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APPLICATION OF INDUSTRIAL ROBOT MANIPULATORS AT LIGHT INDUSTRY ENTERPRISES

Purpose. *Kinematic analysis and computer modelling of a 3D manipulator for the automation of technological operations at light industry enterprises.*

Methodology. *The study uses the method of vector coordinate transformation, in which links are represented as free vectors and characteristic points as radius vectors; the method of kinematic analysis of structural groups; methods of computer simulation and visualisation using the Mathcad software environment and the principles of structural analysis of Assur groups; and the method of parametric synthesis of a mechatronic system.*

Results. *A mathematical model of the position functions of the end effector was obtained, and the workspace, or operating zone, of the manipulator was visualised. Kinematic constraints related to the minimum and maximum rotation angles of the links were established, which is critical for optimising the interaction between the robot and the object. A mechatronic control system based on an Arduino microprocessor platform and servomotors of active kinematic pairs is presented. A program code, or sketch, was developed for accurate scaling of control signals using the map() function, which makes it possible to implement smooth and coordinated movements of the end effector.*

Scientific novelty. *Analytical methods for studying multi-link spatial mechanisms with specific kinematic constraints have been improved.*

Practical value. *The obtained research results provide the possibility of automating such processes as cutting, sewing and packaging, thereby increasing production accuracy and productivity. Analytical expressions were obtained for solving the forward kinematics problem and accurately determining the position of the working tool in space. The obtained results can be used in solving the inverse kinematics problem for the complete automation of trajectory planning for the movements of industrial robot manipulators.*

Keywords: *3D manipulator; spatial mechanism; kinematic analysis; computer modelling; mechatronic system; Arduino; servomotor; light industry; forward kinematics; trajectory planning.*

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ЗАСТОСУВАННЯ МАНІПУЛЯТОРІВ ПРОМИСЛОВИХ РОБОТІВ НА ПІДПРИЄМСТВАХ ЛЕГКОЇ ПРОМИСЛОВОСТІ

ДВОРЖАК ВОЛОДИМИР, РУБАНКА МИКОЛА, ЗАЛЮБОВСЬКИЙ МАРК, ВОЛЯНИК ОЛЕКСІЙ, КОШЕЛЬ СЕРГІЙ
Київський національний університет технологій та дизайну, Україна

Мета. *Проведення кінематичного аналізу та комп'ютерного моделювання 3D-маніпулятора для автоматизації технологічних операцій на підприємствах легкої промисловості.*

Методика. *У роботі використано метод векторного перетворення координат, де ланки представлені у вигляді вільних векторів, а характерні точки – як радіус-вектори; метод кінематичного аналізу структурних груп; метод комп'ютерної симуляції та візуалізації (для моделювання використано програмне середовище Mathcad та принципи структурного аналізу груп Асура); метод параметричного синтезу мехатронної системи.*

Результати. *Отримано математичну модель функцій положення виконавчого органу та візуалізацію робочого простору (зони обслуговування) маніпулятора. Встановлено кінематичні обмеження щодо мінімальних і максимальних кутів повороту ланок, що є критичним для оптимізації взаємодії робота з об'єктом. Представлено мехатронну систему керування на базі мікропроцесорної платформи Arduino та сервоприводів активних кінематичних пар. Розроблено програмний код (скетч) для точного масштабування керуючих сигналів за допомогою функції map(), що дозволяє реалізувати плавні та скоординовані рухи виконавчого органу.*

Наукова новизна. *Вдосконалено аналітичні методи дослідження багатоланкових просторових механізмів зі специфічними кінематичними обмеженнями.*

Практична значимість. *Одержані результати досліджень забезпечують можливість автоматизації таких процесів, як розкроювання, зшивання та пакування, що підвищує точність і продуктивність виробництва. Отримано аналітичні вирази для розв'язання прямої задачі кінематики та точного визначення положення робочого інструмента у просторі. Одержані результати досліджень можуть бути використані при розв'язанні зворотної задачі кінематики для повної автоматизації планування траєкторій рухів маніпуляторів промислових роботів.*

Ключові слова: *промисловий робот; маніпулятор; кінематичний аналіз; комп'ютерне моделювання; легка промисловість.*

Introduction. At the present stage of industrial development, widespread computerisation and the implementation of CAD software have ensured the leading role of analytical methods in the study of mechanisms [1, 7–10]. light industry, the automation of production processes using industrial robot manipulators (pneumatic, electric, hydraulic or servo-driven) is becoming increasingly important for improving efficiency [2]. The application of robotic systems makes it possible to automate complex operations such as cutting and sewing materials, applying markings, including logos and sizes, producing complex seams, such as pockets and folds, and packaging finished products [2]. The use of manipulators not only increases production speed and accuracy, which directly affects product quality, but also makes it possible to significantly reduce waste [3], minimise errors and lower labour costs [2, 4]. Since most modern industrial robots are multi-link manipulators controlled by microprocessor controllers, the development and investigation of their mathematical and computer models for optimising technological motions is a relevant task [2, 5, 11, 12].

Purpose of the study is to conduct kinematic analysis and computer modelling of a 3D manipulator developed for the needs of light industry, using modern software packages, in particular Mathcad, and vector algebra methods to optimise its working processes.

Analysis of previous studies. The current state of industrial robotics is characterised by the transition to fully computerised design and the implementation of analytical methods for studying mechanisms using CAD software. The vast majority of modern industrial robots are multi-link manipulators controlled by microprocessor controllers and equipped with specialised end effectors for performing technological operations [2, 5].

In the scientific literature, the fundamental aspects of the theory of mechanisms and machines, including the classification of mechanisms, are presented in the works of O. Koreniako, Ya. Kinytskyi and other researchers. An important stage in the design of such systems is solving motion planning problems, which in robotics are divided into forward and inverse kinematics problems **[**5**]**. The forward kinematics problem makes it possible to determine the position of the working tool for given rotation angles of the links, whereas the inverse kinematics problem involves calculating the required angles to reach a target point [5, 13].

Research conducted, in particular, at the Department of Mechanical Engineering of Kyiv National University of Technologies and Design emphasises the effectiveness of the vector modelling method, in which the links of a mechanism are represented as free vectors, while characteristic points, namely the centres of kinematic pairs, are represented as radius vectors [1]. This approach, combined with the use of transformation matrices, including rotation and translation matrices, in the Mathcad environment significantly simplifies the analysis of spatial mechanisms, enabling parallel calculations and real-time motion visualisation [1].

Special attention in previous studies has been paid to the development of 3D models of manipulators at the Department of Mechanical Engineering of KNUTD [2]. In particular, manipulators whose structure corresponds to planar mechanisms of the second class according to Assur's classification and which have several degrees of freedom were considered [5]. The conducted studies made it possible to determine the operating zones, or workspace, and kinematic constraints, which is important for preventing problems when performing complex motions [2].

Another important area is the synthesis of mechatronic control systems (MCS), which combine mechanical, energy and information components [6]. In the works of B. Orlovskyi, the use of Arduino-type platforms and servomotors for implementing active kinematic pairs of the manipulator is substantiated. Such systems are programmed using special codes, or sketches, which makes it possible to scale signals from potentiometers for precise control of the rotation angles of servomotor shafts [6].

Problem statement. Despite the existing developments in the field of industrial robotics and computer modelling of mechanisms, the improvement of mathematical models for specific technological operations in light industry, such as the formation of complex seams, marking, cutting and packaging, remains insufficiently studied. These operations require an integrated approach that combines kinematic analysis, vector modelling, computer simulation and the synthesis of mechatronic control systems. Therefore, research aimed at developing a mathematical and computer model of a 3D manipulator, determining its workspace, analysing kinematic constraints and substantiating the principles of precise control of the end effector is a relevant task.

Methodology. To achieve the stated purpose and solve the research objectives, an integrated approach was applied, combining methods of theoretical mechanics, vector algebra and mechatronic synthesis. The research process was based on the following methods: the method of vector coordinate transformation, the method of kinematic analysis of structural groups, the method of computer simulation and visualisation, and the method of parametric synthesis of a mechatronic system.

Method of vector coordinate transformation. This method was selected as the main approach for developing the mathematical model of the manipulator. Its essence consisted in representing each movable link of the manipulator as free vectors P_{i_j}, while the characteristic points, namely the centres of kinematic pairs, were represented as radius vectors P_k originating from the base reference point P_1. To describe the spatial position of the links, a right-handed coordinate system was used with the corresponding unit vectors of the axes [1, 2].

Mathematical modelling in the Mathcad environment. To solve the forward kinematics problem, mathematical models were developed to describe the position functions of the links depending on the generalised coordinates, namely the rotation angles of the driving rocker arms $\varphi_1$andφ_2 (Fig. 1). The calculations were performed using rotation matrices T_X, T_Y, T_Z about the coordinate axes. In particular, the following specific user-defined Mathcad functions were used:

– for rotating a vector by a given angle:

$$\rho_K(r_1, \varphi_K, l_2) = T_K(\varphi_K) \cdot e_r \cdot l_2;$$

– for determining angular parameters between vectors:

$$Kut(l_1, l_2, l_3) = acos\left(\frac{l_1^2 + l_2^2 - l_3^2}{2 \cdot l_1 \cdot l_2}\right);$$

– parameters $W_{3\_4\_5}$, $W_{7\_8\_3}$, $W_{9\_10\_6}$, which determine the assembly variants of Assur groups.

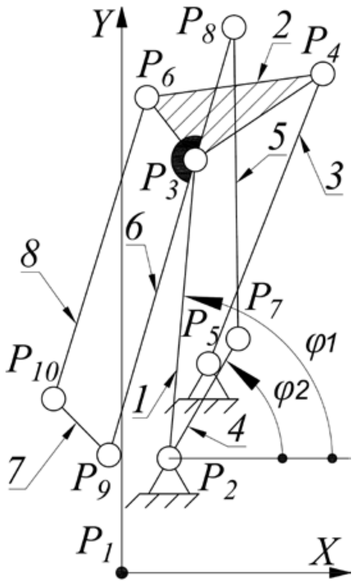

Fig. 1. **Computational diagram of the manipulator kinematic scheme** [5]

Kinematic analysis of structural groups. The study was carried out on the basis of Assur’s classification, in which the manipulator was considered as a second-class planar mechanism consisting of driving links and connected two-link groups, for example, groups 2–3, 5–6, and 7–8 (Fig. 1). This made it possible to determine the position functions for each group step by step through a system of vector equations.

Method of computer simulation and visualisation. Based on the obtained mathematical expressions, a computer model of the kinematic scheme was constructed in the Mathcad software environment (Fig. 2).

By varying the setting angles of the driving links and the magnitude of their stroke, the following operations were performed:

– construction of the trajectories of characteristic points of the moving links;

– visualisation of the operating zone, or workspace, which was marked on the graphs with the symbol "×";

– verification of kinematic constraints to determine the maximum and minimum rotation angles of the links.

Method of parametric synthesis of a mechatronic system. To ensure control of the manipulator, methods for synthesising mechatronic modules were applied, combining mechanical, energy and information components. The control implementation mechanism included:

– the use of an Arduino microprocessor platform and servomotors for active kinematic pairs.

– the development of specialised program code, or a sketch, in which the *map()*function was used to scale analogue signals from potentiometers, ranging from 0 to 1023, to the values of the rotation angles of servomotor shafts, ranging from 0 to 180°.

– the introduction of time delays using the *delay()* function to stabilise system operation.

Research results and discussion. As a result of the study conducted at the Department of Mechanical Engineering of KNUTD, a 3D model of a manipulator intended for the automation of technological operations in light industry was developed and analysed. The developed manipulator has three degrees of freedom and consists of a rotary platform, which provides rotation about the vertical axis, and eight movable links forming revolute kinematic pairs (Fig. 1). In terms of its structure, it is a second-class planar mechanism according to Assur’s classification, with two driving links.

1. Mathematical model of the manipulator kinematics

To analyse the motions of the manipulator, a mathematical model was developed based on the method of vector coordinate transformation in accordance with the vector diagram of the mechanism (Fig. 3).

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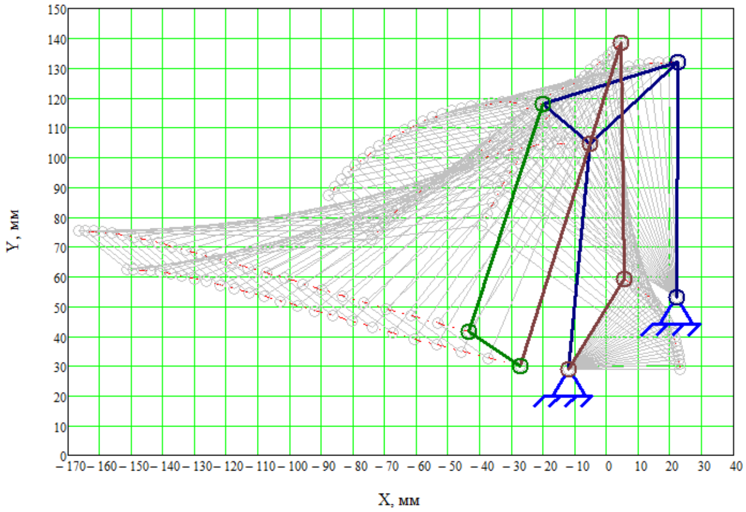


Fig. 2. **Mathcad visualisation of the manipulator kinematic scheme superimposed on the trajectories of characteristic points** [5]

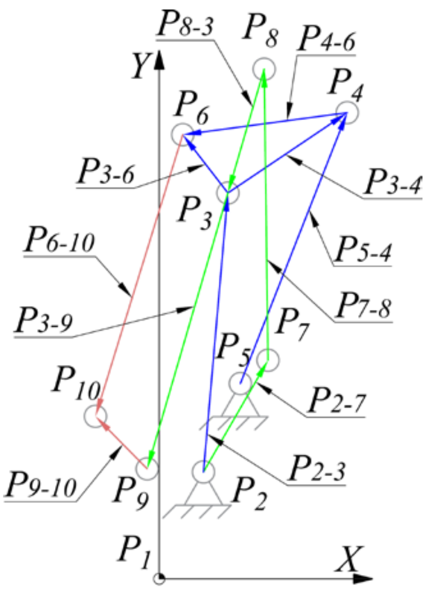


Fig. 3. **Vector diagram of the manipulator**

The links are represented as free vectors P_{i_j}, while the characteristic points, namely the joint centres, are represented as radius vectors P_k. The rotation angles of the driving rocker arm sφ_1 and φ_2, are used as the generalised coordinates of the mechanism.

The main analytical expressions obtained in the study for determining the position functions are as follows [1, 2, 5]:

$$P_{2\_3}(\varphi_1) := \rho_Z(e_X, \varphi_1, l_{2\_3}); \quad P_3(\varphi_1) := P_2 + P_{2\_3}(\varphi_1), \tag{1}$$

where e_X is the unit vector of the abscissa axis; l_{i_j} are the lengths of the moving links corresponding to vectors P_{i_j}; ρ_Z is a Mathcad function for vector rotation [5].

$$P_{5\_3}(\varphi_1) := P_3(\varphi_1) - P_5; \quad U_{3\_5\_4}(\varphi_1) := Kym(|P_{5\_3}(\varphi_1)|, l_{5\_4}, l_{4\_6}), \tag{2}$$

where *Kym* is a Mathcad function for determining the angle between vectors [5]; $U_{3\_5\_4}$ is the angle between P_{5_3} and P_{5_4}.

$$P_{5\_4}(\varphi_1) := \rho_Z(P_{5\_3}(\varphi_1), -W_{3\_4\_5} \cdot U_{3\_5\_4}(\varphi_1), l_{5\_4}); \quad P_4(\varphi_1) := P_5 + P_{5\_4}(\varphi_1), \tag{3}$$

where $W_{3\_4\_5}$ is a parameter that determines the assembly configuration of group *3-4-5*.

$$U_{4\_3\_6}(\varphi_1) := Kym(l_{3\_4}, l_{3\_6}, l_{4\_6}); \quad P_{3\_4}(\varphi_1) := P_4(\varphi_1) - P_3(\varphi_1), \tag{4}$$

$$P_{3\_6}(\varphi_1) := \rho_Z(P_{3\_4}(\varphi_1), U_{4\_3\_6}(\varphi_1), l_{3\_6}); \quad P_6(\varphi_1) := P_3(\varphi_1) + P_{3\_6}(\varphi_1), \tag{5}$$

$$P_{2\_7}(\varphi_4) := \rho_Z(e_X, \varphi_2, l_{2\_7}); \quad P_4(\varphi_2) := P_2 + P_{2\_7}(\varphi_2); \quad P_{3\_7}(\varphi_1, \varphi_2) := P_7(\varphi_2) - P_3(\varphi_1), \tag{6}$$

$$U_{7\_3\_8}(\varphi_1, \varphi_2) := Kym(|P_{3\_7}(\varphi_1, \varphi_2)|, l_{3\_8}, l_{7\_8}), \tag{7}$$

where $U_{7\_3\_8}$ is the angle between P_{3_7} and P_{3_8}.

$$P_{3\_8}(\varphi_1,\varphi_2):=\rho_Z\left(P_{3\_7}(\varphi_1,\varphi_2),-W_{7\_8\_3}\cdot U_{7\_3\_8}(\varphi_1,\varphi_2),l_{3\_8}\right) \quad (8)$$

where $W_{7\_8\_3}$ is a parameter that determines the assembly configuration of group *7-8-3*.

$$P_8(\varphi_1,\varphi_2):=P_3(\varphi_1)+P_{3\_8}(\varphi_1,\varphi_2); \quad (9)$$

$$P_{3\_9}(\varphi_1,\varphi_2):=\rho_Z\left(P_{3\_8}(\varphi_1,\varphi_2),U_{8\_3\_9},l_{3\_9}\right);$$
$$P_9(\varphi_1,\varphi_2):=P_3(\varphi_1)+P_{3\_9}(\varphi_1,\varphi_2), \quad (10)$$

where $U_{8\_3\_9}$ is the angle between P_{3_8} and P_{3_9}.

$$P_{6\_9}(\varphi_1,\varphi_2):=P_9(\varphi_1,\varphi_2)-P_6(\varphi_1);$$
$$U_{9\_6\_10}(\varphi_1,\varphi_2):=Kym\left(\left|P_{6\_9}(\varphi_1,\varphi_2)\right|,l_{6\_10},l_{9\_10}\right), \quad (11)$$

where $U_{9\_6\_10}$ is the angle between P_{6_9} and P_{6_10}.

$$P_{6\_10}(\varphi_1,\varphi_2):=\rho_Z\begin{pmatrix}P_{6\_9}(\varphi_1,\varphi_2),-W_{9\_10\_6}\cdot\\ U_{9\_6\_10}(\varphi_1,\varphi_2),l_{6\_10}\end{pmatrix}, \quad (12)$$

where $W_{9\_10\_6}$ is a parameter that determines the assembly configuration of group *9-10-6*.

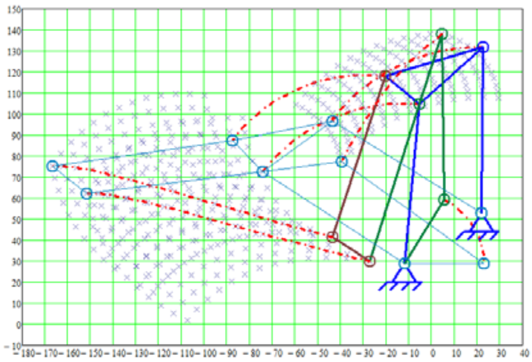
$$P_{10}(\varphi_1,\varphi_2):=P_6(\varphi_1)+P_{6\_10}(\varphi_1,\varphi_2);$$
$$P_{9\_10}(\varphi_1,\varphi_2):=P_{10}(\varphi_1,\varphi_2)-P_9(\varphi_1,\varphi_2). \quad (13)$$

The derived equations for the groups of links make it possible to fully describe the spatial position of link 7, which acts as the holder of the working tool.

2. Computer simulation and visualisation in Mathcad

Based on the developed mathematical models, a computer model was created in the Mathcad environment. The visualisation plot makes it possible to clearly observe the kinematic scheme of the manipulator superimposed on the trajectories of motion of its characteristic points (Fig. 4).

Trajectory analysis. During modelling, it was established that changes in the angles φ_1 and φ_2, as well as in the magnitude of their stroke, directly affect the shape of the trajectory of connecting rod 7. This makes it possible to program the manipulator to produce complex curvilinear seams or to apply markings with high accuracy.



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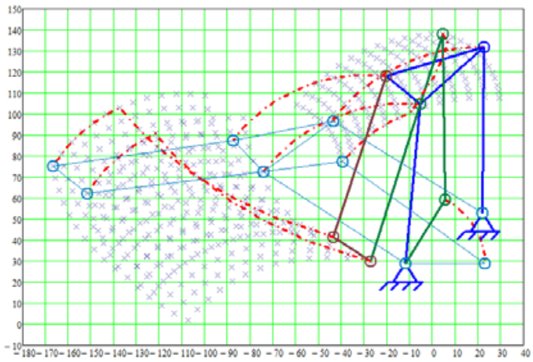

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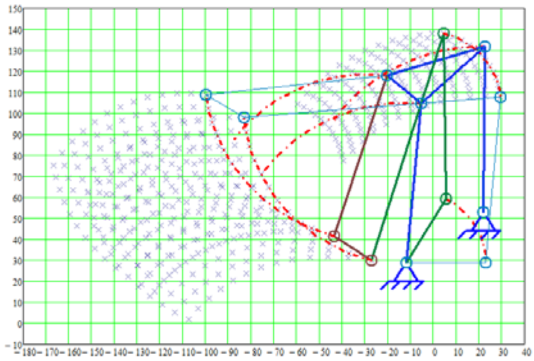

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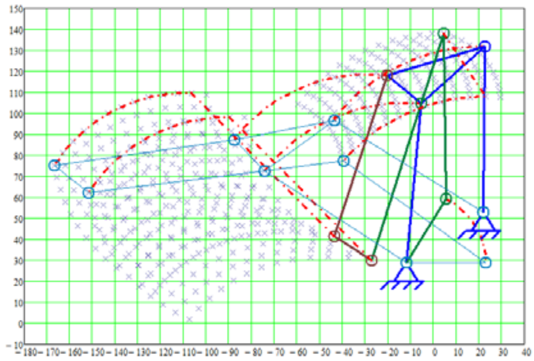

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Fig. 4. **Mathcad visualisation plots of the manipulator** [2]

Operating zone, or workspace. In the plots (Fig. 4), the zones in which the manipulator can perform movements are marked with the symbol “×”. The analysis of this zone makes it possible to determine the kinematic constraints, namely the minimum and maximum rotation angles of the links at which the mechanism remains operational and avoids dead points. Calculation of the operating zone is necessary to ensure efficient interaction between the robot and the object within the specified working volume.

3. Parametric synthesis of the control system

Control of the developed manipulator is implemented as a mechatronic system based on an Arduino controller and four servomotors of active kinematic pairs. The software component, or sketch, ensures the conversion of input signals from the operator or sensors into the motion of the links [6].

The main scaling mechanism is the *map()* function, which converts ADC data ranging from 0 to 1023 into the rotation angles of servomotor shafts ranging from 0 to 180°: *potent1* = *map*(*potent1*, 0, 1023, 0, 180).

To stabilise the movements and prevent jerks, the code includes time delays, *delay(2)*, which ensures smooth displacement of the gripper between technological points. This approach to control synthesis makes it possible to flexibly adapt the manipulator to various operations, from fabric cutting to the packaging of finished products.

Conclusions. As a result of the conducted study, an important scientific and applied task related to the automation of technological processes at light industry enterprises was solved through the development and analysis of a 3D manipulator. Based on the obtained results, the following conclusions can be drawn:

1. A 3D model of a multi-link manipulator with three degrees of freedom and eight movable links was developed. The manipulator is intended to perform such operations as cutting, sewing materials, applying markings and packaging finished products. The use of such a system makes it possible to increase production productivity and accuracy while reducing labour costs.

2. The method of vector coordinate transformation was applied to construct the mathematical model of the manipulator, which made it possible to represent its links as free vectors and the centres of kinematic pairs as radius vectors. This allowed analytical expressions to be obtained for solving the forward kinematics problem and for accurately determining the position of the working tool in space.

3. A computer model was created in the Mathcad environment, by means of which the kinematic scheme was visualised and the trajectories of characteristic points were investigated. The performed analysis made it possible to determine the operating zones, or workspace, and to establish kinematic constraints related to the minimum and maximum rotation angles of the links, which is critical for optimising the interaction between the robot and the object.

4. A mechatronic control system based on an Arduino microprocessor platform and servomotors of active kinematic pairs was synthesised. The developed program code, or sketch, ensures accurate scaling of control signals using the *map()* function, which makes it possible to implement smooth and coordinated movements of the end effector.

Further research in this area should focus on conducting an in-depth dynamic analysis of industrial robot manipulator structures using modern CAD software, as well as on developing algorithms for solving the inverse kinematics problem to achieve full automation of motion trajectory planning.

Література

1. Дворжак В. М. Схемотехнічне моделювання кінематичних схем маніпуляторів промислових роботів. *Актуальні проблеми інженерної механіки: тези доп. V Міжнар. наук.-практ. конф.* (22–25 трав. 2018 р., Одеса). Одеса: ОДАБА, 2018. С. 77-79.

References

1. Dvorzhak, V. M. (2018). *Skhemotekhnichne modeliuvannia kinematychnykh skhem manipuliatoriv promyslovykh robotiv* [Scheme-technical modeling of kinematic schemes of industrial robot manipulators]. *Actual problems of engineering mechanics: abstracts of reports of the 5th International scientific and practical conference* (pp. 77-79). Odesa: OSACE [in Ukrainian].

2. Дворжак В. М. Комп'ютерна симуляція маніпулятора. *Комплексне забезпечення якості технологічних процесів та систем: матеріали XIII Міжнар. наук.-практ. конф.* (25–26 трав. 2023 р., Чернігів). Чернігів: НУ "Чернігівська політехніка", 2023. С. 302–303.

3. Рубанка М. М., Місяць В. П. Відходи легкої промисловості, способи переробки та області подальшого використання. *Вісник Київського національного університету технологій та дизайну*. 2015. № 4 (88). С. 34–39.

4. Білашов К. Ю., Ковальов Ю. А., Рубанка М. М. Аналіз використання робототехнічних пристроїв для автоматизації роботи з настилочними комплексами на швейних виробництвах. *Вісник Хмельницького національного університету. Серія: Технічні науки*. 2025. № 6.2 (359). С. 129–134.

5. Дворжак В. М., Орловський Б. В., Попов В. М. Кінематика 3D маніпулятора з ручним керуванням. *Мехатронні системи: інновації та інжиніринг: тези доп. V Міжнар. наук.-практ. конф.* (4 листоп. 2021 р., Київ). Київ: КНУТД, 2021. С. 45–46.

6. Орловський Б. В., Дворжак В. М., Попов В. М. Синтез мехатронної системи керування маніпулятором з ручним керуванням. *Мехатронні системи: інновації та інжиніринг: тези доп. V Міжнар. наук.-практ. конф.* (4 листоп. 2021 р., Київ). Київ: КНУТД, 2021. С. 49–50.

7. Орловський Б. В., Дворжак В. М. Комп'ютерне моделювання та синтез типового механізму технологічних машин. *Вісник Київського національного університету технологій та дизайну*. 2014. № 5. С. 103–108.

8. Орловський Б. В. Мехатроніка в галузевому машинобудуванні. Київ: КНУТД, 2018. 416 с.

9. Дворжак В. М. Схемотехнічне моделювання кінематичних схем просторових чотириланкових кривошипно-коромислових механізмів технологічних машин. *Вісник Київського національного університету технологій та дизайну. Технічні науки*. 2016. № 2. С. 18–26.

10. Dvorzhak V. M. Scheme-technical modeling of kinematic schemes of industrial robot. *Advanced Problems of Engineering Mechanics: Proc. of the 5th Int. Sci.-Prac. Conf*. Odesa: OSACE, 2018. P. 77–79.

11. Craig J. J. Introduction to Robotics: Mechanics and Control. 4th ed. Pearson, 2017. 408 p.

12. Spong M. W., Hutchinson S., Vidyasagar M. Robot Modeling and Control. Wiley, 2020. 496 p.

13. Corke P. Robotics, Vision and Control: Fundamental Algorithms in MATLAB. 2nd ed. Springer, 2017. 693 p.

2. Dvorzhak, V. M. (2023). Kompiuterna symuliatsiia manipuliatora [Computer simulation of a manipulator]. *Integrated quality assurance of technological processes and systems: materials of the XIII International scientific and practical conference* (pp. 302-303). Chernihiv: NU "Chernihivska politekhnika" [in Ukrainian].

3. Rubanka, M. M., Misiats, V. P. (2015). Vidkhody lehkoi promyslovosti, sposoby pererobky ta oblasti podalshoho vykorystannia [Waste of light industry, types of recycling and the follow-use]. *Visnyk Kyivskoho natsionalnoho universytetu tekhnolohii ta dyzainu. Seriia Tekhnichni nauky*, 4 (88), 34-39 [in Ukrainian].

4. Bilashov, K. Yu., Kovalov, Yu. A., Rubanka, M. M. (2025). Analiz vykorystannia robototekhnichnykh prystroiv dlia avtomatyzatsii roboty z nastylochnymy kompleksamy na shveinykh vyrobnytstvakh [Analysis of manipulators usage for automation of work with laying complexes in sewing production]. *Visnyk Khmelnytskoho natsionalnoho universytetu. Seriia tekhnichni nauky*, 2 (6 (359), 129-134 [in Ukrainian].

5. Dvorzhak, V. M., Orlovskyi, B. V., & Popov, V. M. (2021). Kinematyka 3D manipuliatora z ruchnym keruvanniam [Kinematics of a 3D manipulator with manual control]. *Mechatronic systems: innovations and engineering: abstracts of reports of the V-th International scientific and practical conference* (pp. 45-46). Kyiv: KNUTD [in Ukrainian].

6. Orlovskyi, B. V., Dvorzhak, V. M., & Popov, V. M. (2021). Syntez mekhatronnoi systemy keruvannia manipuliatorom z ruchnym keruvanniam [Synthesis of a mechatronic control system for a manipulator with manual control]. *Mechatronic systems: innovations and engineering: abstracts of reports of the V-th International scientific and practical conference* (pp. 49-50). Kyiv: KNUTD [in Ukrainian].

7. Orlovskyi, B. V., & Dvorzhak, V. M. (2014). *Kompiuterne modeliuvannia ta syntez typovoho mekhanizmu tekhnolohichnykh mashyn* [Computer modeling and synthesis of a typical mechanism of technological machines]. Visnyk KNUTD [Bulletin of KNUTD], (5), 103-108[in Ukrainian].

8. Orlovskyi, B. V. (2018). *Mekhatronika v haluzevomu mashynobuduvanni* [Mechatronics in branch mechanical engineering]. Kyiv: KNUTD. 416 p. [in Ukrainian].

9. Dvorzhak, V. M. (2016). Skhemotekhnichne modeliuvannia kinematychnykh skhem prostorovykh chotyrylankovykh kryvoshypno-koromyslovykh mekhanizmiv tekhnolohichnykh mashyn [Scheme-technical modeling of kinematic schemes of spatial four-link crank-rocker mechanisms of technological machines]. *Visnyk KNUTD. Tekhnichni nauky*, (2), 18-26 [in Ukrainian].

10. Dvorzhak, V. M. (2018). Scheme-technical modeling of cinematic schemes of manufacturers of industrial works. *Advanced Problems of Engineering Mechanics: Proc. of the 5th Int. Sci.-Prac. Conf.* (pp. 77-79). Odesa: OSACE [in Ukrainian].

11. Craig, J. J. (2017). *Introduction to Robotics: Mechanics and Control* (4th ed.). Pearson [in English].

12. Spong, M. W., Hutchinson, S., & Vidyasagar, M. (2020). *Robot Modeling and Control*. Wiley [in English].

13. Corke, P. (2017). *Robotics, Vision and Control: Fundamental Algorithms in MATLAB* (2nd ed.). Springer [in English].