# Application of planning artificial neural networks in solver of tasks of intellectual self-organizing automatic-control systems

**Michail F. Stepanov, Andrew M. Stepanov**

Saratov State Technical University, Saratov, Russia
E-mail: mfs@sstu.ru

**Abstract:** Expansion of orbs of application (appendix) of automatic control has caused development of intellectualization of control systems. One of the important directions are intelligent self-organizing system of automatic-control (ISSAC). They are capable to supply required capabilities of the purpose of control with change of environments and/or their parameters). It is attained by automatic synthesis of the law of control, the most adequate a current situation. For this purpose the intelligent system of synthesis is used.
The planning subsystem creates (in the elementary case selects from already known) the most adequate procedure of synthesis. However existing approaches to planning actions have no property of mass parallelism. It do not allow to apply them in control systems owing to the big costs of time for a solution of task. It is offered to use planning artificial neural networks (PANN) within the planning subsystem of tasks solver. Features of planning of tasks solvings with use PANN are considered. Outcomes of simulation of control by a population of plants with use ISSAC are represented.
**Keywords:** planning artificial neural networks, simulation of intellectual control systems.

## 1. Introduction

Increasing thickening of objects of control in a combination with toughening requests to accuracy and quality of control has reduced to an inconsistency with traditional approaches to construction of control systems. Modern control systems, as a rule, are working (function) in interacting with other systems which can influence on their behavior. The problem is complicated that, those conditions of functioning of control systems are changing during their work. It concerns not only the change of controlled plants and environments of their functioning, but also and the purposes of control. Necessity of organization of interacting of a set of the control systems a population of probably interconnected controlled plants essentially complicates a task of control.

## 2. Intelligent self-organizing control systems

It is expedient to apply the approach based on usage of intellectual systems of synthesis of the law of control to a solution of the indicated problem [1]. Such systems for a solution of a specific task of synthesis of the law of control in the

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beginning create a program of a solution of the task as ordered population of elementary operations and executing them make the required law of control. The amount of the elementary operations used for task solving of synthesis of the law of control, is not big, as they represent procedural definition of concepts of the theory of automatic control (TAC) [2]. Creating of the program a solution of the task is carried out based on knowledge of methods of task solving of the theory of automatic control. For this purpose are traditionally used a tools of automatic theorem proving. It is known, that tasks of scheduling of operations or automatic theorem proving are difficultly for deciding and them referred to category of NP-challenge. For such tasks of an expenditure of resources by searching of a solution will increase under the exponential law with growth of complexity of the task. Thus the most perspective are multilevel systems in which at the expense of introduction of hierarchically interconnected spaces are narrowed down of area for searching a solution of the task. Intelligent self-organizing control systems are understood as systems of automatic control, capable to self-organizing by means of a modification of the law of the control, using methods of an artificial intelligence [3].
Structure of an intelligent self-organizing system of automatic control (see fig. 1): the measuring subsystem, the executive mechanisms, the calculator of control action, the subsystem of identification of models of plant of control and environment based on the data of a measuring subsystem, the block of shaping of the purpose of control on the basis of the own purposes of behavior and an emotional state of an intelligent self-organizing control system, the intellectual subsystem of synthesis of the law of control, the block of a self-estimation realizing an evaluation of a quantitative equivalent of quality estimate ("emotion") of behavior of this intellectual self-organizing system of automatic control, formed on the basis of a self-estimation and the estimations obtained from higher hierarchy levels of control systems.

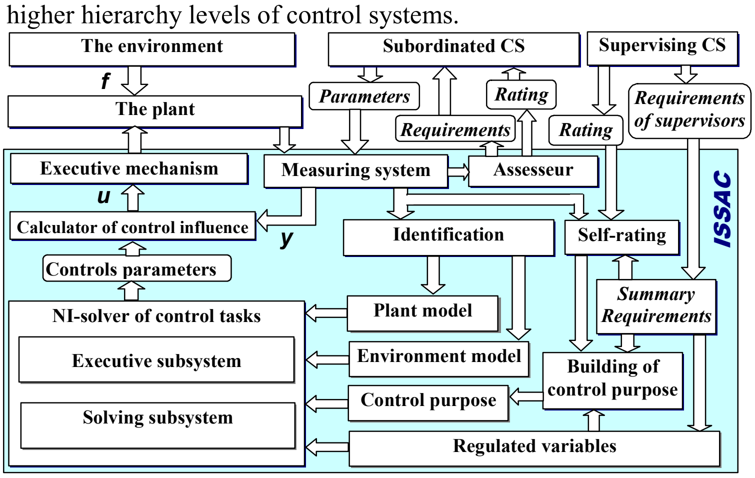


Fig. 1. Structure of an intelligent self-organizing system of automatic control

Setting of the task of synthesis of the new law of control includes exposition of known components of a control system, an environment and the purpose of control, not specifying of a method (procedure) of a solution of the task, i.e. *none procedurally*. The set of methods of synthesis and the analysis of control systems are more not very important yet. More important becomes are availability of capabilities of tools by automatically definition are methods, relevant to the current task.

The problem of an automatic solution non procedural tasks in view demands engaging intelligent tools, understanding under a word "intelligent" ability to decide new tasks [4]. Therefore, the subsystem of automatic synthesis of the law of control of a self-organizing control system should represent the intelligent system of automatic synthesis using methods of an artificial intelligence for preliminary construction of the schedule of a solution of a specific target of synthesis. The new law of control is formed as a result of execution of the constructed plan of action. Thus, most a gorge is the mechanism of scheduling of operations. It is stipulated by that methods used now have no property of mass parallelism, and, therefore, «*the damnation of dimension*» is inherent in them, not permitting to solve tasks of practical complexity.

The complex solution of the indicated problems is known on the basis of the methodology *of automatic* problem solving the theory of automatic control including [2], [3]: 1) *formalizing* knowledge of methods of problem solving of synthesis and analysis control systems as multilevel model of a set of formalized tasks (MMSFT) TAC [2]; 2) construction *of a planning* subsystem as the system of automatic theorem proving representing the application system of calculus of sequent [4], [5] and called as the multilevel axiomatic theory of automatic solutions of formalized tasks (MATASFT) TAC [2], [3]; 3) usage *of planning artificial neural networks* (PANN) [2], [3], [6] as a search engine of output in formal axiomatic systems; 4) Result of the planning (schedule) of a solution of the task is the program on the problem oriented language "Instrument - OP", which supporting a paradigm «rules IF-THEN» [2]; 5) construction *of the executive* subsystem as the application package controlled by the interpreter of the language "Instrument - OP".

Multilevel model of a set of formalized tasks of TAC is $M_O =< \Pi, Д, O >$, were $\Pi = \{п_i \mid п_i =< P_i, H_i, \Psi_i, Q_i >,\ P_i \subseteq \wp, H_i \subseteq \aleph, \Psi_i \subseteq \Im, Q_i \subseteq \Pi\}$ – set of the formalized generalizations of control system components called as *subjects* and possessing: *properties* $p_j \in P_i \subseteq \wp = \{\rho \mid \rho = \{true \mid false\}\}$; *characteristics* $h_j \in H_i \subseteq \aleph = \{\chi_k \mid \chi_k \in \mathbf{C}^{n_k}, n_k \in \mathbf{N}\}$, **C**, **N** – sets complex and natural numbers accordingly; *forms* of mathematical models $m_j \in \Psi_i \subseteq \Im = \{\mu_1,..., \mu_\tau\}$; *components* $q_j \in Q_i \subseteq \Pi$; $Д = \{д_i \mid д_i : \wp \cup \aleph \cup \Im \to \wp \cup \aleph \cup \Im \cup O\}$ – set of operations for processing attributes of subjects; $O = \{o_i \mid o_i : \wp \cup \aleph \cup \Im \to \{true \mid false\}\}$ – set of the predicates defined on attributes of subjects. *Actions*

$д_i = \langle c_i, d_i, r_i, g_i \rangle \in Д$ and *relations* $o_i = \langle c_i, d_i \rangle \in O$ are uniquely identified by the attributes $c_i \in \wp \cup O$ – conditions of applicability, $d_i \in \wp \cup \aleph \cup \Im$ – source data, $r_i \in \wp \cup \aleph \cup \Im \cup O$ – results of an action, $g_i \in O$ – requirements to results of an action. With a view of a raise of effectiveness multilevel representation of knowledge as a three-rank system of submodels is used, each of which has three-level representation of knowledge: $M = \langle M^1, M^2, M^3 \rangle$, $M^1 = \langle M_1^1, ..., M_m^1 \rangle$, $M^2 = \langle M_1^2, ..., M_n^2 \rangle$, $M^3 = \langle M_1^3 \rangle$, $M_i^r = \langle M_{0,i}^r, M_{1,i}^r, M_{2,i}^r \rangle$, $M_{k,i}^r = \langle П_{k,i}^r, Д_{k,i}^r, O_{k,i}^r \rangle$, were $M^r$ - model of r-th rank; $M_i^r$ - i-th submodel of r-th rang; $M_{k,i}^r$ - i-th submodel of k-th level of r-th rank; $П_{k,i}^r$ – set of subjects, $Д_{k,i}^r$ – set of actions, $O_{k,i}^r$ – set of relations of submodel $M_{k,i}^r$. The multilevel model *of M* is created by the scientists on the basis of model $M_O$ by means of multistep generalizations of knowledge [2], [4]. The planning subsystem is the formal logical system representing the application system of calculus of sequents [4], [5], called *as the multilevel axiomatic theory of automatic solutions of formalized tasks (MATASFT)* TAC [2]: $T = \langle T_1^1, ..., T_m^1, T_1^2, ..., T_n^2, T_1^3 \rangle$, $T_i^r = \langle T_{0,i}^r, T_{10,i}^r, T_{1,i}^r, T_{21,i}^r, T_{2,i}^r \rangle$, were $T_i^r$ – *i*-th three-level theory of solutions *r-th* rank; $T_{0,i}^r, T_{1,i}^r, T_{2,i}^r$ – *i*-th single-level theories of solutions 0-th, 1-th, 2-th levels *r*-th rank; $T_{10,i}^r, T_{21,i}^r$ – the translational theories linking 1-th and 0-th, 2-th and 1-th levels of *r*-th rank. Theory *T* is automatically generated [4] on the basis of multilevel model *of M* under the following scheme: subjects of models $\mathrm{M}_{\mathrm{k,i}}^{\mathrm{r}}$ will be converted to variable theories of solutions $\mathrm{T}_{\mathrm{k,i}}^{\mathrm{r}}$, actions – in axioms, a sheaf between subjects – in axioms of translational theories $\mathrm{T}_{\mathrm{kk\text{-}1,i}}^{\mathrm{r}}$. Specificity of data domain TAU has stipulated presence in theories of solutions $\mathrm{T}_{\mathrm{k,i}}^{\mathrm{r}}$ of the own axioms with source data, a required results, conditions for applicability, but also the requirements to results. Therefore production rules of theories of solutions $\mathrm{T}_{\mathrm{k,i}}^{\mathrm{r}}$, in addition to rules systems G4 [2], include the special production rules, which making (playing) a main role during scheduling of solving of task [3].

Scheduling of problem solving of synthesis of control system is complicated that at a stage of scheduling the values of many parameters of models of components of control system are unknown, they will defined only during executing of the scheduled program of a solution of the task. Therefore the developed schedule should include all alternate paths of a solution, choice of the most approaching from which is carried out immediately already at executing of the scheduled program of a solution of the task. Therefore, for example, it is obvious, that before realization of any operation having conditions of applicability, values of appropriate logical expressions should be checked. On the other hand, after realization of operations with requirements to outcome it is necessary to check realization of the indicated requirements. Therefore, in the schedule of a solution of the task, in addition to the operations forming required outcome, should switch on as well the operations computing values of appropriate relations. Thus if requirements to required outcome appear outstanding then actions for elimination of a discordance should be undertaken. A common guideline on this score does not exist, as specificity of problem area here should be taken into account. In our case it reduces in include (appearance) in theories of solutions of axioms for which in conditions of applicability are indicated negation of requirements to outcome. Thus, the operation that was defined by such axiom should be applied to support of realization of requirements to outcome if it became known, that these requirements are not fulfilled. Bypass of "the damnation of dimension" can realize the *planning artificial neural networks* (PANN) [2], [3], [6] which possessing property of mass parallelism. Structurally PANN consist of *resolving artificial neural networks* (RANN) and *archive artificial neural networks* (AANN). The device of synchronization (see fig. 2) coordinates their operation. RANN is representing a three-layer network. She fulfills an inverse method of search of a solution of the task in a formalism of used fragment MATASFT TAC. The constructed schedule of a solution of the task is saved in AANN. RANN is a dynamic artificial neural network. Values on the output are varying with the constant signals on inputs. The initial state of all neurons RANN is not active.

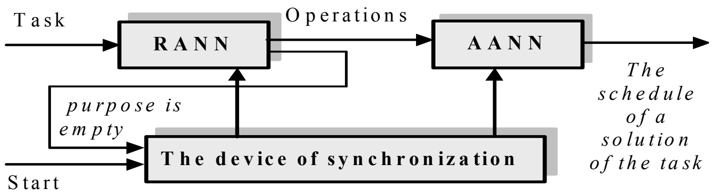


Figure 2. Structure of a planning artificial neural web, where: RANN -resolvelly artificial neural network (ANN), AANN - an archival artificial neural network

For the tasks having a solution, the separate neurons of an outputs layer of RANN short-term are going to an active (excited) state, which then is remembered in AANN for the subsequent inclusion in the schedule of a solution of the task. Values of outputs of neurons of one of interior layers of neurons of RANN is interpreted as values of the searching's purposes of a solution of the current task. Passage of these neurons in a non-active state reduces to appearance (generation) of signal, «the purpose is empty». It means that the solution of a task was obtained. Otherwise, on expiration of the solution time assigned on searching (an amount of pitches), the refusal to search a solution will be made. PANN allows solving simultaneously all subtasks of the source task, forming a united plan of a solution. On paths of usage of neural networks always, it is necessary to solve two problems: preliminary tutoring of a web and interpretation of the obtained outcomes. In PANN both problems are solved by virtue of design features. Basic difference of the given approach is *automatic* generation MATASFT TAC, and after her and PANN on the basis of assigned MMSFT TAC. Instead of traditional tutoring of the neural network, the procedure of automatic creation (result) of the PANN is used based on the appropriate fragment MATASFT TAC, which is called as the single-level theory of solutions. The main idea of the procedure of creation of the PANN consists in shaping a neural network which stratums are compared with units of the single-level theory of solutions. Implementation on basis PANN of a planning subsystem of an intellectual system of automatic task solving of TAC was called as Naturally - Intellectual Solver (NI-solver) of tasks of TAC [2].

## 3. Research of intellectual self-organizing systems of automatic control

The offered concept of automatic task solving of TAC based on planning artificial neural networks has served as methodological base for creation of a system of simulation of intellectual self-organizing systems of automatic control. The task of simulation of intelligent self-organizing systems of automatic control refer to category rather complicated, because includes not only immediate control of the set plant, but also simulation of the intelligent behavior used for the purposes of self-organizing. Therefore, usage of universal software for simulation of such systems in full appeared unacceptable.

Such specialized resource is MISACS - a system of Modeling of Intelligent Self-organizing Automatic Control Systems [3]. MISACS it is intended for research of processes of control by a population probably interconnected and cooperating plants, controlled by the intelligent self-organizing systems of automatic control (ISSAC) organized in hierarchically connected structure.

MISACS gives the user the following possibilities in a graphics interactive regime: 1) To set an amount of levels of hierarchy of population ISSAC, an amount of plants of control and ISSAC in each level; 2) To install connections between plants of control and assigned for them ISSAC; 3) To set criteria of a self-estimation of behavior ISSAC (engineering, analytical); 4) To define MATASFT TAC for everyone ISSAC separately.

We research possibilities ISSAC for control of non-stationary plant (see fig. 3).

Let the plant of control is described by the following equations:

$$\dot{x} = (A + \Delta A)x + u^* + Mf\,,\ x \in R^n\,,\ u \in R^n\,,\ f \in R^\mu\,,\ n = 3\,,\ \mu = 1\,,$$

$$\Delta A = [0]_n\,,\ 0 \le t < t_0\,,\ \Delta A = dA \times \sin(\omega \times (t - t_0))\,,\ \forall t \ge t_0$$

$$A = \begin{bmatrix} 0 & 1 & 0 \\ 0 & -300 & 1000 \\ 0 & -3 & -1 \end{bmatrix},\ M = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix},\ dA = \begin{bmatrix} 0 & 0{,}1 & 0 \\ 0 & 250 & -700 \\ 0 & 2{,}5 & 0{,}7 \end{bmatrix},$$

$$f = \begin{cases} f_0, & 0 \le t < t_s \\ f_0 + f_m \times \sin(\omega_f \times (t - t_s)), & \forall t \ge t_s \end{cases},$$

were $t_0 = 4$ – the moment of the beginning of a modification of model of plant of control; $\omega$ – frequency of a modification of model of plant of control; $f_0 = 1{,}0$ – magnitude of stepping component exterior perturbation; $f_m = 0{,}25$ – amplitude of sine waves of the exterior perturbation; $\omega_f$ – frequency of sine wave of the exterior perturbation; $t_s = 5$ – the moment of inclusion of sine wave of the exterior perturbation; $[0]_n$ – zero matrix $n \times n$.

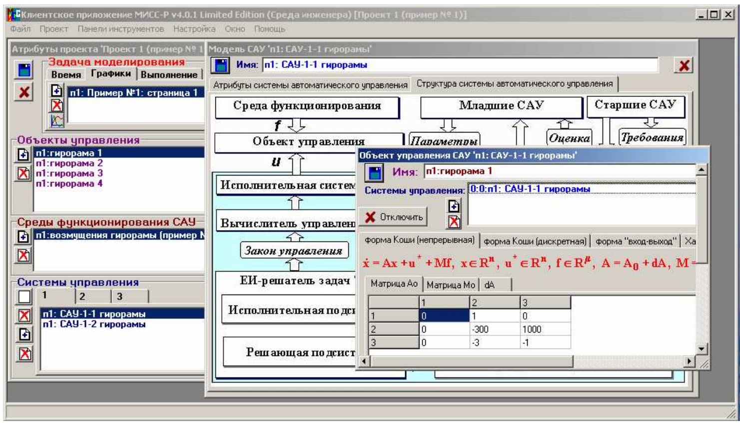


Fig. 3. Attributes of the project of simulation

The purpose of control is set as requirements on the statically errors of controlled variables:

$$\theta = Nx, \theta \in R^{\chi}, N = [1 \quad 0 \quad 0], \qquad \left|\theta_{\text{уст}_i}\right| \le \theta^*_{\text{уст}_i}, \ \theta^*_{\text{уст}}, \theta_{\text{уст}} \in R^{\chi},$$

$\theta^*_{\text{уст}_1} = 0{,}5$ at presence of stepping exterior perturbations $f_0 = 0{,}5$.

The initial law of control was synthesized counting upon stepping exterior perturbation $f_0 = 0{,}5$. Therefore with perturbation $f_0 = 1{,}0$ of the requirement to exactitude of regulating at the disconnected self-organizing are not fulfilled even for stationary plant (a curve 1 on fig. 4). Inclusion of self-organizing in an instant $t_c = 10{,}0$ with periodicity in 1 second and with a velocity of self-organizing **0,17** eliminates a problem, ensuring a required exactitude of regulating (a curve 2 on fig. 4). The transient for non-stationary plant of control at the disconnected self-organizing is mirrored with a curve 3 on fig. 4. Inclusion of self-organizing with the same parameters ensures a required exactitude of regulating and for non-stationary plant (a curve 4 on fig. 4).

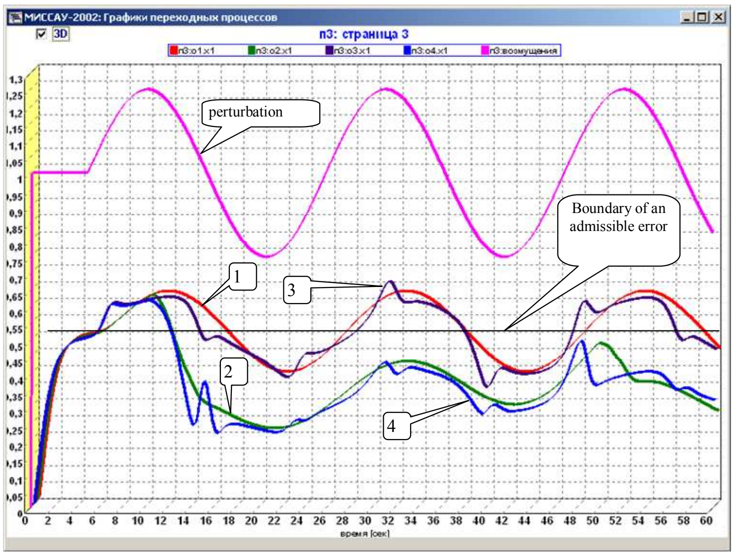


Fig. 4. Control of non-stationary plant

## 3. Conclusions

Tools of self-organizing ISSAC successfully compensate modifications of plant of control and an environment by means of use of new more exact law of control with the help of an intellectual system of automatic synthesis of the law of the control, based on (having) used neural computing organization based on planning artificial neural networks.

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