Technological Aspects of Control Adaptation Based on Neural Network Modeling

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***Abstract*—An innovative technology for adapting control signals of the technological production cycle control system to external control actions and random disturbances is presented. A new solution for reducing the impact of destabilizing environmental factors in real time is proposed. A method for adapting the automated technological cycle control has been developed, based on constructing control feedback algorithms to reduce the sensitivity of process operation parameters to changes in the operating conditions of process equipment and the environment. A description of the tools for implementing the means of adapting the technological cycle control based on constructing control feedback algorithms and synthesizing neuroregulators using neural network algorithms is provided. A procedure for generating a knowledge base in accordance with the "technological processes with probabilistic characteristics" ontology is proposed, providing a formal description of the component classes of the process cycle, their properties and relationships between classes, coding in the SC code format and integration with logical inference mechanisms.**

***Keywords*—adaptive control, neural network modeling, feedback construction algorithms, synthesis of neuroregulators, adaptation technology**

I. Introduction

In the process of real operation of complex technical systems, in particular, the technological production cycle [1], there is a need to take into account external destabilizing factors in real time. Therefore, the issue of developing methods, algorithms and tools that can ensure a significant reduction in the sensitivity of the parameters of the technological cycle to the impact of destabilizing factors, including random external disturbances and control actions, deserves attention.

Development of new technologies for control adaptation based on modern methods of artificial intelligence will allow building an ecosystem of solutions for the automation of modern production systems, improving product quality and economic efficiency.

The article describes the technology for adapting the control of the technological process at the level of technological operations, which ensures the use of intelligent computer systems of adaptive control in real time. The process of synthesis of a neuroregulator is described, including the use of algorithms for automated search for the optimal architecture of a neural network.

II. Creation of a knowledge base on the subject area "technological processes with probabilistic characteristics"

The procedure for generating a knowledge base based on an ontology involves the sequential formation of structured data reflecting the entities and relationships of the subject area. This process is based on the formalization of knowledge about technological and probabilistic technological processes, their elements and characteristics.

The relevance of building a knowledge base using OSTIS technology [2] is due to the increasing complexity of modern technical systems and the need for an integrated approach to their control. The advantages of OSTIS are to ensure a uniform representation of knowledge through the use of a formalized SC-code language, which helps to increase the accuracy and consistency of data, and also allows for the automation of information update and adaptation processes. In addition, OSTIS technology ensures system scalability by supporting the dynamic integration of heterogeneous data sources, which is especially important for intelligent systems operating in a changing environment. Thus, the use of OSTIS for building a knowledge base contributes to the formation of effective, adaptive and highly accurate models that ensure high-quality control of complex technical objects.

The first stage is the extraction of information from regulatory and technical documentation, scientific publications and empirical data related to the operation of complex technical systems. The obtained information is analyzed and interpreted in the context of the ontology, which allows identifying key concepts such as technological processes, technological and microtechnological operations, as well as probabilistic parameters for their implementation.

The next stage consists of structuring the data in accordance with the ontological model. For this purpose, classes and their attributes are formed, connections between entities are established, and constraints and dependencies are defined. For example, a technological operation is linked to the corresponding microtechnological operations, and the probabilistic parameters of the processes are determined based on statistical analysis of data on the actual functioning of the systems.

To represent knowledge, SC-code is used – a formal language used in OSTIS technology [3]. Transformation of formalized data into SC-code ensures the creation of machine-processed semantic networks, where each concept receives an unambiguous description and a clear connection with other elements of the system is established. Knowledge integration is carried out by combining individual semantic modules into a single model, which helps ensure the integrity and consistency of the information presented.

After the coding stage, a comprehensive check of the correctness and completeness of the integrated knowledge base is carried out. Verification is carried out using logical analysis methods to identify and eliminate contradictions in the presented data. Validation, in turn, is carried out using expert assessments and comparative analysis with empirical data, which allows confirming the practical applicability and reliability of the developed system.

The final stage is the integration of the knowledge base with reinforcement learning and adaptive control systems, which provides the ability to conduct intelligent analysis, forecast process parameters and make management decisions in real time. The use of semantic technologies allows dynamically updating the knowledge base and adapting it to changing operating conditions of technical systems.

As a result, a complex system is formed that is capable of dynamically updating knowledge and supporting decision-making at various levels of technological process management.

Thus, the application of the developed ontology for constructing a knowledge base in OSTIS technology is a multi-stage process, including formalization, structuring, semantic coding, integration, as well as verification and validation of the presented knowledge. This approach contributes to the creation of a flexible and adaptive intelligent system capable of providing effective management of technological processes due to automated analysis and updating of information.

Direct loading of data into the knowledge base through specialized interfaces that provide automated recognition and integration of ontology elements into the overall architecture of the system. At the subsequent stage, the process of indexing and optimization of the loaded information is implemented to ensure fast semantic search and correct logical inference, and data synchronization mechanisms are configured to maintain the relevance of the knowledge base [3].

III. Algorithms for the synthesis of neuroregulators

Neural networks are parameterized models that can be used as universal approximators [5], are noise-resistant, and have applications in complex applied problems. The developed control adaptation system uses a procedure for synthesizing a neural regulator using neural network algorithms. The procedure for synthesizing a neural regulator can also include the use of algorithms for searching for the optimal neural network architecture. The general approach assumes that the user of the system can specify numerical criteria for assessing the quality of adaptation (functionality for assessing the quality of adaptation) and has a simulation model [6] of the process control system. Alternatively, it is possible to simulate the known dynamics of a prototype regulator, if available (Fig. 1).

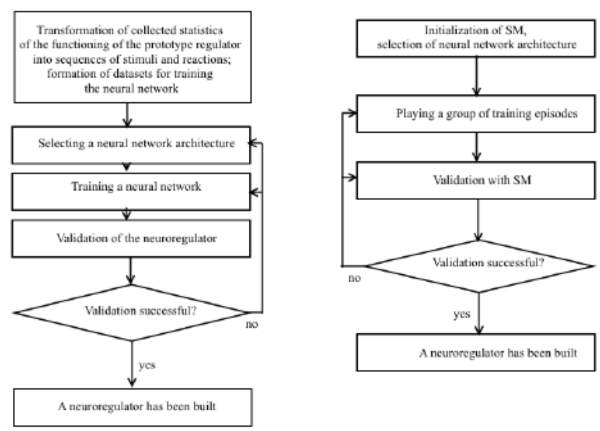

Figure 1. General schemes for synthesizing neuroregulators in the presence of an existing prototype (left) and when searching for an optimal action selection policy using reinforcement learning methods (right)

IV. Modeling the dynamics of an existing regulator

If an existing prototype regulator of the system is available, its dynamics can be simulated using supervised learning [7].

The process of training neural networks (Fig. 2) consists of searching for optimal values of the adjustable parameters of the model (weight coefficients) in the context of the problem being solved, which is usually done by solving some optimization problem, usually by gradient methods [5]. It should be noted that at the data collection stage, it is necessary to ensure the storage of complete and representative statistics of the functioning of the prototype regulator, adequately reflecting the existing space of observations and control actions.

V. Search for the optimal neural network architecture

Since the task of selecting the neural network structure in each case is complex and difficult to formalize, meth-

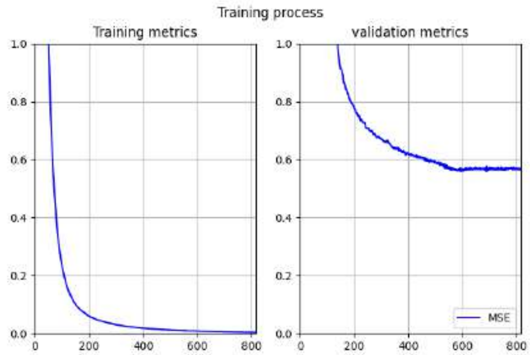

Figure 2. Dynamics of change of loss function (training and validation) in the process of constructing a neuroregulator based on a prototype regulator

ods for partial automation of its solution are proposed. Within the framework of the developed technology, 2 approaches to searching for the optimal architecture of the neuroregulator are implemented: based on the scheme of enumeration of candidate architectures and based on the evolutionary algorithm. In the case of the structure of the observation space of the neuroregulator, which allows the use of neural network architectures that are not deep, the enumeration schemes allow obtaining and clearly displaying the efficiency of the candidate architectures under consideration (Fig. 3).

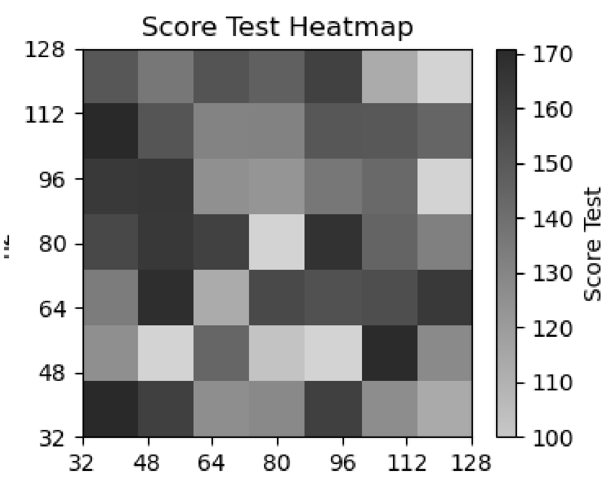

Figure 3. Example of a heat map of average values functionality for assessing the quality of control adaptation in the automated selection of the architecture of the neuroregulator

When solving the problem of searching for a deep architecture for a neuroregulator, the criteria for enumeration are not obvious. Genetic algorithms are potentially universal [10], they allow finding a solution in a situation where it is unknown how to search for it. There are examples when genetic algorithms for searching for neural network architectures have significantly improved the quality of models [11]. The search for the optimal architecture of a neuroregulator within the framework of the described approach is carried out using a modified NEAT neuroevolution algorithm (Fig. 4), in which a sequential movement from simple structures to more complex ones is carried out [11] [12]. Unlike NEAT, the proposed algorithm does not perform optimization of the weights of connections in the neural network using evolutionary methods and operates not with single neurons as nodes, but with modules that can represent an arbitrary given set of layers. The use of an evolutionary algorithm allows constructing a neural network architecture corresponding to the problem being solved (Fig. 5).

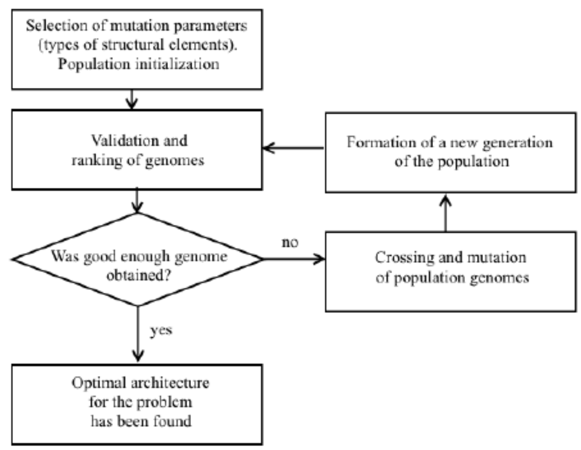

Figure 4. Scheme of evolutionary algorithm for searching for architecture of neuroregulator

VI. Synthesis of a neuroregulator for optimal control adaptation

In real conditions, the principles of constructing optimal control adaptation may not be obvious. In this situation, reinforcement learning methods can be used to solve the problem of synthesizing a neuroregulator [6].

This approach allows taking into account the requirements specified by the technological regulations for the implementation of a technological operation as part of the production process and to synthesize control adaptation to ensure the functioning of the process in accordance with these requirements. Formalization of user requirements for the policy of choosing control adaptation is carried out by defining the function that assesses the quality of control adaptation.

When solving the problem of finding the optimal strategy for servicing the equipment devices of the techonogical process (TP), the function of assessing the quality of control adaptation includes components responsible for assessing the stabilization of the parameters of the TP operation, such as the time of continuous operation of the cycle (R_{nop}), the total volume of costs for servicing and

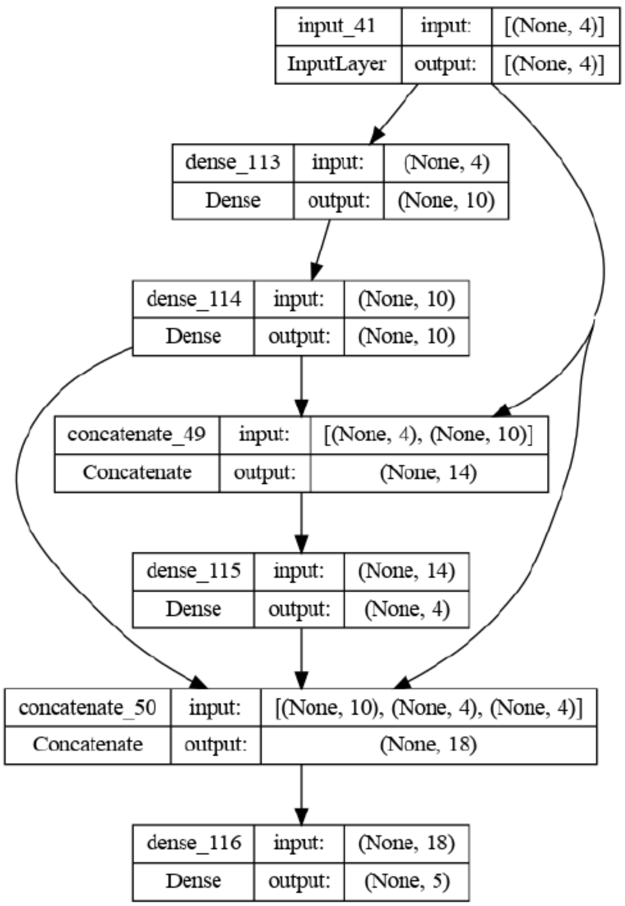

Figure 5. An example of a deep neuroregulator architecture obtained by applying evolutionary search.

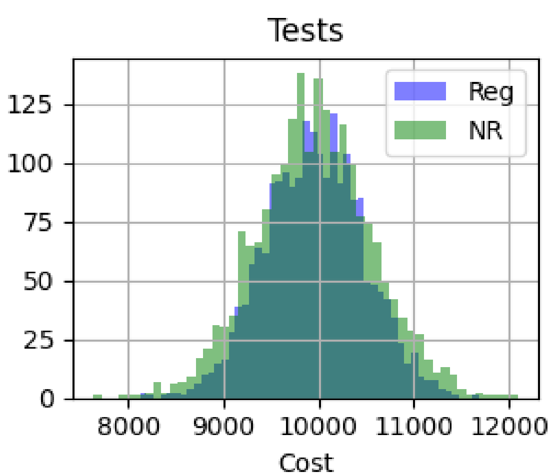

Figure 6. Histograms of distributions of total costs during testing of the standard system regulator and the trained neuroregulator

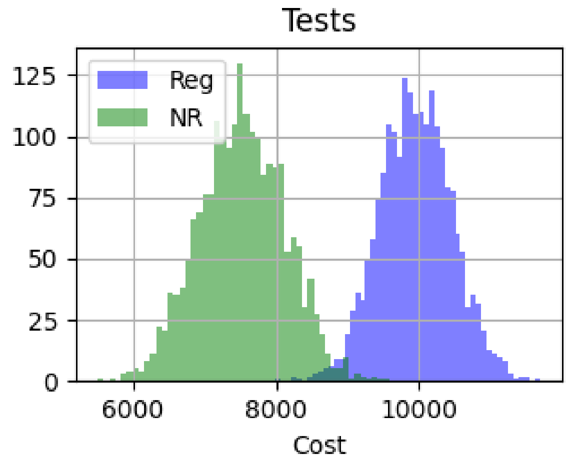

Figure 7. Histograms of distributions of total costs during testing of the standard system regulator and the neuroregulator synthesized with reinforcement learning algorithms

eliminating failures and equipment accidents (R_{cost})), the total number of equipment failures (R_f), including those that led to an accident (R_{fe}), the total number of preventive maintenance per cycle (R_{rep}). The coefficients (α_{1-5}) are set by user of the system to determine the weights assigned to the components. In accordance with the requirements imposed on the process of adaptation of the TP control, the target function is constructed on the basis of these components:

$$R = \alpha_1 R_{nop} + \alpha_2 R_{cost} + \alpha_3 R_f + \alpha_4 R_{fe} + \alpha_5 R_{rep}$$

The neural regulator is trained using policy gradient algorithm (the REINFORCE algorithm [2]). As a result of training, the system with the constructed regulator shows higher efficiency in minimizing maintenance costs than the system with the standard regulator (Fig. 7). At the same time, the cycle downtime associated with failures does not increase. Testing of models allows to establish that the use of a neuroregulator in the control system has reduced the costs of process maintenance by 20-25% according to the specified criteria for the quality of control adaptation.

A similar approach can also be considered when solving the problem of stabilizing the parameters of a technological operation of laser processing of materials [6]. For example, in the problem of single-beam laser thermal splitting of brittle non-metallic materials (Fig. 9), an important issue is maintaining the temperature regime in order to prevent overheating and melting of the work-piece. Structure of the technological operation is shown in Fig. 8 In this problem, the function for assessing the quality of adaptation has the form:

$$R = \alpha_1 R_T + \alpha_2 R_P + \alpha_3 R_\sigma$$

where

- R_T is the component for assessing temperature

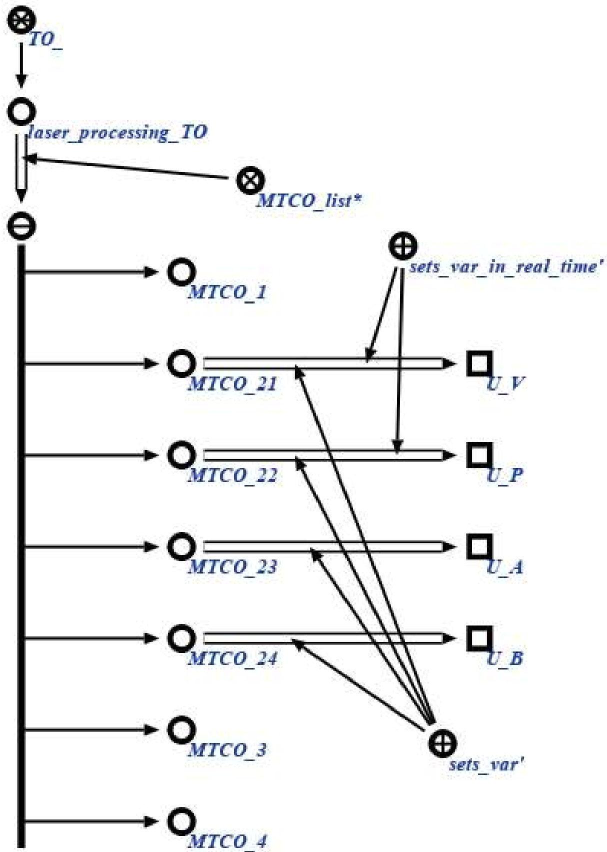

Figure 8. Fragment of the knowledge base about the technological operation of laser cutting

maintenance within the permissible range;

- R_V is the component for assessing the cutting speed;
- R_σ is the component for assessing the maximum tensile stress;
- α_{1-3} are the coefficients defining the weights of the components.

Figure 10 shows the dynamics of the change in the average values of the function for assessing the quality of control adaptation when training the neural regulator of the process operation control system using the REINFORCE algorithm.

Table I shows the results of using the neural regulator of the process operation of laser material processing. It contains the values of the parameters of speed (V), laser radiation power (P), observed temperature (T) and the approximated value of the maximum tensile stress (σ_{yy}). The use of neuroregilator synthesis algorithms for adaptation of the control of the technological operation of laser processing made it possible to increase the processing speed by 21% while maintaining temperature within the permissible range of values.

Table I
Comparison of the values of the parameters of the technological operation of laser processing of materials without the use of a neuroregulator (first line) and with the use of a neuroregulator (second line)

V,m/s	P,Wt	T,K	σ_{yy}, MPa
0.011	24.0	1390	7.04
0.0133	26.5	1395	7.2

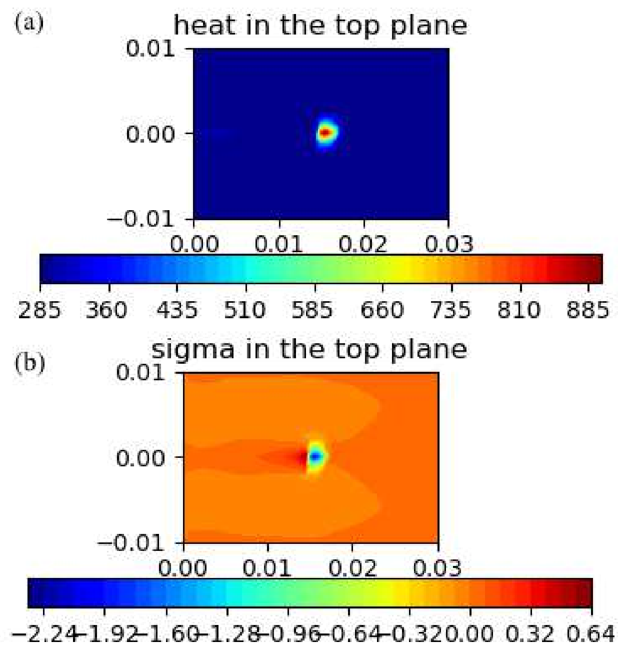

Figure 9. An example of visualization of temperature fields (a) and tensile stress fields (b) on the surface of a glass workpiece during laser processing technological operation

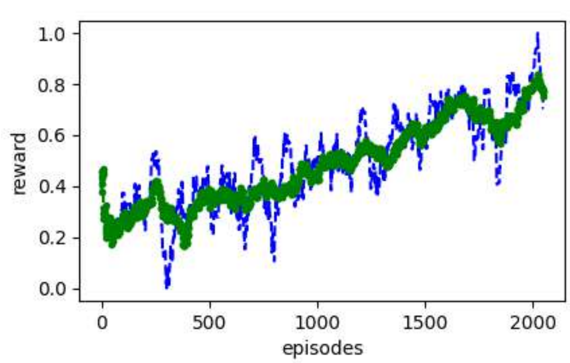

Figure 10. Dynamics of changes in the function of assessing the quality of adaptation in the learning process

VII. Conclusion

Neural networks, having the properties of universal approximation and resistance to noise, allow one to effectively solve control problems under conditions of uncertainty. The article presents the technology of adaptive control of automated production systems based on neural networks, which ensures the use of an intelligent computer system for adapting control of the technological cycle in real time.

The use of neural network modeling algorithms in the implementation of adaptation of the control of the technological operation of laser processing of materials made it possible to increase the processing speed by 21% and reduce the costs of servicing the equipment of the technological production cycle by 20-25%.

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ТЕХНОЛОГИЧЕСКИЕ АСПЕКТЫ АДАПТАЦИИ УПРАВЛЕНИЯ НА ОСНОВЕ НЕЙРОСЕТЕВОГО МОДЕЛИРОВАНИЯ

Смородин В.С., Прохоренко В.А.

Представлена инновационная технология адаптации управляющих сигналов контура управления технологическим циклом производства к внешним управляющим воздействиям и случайным возмущениям. Предложено новое решение для снижения влияния дестабилизирующих факторов окружающей среды в режиме реального времени.

Разработан метод адаптации управления технологическим циклом автоматизированного производства, основанный на построении алгоритмов обратных связей по управлению для снижения чувствительности параметров технологических операций к изменениям условий функционирования технологического оборудования и окружающей среды.

Приведено описание инструментария для реализации средств адаптации управления технологическим циклом производства, основанного на построении алгоритмов обратных связей по управлению и синтезе нейрорегуляторов с использованием нейросетевых алгоритмов. Предложена процедура генерации базы знаний в соответствии с онтологией «технологические процессы с вероятностными характеристиками», обеспечивающая формальное описание классов компонентов технологического цикла, их свойств и взаимосвязей между классами, кодирование в формате SC-кода и интеграцию с механизмами логического вывода.

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