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ENSURING RELIABILITY OF CONTROL DATA IN ENGINEERING SYSTEMS

A. Dychko[1], I.Yeremeyev[2], V. Kyselov[2], N.Remez[1], A. Kniazevych[3]

[1] Institute of Energy Saving and Energy Management, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"
37 Peremohy Ave., Kyiv, 03056, UKRAINE
[2] Taurida National V.I. Vernadsky University
33 Ivana Kudri Str., Kyiv, 04000, UKRAINE
[3] Stepan Demianchuk International University of Economics and Humanities
4 Stepana Demianchuka Str., Rivne, 33027, UKRAINE
E-mail: aodi@ukr.net

The paper presents the approach of determination of rationality coefficients of control system, inputted uncertainty, control of the process, system errors, and uncertainty. Algorithms for identifying the states of system have been developed on the basis of theorems of identification. They actually implement the theoretical multiplication cross-section and establish that increasing the reliability of information is possible only through the use of redundancy (structural, procedural, and informational). The increase in the reliability of control data with the developed methods ensures significant improvement of the functioning of information systems and facilitates the adoption of more substantiated decision making.

Keywords: *control data, engineering system, reliability, theorems of identification, uncertainty*

1 INTRODUCTION

Modern automated control systems, i.e., systems designed to collect, analyse, evaluate, update, and display information relevant to the engineering problem, are adaptive systems that are able to change their structure and data processing technology in order to maximise the reliability of the results. The tasks of monitoring, analysing and improving the reliability of such a system can be reduced to the following functions: identification, evaluation, and measurement.

The need to identify the structure and status of the engineering system as a whole, as well as its separate subsystems, is due to the fact that the system and its components are exposed to external random interference that may interfere with the structure of the system or cause changes in the structure of the messages. The first and the second entails, as a rule, change in the degree of reliability of information processing results. The identification function implies the implementation of the whole spectrum of control procedures and the analysis of their results for revealing the essential features against the background of nonessential details; the elaboration of a more complex and detailed description of the information process, the phenomenon to a simple reference (alternative); registration of properties of the controlled process; checking the statistical hypothesis.

2. PROBLEMS OF CONTROL DATA RELIABILITY

Methods for assessing the state of the process are implemented selectively and unsystematically, which do not allow obtaining a sufficiently high guarantee of the received data conformity with the requirements of existing standards [1], [2]. This, in turn, leads to an inadequate response to changes in indicators in the functioning of the engineering system, as well as to an unreliable forecast of their further development.

Process control and analysis involve managing processes based on the compilation of heuristics with the definition of strata, the set of states, the calculation of possible states, the degree of their feasibility and the likely consequences of this implementation; the definition of the growth of the Euclidean distance between the pairs of real states that are observed and are adjacent to each other at a certain time interval, as well as the probability and possibility of such a transition and the driving forces that cause it [3]–[9].

As it is asserted in [2], it is impossible to consider information without taking into account any situation of uncertainty. Validation of reliability is based on the information obtained during the identification. Its task is to work out quantitative indicators of data reliability.

Changing the structure of the engineering system and technology of data collection and processing, based on the results of identification and evaluation, aims at optimising the operating modes of the information system in the specific circumstances that have developed and maximising the reliability of its functioning results.

Inadequacy in systems is mainly due to the incompleteness of the original data, the nebulosity (fuzziness) of the information and the limitations of the class of implemented algorithms [3], [4], [10], [11].

The incompleteness of the source data, which is the result of limited observation of objects of control and insufficient information about the factors that affect the processes in the reservoir, means that if there is

$$V(N,f) = (\tilde{f} \in F : N(\tilde{f})) = N(f) \tag{1}$$

the set of all elements $\tilde{f}$ that do not differ from the element f using the information *N*, then the value of *N(f)* does not allow determining which of the sets S($\tilde{f}\xi$), where $\tilde{f} \in V(N,f)$, leads to the desired ξ-approximation [10], [12].

The nebulosity (fuzziness) of information resulting from the limited accuracy of measurements and estimates, as well as the presentation and processing of data, failures of equipment, interference in communication channels, drift of equipment parameters and measured parameters, etc., means that if there is

$$V(N_\rho, f) = \{\tilde{f} \in F : N_\rho(f) \in E[N(\tilde{f}), \rho]\} \tag{2}$$

the set of elements *f* for which $N_{\rho(f)}$ can serve as fuzzy (approximate) information and the requirement is fulfilled

$$N_\rho(f) \in E[N(f), \rho] \forall f \in F, \tag{3}$$

where E – the operator of information fuzziness, ρ – the measure of fuzzy information, $E[N(f), \rho]$ – the set that represents fuzzy information about f, $\forall$ – the universal quantifier that confirms the validity of the equation for any values of the predicate f, then only the value of $N_\rho(f)$ does not allow stating which of the sets leads to ξ-approximation.

Limits of the class of admissible algorithms or those algorithms that are implemented to solve a particular task in specific conditions and which, of course, are associated with the duration of the implementation process, stability (perseverance) or correctness of the solution, mean that if

$$Q(h) = \{\varphi(h) : \varphi \in R\} \tag{4}$$

there is a plurality of results of application to $h = N_\rho(f)$ of all algorithms φ from class R of those implemented algorithms, then the knowledge of only $N_\rho(f)$ does not allow stating which specific (or which) of the algorithms of the set R will provide a solution to the problem under acceptable conditions (such that there are real) restrictions. At the same time, the general approach to increasing the reliability of information, if the solution space is not secured either by a norm or by a metric, can be based on the general mathematical theory of optimal reduction of uncertainty.

In case of incompleteness or approximation of the output data, when additional information is required, the required ξ-approximation can be found only under the condition of a non-empty intersection of the ξ sets, i.e.,

$$A(N, f, \xi) = \bigcap_{\tilde{f} \in V(N, f)} S(\tilde{f}_i, \xi) \neq 0 \tag{5}$$

or

$$A(N, f, \xi) = \min_{\tilde{f} \in V(N, f)} S(\tilde{f}_i, \xi) \neq 0. \tag{6}$$

As an example, procedure (5) to increase the reliability of the differentiation of information in the case of incomplete data is given in Fig. 1.

The minimum amount of the required information to solve a specific task with the specified degree of reliability (global radius of information) can be defined as follows. If we accept that

$$\xi_1 \le \xi_2 \Rightarrow A(N, f, \xi_1) \subset A(N, f, \xi_2) \tag{7}$$

and note

$$\text{r(N,f)= } \inf\{\xi : A(N, f, \xi) \ne S \tag{8}$$

as a local radius of information, i.e., the least ξ, for which there still exists an element belonging to sets for all that do not differ from *f* using information *N*, then

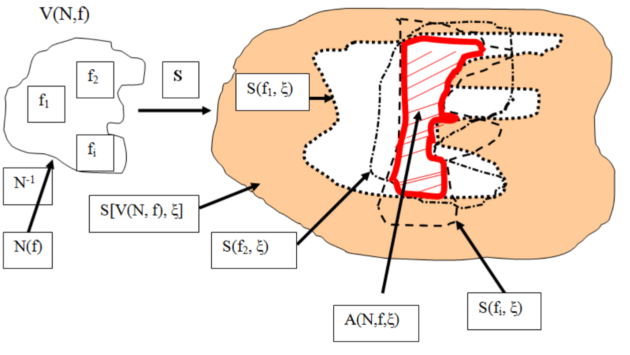

Fig. 1. The scheme of the choice of the set A (N, f, ξ) of all elements that do not differ from the element f using information N (counteraction principle).

the global radius of information may be defined as

$$r(N) = \sup_{f \in F} r(N, f) = \inf\{\xi : A(N, f, \xi), S \forall f \in F\}\,. \tag{9}$$

Then for the exact solution of the problem, i.e., for the case of an unambiguous definition

$$S(\tilde{f}) = S(f) \forall \tilde{f} \in V(N, f)\,, \tag{10}$$

when *S[V(N,f)]* is unique (one and only one),

$$\text{r(N)} = \begin{cases} 0, \text{if S[V(N,f) is unambiguous for all f} \in \text{F} \\ +\infty \text{ in opposite case} \end{cases}. \tag{11}$$

Thus, the search for an exact solution to a problem reduces to the definition of the minimum amount of information, the presence of which *r(N)* is converted to zero. However, since the procedures for such a search are often limited to system resources, or too high for additional information, the decision is sought with an error

$$e(\phi, N) = \sup_{f \in F} e(\phi, N, f)(= \inf\{\ \xi : \phi[N(f) \in S(f, \xi)\forall f \in F\}), \tag{12}$$

where $e(\phi, N, f) = \inf\{\xi : \phi[N(f)] \in A(N, f, \xi)\}$ – the local error in the algorithm (procedures) φ from the class of algorithms (procedures) *φ(N)* that use the information *N*, i.e., the least *ξ*, in which the element *φ[N (f)]* belongs to $S(\widetilde{f}, \xi)$ for all $\widetilde{f}$ that cannot be distinguished from *f* by using information *N*.

If the variation of the information operator *N* (i.e., the addition of any information that is relevant to the solvable problem) is created, the conditions for choosing the "optimal" information are created. If the information operator *N* can be decomposed into a number of simpler information operators, then the term cardinal *N* is introduced:

$$n = card(N), \tag{13}$$

and the information is non-adaptive if the selection of simpler operators occurs independently (with the help of independent processors) and, accordingly, the information is adaptive if this choice is made consistently, taking into account the results already obtained.

Then the minimum radii of non-adaptive and adaptive information (for the class of algorithms R used in solving the problem) can be represented respectively in the form:

$$\begin{aligned} r^{(i\grave{a})}(R, n) &= \inf_{N \in \varphi^{(i\grave{a})}(n)} r[R(N), N], \\ r^{(\grave{a}\ddot{a})}(R, n) &= \inf_{N \in ^{(\grave{a}\ddot{a})}(n)} r[R(N), N], \end{aligned} \tag{14}$$

where

$$\begin{aligned} \varphi^{(i\grave{a})}(n) &= \{N^{(i\grave{a})} : card\ (N^{(i\grave{a})}) \le n\}, \\ \varphi^{(\grave{a}\ddot{a})}(n) &= \{N^{(\grave{a}\ddot{a})} : card\ (N^{(\grave{a}\ddot{a})}) \le n \end{aligned} \tag{15}$$

represent classes of correspondingly non-adaptive and adaptive informational operators of cardinality not higher than *n*. In this case, the information operator *N* only then will become the *n*-th optimal non-adaptive (or adaptive) information (for R) when $N \in \varphi^{(на)}(n)$ either $N \in \varphi^{(ад)}(n)$, $r[R(N), N = r^{(на)}(R, n)$ or $r[R(N), N] = r^{(ад)}(R, n)$.

If approximate information is used

$$N\rho(f) \in E[N(f), \rho]\forall f \in F, \tag{16}$$

where *E* – the information error operator, *ρ* – the measure of error information, then the operator *N* will be the *n*-th optimal non-adaptive (adaptive) approximate information (for *ρ*, *R*) if

$$N \in \varphi^{(n-a)}(n) \quad \text{or} \quad N \in \varphi^{(ad)}(n), \tag{17}$$

$$r[R(N_\rho, \mathrm{E}), \mathrm{N}_\rho, \mathrm{E}] = r^{(n-a)}(R, n, \rho) \quad \text{or} \quad r[R(N_\rho, \mathrm{E}), \mathrm{N}_\rho, \mathrm{E}] = r^{(ad)}(R, n, \rho). \tag{18}$$

Here

$$r^{(n-a)}(R, n, \rho) = \inf_{N \in \varphi^{(n-a)}(n)} r[R(N_\rho, \mathrm{E}), \mathrm{N}_\rho, \mathrm{E}], \tag{19}$$

$$r^{(ad)}(R, n, \rho) = \inf_{N \in \varphi^{(ad)}(m)} r[R(N_\rho, E), N_\rho, E] \tag{20}$$

there are n-th minimum radii of non-adaptive and adaptive approximate information (for ρ, R).

Information systems often have to deal with fuzzy (nebulosity) data. The phenomenon of fuzziness (nebulosity) is due, in particular, to the largely incomplete information about objects (processes), when the unknown exact (complex) dependencies are replaced by approximate (simplified) or for the evaluation of the state of the engineering system (partial or complete) mediating parameters, connections, dependencies are applied. Therefore, methods and means of increasing the reliability of information in the conditions of fuzzy (nebulosity) data can be largely distributed to the area of problem solving with incomplete data. If we consider (2) and take into account that $f \in V(N_\rho, f)$, and on the basis of definition (1)

$$V(N, f) = V(N_\rho, f) \subset V(N_\rho, f) \forall f \in F, \tag{21}$$

we can assert that the required ξ-approximation will be found only if the intersection of the set $S(f_i, \xi)$ is not empty, i.e.,

$$A(N_\rho, f, \xi) \bigcap_{\tilde{f} \in V(N_\rho, f)} S(\tilde{f}, \xi) \neq 0. \tag{22}$$

In this case, the global radius of information

$$r(N_\rho) = \sup_{f \in F} r(N_\rho, f) \; (= \inf\{\xi : A(N_\rho, f, \xi) \neq 0 \; \forall f \in F\}), \tag{23}$$

where $r(N_\rho, f) \geq r(N_0, f) = r(N, f) \, \forall f \in F$ – the local radius of the approximate (nebulosity) information and N_0 characterises N under condition $\rho = 0$, i.e., in fact $N_0(f) = N(f)$.

The traditional way of increasing the reliability in this case is to minimise $r(N_\rho)$ or, that is the same, to minimise ρ.

While solving any problem, there are always two issues: solving the problem with the necessary accuracy, and if possible, the cost of this solution, i.e., the resources needed.

An algorithm compiled from a finite number of simple operations may be acceptable for use when achieving the goal set before the system. However, the resources required for its implementation may be such that the decision will lose all meaning: it will be late, will be unstable or incorrect, or costs may be inadequate to the results that will be achieved. Therefore, from the whole set of admissible algorithms ψ(Nρ) that uses information N_ρ, a subset of implemented algorithms is selected, so that any of the algorithms used in the system φ $\varphi: X = \varphi[N_\rho(f)]$ is included in this subset.

Under the conditions of limited class of implemented algorithms, if we consider (4) and take into account that the element *x* obtained as a result of the application of the algorithm $\varphi \in R$ belongs to the set $A(N_\rho, f, \xi) \cap Q(h)$, the ξ-approximation can be found under the conditions of a nonempty intersection of the set

$$A(N_\rho, f, \xi) \cap Q(h) \neq 0 \tag{24}$$

In this case, the global radius of the approximate information (for *R*) will be the minimum value of ξ, for which the set $\psi\ (\xi)$ has at least one algorithm with *n*, or more precisely the value

$$r(R, N_\rho) = \inf\{\xi : \psi(\xi) \cap R \neq 0\} \tag{25}$$

or

$$r(R, N_\rho) \geq \sup_{f \in F} r(R, N_\rho, f), \tag{26}$$

or

$$r(R, N_\rho, f) = \inf\ \xi : A(N_\rho, f, \xi) \cap Q[N_\rho(f)] \neq 0 \tag{27}$$

and is the local radius of the approximate information (for *R*).

If there is a set of algorithms

$$R = \phi \in \varphi(N_\rho) : \phi[N_\rho(f)] \in Q[N_\rho(f)] \forall f \in F\ , \tag{28}$$

and $R \subset \overline{R}$, then if $R = \overline{R}$

$$r(R, N_\rho) = \sup_{f \in F} r(R, N_\rho, f)\ , \tag{29}$$

and the algorithm for calculating the ξ-approximation (realisable) for an arbitrary f=F according to the information of N_ρ exists only in the case where $r(R, N\rho) < \xi$ or for $r(R, N\rho) = \xi$, if the error

$$\inf_{\phi \in R} e(\phi, N_\rho) = r(R, N_\rho) \tag{30}$$

is achieved by applying a certain algorithm φ for which the following value can be achieved

$$\inf\{\xi : \phi[N_\rho(f)] \in A(N_\rho, f, \xi) \forall f \in F\}. \tag{31}$$

To evaluate one or another algorithm, a criterion such as complexity can be used. Any algorithm can be represented as a set of primes of simple operations, each of which is characterised by the complexity $comp(p_i)$. The information complexity of the operator $N_\rho(f)$, if there is a calculation program consisting of a finite number of operations $p_1, \ldots, p_k$, can be represented in the form

$$comp[N_\rho(f)] = \sum_{i=1}^{k} comp(p_i). \tag{32}$$

If there is a calculation program $\varphi(y)$ that consists of a finite number of simple operations $q_1, \ldots, q_i$, then the combinatorial complexity of the algorithm $\varphi(y)$ can be expressed as follows:

$$comp[\phi(y)] = \sum_{i=1}^{l} comp(q_i). \tag{33}$$

The complexity of the algorithm φ can be represented as

$$comp(\phi) = \sup_{f \in F}\{comp[N_\rho(f)] + comp[\phi(N_\rho(f))]\}, \tag{34}$$

and the algorithm φ^{oc} that is optimal in complexity with $R(N_\rho, \xi)$ for $R(N_\rho)$ if

$$comp(\phi^{oc}) = comp[R(N_\rho), N_\rho, \xi], \tag{35}$$

where $comp[R(N_\rho), N_\rho, \xi] = \inf\{comp(\phi) : \phi \in R(N_\rho, \xi)\}$ – the ξ-complexity [for $R(N_\rho)$] provided that $inf\psi = +\infty$.

If we accept the φ-class of admissible approximate information operators and present the complexity of the problem as ξ-complexity in the class ψ (for R) in the form

$$comp(R,\varphi,\xi)=\inf_{N_\rho\in\varphi} comp[R(N_\rho),N_\rho,\xi], \tag{36}$$

then the algorithm φ^{oc} will be optimal for complexity in the class ψ (for R) if

$$comp(\phi^{oc})=comp(R,\varphi,\xi), \tag{37}$$

and φ^{oc} uses the approximate information N_ρ with ψ and belongs to $R(N_\rho)$.

The above considerations allow selecting (or constructing) algorithms to be implemented (or rather, the set of such algorithms) at the stage of the technical and operational design of the system. Such algorithms will correspond to specific conditions of its functioning, including for the case of decomposition of the system in case of ensuring the problems of resistance to failures, as well as when changing the dynamics of the engineering system, its overloads, etc.

Algorithms (4)–(7), which actually implement the multiplicative theorem operation, state that increasing the reliability of information is possible only through the use of redundancy (structural, procedural, and informational). In this case, the result can be achieved either under the conditions of simultaneous operation of all sets that are formed by parallel structures on the basis of a standard set of output data (structural redundancy), or during the successive execution of the same procedure over each pair of sets that are formed by one structure on the basis of a standard set of output data (procedural redundancy), or, finally, by combining the first two approaches and using additional structures or procedures that provide the formation of new sets based on all available relevant information (or adjustments already existing), as well as the results of its structuring and other types of processing (information redundancy).

In practice, this means the following:

- the use of a set of devices of the same type, communication channels and (or) data processing means instead of one in the case of structural redundancy;
- the use of multiple identical measurement procedures, data transmission and / or processing instead of one-time procedures, as well as the use of various diagnostic procedures in case of procedural redundancy;
- simultaneous use of several measurement methods (several different types of devices) for measuring the same value, entering test digits during data transmission, using multiple models or data processing algorithms that differ from each other at the conceptual level, taking into account a priori, indirect and concomitant information, as well as background information in the case of adoption of the method of informational redundancy.

It should be noted that in practice there is a combination of the above-mentioned, mutually complementary approaches, improving the quality and efficiency of information systems.

When establishing the apparatus and means of control and analysis of reliability of information on the state of an engineering system, it is very important to justify the choice of specific control methods that take into account the specifics of the object of control, the conditions in which the system operates and the requirements for the object and system.

If we know:

- coefficient of output uncertainty K_{ouc};
- coefficient of control of the process

$$K_{\tilde{N}} = \{\sum_{i=1}^{l} \lambda_i D_i\} / \{\sum_{i=1}^{l} D_i\}, \tag{38}$$

where λ_i – the efficiency coefficient of the i-th control method, which is defined as the ratio of the number of errors A detected to the total number of errors (both detected and those that are not detected) $A + B = \delta$, and D_i – i-th operation of information control;

- total amount of information Q;
- a number of system errors that are not detected, B;
- estimated total coefficient of uncertainty

$$K_{\text{uc}}=[\sum_{i=1}^{l} \frac{\delta_i}{Q}\ \text{Kuc} = (1-\lambda_i)D_i]/(\sum_{i=1}^{l} D_i), \tag{39}$$

or

$$K_{uc} = [\sum_{i=1}^{l} B/Q)D_i]/(\sum_{i=1}^{k} D_i), \tag{40}$$

it is possible to determine the coefficient of rationality of the control system

$$K_{r.c.} = [K_{ouc}(1-\hat{E}_c)/K_{uc}, \tag{41}$$

which for values $K_{rc} < 1$, i.e., K_{ouc} (1 - K_c) < K_{uc} indicates that the control system is built irrationally or the technology of data processing in the system is not rational.

The choice of conceptual, informational and behavioural models of the control system and verification of their reliability by using "reverse" operations are equally important. This verification may include the following steps (procedures):

- consideration of the design of the model and the feasibility of its development;
- establishing connection of the idea and the feasibility of developing a model with deterministic, randomized and average values of the characteristics of the model;
- research of accepted approximations of real processes;
- consideration of criteria for the effectiveness of parameters and variables;

- research of accepted propositions and hypotheses;
- detecting the connection of the results of the two previous stages with real processes; analysis of the system of disturbing factors and characteristics of the operator; research of the interconnections of all these factors;
- verification of the information and its sources used for model development;
- consideration of the entire control procedure in connection with the definition of the task of the system;
- consideration of the task.

The above-mentioned approach provides reconsideration of the task from a slightly different point of view, which contributes to a deeper and more comprehensive assessment of the system and ultimately allows creating an optimal conceptual model that is adequate to a mathematical model and, as a result, creates conditions for effective control of reliability.

When selecting controlled parameters, their informational value should be considered (separately for the case of operational control of normal modes and separately for emergency control). For operational control, the information value of a parameter can be determined from the expression

$$Z_{ïï} = (\sigma_x / C_x)\ln(\sigma_x / \lambda_x)\rho, \tag{42}$$

and for emergency according to the expression

$$Z_{à} = \frac{\tilde{N}_x}{x_a - m_x} \ln\frac{\sigma_x}{\lambda_x}\rho \quad (\text{for } \xi \geq x_a), \tag{43}$$

where σ_x – the mean square deviation of the parameter ξ; C_x – the maximum rate of change of the parameter ξ in transitional modes; λ_x – the error of the measuring device; ρ – the coefficient that takes into account the distribution of probabilities of values $x \epsilon \xi$; x_a – the minimum value of the parameter ξ, which corresponds to the emergency situation; m_x – the mathematical expectation ξ.

In this case, the generalized characteristic of the information value of the parameter can be represented as

$$Z_n = Z_{on} \cdot Z_a. \tag{44}$$

In addition, the value of information can be expressed through increasing the probability of achieving the goal:

$$I = log\,(p_1/p_0), \tag{45}$$

where p_0 – the probability of achieving the goal before receiving information, and p_1 – the same after receiving the information. Here it is worth noting that if after receiving additional information the probability of achieving the goal is reduced, this indicates the need to move to an alternative strategy. In this sense, the additional information received has a real value, since it saves resources and time by refusing a hopeless strategy.

4. CONCLUSIONS

The algorithms for identifying the states of the engineering system have been developed on the basis of the theorems of identification. They actually implement the theoretical multiplication cross-section and establish that increasing the reliability of information is possible only through the use of redundancy (structural, procedural, and informational).

The above-mentioned approaches to increasing the reliability of control data ensure stable functioning of engineering systems and facilitate the adoption of substantiated decisions to minimise the consequences of man-made and natural disasters and accidents. However, their use in the absence of accepted patterns of system state, making them sensitive to external influences and focused on precise input information, requires new, non-standard approaches, one of which is the interpretation of information used in the system in terms of theory fuzzy sets and the theory of possibilities that form the basis of intelligent information systems.

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KONTROLES DATU UZTICAMĪBAS NODROŠINĀŠANA INŽENIERSISTĒMĀS

A. Dičko, I.Jeremejevs, V. Kiseļovs, N.Remezs, A. Kņazēvičs

K o p s a v i l k u m s

Darbā aprakstīta vadības sistēmas racionalitātes koeficientu, ievadītās nenoteiktības, procesa vadības, sistēmas kļūdu un nenoteiktības līmeņa novērtēšanas pieeja. Balstoties uz identifikācijas teorēmām, ir izstrādāti algoritmi sistēmas stāvokļu identificēšanai. Kontroles datu ticamības palielināšana ar piedāvātajām metodēm nodrošina būtisku informācijas sistēmu darbības uzlabošanu un atvieglo pamatotāku lēmumu pieņemšanu.

20.09.2019.