FEATURES OF INTELLIGENT MODELS IN THE THEORY OF ROBOTIC AND MECHATRONIC SYSTEMS

Kh.N.Nazarov[1][0000-0002-5811-1585], N.R.Matyokubov[2][0000-0002-2142-6209], T.O.Rakhimov[3][0000-0001-7288-0594]

[1,3]Department of Electronics and Automation, Tashkent state technical university named after Islom Karimov
Address: 2, University str., 100095, Tashkent, Uzbekistan
E-mail: [1]nazarov_hayriddin@bk.ru; [3]Rahimov_timur@bk.ru.
[2]Tashkent State Technical University named after Islam Karimov
Address: 2, University str., 100095, Tashkent, Uzbekistan
E-mail: [2]nm85@mail.ru;

Abstract: *The article discusses the features of intelligent models and tasks in the theory of mechatronic and robotic systems, the algebraic model of artificial intelligence, formalized types of intellectual tasks, intelligent models of the problem area, which are distinguished by their versatility and clarity. Intellectual models and tasks in the field of the theory of robotic systems are formally presented. As part of a set of inference rules, intelligent models as universal rules use rules of substitution and conclusion, similar to the deductive rules of inference in propositional and predicate calculus, and the rules of meaning. The systematization of t the theory of mechatronic and robotic systems problems and an example of the algebra of kinematic structural-mode schemes oriented to solving the problems of kinematics of mechatronic and robotic systems are given.*

Keywords: *algebraic model, artificial intelligence, intelligent model, kinematic structural-mode scheme, mechatronic system.*

Introduction

Modern advances in computer modeling, design automation and new information technology require consideration of the main tasks (description, analysis and synthesis) of the theory of robotic systems from the general positions of the theory of algebraic systems and artificial intelligence. Analysis and synthesis are reduced to the choice of the type of algebra and the execution of procedures associated with direct mappings of the system (object) under study into a set of object state models, object state models, the carrier of algebra through the operations of algebra and an algebraic model into a set of new data and knowledge about the object and inverse mappings [1].

Research Methodology

The main parts of the intelligent model are shown in Fig. 1.

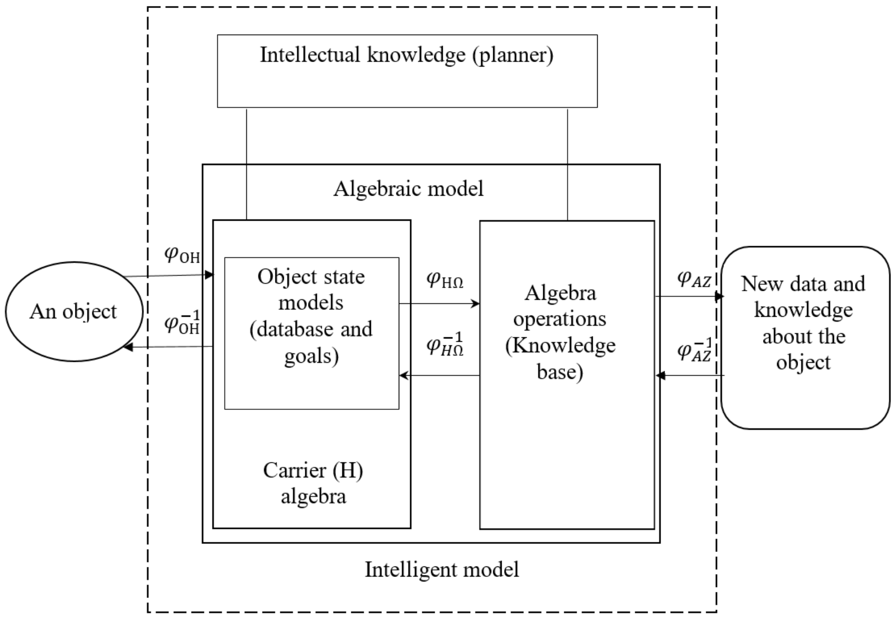

Figure 1. ***Components of an intelligent model.***

If direct methods of analysis (synthesis) of systems use direct mappings $\varphi_{\mathrm{OH}}, \varphi_{\mathrm{H\Omega}}, \varphi_{\mathrm{A}Z}$ (inverse mappings $\varphi_{\mathrm{OH}}^{-1}, \varphi_{\mathrm{H\Omega}}^{-1}, \varphi_{\mathrm{A}Z}^{-1}$), then in indirect methods of analysis (synthesis) - both forward and backward mappings. Therefore, the methods of analysis and synthesis of circuits and systems mainly differ in the types of state models, algebras ($< \mathrm{H}, \Omega, >$) and the types of mappings used, which determines the dominant place of state models, algebras and ways of realizing mappings in systems theory.

The algebraic model (the algebra $< \mathrm{H}, \Omega, >$ by the state models selected in its carrier H) of the object is the most suitable model for implementation on a computer, but despite the presence of a powerful set of operations (including programs, procedures) over the object state models for solving computational problems, it becomes powerless for the automatic solution of intellectual problems (problems with a priori unknown solution algorithms).

This can be avoided by supplementing the algebraic model of the object with intellectual knowledge. The latter in artificial intelligence systems is the content of the planner, designed to imitate the elements of human mental activity. Objects obtained in this way are called intelligent in the work. In them, models of target, initial and intermediate states of an object correspond to the database and goals, and expressions of operations correspond to the knowledge base of intelligent systems [1,2,3].

In relation to an intelligent model (Fig. 1), the task is non-intellectual (elementary) if the set of operations (in the knowledge base) of the model contains an operation corresponding to the algorithm for solving the problem (solution scheme, program, procedure). Otherwise, the task is perceived by the intelligent modeling system, in view of the absence of a model of a ready-made scheme for solving the problem in the knowledge base. In what follows, we will assume that all algorithms known in this field have been introduced into the knowledge base when building intelligent models. Then the intellectual ones include those tasks for which there are no ready-made solution schemes in the considered subject area [2,3].

Analysis and results

Formally, the intellectual problem in the field of the theory of robotic and mechatronic systems will be represented by the four

$$IZ =< M_{ts}, M_i, \Omega_Z, \rho > \qquad (1)$$

where $M_{ts} -$ is a model of target states of the object, modeling; $M_i -$ model of the initial state of the object; $\Omega_Z \leq \Omega -$ a set of operations in the set of states of the modeling object used to solve this problem. $\rho -$ plan (algorithm, program, scheme of solutions) of problems, is represented in the form of a non-empty set of expressions of some language L, which represents the carrier H of the algebraic model (Fig. 1). M_{ts} can be specified as either multiple state models or as a single state model. In the latter case, M_{ts} is represented as a non-empty set of expressions in the language I (that is, at the same level of presentation as M_i). In the case of specifying M_{ts} as a set of models, it can be represented either by an enumeration of the M_{ts} elements represented in the Y language, or by specifying the M_{ts} property in a language higher than the M_i representation language.

Elements of the set of operations Ω_Z as well as other elements of the set of operations Ω of the algebraic model (Fig. 1) are specified in the form "operands - result", where the operands and the result are a subset of the set of state models presented in the language of L.

The plan ρ is represented as an ordered collection of pairs of names of operations and operands. It is always a priori unknown in an intellectual task and is found as a result of modeling the task [2,3,4].

Intellectual tasks, depending on the language levels used for the representation of M_{ts} and M_i, can be single-level or two-level. This is determined by the degree of popularity of M_{ts} and M_i- problems with one (when M_{ts} or M_i is known) or with two (when M_{ts} and M_i are known) fixed ends. In problems with two fixed ends, the new knowledge as a result is a scheme for solving the problem, and in problems with one fixed end, new knowledge and data will be both a scheme for solving the problem and the found unknown state of the object (M_{ts} or M_i).

The intellectual model should contain subject and intellectual knowledge, respectively. We will agree to represent subject knowledge as a set of operations Ω in the set of states of objects in the subject area. Other, integral components of the intellectual model are the available conditions (M_{ts}, M_i) of the intellectual problem solved in the process of modeling, which are subsets or elements of combining the sets of states of objects in the subject area. The latter is considered as the main set (carrier H) of some algebra, whose operations reflect subject knowledge [3,4].

Based on the above considerations, we will represent the intelligent model as

$$IM = < H, M_{ts}, M_i, \Omega, Z_i > \quad (2)$$

This assumes the existence of some multilevel language L for specifying the components of the intellectual model [1,3,4]. Here H, M_i, and the operands and the results of operations from Ω are represented by expressions of the language L at a single level. In general, the level of M_{ts} assignment differs from the level of assignment of the carrier H of the algebra. Only for single-level tasks with two fixed ends is it set on the same level with M_i.

The intellectual knowledge Z_i will include inference rules ($\prod$) for state modules, rules (γ) for applying inference rules from $\prod$, and operations from Ω. The latter also contain procedures that reflect methods and strategies for finding solutions to problems, which can be both universal and problem-oriented. As a rule, intellectual knowledge is set at a different level from the M_{ts} and M_i task levels. Taking these considerations into account, the intelligent model is presented as a six.

$$IM = < H, M_{ts}, M_i, \Omega, \prod, \gamma > \quad (3)$$

where $< H, \Omega >$ is an algebra; $< H, M_{ts}, M_i, \Omega >$ is an algebraic model; $< \prod, \gamma >$ is more intellectual than knowledge [1, 2].

As part of the set of inference rules $\prod$, intelligent models as universal rules use the rules of replacement, substitution and conclusion, similar to the deductive rules of inference in the calculus of statements and predicates [1,5,6], and the rules of meaning.

The inference rule in the intellectual model is

$$\frac{\alpha \in H, (\alpha \to \beta) \in \Omega}{\beta \in H} \quad (4)$$

where $\alpha \in H, (\alpha \to \beta) \in \Omega -$ are the premises of the inference rule, $\beta \in H -$ is the conclusion.

The application of this rule with the aim of generating a new model of object states is reduced to choosing from the knowledge base of an intelligent model of some operation $(\alpha'' \to \beta'')$ and selecting from the database and knowledge such a model of states α' for which (and for α''), a statement or substitution rule is applicable that transforms the pair $(a', \ a'' \to \beta'')$ into the pair (a_0, a_0 → β_0) where $(a_0, a_0 \to \beta_0)$ где $a_0 \in H, (a_0 \to \beta) \in \Omega$. Here, any operation of the form $(a_0 \to \beta_0)$, formed as a result of applying the rules of substitution or replacement from elements of the set Ω is also considered an element of this set.

The application of the meaning rule provides for the presence of corresponding computational procedures in the intellectual model (modeling system), which ensure the replacement of subject and functional symbols and expressions (functions participating in the expressions of state models and operations with the corresponding values. This provides the possibility of solving on intelligent models as computational, and intellectual tasks.

The composition of $\prod$ can include inductive inference rules and rules of inference by analogy. As the universal rules γ for the application of inference rules and operations in the intelligent model, procedures based on the methods of forward, backward, or counterpropagating waves [2,5,6], strategies “depth first”, “breadth first” [1, 6], methods search for solutions with returns, without returns or in graphs [1,5,6,7], widely known from the theory of artificial intelligence.

The tasks considered in the theory of robotic systems are systematized in the form of data (Table 1), the rows of which correspond to the types of tasks (formation of models, analysis, synthesis) columns - aspects of modeling objects of the theory.

From the given tasks, tasks $№11 - 20$ of the "analysis" type, as a rule, belong to the class of non-intellectual ones, since for them the theory relies on a known method (algorithm, plan) and an analysis algorithm. Methods also exist for many problems of the "model formation" and "synthesis" types ($№1 - 10, 21 - 30$) for special cases of problem setting.

Table 1.

Systematization of tasks of the theory of robotic systems.

Task type	Modeling Aspects									
	Problem area (element objects, action signs, relationships)	Structure (relationships in a set of structural features)	Mode (relationships in multiple phase features)	Functioning (relationships in multiple structures and modes)	Structures, modes, functioning	Plan (relationship in a set of actions, method of algorithms program)	Problem (task, question)	Problematic knowledge	Intellectual knowledge	Creation technology (modeling, design, construction, manufacturing, experiments)
Model formation Analysis synthesis	1	2	3	4	5	6	7	8	9	10
	11	12	13	14	15	15	17	18	19	20
	21	22	23	24	25	26	27	28	29	30

In the general case, in the absence of a priori a ready-made solution scheme, all these problems are intelligent, and their automated solution should be based on intelligent models. In the formation of the latter, the most crucial stage is the formation of an algebra suitable for solving the corresponding classes of problems that form the basis of problem knowledge. It should be taken into account that some algebras that are sufficiently effective for solving some classes of problems become unsuitable for solving others. Therefore, an intelligent model for the automated solution of problems of designing, manufacturing and researching robots and robotic should contain a multi-level system of algebras corresponding to multi-level systems of knowledge representation in artificial intelligence.

In conclusion, as an example, let us give the algebra of kinematic structural-regime schemes (KSRS), oriented to solve the problems of kinematics of manipulators and mechanical subsystems of robotic systems [1,3,8,9].

Definition, the pair $< H_k, \Omega_k >$, where H_k is the set of two-pole kinematic branches, Ω_k is the set of equivalent transformations in H_k, is called the KSRS algebra.

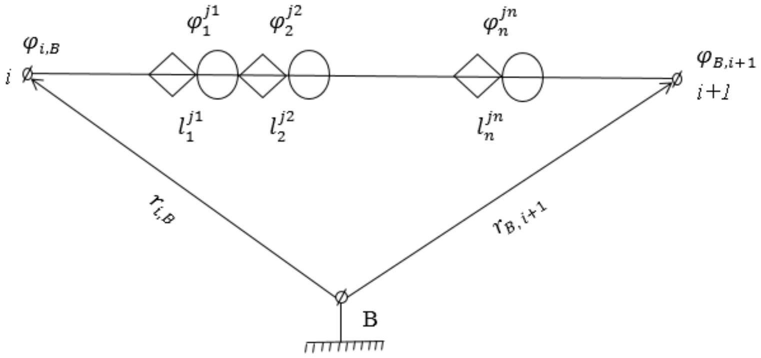

Figure 2. ***Generalized kinematic branch.***

The bipolar kinematic branch (KB) is a type of structural formation [6] and is geometrically displayed using an undirected path (Fig. 2) with end poles i and $i + 1$, and chain intermediate symbols of angular (circles) and (or) linear (rhombuses) displacements and a set of signal arcs between displacement symbols. Depending on the presence and orientation of the signal arcs, the displacement symbols can be independent (when not associated with drags), control, or dependent [8,9,10].

The symbols of the displacements from which the signal arcs emanate are called control ones, and into which they enter - controlled (dependent). By the type of functional dependence on time, they can be constant symbols with shading) or variables (without shading). In special cases, some of the move symbols in KB may be missing. The conditional positive direction of movement in the geometric image KB is recognized by the proximity of the string of symbols to the poles. The chain of displacements is directed towards the pole to which the extreme symbol of displacements in the chain is located closer (in Fig. 2). Shown KB without signal arcs, in which the conditional positive direction for all displacements is chosen from pole i to pole $i + 1$.

The given KB displays the interaction of two material points (links, centers of mass or other points of bodies), each of which is located at the origin of the corresponding rectangular coordinate system $(0_i, X_i, Y_i, Z_i;\ 0_{i+1}, X_{i+1}, Y_{i+1}, Z_{i+1})$. The coordinates of the origin $r_{B,i}, r_{B,i+1}$ in the form of matrixes of columns and orientation of the axes (chains of rotation angles $\varphi_{B,i}, \varphi_{B,i+1}$ of coordinate systems with respect to the base coordinate system $0_B, X_B, Y_B, Z_B$ are described by KB component expressions.

$$\varphi_{B,i+1} = (\varphi_{B,i};\ \varphi_1^{j1};\ \varphi_2^{j2}; \dots ; \varphi_n^{jn});$$
$$r_{B,i+1} = r_{B.i} + [\varphi_{B,i}] * (l_1^{j1} + [\varphi_1^{j1}] * ([l_2^{j2} + [\varphi_2^{j2}] * \dots (l_n^{jn})) \dots) \quad (5)$$

Here $l_k^{jk} = \boxed{l_{k1}^X}\boxed{l_{k2}^Y}\boxed{l_{k3}^Z}^T -$ is a column matrix of displacements l_{k1}, l_{k2}, l_{k3} along the X, Y, Z axes, respectively; $\varphi_{i,B} -$ is a chain of rotation angles that provide the appropriate orientation of the system $0_i, X_i, Y_i, Z_i$ relative to the system $0_B, X_B, Y_B, Z_B$; $\varphi_k^{jk} = (\varphi_{k1}^X;\ \varphi_{k2}^Y;\ \varphi_{k3}^Z) -$ a chain (sequence) of at most three nonzero angles of rotation around the axes X, Y, Z; In the chain φ$\varphi_k^{jk} -$ zero angles are omitted, for example,

$$[\varphi_k^{jk}] = [\varphi_{k1}^X] * [\varphi_{k2}^Y] * [\varphi_{k3}^Z] \quad (6)$$

where $[\varphi_{k1}^X], [\varphi_{k2}^Y], [\varphi_{k3}^Z] -$ are the matrices of rotation by the angles $\varphi_{k1}, \varphi_{k2}, \varphi_{k3}$ around the X, Y, Z axes of the current rectangular coordinate system

$0_{i,k-1}, X_{i,k-1},\ Y_{i,k-1}, Z_{i,k-1}$, moreover,
if $\varphi_{k1} = \varphi_{k2} = 0$, то $[\varphi_{ik}^{jk}] = [\varphi_{k3}^Z]$,
if $\varphi_{k1} = \varphi_{k3} = 0$ то $[\varphi_k^{jk}] = [\varphi_{k2}^Y]$, and so on.

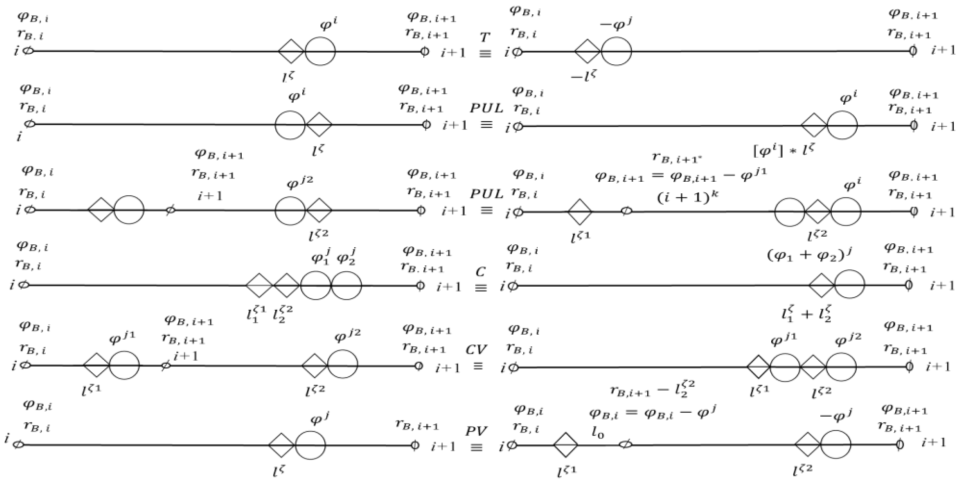

*Figure 3. **Equivalent transformations of KSRS.***

In fig. 3 shows the basic set of equivalent transformationsΩ_k, transposition of displacements(T), transfer of the symbol of angular displacements through the symbol - linear displacement(PUL), transfer of the symbol of angular displacements through the pole(PUL), addition of displacements(C), addition of branches(CV), splitting of branches (PV).

Conclusion

Thus, for the successful development of intelligent models of mechatronic and robotic systems, their specific features have been revealed for the first time, an algebraic model of artificial intelligence, formalized types of intellectual tasks, intellectual models of the problem area are presented. Intellectual models and tasks in the field of the theory of robotic systems are formally presented. As part of the set of inference rules for intelligent models, the rules of substitution, substitution and conclusion, similar to the deductive rules of inference in the calculus of statements and predicates, and the rules of meaning are used as universal rules. The systematization of the problems of the theory of mechatronic and robotic systems and the algebra of kinematic structural-mode schemes, oriented for solving the problems of kinematics of mechatronic and robotic systems, are proposed. The possibility and expediency of using intelligent models for solving various problems of the theory of mechatronic and robotic systems has been substantiated.

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DECISION-MAKING UNDER CONDITIONS OF DEFINITION AND RISK BASED ON STRICT METHODS

O.V.Porubay

Department of Information Technology,
Ferghana Branch of the Tashkent University of Information Technology named after Muhammad Al-Khwarizmi, Uzbekistan
Address: 150100, Mustakillik-185 str., Ferghana city, Republic of Uzbekistan
E-mail: [2]oksanaporubay@gmail.com

Abstract: *In this paper, the problems of decision-making in conditions of certainty and risk based on strict methods are considered. The classification of methods of decision theory is presented, taking into account the uncertainty and related subjectivity in evaluating decision options. Strict methods are considered, which include methods of mathematical optimization, or mathematical programming, designed to solve single- or multi-criteria problems of finding the optimal solution. Thus, based on computational experiments, we can conclude that strict methods are usually used in decision-making under conditions of certainty and possibly risk, heuristic methods in conditions of risk and uncertainty, and also if strict methods are practically impossible due to the large dimension of the cumbersome task computing.*