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Article

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THE DEVELOPMENT OF A METHOD FOR ASSESSING THE SECURITY OF COMPLEX TECHNICAL SYSTEMS USING ARTIFICIAL IMMUNE SYSTEMS

Ensuring the security of complex technical systems of various functional purposes requires a constant search for new scientific and practical approaches in order to ensure its proper level against a growing list of new risks and threats. Nowadays, no state in the world is able to work on the creation and implementation of artificial intelligence in isolation from others. Artificial intelligence technologies are actively used to solve both general and highly specialized tasks in various spheres of society. The problem of synthesis of management of complex technological processes is an urgent task in management theory. A promising direction in the design of such complex ones is the use of bio-inspired algorithms that are effectively used while solving optimization tasks.

Thus, the object of research is complex technical systems. The subject of research is the state security of complex technical systems. The research developed a method for assessing the security of complex technical systems using artificial immune systems. The novelty of the proposed method consists in:

– taking into account while calculating the correction factor for the degree of uncertainty about the state of a complex technical system;

– reducing computing costs while assessing the state of a complex technical system;

– improved implementation of procedures for solving the task of influencing relationships in a complex technical system;

– creating a multi-level and interconnected description of hierarchical complex technical systems;

– the possibility of performing calculations with source data that are different in nature and units of measurement. It is advisable to implement the mentioned technique in specialized software, which is used to analyze the state of complex technical systems and make decisions.

Keywords: *security of complex technical systems, artificial immune systems, uncertainty of the state of complex technical systems.*

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1. Introduction

Nowadays, no state in the world is able to work on the creation and implementation of artificial intelligence (AI) in isolation from others. The NATO strategy on artificial intelligence, adopted in October 2021 with the aim of accelerating the implementation of AI, interprets AI as an opportunity to achieve technological advantage, but at the same time as a source of threats and sets the following goals [1]:

– acceleration and active promotion of AI implementation;

– protection and monitoring of AI technologies and innovative capabilities, taking into account security policy considerations, such as the practical application of the principles of responsible use;

– detection and protection against threats of malicious AI use;

– AI has become widely used in solving various tasks in works [1–3]:

1) ecology and agriculture;

2) telecommunication industry and energy;

3) medicine, scientific activity and education;

4) the sphere of security and defense, etc.

AI is used to increase the efficiency of data processing, processing of large data sets and to decision making support [3–5].

The problem of synthesis of management of complex technological processes is an urgent task in management theory. A promising direction in the design of such complex ones is the use of bio-inspired algorithms that are effectively used while solving optimization problems [1].

Currently, a large number of bio-inspired methods have been developed for the synthesis of optimal control for one-dimensional systems [2, 3], including the artificial immune system (AIS) [4]. Algorithms formed taking into account the functioning of artificial immune systems have proven themselves well while solving the tasks of finding optimal solutions, which is effectively used for the synthesis of optimal control of one-dimensional systems [5].

The clonal selection algorithm is based on the mechanisms of the immune response when foreign antigens are introduced into the body. At the same time, the process of recognition of foreign antigens by antibodies is carried out [6]. In order to solve management problems with the aim of identifying local minimum of the optimization problem, software for the negative selection algorithm, NSA, has been developed. During the implementation of the software, it was concluded that this mechanism allows recognizing and ignoring unwanted extremes during the search for optimal values of quality criteria.

The mechanism of negative selection inherent in the immune system consists in distinguishing body cells from foreign cells [7], includes a mechanism for calculating permissible deviations from the standard functioning of the system. The negative selection algorithm uses the process of generating negative positions of the system. The initial population is generated randomly, but in the future the negative positions of the system are eliminated [8–10]. The result of this process is the detection of anomalies and it is of interest within the scope of detection of local minimum.

In biological systems, the process of negative selection is used before clonal selection. In this work, the principle of negative selection is used to form an algorithm for the initial finding of optimums after the clonal selection algorithm for finding the global minimum.

Taking into account the above, *the aim of the research* is to develop a method for assessing the security of complex technical systems using artificial immune systems.

The object of the research is the complex technical system.

The subject of the research is the state security complex technical system.

2. Materials and Methods

The research problem is to increase the efficiency of decision making regarding the state of complex technical systems. Artificial immune systems were selected as the basic mathematical apparatus in the proposed research.

3. Results and Discussion

3.1. The development of a method for assessing the security of complex technical systems using artificial immune systems. Let the mathematical model, describing a complex technical system, take the form:

$$\begin{vmatrix} y_1(s) \\ y_2(s) \\ \dots \\ y_n(s) \end{vmatrix} = \begin{Vmatrix} G_{11}(s) & G_{12}(s) & \dots & G_{1n}(s) \\ G_{21}(s) & G_{22}(s) & \dots & G_{2n}(s) \\ \dots & \dots & \dots & \dots \\ G_{n1}(s) & G_{n2}(s) & \dots & G_{nn}(s) \end{Vmatrix} \cdot \begin{vmatrix} u_1(s) \\ u_2(s) \\ \dots \\ u_n(s) \end{vmatrix}, \qquad (1)$$

where $G_{ij}, i=j$ are the transfer functions of subsystems of a complex technical system; $G_{ij}, i\neq j$ are the transfer functions of interconnections between subsystems of a complex technical system.

It is necessary to synthesize a complex technical system (1) to achieve the set values of the output values based on AIS algorithms (algorithm for finding associative rules).

The synthesis of a complex technical system is determined by finding the controlling influences for which the proportional-integral (PI) regulation law is chosen:

$$u_i(s)=P_i\cdot e_i(s)+I_i\cdot\frac{1}{s}\cdot e_i(s), i=\overline{1,n}, \qquad (2)$$

where $G_i(t)$, $i=\overline{1,n}$ are the errors between the given ones $r_i(t)$ and the initial values $y_i(t)$.

The transfer functions of PI controllers (2) have the form [8]:

$$C_{PIi}(s)=P_i+I_i\cdot\frac{1}{s}, \; i=\overline{1,n}. \qquad (3)$$

The setting of PI controllers is performed in order to minimize the integral quadratic criteria:

$$ISE_i=\int_{t=0}^{t_1} e_i^2(t)\mathrm{d}t, \; i=\overline{1,n}\to\min. \qquad (4)$$

Quality criteria (4) correspond to local regulators u_i, $i=\overline{1,n}$, which are in separate contours [8].

The task is solved on the basis of formed steps, which include AIS algorithms:

Step 1. An introduction to consideration of isolated system contours without interconnections:

$$\begin{vmatrix} y_1(s) \\ y_2(s) \\ \dots \\ y_n(s) \end{vmatrix} = \begin{Vmatrix} G_{11}(s) & 0 & \dots & 0 \\ 0 & G_{22}(s) & \dots & 0 \\ \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & G_{nn}(s) \end{Vmatrix} \cdot \begin{vmatrix} u_1(s) \\ u_2(s) \\ \dots \\ u_n(s) \end{vmatrix}. \qquad (5)$$

Step 2. Solving problems of synthesis of typical regulators of isolated subsystems without interconnections, AIS regulators.

Step 3. Connection of interconnections of a complex technical system.

Step 4. Implementation of the decision making procedure in the decision making device for compensation for the influence of the interrelationships of a complex technical system.

The algorithms of artificial immune systems [11–14] are used to calculate the parameters of the regulators that provide the minimum criteria (4): AIS-NSA, AIS-CLONALG.

In accordance with the properties of automatic control systems and system requirements for PI-regulators, let's formulate restrictions on solution (4):

$$P_i>0, \; I_i>0, \; i=\overline{1,n}, \qquad (6)$$

at the same time, there are restrictions on the area of changing the parameters of the regulators to ensure the stability of the system.

To search for local minimum and determine the range of finding the global minimum of quality criteria, the AIS-NSA algorithm is implemented – the negative selection algorithm [15–17].

The generalized form of antibodies corresponds to a vector of arguments, which is a set of solutions for the system state:

$$Ab=(y_i, u_i, i=\overline{1, n}). \tag{7}$$

Quality criteria are used as antigens (5):

$$Ag=f(e_i, u_i, i=\overline{1, n}). \tag{8}$$

According to the obtained expressions of the quality criteria (4) and (8), a subset of antigens is identical to the expression that includes the parameters of PI regulators (3), $(P_i, I_i, i=\overline{1, n})$:

$$Ag=f(P_i, I_i, u_i, P_i, I_i, i=\overline{1, n}). \tag{9}$$

During the determination of the global minimum value (*Step 5*) of the optimization problem of a complex technical system and the implementation of the AIS-NSA algorithm, the following steps of the algorithm were performed:

Step 5.1. Population formation taking into account uncertainty about the state of a complex technical system.

Step 5.2. Calculation of the affinity of each member of the population with the objective function.

Step 5.3. Selection of members of the population with the worst indicators (negative). The search of the local minimum.

Step 5.4. Checking the obtained solution for compliance with expression (4). The presented steps of the algorithm provide a solution to the problem of optimal management of a complex technical system.

The end.

3.2. The results of the analysis and discussion of the results. The proposed method differs from the existing ones as it:

- takes into account the degree of uncertainty of information about the state complex technical system;
- creates a multi-level and interconnected description complex technical system;
- increases the efficiency of decision making while assessing the security state;
- solves the problem of falling into global and local extremes.

The advantages of the research include:

- during the calculations, it takes into account the degree of uncertainty about the condition complex technical system;
- the reduction of computing costs while assessing the condition complex technical system;
- the possibility of performing calculations with source data that are different in nature and units of measurement.

The shortcomings of the mentioned research should include the availability of appropriate computing power and time for calculations.

It is advisable to implement the specified method in specialized software that is used for condition analysis of the complex technical system and decision making management.

The direction of further research should be considered the further improvement of the specified method to take into account a greater number of factors during the state analysis.

4. Conclusions

1. The research developed a method for assessing the security of complex technical systems using artificial immune systems.

As a result of the implementation of the optimal control synthesis procedure, the coefficients of typical PI controllers of isolated subsystems of complex technical systems were obtained.

2. The novelty of the proposed method consists in:

- taking into account while calculating the correction factor for the degree of uncertainty about the complex technical system state;
- reducing computing costs while assessing the state of a complex technical system;
- improved implementation process of the procedure for solving the problem of the influence of relationships in a complex technical system;
- creating a multi-level and interconnected description of hierarchical complex technical systems;
- the possibility of performing calculations with source data that are different in nature and units of measurement.

3. It is advisable to implement the specified method in specialized software, which is used to analyze the state of complex technical systems and make management decisions.

Conflict of interest

The authors declare that they have no conflict of interest concerning this research, whether financial, personal, authorship or otherwise, that could affect the study and its results presented in this paper.

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Data availability

The manuscript has no associated data.

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