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DEVELOPMENT AND STUDY OF THE OPERATION OF THE MODULE FOR DETERMINING THE ORIENTATION OF THE MANIPULATOR JOINT

In the field of mechatronic systems, manipulators are often used for automated assembly of products, welding, painting parts and more. An important task is to optimize the travel time along a given trajectory of the manipulator. To solve this problem, it is necessary not only to accurately estimate the speed of the manipulator nodes, but also to provide a linear characteristic of the assessment of the position of the mechanism in a wide range of speeds. The matter of the article are methods for determining the orientation of the joint of the manipulator. The **goal** of the work is to develop a module for determining the orientation of the joint of the manipulator and study its operation in order to determine the suitability **subject** of the structure for practical use. The following **tasks** are solved in the article: to investigate the principles of determining the orientation of the joints of industrial robots; choose the design of the orientation determination module; develop an algorithm for determining the position of the joint at any time; perform experimental studies of the position determination module in order to confirm the suitability of the structure for practical use. The following **methods** used are: experimental research was conducted on a real object - a model of the manipulator joint, created using methods and tools of 3D prototyping; to determine the position of the joint of the manipulator used methods of processing signals received from sensors; processing of experimental results and calculation of values of errors of positioning of a joint of the manipulator is based on methods of the statistical analysis of random sizes. The following **results** were obtained: the principles of determining the orientation of the joints of industrial robots were studied; the design is developed and the module of definition of orientation of a joint of the manipulator is created; developed an algorithm for determining the position of the joint at any time; the suitability of the design for practical use has been experimentally confirmed. **Conclusions:** in this paper, two variants of the sensor design are proposed to determine the absolute angle of rotation of the manipulator joint: resistive and magnetic. The proposed design of the resistive sensor was non-technological and much larger than the design of the magnetic sensor. The data obtained in the process of conducting experimental studies of the proposed method of measuring the angle of rotation of the mechanical gearbox of the manipulator joint indicate a fairly accurate determination of the angle using a magnetic sensor. The calculated measurement error was less than 1.4 degrees. The results of the experiment also showed that in addition to the radial direction of movement of the gearbox of the manipulator joint there is a significant displacement along the working plane, and in some cases, such displacements are chaotic. This is due to some defects and imperfections of the surface of the manufactured parts of the joint model used in research.

Keywords: manipulator; positioning; orientation; angular rotation; designing; industrial robot.

Introduction

Manipulator robots are devices most commonly used in mechatronic systems for automated product assembly, welding, painting parts, etc. The main task of a manipulator is to place the working elements at a given point in space. Most often, this task is solved by using position sensors and adjustable drives. A separate requirement for the operation of technological units is to optimize the movement time by a given trajectory. To solve this problem, it is necessary not only to accurately estimate the speed of movement of manipulator units, but also to provide a given characteristic of estimating the position of the mechanism in a wide range of velocity changes. Thus, the study of methods for determining the position of structural elements at any point of time is quite an urgent task.

Analysis of recent studies and publications

In [1], the authors proposed a methodology for obtaining a sequential chain with less than five connections to realize an approximate end-effector trajectory as close to the target trajectory as possible without selecting any specific positions. This approach is useful when it is difficult to select certain important positions along the target trajectory or when a smooth motion trajectory is required to move along the target trajectory.

Considering the dynamics of the system at [2], the authors proposed a flexible computational approach to optimize the design of robots with open and closed-loop trajectory of motion, using the implicit function theorem. The research of the problem considered in this paper focuses mainly on kinematic synthesis for the implementation of a sequential manipulator circuit, which can help to achieve given configurations of the final effect.

In [3], a method is proposed to optimize the trajectories of robotic arms having manipulators with six degrees of freedom (DOF) and spherical wrists. The trajectories are optimized by maximizing manipulator performance (manipulability). For this purpose, the authors have defined kinematic models of the robot arms, which can be integrated into the algorithm based on the Kalman filter

An adaptive controller based on a nonlinear sliding mode scheme is presented in [4] to control the position of the robot manipulator. The impact of system nonlinearity, uncertainty and unpredictable perturbations is compensated by model-free estimation. The control assignment is implemented using a two-layer control signal. An adaptation capability is built in at the level of the control architecture.

The determination of the position parameters of the joint parts [5] is based on independent measurements using dual encoders mounted on the drive motor and the drive joint. In addition, in [6] it is proposed to calibrate manipulator positions by QR code.

Allocating the previously unsolved parts of the general problem. The aim of the work

To solve the problem of optimization of movement time along a given manipulator trajectory, it is necessary not only to accurately estimate the speed of manipulator nodes, but also to provide a linear characteristic of estimating the position of the mechanism in a wide range of speed changes. It is also important to determine the absolute angular position of manipulator design elements, especially in the interaction of industrial automation objects using the Internet of Things technology [7-11]. Thus, the study of methods for determining the position of structural elements of the manipulator at any point in time is an urgent task. The **subject** of this research are methods for determining the orientation of the manipulator joint. The **aim** of the work is to develop a module for determining the orientation of the manipulator joint and study its operation in order to determine the suitability of the design for practical use.

In order to achieve the set objectives, it is necessary to solve the following tasks:

- to investigate the principles of joint orientation determination of industrial robots;
- to select the design of the orientation determination module;
- to develop an algorithm for determining the joint position at any time;
- to carry out an experimental study of the operation of the position determination module in order to confirm the suitability of the design for practical use.

Materials and methods

Manipulator motion control by individual movement steps can be continuous (contour) or discrete (positional). With discrete control, motion control is performed by specifying a finite sequence of points and then moving through them in steps from point to point. The simplest type of discrete control is cyclic control, in which the number of positioning points for each degree of mobility is minimal and usually limited to two - the initial and final coordinates. The most important parameters of manipulators are speed and accuracy of movements. These parameters are interrelated and characterize the dynamic characteristics of robots. The speed of a manipulator is determined by the speed of its movement through the individual degrees of mobility. Most modern robots have an average speed and only 20% have a high speed. The speed of modern robots is still insufficient, and it is necessary to increase it at least twice. The main difficulties here are related to the well-known contradiction between speed and accuracy. The accuracy of a manipulator is characterized by the resulting positioning error (in discrete motion), or by the execution of a given trajectory (in continuous motion). More often, the accuracy of robots is characterized by the absolute error. The accuracy of robots of general application is divided into three groups:

- small – with a linear error of 1 mm or more;
- medium – with linear error from 0,1 to 1 mm;
- high – with a linear error of less than 0.1 mm.

In this case, the speed of linear movement of the working elements of manipulators does not exceed 1 m/s, although there are some jobs with speeds up to 2 m/s and more. Angular speeds of movements of working elements are mainly in the range of 15...360 deg. /sec.

To determine the position of the manipulator joint, we used methods for processing the signals received from the sensors. Experimental results processing and calculation of positioning error values of the manipulator joint are based on the methods of statistical analysis of random variables. Experimental studies were performed on a real object - a model of a robotic manipulator joint, created using the methods and means of 3D prototyping.

Analysis and development of the design of the manipulator joint model

A special model - a robotic manipulator joint - was made for the research. Fig. 1 shows its appearance.

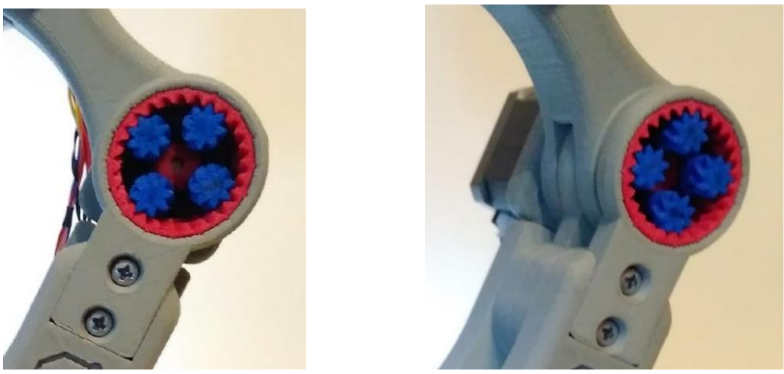
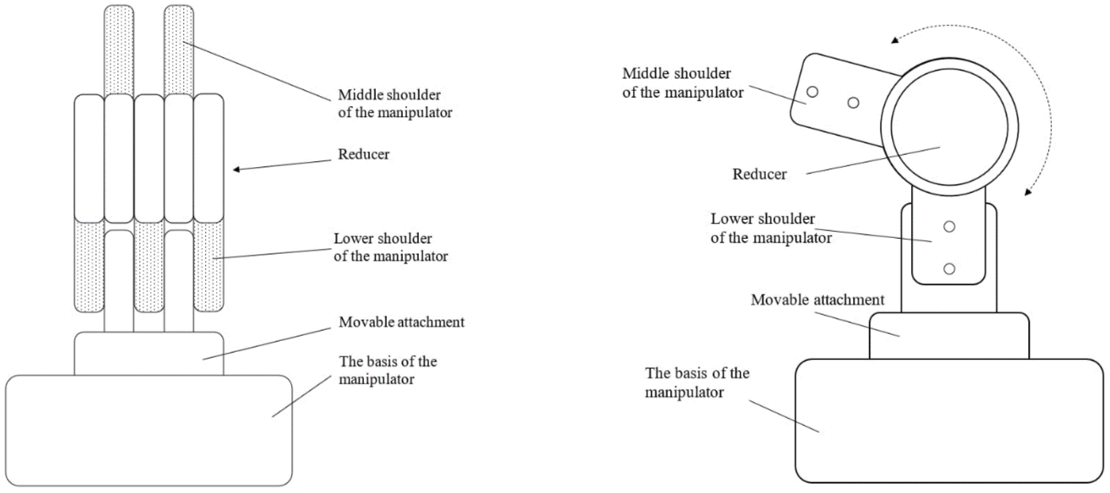


Fig. 1. Appearance of the robot-manipulator joint

The design of the joint should include the principle of fixing a sensor to determine the position of the mechanism when the device is in operation. Figure 2 shows a sketch of the moving part of the manipulator design.

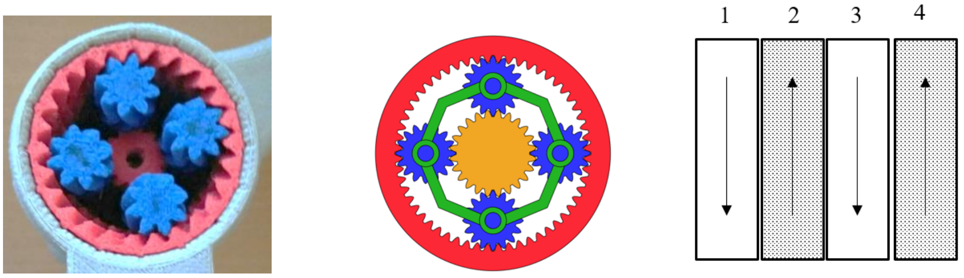
The base of the manipulator model is rigidly fixed on the working surface. A first stepper engine is built into the base. A movable attachment is mounted on the motor shaft. The lower arm structure of the manipulator is mounted on it. Activation of the motor leads to the action of the planetary gear mechanism. Due to it the upper part of the structure is set in motion relative to the lower part, as shown in fig. 2, b (dashed arrow).



a) *b)*

Fig. 2. Drawing of the moving part of the manipulator structure: a - front view; b - side view

There are four sections in the reducer design. Two rotate clockwise and two rotate counterclockwise. Fig. 3 shows how the reducer works. As you can see from this figure, the two sections of the reducer always rotate synchronously and in the same direction. For the application of the reducer, the design of the arm of the manipulator was developed. The reducer is inserted into the arm hole and secured with pins and glue. Four of these parts are needed for one arm. To reduce the number of part sizes, one standard solution was used for the entire arm design.

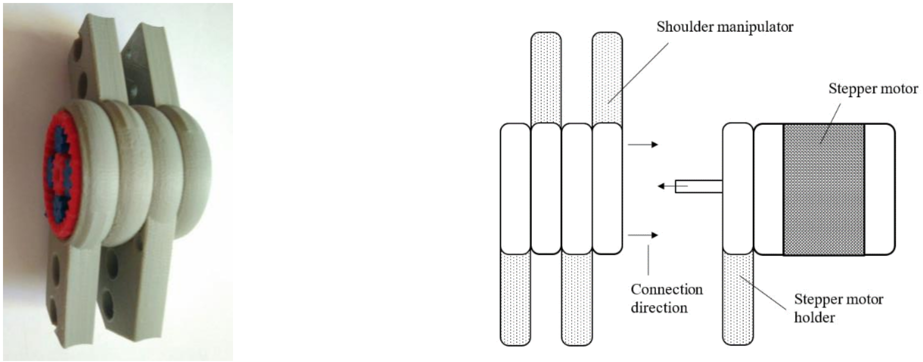


a) *b)* *c)*

Fig. 3. Principle of operation of the reducer: *a* – reducer inserted into the opening of the section arm; *b* – drawing of the reducer; *c* – direction of rotation of the reducer sections

The main parts of the planetary gears are: the central gear wheel, which is stationary, the satellites - gears with movable rotation axes, and the driver - the link in which the satellites' axes are mounted. As a rule, planetary mechanisms are made coaxial.

Fig. 4, a shows a view of the assembled joint of the manipulator with a mounted gearbox, and fig. 4, b - the principle of fixing the stepper motor to the reducer. The motor axle is tightly inserted into the drive wheel due to the properties of ABS material to transfer the motion without skipping.



a) *b)*

Fig. 4. Manipulator joint assembled with reducer (a); principle of stepper motor attachment to the reducer (b)

The result of the joint test was positive - the reducer transmitted motion to the other arm of the manipulator. The study of the design of the manipulator joint model and the analysis of the principles of operation of the driving reducer of its joint showed that the planetary reducer reduces the total number of motor revolutions by 40 times. Using traditional encoders to determine the angular position without using a special mount design is impossible. For further research, it was decided to use two types of encoders: absolute resistive multiturn and absolute magnetic, designed for only one revolution. As a result of further research, the more accurate and technologically advanced version will be chosen.

Development of a test bench design

The structural scheme of the developed test bench is shown in fig. 5.

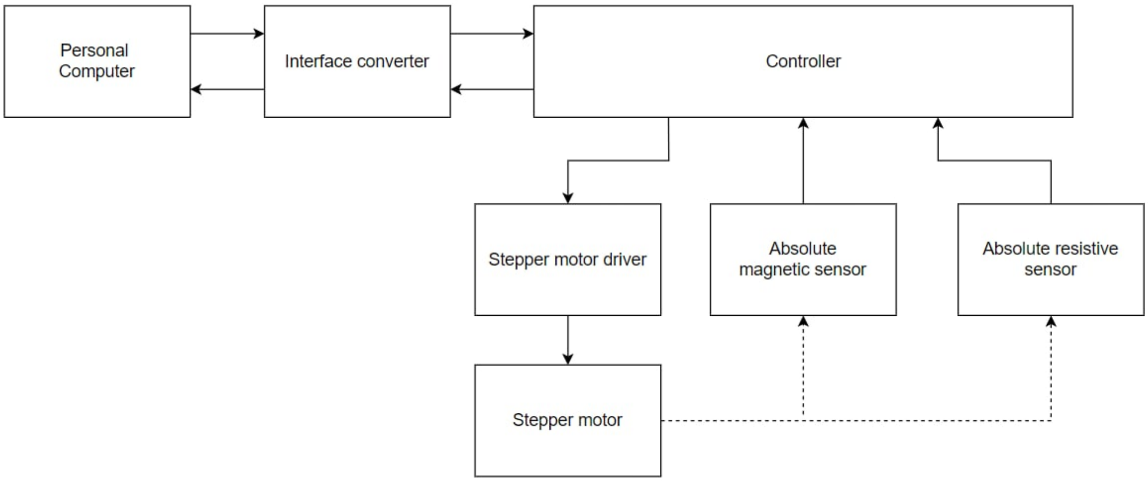


Fig. 5. The structural scheme of the model

The bench consists of the following elements:

- personal computer (PC) with control and data acquisition program;
- interface converter;
- controller;
- DC motor driver;
- absolute magnetic sensor;
- absolute resistive sensor;
- stepper motor;
- model of the manipulator mechanism.

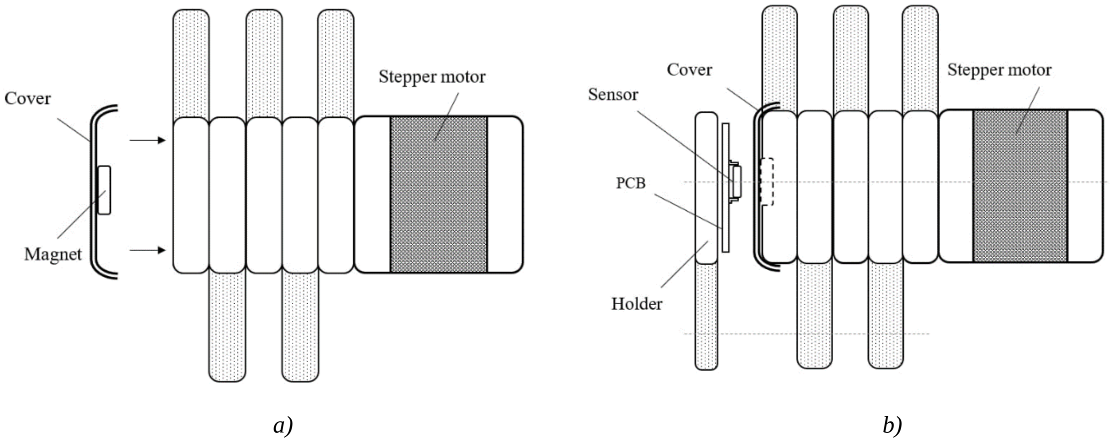
We will use two methods to determine the joint orientation:

- magnetic absolute;
- resistive absolute.

Magnetic sensor design

To determine the absolute angle of rotation of the joint we will use a magnetic encoder type AS5600. This encoder needs an additional element - a magnet, which will be attached to the structural elements of the joint on the same axis as the reducer.

Due to the design of the planetary reducer, the permanent magnet cannot be attached directly to the reducer axis. First, this is due to the fact that the central element of the reducer is the central gear wheel, which makes significantly more revolutions than the manipulator joint. As a result, it was decided to make an additional attachment to the joint, which would be rigidly connected to it and fix a permanent magnet already to it. A drawing of the magnet mount design is shown in fig. 6, a.



a) *b)*

Fig. 6. Principle of attachment of the magnet to the manipulator joint (a); drawing of the reading module attachment variant (b)

The cover has to adapt to the parameters of the joint reducer holder due to its design. The design of the reducer used in the model has a peculiarity - the free space between the satellites within the fourth section of the reducer due to the shortened length of the central pinion (fig. 3, a). Thus, there is an opportunity to place the magnet in the empty space of the reducer, which makes the cover design more flat.

In order to determine the angular position of the joint, another design element must be added - the position reading module and its holder. The reading module is based on the AS5600 chip and is a printed circuit board with the required attachments. The printed circuit board is attached to the bracket, which in turn is attached to the base of the layout. Electrical wiring connects the position readout module to the controller to convert the analog signal into digital combinations, process and transmit to a personal computer for analysis. Fig. 6, b shows a drawing of a mounting option for the readout module.

The AS5600 sensor must be positioned precisely on the axis of the reducer and the permanent magnet, respectively. The distance between the sensor and the permanent magnet should be minimal and not exceed 4 mm. In this design, the sensor is rigidly attached to the moving part of the joint on the base of the model. The maximum rotation angle of the joint is 200 degrees. This limitation is due to the design of the prototype.

Fig. 7 shows a drawing of the prototype. In this figure, you can see that in addition to the manipulator joint model itself there is also a control device, the role of which is performed by a protractor. It is used to visually determine the deflection angle of the manipulator arm.

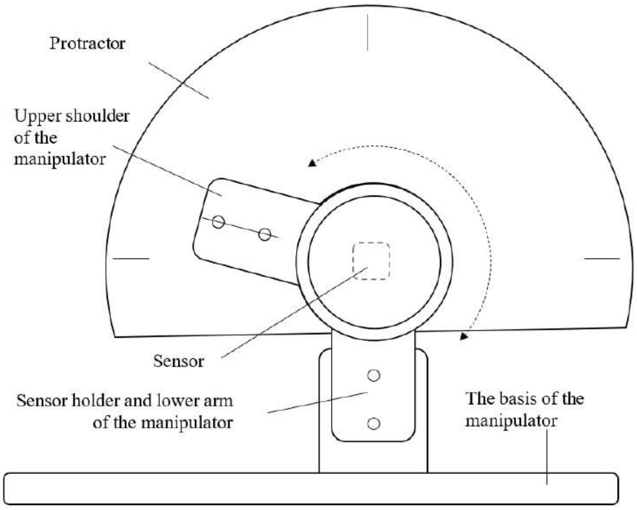
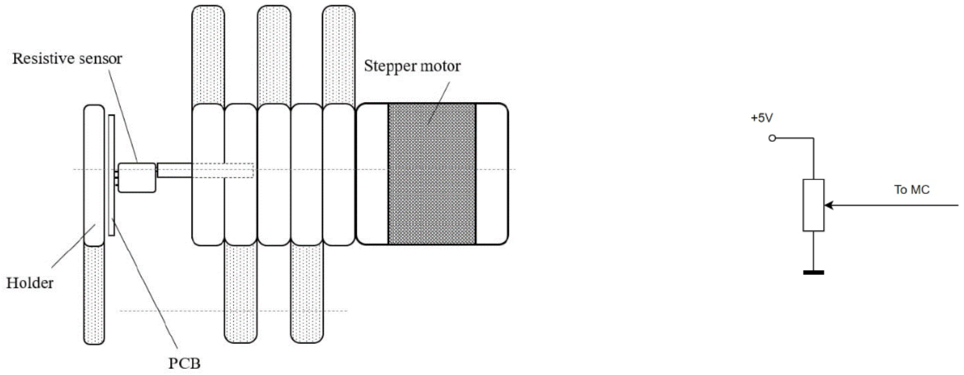


Fig. 7. Drawing of the model

Development of the resistive sensor design

The 3296Y-10K is used as a resistive sensor. This type of resistor is characterized by a large number of revolutions (28 revolutions). Considering the reducer ratio of 1:40, this number of revolutions is enough to shift the arm by 200 degrees. The screw for setting the resistor is quite small. This is a disadvantage in this case, as it adds complexity to the design of the mount and adapter to the reducer.

As mentioned above, the resistor has a large number of revolutions, so it can be connected directly to the central gearwheel with an adapter and determine the angle of rotation based on the current resistor resistance value obtained. It takes 23 revolutions of the central reducer wheel to rotate the arm by 200 degrees. Therefore, this resistor is suitable for the task of determining the absolute angle. Fig. 8, a shows a design of the absolute resistive sensor.



a) b)

Fig. 8. Drawing of the absolute resistive sensor design (a); connection diagram of the resistive sensor to the controller (b)

The resistor represents the amount of free space inside the reducer, so the sensor itself must be located at a much greater distance from the reducer than the magnetic sensor. This distance depends on the size of the resistor and is more than 10 mm. This is another disadvantage of this type of sensor design.

The output of the sensor, as in the case of the magnetic sensor, is analog. The sensor is connected to the controller input according to the circuit shown in fig. 8, b. This circuit is a kind of voltage divider and is often used to determine the input voltage in analog circuits for measuring electrical quantities. Thanks to the multi-turn resistor, the accuracy of the joint position measurement is ±4%.

Experimental studies

At the beginning of the experiment, the operator visually checks the position of the arm of the manipulator and moves it to the zero position. The position is determined by means of a protractor. Then the desired angle of rotation is set. The stepper motor control program is started and waits until it finishes its work. Then the controller receives the signal from the AS5600 absolute encoder and sends it to the PC for analysis. At the same time, the operator records the position of the arm using a protractor and enters the values into the corresponding cell in the measurement table. All data from the experiment is recorded for theoretical investigations and positioning error determinations. The current angle of rotation is set from the personal computer and the control signals to the DC motor are applied with the help of the control controller. Fig. 9 shows the algorithm of the model operation.

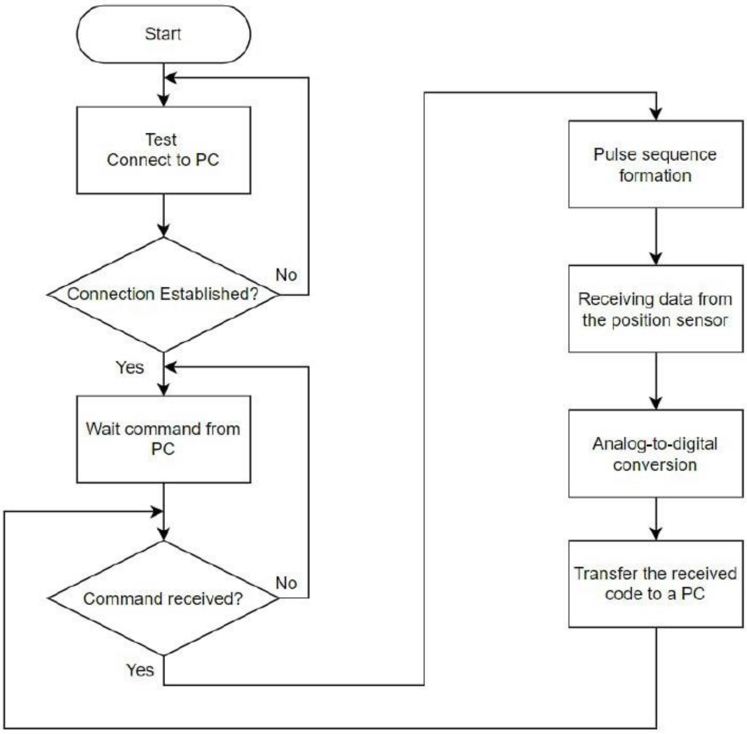


Fig. 9. Controller program algorithm

At the beginning of the work the communication with the personal computer via the serial interface is checked. If the connection is established, you can continue to work. After receiving a command from the PC, the controller forms a sequence of pulses to shift the stepper motor shaft to the desired angle, taking into account the transmission ratio of the reducer. In our case, this number is 1:42. The angle of displacement of the motor shaft at full step is 1.8 degrees. Given the gear ratio, the mechanism can theoretically provide an accuracy of 0.045 degrees.

When the movement is complete, the controller stops the reducer and reads the position sensor data. The data obtained are converted from an analog signal into a digital signal and transmitted to the PC. After the rotation angle measurement is completed, the control cycle is repeated until the controller power supply is turned off. At this stage, the positioning accuracy is determined visually by comparing the values set by the operator and the actual values obtained from the protractor. Figure 10 shows the appearance of the model.

The prototype includes a control module based on Arduino Mega 2560, a reducer model and a measuring device. The protractor is used to visually control the accuracy of the movement. Control lines for measuring the angle of rotation are plotted in 5-degree increments. The center part must be aligned with the center axis of the reducer. To determine the angle more accurately, a pointer arrow is attached to the moving part of the reducer.

An absolute magnetic encoder is used to electrically control the angle of rotation. The encoder board is attached to the reducer with a bracket. The reducer is completely made by 3D printing.

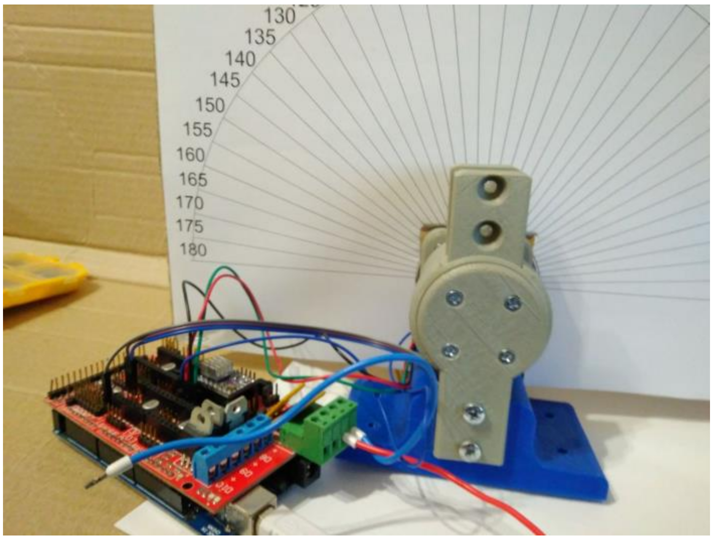


Fig. 10. Appearance of the model

The application written for the Arduino controller was used for the experimental research. The operator has the ability to enter control commands to perform a turn by a certain number of steps or degrees. The command "S" big turns on the counterclockwise rotation mode for 230 steps. The "s" small command enables the clockwise rotation mode for 230 steps. The stepper motor moves 230 steps in one measurement cycle, which is 5 degrees when transferred to the angle of rotation.

To control the driver it is necessary to output one clock pulse for each step. The DIR pin must be set high or low to determine the direction of rotation. After each step, the voltage at the analog output of the absolute position sensor is measured and transmitted through a serial interface to the computer [12, 16]. Table 1 shows the experimental data. The experiment was performed for both clockwise and counterclockwise rotation. This was done to determine the positioning accuracy of the reducer in different directions of operation.

Table 1. *The experiment results*

Measurement number	**Expected value of the rotation angle**	**The value of the position sensor when turning counterclockwise**	**Measured angle of rotation with a protractor**	**Position sensor value for clockwise rotation**	**Measured angle of rotation with a protractor**
1	90	124	90	124	90
2	95	133	94	133	96
3	100	148	101	149	103
4	105	163	105	163	108
5	110	180	110	180	114
6	115	196	115	195	118
7	120	196	116	197	120
8	125	217	123	217	125
9	130	229	127	229	129
10	135	251	133	251	135
11	140	260	137	259	140
12	145	278	144	278	146
13	150	289	149	289	150
14	155	300	154	300	155
15	160	320	159	320	159

Fig. 11 shows a graph of the change in the measured parameter. It is possible to observe the anomalous behavior of the graph at the moment of change of rotation angle from 115 to 120 degrees. The measurements showed the absence of radial movement of the reducer. The same behavior was observed during the reverse rotation of the reducer. This was due to a mechanical flaw in the design made by 3D printing.

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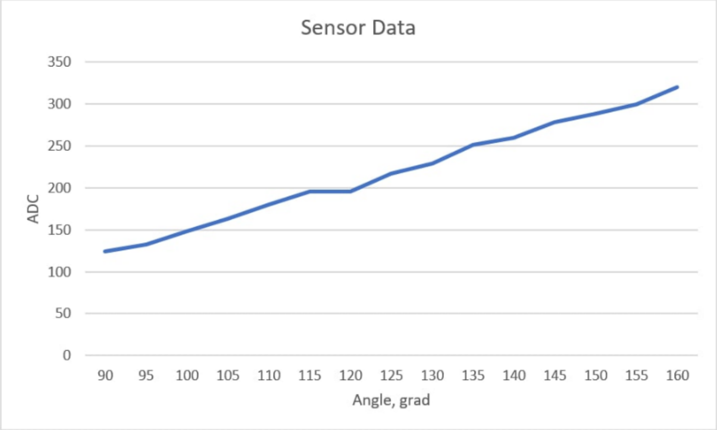


Fig. 11. The graph of change of the measured parameter

Analysis of the results of the experiment. Determination of the magnitude of the error

The positioning error arises due to the error of processing by the drives of the system of programmed values of coordinates corresponding to the given position of the sensor.

During the experiment, the actual values of the sensor coordinates differ from the programmed values by the value Δq_i of where i is a coordinate number. If a Cartesian rectangular coordinate system is linked to the sensor, then the given (programmed) position $X_g Y_g Z_g$ will differ from its actual position $X_a Y_a Z_a$ by the value:

$$\begin{aligned}\Delta r &= \sqrt{\left(X_g - X_a\right)^2 + \left(Y_g - Y_a\right)^2 + \left(Z_g - Z_a\right)} = \\ &= \sqrt{\Delta q_1^2 + \Delta q_2^2 + \Delta q_3^2}\end{aligned} \quad . \qquad (1)$$

The value Δr is called the linear positioning error, and the angle of rotation ϕ by which the system $X_g Y_g Z_g$ must be rotated to make its axes parallel to the corresponding axes of the system $X_a Y_a Z_a$ is called the angular positioning error. Such a rotation is always possible based on the well-known Euler-Dalembert theorem. The radius vector $\overline{r}$ of a random sensor point can be written in the form:

$$\overline{r} = r\left(q_i\right), \qquad (2)$$

where $i = 1..n$, n is a number of moving degrees of freedom.

By integrating expression (2) over the coordinates q_i, we obtain the following expression:

$$dr = \sum_{i=1}^{n} \frac{\partial r}{\partial q_i} dq_i \, . \qquad (3)$$

If we replace the differentials in expression (3) with finite increments, we can determine the linear positioning error of the sensor Δr:

$$\Delta r = \sum_{j=1}^{p} \Delta\phi_j \overline{e}_j + \sum_{i=1}^{s} \Delta S_i \overline{e}_i \, , \qquad (4)$$

where $\Delta\phi$ and ΔS are errors in the rotary and translational pairs of the positioning mechanism; p – number of rotating pairs; s – number of translational pairs; $\overline{e}_j$ and $\overline{e}_i$ – orts of rotating and translating pairs in the positioning mechanism.

The angular error of the solid position can be defined by an error matrix, which is a matrix of transition from system $X_{\partial} Y_{\partial} Z_{\partial}$ to system $X_{з} Y_{з} Z_{з}$ by rotation by three Euler angles, which are considered small. Since such a matrix contains the value of three Euler angles, it does not allow to express the angular error by a single value. As a result, it is necessary to find a vector formula to cover the yuto error of the sensor position.

Suppose the linear and yuto errors of the sensor are small. Then, based on the known rule of addition of small rotations of a solid body, we can write down the expression:

$$\Delta\phi = \sum_{i=1}^{s} \Delta q_i = \sum_{j=1}^{p} \Delta q_j \overline{e}_j \, . \qquad (5)$$

The linear positioning error of the sensor is most conveniently determined by formula (4), which does not contain the differentiation operation. In this case, the linear error of the position of the mass sensor center Δr_c is defined as

$$\Delta r_c = \Delta\phi_1\left(\overline{e}_1 \times \overline{r}_{1c}\right) + \Delta S_1 \overline{e}_1 + \Delta\phi_2\left(\overline{e}_2 \times \overline{r}_{2c}\right) + \Delta S_2 \overline{e}_2 + \ldots \, . \, (6)$$

Assuming that the mass center is on the axis of rotation of the sensor on the manipulator, the linear error module is defined as

$$\Delta r_c = \sqrt{\Delta r_{cx}^2 + \Delta r_{cy}^2 + \Delta r_{cz}^2} \, , \qquad (7)$$

where Δr_{cx}, Δr_{cy}, Δr_{cz} – projections of the linear error vector Δr_c on the Cartesian coordinate system axes.

With a one-sided approach to the set points, the positioning error is determined by the value calculated by the formula:

$$\Delta_{pos.val.} = \overline{Z} - Z_{pr.} \pm 3\sigma_{val.} \qquad (8)$$

where $\bar{Z}$ is an arithmetic mean value of the actual state of the moving part of the reducer (mathematical expectation), mm; $Z_{pr.}$ – the amount of the programmed movement of the moving part of the reducer; $\sigma_{val.}$ – value of the scatter of values from the arithmetic mean (standard deviation), characterizing the effect of random processes, μm.

$$\bar{Z} = \frac{\sum_{i=1}^{n} Z_i}{n}, \tag{9}$$

where n is the number of measurements of the reducer position ($n = 5$).

The value of the expected estimate of the positioning error variation is calculated by the formula:

$$S = \sqrt{\frac{\sum_{i=1}^{n}\left(Z_i - \bar{Z}\right)^2}{n-1}}\ . \tag{10}$$

The value of the greatest probable random dispersion of deviations from the arithmetic mean is taken to be

$$\pm 3\sigma = \pm 3S\ . \tag{11}$$

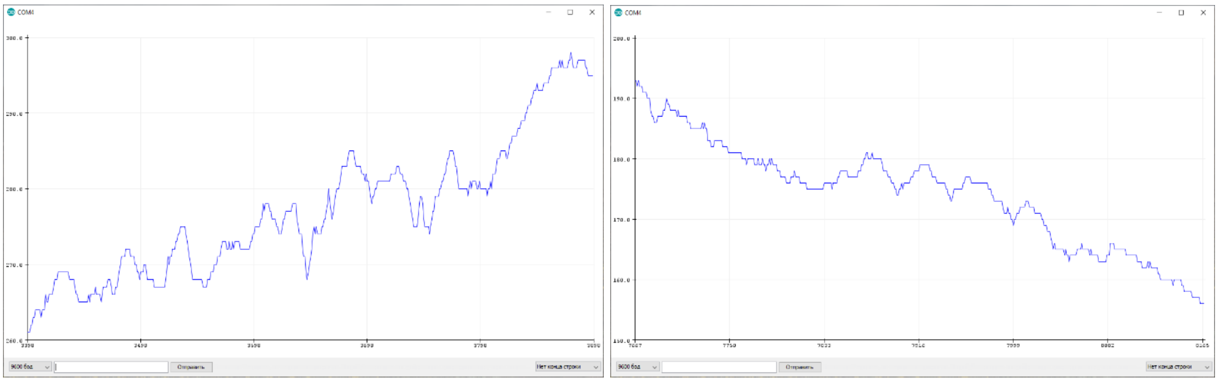
According to the normal law, the dispersion distribution within $\pm 3\sigma$ covers more than 99% of all possible deviations. The results of the estimation of the positioning error are recorded in table 2.

Table 2. *Results of positioning error estimation*

Experiment number	**1**	**2**	**3**	**4**	**5**
Expected angle of rotation	90	110	130	150	160
1 measurement	90	110	127	149	159
2 measurement	90	114	129	150	160
3 measurement	89	114	128	149	160
4 measurement	90	115	124	150	159
5 measurement	90	114	130	149	159
$\bar{Z}$	89,8	113,4	127,6	149,4	159,4
S	0,447213	0,447213	0,447213	0,447213	0,447213
$\pm 3\sigma$	1,341640	1,341640	1,341640	1,341640	1,341640

The data obtained indicate sufficient accuracy of angle determination using a magnetic sensor. The angle measurement error is less than 1.4 degrees. With several consecutive measurements, the displacement of the moving part of the reducer always occurs in the predicted position. However, the results of the experiment also showed poor performance of the reducer itself. In addition to the radial direction of motion, there is a significant displacement along the working plane. The parts undergo considerable displacement, and in some cases, these displacements are chaotic in nature.

Fig. 12 shows the results of continuous measurements for a full rotation angle of the reducer counterclockwise and clockwise. From these figures, you can see how the value of the angle measurement changes depending on the direction of rotation.



a) *б)*

Fig. 12. Results of continuous measurements for a full rotation angle of the reducer: a - counterclockwise rotation; b - clockwise rotation

Conclusions and prospects for further development

In this paper, we proposed two sensor designs for determining the absolute angle of joint rotation: a resistive sensor and a magnetic sensor. The proposed design of the resistive sensor turned out to be non-technological and much larger in size than the design of the magnetic sensor, so it was not used in the research. A model was made using 3D prototyping tools. In this model design, the sensor is rigidly fixed relative to the moving part of the joint on the base of the model. The maximum rotation angle of the joint is 200 degrees. A control device - protractor - is used to visually determine the angle of deviation of the arm of the manipulator.

Experimental studies of the proposed method of measuring the angle of rotation of the mechanical reducer of the manipulator joint were conducted. The data obtained show that the angle is accurately determined using a magnetic sensor. The positioning error is less than 1.4 degrees, which is acceptable for reducers of this type, fully manufactured using 3D printing.

However, the results of the experiment also showed the disadvantages of the reducer design related to the manufacturing technology using 3D printing. In addition to the radial direction of motion, there is a significant displacement along the working plane, and in some cases, such displacements are of a chaotic nature. Thus, in the future it is necessary to study the influence of technological printing parameters on the quality of positioning of the manipulator joints.

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РОЗРОБКА МОДУЛЯ ВИЗНАЧЕННЯ ОРІЄНТАЦІЇ СУГЛОБА МАНІПУЛЯТОРА І ДОСЛІДЖЕННЯ ЙОГО РОБОТИ

В галузі мехатронних систем часто використовуються роботи-маніпулятори для автоматизованого збирання виробів, зварювання, фарбування деталей тощо. Важливим завданням при цьому є оптимізація часу руху по заданій траєкторії маніпулятора. Для вирішення такого завдання, необхідно не тільки точно оцінити швидкість руху вузлів маніпулятору, але і забезпечити лінійну характеристику оцінки позиції механізму в широкому діапазоні зміни швидкостей. **Предметом** дослідження в статті є методи визначення орієнтації суглобу маніпулятора. **Мета** роботи – розробка модуля визначення орієнтації суглобу маніпулятору і дослідження його роботи з метою визначення придатності конструкції для практичного використання. В статті вирішуються наступні **завдання:** дослідити принципи визначення орієнтації суглобів промислових роботів; обрати конструкцію модуля визначення орієнтації; розробити алгоритм визначення позиції суглобу в будь-який час; виконати експериментальні дослідження роботи модуля визначення позиції з метою підтвердження придатності конструкції для практичного використання. Використовуються такі **методи:** експериментальні дослідження проводилися на реальному об’єкті – моделі суглобу робота-маніпулятора, створеного за допомогою методів і засобів 3D-прототипування; для визначення положення суглобу маніпулятора використовувалися методи обробки сигналів, отриманих від датчиків; обробка результатів експериментів і розрахунок величин похибок позиціонування суглобу маніпулятора базується на методах статистичного аналізу випадкових величин. Отримано наступні **результати:** досліджено принципи визначення орієнтації суглобів промислових роботів; розроблено конструкцію і створено модуль визначення орієнтації суглобу маніпулятора; розроблено алгоритм визначення позиції суглобу в довільний час; експериментально підтверджено придатність конструкції для практичного використання. **Висновки:** в даній роботі запропоновано два варіанта конструкції датчика для визначення абсолютного куту оберту суглоба маніпулятора: резистивний і магнітний. Запропонована конструкція резистивного датчика виявилася нетехнологічною і набагато більша за розмірами ніж конструкція магнітного датчика. Отримані в процесі проведення експериментальних досліджень запропонованого методу вимірювання куту оберту механічного редуктора суглобу маніпулятора дані свідчать про досить точне визначення кута за допомогою магнітного датчика. Розрахована похибка вимірювань становила менше 1,4 градуси. Також результати експерименту показали, що крім радіального напрямку руху редуктора суглобу маніпулятора відбувається істотне зміщення вздовж робочої площини, причому в деяких випадках такі зміщення мають хаотичний характер. Це обумовлюється деякими дефектами і недосконалістю поверхні виготовлених деталей моделі суглобу, що використовувалися у дослідженнях.

Ключові слова: маніпулятор; позиціонування; орієнтація; кутове обертання; проектування; промисловий робот.

РАЗРАБОТКА И ИССЛЕДОВАНИЕ РАБОТЫ МОДУЛЯ ОПРЕДЕЛЕНИЯ ОРИЕНТАЦИИ СУСТАВА МАНИПУЛЯТОРА

В области мехатронных систем часто используются работы-манипуляторы для автоматизированной сборки изделий, сварки, окрашивания деталей и т.п. Важной задачей при этом является оптимизация времени движения по заданной траектории манипулятора. Для решения такой задачи необходимо не только точно оценить скорость движения узлов манипулятора, но и обеспечить линейную характеристику оценки позиции механизма в широком диапазоне изменения скоростей. **Предметом** исследования в статье являются методы определения ориентации сустава манипулятора. **Цель** работы – разработка модуля для определения ориентации сустава манипулятора и исследования его работы с целью определения пригодности конструкции для практического использования. В статье решаются следующие **задачи:** исследовать принципы определения ориентации суставов промышленных роботов; выбрать конструкцию модуля определения ориентации; разработать алгоритм определения позиции сустава в любое время; выполнить экспериментальные исследования работы модуля определения позиции с целью подтверждения пригодности конструкции для практического использования. Используются следующие **методы:** экспериментальные исследования проводились на реальном объекте – модели сустава робота-манипулятора, созданного с помощью методов и средств 3D-прототипирования; для определения положения сустава манипулятора использовались методы обработки сигналов, полученных от датчиков; обработка результатов экспериментов и расчет погрешностей позиционирования сустава манипулятора основываются на методах статистического анализа случайных величин. Получены следующие **результаты:** исследованы принципы определения ориентации суставов промышленных роботов; разработана конструкция и создан модуль определения ориентации сустава манипулятора; разработан алгоритм определения позиции сустава в любое время; экспериментально подтверждена пригодность конструкции для практического использования. **Выводы:** в данной работе предложены два варианта конструкции датчика для определения абсолютного угла поворота сустава манипулятора: резистивный и магнитный. Предложенная конструкция резистивного датчика оказалась нетехнологичной и намного больше по размерам, чем конструкция магнитного датчика. Полученные в процессе проведения экспериментальных исследований предлагаемого метода измерения угла поворота механического редуктора сустава манипулятора данные свидетельствуют о точном определении угла с помощью магнитного датчика. Рассчитанная погрешность измерений составляла менее 1,4 градуса. Также результаты эксперимента показали, что помимо радиального направления движения редуктора сустава манипулятора происходит существенное смещение вдоль рабочей плоскости, причем в некоторых случаях такие смещения носят хаотический характер. Это обуславливается некоторыми дефектами и несовершенством поверхности изготовленных деталей модели сустава, которые использовались в исследованиях.

Ключевые слова: манипулятор; позиционирование; ориентация; угловое вращение; проектирование; промышленный робот.

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