Angular displacement measurement and control sensors of agricultural robot-manipulators

Almardon Mustafoqulov[1*], *Rustam* Baratov[1], Zafar *Radjapov*[2], *Sardor* Kadirov[2], and *Bogibek* Urinov[2]

[1]"Tashkent Institute of Irrigation and Agricultural Mechanization Engineers" National Research University, 39 K. Niyazov, Tashkent, 100000, Uzbekistan
[2]Urgench state university 14, Kh. Alimdjan str, Urgench city, 220100, Uzbekistan

Abstract. This article describes the types of agricultural robots, robotic manipulators, and the challenges that arise when measuring their rotation mechanisms. The reasons for their appearance, the physical and technical phenomena occurring in the process are explained. Measurement transducers with different modes of operation required for their measurement are analyzed and the main requirements for these transducers are presented. In addition, this paper presents sensors for controlling the rotating parts of an energy-saving, intelligent robot for picking tomatoes. One of the main goals of this research is to measure and control the change of rotating parts of energy-saving robotic manipulators used in agriculture to develop modern farming, save energy and harvest quality products. The novelty of this research is that the rotating part of the robotic manipulators is controlled depending on the type of product and its size.

1 Introduction

Today's modern market requires a seamless transition from manual to automated harvesting using innovative fruit and vegetable harvesting systems. Improving the efficiency of fruit and vegetable production, reducing the demand for manual labor ensures a high-yielding food product and its competitiveness. Despite the progress made in the field of agricultural robotics, 1 million tons of fruits and vegetables are picked by hand in open fields and greenhouses every year in our republic. Heavy and repetitive work in the fields and greenhouses during harvesting causes a sharp increase in skilled labor and, in turn, a sharp increase in costs. The robotic harvesting process needs to be simplified and the yield maximized to offset the additional automation costs. Otherwise, the plant branches will become densely packed with fruit, making it difficult for the autonomous robot to identify, separate and harvest the fruit at the same time. According to data, 1.9 million tons of sweet pepper are produced annually in European countries. According to estimates, it takes an average of 6 seconds for an automated robot to harvest each sweet pepper fruit [1-6].

* Corresponding author: mustafoali777@gmail.com

Table 1. Types of robotic manipulators.

Types	Tasks
Industrial robots	Industrial robots are robots used in industrial production environments. These are usually articulated arms specifically designed for applications such as welding, material handling, painting, and more. If we are only assessing demand, this category includes some automated guided vehicles and other robots.
Agricultural robots	Processing of agricultural crops, harvesting, determining the condition of crops, etc., are designed to perform such tasks. Currently, it is one of the most widespread industries.
Military robots	War robots are robots used in the military. These types of robots include bomb disposal robots, various transport robots, and reconnaissance drones. Often designed for military purposes, robots can be used in law enforcement, search and rescue, and other related fields.
Service robots	Service robots are robots that are not used by other types of robots. These can be various robots for data collection, robots created for technology demonstration, robots used for research, etc.

Above we have looked at the areas where robots can be used, and as with all robots, there are many challenges that need to be addressed in agricultural robots. We focus on the field of agricultural robots.

2 Materials and methods

The decrease in the efficiency of small-power electric motors used in agricultural robotic manipulators and the sharp increase in electricity consumption are associated with uncontrolled angular displacement of their rotation mechanisms (ADRM). Therefore, improving the technical means of its measurement and control is one of the important issues. In the measurement of ADRM of agricultural robotic manipulators, stepper motors are mainly used, and we analyze the problems caused by not controlling their angular displacement.

High income in a modern farm directly depends on the number of workers. Harvesting of ready-made crops also requires a large number of workers, but the use of robotic manipulators instead of these workers is useful for continuous work. Agricultural robots have reduced the US agricultural workforce by 2%. Josh Lessing has been working to overcome this problem since he founded the agricultural robotics project Root AI in 2018. Currently, this company has developed a robot named "Robot AI Virgo". harvest ripe tomatoes. One of the disadvantages of this robot is that the arm picking the same product (tomatoes) rotates through the same 90^0 angle (Table 2) [7-14].

It is known that agricultural products (for example, tomatoes) do not ripen at the same time.

Table 2. The process of determining the state of the tomato product by the robot "Robot AI Virgo".

№	**Tomato ripening (%)**	**Turning state (Degree (^{0}))**	From this table, you can see the classifications of the rotary part of the harvesting part of the American agricultural harvester robot called "Root AI Virgo". It can be seen that both the finished product and the semi-finished product are turned by 90 degrees. This, in turn, leads to excessive energy and time consumption [12, 13, 14].
1	95-100	90	
2	80-95	90	
3	60-80	90	

According to the above existing problems, the main goal of this article is to control the rotation mechanisms of robotic manipulators designed for harvesting agricultural products. And the angular displacement sensor that measures them is to increase the reliability and extend the measurement range.

Many types of sensors are used to measure rotational parameters (displacement, velocity, acceleration). Many sensors, their functions, methods of application, the principle of transformation, methods of obtaining transformation results are presented in the cited works. Without analyzing the classification of angular displacement sensors (ADS), we will focus on their main types, that is, sensors with important characteristics. Thus, angular displacement sensors are divided into direct displacement and compensatory type angular acceleration sensors according to the conversion method. Currently, most ADSs are based on the correct replacement method [15].

Basically, the principles of kinematic, dynamic and optical measurement are used in the measurement of angular displacement. The kinematic principle involves measuring the coordinates of the points of the control object relative to the selected fixed coordinate system. Examples include immovable elements of the sensor or immovable objects outside the sensor.

The dynamic principle of measurement implies the measurement of rotating parameters relative to an artificially fixed system. In most cases, it is an inertial element that connects rotating objects through a flexible hook.

Optical angular displacement measurement sensors (encoders) where the position of each shaft corresponds to a digital output code. Accordingly, the rotation mechanism starts working immediately after starting.

Figure 1 shows the principal diagram of a tracking system with a two-phase asynchronous motor. This system works as follows. The position of the input and output axes in the system is compared using a mechanical differential Dr, which is mechanically connected to the potentiometer P. The voltage (Um) obtained from the output of the potentiometer P is amplified by an amplifier and fed to the power supply. control scheme (BCh) of a two-phase asynchronous motor (AM) in the form of voltage (Uk). (AM) The torque current (TC) is also supplied from the industrial frequency network connected to the potentiometer. A capacitor connected in parallel to the secondary winding of the output transformer (Tr_{out}) serves to gradually transfer the voltage (Uk) supplied to the control winding (BCh) of the asynchronous motor S AM. In this system, the mechanical differential Dr, mechanically connected to the potentiometer P, acts as O'O', which provides information about the difference in angular displacements [13-14].

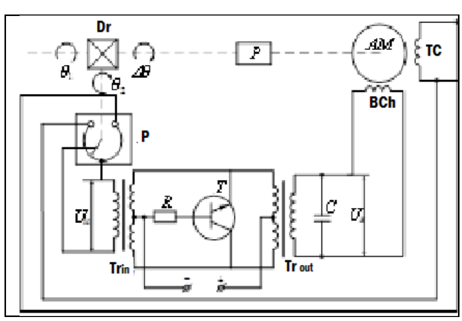

Fig. 1. The main scheme of the two-phase asynchronous motor tracking system. Dr - mechanical differential; P - potentiometer; BCh - control board; TC - torque coil; R – reducer; AM is an asynchronous motor.

In order for the automatic monitoring system under analysis to be at the required level, it must have linear static characteristic of MC, high measurement accuracy and sensitivity, and satisfactory metrological characteristics even under severe operating conditions.

Based on the analysis of the schemes of ADSs mentioned above and the schemes of relevant systems given in educational and scientific literature devoted to ADSs of technological processes and production, we formulate the main requirements imposed by ADS on the MCs used in them as follows:

1) high measurement sensitivity and accuracy;
2) linearity of the transformation function in the entire measurement range;
3) moderation of characteristics over time;
4) moderation of the characteristics even in severe operational (extreme) conditions (ambient temperature, wide variation of external electromagnetic fields, high value vibration, high humidity, high amount of dust, presence of aggressive environment, etc.);
5) high speed (small time constant MC);
6) small size of weight and dimensions;
7) One-value connection of the output value MC with its input value, i.e. absence of hysteresis.

The delay (difference) between the time when the ultrasound wave appears at the source and the time it returns from the moved object makes it possible to measure the distance between the ultrasound source and the object. Ultrasound measurement converter (MC), like optical MC, has advantages and disadvantages.

Electromagnetic sensors are the most common series of sensors that measure angular displacements in technological processes and production ADSs. In the following paragraphs, we will briefly get acquainted with the structural schemes and technical capabilities of these MCs.

To study the technical capabilities of transformers, we will consider several of their characteristic construction schemes.

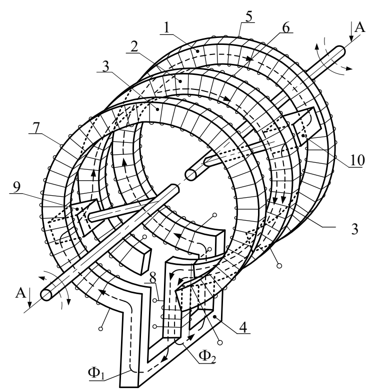

Fig. 2. Transformer O'O' construction scheme, the moving parts of which consist of ferromagnetic cores: 1-3 - non-closed ferromagnetic rings; 4 - Ш - types ferromagnetite sturgeon; 5, 6, 7 - measurement problems; 8 - excitation coil; 9, 10 - movable ferromagnetic cores.

It consists of three 1-3 non-closed ferromagnetic rings located in mutually parallel planes at the same distance along one axis MC, the ends of which are connected to each other by means of ferromagnetic rods of different names Ш-shaped 4. Conductors wrapped in ferromagnetic rings 1-3 are equally distributed and connected according to the mutual differential scheme, three identical measuring pieces 5-7 are installed, the driver is mounted on the middle rod of the Ш-shaped ferromagnet firing pin 8 is placed. rod 4. In the angular air spaces between each two adjacent rings 1 and 2 and rings 2 and 3, two moving ferromagnetic cores 8 and 9 are placed, one of which is directed to the first object whose angle of rotation is controlled, and the second is controlled. to the second object. installed using bars (not shown in Figure 4).

Figure 3 shows the structural scheme of another moving core MC transformer consisting of a ring-shaped magnetic bridge 1, its shoulders 2-5 and ferromagnetic rod-shaped diameter connector 6 and a measuring device. 7 (diagonal measuring device), C-shaped external diameter magnetic conductor 8 and the excitation device installed in it 9. The excitation coil to the alternating current source 10. One axis when it is necessary to measure the difference in the angular displacement of two bodies located along the line, one of them is attached to the magnetic bridge 1, and the other to the magnetic conductor 8. (not shown in the diagram).

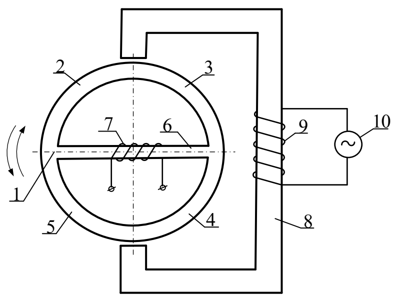

Fig. 3. The construction scheme of the moving core transformer MC measuring angular displacements: 1 - magnetic bridge; 2-5 - bridge shoulders; 6 – diameter connector; 7 - measuring rod; 8 - external S-shaped diameter magnetic conductor; 9 - excitation coil; 10 - alternating current source.

When MC is in the neutral position, the resulting magnetic flux in the measurement diagonal is zero, and therefore the signal in the measurement section is zero. When the objects and the moving parts connected to them turn to certain angles MC, the magnetic flux generated in the measurement diagonal as a result of the imbalance of the magnetic bridge appears and the objects in the measurement piece rotate. Electrical power, which is proportional to the angle difference, is induced [15-19].

The main disadvantages of this MC include its low sensitivity (this issue will be analyzed in detail in the next chapter of the dissertation) and relatively large weight measurement indicators (due to the presence of a magnetic conductor with an external S-shaped diameter). 8 in the design).

It can be seen from the theoretical analysis that the existing angular displacement sensor can only accurately measure up to 90 degrees. On the contrary, the sensitivity of the sensor for measuring angular change with the recommended Transformer sensor increases when measuring this angular range ($50< a <130$). This, in turn, represents the disadvantages of the sensor that measures the angle change with the transformer.

Energy-informational and morphological methods of technical creativity in the process of developing new designs of transformer transducers that measure angular displacement, including groups of inventions measuring transducers and other scientific and designated devices and their closest analogs (prototypes) Internet resources were analyzed.

A transformer converter for measuring angular displacement, created based on the methods mentioned above and one of the constructions presented in this paragraph, is shown in Figure 6.

The magnetic resistance of the shoulders of the developed measuring device (MD) is made of ferromagnetic material (Figure 4) with two four-shoulder bridges of the form 1, 10, 11 and 12 and its 1 Shoulders 10 and 11-12 diameter ferromagnetic interconnected using connector 16. The measuring piece 5 is placed inside the magnetic conductor 2, which is made in the form of a closed ring, and the bridge is connected to the ferromagnetic connector 16. On both sides of this closed ring, the excitation pieces 3-4 and 7. -8 placed.

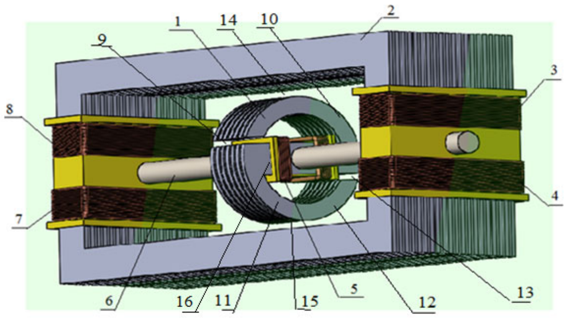

Fig. 4. Construction schemes of the transformer with the measuring transformer of the angular displacement.

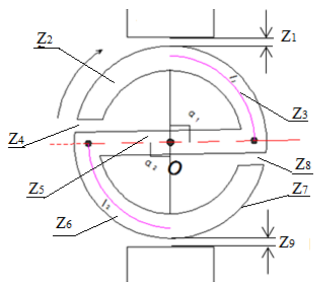

Fig. 5. Circuit diagram of a transformer angular displacement sensor.

At the ends of the 16-diameter connector of the bridge-shaped shoulders, there are non-working (at rest) air gaps Z_4 and Z_8. In addition, spiral shoulders (Z_2, Z_3, Z_6, Z_7) and diameter connector Z_5 are connected. A rectangular magnetic conductor 2 or a diameter bridge connector 16 is connected to the controlled object. When it is necessary to measure the angular displacement of the moving body, the rectangular magnetic conductor 2 is tightly connected to one of them by means of the connector 16, shaft 6 with a diameter [19].

3 Discussion

The bullet works as follows. When the excitation coil is connected to a DC voltage source, due to the sinusoidal current generated in both sections, the parts of the coil in the closed-circuit magnetic conductor 2 are inductively connected to each other. Two magnetomotive forces (MIUK) and their effect create an electromotive force (EYuK) at the diametrically located pole tip.

The induced magnetic flux in the proposed OQ measuring coil is equal to:

$$\dot{E}_{o\prime lch.} = -j\omega w_{o\prime lch.}\dot{Q}_{\mu} \tag{1}$$

where ω is the angular frequency of the source voltage, [s(-1)]; wolch - the number of rolls of measuring tape, [-].

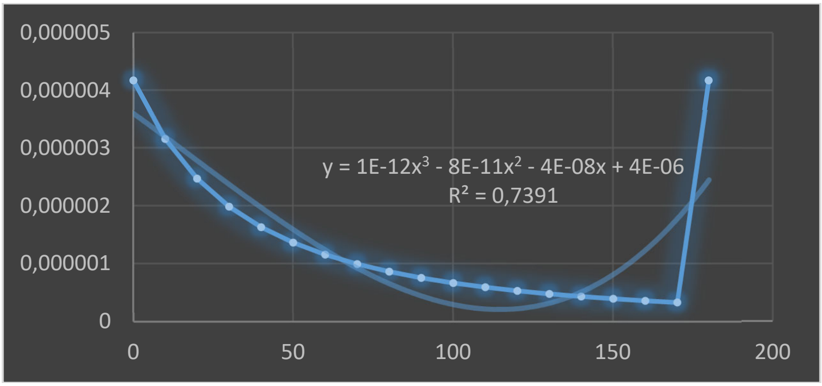

Fig. 6. The voltage dependence diagram of the rotation angle of the proposed angular displacement sensor.

As you can see, the value of the output voltage in the measuring circuit is very small. This voltage is amplified using special amplifiers and adjusted to the angle of rotation by a special Arduino mixoplate. The results of the experiment showed that with the help of this angular displacement sensor, the turning position of the rotating mechanisms can be accurately measured up to 170^0. At the same time, the sensitivity is very high. [10, 19, 20, 21, 23].

$$\dot{E}_{mes.} = -j\omega w^2{}_{mes.}\frac{I}{Z} \quad (2)$$

Equation 2 is also known from the formula that the output voltage is inversely related to the value of the resistance, which means that as the resistance decreases, the output voltage increases. According to Figure 5, the resistance depends on the length of the magnetic conductors.

4 Conclusion

In conclusion, it can be said that development in agriculture is developing much slower than in other sectors. In particular, in the last 20 years, research on the creation of agricultural robots has developed very slowly. In particular, the use of robotics in agriculture has not yet reached a commercial scale. In today's booming and developing world, shrinking workforces and rising production costs are causing robotic livestock firms to focus more on cleaning and harvesting. There are ways to reduce the energy used in harvesting and harvesting agricultural products. In addition, the reduction in harvesting time is directly related to the measurement of angular displacement. Failure to precisely control the angular displacement of the rotation mechanisms of existing robots leads to a decrease in the speed of product assembly. To overcome such problems, a sensor has been developed to control the rotating parts of robotic manipulators. This developed sensor allowed accurate measurement up to 180 degrees. And the rotating part in the middle was changed without changing the input voltage. According to the theoretical analysis, the voltage of the measuring circuit has changed. This project proposed an angular displacement sensor for precision use for arm parts for agricultural robots. We plan to apply it to rotation mechanisms and provide images of the prototype during the experiment and in our future research.

The authors of this article are very grateful to the organizers of this conference and the reviewers for their relevant and constructive suggestions to improve the research work.

References

1. Muhammad Dede Yusuf, Rd Kusumanto, Yurni Oktarina, Pola Risma, Computer Engineering and Applications Journa l **7(1)**, 25-36 (2018). https://www.doi/org.10.18495/comengapp.v7i1.237
2. A. Bhargava, A. Bansal, Journal of King Saud University. Computer and Information Sciences (2018)
3. T. Duckett, S. Pearson, S. Blackmore , B. Grieve, Agriculture Robotics: The Future of Robotic Agriculture, UK-RAS Network Robotics & Autonomous System ISSN 2391-4414 (2018)
4. R.R. Shamshiri et. al., Int. J. Agric & Biol Eng. **11(4)**, 1-14 (2018)
5. T. Dewi, P. Risma, Y. Oktarina, S. Muslimin, *Visual Servoing Design and Control for Agriculture Robot;* International Conference on Electrical Engineering and Computer Science (ICECOS), pp. 57-62 (2018). https://www.doi/10.1109/ICECOS.2018.8605209
6. R. Baratov, A. Mustafoqulov, E3S Web of Conferences **401** 04006 (2023). https://doi.org/10.1051/e3sconf/202340104006
7. Y. Zhao, Q. Sun, C. Wang, C. Zhang, Larva Nets Journal of Robotics **436490**, 7 (2015). https://doi.org/10.1155/2015/436490
8. M. Stoelen, K. Krzysztof, V. F. Tejada, N. Heiberg, C. Balaguer, A. Korsaeth, *Low-Cost Robotics for Horticulture: A Case Study on Automated Sugar Pea Harvesting* 10th European Conference on Precision Agriculture (ECPA) (2023). https://doi.org/10.3920/978-90-8686-814-8_34
9. M.D. Yusuf, R.D. Kusumanto, Y. Oktarina, T. Dewi, P. Risma, BLOB Analysis for Fruit Recognition and Detection Compengapp Jurnal **7(1)**, 626-631 (2018).
10. C. Wang, Y. Tang, X. Zou, W. SiTu, W. Feng, Optik **131**, 626-631 (2017). http://dx.doi.org/10.1016/j.ijleo.2016.11.177.
11. C. Xiong, C. Xiaoman, X. Zou, Journal of Applied Biotechnology & Bioengineering **3(6)**, 4 (2017). https://doi.org/10.1016/j.jksuci.2018.06.002
12. R. Baratov, N. Pirmatov, A. Panoev, Y. Chulliyev, S. Ruziyev, A. Mustafoqulov, IOP Conf. Ser. Mater. Sci. Eng. **1030(1)** (2021). https://doi.org/10.1088/1757-899X/1030/1/012161
13. Y. Bai, Y. Guo, Q. Zhang, B. Cao, B. Zhang, Comput. Electron. Agric. **194** (2022). https://doi.org/10.1016/j.compag.2022.106789
14. Y. Bai, B. Zhang, N. Xu, J. Zhou, J. Shi, Z. Diao, Comput. Electron. Agric. **205** (2023). https://doi.org/10.1016/j.compag.2022.107584
15. A. Denmukhammadiev, A. Mustafoqulov, H. Valikhonova, E. Sobirov, T. Raimov, E3S Web Conf. **264** 05051 (2021). https://doi.org/10.1051/E3SCONF/202126405051
16. R. Baratov, A. Mustafoqulov, E3S Web of Conferences. **386** 03008 (2023). https://doi.org/10.1051/e3sconf/202340104006
17. R. Baratov, A. Mustafoqulov, E3S Web of Conferences **401** 04006 (2023). https://doi.org/10.1051/e3sconf/202338603008
18. I. Davletov, N. Khakimov, A. Qodirov, M. Akhmedov, J. Sadullayev, O. Khamraev, E3S Web Conf. **461** 01066 (2023). https://doi.org/10.1051/e3sconf/202346101066
19. I.Y. Davletov, N.Z. Khakimov, A.K. Qodirov, M.M. Akhmedov, J.O. Sadullayev, O.O. Khamraev, *"Increasing the Efficiency of Asynchronous Motors by Improving the Quality of the Electric Current,"* in 2023 IEEE XVI International Scientific and

Technical Conference Actual Problems of Electronic Instrument Engineering (APEIE), 1820-1824 (2023). https://doi.org/10.1109/APEIE59731.2023.10347842

20. Vladimir Ivanovich Polyakov, Sergey Nikolaevich Sysoev, Igor Nikolaevich Stepanenkov, *"Set of devices for assembly of magnetic angle converter and method of its assembly"* Federal service for intellectual property, trademark patents. (73) I.K. Patentu, “C1,” **30(19)**, 1-9 (2006)
21. A. Safarov, K. Sattarov, M. Bazarov, and A. Mustafoqulov, E3S Web Conf. **264** 05038 (2021). https://doi.org/10.1051/E3SCONF/202126405038
22. Transformer inverter angular movements (accessed May 02, 2022). https://russianpatents.com/patent/216/2161774.html
23. Torsten Harder, Dirk Beiser, Fabio Conticelli, Patrick Boren, *"Method for determining the angular position of the rotor of a rotating electrical machine (57)"* Federal service for intellectual property, trademark patents. I.K. patentu, “C2,” **19**, 1-7 (2006)
24. In-Soung Jung, Jin Hur. Dong-Seok Hyun, IEEE Transactions on Magnetics **35(5)**, 3736-3738 (1999). https://doi.org/10.1109/20.800648