Chemical Technology, Control and Management

Volume 2021 | Issue 3 | Article 5

6-28-2021

PROBLEM SOLVING METHODS FOR SYNTHESIS OF PHYSICAL PRINCIPLES OF MECHATRONIC MODULE OPERATIONS IN INTELLIGENT ROBOTIC SYSTEMS

Nazarov Khayriddin Nuritdinovich
Prof, department. "Mechatronics and Robotics", Tashkent State technical university named after Islom Karimov E-mail: nazarov_hayriddin@bk.ru, Phone: + 99890-988-06-75., nazarov_hayriddin@bk.ru

ISSN 1815-4840, E-ISSN 2181-1105
Himičeskaâ tehnologiâ. Kontrol' i upravlenie
CHEMICAL TECHNOLOGY. CONTROL AND MANAGEMENT
2021, №3 (99) pp.41-49. https://doi.org/10.51346/tstu-02.21.3-77-0018
International scientific and technical journal
journal homepage: https://uzjournals.edu.uz/ijctcm/
Since 2005

PROBLEM SOLVING METHODS FOR SYNTHESIS OF PHYSICAL PRINCIPLES OF MECHATRONIC MODULE OPERATIONS IN INTELLIGENT ROBOTIC SYSTEMS

Nazarov Khayriddin Nuritdinovich

Prof, department. "Mechatronics and Robotics", Tashkent State technical university named after Islom Karimov
E-mail: nazarov_hayriddin@bk.ru, Phone: + 99890-988-06-75.

Abstract: *The scientific paper investigates the methods for solving problems of synthesis of physical principles of operation of mechatronic modules of intelligent robotic systems are considered.*

In addition, it deals with the specifics of the process of synthesis of the physical principles of the operation of mechatronic modules using predicate models, list models and information matrices of physical and technical effects.

It shows the interpretation of the components of the model of the system for the synthesis of the physical principles of operation of mechatronic modules of intelligent robotic systems and automatic control and the features of the synthesis algorithm for the physical principles of operation of mechatronic modules of intelligent robotic systems based on list models of physical and technical effects are considered.

Key words: *mechatronic module, physical principle of operation, intelligent robotic system, predicate model, information matrix, physical and technical effect.*

Аннотация: *Интеллектуал робототехник тизимларининг мехатрон модулларини физик қуриш принципини синтезлаш масаласини ечиш усуллари кўриб чиқилган.*

Предикат моделлар, рўйхатли моделлар ва ахборот матрицалардан фойдаланган холда мехатрон модулларни физик қуриш принципларини синтезлаш жараёнининг ўзигахос хусусиятлари баён этилган.

Интеллектуал робототехник тизимлар ва автоматик бошқарув тизимларнинг мехатрон модулларининг физик ишлаш принципларини синтезлаш тизими моделининг компонентлари талқини келтирилган.

Физик техникавий эффектларнинг рўйхатли моделлари асосида интеллектуал робототехник системаларнинг мехатрон модулларини физик ишлаш принципларини синтезлаш алгоритмининг хусусиятлари кўриб чиқилган

Таянч сўзлар: *Мехатрон модул, физик ишлаш принципи, интеллектуал робототехник тизим, предикат модел, ахборот матрицаси, физик техникавий эффект.*

Аннотация: *Рассматриваются методы решения задач синтеза физических принципов действия мехатронных модулей интеллектуальных робототехнических систем.*

Описывается специфика процесса синтеза физических принципов действия мехатронных модулей с использованием предикатных моделей, списковых моделей и информационных матриц физико-технических эффектов.

Приведена интерпретация компонентов модели системы синтеза физических принципов действия мехатронных модулей интеллектуальных робототехнических систем и систем автоматического управления.

Рассмотрены особенности алгоритма синтеза физических принципов действия мехатронных модулей интеллектуальных робототехнических систем на основе списковых моделей физико-технических эффектов.

Ключевые слова: *мехатронный модуль, физический принцип действия, интеллектуальная робототехническая система, предикатная модель, информационная матрица, физико-технический эффект.*

Introduction

Currently, there is a whole set of methods for solving problems of the synthesis of physical principles of constructing mechatronic modules of intelligent control systems. They differ in complexity, level of complexity, degree of automation, specificity of application.

Any method of synthesis of the physical principle of the device (PPD) of mechatronic modules of intelligent robotic systems (MMIRS) is represented by a set of synthesis problems and a synthesis problem solver. In this case, the SD-source data are reflected, which are the input physical quantities or parameters of the projected mechatronic module; TR - output values of MMIRS, information about the nature and ranges of changes in output values and limitations; the solution of the problem, which is a model of the physical principle of action, which is an ordered set of physical and technical effects (PTE) and techniques, and converts the input value into the output; FPD synthesizer, or otherwise a synthesis problem solver.

The components of the synthesis problem solver are the carrier of the algebra M, the inference rules Π, and the γ −rules for applying the rules and operations Ω, which contains many names and properties of physical quantities, many names and models of PTE and general laws of the problem area, as well as relations in a set of physical quantities and PTE.

In this case, PTE is understood as physical phenomena, effects, laws and techniques that transform some input physical quantities and parameters into output ones. The system of physical and technical effects is characterized by some sets of quantities and ratios in a set of quantities and is displayed by an information model.

The component Ω of the synthesizer (and algebra) is a system of partial operations in the set M, the composition of which is in accordance with the composition of M (that is, operations on physical quantities, models, or relations);

Π- partial operations specified in the union of the sets M and Ω, and representing the rules of inference;

γ is a system of rules for applying Π and operations Ω to a set M, which is a control structure (strategies: “deep first”, “breadth first”, methods of wave, backward wave, and counter waves, etc.) for the search for the principles of operation of the MMIRS. The system of rules γ includes the possibility of increasing and changing the database and the knowledge base of the system.

Research methodology

Let us consider the models of physical and technical effects used in most of the existing systems for the synthesis of PPD MMIRS [1,2], which reflect the cause-and-effect relationships of the PTE and, as a rule, in the single-input version of graph models are represented as an arc with its initial and final vertices, or elementary link of the parametric structural diagram [3]. The initial and final vertices correspond to the input and output physical quantities, parameters. An arc indicates a causal relationship between the input and output quantities.

The PTE models will be presented in multi-output and single-input [2,4] versions. The outputs of the models reflect not only the output values, but also their qualitative nature of change, the name and function of the "input-output" dependence. Thus, the compiled models carry information about all the input values of the PTE. Such models correspond to the parts of the graph (structures) of the "entry star" type, the peaks-sinks of which correspond to the output quantities, the peaks-sources correspond to the input quantities. Examples of such PTE models are shown in Fig. 1.

The set of FTE models forms a graph of interrelations of physical quantities (GIPQ) [2,5]. The systematization of the values by the types of circuits makes the GIPQ multilayer. Under the layer of the GIPQ we mean a set of quantities of one type of chain. For example, electrical, optical, hydraulic, magnetic, mechanical, etc. In this regard, PTEs are divided into interchain and intrachain. Interchain FTEs are those in which a physical quantity of one nature is converted into a physical quantity of another nature. Accordingly, in intrachain PTEs there is a transformation of quantities of the same physical nature [1,6]. In most cases, the projection of the intrachain PTE of one layer of the GPIQ onto another layer (other layers) of the PTE of a different physical nature shows the existence of an analogy between the FTE of a different nature.

The list model of the form $<\text{output value}: -V_{i=1}^{n}\ \text{input value}\ (i)>$ has a "star input" structure. For the manifestation of the PTE corresponding to this model, it is necessary to excite one of its inputs. At the same time, the necessary modes must be supported at other (side) inputs.

This PTE model is convenient in that, as the PPD of the MMIRS is synthesized, the numbers of the side inputs of the principle of operation corresponding to the unconnected input vertices of the PTE models, which form the principle of operation of the mechatronic module, are simultaneously accumulated. The described model makes it possible to use the methods of deductive inference for the synthesis of PPD MMIRS [1,3,5,7].

Another proposed formalized model of the FTE is a model in the form of the so-called predicate matrix (PM) [7,8]. This is a tabular representation of some predicate expression describing the essence of FTE. The predicate model of the PTE is a matrix of order 3 x n (where n is the number of input values), the elements of the first line of which are predicate symbols (or predicate code), the elements of the remaining lines are terms [8,9] (Fig. 1). Predictive, the symbol in this case represents the type of causal relationship. "Input-output" PTE. The element of the second line of PM is the code of the output value of the PTE. The elements of the third line are the codes of the input values of the PTE. The representation of the PTE in the form of PM allows one to synthesize the PPD of the mechatronic module using the resolution method [7, 10] used in artificial intelligence systems.

Methods for finding the principles of constructing MMIRS are also proposed below. using PTE models in the form of information matrices (IM) [11,12,13]. In the simplest case, an information matrix is a square adjacency matrix of an information graph. Moreover, all diagonal elements of the IM are zero, which indicates the absence of loops in the information graph. The rest of the IM elements reflect the numbers of phenomena, formulas and properties of the corresponding arcs of the information graph.

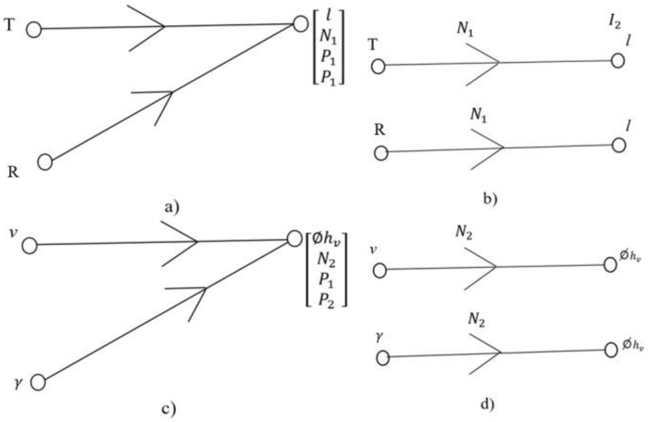

Fig. 1. ***Examples of graph models of PTE:***
a) model of the effect of thermal expansion; b) model of the Vavilov-Cherenkov effect (radiation); b, d) corresponding single-entry models; N_i *and* P_i *- respectively, the PTE number and the property number.*

A1: :

1
4
16

; A2: :

-1
56
22

A3: :

-1
8
98

; A4: :

2
10
2

A3: :

2	2
4	4
-2	8

Fig. 2. ***Examples of PTE models in the form of predicate matrices.***

Let us consider the synthesis of the physical principles of operation of mechatronic modules and elements of intelligent robotic systems using predicate models of physical and technical effects.

The synthesis of PPD MMIRS by the method of predicate matrices is based on the representation of knowledge about the PTE and general laws of the problem area by predicate models and the use of resolution and factorization procedures [8, 14] to deduce a contradiction in the set of predicate models of the problem area, including the inversion of the predicate model, the required transformation of the input quantity into weekend.

The model of the problem area (PA) in the form of an interconnected system of PTE is represented by a set of predicate matrices of the PM that describe specific PTE and general laws of the problem area. In PM, predicate symbols reflect the properties of the output quantities of the PTE, and terms are physical quantities, variables and functions of quantities and variables. For example, $P_2 -$ increasing, $\overline{P_2} -$ decreasing, $P_3 -$ radiation, $\overline{P_3} -$ absorption, etc. Predicate symbols in PM are replaced by their codes as: $2, -2, 3, -3$ etc. Let us consider an example of the synthesis of the PPD of MMIRS using predicate models of the PTE. For clarity, we will operate not with predicate matrices, but with the corresponding expressions of the predicate calculus language [5, 8, 15] in the form of clauses. In this case, the axioms of transitivity are involved as a general law of the problem area. In particular, the following transitive sentence $P_1(X,Y) \wedge P(Y,Z) \rightarrow P(X,Z)$, meaning "For any X, Y, Z: if a change in X leads to a change in Y, and a change in Y leads to a change in Z, then a change in X leads to a change in Z". For ease of use, we will bring this proposal into a standard form by transformations (standardization procedures) [7, 14, 16], removing the implication sign " $\rightarrow$ ", we obtain $\overline{P_1(X,Y), \wedge P_1(Y,Z)} \vee P_1(X,Z)$ and using the De Morgan rule, we arrive at the expression $\overline{P_1}(XY) \vee \overline{P_1}(Y,Z) \vee P_1(X,Z)$. Let us consider, as a simple example, the course of solving the following problem: it is required to synthesize the PPD of a temperature-to-voltage converter. As a model of the world, we use, along with the obtained expression of the general law of software, the following fragment of the set of particular predicate models of the PTE: $P_1(t,l) -$ the law of thermal expansion; $P_1(l,s) -$the dependence of the area s on the linear size l of one of its sides; $P_1(l,r) -$ the dependence of the resistance of the conductor on its length (or on the position of the rheochord brush); $P_1(r,U) -$ is a partial view of Ohm's law. We represent the inverted model of the required transformation in the form $\overline{P_1}(t,U)$. Based on the above expressions, using the resolution procedures [8, 14, 16] and factorization, we obtain the sets of resolvents [10, 16]. The sequence of obtaining resolvents (models of elementary intermediate transformations that will also participate in the synthesis of PPDs) is ordered as follows. From the transitive sentence and $\overline{P_1}(t,U)$ we get the resolution $\overline{P_1}(t,Y) \vee \overline{P_1}(Y,U)$. From this resolvent and the set of PTE models, we obtain a subset of new resolvents $\overline{P_1}(l,U), \overline{P_1}(t,r)$. These resolvents are inverted of new elementary transformations, which respectively read as "A change (increase) in l leads to a decrease in U, and a change (increase) in t leads to a decrease in r". These resolvents turned out to be inverted because they are child resolvents of the required transformation. Inverted resolvents are required to produce inconsistent models. Since the inverted resolvents do not contradict the PTE models, further we will continue the procedure for generating new resolvents using the previously obtained inverted resolvents. So, from the transitive sentence and $\overline{P_1}(l,U)$ we get $\overline{P_1}(l,Y) \vee \overline{P_1}(Y,U)$, then from this resolvent and the set of PTE models we get a new subset of resolvents: $\overline{P_1}(s,U), \overline{P_1}(r,U)$. The new resolution $\overline{P_1}(r,U)$ contradicts the model $\overline{P_1}(r,U)$. They give an empty resolution $-NIL$. The FTE models participated in obtaining NIL: $P_1(t,l), P_1(l,r), P_1(r,U)$.

As discussed above, the synthesis of the PPD of MMIRS is reduced to finding a certain set of interrelated models of the PTE and the structure of the compounds of these models. The above method for synthesizing the PPD of MMIRS on the basis of predicate matrices is based on the application of the inference rule (P) to the set of predicate models, which can be represented in the form

$$\frac{(M \vee a) \in M, (\bar{a} \vee \beta) \in M}{(M \vee \beta) \in M}, \tag{1}$$

and read as: "If M or a is an element of the set M and $(\bar{a} \vee \beta) -$ is an element of the set M, then either M or β is an element of the set M. Here $M, a, \beta, (\bar{a} \vee \beta)$are interpreted as predicate models of PTE. The inference rule in the list method is interpreted differently: $\bar{a} \vee \beta$ is the one-input model of the PTE, where a and β are respectively the models (names) of the input and output values of the PTE. This is convenient in the case when all PTE are described by a model of the form $\beta{:} -a$, which is equivalent to the expression $(\bar{a} \vee \beta)$. However, most PTEs are described by a list model of the form $\beta{:} -a_1 \vee a_2 \vee \ldots \vee a_n$, which is interpreted as "out: $-\beta x_1 \vee \beta x_2 \ldots \beta x_n$", where n is the number of inputs of the PTE model.

$$\frac{a_j \in M, ((\vee_{i=1}^{n}) \rightarrow \beta) \in M}{\beta \in M}, \quad (2)$$

where $j \in \overline{1,\ n}$. The main advantage of this inference rule is that after the inclusion of the PTE model of the form $(\vee_{i=1}^{n} a_i \rightarrow \beta)$ into the FPD at the input a_i, the remaining inputs of the FTE model are included in theFPD as side inputs (or " hanging arcs). The application of this rule makes it possible to create a simple control structure, despite the comparative complexity of the list model of the FTE, which consists in the following: as a (initial data ID) (the input value of the projected MMIRS); from the set of FTE list models, a certain model is found $(\vee_{i=1}^{n} a_i \rightarrow \beta)$, (where $j \in \overline{1,\ n}$), converting the value a_j into some intermediate value β; the values a_j (where $j \in \overline{1,\ n}$ and $i \neq j$) are stored as side inputs of the PDF; β is compared as with TR: if $\beta\ =\ TR$, then the PPD is found and it consists of the PTE corresponding to the given model, otherwise β is taken as the next value o and a new model is found for this a_j. until the equality $\beta\ =\ TR$ is obtained.

The interpretation of the components of the formal model of the PPD synthesis system MMIRS to the above synthesis methods is given in Table. 1.

Let us consider the features of the algorithm for synthesizing the physical principles of operation of MMISU based on list models.

The proposed methods for the synthesis of PPD MMIRS are focused on implementation on a computer, in particular on personal computers. The algorithms and machine programs of these methods differ from the existing ones mainly in the data models used in them and the solution methods underlying them. Programs. implementing the described methods, are the main computer system for the synthesis of PPD MMIRS.

Based on the method for the synthesis of PPDs using list models of the PTE and the inference rule (2), an algorithm for the synthesis of PPDs of mechatronic modules has been developed. As the control structure of the algorithm, the strategy "first in depth" with backtracks is adopted. This algorithm allows one to synthesize the PPD of the MMIRS taking into account its side inputs.

The side inputs of the PPD MMIRS can be used to form one of the following structures, depending on the types. side values: structures with direct transformation (with stabilization of side values), differential structure, structure with feedback (F).

The stabilization of the side inputs can be active or passive. In the first case, special techniques are used that maintain a constant corresponding to a physical quantity for some time or simulate it with a signal with certain parameters. The numbers of the side inputs subject to active stabilization are set in a special, so-called table of active values.

In most cases, active stabilization of side inputs is achieved by constructing transformation trees whose roots coincide with the stabilized inputs. Here, by a tree of transformations we mean a chain (sequential transformations of PTE models), starting with a certain passively stabilized value or with an ID (an input value of the MMIRS or from one to intermediate values of the PPD model). In the case when the transformation tree begins with an ID, you get a particular form of a PDP with a differential structure [14,16].

In the case when the transformation tree starts with TR (the output value of the projected MMIRS), a particular form of the PPD with the P will be obtained.

Passive stabilization of side inputs is achieved by isolating the corresponding physical quantity from external disturbances. PPD structures that do not have a P and are not differential are called direct transformation structures (Fig. 3). In such structures, there are usually only passively stabilized side inputs, or there are no side inputs. MMIRS, built according to the direct transformation structure, are quite simple and reliable. However, they have significant drawbacks, namely, the presence of uncompensated errors, both multiplicative (due to the instability of sensitive components) and additive (due to possible unaccounted for external disturbing influences), and, consequently, low conversion accuracy.

PPDs with a differential structure include, in the general case, two structures with direct transformation, the beginning of each of which is associated with an input value, and their ends are

Table 1.

Interpretation of the components of the model of the PPD synthesis system MMIRS

Components / Methods	Native algebra (M)	Operations (Ω)	Inference rule (P)	Rules for applying the rules (γ)
The predicate model method (PM)	PM	Algebra operations PM	1. Rule of substitutions. 2. Rule of conclusions $\frac{a \in M,\ (a \to \beta) \in M}{\beta \epsilon M}$.	Resolution and factorization procedures based on the depth-first strategy and the straight line method are complete
List Models Method (LM)	LM	- - - -	1. Substitution rule. 2. $\frac{a_j \in M, (\vee_{i=1}^{n} a_i \to \beta) \in M}{\beta \epsilon M}$	Depth first strategy with backtracking
1st method of information matrices (IM)	IM	Operations $*, \sum$ algebra IM	- - - -	MI order enhancement programs
2nd method of information matrices (IM)	IM	Operations $\vdash$ algebra IM	- - - -	Dimension reduction programs for IM

connected to each other through a comparison organ (Fig. 4). These structures are included in such a way that useful signals are summed up in the comparison organ, and interfering disturbances are subtracted. Thus, a certain compensation of constant components and a number of additive errors is achieved. Consequently, MMIRS with a differential structure have higher accuracy, greater linearity of control characteristics.

P are used to improve all kinds of characteristics of the MMIRS. The feedback circuits can be passive, integrating, differentiating, summing, with a resonant filter, etc. In fig. 5 shows an example of the structure of a PPD with a P.

Thus, the algorithm for the synthesis of PPDs of MMIRS using the list models of the PTE and the above inference rule (2) in the systems for the synthesis of PPDs of mechatronic modules makes it possible to design practically realizable MMIRS as a result of taking into account and activating all side inputs.

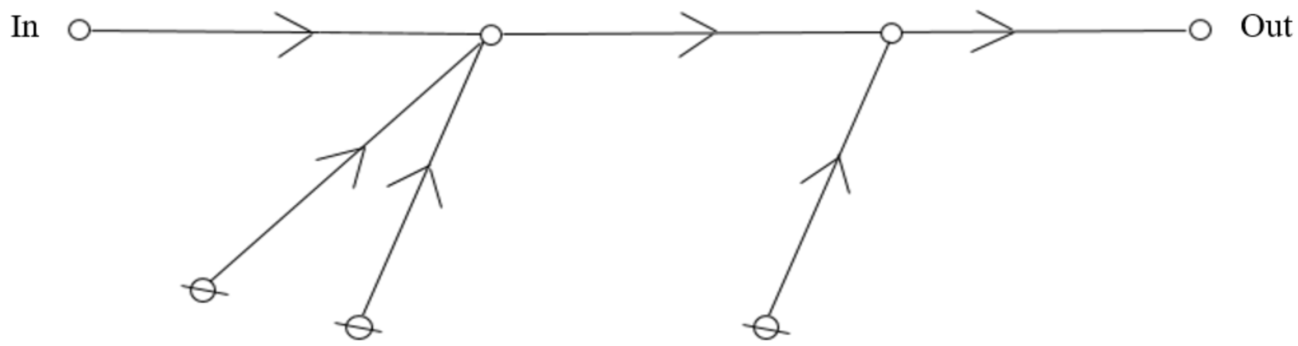

Fig. 3. ***Structure of PPD MMIRS with stabilization of side inputs***

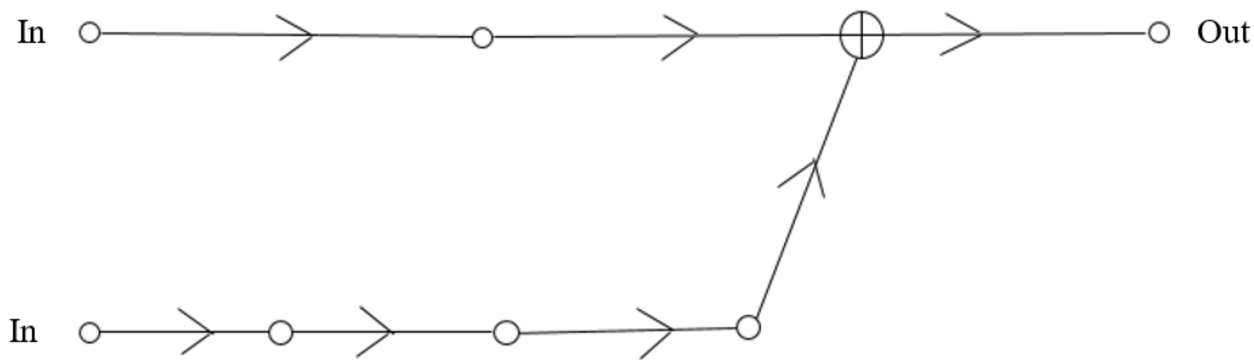

Fig. 4. ***PPD structure of mechatronic modules with differential transformation***

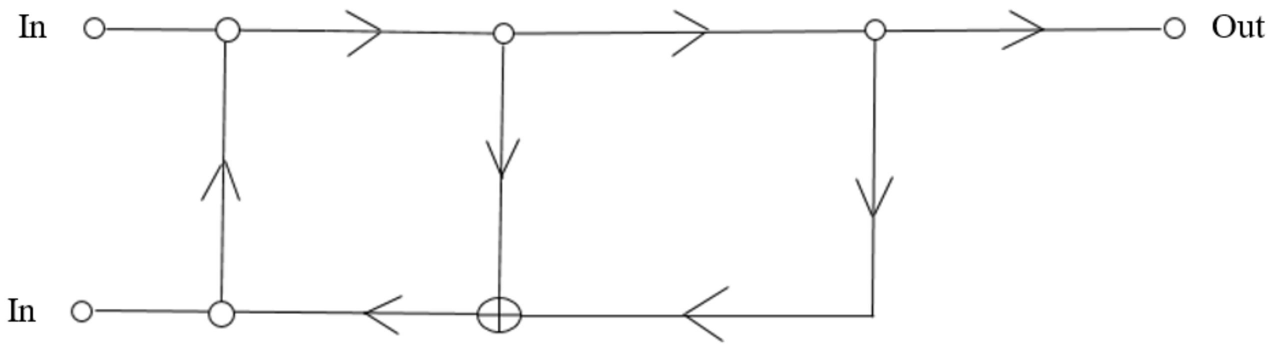

Fig. 5. ***The structure of the PPD MMIRS with P.***

The block diagram of the algorithm for synthesizing the PPD of the MMIRS using the list models of the PTE is shown in Fig. 6.

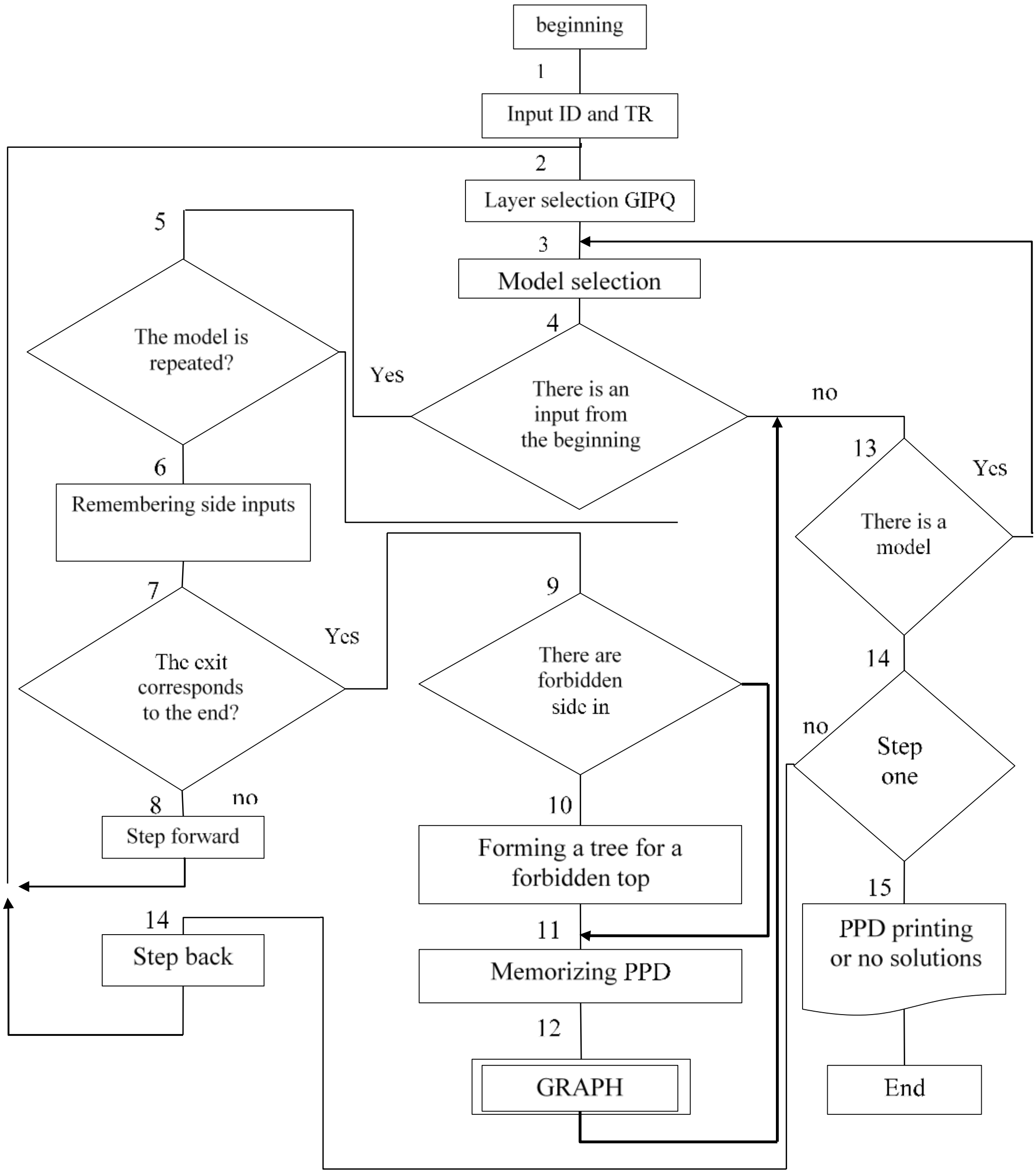

Fig. 6. ***Block diagram of the synthesis algorithm using list models of the PTE.***

Analysis and results

The analysis of methods for solving problems of synthesis of physical principles of operation of mechatronic modules of intelligent robotic systems is carried out. Particular attention is paid to the processes of synthesis of the physical principles of the operation of mechatronic modules using predicate models, list models and information matrices of physical and technical effects.

The given interpretation of the components of the model of the system for the synthesis of the physical principles of operation of mechatronic modules reflects their features, taking into account the carrier of algebra (M), a set of operations (Ω), inference rules (P) and rules of application (γ).

The features of the proposed methods for solving the problems of synthesis of mechatronic modules using predicate models and information matrices are determined.

A formal description of the methods of synthesis of the physical principles of mechatronic modules from the standpoint of artificial intelligence is made.

From a scientific point of view, the components of the models of the PPD synthesis system of mechatronic modules of intelligent control systems are characterized.

A synthesis algorithm using list models of physical and technical effects has been developed.

Conclusion

The paper presents an exposition and analysis of the position of methods for solving problems of synthesis of physical principles of operation of mechatronic modules of intelligent robotic systems.

Models of physical and technical effects used in most of the existing systems for the synthesis of PPD MMIRS, reflecting the cause-and-effect relationships of physical and technical effects, are considered.

A formal description of the method for synthesizing PPDs of MMIRS is given, which a set of synthesis problems and a solver of these problems represent.

Methods for the synthesis of PDPs of mechatronic modules using predicate models, list models and information matrices, as well as the interpretation of the components of the PDP synthesis model are proposed.

As an example, a synthesis algorithm was developed using list models of the PTE.

Based on the results of the analysis, it can be noted that the proposed methods for solving problems of synthesizing the physical principles of operation of mechatronic modules of intelligent robotic systems make it possible to increase the efficiency of the synthesis of new principles of functioning of mechatronic modules.

References

1. A.I.Polovinkin, *Osnoviy injenernogo tvorchestva [Fundamentals of engineering creativity]*. Moskva: Mashinostroenie, 1988, 368 p. (in. Russian).
2. A.M.Dvoryankin, A.I.Polovinkin, A.N.Sobolev, *Metodi sinteza texnicheskix resheniy [Methods of synthesis of technical solutions]*. Moskva: Nauka, 1977, 104 p. (in. Russian).
3. D.A.Pospelov, *Iskusstvenniy intellect [Artificial intelligence]*. Moskva: Radio i svyaz, 1990, 134 p. (in. Russian).
4. N.R.Yusupbekov, R.A.Aliev, R.R.Aliev, A.N.Yusupbekov, *Intellektual'nye sistemy upravleniya i prinyatiya reshenij [Intelligent management and decision-making systems]*. Tashkent: Uzbekiston millij ehntsiklopediyasi, 2014. 572 p. (in Russian).
5. N.Nilson, *Prinsipi iskusstvennogo intellekta [The principle of artificial intelligence]*. Moskva: Radio i svyaz, 2005, 376 p. (in. Russian)
6. D.A.Pospelov, *Logiko-lingvisticheskie modeli v sistemax upravleniya [Logical-linguistic models in the management system]*. Moskva: Energoizdat, 1981, 231 p. (in. Russian).
7. Dj.F.Lyuger, *Iskusstvenniy intellekt: strategii i metodi resheniya slojnix problem [Artificial intelligence: strategy and methods for solving a complex problem]*. Moskva: Izdatelskiy dom "Vilyame", 2003, 864 p. (in. Russian).
8. X.N.Nazarov, *Intellektualnie mnogokoordinatnie mexatronnie moduli robototexnicheskix system [Intelligent multi-coordinate mechatronic modules of a robotic system]*. Monografiya, Toshkent: izd “Mashxur-Press”, 2019, 143 p. (in. Russian).
9. Kh.N.Nazarov, “Intellektualnie mexatronnie moduli lineynogo dvijeniya robototexnicheskix system” [Intelligent mechatronic modules of linear motion of a robotic system], *Mexatronika, avtomatizasiya i upravlenie*, no. 4, pp. 26-31, 2005. (in. Russian).
10. I.M.Makarov, *Iskusstvenniy intellekt i intellektualnie sistemi upravleniya [Artificial intelligence and intelligent control systems]*. Moskva: Nauka, 2006, 333 p. (in. Russian).
11. I.M.Makarov, *Intellektualnie sistemiy avtomaticheskogo upravleniya [Intelligent automatic control systems]*, Moskva: FIZMATLIT, 2001, 576 p. (in. Russian).
12. T.A.Gavrilova, V.F.Xoroshevskiy, *Bazi znaniy intellektualnix system [Knowledge bases of intelligent systems]*. Sankt-Peterburg: Piter, 2001, 384 p. (in. Russian).
13. H.H.Kwee, J.J.Duimel, J.J.Smits, A.A.T.de Moed, J.A.van Woerden, L.W.V.D.Kolk, et al., “The MANTUS wheelchair-borne manipulator: system review and first results”, *Proc. Second Workshop on Medical and Healthcare Robotics*, pp. 385-396, 1989.
14. Kh.N.Nazarov, N.R.Matyokubov, T.O.Rakhimov, “Simulation model of the functioning of a multi-position mechatronic module of an intelligent robot”, *Advances in Intelligent Systems and Computing Volume*, no. 1323, AISC, pp. 201 – 206, 2021. DOI:10.1007/978-3-030-68004-6_26.
15. J.C.Rosier, J.A.van Woerden, L.W.van der Kolk, H.H.Kwee, J.J.Duimel, J.J.Smits, et al., “The MANUS wheelchair-mounted manipulator: Control aspects and man-machine interface”, *Proc. 20th Intern. Symp. on Industrial Robots*, pp. 443-450, 1989.
16. Kh.N.Nazarov, N.R.Matyokubov, T.O.Rakhimov, R.A.Pulatov, “The concept of constructing set-theoretic models of structures of intelligent multi-axis mechatronic robot modules”, *Bulletin of TUIT: Management and Communication Technologies*, vol. 4, no. 1, pp. 1-12, 2021. https://uzjournals.edu.uz/tuitmct/vol4/iss1/1.