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SYSTEM-INFORMATION MODELS FOR INTELLIGENT INFORMATION PROCESSING

The subject of the study is system-information models of processes and systems and their use for intelligent processing of information in production tasks. The use of intelligent information processing in production management systems is currently one of the key areas of development of informatics. **The aim** of the work is to develop system-information models of processes and systems for intelligent information processing allowing to analyze and solve production problems, in conditions of uncertainty. In the article **the following tasks** are solved: to analyze approaches to the definition of information characteristics of processes and systems; to develop the basis for modeling of system-information processes and systems for intelligent information processing; to develop system-information models and ways of their application for intelligent information processing in the tasks of production. **The following methods** are used: system-information approach to processes and systems; system-information modeling of processes and systems. **The following results** were obtained: the analysis of approaches to the definition of information characteristics of processes and systems; developed principles of modeling system-information processes and systems for intelligent processing of information; introduced the concepts of system information and information measure; developed system-information models and methods of their application for the intelligent processing of information in the tasks of production. **Conclusions.** The development of methods for solving various classes of practical problems using intelligent information processing is one of the key areas of research in computer science. The developed system-information models of processes and systems for intelligent information processing allow analyzing and solving problems. Thereby increase the efficiency of solving problems of analysis, synthesis and forecasting of production systems and technologies, as well as problems of production management. The system-information approach to processes and systems operates with new concepts – system information and information measure, it allowed developing system-information models for intelligent processing of information, as well as ways of their application at stages of product life cycle, which allowed solving problems of production. System-information models of processes and systems describe interaction between source and receiver on information level on the basis of sensitivity threshold. The communication channel between the source and the receiver of information operates, as a rule, under conditions of uncertainty, which can lead to the loss of information during transmission due to possible changes in the characteristics of the system. To describe their interaction, some models of intelligent information processing can be used, in particular, neural network models or fuzzy inference models. Their use will improve the efficiency of receiver state prediction, taking into account the state of the transmitter and the conditions of communication channel operation. The presented article has shown the relevance of developing system-information models for intelligent information processing at the levels of data reception, interpretation and communication, which allows expanding the class of solved production tasks.

Keywords: system-information models; system information; information measure; sensitivity threshold; intelligent information processing.

Introduction

The development of methods for intelligent information processing of processes and systems is currently one of the key areas of development of computer science.

The definition of the term information plays a key role in the development of intelligent information processing methods. Despite its widespread occurrence, the concept of information remains one of the most debatable in science, and the term can have different meanings in different branches of human activity [1, 2]. The development of approaches to the definition of the meaning of the term information allows us to expand the boundaries of the application of intelligent information processing in specific branches of human activity.

The systems-information approach to processes and systems is one of the approaches to defining the meaning of the term information, and is used in developing models for intelligent information processing. As a scientific direction in information theory, it was summarized in [3, 4]. From the position of the system-information approach the amount of a priori and a posteriori information, which the object possesses, as well as the information process of interaction between objects are subject to measurement. The model of a priori information characterizes an object before interaction, the model of information process – in the process of interaction, and the model of posterior information – after interaction.

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System-information models consist of attributes [3, 4]:

1) extent information (space) in three coordinates;

2) duration information (time);

3) intensity information (value) of objects properties.

The above interrelated information attributes represent a system-information space as a whole. Each manifested property of a system (internal and external) in the information space is characterized by the amount of information. This quantity is determined by a set of information of intensity, extent and duration of the system's properties and characterizes the process of its functioning.

Interaction of system and environment is reflected by a fragment of reality of manifestation of system in the information space. The information space structures attributes by quanta of sensitivity threshold interval of lower and upper values of intensity of properties, duration and extent. The change of system state characteristics depends on the change of attributes and their values that make up the information space. In this case, the change of the state of the system occurs in the presence of information connection between the system and the environment.

The methodology of system-information modeling of processes and systems is based on the principle of determining the information measure (number), which is the ratio of the total (limits of possible) value of an attribute to its partial (variable) value of sensitivity threshold. This dimensionless measure indicates the information of the place of the particular in the general.

The development of system-information models for intelligent information processing in tasks of various classes, including production, and is an important direction in the development of computer science.

Analysis of approaches to defining information characteristics

The object of research in the science of computer science is "information". With all the different interpretations of the concept of information, it is indisputable that information is manifested in material and energy form in the form of a "signal". In its most general form, a "signal" is understood as a value that reflects in some way the state of the system. In this sense, it is natural to consider a signal as the result of some measurements carried out over the system in the process of its observation. The signal reflects both the information of the state of the system and is the cause of the change in the state of the interdependent system.

Information in general can be structured into the following main groups:

1) information of non-living matter (physical information, including technical information),

2) information of living matter (biological, including social),

3) artificial information (coded information), and

4) a combination of information from these three components.

Each of the presented information groups is characterized by its own type of information carrier – «signal», which can be represented in a material-energetic or immaterial-energetic form.

Material-energy signal is a time-varying physical quantity described by a function of time and can be classified:

1) by the physical nature of the information carrier – electrical, electromagnetic, optical, acoustic and others;

2) according to the way the signal is defined – regular (deterministic), defined by an analytical function and irregular (random), taking arbitrary values at any time.

The apparatus of probability theory is used for irregular signals. Depending on the function that describes the parameters of the signal, there are: continuous (analog), continuous-quantized, discrete-continuous and discrete-quantized signals.

Intangible-energy signal is a carrier of information, which so far has not been sufficiently investigated. An example is a signal, which is a representation of such phenomenon as entropy of a system, or a signal in a quantum system.

A special kind of signals are "signs", which, unlike signals of natural origin, are created by self-organizing systems and are intended for the transmission and storage of information. A sign is a material sensually perceived signal (phenomenon, action), which acts as a representative of another object of property or attitude. The science that studies the properties of signs and sign systems is called semiotics. The subject of semiotics is the questions of connection of signs with each other, signs with the phenomena of the external world and signs with the subjects using them as a tool for the purposes of communication.

With all the variety, complexity and multi-level manifestation of information processes, they all contain the basic components:

1) perception by the system of some phenomenon as a signal;

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2) change of the system's state under the influence of a received signal;

3) spatial and temporal transmission of signals.

These three components of the information process, which at different levels of forms of reflection acquire specific characteristics and can be expressed in such concepts as reception, interpretation and communication.

One of the important issues in the development of information technologies that are implemented in intelligent information processing systems is the use of the mathematical form of representation of the processed information. This affects the limitations of the possible choice of information technology for the list of the types of tasks to be solved in intelligent systems, as well as the indicators of the effectiveness of their application.

Information technologies of intellectual information processing systems in conditions of uncertainty are widely used for solving complex tasks that are difficult to formalize [5]. The lack of a universal approach to the form of information representation when solving such problems leads to the need to develop and apply new methods, information technologies, and their complex combination with traditional methods of artificial intelligence.

The main limitations of the known methods and information technologies currently used in intelligent systems for solving problems that are difficult to formalize are due to the methods of information representation and insufficient efficiency in solving the problems of learning, adjustment and adaptation to the problem domain, processing the measured values of incomplete and inaccurate source information, data interpretation and knowledge accumulation, uniform presentation of information coming from different sources, etc. These limitations can be eliminated on the basis of using the system-information approach to the formalization of the measured values of the system information and promising hybrid methods of soft computing – Soft computing [6]. With the help of methods that use a hybrid approach to the representation of information values, it is possible to generate new knowledge under conditions of knowledge deficit and uncertainty, which allows expanding the logical possibilities of intelligent systems that use these technologies.

Significant scientific interest and important practical importance is the development of information models of the subject area in conditions of uncertainty, characterized by incompleteness, unreliability, uncertainty of the initial information, diversity and complexity of the influence of various factors on the decision process, etc. Depending on the degree of uncertainty, information processing tasks can be divided into [7]:

1) tasks, for which an objective assessment of solution results or comparative assessment of at least two solutions is possible;

2) tasks for which an objective assessment is impossible, and it is replaced by expert assessments of specialists in the subject area under study.

The first type of problems refers to poorly structured and difficult to formalize problems characterized by the presence of both quantitative and qualitative dependencies between the elements of the systems under study, with qualitative dependencies tending to dominate. Tasks of this type can be structured as system information on the basis of the theory of systems-information approach.

The second type of problems refers to unstructured (unformalizable) problems whose peculiarity consists only in a qualitative description of the systems, while quantitative dependences between the elements of the system are absent, which determines the necessity of using expert evaluations [7].

Currently, the most effective models of intelligent systems, implemented within the hybrid approach for intelligent information processing, are neuro-fuzzy models [8], which combine the universal approximating capabilities of neural networks, as well as the transparency and interpretability of fuzzy inference systems. The structures of neuro-fuzzy models of intelligent systems in most cases are fixed and, as a rule, redundant, which leads to a decrease in the speed of learning and adaptation of models when external conditions change. A way out in this situation is associated with the possibility of building neuro-phase models of intelligent systems, in which not only parameters, but also the structure of the model as a whole is trained and adapted, which allows to obtain the most effective hybrid models for specific problems of intelligent information processing.

The problem arising in the problems of intelligent information processing in conditions of uncertainty is the problem of constructing an adequate information model of the investigated subject area, as well as the formation of effective models and procedures for finding optimal or close to them solutions. Methods for building information models, allowing a reliable description of design objects and processes occurring

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in them, are determined by the nature of the tasks being solved. That is why the formation and choice of this or that information model can be carried out only after the definition of a particular problem, and even for the same problem, it is possible to use different types of models.

The process of finding solutions for a problem that is difficult to formalize can be represented by two methods.

The first one consists of the following stages [9]:

1) extraction (acquisition), representation and structuring of knowledge about the problem domain;

2) construction of adequate mathematical models of the subject area;

3) prediction of possible variants of solutions (search for solutions);

4) analysis and evaluation of effectiveness of proposed solutions;

5) choice of solution.

Since system information combines quantitative and qualitative characteristics of objects in the information description of the elements of the systems under study, the second method consists in formalizing the problem on the basis of system-information models [10] and consists of the following stages:

1) construction of adequate system-information models of the subject area;

2) analysis and evaluation of the information process;

3) determination of the main characteristics of information objects.

When building system-information models, the key issue is to determine the sensitivity threshold of the subject domain attributes. For example, fuzzy sensitivity threshold is determined using various expert methods, including statistical methods.

An information system is characterized by the presence of internal and external connections, which may have an energy or material character. A distinctive property of an information system is that the structure of energy and material connections is a carrier of information about the properties of the objects of the external world and the internal environment of the system. These links with essential structural features are information links.

The basis of the classical theory of information is based on the results of solving a number of problems on the syntactic level. It relies on the concept of «quantity of information», which is a measure of the frequency of use of signs, which in no way reflects the meaning or importance of the messages transmitted.

The exchange of information between two objects occurs due to deterministic or stochastic information process in accordance with the expressions [3, 4]:

$$I=\log_2\frac{X}{\Delta x},\quad I=\log_2\frac{\mu}{\sigma},$$
$$\log_2\frac{X_1}{\Delta x_1}=\log_2\frac{X_2}{\Delta x_2},\quad \log_2\frac{\mu_1}{\sigma_1}=\log_2\frac{\mu_2}{\sigma_2}. \qquad (1)$$

where: Δx – sensitivity threshold X, σ – standard deviation, μ – expected value.

If the system information is transmitted in error, in the equations of the information process the sign of equality $(=)$ is replaced by a sign of approximation $(\approx)$.

System information is characterized by quantity, quality and value. The quantity of system information is calculated as the logarithm of the ratio of the sign value to the sensitivity threshold in accordance with (1). The quality of system information refers to information processes and characterizes the value of possible losses of received information during the transfer of optimal values of the quantity of system information. The less possible losses in the received information, the more qualitative the received system information, which is calculated on the basis of a posteriori information [3, 4]:

$$\sum_{i=1}^{m}I(x_i)=\sum_{j=1}^{n}I(y_j)\quad I(y)_{кач}=\frac{\sum_{i=1}^{n}I_{x_i}}{\sum_{j=1}^{n}\left(1+\left|\Delta y_j-U_{y_j}\right|\right)}. \qquad (2)$$

where: Δy – sensitivity threshold, U – expanded uncertainty.

The value of system information refers to information processes and is characterized by the efficiency of using the optimal value of the quality of system information:

$$\sum_{i=1}^{m}I(x_i)=\sum_{j=1}^{n}I(y_j)$$
$$I(y)_{val}=\frac{\sum_{j=1}^{n}I_{y_j}}{\sum_{i=1}^{m}I_a(x_i)\times\sum_{j=1}^{n}\left(1+\left|\Delta y_j-U_{y_j}\right|\right)}. \qquad (3)$$

where: Δy – sensitivity threshold, U – expanded uncertainty.

The analysis of approaches to determining the information characteristics of processes and systems showed the relevance of developing system-information models for intelligent information processing at the levels of data reception, interpretation and communication, which will expand the class of solved production tasks.

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System-information models and their application to intelligent information processing

The principles of developing system-information models are based on the scientific provisions in the field of information theory outlined in [10]. The significance of these provisions for science is that they eliminate the drawback of the modern scientific paradigm – the desire to describe everything using the language of dimensionless models, and also allow to reflect such a property of systems and processes as discreteness and specify their absolute optimum dimensions.

The information object of research of the system-information approach is a system – a set of elements X, which are in relations and information links with each other, which forms a certain integrity and unity. System information possessed by elements of the set X is characterized by the interval between the upper X_{up} and lower X_{low} limits of its manifestation, as well as the sensitivity threshold $\Delta x = \left(x - X_{low}\right)/n$, where x is a discrete variable, n is a multiple of Δx – sensitivity threshold on the interval $X_{up} - X_{low}$. In this case the sensitivity threshold takes on the value on the interval $X_{low} - X_0$.

The system information of an object is characterized by the information measure, which is equal to the proportion of the ratio of the total value of the attribute to its private value. The system information indicates the place of the particular in the general. The information measure $\left|I\left(X\right)\right|$ is a function of the absolute value of the qualitative and/or quantitative proportion of the ratio

$$\left|I\left(X\right)\right| = f\left(\frac{X_{up} - X_{low}}{\Delta x}\right) \tag{4}$$

where: $\Delta x = x - X_{low}/n$ – sensitivity threshold.

The information measure is a dimensionless quantity in any system of physical quantities, and is a number. Information $I\left(X\right)$ is a dimensional value of a logarithmic function, and is measured in bits.

From the presented function of the information measure the following tasks are solved.

1. Definition of the discrete variable of a discrete value x:

$$x = \frac{\left(X_{up} - X_{low}\right)\times n}{\left|I\left(X\right)\right|} + X_{low}. \tag{5}$$

2. Determination of the upper limit value of X_{up}:

$$X_{up} = \left|I\left(X\right)\right|\Delta x + X_{low}. \tag{6}$$

3. Determination of the lower limit value X_{low}:

$$X_{low} = X_{up} - \left|I\left(X\right)\right|\Delta x. \tag{7}$$

4. Determination the sensitivity threshold value $\Delta x = \dfrac{x - X_{low}}{n}$:

$$\Delta x = \frac{X_{up} - X_{low}}{\left|I\left(X\right)\right|}. \tag{8}$$

5. Determination of the multiplicity n of the sensitivity threshold Δx in a discrete variable value x:

$$n = \frac{x - X_{low}}{\Delta x}. \tag{9}$$

The above formulas of transformation of information measure are used in intelligent information processing for tasks of analysis, synthesis of objects and forecasting based on the methodology of system-information modeling.

The presented approach to the definition of the concept of information differs from the generally accepted one, where numerical values of data X_{up}, X_{low}, Δx, x, but not their relations, are taken as information.

The next step is to formalize the information connection between elements of the set X, i.e. the information process of transmission of system information.

All qualitative and quantitative characteristics of information assume the presence of a transmitter and a receiver (sender and receiver) of information, i.e. in some kind of information interaction of objects. Formalization of information process of information transfer from sender to receiver describes the equilibrium of information measures of interacting objects:

System-information models of the information process allow us to solve prediction problems on the basis of knowledge of the information parameters of causes, which are informationally related to the information parameters of the receiver. Knowledge of receiver information parameters is obtained directly by the measurement method.

The system-information model of the information process looks like

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$$\begin{aligned}
&\left|I(X_i)\right| = \left|I(X_j)\right|, \quad \left|I(X)\right| = f\left(\left(X_{up} - X_{low}\right)/\Delta x\right),\\
&f_{trans}\left(\frac{X_{iup} - X_{ilow}}{\Delta x_i}\right) = f_{rec}\left(\frac{X_{jup} - X_{jlow}}{\Delta x_j}\right),\\
&\frac{X_{(trans)up} - X_{(trans)low}}{\Delta x_{(trans)}} = \frac{X_{(rec)up} - X_{(rec)low}}{\Delta x_{(rec)}},\\
&n = \frac{x - X_{up}}{\Delta x}, \quad \Delta x = \frac{x - X_{low}}{n},\\
&\frac{\left(X_{(trans)up} - X_{(trans)low}\right) n_{(trans)}}{x_{(trans)} - X_{(trans)low}} = \frac{\left(X_{(rec)up} - X_{(rec)low}\right) n_{(trans)}}{x_{(rec)} - X_{(rec)low}},\\
&\log_2 \frac{\left(X_{(trans)up} - X_{(trans)low}\right) n_{(trans)}}{x_{(trans)} - X_{(trans)low}} = \log_2 \frac{\left(X_{(rec)up} - X_{(rec)low}\right) n_{(trans)}}{x_{(rec)} - X_{(rec)low}}.
\end{aligned} \tag{10}$$

From the equation of system-information model of information process on the basis of proportional ratio of information parameters of attribute (number) of transmitter and receiver, we get knowledge about parameters of information transmitted by transmitter in conditions of uncertainty of sensitivity threshold.

That is, from the equation we determine all previously unknown knowledge about parameters of information of the transmitter beyond the limits of previous experience at this particular moment.

System-information models of processes and systems describe interaction between source and receiver on information level based on sensitivity threshold. The communication channel between source and receiver of information operates, as a rule, under conditions of uncertainty, which can lead to loss of information during transmission due to possible changes in system characteristics. To describe their interaction, some models of intelligent information processing can be used, in particular, neural network models or fuzzy inference models. Their use will improve the efficiency of receiver state prediction, taking into account the state of the transmitter and the conditions of communication channel operation.

The physical interpretation of the information transmission process can be represented as follows. Variable value of the transmitter Δx_2 increases under the influence of various factors till the moment of achievement of information connection to the threshold of sensitivity of its receiver X_{1low}. At the moment of achievement of the threshold of sensitivity of the receiver to the transmitter the information resonance occurs between the transmitter and the receiver, at that Δx_1 jumps up to the proportional value Δx_2 of the transmitter:

$$\Delta x_i = \frac{\left(X_{iup} - X_{ilow}\right) \times \Delta x_j}{X_{jup} - X_{jlow}}. \tag{11}$$

Thus, at the moment of information resonance between objects, the information of the proportional ratio of the common to the particular is transmitted from the transmitter to the receiver. With the known information of the transmitter $I(X_j)$ the information of the receiver $I(X_i)$ is calculated. With N transmitters independent of each other the receiver's information is added and the measures are multiplied:

$$\begin{aligned}
&I(X_i) = \sum_{j=1}^{N} I(X_j), \quad \left|I(X_i)\right| = \prod_{j=1}^{N} \left|I(X_j)\right|\\
&\left|I(X_i)\right| = \frac{X_{iup} - X_{ilow}}{\Delta x_i} = \frac{\prod_{j=1}^{N}\left(X_{jup} - X_{jlow}\right)}{\prod_{i=1}^{N} \Delta x_j}.
\end{aligned} \tag{12}$$

If N transmitters from the set X are interdependent, then the formula for the information measure of the receiver when transmitting information from N interdependent transmitters has the following form

$$\begin{aligned}
&I(X_i) = \sum_{i=1}^{N} I(X_j),\\
&\left|I(X_i)\right| = \frac{X_{iup} - X_{ilow}}{\Delta x_i} = \frac{\prod_{j=1}^{N}\left(X_{jup} - X_{jlow}\right)}{\prod_{j=1}^{N}\left(\Delta x_j + \Delta x'_j\right)},\\
&\Delta x'_j = \frac{\prod_{j=1}^{N}\left(X_{N-j\,up} - X_{N-j\,low}\right)}{\prod_{j=1}^{N} \Delta x_{N-j}}.
\end{aligned} \tag{13}$$

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In a closed system with a set of X elements with $N \to X$ interdependent elements, $\Delta x \to X$ up, and $I(X) \to 0$, i.e. the system tends to information zero equilibrium.

The general approach to system-information modeling has particular cases depending on the kind of information that is formalized. This occurs when the value of the set X is an argument function of a particular particular kind of information $B(I_i) = fI(X_i)$.

From the general approach, the following private options can be distinguished.

1. For identification of properties of physical world mankind uses a principle of information measure, at that fixes a value of threshold of sensitivity of physical property in the form of a standard of physical quantity $\Delta x = 1St(standard)$, having presented value $X_{low} = 0$, at that $X_{up} = x$ is discrete variable X, and value of information measure of physical quantity has a form:

$$|I(X)| = f\left(\frac{x - X_{low}}{\Delta x}\right) \quad (14)$$

All natural sciences are built on this principle, which uses the proportion of the general to the particular as a generally accepted notion of information. When solving analysis and synthesis problems in the traditional way on the basis of a physical quantity to determine and optimize its place in the system, various rather complex scientific approaches have been developed.

The system-information approach greatly simplifies the solution of analysis and synthesis problems due to the possession of physical quantity of system information, which determines the place of the particular in the general. The equation of the amount of system information of a physical quantity has the form:

$$I(X) = \log_2 \frac{x}{\Delta x}. \quad (15)$$

where: x – discrete variable of the value X, Δx – sensitivity threshold.

2. When $\Delta x = f(IT)$ is a function of the tolerance on the accuracy of the parameter, then the system-information model acquires the characteristics of the information of the accuracy of the parameter. The higher the IT tolerance on the accuracy of the parameter, the more complex and costly the technology of its production. In this case, the system information characterizes the technological costs of the products.

3. When $\Delta x = f(PL)$ is a function of the Planck unit [12], and X_{up} is the sought variable, then the system-information model acquires the information characteristics of the Planck units of physical quantities. Since the values of the Planck units are derived from the fundamental physical constants, in this case the information characterizes the equilibrium of the system at the optimal numerical value of the objects' properties.

4. When $\Delta x = f(U)$ is a function of the interval of expanded uncertainty of the value of a physical quantity, then the system-information model acquires the characteristics of uncertainty when solving problems in intelligent systems. In this case the information characterizes the probability of quality of the system under conditions of uncertainty.

5. When $\Delta x = f(\mu_A(x))$, $x€X$, where $\mu_A(x)$ – the membership function, then the system-information model acquires the characteristics of fuzzy information in an intelligent system.

6. When $\Delta x = f(p)$ is a function of probability. Such an information measure in the form of a ratio was used by K. Shannon in his formula for calculating the amount of information: $I(p) = log_2 \frac{1}{p}$, $p = \frac{n}{m}$, $|I(p)| = \frac{1}{p} = \frac{m-0}{n-0}$; where: $X_{up} = m$, $X_{low} = 0$, $x = n$, $\Delta x = n - 0$, $|I(p)|$ – informational measure, m – $(total)$ number of attempts, $n - (private)$ value of realized.

Thus, the characteristic of a particular kind of information to be formalized depends on the properties that are attributed to the elements of the information measure function.

In the transition from the abstract mathematical formulation to the physical interpretation of system information the set X is represented by the set of physical properties of objects that are identified as physical quantities and their values are estimated due measurement. The material physical world can be modeled on the basis of system information of space, time and physical properties of objects. Each of the attributes presented can be formalized as a function of the information measure. The union of these attributes represents the information space 5D.

The objects of systems-information research are various systems: physical, chemical, biological, social,

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technical, informational, etc. For each of these systems, there is both a general and a private information measure of transformation and development. For each system-information model of the hierarchical level of a material object, methods for calculating quantitative values of information may be different. Numerical methods for determining the quantity, quality and value of information are based on the information measure.

The presented analysis of information characteristics is based on information interaction. The interaction of objects, leading to a change in knowledge of at least one of them, is called information interaction. Despite the nature of the definition of information interaction, it is useful for analyzing different definitions of information. Thus, the entropic approach describes information at the signal level, the algorithmic and algebraic approach – at the linguistic level, and the logical approach – at the semantic level.

For information interaction it is not enough only to transmit a message, it is necessary that the receiver (addressee) has a possibility to perceive it adequately. From this follows the thesaurus principle: the importance of having a priori information, sufficient to decode and assimilate the message received. This means, in particular, that participants in information interaction must have consistent information about the codes, languages and their semantics being used. This principle emphasizes the paramount importance for informatics of linguistic and semantic research in the broad sense of the word. First of all, we are talking about fragments of human communication languages and their semantics, which have become the basis for the development of human-machine dialogue tools today.

System-information models in production tasks

The product in production is characterized by the product life cycle (PLC), which includes the following stages: marketing, research and development, design, technological preparation of production, production, quality control, operation, maintenance and disposal. Each stage of the PLC is an open information system, in which the information comes from external sources, is processed and issued to the next stage. At each stage of PLC both deterministic and stochastic information processes between objects which possess the certain information necessary for performance of a concrete industrial task proceed.

On the basis of the system-information approach considered, four basic models of information technology can be distinguished for use in intelligent information processing systems for product manufacturing [13].

Absolute system-information model (ASIM)

The design of information technology uses absolute numerical values of system information of the parameters of design documentation (CD), technological system (TS) and technological process (TP) on the basis of deterministic and stochastic system-information models. ASIM defines: the numerical value of the quantity of system information of production objects parameters, which characterizes the complexity of production; quality of system information parameters, which characterizes the level of used technology; value of system information parameters, which characterizes the efficiency of production. These system information models are used in the analysis of the state of production in solving economic and managerial problems.

ASIM are used in the early stages of PLC in solving the problems of optimizing the redundancy of both product design and technological process based on the ratio of the amount of system information incorporated in the product parameters to the indicators of technical characteristics of the technological system and process, as well as to the parameters of the product service purpose.

Relative system-information model (RSIM)

RSIM characterizes the quality of production processes in the manufacture of the product and is equal to the coefficient of information connection ASIM and KPI (technical and economic indicators) of production:

$$RSIM_{Old} = \left(K_{inf}\right) = \frac{KPI_{Old}}{ASIM_{Old}}, \quad KPI_N = K_{inf} \times ASIM_N. \qquad (16)$$

RSIM is used in the stages of PLC when solving problems of optimization and forecasting of production resources for the manufacture of the product: energy, time, material and others at the level of technological equipment, production area, shop and production as a whole.

<u>Example 1.</u> Conduct a preliminary prediction of the cost of resources: electrical energy C_{El}^{N}, the time

of manufacture ${C_T}^N$ and the estimated cost of ${C_{PROD}}^N$, when launching a new (n) product in production on the basis of existing enterprise technologies in the manufacture of an old (old) product:

$$K_{el} = \frac{C_{el}^{old}}{\sum_{i=1}^{n} I_{i(prod)}^{old}}, \quad K_T = \frac{T_{prod}^{old}}{\sum_{i=1}^{n} I_{i(prod)}^{old}}, \quad K_c = \frac{C_{prod}^{old}}{\sum_{i=1}^{n} I_{i(prod)}^{old}},$$
$$C_{el}^{n} \approx K_{el} \times \sum_{i=1}^{n} I_{i(prod)}^{n}, \quad T_{prod}^{n} \approx K_T \times \sum_{i=1}^{n} I_{i(prod)}^{n}, \quad C_{prod}^{n} \approx K_c \times \sum_{i=1}^{n} I_{i(prod)}^{n}. \qquad (17)$$

where: K_{el}, K_T, K_c – coefficients of information communication for existing production technologies; OLD – old product, N – new product, I_i – system information of the product parameter according to the design documentation.

Forecasting tasks according to the given method to calculate resource costs for launching a new product have not been solved in production before. The method is simple and effective using computer technology. The traditional method of solving such problems requires a large expenditure of resources, both labor, time and financial, it consists in the development of preliminary (approximate) technological processes for the manufacture of product elements and their assembly with the calculation of economic indicators.

Equivalent system-information model (ESIM)

One of the conceptual features of the system-information approach is the possibility to represent system information of physical quantities on the basis of Planck units. The values of Planck units (l_{pl} – length, t_{pl} – time, m_{pl} – mass, E_{pl} – energy and other derived physical quantities are calculated on the basis of the fundamental physical constants C (speed of light, m/s); $\hbar$ (Dirac constant, $J \cdot s$); G (gravitational constant, $m^3/kg \cdot s^2$) [12]:

$$l_{PL} = \sqrt{\frac{G\hbar}{C^3}} m, \; t_{PL} = \sqrt{\frac{G\hbar}{C^5}} s, \; m_{PL} = \sqrt{\frac{C\hbar}{G}} kg, \; e_{PL} = \sqrt{\frac{\hbar C^5}{G}} J.$$

Basic Planck units, as well as fundamental physical constants, have invariable values of relative uncertainties and have approximately the same order – 10^{10} [14]. The value of the information measure is the inverse of the relative uncertainties of the Planck units and their numerical values are equal to each other. Therefore in the system-information approach the value of Planck units are taken as a threshold of sensitivity of reference physical quantities. Thus, the value of the amount of system information of the reference physical quantity, calculated on the basis of the Planck unit, can be equivalently expressed through another physical quantity by means of the coefficient of agreement between them.

The universal ESIM parameter is the physical quantity energy, i.e. the quantity of system information of any physical quantity on the basis of the Planck unit can be equivalently expressed through the system information energy.

Example 2: Determine the ${E^q}_{PL}$ equivalent of the P power value through the energy equivalent using a matching factor $K_{match}\left(E_{PL}/P_{PL}\right)$:

$$E_{pl} = \sqrt{\frac{\hbar C^5}{G}}, \quad LSI\left(E_{PL}\right) = \log_2\left(\frac{1}{E_{PL}}\right), \quad LSI\left(P_{PL}\right) = \log_2\left(\frac{1}{P_{PL}}\right),$$
$$P\left[kg \cdot \frac{m^2}{s^3}\right], \quad \log_2(P) = \log_2(m) + 2\log_2(l) - 3\log_2(t),$$
$$\log_2\left(\frac{1}{P_{PL}}\right) = \log_2\left(\frac{1}{m_{PL}}\right) + 2\log_2\left(\frac{1}{l_{PL}}\right) - 3\log_2\left(\frac{1}{t_{PL}}\right), \qquad (18)$$
$$P_{pl} = \frac{1}{2^{\left(\log_2(1/m_{PL}) + 2\log_2(1/l_{PL}) - 3\log_2(1/t_{PL})\right)}}, \quad K_{match}\left(\frac{E_{PL}}{P_{PL}}\right) = \frac{LSI\left(E_{PL}\right)}{LSI\left(P_{PL}\right)},$$
$$\log_2 \frac{E_P^{eq}}{E_{PL}} = K_{match}\left(\frac{E_{PL}}{P_{PL}}\right) \times \log_2 \frac{P}{P_{PL}}; \quad E_P^{eq} = E_{PL} \times 2^{K_{match}\left(E_{PL}/P_{PL}\right) \times \log_2\left(P/P_{PL}\right)}.$$

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where: LSI – the logarithmic single index of the Plank unit of physical value; E_{pl}, P_{pl} – Plank units of energy and power; E_p^{eq} – equivalent of the power value in energy units E_{pl}; P – power, p – power symbol in the equivalent of energy E_p^{eq}; $K_{match}\left(E_{pl}/P_{pl}\right)$ – matching factor.

Problems solved on the basis of the ESIM method refer to engineering problems, both in science and in production.

Mixed system-information model (MSIM)

System-information models MSIM represent a combination of the above models ASIM, RSIM, ESIM used for intelligent information processing in solving a wide range of problems. Economic and social tasks are some of the complex tasks that are currently being solved using intelligent information processing systems. Research of information processes of these systems and development of information models for solving problems are labor- and resource-intensive.

When analyzing complex information systems (e.g., economic or social), MSIMs with limited information resources are used based on the use of the three system-information models presented above. The information elements of the system are modeled on the basis of ASIM, the information process in the system is modeled on the basis of RSIM, the system information for analysis is presented by ESIM. The use of MSIM allows you to get the most objective result of the economic task of determining the effectiveness of processes and systems, which is calculated on the basis of the ratio of system information result to the costs of the work done.

In the theory of economics, the task of determining the efficiency of systems in a strict plan is currently not solved [15], because the result and cost of work indicators use different qualitative and quantitative attributes, measured by different units on different scales. ESIM eliminates this contradiction, it allows to evaluate the effectiveness of the system, representing the values of the result and cost of work in the form of system information equivalent to the energy measured in unified units of bits (bits).

Application of system-information models for intelligent information processing in production tasks

System-information models of production processes and systems are used to solve production problems. System-information models for intelligent information processing, provide the definition of optimal ways in solving the problems of resource planning and building a strategy for achieving the goal of production.

To use system-information models for solving various practical problems, different models based on the use of certain methods of intelligent information processing can be applied, the main ones are [16].

1) artificial neural networks (NN), the advantage of which is the ability to represent some limited continuous function with any small approximation error;

2) fuzzy logic, which allows inputs or variables in a decision problem to be represented as people reason about them;

3) expert systems, used to describe a problem and using the intelligence of one or more identified experts;

4) evolutionary computing, characterized by the ability to adapt to adapt to the environment by modeling the emergence, survival, and improvement of a population of individuals;

5) multi-agent systems, consisting of groups of agents with different goals and tasks, with certain characteristics and which are an active area of research in complex applications.

For the analysis of system-information models as objects of information interaction we will use both neural network approach and fuzzy logic, which are effective tools for solving a wide range of problems of intelligent data analysis, which can include and production tasks.

Let us consider some characteristics of functional dependences of technical and economic production indicators to the numerical values of system information (I) of product parameters DD (design documentation), TS (technological system) and TP (technological process). Timely and justified assessment of production indicators on the basis of information technology provides effective forecasting and management of the state of production.

1. Any mode of production is displayed through the system information (I) of the monitored parameters of the production objects.

2. The parameters of the product, technological process and system have the final numerical value of the system information (I) and are the most objective characteristics of production.

3. Quantitative indicators of resource costs of material, labor and energy to produce the product is a function of the numerical value of the system information (I) of the parameters of DD, TS and TP:

$$Resource\ costs\left(material,\ labor,\ energy\right) = \\ = f\left(\ I(DesDoc);\ I(TechSist);\ I(Tech\Pr oc)\right). \quad (19)$$

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4. Technical and economic indicators of production (KPI) is a function of redundancy or lack of system information of DD parameters of the product, TS, TP (characteristic of the quality of system information in the production process):

$$KPI = f\left(I_{excess}\left(DesDoc, TechSist,\ Tech\Pr oc\right), I_{deficiency}\left(DesDoc, TechSist,\ Tech\Pr oc\right)\right). \qquad (20)$$

5. Production efficiency is characterized as a function of the ratio of transferred system information by the technological system and process (costs) to the received system information by the product (result) (characteristic of the value of system information in the production of the product):

$$Production\ efficiency = f\left(I_{Tech\Pr oc} / I_{DesDoc}\right). \qquad (21)$$

The presented system-information models and ways of their use can be applied in systems of intelligent information processing to solve a wide class of practical problems.

Conclusion

The development of methods for solving various classes of practical problems using intelligent information processing is one of the key research areas in computer science. The developed system-information models of processes and systems for intelligent information processing allow analyzing and solving production problems. Thereby increase the efficiency of solving problems of analysis, synthesis and forecasting of production systems and technologies, as well as problems of production management.

The system-information approach to processes and systems introduced new concepts of system information and information measure, which allowed to develop system-information models for intelligent information processing.

The concept of systemic information corresponds to the generally accepted classical definition of "information". The information process is based on the information interaction of system elements, which leads to a change in their state and is caused by a positive or negative increase in the amount of system information.

The paper proposes:

1. The concept of a term of information as the value of a number equal to the proportional ratio of the total value of the attribute to its private value.

2. In the information process, the proportion (number) of the ratio of the general to the particular is to be transmitted.

3. The notion of the type of information is given, which is determined by the type of sensitivity threshold of the attribute that possesses the information (examples are given).

4. System-information models are used to obtain knowledge of any processes or systems beyond previous experience. That is, by getting information (number) of different data of design documentation parameters, technological documentation, technological process we determine the new knowledge, characterizing the production.

System-information models of processes and systems describe the interaction between source and receiver at the information level based on the sensitivity threshold. The communication channel between the source and the receiver of information operates, as a rule, under conditions of uncertainty, which can lead to loss of information during transmission due to possible changes in system characteristics. To describe their interaction, some models of intelligent information processing can be used, in particular, neural network models or fuzzy inference models. Their use will improve the efficiency of receiver state prediction, taking into account the state of the transmitter and the conditions of communication channel operation.

The presented article has shown the relevance of developing system-information models for intelligent information processing at the levels of data reception, interpretation and communication, which allows to expand the class of solved production tasks.

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СИСТЕМНО-ІНФОРМАЦІЙНІ МОДЕЛІ ДЛЯ ІНТЕЛЕКТУАЛЬНОГО ОБРОБЛЕННЯ ІНФОРМАЦІЇ

Предметом дослідження є системно-інформаційні моделі процесів і систем та їхнє використання для інтелектуального оброблення інформації у виробничих завданнях. Застосування інтелектуального оброблення інформації в системах управління виробництвом є нині одним із ключових напрямів розвитку інформатики. **Мета роботи –** розроблення системно-інформаційних моделей процесів і систем для інтелектуального оброблення інформації, що дають змогу аналізувати й виконувати виробничі завдання, які виходять за межі попереднього досвіду в умовах невизначеності. У статті вирішуються такі **завдання:** аналіз підходів до визначення характеристик інформації процесів та систем; розроблення основ моделювання системно-інформаційних процесів і систем для інтелектуального оброблення інформації; створення системно-інформаційних моделей і способів їхнього застосування для інтелектуального оброблення інформації в завданнях виробництва. Використовуються такі **методи:** системно-інформаційний підхід до процесів та систем; системно-інформаційне моделювання процесів і систем. Отримано такі **результати:** проаналізовано підходи до визначення характеристик інформації процесів і систем; розроблено основи моделювання системно-інформаційних процесів і систем для інтелектуального оброблення інформації; запроваджено поняття системної інформації та інформаційної міри; розроблено системно-інформаційні моделі та способи їхнього застосування для інтелектуального оброблення інформації в завданнях виробництва. **Висновки.** Розроблення методів для вирішення різного класу практичних завдань із використанням інтелектуального оброблення інформації є одним із ключових напрямів досліджень в інформатиці. Створені системно-інформаційні моделі процесів і систем для інтелектуального оброблення інформації дають змогу аналізувати й вирішувати завдання, що виходять за межі попереднього досвіду. Тим самим вони підвищують ефективність вирішення завдань аналізу, синтезу та прогнозування виробничих систем і технологій, а також завдань управління виробництвом. Системно-інформаційний підхід до процесів і систем оперує новими поняттями – "системна інформація" та "інформаційна міра".

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Завдяки цьому розроблено системно-інформаційні моделі для інтелектуального оброблення інформації, а також способи їхнього застосування на етапах життєвого циклу виробу, що дало змогу вирішувати завдання виробництва. Системно-інформаційні моделі процесів та систем описують взаємодію джерела та приймача на інформаційному рівні на основі порога чутливості. Канал зв'язку між джерелом та приймачем інформації працює, як правило, в умовах невизначеності, що може спричинити втрату інформації під час передачі внаслідок можливої зміни характеристик системи. Для опису їхньої взаємодії можуть бути використані ті чи інші моделі інтелектуального оброблення інформації, зокрема нейромережні моделі або моделі нечіткого виведення. Їхнє використання дасть змогу підвищити ефективність прогнозування стану приймача з урахуванням стану передавача та умов функціонування каналу зв'язку. Ця стаття показала актуальність розроблення системно-інформаційних моделей для інтелектуального оброблення інформації на рівнях рецепції, інтерпретації та комунікації даних, що дозволяє розширити клас виробничих завдань, які вирішуються.

Ключові слова: системно-інформаційні моделі; системна інформація; інформаційна міра; поріг чутливості; інтелектуальне оброблення інформації.

СИСТЕМНО-ИНФОРМАЦИОНЫЕ МОДЕЛИ ДЛЯ ИНТЕЛЛЕКТУАЛЬНОЙ ОБРАБОТКИ ИНФОРМАЦИИ

Предметом исследования являются системно-информационные модели процессов и систем и их использование для интеллектуальной обработки информации в производственных задачах. Использование интеллектуальной обработки информации в системах управления производством является в настоящее время одним из ключевых направлений развития информатики. **Цель** работы – разработка системно-информационных моделей процессов и систем для интеллектуальной обработки информации, позволяющих анализировать и решать производственные задачи в условиях неопределенности. В статье решаются следующие **задачи:** проведение анализа подходов к определению характеристик информации процессов и систем; разработка основ моделирования системно-информационных процессов и систем для интеллектуальной обработки информации; разработка системно-информационных моделей и способов их применения для интеллектуальной обработки информации в задачах производства. Используются следующие **методы**: системно-информационный подход к процессам и системам; системно-информационное моделирование процессов и систем. Получены следующие **результаты:** проведен анализ подходов к определению характеристик информации процессов и систем; разработаны принципы моделирования системно-информационных процессов и систем для интеллектуальной обработки информации; введены понятия системной информации и информационной меры; разработаны системно-информационные модели и способы их применения для интеллектуальной обработки информации в задачах производства. **Выводы.** Разработка методов для решения различного класса практических задач с использованием интеллектуальной обработки информации является одним из ключевых направлений исследований в информатике. Разработанные системно-информационные модели процессов и систем для интеллектуальной обработки информации позволяют анализировать и решать задачи, которые выходят за рамки предыдущего опыта. Тем самым они повышают эффективность решения задач анализа, синтеза и прогнозирования производственных систем и технологий, а также задач управления производством. Системно-информационный подход к процессам и системам оперирует новыми понятиями – "системная информация" и "информационная мера". Это позволило разработать системно-информационные модели для интеллектуальной обработки информации, а также способы их применения на этапах жизненного цикла изделия, что помогло решать задачи производства. Системно-информационные модели процессов и систем описывают взаимодействие источника и приемника на информационном уровне на основе порога чувствительности. Канал связи между источником и приемником информации работает, как правило, в условиях неопределенности, что может приводить к потере информации при передаче вследствие возможного изменения характеристик системы. Для описания их взаимодействия могут быть использованы те или иные модели интеллектуальной обработки информации, в частности нейросетевые модели или модели нечеткого вывода. Их использование позволит повысить эффективность прогнозирования состояния приемника с учетом состояния передатчика и условий функционирования канала связи. Представленная статья показала актуальность разработки системно-информационных моделей для интеллектуальной обработки информации на уровнях рецепции, интерпретации и коммуникации данных, что позволяет расширить класс решаемых производственных задач.

Ключевые слова: системно-информационные модели; системная информация; информационная мера; порог чувствительности; интеллектуальная обработка информации.

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