Development of a control system for sorting agricultural products according to specified criteria

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Abstract. The article presents a process control system for sorting agricultural products. The technological process of sorting is described, the composition of the system is indicated, the sorting algorithm is developed. ProgramLab software was used as the modeling environment. Color and weight were selected as sorting criteria. The parameters at the input of the control object, which have the greatest influence on the process were selected. The output parameters were the conveyor speed and the final position of the sorting object. A scheme of cause-and-effect relationships of the sorting process is obtained. A block diagram of the sorting process has been developed. A mathematical model for calculating the speed of a conveyor depending on the distance between the robotic arm and the conveyor, as well as between the robotic arm and the parts unloading points was obtained. A 3d model of the sorting process has been developed. Three basic scenarios for the location of places for unloading agricultural products are considered. The introduction of the developed system will help reduce number of rejects during sorting, increase the efficiency of the sorting process and improve economic performance. Improving the sorting process will help reduce equipment wear and extend equipment life.

1 Introduction

In modern conditions, work on sorting objects at a number of agricultural enterprises is still carried out manually. Consequently, there is a large amount of defects and low efficiency. Automation of the sorting process is an urgent task for agriculture, food, pharmaceutical, and waste processing industries.

The aim of the work is to develop an automated control system for the process of sorting products according to several criteria [1-3]. Achieving this goal will lead to minimizing human participation in this process, therefore, the number of errors will decrease, and the sorting speed will also increase. The introduction of an automatic control system for the

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sorting process will make it possible to achieve a more efficient energy resources usage, and therefore a significant economic effect for the enterprise [4, 5].

2 The technological process description

A typical task is to sort agricultural products moving along a conveyor, depending on a number of predetermined parameters.

The system consists of several conveyor lines, each of which can move objects at different speeds, a Dobot Magician robotic arm, a diffuse photoelectric sensor (position sensor), a color sensor, and a mass sensor [6]. The simulation of the system operation took place in the ProgramLab software. In the model representation, parallelepipeds of red, yellow, green and blue colors, having different masses, were considered as agricultural products. Color and weight were considered as sorting criteria. Depending on the signals received from the sensors, the control system decides whether the object corresponds to one or another given group and sends a control signal to the control device and to the conveyor.

The object is placed on the main conveyor and travels along it to the diffuse photoelectric sensor. The sensor is triggered, the controller [7] reads the signal from it, sends a control action to the conveyor, after which it stops. Next, the robotic arm [8] grabs the object with the help of a special nozzle and transfers it to the color sensor and the mass sensor. The robotic arm consists of the following parts (from bottom to top): base, arm, boom and working tool (Figure 1). All of them are interconnected by means of servo drives (connection 1, connection 2, connection 3, connection 4, respectively), which makes it possible to achieve a large volume of the working area of the robotic arm. Depending on the data read from the sensors, the robot-manipulator moves the object to a place determined by a given work algorithm. Next, the main conveyor is turned on again and the next object is processed.

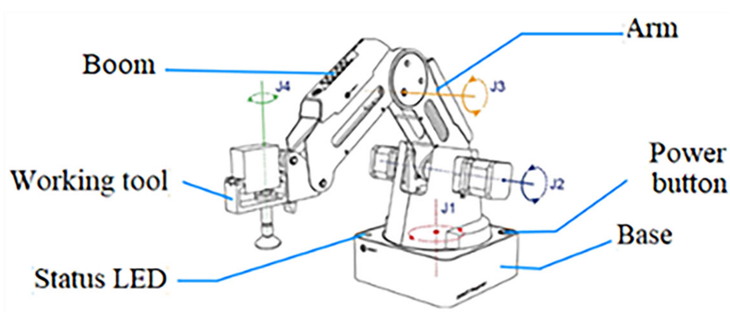

Fig. 1. Components of a robotic arm where J1, J2, J3, J4 are the connections of the main parts of the robot through servo drives.

3 Control system creation

For the correct operation of the control system, it is important to correctly select the influencing input and output parameters of the system [9]. The initial position of the object, color and mass were chosen as input parameters. As output parameters conveyor speed and final position of the object were chosen. As a result, a scheme of cause-and-effect relationships of the sorting process was obtained (Figure 2).

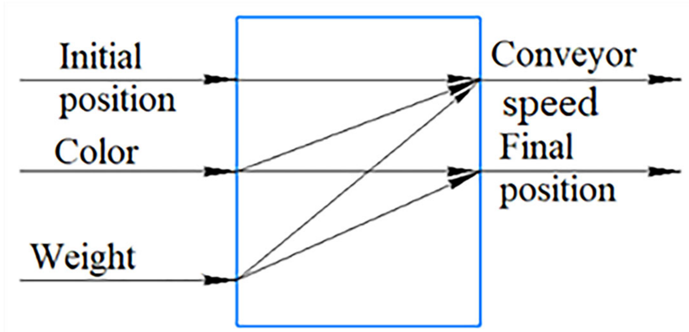

Fig. 2. Cause-and-effect relationships of the sorting system.

Every control system includes a control object and a control device. Let us consider a conveyor as a control object, a controller as a control device, and a Dobot Magician robotic arm as an actuator. The processing of the signals received from the sensors, as well as the issuance of signals to the actuators, is carried out by the Owen controller and its auxiliary units. For the correct operation of the actuator, it is necessary to correctly set the robot arm to its original position and return to it, indicate the initial position of the object when it reaches the position sensor, and correctly indicate the coordinates of the places where objects are stored depending on the data received from the sensors. The scheme of the sorting process control system is shown in Figure 3.

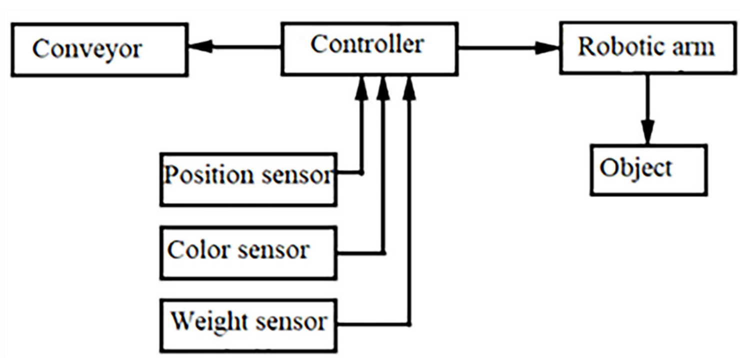

Fig. 3. Sorting process control system.

Mathematical model for calculating conveyor speed

Let the conveyor have a belt length L. The distance from the robotic arm to the conveyor is constant and equal to l_1 (Figure 4). The distance from the conveyor to shipping points 1, 2 and 3 is also constant and is equal to l_2, l_3 and l_4, respectively. The distances from the shipping points to the base of the robot will be denoted as l_5, l_6 and l_7, respectively. In the controller, we put the following algorithm for working with a robot manipulator: the robot arm travels the distance from the initial location point to the end of the main conveyor of the system (point 4) and captures the object. Then it goes either to point 1, or to point 2, or to point 3, depending on the readings of the color and mass sensors, and ships agricultural products. After that, the boom of the robotic arm returns to its original position on the base. The process is cyclical.

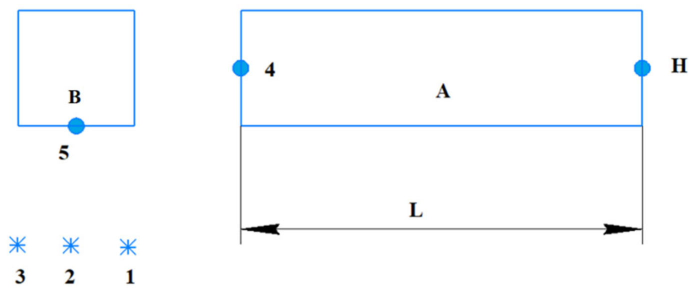

Fig. 4. Block diagram of the sorting system where A is a conveyor, B is a robotic arm, H is the starting point of the object's movement.

Let's denote as t_{54} the time of movement of the arrow of the robotic manipulator from point 5 to point 4, t_3 is the time spent on capturing one object. Let's denote as t_Δ - the time required to transfer the object from point 4 to the point of shipment. Accordingly, t_Δ can take one of three values: either t_{41}, or t_{42}, or t_{43}. Where t_{41} is the time spent on moving the object by the robot-manipulator from point 4 to point 1, t_{42} is the time spent on moving the object by the robot-manipulator from point 4 to point 2, t_{43} is the time spent on moving the object by the robot-manipulator from point 4 to point 3.

Let us assume that the capture of each object takes the same time t_3. Therefore, $t_3 = \text{const}_1$. We also assume that the shipment of one object takes the same time to each time. value $t_0 = \text{const}_2$.

Let us represent the time of one cycle of the sorting system t_{1c} in the form (1):

$$t_{1c} = t_{54} + t_3 + t_\Delta + t_o + t_в, \quad (1)$$

where t_Δ can be determined from the expression (2):

$$t_\Delta = \begin{cases} t_{41}, \ \textit{if the condition } 1 \textit{ is satisfied}, \\ t_{42}, \textit{if the condition } 2 \textit{ is satisfied}, \\ t_{43}, \ \textit{if the condition } 3 \textit{ is satisfied}, \end{cases} \quad (2)$$

where condition 1: color is green, weight is more than 50 g, condition 2: color is not green, weight is more than 50 g, condition 3: any color, weight is less than 50 g.

Parameter $t_в$ is the time required to return the robotic arm to its original position after the object has been shipped. It can be determined by relation (3):

$$t_в = \begin{cases} t_{15}, \ \textit{if the condition } 1 \textit{ is satisfied}, \\ t_{25}, \ \textit{if the condition } 2 \textit{ is satisfied}, \\ t_{35}, \ \textit{if the condition } 3 \textit{ is satisfied}, \end{cases} \quad (3)$$

Let us take the speed of the robot-manipulator in each section of the sorting scheme to be constant and equal to$V_{рм}$. Therefore, the times t_{54}, t_{41}, t_{42}, t_{43} can be expressed according to formulas (4)-(7):

$$t_{54} = \frac{l_1}{v_{рм}}, \quad (4)$$

$$t_{41} = \frac{l_2}{v_{рм}}, \quad (5)$$

$$t_{42} = \frac{l_3}{v_{рм}}, \quad (6)$$

$$t_{43} = \frac{l_4}{v_{рм}}, \quad (7)$$

The return times t_{15}, t_{25}, t_{35} can be determined by relations (8)-(10):

$$t_{15} = \frac{l_5}{v_{рм}}, \quad (8)$$

$$t_{25} = \frac{l_6}{v_{рм}}, \quad (9)$$

$$t_{35} = \frac{l_7}{v_{\text{рм}}}, \qquad (10)$$

Taking into account formulas (2) - (10), expression (1) will take the form (11):

$$t_{1c} = \frac{l_1}{v_{\text{рм}}} + t_3 + \frac{l_i}{v_{\text{рм}}} + t_o + \frac{l_j}{v_{\text{рм}}}, \qquad (11)$$

where i is either 2, 3, or 4, j is either 5, 6, or 7.
The conveyor speed V_k can be found from relation (12):

$$V_k = \frac{L}{t_{1c}}, \qquad (12)$$

Finally (13):

$$V_k = \frac{L}{\frac{l_1}{v_{\text{рм}}} + t_3 + \frac{l_i}{v_{\text{рм}}} + t_o + \frac{l_j}{v_{\text{рм}}},}. \qquad (13)$$

Therefore, we have obtained a relationship between the speed of the conveyor line and the distances between the robotic arm and the conveyor, as well as between the robotic arm and the places for unloading objects. As a result, knowing the readings of the sensors and the sorting algorithm, you can get the optimal speed of the conveyor belt, thereby reducing equipment wear and extending its service life.

4 Sorting process 3d model

To check the adequacy of the mathematical model for calculating the speed of the conveyor belt, as well as to visualize the process under study, a 3d model was developed in the ProgramLab software (Figure 5).

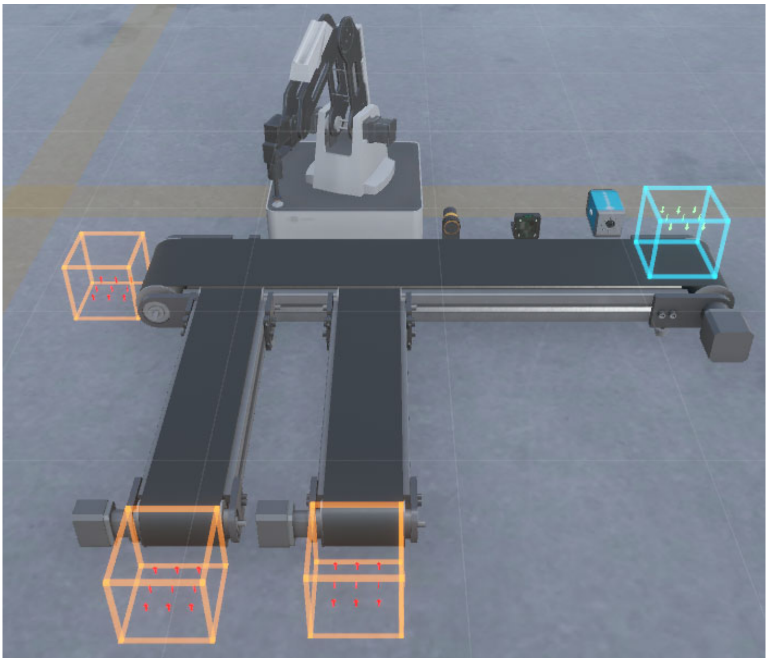

Fig. 5. The sorting system 3d model.

The sorting system being simulated [10-12] consists of a main conveyor and three distribution conveyors. To simulate the flow of objects entering the conveyor, an element called the Object Generator (the blue cube on the right side of the diagram) was added. Itcan create rectangular boxes with a random set of properties. They replace objects in the 3d model. Once created, the cuboid moves along the main conveyor belt. It passes through several sensors: a color sensor, a mass sensor and a diffuse photoelectric position sensor. In accordance with the information received from the sensors, the robot moves the box to one of the three branches of the conveyor according to the specified work algorithm described earlier. After that, the box hits an element called the Object Destroyer (one of the three orange cubes). Next, the Object Generator creates a new object with a random set of properties. The process is cyclical.

5 Improving the sorting process

It is necessary to find the optimal location of the places for unloading objects so that the unloading time is minimal. It is logical to assume that the unloading points should be located as close as possible to the robot and to each other. But physically, there may be difficulties associated with loading and unloading operations, emergencies, etc.

First, we impose restrictions on the process under consideration. Let the distance from the robot to the place of unloading in all three cases be not less than the fixed value "a". The value $a > 0$. The sorting algorithm corresponds to the one described earlier. The probability of an object hitting the conveyor for each of the three cases described in the algorithm is the same.

Consider three basic scenarios.

In the first scenario, the unloading points are located at the vertices of a regular triangle (Figure 6). The distance from each vertex to the robot is $a = 28$ cm. A full-scale experiment was carried out to unload three objects of different parameters. The unloading time was 12.4 s.

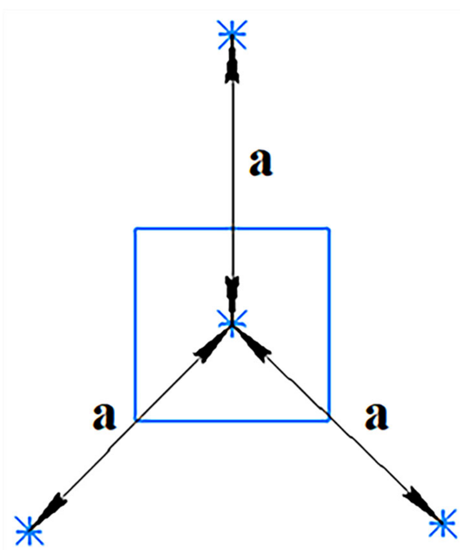

Fig. 6. Scenario №1.

In the second scenario, the unloading points are located on the same straight line (Figure 7). The distance from the central unloading point to the robot is a, the distance from the remaining two places is respectively greater than a. The distance between adjacent places of unloading was also taken equal to a. The total time of the full-scale experiment on sorting three different objects was 10.3 s.

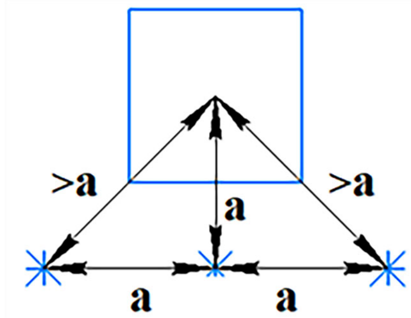

Fig. 7. Scenario № 2.

In the third scenario, the unloading points are located on a circular arc (Figure 8). The radius of the circle is a. The distance between adjacent places of unloading was also taken equal to a. The sorting time for this arrangement was 9.3 s.

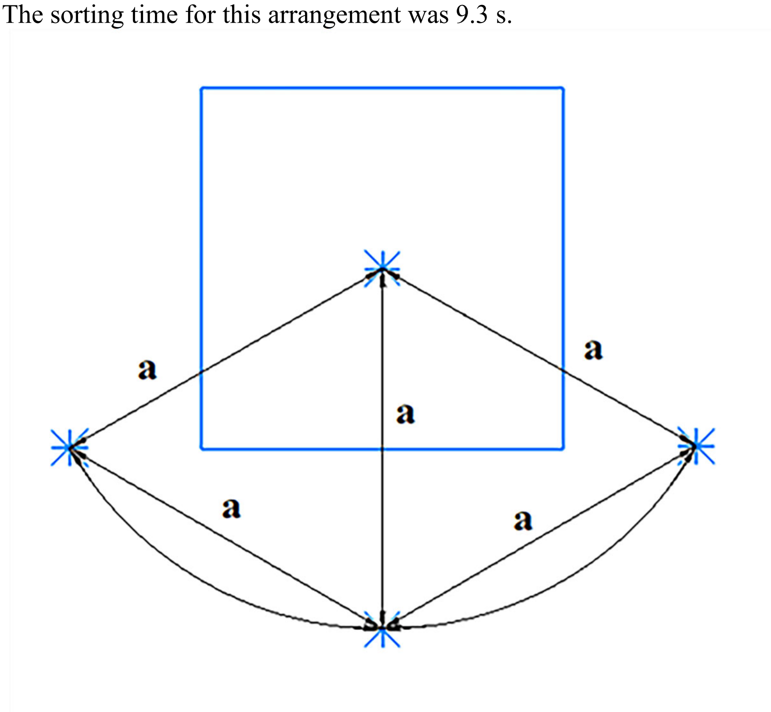

Fig. 8. Scenario №3.

Scenario No. 3 was recognized as the most profitable, since the sorting time for it turned out to be the smallest.

The resulting sorting system can be improved in several ways, for example, by using a delta robot as an actuator. The delta robot differs from other types of robots in its higher speed [13-15]. This allows it to excel in sorting and stacking a large flow of products. Also, the actual solution will be the introduction of a machine vision system.

6 Conclusion

In the present work, a sorting process control system has been developed. A mathematical model for calculating the conveyor speed is proposed. A 3d model of the sorting process has been developed. The sorting process has been improved. Three options for the location of sorting places are proposed and the most time-efficient option is found. The introduction of the designed control system will increase the speed of sorting, reduce the amount of defects in production, increase the safety and reliability of the conveyor line.

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