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Model of field robot manipulators and sensor for measuring angular displacement of its rotating parts

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Abstract. This research aims to measure and control the angular change of rotation mechanisms of (energy-saving) robotic manipulators used in agriculture to develop digital farming, energy saving, and quality product harvesting. The novelty of this research is that different processes and images are placed in a special processor for processing, and this robot processes the image according to the size of the tomato plant and tomato and tries to harvest the crop. This study presents the electromagnetic angular displacement sensor and its technical characteristics. The existing electromagnetic angular displacement sensors have been thoroughly analyzed and compared with other types of sensors. The reason for the low sensitivity of the electromagnetic angular displacement sensor has been investigated, and some technical modification to the existing sensor has been made. The magnetic circuits of the electromagnetic sensors have been analyzed. A method is proposed for expanding the range of angular measurements up to 180 degrees and increasing the sensitivity of the electromagnetic sensor without compromising the measurement accuracy. This, in turn, allows high-precision control and measurement of rotating mechanisms of all types of mechatronic systems and agricultural robots.

1 Introduction

The development of digital farming will allow to find solutions to pressing problems in agriculture in the future. The rapid growth of the world's population imposes requirements to control the quality and quantity of all products [1]. Digitization or automatic farm control is a method that can be used in all areas of agriculture. It is said to automate the processes from sowing the seeds to harvesting the ripened agricultural product. The data presented in the studied literature show that these robots are capable of harvesting tomatoes with good quality, and this robot vision proves that agricultural robots will achieve high efficiency in the future [2, 3, 4]. The use of robots allows for perfect agricultural design. Using agricultural robot-manipulators, it is possible to obtain continuous information about the specified area and analyze many problems encountered in farming. Many examples can be given as agricultural robot manipulators. Drones allow for regular monitoring of fields and

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crop management [5]. It is advisable to use special agricultural machinery during harvesting. It is known that using robot-hand manipulators for harvesting is more convenient. Robotic hand manipulators are also capable of harvesting. Because the hand part of the robot hand manipulators is designed to catch and collect various fruits[6], [7], [8], [9]. A special camera is needed to ensure accuracy during harvesting and to perform the cutting operation accurately. As the dimensions of modern cameras are getting smaller, they do not put too much weight on robotic manipulators. It is recommended to install the camera on the monitor in two ways: by hand and inside the hand. The camera is designed to be installed on the arm (itself) of the robot manipulator or anywhere on the robot. Both of these methods have their advantages and disadvantages. A camera installed anywhere (except for the hand) of robotic manipulators cannot detect objects. If the camera is mounted on the arm, the camera can detect the object, but there is a high probability of getting stuck in the branches of the plant. The camera must process the image to distinguish the photographed object (product) from the background. This way, the robot arm knows which ones to pick and cut and which ones to ignore. For example, it is important to determine the location of fruits in relation to plants. To increase the reliability of the robot arm, it is recommended to use a distance sensor to determine the exact location of the product [10], [11], [12], [13], [14], [15]. [16]. This article presents the project of using a robotic manipulator as a harvesting robot. It is equipped with an ATMEGA microcontroller as a controller for the base of servo motors to move the robot arm, a special "Raspberry Pi3" chip for image processing, a special camera for capturing object images, and a distance sensor for providing information. about the distance between the robot and the object. The purpose of this research is to increase the role of robots in agriculture and to develop a project for high-quality and safe harvesting of fruits and vegetables. The novelty of this study is that this method is simple and convenient for image processing and storage of captured images[20-35].

2 Materials and Methods

This section presents the design of a robot manipulator that collects and collects tomato products. Figure 1 shows the functional diagram of the robot manipulator, Figure 2 shows the electrical diagram, and Figure 3 shows the 3D design of the robot arm manipulator. Figure 1 shows the components of the input and output processes. The camera takes a picture of the factory and sends the image to the Raspberry Pi3 and the PC. The distance sensor is designed to determine the distance between the product and the device that collects it. In this project, a web camera and a distance sensor are installed on the arm part of the manipulator as an "eye" product picking device.

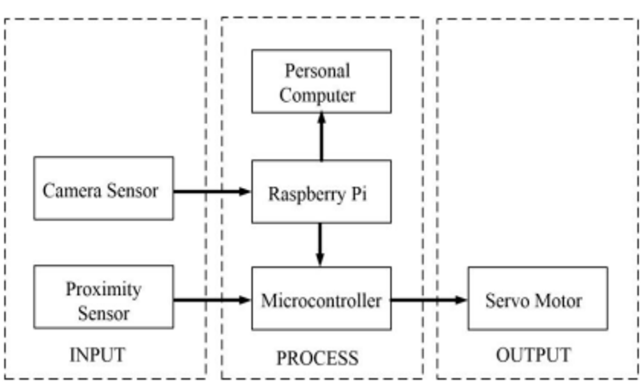


Fig. 1. Diagram block of proposed method

The process in Figure 1 involves processing the raw image (detected output) from the camera on a PC. Sends the image to the Raspberry Pi3 for processing. A detected tomato product gives the number "1" in the binary code system and sends it to the microcontroller. The "output" part (block diagram) in Figure 1 consists of servo motors that move the robotic manipulator's arm closer to the tomato crop. Here, servo motors are placed on the joints of the robot manipulator and perform the necessary movement depending on the identified object [5].

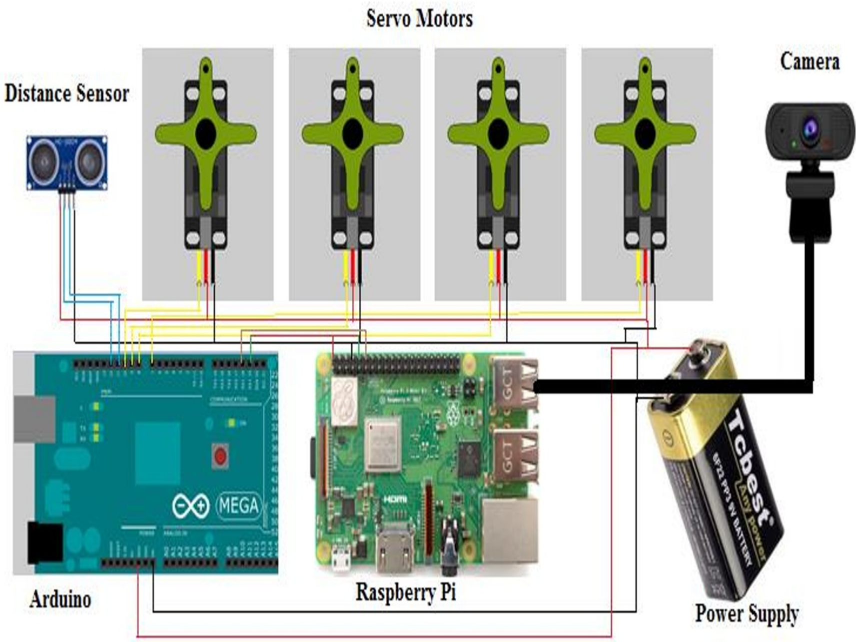


Fig. 2. Electrical connection among components of harvesting robot.

Figure 2 shows the electrical diagram of the harvesting robot. The camera used in this project is a very common webcam that plugs directly into the Raspberry Pi3 board. HC-SR04 ultrasonic sensor is used to determine the distance between the product and the monitor. The range of this sensor is 2cm to 400cm, and the sensing angle is 300. This sensor can be connected to an Arduino board. This research model's 3D view and electrical schematic are assembled and consist of a Raspberry Pi3 processor for image processing, an Arduino Mega 2560 as the main device, and Servo motors connected through actuators. The robot arm in this model consists of 2 joints controlled by Servo motors.

Figure 3 shows the movement states of the robot. It shows the dimensions of the robot arm's base, joints, legs, and overall height. This mode of operation is designed according to the size of the tomato plant and can be adjusted according to the size of the plant.

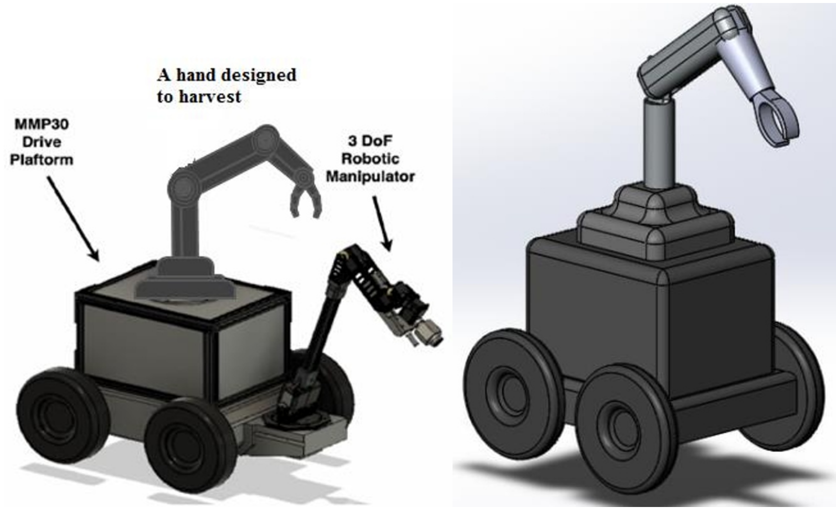


Fig. 3. 3D model of device

The 1st stage of the tomato harvesting robot-manipulator consists of cleaning the tomatoes. Table 1 shows the power consumption of Servo motors that provide robot movements in picking tomatoes. These motors are connected in Figure 2. The voltage values maintain how the robot moves in and out of the state. The robot is powered by a servo motor that supports the manipulator to print and position it to the right. Servo motors on links 1 and 2 are activated to load up and down. Systematic control of the angular displacement of rotating mechanisms of robotic manipulators remains an urgent problem. An attack on the use of transformer-transformer angular displacement sensors in the measurement and control of angular displacements over a wide range is discussed [17, 18, 19].

The income of a modern farm is directly related to the number of workers. Harvesting the ripe crops will also require many employees, but using robot manipulators instead of people will be useful in carrying out routine work. The U.S. agricultural workforce has decreased by 2% because of agricultural field robot manipulators. Josh Lessing has been working on overcoming this problem since he founded the Root AI project on agricultural robotics in 2018. The company has now developed a robot called Robot AI Virgo, which is used to determine whether a tomato is ripe and is designed to selectively pick ripe tomatoes [11]. As above mentioned, a major problem is the precise control of the angular displacement of rotating mechanisms of agricultural field robot manipulators. Because the study is devoted to developing electromagnetic angular displacement sensors more reliable than others, it is possible to save electricity and time by controlling the rotation mechanisms of robotic manipulators used in agriculture.

As we know, agricultural products (like tomatoes) do not ripen simultaneously. The following table (Table 1) provides information about the importance of the sensor in the process of its collection in the example of a tomato product.

Table 1. Table of dependence of the sensor turn of the finished tomato product.

№	Tomato readiness (%)	Sensor deflection position (Degree ^{0})	The time it pickes to spend one product (time, s)
1	95-100	40	2
2	90-95	60	4
3	80-90	100	8

It can also be seen from Table 1 that time and energy savings can be achieved by controlling the rotating mechanisms of the existing machinery in the quality and efficient harvesting of agricultural products. To avoid these problems, analyzing different angular displacement sensors is necessary.

The two-coordinate ferromagnetic angle displacement sensor consists of the permanent magnetic field, which consists of two mutually perpendicular intersecting circular discs with windings distributed across opposite sections through the diameter of the rotating part and a winding of the driving part. The disadvantages of the two-coordinate angle displacement sensor are the complexity of the design and the low reliability, which is due to the presence of a ferromagnetic fluid located inside the spherical surface. The operation of the device with magnetic fluid results in a highly dense state of the spherical surface. In addition, the magnetic fluid is an expensive thing. We also investigated optical sensors designed to measure angular displacement. Optical angular displacement sensors (encoders) in which each shaft position corresponds to a digital output code. Therefore, the rotating mechanism starts working as soon as it starts. The disadvantages of this type of angular displacement sensor are that it can miss angular pulses for any reason. This leads to errors in determining the rotation angle until the zero mark returns to its original position [12-14].

Usually, an electromagnet transformer type of angular displacement sensor has high reliability in extreme conditions. So in this study, we have reviewed different types of angular displacement sensors.

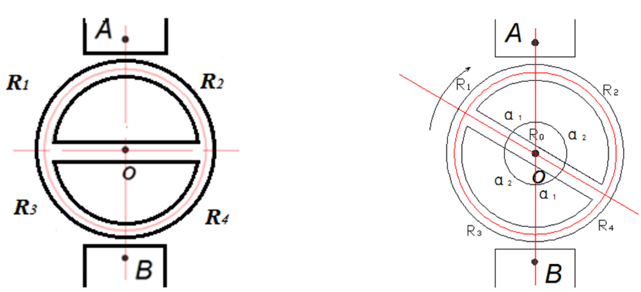
However, the analysis performed showed that the sensitivity of the electromagnetic sensor was significantly low than others [15]. This is because only part of the magnetic flux generated by the magnetic motive force crosses the diameter of the ring. After all, the sensor's sensitivity is directly related to its output signal.

The technical parameters of the angular displacement sensor obtained as the prototype have been calculated initially. The prototype belongs to the control and measurement technology field and is designed to measure angular displacement in aviation technology, including various control circuits of electrical and electromechanical devices [16].

3 Results and Discussions

3.1 Structure and technical parameters of the existing sensor

First, we have considered the magnetic circuits of the transformer type of angular displacement sensor, which is taken as a prototype. Figure 1 shows the magnetic circuits of the angular displacement sensor, and as is known, the total value of the magnetic resistance between points A and B is determined as follows:



a *b*

Fig. 4. Magnetic circuit of the angular displacement sensor (a is initial position of the rotating ferromagnetic disk, b is position of the rotating ferromagnetic disk at the beginning of the movement)

As can be seen from Fig. 1, after the movement of the rotating ferromagnetic disk begins, the magnetic resistances on the arms of the moving disk change depending on the movement (R_1, R_2, R_3, R_4). But the magnetic resistances on the opposite arms are equal to each other ($R_1 = R_4$, $R_2 = R_3$). Here only the magnetic resistance of the diameter of the rotating ferromagnetic disk does not change, i.e., it does not depend on motion (R_0 = const.).

$$R_1 = R_4 = \frac{l_1}{\mu\mu_0 S} \quad (1)$$

$$l_1 = \alpha_1 \cdot \frac{\pi}{180} r \text{ and } l_2 = \alpha_2 \cdot \frac{\pi}{180} r \quad (2)$$

Where: D is diameter of the magnetic field path on the rotating ferromagnetic disk; S_0 is cross- section area of the diameter of the rotating ferromagnetic disk; S is cross-section area of an arm of the rotating ferromagnetic disk; μ_0 is absolute permeability; μ is permeability of the material; 1_1 and l_2 are the length of the magnetic field path on a rotating ferromagnetic disk.

As can be seen from Fig. 1, after the movement of the rotating ferromagnetic disk begins, the magnetic resistances on the arms of the moving disk change depending on the angle. Depending on the state of change of the rotating disk, the dependence of the total magnetic resistance between points A and B on the angular displacement is as follows.

$$\sum R = f(\alpha) \quad (3)$$

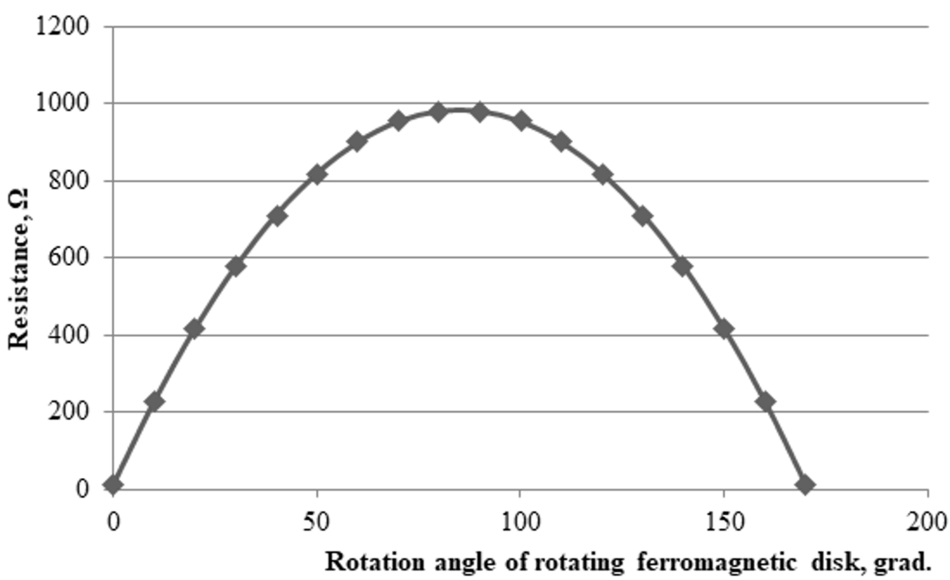


Fig. 5. Diagram of the total magnetic resistance depending on the angle of rotation

It is known from the diagram that the rotating ferromagnetic disk of the sensor measuring the angular displacement of the transformer converter returns to its original position again at 90 degrees. According to Figure 5, we determine the reading of the voltmeter in the measuring vessel depending on the state of change of the rotating ferromagnetic disk. When a constant current (I) is applied to the ferromagnetic core (housing), the magnetic flux generated in it is as follows (Figure 5) [17-19].

$$\Phi = \frac{\omega l}{\sum R_\mu} \tag{4}$$

ω is the number of turns of the reel.

$$e = -\omega \frac{\Delta \Phi}{\Delta t} \tag{5}$$

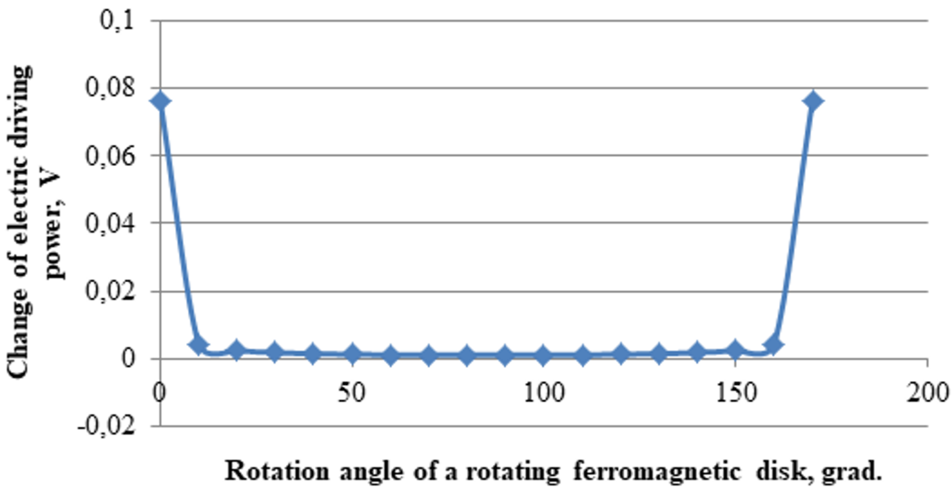


Fig. 6. Diagram of voltage dependence of angular displacement

As seen from this figure, using an existing angle displacement sensor, it is difficult to accurately measure the angular displacement from 50 degrees to 130 degrees. The sensitivity of the sensor that measures the angular displacement of a transformer converter increases when measuring the range of this angle ($50^0 < \alpha < 130^0$). This, in turn, represents a shortcoming of the Transformer converter angle displacement sensor.

3.2 Calculation of the magnetic parameters of the sensor that measures the proposed angular displacement

We will now consider the sensor's magnetic parameters that measure the recommended angular displacement. The shape of the rotating ferromagnetic disk is different, as is the principle of operation of the sensor that measures the angular displacement of a transformer converter (Figure 6a).

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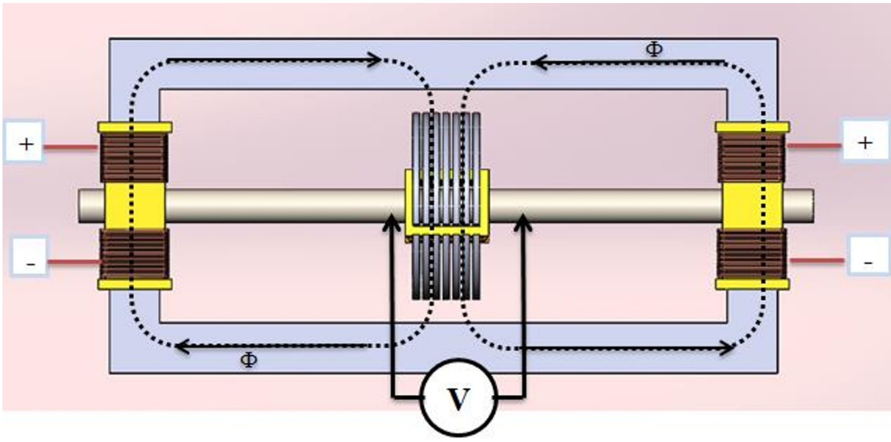

Fig. 7. 3D view of the proposed angular displacement sensor

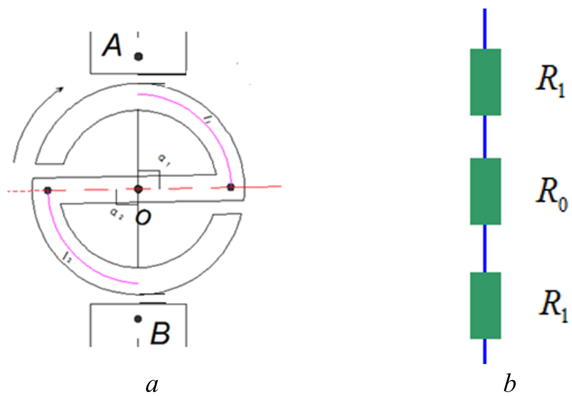

Fig. 8. a is the stationary state of the rotating ferromagnetic disk, b is the circuit for switching the magnetic chains to the electrical circuit

$$R_1 = \frac{l_1}{\mu\mu_0 S_1} \quad (6)$$

$$R_0 = \frac{D}{\mu\mu_0 S_0} \quad (7)$$

$$\sum R = 2R_1 + R_0 \quad (8)$$

3.3 The result of the calculation of the recommended angular displacement sensor

Consider the voltage change depending on the clockwise position of the rotating ferromagnetic disk of the sensor that measures the recommended angular displacement according to Figure 5 [20]. When the ferromagnetic material (housing) is connected to a fixed source, the direct current (F) is calculated as follows:

$$\Phi = \frac{\omega l}{\sum R_{\mu}} \quad (9)$$

$$e = -\omega \frac{\Delta \Phi}{\Delta t} \quad (10)$$

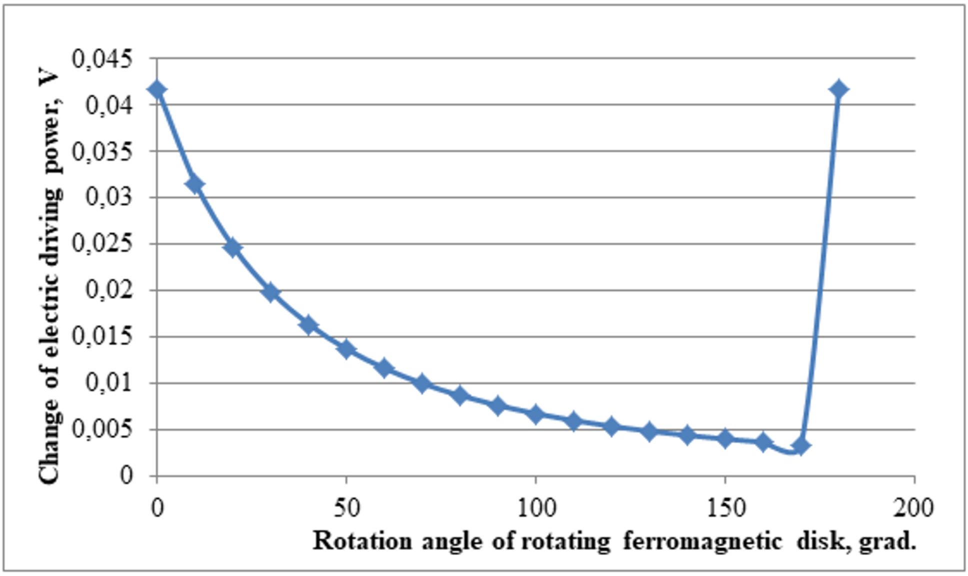

Fig. 9. Voltage-dependent diagram of the angle of rotation of the proposed angle shear sensor

As can be seen from this figure, the sensitivity of the proposed angular displacement sensor allows accurate measurement of angular variation up to 180^0, uniform at each point of the rotating ferromagnetic disk (Figure 7). The main difference from the current sensor is that, due to the design change, its range can be accurately measured from 50^0 to 130^0.

4 Conclusions

The existing problems in the quality harvesting of agricultural products through robots can provide continuous information about its location and accurate analysis of many aspects of the farm. The lack of precise control of the bursa movement of the rotating mechanisms of existing robots leads to a decrease in the speed of product assembly. To solve the existing problem, a sensor to control the rotating mechanisms of robotic manipulators was developed. This article presents a project of a tomato-picking robot. Therefore, the developed robot is adapted to the tomato tree and tomato size. This time difference does not depend on the tomato's color but on the robot's distance to the tomato. The experiment shows that the robot successfully harvests tomatoes under the conditions presented in this study and proves the effectiveness of this robot design as an agricultural robot. It should be noted that research on the creation of agricultural robots has been developing very slowly in the last 20 years. Robotics has not yet reached commercial scale for use in agriculture. With the labor force reduction and the production cost increase, in recent years, more attention has been paid to the research areas of cleaning and harvesting of robotic livestock firms. Existing problems of quality harvesting of agricultural products can be solved by using a robot, providing constant information about the area where it is located, and correctly analyzing many aspects of the farm. Lack of accurate control of the movement of the rotation mechanisms of existing robots leads to a decrease in the speed of product assembly. To solve the existing problem, a sensor was developed to control the rotation mechanisms of robotic manipulators. The reliability of the proposed angular displacement sensor is higher than the reliability of the existing sensor. In addition, it can measure angular displacements of up to 180 degrees in precise values.

The reliability of a sensor that measures the recommended angle displacement is higher than that of an existing sensor. It can also measure angular displacement up to 180 degrees at exact values. This project is planned to apply the proposed angular displacement sensor to the rotation mechanisms of agricultural robotic manipulators and provide prototype views during the pilot process and in our further research.

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