Adaptive Control System for Technological Process within OSTIS Ecosystem

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***Abstract*—In this paper an approach to building a hybrid intellectual computer system for adaptive control of a technological production cycle is being proposed in the form of an ostis-system solver based on the ontology of the "technological production processes with probabilistic attributes" domain knowledge. The idea of development and implementation of mathematical models of neural network regulators for control optimization problems is the basis for the system solver. Such an implementation makes it possible to integrate the proposed solution with other developed solutions as well as the company's software in order to allow building intellectual systems for automated control, recommendation systems and decision support systems, information support systems for the company's personnel.**

***Keywords*—technological production process, adaptive control, neural network, reinforcement learning, Industry 4.0, standard**

I. Introduction

The constant efforts of scientific and technological advances in the sphere of optimization of production systems operation require the development of up-to-date approaches to adaptive control of production processes that would include elements of artificial intelligence, neural network modeling and development of intellectual computer systems of new generation.

In this paper an approach is being proposed for building a hybrid intellectual computer system for adaptive control of a technological production cycle within the framework of OSTIS Ecosystem. The formal description of the control object is based on ontologies of the "technological production processes with probabilistic attributes" domain knowledge and ISA 5.1, ISA-88, ISA-95 standards, implemented through the means of OSTIS Technology.

Control adaptation is implemented using the means of software-hardware coupling of neural network regulators and hardware control system of the technological object in real-time.

The idea of the hybrid intellectual system for adaptive control is based upon development and implementation of mathematical models of neural network regulators for solving problems of control optimization, implementation of methods and algorithms of synthesis of feedback control for technological cycle, depending on changing parameters of the control object operation.

II. Terms and Definitions

The central concepts within the knowledge domain under consideration are technological process (technological cycle) and probabilistic technological process [2].

1) A technological process (TP) (technological cycle) of production is a sequence of interconnected operations, that is defined by technological documentation, directed at the object of process with purpose of producing the required output. Within ISA-88 standard's procedural control module TP is defined as a procedure, that produces a batch of product (that may be a final product or intermediate product used in the further stages of production of the final product).
2) A technological operation is part of a technological process, that is being run continuously at one workplace on one or more simultaneously processed or assembled products by one or more operators. Within ISA-88 standard it is defined as operation that results in substantially altered product properties. Operations can be run by an operator who can start, pause and resume them. At each moment of time only one operation can be active within a machine (unit).
3) Microtechnological operation is a finite sequence of elementary operations which constituent the contents of a technological operation, that is run continuously at one workplace. Within ISA-88 standard it is a phase that results in small changes in the properties of a product. Those steps can be run in parallel, in sequence or as a combination of two. Operator can't directly control the steps (start/pause/resume).
4) A Probabilistic technological process is a technological process that has probabilistic parameters of operation; a technological process with a structure that may change during its operation.

5) A Control system is a well-defined set of hardware-software means for control of a technological object, that makes it possible to collect readings of its state and to influence its operation in order to achieve the given goals.
6) Adaptive control is a set of methods and algorithms that allow synthesizing the control feedback connections that can change parameters (control structure) of the neuroregulator based on the control actions and external disturbances.
7) Automated control system of a technological process (ACSTP) is a complex of technical and software means that makes it possible for technological units to operate in automated mode based upon the chosen control criteria.

technological process
:= [technological cycle]
:= [is a sequence of interconnected operations, that is defined by technological documentation, directed at the object of process with purpose of producing the required output]
:= [a set of technological operations $\{TCO_{ij}\}$, where $i, j = \overline{1, N}$, as well as the resources consumed by those operations]

probabilistic technological process
:= [PTP]
⊂ *technological process*
:= [technological process that has probabilistic parameters of operation]
:= [a technological process with a structure that may change during its operation]

technological operation
:= [TCO]
⊂ *technological process*
:= [subset of a technological process, that is being run continuously at one workplace on one or more simultaneously processed or assembled products by one or more operators]

microtechnological operation
:= [MTCO]
⊂ *technological operation*
:= [finite sequence of elementary operations which constituent the contents of a technological operation, that is run continuously at one workplace]

III. Problems of adaptive control of production processes in the context of new generation computer systems development

Enterprise automation tools must be able to adapt to any changes in the production process itself with minimal costs and time delays. Such changes may include expansion or reduction in production volumes, changes in production nomenclature, replacement or changes of technological units, alteration of the overall production structure, changes of interactions between suppliers and consumers, changes of the legal acts and standards, as well as other unforeseen circumstances of different nature.

Analysis of the field in the sphere of the modern controlled production systems research demonstrates that the problem of determining the real-time operation parameters of such research objects emerges primarily in the cases of complex technical products production that requires high manufacturing precision and high labor productivity.

In such cases when solving a multicriteria control optimization problem high standards need to be applied to the algorithms of the operation of the production process, minimization of human factor impact on the technological production cycle operation quality, prevention of occurrence of technogenic emergencies. Such a case is typical for robotic production systems that operate under control of the hardware and software controller that administers the functioning of the technological cycle control system according to the given programs.

At the same time the arising emergency situations due to equipment failures, random external control actions, including human factor, lead to deviation of the operation parameters of the production system from the desired values, which leads to the necessity of their correction in real-time based on the neuroregulator models that operate within the hardware-software coupling means of the technological production cycle.

The existing special artificial intelligence models such as neural networks have unique properties and can be used as universal approximators that have a capability to generalize the data against which they were trained. Such features make it practical to use such models when solving complex problems in the domain of adaptive control.

The modern convergence tendencies in the sphere of intellectual systems development [1] requires the development of the appropriate software that would feature elements of cognitive abilities based on semantically compatible technologies of artificial intelligence. This sphere also includes the development of computer systems that are able to provide intellectualization of the processes of making analytical control decisions (which are directly related to adapting control processes for complex dynamic systems (technological objects) in real-time), building semantically compatible knowledge bases in the domain of dynamic systems operation analysis and optimization of the operation of complex control systems based upon them through open-source intellectual decision support systems development.

IV. Building a mathematical model of a production system in the context of Industry 4.0

Implementation of Industry 4.0 concept at industrial enterprises is accompanied by creation of a unified ontological model of the production process. This model is the core of integrated information service for the company [13].

In order to allow a wide implementation of the artificial intelligence technologies for automating the company, all corporate knowledge must be transformed into the formal language for knowledge representation. Such knowledge may be obtained from the existing documentation that describes the enterprises' operation within the framework of accepted international standards.

It is necessary to transform each existing standard into a knowledge base based on the appropriate set of ontologies related to the standard. Such an approach allows to significantly automate the processes of standard development and its application.

As an example let us consider ***ISA-88*** standard [16] (the base standard for prescription production). Even though this standard is widely used by American and European companies (and is being actively introduced in Republic of Belarus) it has a number of flaws that are listed below. Authors' experiences with ISA-88 and ISA-95 have demonstrated the following problems related to versions of the standard (see [8]):

1) American version of standard – *ANSI/ISA-88.00.01-2010* – has been updated and is in its 3rd edition (as of 2010);
2) *ISA-88.00.02-2001* – includes data structures and guidelines of languages;
3) *ANSI/ISA-TR88.00.02-2015* – describes an implementation example of ANSI/ISA-88.00.01;
4) *ISA-88.00.03-2003* – an activity that describes the use of common site recipes with and across companies;
5) *ISA-TR88.0.03-1996* – shows possible recipe procedure presentation formats;
6) *ANSI/ISA-88.00.04-2006* – structure for the batch production records;
7) *ISA-TR88.95.01-2008* – describes how ISA-88 and ISA-95 can be used together;
8) At the same time, the European version approved in 1997 – *IEC 61512-1* – is based on the older version *ISA-88.01-1995*;
9) Russian version of the standard – *GOST R IEC 61512-1-2016* – is identical to *IEC 61512-1*, that is also outdated. Also it raises a number of questions related to the not very successful translation of the original English terms into Russian.

Another standard that is often used in the context of Industry 4.0 is ***ISA-95*** [17]. ***ISA-95*** is an industry standard for describing high level control systems. Its main purpose in to simplify the development of such systems, abstract from the hardware and provide a single interface to interact with ERP and MES layers. It consists of the following parts (see [8]):

1) *ANSI/ISA-95.00.01-2000*, Part 1: «Models and terminology» — it consists of standard terminology and object models that can be used to determine what information is exchanged;
2) *ANSI/ISA-95.00.02-2001*, Part 2: «Object Model Attributes» — it consists of attributes for each object defined in Part 1. Objects and attributes can be used to exchange information between different systems and can also be used as the basis for relational databases;
3) *ANSI/ISA-95.00.03-2005*, Part 3: «Models of Manufacturing Operations Management» — it focuses on Level 3 (Production/MES) functions and activities;
4) *ISA-95.00.04* Part 4: «Object models and attributes for Manufacturing Operations Management». The SP95 committee is yet developing this part of ISA-95. This technical specification defines an object model that determines the information exchanged between MES Activities (defined in Part 3 of ISA-95). The model and attributes of Part 4 form the basis for the design and implementation of interface standards, ensuring a flexible flow of cooperation and information exchange between various MES activities;
5) *ISA-95.00.05* Part 5: «Business to manufacturing transaction (B2M transactions)». Part 5 of ISA-95 is still in development. This technical specification defines operations among workplace and manufacturing automation structures that may be used along with Part 1 and Part 2 item models. Operations join and arrange the manufacturing items and activities described withinside the preceding a part of the standard. Such operations arise in any respect ranges withinside the organization, however the attention of this technical specification is at the interface among the organization and the management system;
6) *ISA-95.00.06* Part 6: «Transactions between Manufacturing Operations»;
7) *ISA-95.00.07* Part 7: «Model of Service Messages»;
8) *ISA-95.00.08* Part 8: «Profiles of Information Exchange».

Models help define boundaries between business and control systems. They help answer questions about which functions can perform which tasks and what information must be exchanged between applications.

The first phase of building a digital twin model requires