Intellectual self-organizing control systems: user interface of knowledge processing and analysis of the actions planning processes

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Abstract. Automatic control systems are created as optimality for the execution of the set operation. Change of operating conditions leads to loss of optimality. The self-configured (adaptive) systems are not always effective. They have the predetermined structure of a control algorithm. However, in new conditions it cannot meet the new requirements. The Intellectual Self-organizing Automatic Control Systems (ISACS) are capable to rebuild also structure of the control law. It is reached by the automated solution of a problem of synthesis of the control law. At creation of the interface of the developer of intellectual systems it is necessary to consider many factors, for example, ways of representation of knowledge, features of algorithms of processing of knowledge, etc. For development and the research ISACS the software “Modeling of Intellectual Self-organizing Automatic Control Systems” (MISACS) is created. This article is devoted to consideration of implementation in the MISACS system of the interface of the ISACS developer. The structures of representation of knowledge, elements of the mechanism of planning of actions on the basis of the artificial neural planning networks and the interface of the debugger of knowledge are presented.

1. Introduction

In all spheres of life and activity of the person are applied of automatic control systems. A variety of types of control plants and the goal of control caused variety of design methods of control laws. On spheres of applicability of each of them, there are different restrictions. For example, types of the mathematical description of plant, aim of control and their combination. In addition, different methods using to solution of the same task definition. It becomes more difficult to pick up the most adequate procedure of a solution of a specific objective. Therefore, before the developer of control systems even more often there are "intellectual" tasks. In the conditions of constraint in terms, it more needs of Computer-Aided Control Systems Design (CACSD) as specialized of the CAE/CAD/CAM systems.

However, the modern CACSD, as a rule, give opportunities of a tasks solution in the command mode. The designer is given an opportunity to save routines. So the user can create own procedures of a tasks solution, specific to it. For the majority of popular tasks the creator of a CACSD develops such procedures. This easy way allows increasing automation level significantly. Nevertheless, the design engineer is limited in time. He has to create control systems. Its task does not include creation of the automation equipment. In addition, developers of the automation tools are not specialists in specific problem area. It is not always possible to involve highly qualified specialists of problem area. Therefore, basic opportunities of the automation equipment allow solving standard problems.
However, at the same time the opportunity is given to users independently to create new procedures in the form of a saving sequence of commands. Popular among specialists in the control theory the Matlab software [8] can be a classical example.

To intellectual control systems it is traditional [1]-[3] carry the control systems constructed on the basis of technologies of expert systems [4], technologies of neural network structures [5], technologies of an associative memory [1], [3], technologies of a fuzzy logic [3]. Not all of them can be considered as intellectual. The term "intellectual" should be treated [6] as "capable to solve new (intellectual) problems". For small problem areas, it is possible to list all tasks. It is maybe (possible) to construct and write all procedures of their solution in advance. For example, in memory of the robot rearranging cubes in the closed room. New tasks do not arise. It is possible to pick up the effective search algorithm of the suitable procedure for the set signs. For example, maybe using of hash addressing. For difficult problem areas, the situation is different.

Automatic systems function independently, without participation of the person. Therefore change of operating conditions demands change of the control law. However the required procedure of a solution of a specific objective it maybe not existing (appear) among a set of previously prepared procedures. So there are new tasks. For their solution the problem area knowledge is required. Such knowledge is called model of problem area. Only specialists in problem area are capable to create such models. Therefore work benches of support of their creation have to be implemented as a part of CACSD. On the other hand, the mechanism of actions planning allows solving of declaratively defined tasks within the available model of problem area. Therefore, inclusion of the planning mechanism into structure of automatic system will supply for control system a new opportunities. Such system will become intellectual in the considered sense. ISACS [9], thus, are intellectual.

For development and research ISACS the MISACS software [10] is created. Its client-server version received the name - MISS. The MISACS system inherited tools of the automated solution of tasks of system INSTRUMENT-3m-I [11]. The tendency to consolidate different work benches leads to creation of the integrated systems of automation. It found reflection in the GAMMA-3 system [12] (GAMMA-3 Ω [13] - cloudy option of implementation). Distinctive feature of work benches is an opportunity to control functioning of the developed intellectual system. In this case into GAMMA-3 system was realized of not only visualization of knowledge, but also control of their use in the course of a solution of tasks - debugging of knowledge. The subsystem of actions planning of the intellectual control system can solve of task in real time. Therefore the major are requirements of minimization of expenses of time of a task's solution. The best results of work time minimization can be achieved, applying means of parallel information processing. Therefore as the mechanism of planning of actions in MISACS the artificial neural planning networks are applied [14].

Algorithms of a solution of tasks of control law synthesis are defined by knowledge of problem area of automatic control. Therefore the most important factor of efficiency of ISACS is the completeness of model of representation of knowledge. However for control of a specific plant in the changing conditions it is often difficult to define an adequate method among a big quantity of methods of the theory of automatic control. Therefore process of creation of model of knowledge for specific ISACS is very difficult. It is necessary to develop the convenient interface that take into account the specific features of the used representation of knowledge for increase in overall performance of the ISACS developer. The MISACS system carries out formal researches of consistency of the constructed model of knowledge automatically. The following step of a research is composition check of the constructed model of knowledge. Composition check of model of knowledge of applied intellectual systems is usually carried out by means of a solution of a set of test tasks. Creation of a set of test problems is independently difficult task and in this work is not considered. In the course of the research not only the fact of existence or lack of the constructed task solution is important. It is important to find existence or lack of elements of model of knowledge which did not allow to solve the specific test task. Detection of such elements is usually carried out with use of debuggers of knowledge. Debuggers of knowledge represent, in fact, means of recording of current results of process of a solution of a task. At the same time it is necessary to have a possibility of level variation of a detail of forming of the protocol of work of the planning subsystem. It is obvious that the
debugger of knowledge should consider features of the used mechanism of planning of actions on a solution of tasks. The convenience of the interface of the debugger of knowledge is an important factor of increase in efficiency of development process of ISACS.

2. Model of representation of knowledge of data domain of the control theory

The formalized representation of knowledge of the control theory (domain model) is offered [15]:

\[ M = \{D, \mathcal{R}, O\} \tag{1} \]

where \( D = \{d_1, d_2, \ldots, d_i\} \) is the set of the formalized generalizations of mathematical models of components of the control systems called by "objects", possessing:

- properties \( \rho_j \in \varphi(d_i) = \{\rho \mid \rho \in \{true \mid false\}\} \) is the Boolean values which values reflect availability or absence at a subject of the corresponding features, for example, a dynamic stability.

- characteristics \( \chi_j \in \mathcal{S}(d_i) = \{x_k \mid x_k \in C^{N_u \times C^{N_y \times \ldots \times C^{N_k}}\} \), where \( C \) is the set of complex numbers,

- forms of mathematical models \( \mu_j \in \mathcal{I}(d_i) = \{\mu_1, \ldots, \mu_t\} \), where \( \mu_j = \{r_j, m_j\} \), \( r_j = \{r_{j1}, r_{j2}, \ldots, r_{jn}\} \) is the set of dimensions of components (matrixes) of a mathematical model \( \mu_j \), \( m_j = \{m_{jk} \mid m_{jk} \in C^{r_{1j} \times C^{r_{2j} \times \ldots \times C^{r_{nj}}}}\} \) is the set of coefficients of components (matrixes \( m_{jk} \)) of a mathematical model \( \mu_j \);

- classification signs representing the selected properties of objects \( \xi_j \in \Xi(d_i) \subseteq \varphi(d_i) \):

\[ \mathcal{R} = \{r \mid r = \langle c, s, g \rangle : \varphi \cup \mathcal{S} \cup \mathcal{I} \cup \mathcal{R} \cup O \rightarrow \{true \mid false\}\} \]

is the set of the relations (predicates) over objects, their components and attributes, actions (operations);

\[ O = \{o \mid o = \langle c, s, g, q \rangle : \varphi \cup \mathcal{S} \cup \mathcal{I} \cup \mathcal{R} \rightarrow \varphi \cup \mathcal{S} \cup \mathcal{I} \cup \mathcal{R}\} \]

is the set of actions (operations) over objects and their attributes.

Actions \( o_i = \langle c_i, s_i, g_i, q_i \rangle \in O \) and the relations \( r_i = \langle c_i, s_i, g_i \rangle \in \mathcal{R} \) are characterized by the attributes: \( c_i \in \varphi \cup \mathcal{R} \) are the applicability conditions, \( s_i \in \varphi \cup \mathcal{S} \) is the input data, \( g_i \in \varphi \cup \mathcal{S} \cup \mathcal{I} \cup \mathcal{R} \) is the result of execution of action (operation), \( q_i \in \mathcal{R} \) and are the requirements to result of execution of action (operation).

The model of a look (1) is an exterior (user) form of representation of knowledge. In such form specialists, experts in the control theory develop fragments of the formalized representation of knowledge of methods of solution of tasks of control theory. In this regard and means of preparation and visualization of knowledge in system INSTRUMENT-3m-I, and, therefore, and in the MISACS systems, GAMMA-3 support such approach to formalization of knowledge.

Expenses of time for planning of actions is defined not only the used planning method, but also by the size of model of knowledge. In this regard we use multi-level model of knowledge (2) - (3).

\[ M = \{M^3, M^2, M^1\}, \quad M^3 = \{M_3^1\}, \quad M^2 = \{M_1^2, M_2^2, \ldots, M_n^2\}, \quad M^1 = \{M_1^1, M_2^1, \ldots, M_n^1\}, \]

where \( M_r \) is model of \( r \)-th rank, \( M^r_i \) is \( i \)-th model of \( r \)-th rank. The structure of each model \( M^r_i \) is reflected by expression (3).

\[ M^r_i = \{M^r_{2,j}, M^r_{1,j}, M^r_{0,i}\}, \quad M^r_{k,j} = \{D^r_{k,j}, \mathcal{R}^r_{k,j}, O^r_{k,j}\}, \]
where $M_{i,k}^r$ is $i$-th model of $k$-th level of $r$-th rank, having the structure (3) similar to structure of model (1). Models $M_{i,k}^r$ of representation of knowledge include means of comparison of the elements to elements of overlying $(k+1)$ and underlying $(k-1)$ levels. The realization of the specified relations between elements of models of the neighbor levels is created with use of slots of frame structure of an element of model of knowledge called "Consists from" and "Is a part" (2) - (3).

Process of the solution of a task begins on model of the senior rank ($r = 3$) with the subsequent broadcast of the received solution as subtasks for models of underlying rank. The final decision forms by means of combination (composition) of solutions of all subtasks on models of a younger rank ($r = 1$). As a result, the interface of the developer of model of knowledge has to consider hierarchical structure of model of knowledge (2) - (3).

3. Overview of the interface of knowledge processing

Due to the fundamental difference of the purposes of design engineers of control systems (development of specific control systems) and experts-researchers (development of new solution methods of both the known and new tasks), in system INSTRUMENT-3m-I, and after it and in the MISACS systems, GAMMA-3 working environments are developed for different categories of users: "Engineer environment" and "Researcher environment".

The "Engineer environment" gives to the user opportunities of a solution of tasks in declarative setting on the basis of use of the available knowledge of system.

The "Researcher environment" - "for Scientist" is intended for experts and gives opportunities of development of new methods of solution of tasks, realizing them in the form of procedures (the sequence of execution of design operations); development (formalization) of knowledge of methods of control tasks solution in the form of (1); developments of test tasks of composition check and consistency of knowledge.

Therefore, further we will place the main emphasis for work among "Researcher environment". The actions used in model of knowledge are classified on elementary and enlarged. Elementary actions (operations) declared as procedures set in the form of the programming modules, which are made out by application programmers in the form of libraries of dynamic loading. Connection of elementary actions to system is carried out by the researcher by means of the indication of a name of programming module and a name of the library supporting him.

The enlarged actions represent set of other actions (elementary or enlarged) which execution order is defined by the plan on application-oriented languages the Instrument-3m (it is intended for development of plans of tasks solution by the researcher) or Instrument-OP (it is intended for submission of plans of a solution of the tasks constructed by means of ANPN). The Instrument-3m language provides the standard managing constructions configured by the user lexicon and a set of operations, allowing to adapt language to user requirements, bringing closer them to a vernacular of the specialist in data domain. The subsystem of representation of knowledge allows to develop and keep any quantity of models of problem area in system (it is limited to the extent of an available external bulk memory).

All models of knowledge have identical structure (3). Because in model (1) declarative and procedural components are accurately separated, and implementation of means of their representation are also simply separated: a declarative component (description of objects, actions and relations) are entered in the database, and the procedural component (program implementation of actions of model) is stored in a type of the programming modules placed in libraries of dynamic loading.

Respectively only the declarative component of models of knowledge is displayed by visualization tools. The procedural component is shown only during a solution of specific tasks. The type of a screen form of visualization of components of representation of knowledge model (Objects, Actions, and Relations) of researcher environment of INSTRUMENT-3m-I system is presented on Figures 1-3.

MISACS systems, GAMMA-3 there are some differences, caused their implementation as distributed systems of information processing.
Fragments of a form of the description of actions of model (1), including declarative procedural components are presented on Figures 4-7. On Figure 8 tasks list is presented on model of knowledge.

Figure 1. Type of a screen form of visualization of components of model of representation of knowledge (Objects).

Figure 2. Type of a screen form of visualization of components of model of representation of knowledge (Actions).

Figure 3. Type of a screen form of visualization of components of model of representation of knowledge (Relations).
Figure 4. Screen form of action visualization of knowledge model (Applicability Conditions attribute).

Figure 5. Screen form of action visualization of model of knowledge (Source Data attribute).

Figure 6. Screen form of action visualization of model of knowledge (Required Result attribute).

Figure 7. Screen form of action visualization of model of knowledge (Implementation attribute).

Figure 8. Screen form of tasks visualization on model of knowledge (task list of M1 model).
4. Example of the solution of a test task with use of the debugger of knowledge

Let review an example of planning of actions on a solution of a problem of synthesis of the control law. Let the plant described by a mathematical model in the state space (2), (3) be set. It is required to synthesize the control law (4), (5) providing for the control system execution of requirements to accuracy (6) and overshoot (readjustment) (7) on controlled variables (8) at action of external perturbations (9).

\[
\begin{align*}
\dot{x} &= Ax + Bu + Mf, \quad x \in R^n, u \in R^m, f \in R^\mu \\
y &= Cx + Du + Gv, \quad y \in R^r, v \in R^r \\
\dot{x}_c &= A_c x_c + B_c y, \quad x_c \in R^{n_c} \\
u &= C_c x_c + D_c y \\
\bar{\theta}_i &= \lim_{t \to \infty} |\theta_i(t)| \leq \theta_i^*, \quad \theta, \theta^* \in R^k \\
\sigma_i &= \max_{\theta_i} |\theta_i(t)| - \bar{\theta}_i \leq \sigma_i^* \\
\theta &= N\theta, \quad \theta \in R^k \\
f_i(t) &= \begin{cases} 
0, & t < t_0 \\
1, & t \geq t_0 
\end{cases}
\end{align*}
\]

On knowledge model of "Model of Set of Formalized Tasks of Control Theory No. 1" the definition of specified task will take the form presented on Figures 9 - 11 ("Data", "Result" and "Requirements to required result" attributes respectively).

Figures 12 - 14 illustrate the choice of the mode of a solution of a task (automatic or step-by-step), recording of actions planning (Report) and display of the constructed plan of a task's solution.

**Figure 9.** A screen form of visualization of "Data" attribute of the definition of specified task on "Model of Set of Formalized Tasks of Control Theory No. 1" of knowledge representation.

**Figure 10.** A screen form of visualization of "Result" attribute of the definition of specified task on "Model of Set of Formalized Tasks of Control Theory No. 1" of knowledge representation.
Figure 11. A screen form of visualization of "Requirements to required result" attribute of the definition of specified task on "Model of Set of Formalized Tasks of Control Theory No. 1" of knowledge representation.

Figure 12. Choice of the mode of the solution of a task.

Figure 13. Report (fragment) of the solution of a task.
5. Conclusion
In work, questions of implementation of subsystems of the automated solution of problems of a number of program complexes of design and a research of intellectual control systems are stated. The conducted researches confirm prospects and expediency of application of the artificial neural planning networks for problems solution of actions planning of non-procedural (is declarative) objectives. Being means of parallel processing of information, ANPN allows solving problems for a finite number of steps, providing, thus, an operation mode, comfortable for users.

Implementation of the artificial neural planning networks in INSTRUMENT-3m-I system executed by means of modeling of their functioning. The concept of the artificial neural planning networks was fruitful. Even program implementation (modeling) of artificial neural planning networks showed high performance. At the same time the comfortable dialogue operation mode of the user-designer at the expense of the high speed of work of the planning subsystem is provided. Further expansion of classes of solvable tasks inevitably leads to expansion of model of problem area of the theory of automatic control. As a result, the sizes of automatically generated artificial neural planning network for a solution of a specific objective will also increase. Respectively, as program implementation of the artificial neural planning network is used, also time of its modeling will increase. As a result the overall effectiveness of a subsystem of a solution of tasks will decrease.

For elimination of the imminent problem two main ways are possible.

The first direction is further improvement of program implementation. For example, use of multithreaded processing, creation of the distributed information system, use of event modeling.

The second direction is connected with use of specialized hardware. At the same time it is possible to implement real parallelization of information processing in the course of a solution of a problem of planning of actions.

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