information to establish the exact value ξ in the presence of a known and sufficient amount of values $\eta = y_j$ equals

$$S(\xi \mid \eta = y_j) = -\sum_i p_{i|j} \log_2 p_{i|j},$$

(in the proposed version of the analysis according to fig. 2 $\Delta S(\xi \mid \eta = y_j) = -\sum_i p_{i|j} \log_2 p_{i|j}$, where $p_{i|j}$ incompatible probability distribution $P\{\xi = x_i, \eta = y_j\} = p_{ij}$, and the difference between the probability of obtaining data / information about the studied object and the actual one with clearly defined properties or target, ie

which is on average

$$MS(\xi \mid \eta) = -\sum_j P(\eta = y_j) \sum_i p_{i|j} \log_2 p_{i|j},$$

on offer

$$M\Delta S(\xi \mid \eta) = -\sum_j P(\eta = y_j) \sum_i p_{i|j} \log_2 p_{i|j},\ p_{i|j} = \Delta p_{i|j} \tag{4}$$

[24]–[25].

The amount of information relatively ξ, contained in the results of the previous stage (task) or determined by the characteristics of the system η, is equal to the difference

$$I(\xi \mid \eta) = S(\xi) - MS(\xi \mid \eta);$$

and informational changes about the studied object will be $\Delta I(\xi \mid \eta) = \Delta S(\xi) - M\Delta S(\xi \mid \eta)$ according to the obtained observation data

$$I(\eta \mid \xi) = -\sum_i p_{ij} \log_2 \frac{p_{ij}}{P\{\xi = x_i\} P\{\eta = y_j\}}, \quad \Delta I(\eta \mid \xi) = f(\Delta p_{ij}) \tag{5}$$

According to equations (2)–(5) we have the final calculated definitions of the information background of the studied questions:

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$$\Delta S_W(x) = -\sum_x \Delta p(x) \cdot \log_2 \Delta p(x);$$
$$\Delta S_W(y \mid x) = -\sum_i \Delta p(y \mid x) \cdot \log_2 \Delta p(y \mid x); \qquad (6)$$
$$\Delta I_W(x : y) = \Delta S_W(y) - \Delta S_W(y \mid x).$$

Thus, when determining an object state according to statistical data, sets of microstates of the system are considered according to the statistical function of Boltzmann entropy in order to determine the probability of obtaining a macroscopic system realization. When studying the system "object – environment" it is advisable to have information on the change in the probability of supporting the implementation of the macro-situation, which is responsible for the target equilibrium in the space of states and processes in such a system (see Fig. 2):

$$\Delta S = k \cdot \ln \Delta \Omega . \qquad (7)$$

Subject to changes in the system, when the object interacts with the environment, certain results are obtained N-probable consequences (outputs) p_n, of which interesting are the modified ΔN, determining the realization of equilibrium or purpose in accordance with changes in the Hartley entropy:

$$\Delta S = \log_2 \Delta N . \qquad (8)$$

This sequence of obtaining a chain of entropy changes in the analysis of states and processes allows us to move in the direction of probable trajectories in space "object – environment", leading to the goal or desired development in such a system or object in its current conditions. Thus, the level of knowledge about the system state (final decision) is defined as Shannon's information entropy for independent changes in events X, which corresponds ΔN-altered probabilistic states described by probabilities $p_n \left(n = \overline{1, N}\right)$:

$$\Delta S_x = -\sum_{n=1}^{N} p_n \cdot \log_2 p_n = -M\left[\log_2 \Delta p_n\right]. \qquad (9)$$

The final result of the search for a solution is evaluated as follows:

– the minimum probability of change, which corresponds to the implementation of the required macrostate with a single probability;

– the maximum probability of change, which leads to a uniform distribution of the probability of realization of states close to the solution $\Delta n = \overline{1, \Delta N}, \Delta p_n = 1/\Delta N$;

– zero for other cases of changes in statistical entropy according to Shannon:

$$\Delta S_x = -\sum_{s=1}^{l} \frac{\Delta N_i}{\Delta N} \cdot \ln \frac{\Delta N_i}{\Delta N} . \qquad (10)$$

The final state is determined by the structural entropy, according to which the system's desire for equilibrium is formed ($\Delta S \to 0, S_1 \to \min \to \Delta S > 0, S_2 \to \max$)

For all solutions, the system or object must reach the *attractor* – a structure (function) that sets (determines) the stable system state (synergetics, nonlinear thinking). Thus, for any statement of the problem of ecological assessment of the situation for the studied object "system – environment" it is important to establish the current situation as a starting point for establishing the changes occurring, by probabilistic estimation through the entropy function taking into account the interaction between object components at the level of "impact – response" to increase the information field of the study and achieve real and accurate results.

2 REVIEW OF THE LITERATURE

Complex systems study, which are open and multidimensional formations, is based on the creation of models taking into account their stochastic nature of behavior and the relationship with the elements. System analysis of such objects is proposed to be carried out on the so-called entropy model, which is a promising direction for studying complex systems with ambiguous or probabilistic behavior and building methods for their study. The use of the entropy function as a universal function of the systems state and processes is often considered in the development of methods for identifying the properties of studied objects and in their modeling to study and create projects for the use of natural resources for economic purposes [9–12].

The authors of recent generalized publications on the modeling of complex systems argue that complexity is an integral feature of the system. In general, any object of study consists of elements set, and the more elements it contains, the more complex it is. However, the number of elements that make up the system is not the only factor of complexity. Not only the number of elements is a factor, but also the number of interactions between these elements, as well as how the intensity of these interactions should be taken into account when analyzing the complexity of any formation level. The number of interactions with the system environment and their intensity should be taken into account in the analytical consideration. An important factor is the functions delivered by the system and their status (ie stability in the performance of activities and security of the system) [2]. There are two main types of system complexity:

– internal complexity: refers to the system structural complexity – is a function of the elements number, the number of interactions and the intensity (or strength) of these interactions;

– external complexity: refers to the system / complexity of the interface environment – is a function of the interactions number between the system and its environment, the intensity of these interactions and their probabilistic expected performance functions.

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In such studies, Shannon's information entropy is proposed as an indicator of complexity. Its value depends on the detail level of the object study, the number of elements in a particular system and the relationship between them, the hierarchy levels number, and so on. As shown in the articles, according to Shannon's information entropy, smaller sets mean less complexity. The choice of aggregation allows you to deal with subsets separately to determine the complexity. To do this, it is proposed to focus on the complex system properties and the needs and goals of the study of complex systems through the process of modeling at the stage of problem identification and focus on the diagnosis of the interests system.

Since the complexity requires an unambiguous structure, it is proposed to clearly define the properly measured basic indicators of system properties based on calculations of the model complexity of the form Higraph. This model allows you to display the complexity of the system in accordance with the relationship of the Hygraph components and simplify it by aggregating in a useful way according to the constraints without losing the content of the studied system.

Despite the developed appropriate proposals for working with complex systems, it remains a problem to organize the elements at each level of the hierarchy or study stage so that the results correspond not only to the holistic model of the analyzed complex object, but also to real monitoring or practice. This applies to the need to maintain the amount of information load on the system element in any research schedule, ie not to provide conditions for restrictions, but to take into account the internal connections and interactions with the surrounding environmental systems.

In the study of ecological systems and the use of natural resources, an entropy-based index is proposed to establish the optimal type of hydraulic system and its condition for water softening to avoid natural and man-made hazards [11–12]. Entropy as a measure of the system state of natural and man-made species is proposed by the authors as a modified indicator to assess the suitability of water distribution network, where there are hydraulic uncertainties, such as flow rate in the pipes, uncertainty due to mechanical parameters, the probability of failure that consider simultaneosly [11]. The entropy measure in the proposed method of determining the quality of network demand is calculated by establishing a coefficient based on the ratio of nodal requirements to the total costs of all parts of the network. The probability of failure of hydraulic systems is also based on the entropy function assessment of the hydraulic network state based on the probability of their failure in any specified hazard scenario using the penalty function, which is satisfactorily inserted into the existing entropy function. This comprehensive approach in solving problems of quality assessment of a complex system object based on one entropy function allowed to combine the assessment of mechanical behavior of units in a functioning hydraulic network, finding the optimal hydraulic scheme for designing a new system, deciding on the best water softening plan for existing network, exposed to various hazards of natural and man-made origin. For this purpose, the entropy-based index is proposed as an effective tool for comprehensive assessment of the entire hydro network state, which, however, does not provide information about the causes of hazards and their consequences. Therefore, it is still necessary to position the object of study in an appropriate manner to the environment and interaction with external systems, taking into account changes over time in the object.

Similarly, Canadian scientists [12] propose to overcome the uncertainties arising from data processing such as time series when modeling situations from the state of hydrometric networks based on the use of entropy as a methodology of so-called EnDEMO, which takes into account the uncertainties from the generation of the input data ensemble. The proposed offers for the Endemo approach provided a more reliable result by creating an ensemble to account for uncertainty in the simulated time series datasets, provided opportunities to identify more reliable locations for potential stations.

To solve the problem of environmental pollution and rational use of environmental resources in the socio-economic aspect, entropy is considered as a component of analysis methods, in accordance with the common thermodynamic nature of ecological, socio-economic systems and the uniqueness of entropy maximization in achieving such targets or equilibrium state. it is proposed to introduce an entropy function to determine compliance with the safety requirements of the analyzed natural and man-made objects both separately and in their interaction [13–15].

Thus, scientists at Wuhan University [13] proposed solutions to the rational use of water resources and environmental and man-made safety through the application of the principle of ME for frequency floods analysis (FFA), which is the basis for determining the size of hydraulic structures. In this study, entropy properties as a measure of chaos / equilibrium of the system are proposed to be considered for a comprehensive analysis of the studied object state in combination with Halphen distribution (HD) in Monte Carlo modeling was used to evaluate descriptive and predictive abilities of suggested procedure HD/ME which have good descriptive ability due to its flexible shape and excellent tail properties, least RMSE and higher efficiency compared to the procedure in several simulated cases. The proposed HP / ME procedure is well suited for estimating project floods in two selected areas and is offered as an alternative candidate for hydrological frequency analysis, but in addressing flood behavior, this approach is simplified and static for situation analysis.

Similar proposals for the introduction of entropy in the analytical system of research were provided by scientists from the Department of Biological and Agricultural Engineering at the University of Texas and the College of Water Resources and Architectural Design of Northwestern University in China [14]. Water flows are complex systems of stochasticity, seasonality, and periodicity that are proposed to be studied using configurational entropy spectral analysis (CESA), which combines spectral analy-

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sis and time series analysis to characterize the periodically obtained picture of the situation and the corresponding manifestations of stochasticity.

In the field of water resources management, irrigation and estimation for forecasting monthly groundwater levels [15], it is proposed to introduce the domain of entropy determination into the methodological support of spectral analysis – this is the frequency domain in which three types of entropy are known. This entropies from the basis for three types of spectral analysis in research predicting monthly and annual groundwater levels, which is a stochastically nonequilibrium system, namely (1) BESA, (2) CESA and (3) relative spectral analysis. In general, the proposal concerns not so much the complexity of entropy research as the possibility of comparing different parameters of groundwater state based on their representation as an entropy function.

Special natural biological objects of ecological research include the human body, which is considered as a complex stochastic system formation, in which the systems are functionally and corporately combined to ensure human life in certain environmental conditions. To establish the state of such a systemic object as an organism, it is proposed to use various entropic functions and methods of entropy analysis in order to diagnose changes and predict the consequences of effects on its functionality at the violations risk [16–22].

Quantitative assessment of irregularity (lack of order) in the obtained measurement data or monitoring observations of the system state or system object is overcome by entropy spectral analysis, which in recent decades has been innovatively improved to remove some limitations for studying biological signals such as entropy approximation ApEn and SampEn. The latter are used to study endocrine-metabolic functionality and heart rate, EEG, vocals and hemodynamics of time series.

Stochastic and unpredictable components of the system order for diagnosing the state of body systems due to EEG are proposed to be considered when estimating changes in the amplitude component of the EEG power spectrum at each frequency as probabilities in entropy calculation and as information on temporal changes in EEG signal. Such propositions apply to so-called SpecEn, based on Shannon entropy in the form of Fourier transform peaks as a reflection of the regularity of the relative spectral power density of the EEG. In statistical studies to obtain short and noise data sets, such as biomedical signals, the ApEn is used to study time series for similar data, taking into account N samples (points). ApEn (m, r, N) measures the logarithmic probability of close (within r) sections of m models of continuous observations. Thus, in the entropy analysis of background EEG activity in patients with Alzheimer's disease, ApEn remain close within the same tolerance width r in the following comparisons. For a sequence with larger response values corresponding to greater complexity or irregularity in the data, a non-negative number is assigned to avoid the appearance of ln (0) in the calculations. To avoid the disadvantages of such data analysis, the calculation of SampEn is proposed. SampEn (m, r, N) for certain parameters of the path length m and the tolerance r as the negative logarithm of the conditional probability that two sequences similar to m points remain similar in the next paragraph, where the coincidence is not included in the probability calculations. Thus it is possible to avoid dependence on the length of the EEG recording and to obtain relative consistency under certain circumstances, to reduce the computation time.

Thus, Shannon's entropy formula is accordingly normalized and considered convenient as a way to quantify the distribution of spectral power in spectral analysis to identify objects of study, such as the state of the body in Alzheimer's disease [16]. Quantitative determinations of traditional BG values based on linear spectral analysis are performed using a nonlinear MSE method, which determines the signal complexity using a popular SampEn to measure its inequalities in various time scale [17].

In the system data processing of system state in spectral analysis uses the so-called optimal threshold to distinguish between AD and normal EEG signals, which is best obtained by the concept of fuzzy entropy defined in a complex wavelet with multiple resolution [18]. This methodology allows to obtain a high signal-noise ratio and a lower root mean square error than with the traditional approach.

Socio-environmental issues in the study of safety monitoring are proposed to be considered through the prism of entropy to overcome its increase in the infection control system to find internal and external, micro- and macromotivators that maintain a stable institutional focus and optimal allocation of resources [19]. Prioritization, new destabilization factors and lack of resources accompany the monitoring of objects as a control system of specific intervention in the presence of the inevitable tendency to increase entropy in an endless cycle of periodic activity, modernization of the system in a constant feedback cycle with the external environment.

Thus, overcoming the disorder and nonlinear system signals (responses) of the systems studied on the aspect of studying their state and functionality is considered in accordance with the properties of changes in entropy function of various kinds, which allows to obtain heterogeneous knowledge of the tasks. Due to the combinatorial nature of entropy, cognition in the study of objects concerns not only the statics of its existence, but also the processes that support it or lead to its reconstruction. In this case, we are dealing with the enthalpic part of the change in free energy, the modulation of thermal oscillations as the fraction of free energy in entropy. The process of studying stochastic interactions between more elements in the system and between their systems requires modeling a portrait of events within the object, a complete picture of interactions with entropy forces as a universal feature of self-organization of systems and the use of several areas of knowledge that often remain unconnected. obtaining the integrity of the phenomena perception. This applies to the study of both micro- and macrosystems, such as protein structures and human behavior, which is a conse-

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quence of emotional states in areas of the brain [20–21]. The results of the review show that a combination of applied spectral, entropy and time functions has positive results in such works, which can provide and transmit reliable biomarkers for determining the profiles of SS, ES and TS for a complete description of a person and intervention in his brain.

Thus, the experience of research of complex systems to study their properties and some process phenomena has shown the benefits of using the entropy approach, which will be appropriate in the study of system objects of the type "system – environment" for learning the system and DM regarding the achievement of the target state by this system, ie regulation as a directed influence from environmental systems.

3 MATERIALS AND METHODS

Software applications have been developed for entropy analysis, for example, for statistical monitoring studies on entropy analysis of time series, EZ Entropy in MATLAB environment in object-oriented style with graphical user interface has been proposed [22]. This application offers various stages of analysis, including (1) data recording processing, (2) batch processing of several data files, (3) calculation windows, (4) revocation, (5) display of intermediate data and final results, (6) adjustment input parameters and (7) export the results of calculations after startup or in real time during the analysis.

In accordance with the proposed entropy approach to the study of the object "system – environment" introduced an experimental model of transition from baseline to target in accordance with the identified factors of significant influence on the development of events in the system with internal changes and external interaction with the environment, namely "system – (system – environment) – process – the situational state of the system", based on logic, knowledge and experience [23–24].

In the building process of a complex study object model, one of the important issues is to substantiate the probability of its implementation, compliance with functional sustainable development "system – environment", which is achieved if the system model is stable and itself in response to environment, ie maintaining equilibrium behavior. The latter is characterized by the reflection of the real situation through a logical sequence of causal relationships, ie a system of dependent events, processes, phenomena, states of use of conditional entropy. In this case, the interconnected systems and processes are determined by combining into a hypersystem or system formation, which is the "memory" of the system by estimating the rate of information loss, the degree of chaos of the system, namely Kolmogorov entropy or K-entropy. Gradual changes in the time of the system are not related and do not determine information about the current and future state, it is only a reflection of gradual movement due to transformations of a certain degree of determinism or stochasticity.

For static analysis, it is natural to evolve the Boltzmann entropy, defined as a measure of the information incompleteness about the system, into Shannon's information entropy, which is the basis of quantitative information theory [9]. The study of the functionality over time of complex system formations, processes in them and external interactions cannot be considered simply on the basis of their modeling by studying discrete random events in the form of probability distribution and information to determine the required event in such space – Hartley entropy.

The system movement in the space of time and states in accordance with the situation of its environment occurs to a certain position of immutability or to a certain target state, naturally conditioned or desired or planned. Achieving such a position will be determined by the Rainier entropy according to the definitions of the Kulbak-Leibler distance as information divergence, relative entropy, distance from the true distribution of events or states. If in ecology these are diversity indices, then in the case of studies of a damaged system or a system that moves away from natural development (for example, the human body or its individual systems), it is a measure of the complexity of the situation according to the introduced range indicator, divergence.

System approximation to the natural target occurs through certain microstates, a number of which are not additive for entropy generalization, as indicated in the Tsallis entropy. This allows the study of complex system objects to provide statistical observations as descriptions of states, which take into account the interaction of system elements with neighboring neighbors, the system as a whole and its components.

Thus, the representation of a complex system in the form of an entropy model allows you to fully take into account statistics about it and consistently resolve uncertainties about the presence of ignorance of internal processes and existing interactions with external systems. With this approach to obtaining information about the studied object, the entropy of the multidimensional stochastic system "object – environment (external systems)" is calculated, which consists of two components – the boundary entropy, which determines the independence of the object integrity in the system at available internal systems (additivity of the entropy state function) and the entropy of the relationships degree between the system elements, ie processes in the space of coexistence of the elements of the stochastic system (fig. 1).

The following criteria are used to assess the sustainability of a system object:

1) integrity – the failure of the trajectory of object development at a certain forecast time interval from the set of safe states;

2) monotony of growth of object development indicators on a certain time interval with the subsequent preservation of them in the set intervals of admissible values;

3) compliance of the development trajectory with targeted changes in terms of security and sustainable development;

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4) resistance to perturbation, including asymptotic stability of the program trajectory and structural stability of the system.

In the conditions of nonlinear development of events and processes spontaneity "object – external systems" at stable structure of system object of research it is expedient to apply the entropic approach and knowledge from the field of the stability theory developed for technical and cybernetic systems. In this case, the stochasticity and uncertainty of the situation is overcome by consistent presentation and analysis of qualitative information to obtain results on the conditions for maintaining structural stability in the study system "object – environment" in accordance with changes in entropy function ΔS from analysis "state – processes". According to the results obtained with this approach, it is likely to establish spontaneous processes of equilibrium regulation in the system formation or transition to new states of equilibrium with changes that are associated with increasing entropy in the studied system (Fig. 2).

The changes that occur in the object under the influence of factors influencing its elements of the surrounding environmental systems, in accordance with the entropy approach have a similar sequence and effectiveness (Fig. 3).

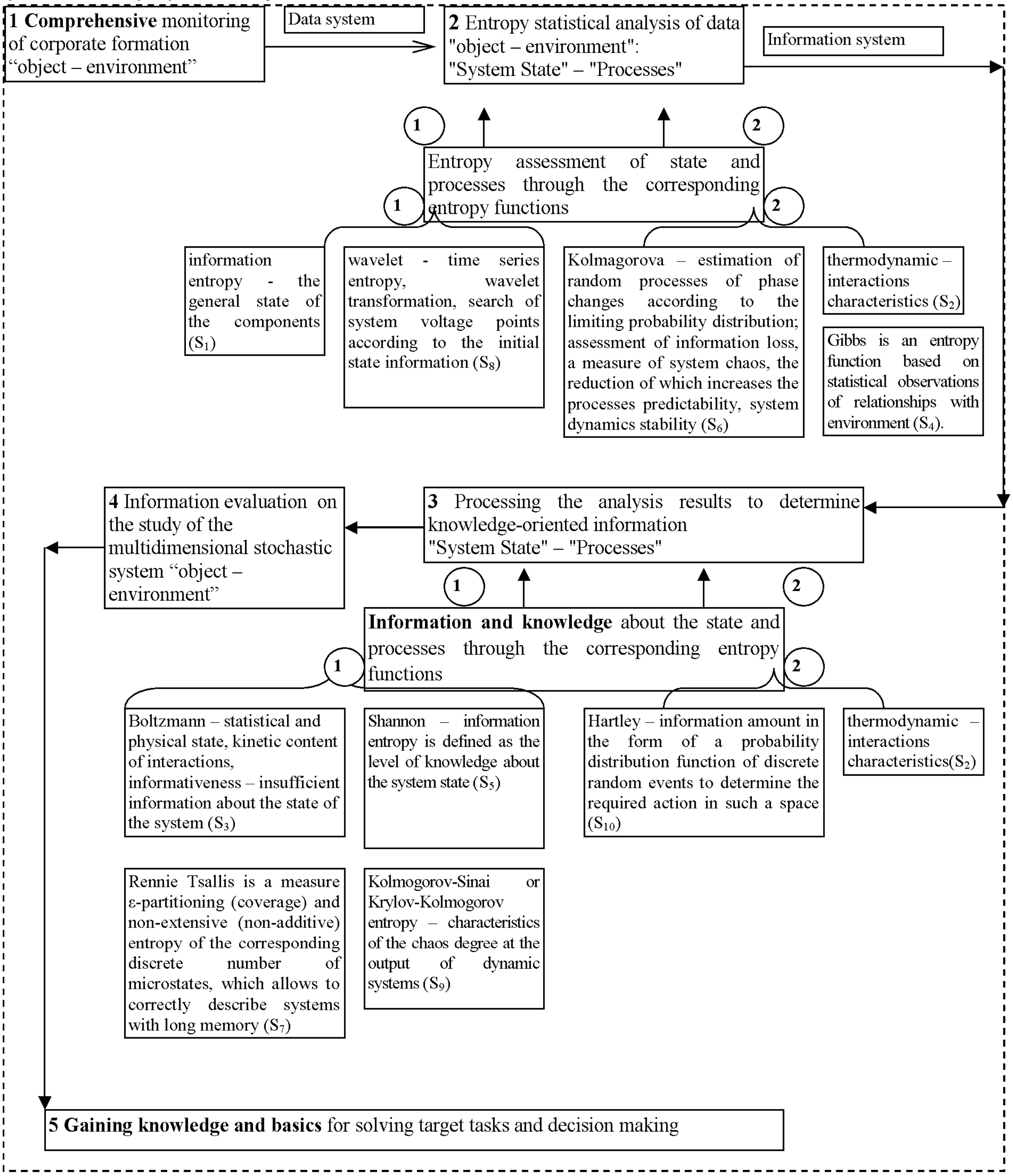

Figure 1 – Scheme of entropy approach implementation in the study of complex system formations "object – environment" (the author's proposal)

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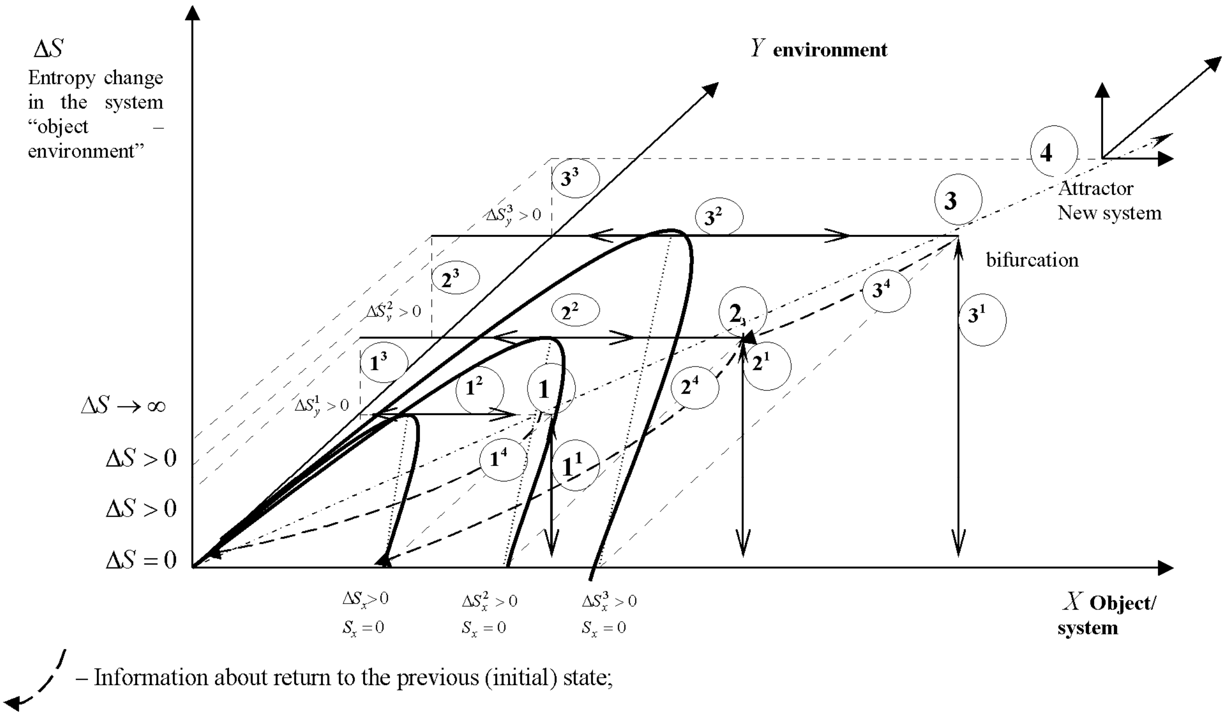

Figure 2 – Scheme for assessing the state of the studied system "object – environment" on the entropy approach to the analysis of "state – process" (the author's proposal): 1, 2, 3, 4 – states of the system in accordance with the conditions of interaction "object – environment"; 1^1, 2^1, 3^1 – arbitrary inverse processes of returning the system to its initial state, ie $S_x = 0$; 1^2, 2^2, 3^2 – arbitrary processes of changes from the interaction "object – environment", which leads to $\Delta S > 0$; 1^3, 2^3, 3^3 – changes in the system "object – environment" in relation to the state of external systems, leading to new states; 1^4, 2^4, 3^4 – processes of self-regulation between the object and the environment within the studied system, maintaining balance in the system with its allowable changes

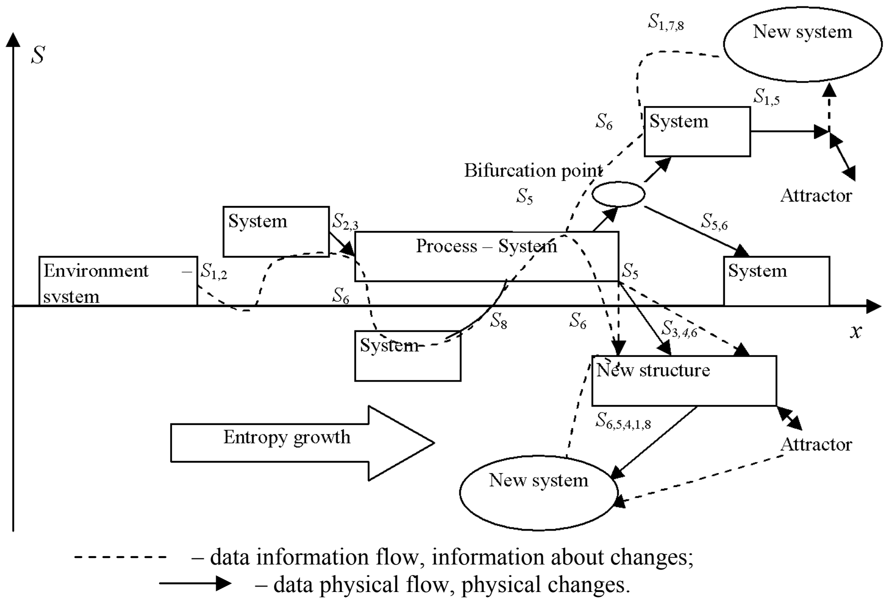

Figure 3 – Scheme of changes in the state of the system according to entropy-information estimates equilibrium search: $S_{1,2,3,4,5,6,7,8}$ – information entropy, thermodynamic, Boltzmann, Gibbs, Shannon, Kolmagorov, Rainy-Tsalles, wavelet entropy (author)

According to Figure 2, the systems state is assessed by qualitative and quantitative characteristics of entropy change, and Figure 3 shows the individual trajectory of the final structuring of the object in the space of interaction with the environment through the prism of entropy function. To obtain an unambiguous answer to the need to adjust the relationship in the studied system between the object and environmental systems, it is proposed to use not the value of the entropy function, but its changes as characteristics of entropy shift state or process from the established trajectory of their development (natural, reference, standard, boundary, etc).

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4 EXPERIMENTS

The practical application of the provided methodological proposal for finding solutions in conditions of uncertainty of a certain kind is considered on the example of determining measures to influence the course of positive development of the child's body in the situation of cerebral palsy (CP) diagnosis in the form of information and software application at realization of the appointments of medical character applied to them (environment influence factors).

The condition of the child's body is assessed on the basis of qualitative observations of children groups of different gestational periods: healthy (19) (health groups), cerebral palsy (68), hydrocephalus (11) to study the effects of internal gastric hemorrhage (IGH of certain degree (dg), 2dg, 3dg, 4dg) on the result of "walking" (includes the category of help_walk) or not walking in combination with parallel disorders in the body of PV, PVL 1dg, 2dg, 3dg; PVI, EP [26].

According to the obtained monitoring data in the medical institution of health level of the above children groups, it is proposed to determine their condition according to the probability of walking opportunities for children of different ages and genders. The target point of the treatment process is the maximum walking of the child, which is fixed by the absence of changes in entropy function, ie during the implementation of decisions to return the natural movement of the child (see Fig. 2). In this case, the probability of deviations absence of these parameters of qualitative observations by children groups of different gestational periods from the health indicators of the walking group without restrictions is achieved, the following set of changes of possible microstates is considered:

$$\Delta\Omega = F\{\text{IGH1dg, IGH2dg, IGH3dg, IGH4dg, PVL1dg, PVL2dg, PVL3dg, PVI, EP}\}, \quad (11)$$

In order to determine the body moving trajectory affected by cerebral palsy to the most healthy state based on the results of monitoring the child's body during treatment, it is proposed to automatically establish the state according to this algorithm.

Step 1. The implementation of the macro-situation is determined by five groups of indicators of the state of the organism (IGH, PVL, PVI and episyndrome), which corresponds to certain changes in the entropy of the system (see equation (7)).

Step 2. Calculated the total number of changes in the system ΔN as the probability of changing the deviations number of healthy movement indicators in the observation groups walking, auxiliary walking – $\Delta n = \overline{1, \Delta N}, \Delta p_n = 1/\Delta N$.

Step 3. The system achievement of the desired result at this stage is determined – walking without restrictions (see Hartley entropy (8)).

Step 4. Establishment of the information characteristic concerning determinations of results of changes in in groups of supervision walking, auxiliary walking (see the equation (5)).

Step 5. The general characteristic of changes in the investigated object concerning positive development of child organism in a situation of the diagnosis of a cerebral palsy (see realization of consecutive calculations (6)) is given (Fig. 4).

The proposed entropy approach to analysis is determined by the fact that the object is characterized from the standpoint of compliance with acceptable regulatory constraints and processes regarding the acceptability of the object of the external environment or the possibility of resolving the situation of coexistence "object – environment".

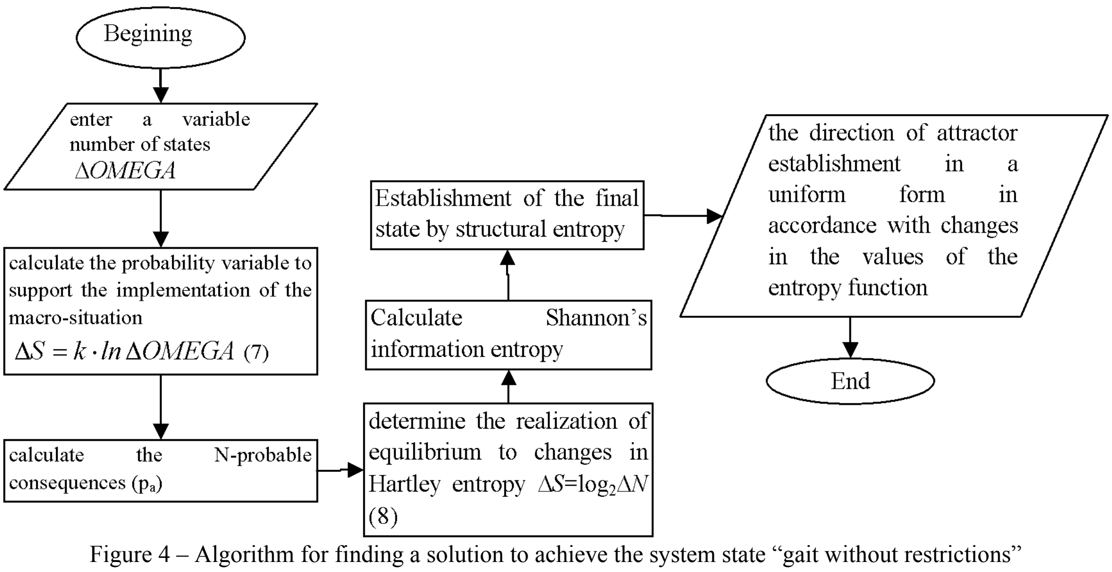

Figure 4 – Algorithm for finding a solution to achieve the system state "gait without restrictions"

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5 RESULTS

According to the proposed entropy approach, the above dynamics of the system in the environment of other systems is proposed to identify the direction of the attractor in a uniform form in accordance with changes in entropy function in the sequence "system state – excitation – changes – process – state of stabilized system". This makes it possible to study biological systems on the basis of a complementary methodology with an idea of current instantaneous events.

During the implementation of experimental studies on the proposed algorithm for entropy assessment of states and processes C# software application using Windows-Forms technology is developed. As a result of working with the software application, a graph is obtained, which shows four groups of children: healthy, walking without restrictions, auxiliary walking and non-walking, who have the appropriate quantitative IGH, PVI, PVL and episyndrome (Fig. 5).

The Oy axis reflects the probability of one of the four parameters for a particular child state. The Ox axis reflects week on which the child was born. The left part of Figure 5 provides recommendations for increasing or decreasing the value of each of the indicators for children to achieve the state "walking without restrictions".

6 DISCUSSION

The proposed entropy approach to the choice of decision-making problems for determining the state and changes as a result of process transformations in system objects of the type "studied system – environment" in conditions of uncertainty does not require additional conditions characteristic of known estimates by criteria in common mathematical means of DM. The application of the entropy approach ensures full compliance with the methodology of the stability theory, according to which the result of data processing invariant with respect to the processing method corresponds to reality, while using known criteria the processing result depends on the processing method and reflects the subjectivity of the researcher but not objective ratio.

At the same time, it should be noted that when processing monitoring data for the transition to information results, there are difficulties in the transition to the probabilistic characteristics of the state and dynamic phenomena. Therefore, in this paper, the entropy estimate is closely related to statistical data processing (Fig. 6).

CONCLUSIONS

The following tasks have been solved:

1) Theoretically proved that for DM to achieve a certain target function that is responsible for the state and functionality of the studied object in certain surrounding conditions by environment systems, it is advisable to use not the function S itself as the implementation of the complex system macrostate through certain experiments of microstates, but its changes in the system "object – environment" in relation to the state of external systems ΔS^{123}_{y}(see Fig. 2) using for certain situations different entropy functions with their processing in relation to the

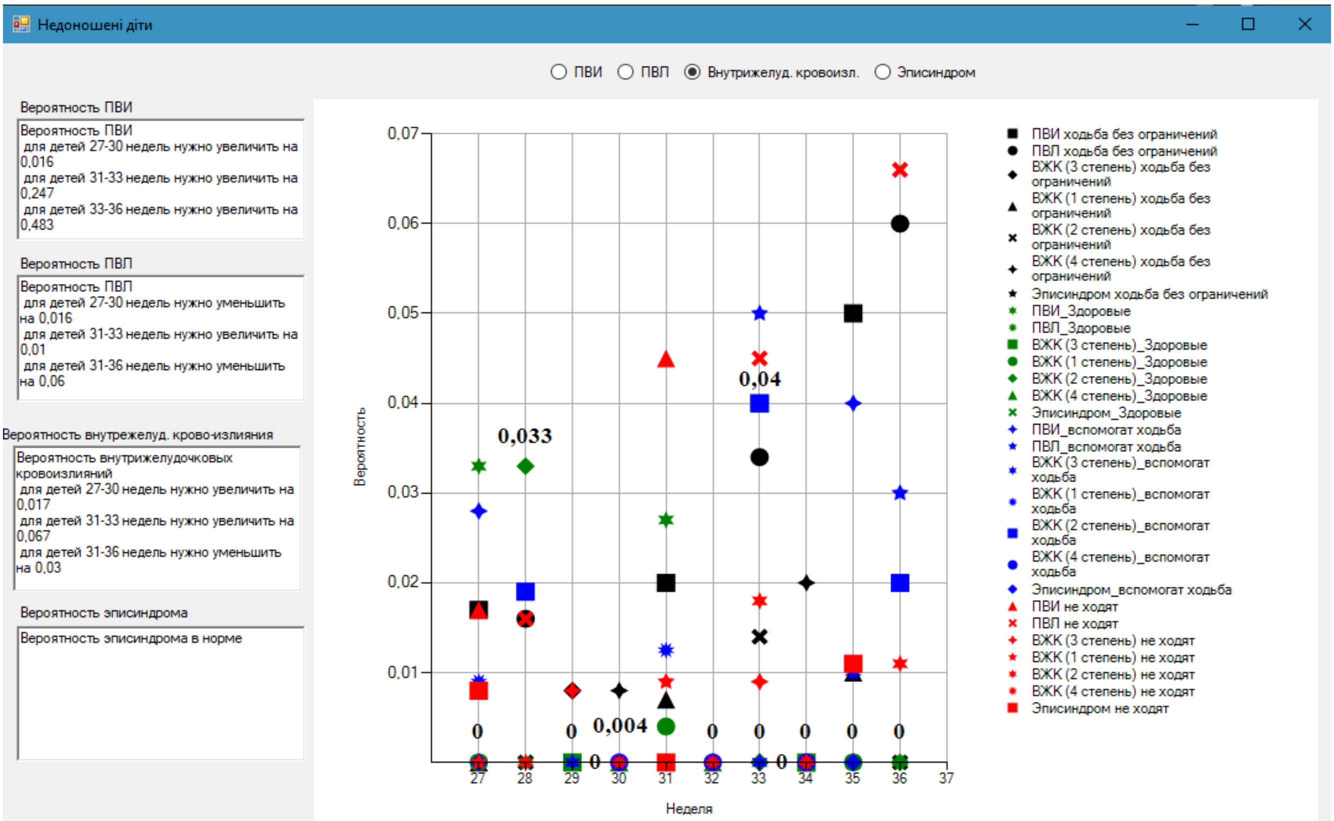

Figure 5 – Graphic interpretation of child's condition determination and decisions to improve it

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Initial data for the analysis of the patients condition in the "walking" group

	1 NewVa	2 NewVa	3 IGH	4 IGH I	5 IGH I	6 IGH V	7 PVL	8 PVL I	9 PVL II	10 PVL III	11 EП	12 27_boy	13 31_boy	14 34_boy	15 27_girl	16 31_girl	17 34_girl
1	0,275	0,05	0	0	0,008	0,008	0,008	0,008	0	0,01		0,05	0,075	0,15	0,107	0,107	0,179
2		0,075	0,00	0,014	0	0	0	0,034	0	0,02		0	0,007	0,012	0	0	0
3		0,15	0,01	0	0	0,023	0,012	0,035	0,023	0,04		0	0,014	0	0	0,015	0
4	0,393	0,107	0	0	0,015	0	0,015	0,031	0	0,04		0,08	0	0	0,015	0	0
5		0,107	0	0,015	0	0	0	0,031	0,015	0,04		0,008	0	0,023	0	0	0
6		0,179	0	0	0	0	0,018	0,036	0,036	0,08		0,008	0	0,012	0,015	0	0,018
7												0,008	0,034	0,035	0,031	0,031	0,036
8												0	0	0,023	0	0,015	0,036
9												0,017	0,02	0,046	0,046	0,046	0,089

New Var 1 – probability of boys and girls getting into the "walking" group;

New Var 2 – probability distribution by gestational age

Factor analysis results of the "walking" state factors

Variable	Factor Loading Extraction: Prin (Marked loadin) Factor 1
NewVar2	-0,991
IGH I	-0,194
IGH II	0,408
IGH III	0,372
IGH IV	-0,242
PVL I	-0,677
PVL II	-0,647
PVL III	-0,928
PVI	-0,9077
Expl.Var	3,9464
Prp.Totl	0,4385

Variable	Factor Loadings (Unr Extraction: Principal (Marked loadings are) Factor 1	Factor 2
NewVar2	-0,991	-0,048
IGH I	-0,194	-0,557
IGH II	0,408	-0,792
IGH III	0,372	0,827
IGH IV	-0,242	-0,086
PVL I	-0,677	0,706
PVL II	-0,647	-0,484
PVL III	-0,928	-0,150
PVI	-0,908	0,148
Expl.Var	3,946	2,409
Prp.Totl	0,438	0,268

Variable	Factor Loadings (Unrotated) (Extraction: Principal compone (Marked loadings are > .7000) Factor 1	Factor 2	Factor 3
NewVar	-0,991	-0,048	0,074
IGH I	-0,194	-0,557	-0,751
IGH II	0,408	-0,792	0,439
IGH III	0,372	0,827	0,003
IGH IV	-0,242	-0,086	-0,939
PVL I	-0,677	0,706	-0,128
PVL II	-0,647	-0,484	0,215
PVL III	-0,928	-0,150	0,083
PVI	-0,908	0,148	0,387
Expl.Var	3,946	2,409	1,863
Prp.Totl	0,438	0,268	0,207

Factor load in the group "walking"

Value	Eigenvalues (walking.sta) Extraction: Principal components Eigenvalue	% Total variance	Cumulative Eigenvalue	Cumulative %
1	3,946	43,849	3,946	43,849
2	2,409	26,762	6,355	70,611
3	1,863	20,699	8,218	91,310

Figure 6 – Fragment of statistical analysis of experimental data

proposed approaches (equations (3)–(10)); this, in turn, allows for a consistent analysis of uncertainties and their resolution to establish the conditions for stabilizing the object or achieving the goal of regulating the situation with the development of certain solutions;

2) An example of solving problematic issues regarding the stabilization of the disturbed organism in certain conditions by probabilistic entropy, namely its changes for children of different ages and conditions with pathological deviations to the function of "walking", which allowed to offer a software application that allows you to automatically provide an answer to the child's condition (assignment to a certain group of health on the move) and a decision on the maximum approach of the system to the state "walking without restrictions" (see Fig. 5).

Scientific novelty – the entropy-information representation of the compound of complex systems of the form "object – environment" at the level of state and resources of its change when interacting with the environment.

Further development is the immitational modeling of real dynamic systems based on the entropy and informational presentation of their states and dynamics.

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REFERENCES

1. Shuangshuang Li, Sokchhay Heng, Sokly Siev, Chihiro Yoshimura, Oliver Saavedra, Sarann Ly Multivariate interpolation and information entropy for optimizing raingauge network in the Mekong River Basin, *Hydrological Sciences Journal*, 2019, Vol. 64, Issue 12, pp. 1439–1452. DOI: https://doi.org/10.1080/02626667.2019.1646426
2. Hadi Mahmoudi-Meimand, Sara Nazif, Ali Abbaspour Rahim, Sabokbar Hasanali Faraji An algorithm for optimisation of a rain gauge network based on geostatistics and entropy concepts using GIS, *Journal of Spatial Science*, 2016, Vol. 61, Issue 1, pp. 233–252. DOI: https://doi.org/10.1080/14498596.2015.1030789
3. Azadeh Gholamia, Bonakdari Hossein, Mohammadianb Majid, Zajia Amir Hossein, Gharabaghi Bahram Assessment of geomorphological bank evolution of the alluvial threshold rivers based on entropy concept parameters, *Hydrological Sciences Journal/Journal des Sciences Hydrologiques*, 2019, Vol. 64, Issue 7, pp. 856–872. DOI: https://doi.org/10.1080/02626667.2019.1608995
4. Hao L., Su X., Singh V. P., Ayantobo O. O. Spatial Optimization of Agricultural Land Use Based on Cross-Entropy Method, *Entropy,* 2017, № 19, pp. 592–607. DOI: https://doi.org/10.3390/e19110592
5. Kozulia T., Kozulia M. Integrated information system assessment of complex objects environmental safety level, *Visnyk NTU «HPI». Serija Systemnyj analiz, upravlinnja ta informacijni tehnologii'*. Harkiv, NTU «HPI», 2017, № 55 (1276), pp. 39–44. DOI: https://doi.org/10.20998/2079-0023.2017.55.07
6. Kozulia T. V., Bilova M. A., Kozulia M. M., Fonta N. G. Informacionnoe obespechenie analiza bezopasnosti prirodno-tehnogennyh ob#ektov v kontekste ih vzaimodejstvija s okruzhajushhej sredoj, *International scientific journal*, Tbilisi, 2017, №3 (53), pp.72–80
7. Kozulia T. V., Kozulia M. M. Using graph-analytical methods modeling of system objects to determine integrated assessment of their state, *Problems of Atomic Science and Technology*, 2019, No. 3(121), pp. 116–123.
8. Kozulia T., Kozulia M., Didmanidze I. Comprehensive study of the systemic formation «object – environment» safety state, *Technogenic and Ecological Safety*, 2020, No. 7(1/2020), pp. 3–12.
9. Tyrsin A. N. Jentropijnoe modelirovanie mnogomernyh stohasticheskih sistem. Monografija. Voronezh, «Nauchnaja kniga», 2016, 156 p.
10. Aboutaleb Hycham, Monsuez Bruno Entropy in Design Phase: a Higraph-Based Model Approach, *2017 IEEE International Conference on Information Reuse and Integration (IRI), 4–6 Aug. 2017: proceedings. San Diego, IEEE,* 2017, pp. 526–534. DOI: https://doi.org/10.1109/iri.2017.51
11. Hosseini M., Emamjomeh H. Entropy-based Serviceability Assessment of Water Distribution Networks, Subjected to Natural and Man-made Hazards, *International Journal of Engineering*, 2014, Vol. 27, No. 5, pp. 675–688. DOI: https://doi.org/10.5829/idosi.ije.2014.27.05b.02
12. Keum Jongho, Frezer Seid Awol, Ursulak Jacob, Coulibaly Paulin Introducing the Ensemble-Based Dual Entropy and Multiobjective Optimization for Hydrometric Network Design Problems: EnDEMO, *Entropy,* 2019, No. 21, P. 947 DOI: https://doi.org/10.3390/e21100947
13. Xiong Feng, Guo Shenglian, Chen Lu, Jiabo Yin, Pan Liu Flood Frequency Analysis Using Halphen Distribution and Maximum Entropy, *Journal of Hydrologic Engineering*, 2018, 23(5), 04018012. DOI: https://doi.org/10.1061/(asce)he.1943-5584.0001637
14. Zhou Zhenghong, Juanli Ju, Xiaoling Su, Vijay P. Singh, Gengxi Zhang Comparison of Two Entropy Spectral Analysis Methods for Streamflow Forecasting in Northwest China, *Entropy,* 2017, №19 (11), P. 597. DOI: https://doi.org/10.3390/e19110597
15. Cui Huijaun, Vijay P. Singh Entropy Spectral Analyses for Groundwater Forecasting, *Journal of Hydrologic Engineering*, 2017, №22(7), 06017002. DOI: https://doi.org/10.1061/(asce)he.1943-5584.0001512
16. Abásolo D., Hornero R, Espino P, Álvarez D, Poza J. Entropy analysis of the EEG background activity in Alzheimer's disease patients, *Physiological Measurement* 2006, №27(3), pp. 241–53. DOI:10.1088/0967-3334/27/3/003
17. Fabris C., Sparacino G, Sejling AS, Goljahani A, Duun-Henriksen J, Remvig LS, Juhl CB, Cobelli C. Hypoglycemia-related electroencephalogram changes assessed by multiscale entropy, *Diabetes Technology & Therapeutics,* 2014, №16(10), P. 688–94. DOI: https://doi.org/10.1089/dia.2013.0331
18. Lazar P., Jayapathy R, Torrents-Barrena J, Mol B, Mohanalin, Puig D. Fuzzy-entropy threshold based on a complex wavelet denoising technique to diagnose Alzheimer disease, *Healthcare Technology Letters* 2016, №3(3), pp. 230–238. DOI: https://doi.org/10.1049/htl.2016.0022
19. Baracco G J. Battling Entropy in Infection Control Systems, *Infection Control & Hospital Epidemiology,* 2017, №38(12), pp. 1428–1429. DOI: https://doi.org/10.1017/ice.2017.225
20. Kornev A. P. Self-organization, entropy and allostery, *Biochemical Society Transactions*, 2018, №46(3), pp. 587–597. DOI: https://doi.org/10.1042/bst20160144
21. Al-Qazzaz NK. Sabir MK, Ali SHBM, Ahmad SA, Grammer K. Electroencephalogram Profiles for Emotion Identification over the Brain Regions Using Spectral, Entropy and Temporal Biomarkers, *Sensors (Basel).* 2019, №20(1), P. 59. DOI: https://doi.org/10.3390/s20010059
22. Li Peng Entropy: a software application for the entropy analysis of physiological time-series, *BioMedical Engineering OnLine,* 2019, №18(1), P. 30. DOI: https://doi.org/10.1186/s12938-019-0650-5
23. Lennikov R. V. Informacionno-jentropijnye modeli innovacionnyh processov v jekonomicheskih sistemah, *Izvestija Tul'skogo gosudarstvennogo universiteta Estestvennye nauki. Informatika,* 2011, Vyp. 1, pp. 167–176.
24. Kozulia T. V., Kozulia M. M. Informacijno-programne zabezpechennja obrobky ta analizu stanu skladnyh ekologichnyh ob'jektiv, *Informacijna bezpeka ta informacijni tehnologii': monografija*. Harkiv, TOV «DISA PLJuS», 2019, pp. 202–231.
25. Kolmogorov A. N. Teorija informacii i teorija algoritmov. Moscow, Nauka, 1987, 304 p.
26. Litovchenko T. A., Vareshnjuk E. V., Sharonova N. V., Kozulia T. V. Matematicheskij analiz i prognozirovanie razvitija bol'shih motornyh funkcij u detej, rozhdennyh nedonoshennymi, *Nauchnye vedomosti. Serija Medicina. Farmacija.* 2014, № 11 (182). Vyp. 2, pp. 109–112.

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ЕНТРОПІЙНИЙ ПІДХІД У СИСТЕМНИХ ДОСЛІДЖЕННЯХ ОБ'ЄКТІВ РІЗНОЇ СКЛАДНОСТІ З ОЦІНКИ ЇХ СТАНУ ТА ФУНКЦІОНАЛЬНОСТІ

Козуля Т. В. – професор, доктор технічних наук, професор кафедри Програмної інженерії та інформаційних технологій управління, Національний Технічний Університет «Харківський Політехнічний Інститут».

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Свірідова А. С. – магістр кафедри Програмної інженерії та інформаційних технологій управління, Національний Технічний Університет «Харківський Політехнічний Інститут».

Козуля М. М. – канд. техн. наук, доцент кафедри Програмної інженерії та інформаційних технологій управління, Національний Технічний Університет «Харківський Політехнічний Інститут».

АНОТАЦІЯ

Актуальність. Розгляд комплексно дослідженого об’єкта у вигляді «система – навколишнє середовище» для отримання наближено точного відображення реальної ситуації.

Мета. Пошук рішень проблемних питань наукових досліджень на базі ентропійного підходу для систем «об’єкт – навколишнє середовище» різної природи і складності, вивчення їх і отримання знань (стійкої інформації) та надання їх у вигляді комплексу завдань складної системи, модульованих завдяки різним ентропійним функціям.

Метод. Для оцінки стійкості розвитку системного об’єкта використовують такі критерії: цілісність – невихід траєкторії розвитку об’єкта на певному прогнозному інтервалі часу з множини безпечних станів; монотонність зростання індикаторів розвитку об’єкта на певному інтервалі часу з наступним збереженням їх у заданих інтервалах припустимих значень; відповідність траєкторії розвитку цільовим змінам за вимогами безпеки і сталого розвитку;стійкість до збурювання, у тому числі, асимптотична стійкість програмної траєкторії й структурна стійкість системи.

В умовах нелінійного розвитку подій і самодовільності процесів «об’єкт – зовнішні системи» при стійкій структурі системного об’єкта дослідження доцільним є застосування ентропійного підходу та знань із області теорії стійкості, розробленої для технічних і кібернетичних систем.

Результати. Запропонований ентропійний підхід щодо аналізу визначається тим, що об’єкт характеризується з позицій дотримання допустимих нормативних обмежень і процеси стосовно прийнятності об’єктом впливів зовнішнього оточення чи можливості урегулювання ситуації співіснування «об’єкт – навколишнім середовищем».

У межах аналізу системного об’єкта це означає, що і для стаціонарних, і для динамічних умов їх стан описується певною функцією, зміни якої вказують на наближення до певної точки гомеостатичних відносин з навколишнім середовищем.

Практичне застосування наданої методологічної пропозиції з пошуку рішень в умовах невизначеності певного роду розглянуто на прикладі визначення заходів впливу на хід позитивного розвитку організму дитини в ситуації діагнозу дитячий церебральний параліч (ДЦП) у вигляді інформаційно-програмного додатку щодо імовірності віднесення дитини до групи ходьба або не ходьба при реалізації застосованих до них призначень лікувального характеру (фактори впливу НС).

Висновки. Запропонований ентропійний підхід до вибору розв’язку задач прийняття рішень щодо визначень стану і змін в наслідок процесних перетворень в системних об’єктах виду «досліджена система – навколишнє середовище» в умовах певної невизначеності не вимагає виконання додаткових умов, характерних для відомих оцінок за критеріями в поширених математичних засобах ПР.

КЛЮЧОВІ СЛОВА: ентропійний підхід, ентропійно-інформаційні оцінки, програмне забезпечення, складні об’єкти, технологія WindowsForms.

УДК 519.2

ЭНТРОПИЙНЫЙ ПОДХОД В СИСТЕМНОМ ИССЛЕДОВАНИИ ОБЪЕКТОВ РАЗЛИЧНОЙ СЛОЖНОСТИ ПО ОЦЕНКЕ ИХ СОСТОЯНИЯ И ПРОИЗВОДИТЕЛЬНОСТИ

Козуля Т. В. – профессор, доктор технических наук, профессор кафедры Программной инженерии и информационных технологий управления, Национальный Технический Университет «Харьковский Политехнический Институт».

Свиридова А. С. – магистр кафедры Программной инженерии и информационных технологий управления, Национальный Технический Университет «Харьковский Политехнический Институт».

Козуля М. М. – канд. техн. наук, доцент кафедры Программной инженерии и информационных технологий управления, Национальный Технический Университет «Харьковский Политехнический Институт».

АННОТАЦИЯ

Актуальность. Рассмотрение комплексно исследованного объекта в виде «система – окружающая среда» для получения приближенно точного отражения реальной ситуации.

Цель. поиск решений проблемных вопросов научных исследований на базе энтропийного подхода для систем «объект – окружающая среда» различной природы и сложности, изучение их и получения знаний (устойчивой информации) и предоставления их в виде комплекса задач сложной системы, модулированных благодаря различным энтропийным функциям.

Метод. Для оценки устойчивости развития системного объекта используют следующие критерии: целостность – невыход траектории развития объекта на определенном прогнозном интервале времени из множества безопасных состояний; монотонность роста индикаторов развития объекта на определенном интервале времени с последующим сохранением их в заданных интервалах допустимых значений; соответствие траектории развития целевым изменениям по требованиям безопасности и устойчивого развития; устойчивость к возмущению, в том числе, асимптотическая устойчивость программной траектории и структурная устойчивость системы.

В условиях нелинейного развития событий и самодовильности процессов «объект – внешние системы» при устойчивой структуре системного объекта исследования целесообразно применение энтропийного подхода и знаний из области теории устойчивости, разработанной для технических и кибернетических систем.

Результаты. Предложенный энтропийный подход к анализу определяется тем, что объект характеризуется с позиций соблюдения допустимых нормативных ограничений и процессы относительно приемлемости объектом воздействий внешнего окружения или возможности урегулирования ситуации сосуществования «объект – окружающая среда».

В рамках анализа системного объекта это значит, что и для стационарных, и для динамических условий их состояние описывается определенной функцией, изменения которой указывают на приближение к определенной точке гомеостатических отношений с окружающей средой.

Практическое применение предоставленной методологической предложения по поиску решений в условиях неопределенности своего рода рассмотрен на примере определения мер воздействия на ход позитивного развития организма ребенка в ситуации диагноза детский церебральный паралич (ДЦП) в виде информационно-программного приложения по вероятности отнесения ребенка к группе ходьба либо не ходьба при реализации примененных к ним назначений лечебного характера (факторы влияния НС).

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Выводы. Предложенный энтропийный подход к выбору решении задач принятия решений относительно определений состояния и изменений вследствие процессных преобразований в системных объектах вида «исследована система – окружающая среда» в условиях некоторой неопределенности не требует выполнения дополнительных условий, характерных для известных оценок по критериям в распространенных математических средствах ПР.

КЛЮЧЕВЫЕ СЛОВА: энтропийный подход, энтропийно-информационные оценки, программное приложение, сложные объекты, технология WindowsForms.

ЛІТЕРАТУРА / ЛИТЕРАТУРА

1. Shuangshuang Li Multivariate interpolation and information entropy for optimizing raingauge network in the Mekong River Basin / [Li Shuangshuang, Heng Sokchhay, Siev Sokly et al.] // Hydrological Sciences Journal . – 2019 – Vol. 64, Issue 12. – P. 1439–1452. DOI: https://doi.org/10.1080/02626667.2019.1646426
2. An algorithm for optimisation of a rain gauge network based on geostatistics and entropy concepts using GIS / [Mahmoudi-Meimand Hadi, Nazif Sara, Rahim Ali Abbaspour, Hasanali Faraji Sabokbar] // Journal of Spatial Science. – 2016. – Vol. 61, Issue 1. – P. 233–252. DOI: https://doi.org/10.1080/14498596.2015.1030789
3. Azadeh Gholamia Assessment of geomorphological bank evolution of the alluvial threshold rivers based on entropy concept parameters. / [Azadeh Gholamia, Hossein Bonakdari, Majid Mohammadianb et al.] // Hydrological Sciences Journal/Journal des Sciences Hydrologiques. – 2019. – Vol. 64, Issue 7. – P. 856–872. DOI: https://doi.org/10.1080/02626667.2019.1608995
4. Spatial Optimization of Agricultural Land Use Based on Cross-Entropy Method. / [L. Hao, X. Su, V. P. Singh, O. O. Ayantobo] // Entropy. – 2017. – № 19. – P. 592–607. DOI: https://doi.org/10.3390/e19110592
5. Kozulia T. Integrated information system assessment of complex objects environmental safety level / T. Kozulia, M. Kozulia // Visnyk NTU «HPI». Serija Systemnyj analiz, upravlinnja ta informacijni tehnologii'. Harkiv: NTU «HPI», 2017. – № 55 (1276). – P. 39–44. DOI: https://doi.org/10.20998/2079-0023.2017.55.07
6. Kozulia T. V. Informacionnoe obespechenie analiza bezopasnosti prirodno-tehnogennyh ob#ektov v kontekste ih vzaimodejstvija s okruzhajushhej sredoj / [T. V. Kozulia, M. A. Bilova, M. M. Kozulia, N. G. Fonta] // International scientific journal, Tbilisi, – 2017, – №3 (53). – P.72–80.
7. Kozulia T.V. Using graph-analytical methods modeling of system objects to determine integrated assessment of their state. / T. V. Kozulia, M. M. Kozulia // Problems of Atomic Science and Technology. – 2019. – № 3 (121). – P. 116–123.
8. Kozulia T. Comprehensive study of the systemic formation «object–environment» safety state / T. Kozulia, M. Kozulia, I. Didmanidze // Technogenic and Ecological Safety. – 2020. – №7(1/2020). – P. 3–12.
9. Tyrsin A. N. Jentropijnoe modelirovanie mnogomernyh stohasticheskih sistem. Monografija. / A. N. Tyrsin. – Voronezh : «Nauchnaja kniga», 2016. – 156 p.
10. Aboutaleb Hycham. Entropy in Design Phase: a Higraph-Based Model Approach. / Hycham Aboutaleb, Bruno Monsuez // 2017 IEEE International Conference on Information Reuse and Integration (IRI). – P. 526–534. DOI: https://doi.org/10.1109/iri.2017.51
11. Hosseini M. Entropy-based Serviceability Assessment of Water Distribution Networks, Subjected to Natural and Man-made Hazards. / M. Hosseini, H. Emamjomeh // International Journal o f Engineering, (May 2014) – Vol. 27, No. 5. – P. 675–688. DOI: https://doi.org/10.5829/idosi.ije.2014.27.05b.02
12. Keum Jongho Introducing the Ensemble-Based Dual Entropy and Multiobjective Optimization for Hydrometric Network Design Problems: EnDEMO / [Jongho Keum, Seid Awol Frezer, Jacob Ursulak, Paulin Coulibaly] // Entropy. – 2019. – № 21. – 947 p. DOI: https://doi.org/10.3390/e21100947
13. Xiong Feng. Flood Frequency Analysis Using Halphen Distribution and Maximum Entropy / [Feng Xiong, Shenglian Guo, Lu Chen et al.] // Journal of Hydrologic Engineering. – 2018. – 23(5). – 04018012. DOI: https://doi.org/10.1061/(asce)he.1943-5584.0001637
14. Zhou Zhenghong. Comparison of Two Entropy Spectral Analysis Methods for Streamflow Forecasting in Northwest China / [Zhou Zhenghong, Ju Juanli, Su Xiaoling et al.] // Entropy. – 2017. – №19 (11). – P. 597. DOI: https://doi.org/10.3390/e19110597
15. Cui Huijaun Entropy Spectral Analyses for Groundwater Forecasting / Cui Huijaun, P. Singh Vijay // Journal of Hydrologic Engineering. – 2017. – №22(7). – 06017002. DOI: https://doi.org/10.1061/(asce)he.1943-5584.0001512
16. Entropy analysis of the EEG background activity in Alzheimer’s disease patients / [D. Abásolo, R. Hornero, P. Espino et al.] // Physiological Measurement. – 2006 – № 27(3). – P. 241–53. DOI:10.1088/0967-3334/27/3/003
17. Hypoglycemia-related electroencephalogram changes assessed by multiscale entropy. / C Fabris, G Sparacino, AS Sejling et al.] // Diabetes Technology & Therapeutics. – 2014. – №16(10). – P. 688–94. DOI: https://doi.org/10.1089/dia.2013.0331
18. Lazar P. Fuzzy-entropy threshold based on a complex wavelet denoising technique to diagnose Alzheimer disease. / [P. Lazar, R. Jayapathy, J. Torrents-Barrena et al.] // Healthcare Technology Letters 2016, – №3(3). – P. 230–238. DOI: https://doi.org/10.1049/htl.2016.0022
19. Baracco GJ. Battling Entropy in Infection Control Systems / GJ. Baracco // Infection Control & Hospital Epidemiology. – 2017 Dec. – № 38(12). – P. 1428–1429. DOI: https://doi.org/10.1017/ice.2017.225
20. Kornev A. P. Self-organization, entropy and allostery. / A. P. Kornev // Biochemical Society Transactions. – 2018. – Jun 19. – № 46(3) – P. 587–597. DOI: https://doi.org/10.1042/bst20160144
21. Al-Qazzaz NK. Electroencephalogram Profiles for Emotion Identification over the Brain Regions Using Spectral, Entropy and Temporal Biomarkers / [NK Al-Qazzaz, MK Sabir, SHBM Ali et al.] // Sensors (Basel). – 2019. – Dec. 20. – № 20 (1). – P. 59. DOI: https://doi.org/10.3390/s20010059
22. Li Peng Entropy: a software application for the entropy analysis of physiological time-series. / Li Peng // BioMedical Engineering OnLine. – 2019. – Mar 20. – № 18 (1). – P. 30. DOI: https://doi.org/10.1186/s12938-019-0650-5
23. Lennikov R. V. Informacionno-jentropijnye modeli innovacionnyh processov v jekonomicheskih sistemah / R. V. Lennikov // Izvestija Tul’skogo gosudarstvennogo universiteta Estestvennye nauki. Informatika. – 2011. – Vyp. 1. – P. 167–176.
24. Kozulia T. V. Informacijno-programne zabezpechennja obrobky ta analizu stanu skladnyh ekologichnyh ob’jektiv / T. V. Kozulia, M. M. Kozulia // Informacijna bezpeka ta informacijni tehnologii’: monografija. – Harkiv : TOV «DISA PLJuS», 2019. – P. 202–231.
25. Kolmogorov A. N. Teorija informacii i teorija algoritmov / A. N. Kolmogorov. – M. : Nauka, 1987. – 304 p.
26. Matematicheskij analiz i prognozirovanie razvitija bol’shih motornyh funkcij u detej, rozhdennyh nedonoshennymi. / [T. A. Litovchenko, E. V. Vareshnjuk, N. V. Sharonova, T.V. Kozulia] // Nauchnye vedomosti. Serija Medicina. Farmacija. – 2014. – № 11 (182), Vyp. 2. – P. 109–112.

DOI 10.15588/1607-3274-2021-4-14