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ALGORITHM OF ADAPTIVE CYCLIC CONTROL OF POSITION-TRAJECTORY MOVING OBJECTS (IN THE CASE OF AN INDUSTRIAL ROBOT MANIPULATOR)

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Abstract: *This article is devoted to the adaptive cyclic control of an industrial robot manipulator on the example of moving objects with a positional trajectory. The specific features of applying the principle of adaptive cyclic control to industrial robots are also presented. The kinematic scheme describing the movement of the robot working body with the adaptive cycle control system and the transition states of the working body based on limited positions in space are presented, the sequence of movement of the manipulator links and the selection of information about the actions at individual levels of mobility, control in the case of a variable sequence of links by positional coordinates the formation of programs was considered. During the control process, a model describing the transition states of the robot working body movement zone according to the positional coordinates corresponding to the cyclic control signals was developed, and mathematical models reflecting the interdependence of each state were presented. Based on the mathematical models that describe these transition states and reflect the interdependence of each state, an algorithm for controlling the movements of the industrial robot manipulator with high accuracy and speed has been developed.*

Keywords: *industrial robot, cyclic control, control algorithm, kinematic scheme, working body zone, positional coordinates of the cycle, control signals of the cycle, transition states.*

Аннотация. *Ушбу мақола позицион траекторияли ҳаракатланувчи объектлар мисолида саноат робот манипуляторининг адаптив циклик бошқаришга бағишланади. Шунингдек адаптив циклик бошқариш тамойилини саноат роботларига қўллашнинг ўзига ҳос хусусиятлари келтирилган. Адаптив циклли бошқариш тизими билан робот ишчи органининг ҳаракатланишини тавсифловчи кинематик схемаси ва ишчи органининг фазода чекланган позициялари бўйича ўтиш ҳолатлари келтирилган бўлиб, манипулятор звеноларининг ҳаракатланиш кетма-кетлигини ҳамда ҳаракатчанликнинг индивидуал даражаларидаги ҳаракатлар тўғрисидаги маълумотларни танлаш, позицион координаталар бўйича звеноларнинг ўзгарувчан кетма-кетлиги бўлган ҳолатда бошқариш дастурларини шакллантириш кўрилган. Бошқарув жараёнида циклик бошқариш сигналларига мос робот ишчи органи ҳаракатланиш зонасининг позицион координаталари бўйича ўтиш ҳолатларини тавсифловчи модели ишлаб чиқилган ва ҳар бир ҳолатнинг ўзаро боғлиқлигини акс эттирувчи математик моделлари келтирилган. Ушбу ўтиш ҳолатларини тавсифловчи ва ҳар бир ҳолатнинг ўзаро боғлиқлигини акс эттирувчи математик моделлар асосида саноат робот манипуляторининг ҳаракатларини юқори аниқликда ва тезкорликда бошқариш алгоритими ишлаб чиқилган.*

Калит сўзлар: *саноат роботи, циклик бошқариш, бошқариш алгоритми, кинематик схема, ишчи орган зонаси, циклнинг позицион координаталари, циклнинг бошқариш сигналлари, ўтиш ҳолатлари.*

Аннотация: *Данная статья посвящена адаптивному циклическому управлению манипулятором промышленного робота на примере движущихся объектов с позиционной траекторией. Представлены также особенности применения принципа адаптивного циклического управления к промышленным роботам. Представлены кинематическая схема, описывающая движение рабочего органа робота с адаптивной системой управления контуром и переходные состояния предельных положений рабочего органа в пространстве, рассмотрены выбор последовательности движения звеньев манипулятора и информации о перемещениях отдельных уровней подвижности, формирование программ управления в случае переменной последовательности звеньев по позиционным координатам. В процессе управления была разработана модель, описывающая переходные состояния зоны движения рабочего органа робота по позиционным координатам, соответствующим циклическим сигналам управления, и*

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представлены математические модели, отражающие взаимозависимость каждого состояния. На основе математических моделей, описывающих эти переходные состояния и отражающих взаимозависимость каждого состояния, разработан алгоритм управления движениями промышленного робота-манипулятора с высокой точностью и скоростью.

Ключевые слова: *промышленный робот, циклическое управление, алгоритм управления, кинематическая схема, зона рабочего тела, позиционные координаты цикла, управляющие сигналы цикла, переходные состояния.*

Introduction

The accuracy and speed of position-trajectory moving objects depends on the principle of their control. Important characteristics of objects moving along the trajectory, such as displacement, speed and acceleration, describe their quality indicators [1,2]. The process of adaptive loop control of position-trajectory moving objects can be seen in the example of multi-link manipulators. In the case of position-trajectory moving objects, the cyclic control system of robots with an intermediate position is characterized by a number of features, using various technological devices with expandable stops and complex control logic of individual parts of the manipulator [1,3]. The main principle of application of cyclic control to industrial robots is to determine the position of the manipulator in terms of spatial coordinates, and also includes the following specific features in the control process:

- programming of logical and technological process data of a discrete type, which determines the sequence of movement of the flexible links of the manipulator, the position according to space coordinates and determines its duration;
- selection of information about actions at individ levels of mobility indicated by means of stop points or position sensors with the help of an adjustment regulator;
- comparison of the set and real state of the manipulator links through position sensors installed on mechanical parts;
- open loop management;
- extended parking spaces are managed;
- practical application of algorithms for braking robot links when approaching a parking place;
- formation of technological programs in the case of a variable sequence of links according to positional coordinates;
- quick blocking in case of emergencies.

Research methodology

A characteristic feature of a trajectory-moving robot with a cyclic control system is that the manipulator handle is located at a limited number of points in space, that is, with a cyclic control system, the area in which the manipulator handle can move can be limited [1,3,4]. If the manipulator has k degrees of mobility, each of them contains p_i points, $i = 1,2,\dots,k$, where the corresponding link can be located, then the number of points n that can be gripped is written as follows: $n = \sum_{i=1}^{k} p_i$. Manipulators of this class are equipped with information sensors, which inform about the entry of the internal $i -$ moving link into each permissible position with a d_j^i signal. Then, for each mobility level i, a separate control signal u_j^i can be given, which will move this level to the desired state [1,3,4]. Class 1 manipulators can then be defined as finite-state automated robots with the following attributes:

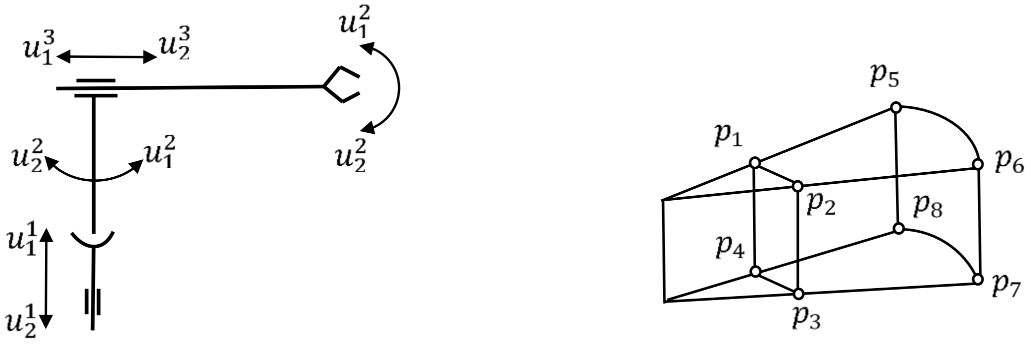
$$U = \{u_j^i\}, \qquad X = \{p_i\}, \qquad Z = \{d_j^i\}.$$

The type of functions $f(\cdot)$ and $h(\cdot)$ is determined by the kinematic scheme of the manipulator. Fig. 1 a and b show the structure of a typical kinematic scheme of the manipulator and the working movement zone [2,5]. Each stage has two positioning points. The mathematical description of the manipulator as a control object looks like this:

$$U = \{u_1^1, u_2^1, u_1^2, u_2^2, u_1^3, u_2^3\},$$

$$X = \{p_1, p_2, \dots, p_8\}, \qquad Z = \{d_1^1, d_2^1, d_1^2, \dots, d_2^3\}.$$

It can be described on the example of the state diagram of the manipulator as a cyclic control object (Fig. 2).



a b

Fig. 1. Manipulator with cyclic control system: a – kinematic scheme; b – working movement zone.

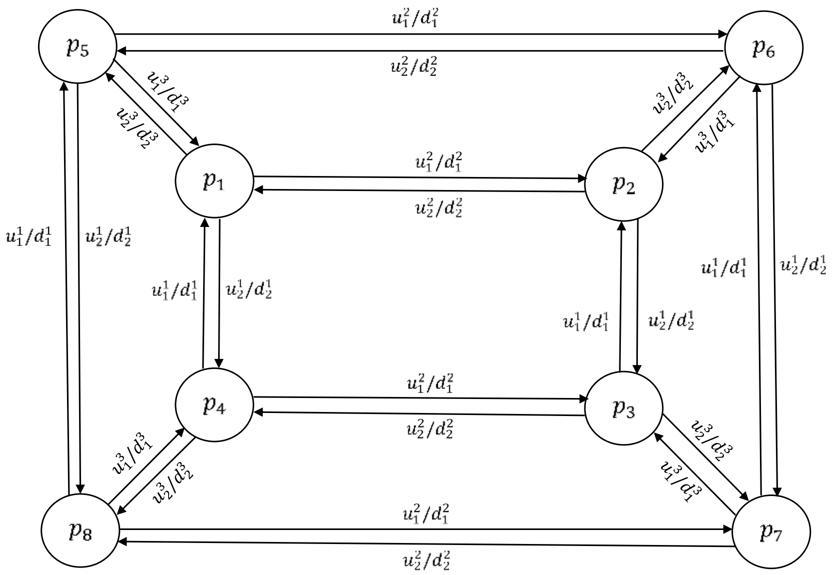


Fig. 2. State diagram of a manipulator with a cyclic control system

Analysis and results

Using this state diagram, as we mentioned above, it is possible to express a limited number of cases of a position-trajectory moving robot part or technological equipment with cyclic control [4,5]. Therefore, considering the model of these states as limited automaton states, they can be described by finite state equations:

$$x_p[t] = \varphi_{q\,kp}\big(x_q\,[t-1], u_k[t-1]\big);$$
$$y_r\,[t] = \psi_{qkr}\,(x_q\,[t], u_k) \qquad (1)$$
$$p = 1,\cdots,n;\ r = 1,\cdots,m;\ q = 1,\cdots,n;\ k = 1,\cdots,ur;$$

where $p-$ number x_{1p} is the position of the manipulator moving along the x coordinate; transition state of the $i-$ th link x_q with number q; y_r- output signal $r-$ with number; output signal u_k with number k; $r = I,\cdots,N-$ moments of time in the motion cycle; $\varphi_{q\,kp}-$ transition functions; $\psi_{qkr}-$ state transition output functions can be represented.

Using the state diagram of the manipulator shown in Figure 1, the kinematic diagram describing the directions of movement in an expanded [6,7] manner and the states of the positional coordinates of the movement zone of the robot working body corresponding to the cyclic control signals can be presented in Figures 3 a and b.

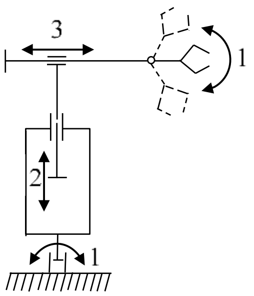


Fig.3 a. Kinematic scheme of the manipulator

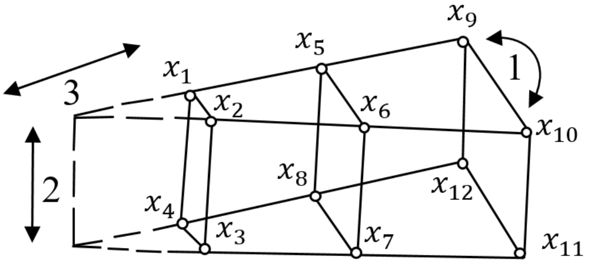


Fig.3 b. Working movement zone of the manipulator handle.

In this case, it is possible to construct a table of transition states for all possible coordinates of the working movement zone of the [3,7,8] manipulator handle presented in Figure 3-b (Table 1). The task of the finite state is to describe each of the elements included in equations (1). The functions $\varphi_{q\,kp}$ and ψ_{qkr} can be represented in the form of a transition table, the rows and columns of which are defined by the names of states and input signals. The elements of the transition table are the names of the new states that the robot will pass through (in t), as well as the names of the output signals [1,4,8].

To represent manipulator movement, arrow 1 represents half-angular rotation through the x coordinate, arrow 2 represents elevation through the y coordinate, and arrow 3 represents the positions corresponding to the manipulator's links for linear motion through the x coordinate. To perform movements, there are three positions to move forward along the directions of the 3 arrows, and Figure 3 shows the positions resulting from the three movements. The points $x_1,\cdots,x_{12}-$ are the final position of the handle [3,9]. We usually do not take into account the correct movement of the handle. The total number of manipulator states is $n = 12$. Limit switches, equal to the number of output signals, are represented by $m = 7$, the number of direction sensors. The number of input signals is $w = 6$ and describes the control commands of the mechatronic modules that provide movements in the robot links with a cyclic control system.

It can be seen from Table 1 that the input signals are: $u_1, u_2 -$ for moving the manipulator to the right and left when turning; $u_3, u_4 -$ to move up and down in the rise of the manipulator; $u_5, u_6 -$ are given for moving the manipulator back and forth [4,7,10].

Let us assume that there is no motion when $u_k = 0$, but there is motion in the given direction when $u_k = 1$. In that case, the execution of the commands is determined by the output signals y_j received from the direction sensors.

Output signals: $y_1, y_2 -$ signals received from the right and left turn sensors; $y_3, y_4 -$ signals received from upper and lower lift sensors: $y_5, y_6, y_7 -$ represent signals received from three transmission sensors.

Table 1

All possible transition states for a manipulator with a cyclic control system

Positional coordinates of the cycle.	Cyclic control signals $u_m[t-1]$					
	u_1	u_2	u_3	u_4	u_5	u_6
x_1	x_2			x_4	x_5	
x_2		x_1		x_3	x_6	
x_3		x_4	x_2		x_7	
x_4	x_3		x_1		x_8	
x_5	x_6			x_8	x_9	x_1
x_6		x_5		x_7	x_{10}	x_2
x_7		x_8	x_6		x_{11}	x_3
x_8	x_7		x_5		x_{12}	x_4
x_9	x_{10}			x_{12}		x_5
x_{10}		x_9		x_{11}		x_6
x_{11}		x_{12}	x_{10}			x_7
x_{12}	x_{11}		x_9			x_8

If $y_r = 0$, the direction sensor of the manipulator has not been reached, then its signal is determined by the output signal y_r. When $y_r = 1$, the manipulator is in this state.

The elements of the transition table are the states $x_p = x_p[t]$, from which we get the logical functions:

$$x_1[t] = x_2[t-1] \cdot u_2[t-1] + x_4[t-1] \cdot u_3[t-1] + x_5[t-1] \cdot u_6[t-1];$$
$$x_2[t] = x_1[t-1] \cdot u_1[t-1] + x_3[t-1] \cdot u_3[t-1] + x_6[t-1] \cdot u_6[t-1].$$

Then, we omit the $t-1$ argument:

$$x_3[t] = x_4 \cdot u_1 + x_2 \cdot u_4 + x_7 \cdot u_6;$$
$$x_4[t] = x_3 \cdot u_2 + x_1 \cdot u_4 + x_8 \cdot u_6;$$
$$x_5[t] = x_6 \cdot u_2 + x_6 \cdot u_3 + x_1 \cdot u_5 + x_9 \cdot u_6;$$
$$x_6[t] = x_5 \cdot u_1 + x_7 \cdot u_3 + x_2 \cdot u_5 + x_{10} \cdot u_6;$$
$$x_7[t] = x_9 \cdot u_1 + x_6 \cdot u_4 + x_3 \cdot u_5 + x_{11} \cdot u_6;$$
$$x_8[t] = x_7 \cdot u_2 + x_5 \cdot u_4 + x_4 \cdot u_5 + x_{12} \cdot u_6;$$
$$x_9[t] = x_{10} \cdot u_2 + x_{12} \cdot u_3 + x_5 \cdot u_5;$$
$$x_{10}[t] = x_9 \cdot u_1 + x_{11} \cdot u_3 + x_6 \cdot u_5;$$
$$x_{11}[t] = x_{12} \cdot u_2 + x_{10} \cdot u_4 + x_7 \cdot u_5;$$
$$x_{12}[t] = x_{11} \cdot u_2 + x_9 \cdot u_4 + x_8 \cdot u_5;$$

In the case under consideration, there is the following relationship in the form of logical functions between the output signals $y_r (r = 1, \cdots, 7)$ and the states $x_p (p = 1, \cdots, 12)$:

$$y_1[t] = x_2[t] + x_3[t] + x_6[t] + x_7[t] + x_{10}[t] + x_{11}[t];$$
$$y_2[t] = x_1[t] + x_4[t] + x_5[t] + x_8[t] + x_9[t] + x_{12}[t].$$

Then, we omit the t argument:

$$y_3 = x_1 + x_2 + x_5 + x_6 + x_9 + x_{10};$$
$$y_4 = x_3 + x_4 + x_7 + x_8 + x_{11} + x_{12};$$
$$y_5 = x_1 + x_2 + x_3 + x_4;$$
$$y_6 = x_5 + x_6 + x_7 + x_8;$$
$$y_7 = x_9 + x_{10} + x_{11} + x_{12}.$$

It can be seen from the $y_r[t]$ coupling formulas that they mean that the output signals $y_r[t]$ are separate from the input signals $u_k[t]$. We should also not forget that the time period between moments i and $i+1$ is equal to the time of development of the next position of the manipulator and depends on its inertia and the mass of the load carried by the handle. In this regard, the duration of this period is not important [9,10,11]. Thus, instead of system (1), the state of the manipulator should be represented by a system of simplified equations.

$$x_p[t] = \varphi_{q\,kp}\big(x_q\,[t-1], u_k[t-1]\big);$$
$$y_r[t] = \psi_{q\,kr}\big(x_q\,[t]\big), \qquad (2)$$

where $p = 1, \cdots, 12$; $r = 1, \cdots, 7$; $q = 1, \cdots, 12$; $k = 1, \cdots, 6$, represent the values of transition states. From the transition table, we get a set of arbitrary [7,12] logical functions $u_k[t] = F_{pk}(x_p[t], x_p[t+1])$:

$$u_1[t] = x_1[t] \cdot x_2[t+1] + x_4[t] \cdot x_3[t+1] + x_5[t] \cdot x_6[t+1] + x_8[t] \cdot x_7[t+1] + x_9[t] \cdot$$
$$\cdot\, x_{10}[t+1] + x_{12}[t] \cdot x_{11}[t+1];$$

$$u_2[t] = x_2[t] \cdot x_1[t+1] + x_3[t] \cdot x_4[t+1] + x_6[t] \cdot x_5[t+1] + x_7[t] \cdot x_8[t+1] + x_{10}[t] \cdot \\ \cdot x_9[t+1] + x_{11}[t] \cdot x_{12}[t+1];$$

$$u_3[t] = x_3[t] \cdot x_2[t+1] + x_4[t] \cdot x_1[t+1] + x_7[t] \cdot x_6[t+1] + x_8[t] \cdot x_5[t+1] + x_{11}[t] \cdot \\ \cdot x_{10}[t+1] + x_{12}[t] \cdot x_9[t+1];$$

$$u_4[t] = x_1[t] \cdot x_4[t+1] + x_2[t] \cdot x_3[t+1] + x_5[t] \cdot x_8[t+1] + x_6[t] \cdot x_7[t+1] + x_3[t] \cdot \\ \cdot x_{12}[t+1] + x_{10}[t] \cdot x_{11}[t+1];$$

$$u_5[t] = x_1[t] \cdot x_5[t+1] + x_2[t] \cdot x_6[t+1] + x_3[t] \cdot x_7[t+1] + x_4[t] \cdot x_6[t+1] + x_5[t] \cdot \\ \cdot x_9[t+1] + x_6[t] \cdot x_{10}[t+1] + x_7[t] \cdot x_{11}[t+1] + x_8[t] \cdot x_{12}[t+1];$$

$$u_6[t] = x_5[t] \cdot x_1[t+1] + x_6[t] \cdot x_2[t+1] + x_7[t] \cdot x_3[t+1] + x_8[t] \cdot x_4[t+1] + x_9[t] \cdot \\ \cdot x_5[t+1] + x_{10}[t] \cdot x_6[t+1] + x_{11}[t] \cdot x_7[t+1] + x_{12}[t] \cdot x_8[t+1].$$

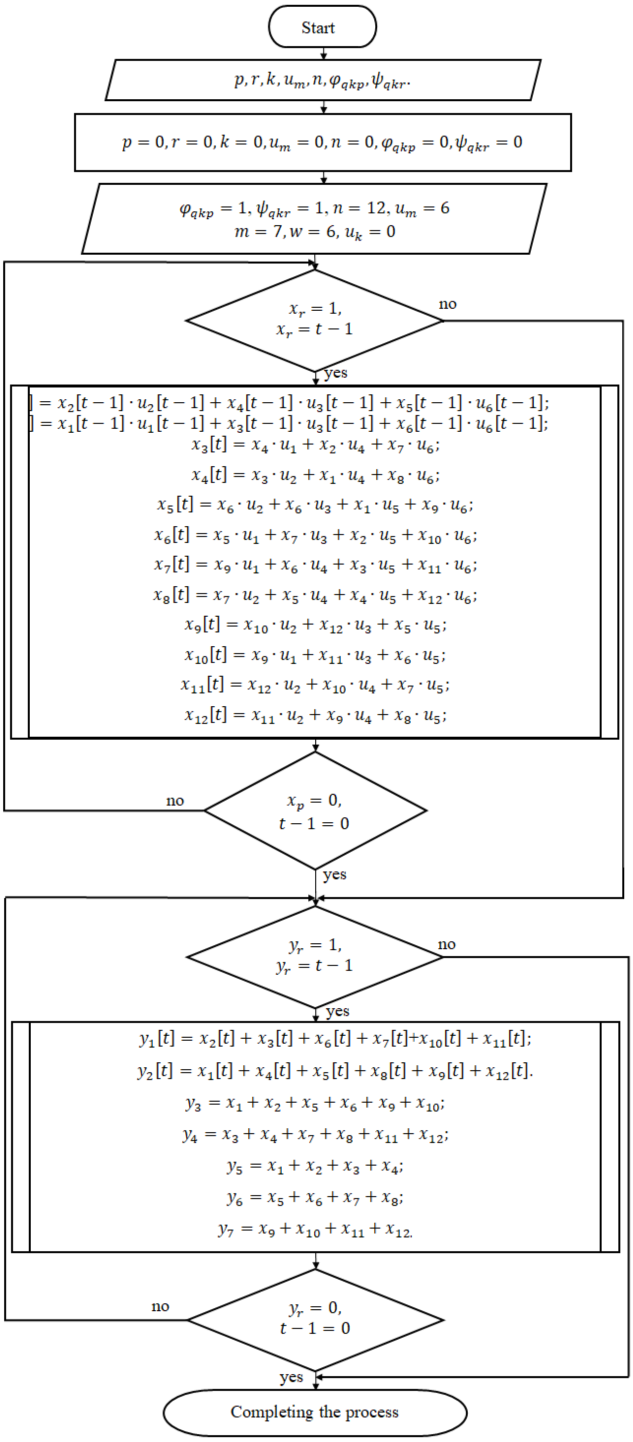


Fig.4. Cyclic control algorithm of industrial robot manipulator

The desired control algorithm can be constructed using the given transition table, and in this case, the formulas $u_1[t], \cdots, u_6[t]$ are used, excluding [1,13,14] unnecessary links from the right side. The set of formulas obtained in this way represents the cyclic control algorithm of the robot and is also a control model (Fig. 4). The signals $u_1[t], \cdots, u_6[t]$ presented as input signals of the finite transition state are the signals of the tasks of moving the output elements by the mechatronic module with three degrees of freedom of movement for the manipulator. Robot control levels and the operation of technological equipment can be described by decision tables containing y_r decision fields u_k and x_p states [6,15]. These tables do not contain all possible transitions between x_p and marked only, since they are less complete for marked transitions than transition tables. Therefore, adaptive loop control models are convenient for accurately expressing important characteristics of robots moving along a trajectory [3,16], such as displacement, velocity, and acceleration, and their quality indicators.

Conclusion

In the article, the structure and algorithm of adaptive cyclic control of an industrial robot manipulator is considered as an example of moving objects with a positional trajectory. As well as a kinematic scheme describing the movement of a robotic working body with a cyclic control system, which presents transition states on the space-limited positions of the working body, allows obtaining the movement sequence of manipulator zvenos and information about movements at individual levels of mobility. The kinematic scheme of the manipulator reflecting all possible transitions in positions and the transitions in limited positions of the working body in space are considered. Using the given state scheme, a model describing the transition states of the robot working body movement zone according to the positional coordinates corresponding to the cyclic control signals in the control process and mathematical models reflecting the interdependence of each state were developed. Based on these mathematical models, an algorithm for controlling the movements of an industrial robot manipulator with high accuracy and speed has been developed, which allows simulating the cyclic control of the manipulator using high-level programming languages. This serves to prevent and eliminate errors in the management process.

References

1. Zenkivich, S.L., Jushhenko A.S. (2000). Upravlenija robotami. osnovy upravlenija manipuljacionnymi robotami [Robot control. basics of manipulating robots control]. MGTU im. N.Je.Baumana, Moscow, 400 p. (in. Russian).
2. Glazunov, V.A. (2018). Novye mehanizmy v sovremennoj robototehnike [New mechanisms in modern robotics]. TEHANOSFERA, Moscow, 316p (in. Russian).
3. Pol, R. 1986. Modelirovanie, planirovanie traektrorij i upravlenie dvizheniem robota-manipuljatora. -M.: Nauka, — 103 s (in. Russian).
4. Dzhozef L. (2019). Izuchenie robototehniki s ispol'zovaniem Python. per. s ang. A.V.Korjagina. – M.: DMK Press, – 250 s. (in. Russian).
5. Igamberdiev H.Z., Sevinov Zh.U., Zaripov O.O. (2014). Reguljarnye metody i algoritmy sinteza adaptivnyh sistem upravlenija s nastraivaemymi modeljami. – T.: TashGTU, – 160 s. (in. Russian).
6. Nazarov H.N. (2019). Intellektual'nye mnogokoordinatnye mehatronnye moduli robototehnicheskih sistem // Monografija, Toshkent izd “Mashhur-Press”. –143 s. (in. Russian).
7. Jusupbekov N.R. i dr. (2015). Intellektual'nye sistemy upravlenija i prinjatie reshenij. -Tashkent: Izdatel'stvo Nacional'noj jenciklopedii Uzbekistana, – 572 s. (in. Russian).
8. Kozlov V.V., Makarychev V.P., Timofeev A.V., Jurevich E.I. (1984). Dinamika upravlenija robotami. – M.: Nuka. -336 s. (in. Russian).
9. Zaripov O.O., Sevinova D.U. Sevinov I.U. (2019). Synthesis Algorithms for Adaptive Process Control Systems Based on Associative Memory Technology. *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, Vol.9 Issue 2. ISSN: 2278-3075, pp-38-42. DOI: 10.35940/ijitee.A4745.129219
10. Zaripov Oripjon Olimovich, Sevinova Dildora Usmonovna, Bobojanov Sukhrob Gayratovich. (2024). Adaptive Posision-Determination and Dynamic Model Properties Synthesis of Moving Objects With Trajectory Control System (In the Case of Multi-Link Manipulators). *Transactions of the Korean Institute of Electrical Engineers*, Vol. 73, № 3, pp 576 – 584.
11. Oripjon Zaripov and Dildora Sevinova. (2023). Structural and Kinematic Synthesis Algorithms of Adaptive Position-Trajectory Control Systems (In the Case of Assembly Industrial Robots) // *ICoRSE 2023*, LNNS 762, pp. 1–16, https://doi.org/10.1007/978-3-031-40628-7_50.
12. Tadzhiev, H.H. Sevinova, D.U. (2018). Algoritmy adaptivnyh pozicionno-traektoryh sistem upravlenija podvizhnymi obektami [Algorithmic adaptive position-trajectory system control of movement object]. In: Rol' intellektual'noj molodezhi v razvitii nauki i tehniki, Sbornik dokladov respublikanskoj nauchno - tehnicheskoj konferencii. TashGTU, Tashkent, pp. 31-33.
13. Afanas'ev V.A., L. Degtjarev G., Meshhanov A.S., Sirazetdinov T.K. (2007).Sintez adaptivnogo upravlenija razvorotami letatel'nogo apparata v atmosfere / Vestn. Kazan. gos. tehn. un-ta im. A. N. Tupoleva. № 4. S. 39–42, (in. Russian).
14. Putov V. V. Razvitie bespoiskovyh adaptivnyh metodov i ih prilozhenija k zadacham upravlenija slozhnymi mehanicheskimi ob#ektami // Aviakosmicheskoe priborostroenie. 2003. №6. -S.31-42, (in. Russian).
15. Sevinov J.U., Mallaev A.R., Xusanov S.N. (2021) Algorithms for the Synthesis of Optimal Linear-Quadratic Stationary Controllers. In: Aliev R.A., Yusupbekov N.R., Kacprzyk J., Pedrycz W., Sadikoglu F.M. (eds) 11th World Conference “Intelligent System for Industrial Automation” (WCIS-2020). WCIS 2020. Advances in Intelligent Systems and Computing, vol 1323. Springer, Cham. https://doi.org/10.1007/978-3-030-68004-6_9.
16. Yusupbekov, A.N., Sevinov, J.U., Mamirov, U.F., Botirov, T.V. (2021). Synthesis Algorithms for Neural Network Regulator of Dynamic System Control. Advances in Intelligent Systems and Computing, vol 1306. pp. 723–730. Springer, Cham. https://doi.org/10.1007/978-3-030-64058-3_90.