Stabilization of Parameters of Technological Operations in the Presence of External Control Actions

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Abstract—A new technique for formalizing probabilistic technological processes when stabilizing the parameters of functioning of technological operations using open semantic technologies for designing intelligent systems is proposed. To stabilize the parameters of technological operations in real time, a procedure for adapting control to variable external control influences is presented based on the neuroregulators algorithms of an intelligent stabilization system that implement control feedback. The principles of development and implementation of intelligent system for stabilizing parameters and a controller for an automated process control system are described.

Keywords—formalization methodology, neuroregulator algorithms, simulation models, stabilization of controlled parameters, controller

I. Introduction

The operating efficiency of the created automated control systems for real objects largely depends on the quality and adequacy of mathematical models of the research object, which are used at the control system design stage [1]. For this reason, the most significant scientific results in the field of research of the operation of automated production systems and control systems are the development of effective algorithms for adaptive control of automated production based on new methods of neural network modeling of the research object [2]–[4]. The current stage of development of industrial automation means requires ensuring interoperability and semantic compatibility of heterogeneous components of intelligent systems [5].

The paper presents a methodology for synthesizing feedback loops for controlling the technological cycle of automated production based on the use of open semantic technologies for designing intelligent computer systems and algorithms for neural network modeling of control feedback loops.

II. Problems of stabilization of technological cycle parameters

The problem of determining the optimal parameters for controlling technological systems in real time is an important problem of production management in the presence of external control influences during technological operations and random disturbances associated with the design and reliability characteristics of the equipment.

This paper proposes a solution to the problem of stabilizing the parameters of the technological cycle based on the creation of a new generation intelligent computer system capable of stabilizing the parameters of the technological cycle in the presence of external disturbances in real time.

The use of mathematical models of neural networks within the framework of this approach ensures the creation of a new generation of intelligent systems for adapting the control of complex technical complexes, determining optimal control parameters and stabilizing the controlled variables of technological operations in specified ranges of acceptable values depending on external control influences and random disturbances.

The versatility of the proposed approach is determined by a limited set of parameterized procedures that implement algorithms for creating a knowledge base open for expansion based on the ontology of the "probabilistic technological production processes" subject area. The practical and economic significance of the results obtained are determined by the new opportunities provided by the study of existing and design of new complex technological objects.

The construction of a new generation intelligent computer system involves the following development stages:

- methods for formalizing the technological production process based on the use of the ontology of the subject area "technological production processes with probabilistic characteristics";

- schemes for the functioning of a hybrid intelligent computer system, providing the possibility of semantic compatibility and sharing with other solutions at industrial enterprises in the context of the Industry 4.0 concept [6];
- algorithms for the synthesis of control feedback based on the use of neuroregulators;
- method of adaptive control of automated production systems in the presence of external control influences;
- software support for intelligent systems based on adaptation algorithms and the proposed method in real time.

The results provide a new constructive approach to the formalization of the technological cycle, based on the use of open semantic technologies for the design of intelligent systems, and the synthesis of feedback on the management of the production process using neural network modeling, which allows to:

- develop hybrid intelligent computer systems designed to solve problems of adapting the management of complex technical systems, in particular, the technological production cycle;
- ensure integration and semantic compatibility of the components of the control system model with other intelligent systems;
- search for optimal parameters for adapting control and stabilizing controlled variables of technological operations in specified ranges of permissible values.

The described tools make it possible to create flexible intelligent computer control adaptation systems (CCAS), which are a set of semantically compatible and easily replaceable components depending on the range of tasks being solved.

The interaction of the system and its corresponding solvers with the control rack of the automated technological system is carried out using means of software and hardware interface of production.

III. Constructing components of a multi-level control system model in conditions of incomplete information

Optimization of the parameters of the technological cycle of automated production requires the development of effective control adaptation algorithms and methods for constructing neuroregulators that stabilize the parameters of technological operations, taking into account current information about the functioning of the object of study, random disturbances and external control influences, which are recorded during the operation of the control system controller and stored at the control rack automated control system (ACS) for the technological process (TP).

The structural diagram of the interaction of the components of the intelligent control adaptation system is presented in figure 1. A formal description of the control object is carried out based on the use of the ontology of the "probabilistic technological production processes" subject area. When implementing this approach, formalized knowledge is used to describe technological processes with probabilistic characteristics of technological operations and model technological processes.
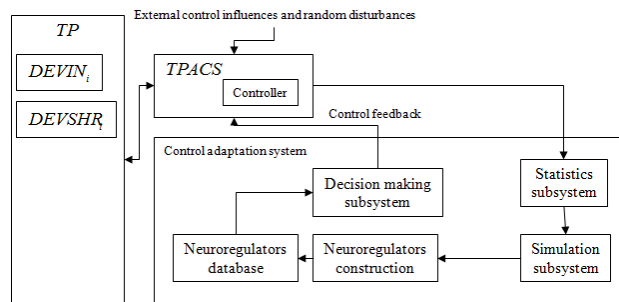

Figure 1. Diagram of interaction of the components of the intelligent control adaptation system

The formalization used is based on the scientific research of the authors in the field of simulation modeling of complex technical systems and implies the use of libraries of simulator units of technological operations integrated into the OSTIS ecosystem on the principles of semantic compatibility [7].

When the characteristics of technological operations of a control object are highly non-stationary, simulation models, neuroregulators and multi-step learning algorithms with better dynamic properties are used to build multi-level mathematical models.

As follows from the interaction diagram of the system components, the formation of control feedback comes down to the search for control adaptation that satisfies user-specified criteria, carried out according to the closed-loop principle, in which neuroregulator models are built on the basis of the collected statistics of the operation of the automated process control system and a collection of simulation models. The decision-making system, operating using the constructed neuroregulators, carries out in real time the formation of corrective influences on the controller of the automated control system of the TP.

The introduction of the Industry 4.0 concept at industrial enterprises is accompanied by the creation of a digital twin of the enterprise and the construction of a unified ontological production model, which is the core of comprehensive information services for the enterprise. One of the stages of building a digital twin model of an enterprise is the embedding of data on low levels of production, such as production processes and equipment [8].

IV. Methodology for formalizing a technological system when stabilizing control parameters

In order to ensure the possibility of using an intelligent control adaptation system, knowledge about the technological process of an enterprise must be recorded in a formal knowledge representation language. The sources of such knowledge can be existing descriptions of the work of enterprises within the framework of accepted international standards (such as ISA 5.1, ISA88) [6], [9]–[11]. Thus, within the framework of the ISA-88 standard, a technological cycle is called a procedure, and a technological operation is called a phase.

If there is a known set of devices and maintenance of the technological cycle, as well as statistical data on their operation, it is possible to move on to simulation modeling of the technological process by replacing devices in the probabilistic network diagram (PND) describing the cycle with units simulating the operation of shared use and individual use devices. The operations present in the model can be implemented as a set of event simulator units and technological operations simulator units. Based on simulation models of the technological cycle constructed using the current operation statistics it is possible to construct neuroregulators that carry out corrections of the controller's control actions [12].

With this approach, the adaptive control system requires a minimum amount of initial information about the incoming signals, and the described formalization makes it possible to synthesize knowledge bases about an industrial enterprise and its technological processes based on the domain ontology within the framework of the Industry 4.0 concept of automation of industrial enterprises.

V. Stabilization of control parameters based on an intelligent computer system

The basis for creating a hybrid intelligent control adaptation system is the idea of developing multi-level simulation models and mathematical models of neural network regulators [12] to solve problems of control optimization, constructing algorithms for synthesizing control feedback for the technological cycle depending on changes in the operating parameters of the controlled object.

The hybrid intelligent control adaptation system includes the following components:

- subsystem for processing and storing statistics of the operation of TP ACS;
- simulation subsystem;
- subsystem for constructing models of neuroregulators;
- database of constructed neuroregulators;
- decision-making subsystem.

TP operation statistics include the values of signals describing the state of TP devices, as well as the values of control signals. The statistics processing and storage subsystem is responsible for saving the historical values of signal data.

The simulation subsystem allows construction and execution of simulation models of a technological process and its control system based on the ontological model of production and the described formalization. Historical values saved by the subsystem for processing and storing performance statistics are used as initial data. Based on them, distribution functions are constructed for resources consumed by technological operations and reliability characteristics of equipment, stored in the knowledge base. Simulator units of the operation of devices for shared and individual use are the basis for creating TP simulation model.

The subsystem for constructing models of neuroregulators implements neural network modeling algorithms to find the optimal control adaptation strategy. Provided that there are known target values of correction signals (for example, in the case of manual data marking, or the presence of an existing high-quality regulator of the system regulator), a neuroregulator can be built using the collected statistics of the operation of the technological process and automated control system [13], [14]. In the absence of a regulator prototype, algorithms are used to search for the optimal policy for selecting actions in an environment built on the basis of a TP simulation subsystem [7], [12].

It should be noted that algorithms of this type allow to automate the search for an adaptation policy, taking into account the criteria specified by the system user for assessing the quality of the policy for selecting actions by the neuroregulator [12]. The target function of the neural network training algorithm may "reward" for reducing production costs and "fine" for equipment downtime, equipment failures or emergences based on the coefficients selected by system user.

Adaptive-critic-based schemes [15]–[20] for searching for an optimal control adaptation strategy have the potential to build an effective regulator of a control system due to the presence of a research element in the process of determining the optimal control policy, which can have a positive effect when solving problems with a complex structure of control decision-making space.

If necessary, a search for the optimal neural network architecture can also be carried out based on grid search or genetic algorithms [21] (Figure 3) using training and validation procedures to evaluate the candidate architectures. A feature of the latter approach is the tracking of genes using historical marks, which allows for the crossing of successful topologies, species division to preserve innovations, consistent movement from simple architectures to more complex ones.

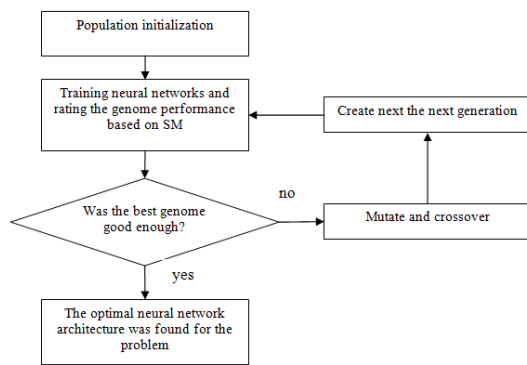The general scheme of the algorithm for constructing a neuroregulator is shown in Figure 3.

Figure 2. A genetic algorithm scheme to search for the optimal neural network architecture
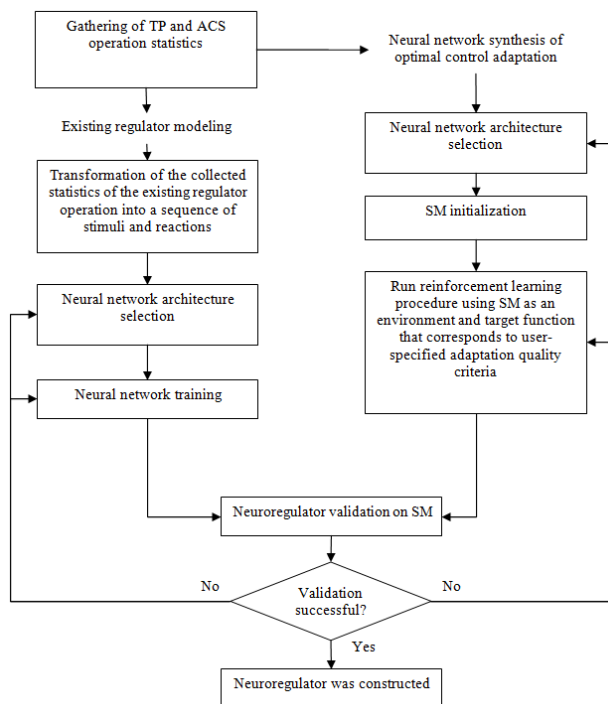

Figure 3. Neuroregulator synthesis algorithm scheme

Simulation modeling allows for model validation after training. Models of neuroregulators are saved to the database for further use or additional training using updated statistics.

The decision-making subsystem uses the constructed models of neuroregulators.

Adaptation of the technological cycle control is carried out on the basis of the operation of the constructed neuroregulator, which forms corrective influences on the process control system to prevent the range of changes in the components U_{fh} of the control vector variables U_h from going outside the allowed range.

Returning the values of control variables within the acceptable intervals is carried out by means of special adjustment means - initiating the launch of MTSO TP, which change the values of the components of the set of control variables U_s or use equipment redundancy schemes.

Provided that appropriate hardware and software interface tools are available, it is possible to implement control adaptation in an automated mode, or to form a recommendation system used by personnel servicing the technological cycle.

Thus, when solving the problem of stabilizing the parameters of technological operations in real time, multi-level mathematical models were used, including neural network and simulation ones, and a new generation hybrid intelligent computer adaptive control system was implemented, created on the basis of open semantic technologies for designing intelligent systems [7].

VI. An example of a simulation model of a probabilistic technological process control system

Simulation modeling of the interaction of control system elements and components of a probabilistic technological process can be carried out on the basis of synchronization schemes of their operation [7].

Simulation modeling of the implementation of a probabilistic technological process includes modeling of microtechnological operations associated with resource requests of a probabilistic nature, as well as possible changes in control variables U, and the operation of devices with possible device failures and their consequences.

The initial parameters for constructing a control system simulation model (CS SM) of an probabilistic technical process (PTP) are a set of parameters characterizing its composition and structure [7], including estimates of the distributions of various parameters of the TP, collected during its operation observation using appropriate software and hardware interface tools. In particular, these include the number of implementations of the simulation model N, the set X_i of PTP resource requests required to run the executive elements of the control system, the parameters of commutation of the executive elements with synchronization elements, input signal generators and the final operating element, configuration vector of the equipment composition and a set of reliability characteristics of the equipment.

Simulation modeling of control system of TP is based on the operation of a set of simulator units. Within the framework of OSTIS technology, the solution to the problem of operation of simulator units can be formalized on the basis of a multi-agent approach [7], when the SM of the PTP control system is implemented as a set of agents corresponding to simulator units that can exchange data through sc-texts.

Within the framework of the problem under consideration, the solver of the problem of operation of a simulator

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unit can be represented as a decomposition of an abstract non-atomic agent (Figure 4).

abstract non-atomic sc-agent of unit-simulator operation
$\Rightarrow$ *decomposition of abstract sc-agent**:
  {• *abstract sc-agent of input signals processing*
   • *abstract sc-agent of output signals generation*
  }

Figure 4. Decomposition of the abstract non-atomic sc-agent of the operation of the simulator unit of the CS SM of TP

The operation of the simulator unit depends on some set of input signals that may be a result of operation of other simulator units or signal generator units. The simulator unit must process them and generate the appropriate output signals according to certain rules. Thus, in the context of the OSTIS ecosystem, the agent of the simulator unit operation is represented by a set of two agents for processing input signals and generating output signals.

Figure 5 shows a block diagram of a control system for a probabilistic technological process when modeling the problem of stabilizing operating parameters by searching for an optimal strategy for servicing TP devices.
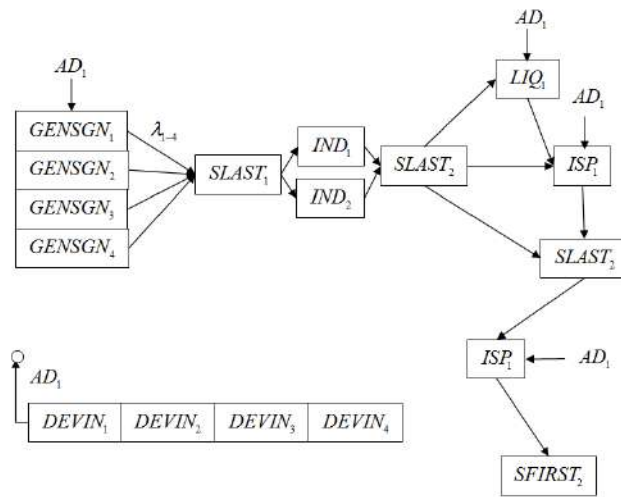

Figure 5. Example of a PTP control system

This control system is responsible for the execution of the technological cycle, during which maintenance of technological cycle equipment devices can occur, as well as the elimination of equipment failures and the elimination of emergences when they occur. The equipment of the technological cycle is represented by 4 devices for individual use, each of which performs a corresponding microtechnological operation.

$GENSGN_{1-4}$ are signal generator units, the intensity of which is set by the corresponding distribution of reliability characteristics of equipment devices. The intensities of the generated signals during the simulation process determine the probability of failures occurring in the corresponding devices.

Synchronizer $SLAST_1$ (type "AND") starts the process of indicating equipment (IND_1) and control variables (IND_2). If an accident is indicated on one of the equipment devices, the consequences of the accident are eliminated (LIQ_1). If the specified intensity value of the control variable (variables) (U) is exceeded, the corresponding device is serviced (ISP_1 - the corresponding operation is performed). If the maintenance was completed or was not performed, microtechnological operations determined by the technological process are performed on each of the devices.

When the $SFIRST_2$ unit is executed, the technological cycle finishes it's operation.

VII. Conclusion

The paper proposes a method for constructing a new generation intelligent computer system for adapting the control of the technological cycle of automated production with control feedback in the presence of random disturbances and external control influences in the integrated environment of open semantic technologies for designing intelligent systems OSTIS. Control feedback is formed on the basis of algorithms for constructing neuroregulators using simulation modeling to find the optimal control adaptation strategy according to specified criteria. An example of a simulation model of a TP control system is given when solving the problem of servicing TP equipment devices and a method for describing its elements within the OSTIS ecosystem is given.

When considering the problem of synthesizing the optimal structure of a technological system with an arbitrary organization of the technological production process and stabilizing the parameters of technological operations, algorithms for constructing control feedback based on genetic algorithms and artificial neural network models were implemented. Stabilization of the parameters of technological operations is carried out within the framework of solving the multi-criteria problem of assessing the quality of the technological process while minimizing the costs of performing a closed technological production cycle based on effective control adaptation algorithms.

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СТАБИЛИЗАЦИЯ ПАРАМЕТРОВ ТЕХНОЛОГИЧЕСКИХ ОПЕРАЦИЙ ПРИ НАЛИЧИИ ВНЕШНИХ УПРАВЛЯЮЩИХ ВОЗДЕЙСТВИЙ

Смородин В. С., Прохоренко В. А.

Предложена новая методика формализации вероятностных технологических процессов при стабилизации параметров функционирования технологических операций с использованием открытых семантических технологий проектирования интеллектуальных систем. Для стабилизации параметров технологических операций в режиме реального времени представлена процедура адаптации управления под изменяющиеся внешние управляющие воздействия на основе разработки алгоритмов нейрорегуляторов интеллектуальной системы стабилизации, реализующих обратные связи по управлению. Изложены принципы создания и разработки системы стабилизации параметров и контроллера автоматизированной системы управления технологическим процессом.