Development of theoretical foundations for the creation of intelligent technology based on a unified artificial immune system for complex objects control of the oil and gas industry

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Abstract. The article is devoted to the current and promising direction of the implementation of the Industry 4.0 program based on the introduction of artificial intelligence (AI) approaches in the industrial production of the oil and gas industry. A review of the application of modern bioinspired AI approaches for solving problems of control and diagnostics of industrial equipment is carried out. The application of the approach of artificial immune systems (AIS) and various modified AIS algorithms is substantiated in the creation of innovative and competitive applications for solving various specific engineering problems and creating a modern highly efficient technology for automating production processes at oil refineries. The theoretical foundations for the creation of an intelligent innovative technology based on a unified artificial immune system (UAIS) for distributed systems for complex objects control using modern computer technology have been developed. Definitions of UAIS and immunological homeostasis are given. Unification is carried out with the aim of reducing the variety of modified AIS algorithms and their optimal use for solving the assigned tasks for the technological processes control. The classification and assessment of the effectiveness of the application of modified AIS algorithms is carried out. The block diagram of an intelligent control system based on the developed UAIS is presented.

1. Introduction
The development of bioinspired approaches of artificial intelligence is closely related to biocybernetics, which considers the problems of control and information transfer in biological systems [1, 2]. The rapid development in recent decades of neural networks [3], swarm intelligence algorithms [4,5], evolutionary algorithms [6], artificial immune systems (IIS) [7], etc., as well as the development of a number of powerful highly efficient applications proves that this direction is promising.

The approach of artificial immune systems (AIS) occupies a special place in the development of artificial intelligence and numerous publications in this area of science published in the world publishing houses Springer, Elsevier and others confirm the relevance of the research being carried out. A number of scientists from the USA, Great Britain, Italy, China, Russia, Japan and other countries are actively involved in the development of AIS [8, 9, 10, 11, 12]. Various interesting applications are being developed on the basis of AIS for information security, in technology, medicine, education, and nevertheless, one of the main directions of modern development of AIS is directly related to the
implementation of the Industry 4.0 program for the intellectualization of industrial production, the creation of modern highly effective technologies for automating production processes and solving control problems, as well as diagnostics of industrial equipment. These problems are especially relevant for the oil and gas industry. For example, in [13], there was developed a system of diagnostics and forecasting for industrial use in various conditions on the basis of the AIS approach and multi-agent architecture. The advantages of AIS and the multi-agent approach allow distributed data processing and maintain autonomy. Studies [14] are devoted to the comparative analysis of various AIS algorithms and algorithms based on a neural network for solving the classification problem. The advantages and disadvantages of the considered approaches are shown.

It should be noted that the AIS approach uses various mechanisms of human immunity functioning, such as molecular recognition, clonal selection, negative selection, etc. The adaptive properties of AIS are especially promising. For example, in [15], there was developed a cognitive-adaptive AIS algorithm, which implements the mechanisms of innate and adaptive immunity to protect databases. This algorithm is based on negative selection algorithms and hazard theory.

Due to the fact that the work of the immune system is distinguished by a huge number of complex and interrelated processes occurring in parallel, models and algorithms of AIS are still being developed, which implement individual fragments of the functioning of the immune system, but not the entire system as a whole. Although the first attempts to create UAIS were undertaken long ago [16], nevertheless, today the problem of creating a highly efficient UAIS remains open. As a rule, applications are developed to solve local problems using separate AIS algorithms. The creation of an integral immunity system based on the AIS is complicated by the fact that recently, in connection with the active development of this direction of AI, a lot of new improved modified AIS algorithms have appeared, aimed at working in certain conditions and having their own operating limitations, advantages and disadvantages. For example, in the article [17], there is considered the application of a modified AIS algorithm to optimize the design of a gear transmission. Comparison with the original model proves that the proposed approach is promising. Studies [18] are devoted to the issues of diagnostics and fault detection for the safe operation of technical systems based on an improved negative selection algorithm with detectors that do not require information about the types of faults. Testing on three data sets showed a higher detection accuracy in online mode than the classical algorithm. Thus, the systematization and classification of this variety of modified AIS algorithms is an urgent task, the solution of which will make it possible to compile a catalog of scenarios for the optimal immune response in various situations of complex object functioning. The analysis of publications confirms the relevance of research on the development of the theoretical foundations of AIS and intelligent technology for complex objects control using the bioinspired AIS approach.

The following article structure is proposed. The second section contains the statement of the problem, definitions and research methods. The third section is devoted to the development of a knowledge base of modified UAIS algorithms for information technology for complex objects control of the oil and gas industry. In the fourth section, a structural diagram of an intelligent process control system based on modified UAIS algorithms is proposed. At the end, there are given a conclusion and information on grant funding for these studies.

2. Problem statement, definitions and research methods

The problem statement is formulated as follows: it is necessary to develop theoretical foundations for creating an effective intelligent innovative technology based on a unified artificial immune system and modified AIS algorithms for a distributed system of complex objects control at oil and gas enterprises using modern computer technology.

Unification is carried out with the aim of reducing the variety of modified AIS algorithms and their optimal use for solving the assigned tasks for controlling technological processes and diagnosing malfunctions of industrial equipment at modern oil and gas refineries.

Definition 1. UAIS is understood as a system created by systematizing and classifying modified AIS algorithms, taking into account the strengths and weaknesses to select the most effective immune
response mechanisms in order to analyze and predict multidimensional data different in structure, type and size for complex industrial automation objects control [19].

The rapid development of artificial intelligence and especially bioinspired areas prove the need for a detailed study of biological prototypes in order to introduce the fundamental principles of the functioning of natural biological systems based on homeostasis into real industrial production for more efficient management of high-tech complexes. A number of works on the application of homeostatics in the development of intelligent control systems have been published recently. A large series of applications on the application of homeostasis principles have been developed under the direction of Jon Timmis. For example, in [20], there are considered the issues of creating engineering systems based on the principles of AIS and homeostasis, problems and requirements for the architecture of these systems are discussed. The most developed direction is the use of homeostatics in the creation of robotic systems. Studies [21] are devoted to the development of a homeostatic robotic adaptive system PerAda based on AIS for operation for a long period without human support in a changing aggressive environment. Thus, the use of homeostatic principles for various technical applications is relevant and promising. In the proposed studies, there is introduced the concept of immunological homeostasis, which is used in the development of an intelligent system for a complex object control of the oil and gas industry based on modified UAIS algorithms.

Definition 2. By immunological homeostasis in the approach of artificial immune systems, we mean a certain balance to support the stable operation of the system between immunity to external disturbances and an adequate immune response.

3. Development of a knowledge base of modified UAIS algorithms for information technology for complex objects control of the oil and gas industry

To create an AIS based on modified AIS algorithms, there was developed a knowledge base [22] using ontological models and various scenarios of the immune response in order to effectively control a complex object.

Let's consider the most commonly used algorithms in the AIS approach. In the first case, data preprocessing for the selection of informative features is carried out on the basis of some improved intelligent algorithm (for example, a modified cooperative algorithm for a swarm of particles with a weight of inertia), pattern recognition and prediction using the classical AIS algorithm (for example, clonal selection or negative selection). In the second case, the data preprocessing algorithm is classical, and the AIS algorithm for pattern recognition is improved. In the third case, modified algorithms are used for both data preprocessing and AIS recognition algorithms. The effectiveness of various modifications depends on the goals, objectives and conditions of their application. Table 1 presents an example of the classification of modified AIS algorithms and considers the applications of their implementation, advantages and disadvantages, and also provides references to the literature.

| Data preprocessing algorithms | Algorithms of artificial immune systems and their designations | Designation and scope | Evaluation of the effectiveness of the modified AIS algorithm, advantages and disadvantages |
|------------------------------|---------------------------------------------------------------|-----------------------|---------------------------------------------------------------------------------|
| Cooperative algorithm of Immune network AIS, a swarm of particles with algorithm a weight of inertia (CPSOIW) [23] | CPSOIW-AIS, Promengineering, medicine, education | The main advantage of this algorithm is the increase in the rate of convergence due to the parallelization of computational procedures when selecting the optimal data set. Updating the weight of inertia at each iteration improves the variety of solutions [1] | |
| Gases Brownian Motion Optimization (GBMO) | Clonal Selection Algorithm (CSA) | PGClnal | The proposed hybrid method is based on the advantages of PSA, GBO and CSA algorithms and is a fast, reliable |
and Particle Swarm Optimization (PSO) [24] Economic Load Dispatch Problem, ELDP

Fuzzy-based feature selection algorithm [25] Clonal Selection Algorithm (CSA) SAMCSA-ANN

The problem of electricity consumption. Short Term Load Forecasting (STLF) The advantage of this algorithm is to increase the efficiency and accuracy of forecasting the load by identifying informative features based on fuzzy logic and a modified evolutionary optimization algorithm SAMCSA (Self-Adaptive Modified CSA)

4. Intelligent process control system based on UAIS
Figure 1 shows a triad for maintaining immunological homeostasis at a complex object control. Figure 2 shows a block diagram of an intelligent system for a complex object control based on modified UAIS algorithms.

**Figure 1.** Immunological homeostasis.

**Figure 2.** Intelligent system for a complex object control based on modified UAIS algorithms.
Here $X(x_1, x_2, \ldots, x_n)$ – vector of input variables; $Y(y_1, y_2, \ldots, y_n)$ – vector of output variables; $Z(z_1, z_2, \ldots, z_n)$ – vector of random disturbances; $U(u_1, u_2, \ldots, u_n)$ – control vector; $R$ - resources; $G$ - control goal; $L$ – control algorithm; $U=\text{F}(x,y,G,R)$; $\text{MA}_1, \ldots, \text{MA}_N$ – modified UAIS algorithms.

5. Conclusion

Thus, the developed concept of applying the principles of immunological homeostasis to create a unified artificial immune system for complex objects control of the oil and gas industry, in contrast to the known approaches, has a number of features. Firstly, in the development of the AIS, the classical AIS algorithms were usually considered. In the proposed approach, numerous modified AIS algorithms are investigated, which make it possible to use them more flexibly and optimally in a specific situation. The development of UAIS is aimed at systematizing these algorithms in order to select the most effective ones for use in certain conditions. Secondly, the idea of using the principles of homeostasis for technical applications was not implemented at UAIS. Another distinctive feature is the implementation of this concept on modern industrial equipment for distributed control systems, in contrast to the more developed direction of application of the basics of homeostasis in robotic systems. Such properties of AIS as self-organization, decentralization, the ability to make a decision in an unfamiliar situation and others determine those advantages that allow to move to a higher level of intellectualization of industrial production and have great development prospects.

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