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A METHOD OF SORTING PARTS IN AN INTELLIGENT FACTORY BASED ON A MANIPULATOR WITH A PNEUMATIC GRIPPER IN COMBINATION WITH A COMPUTER VISION SYSTEM

Igor NEVLIUDOV[1], Serhii NOVOSELOV[1], Oksana SYCHOVA[1]

[1]Department of Computer-Integrated Technologies, Automation and Mechatronics, Faculty of Automatics and Computerized Technologies, Kharkiv National University of Radio Electronics, Kharkiv, Ukraine

ABSTRACT

This work presents the results of research in the field of automation of technological processes at a modern intelligent factory. A solution for improving the method of sorting parts on a production line using a manipulator with a pneumatic gripper in combination with a computer vision system is described. An analysis of the pneumatic scheme of the parts distribution station is carried out, the main pneumatic units of the production line are shown. Selected components for building a layout of an automated system for sorting parts on a production conveyor. Experimental studies were conducted to confirm the correctness of theoretical solutions. The model uses a manipulator with three degrees of freedom and a vacuum grip. The program uses the OpenCV library to perform the task of recognizing parts on the assembly line. Experimental studies have shown the correctness of the developed layout and program.

Keywords: Computer vision, conveyor, pneumatic gripper, Industry 4.0, Open CV.

1. INTRODUCTION

Conveyors are an integral part of production processes in various industries. The relevance of their application is determined by a wide range of advantages that they brought to the production process of the intelligent factory.

Conveyors significantly increase production productivity. The speed and automated nature of conveyor systems allow materials and products to be efficiently transported throughout the manufacturing process, reducing the time required to deliver parts from one machine to another, increasing production volume.

In modern intelligent factories, the use of robot manipulators in mechanical production is becoming an increasingly widespread solution. This makes it possible to create productions with a working shift of up to 24 hours a day without days off, which leads to a significant reduction in the cost of production, accelerates the investment payback period and reduces the impact of the human factor on the quality of manufactured products.

The purpose of this work is to improve the method of sorting parts on a production line using a manipulator with a pneumatic gripper together with a computer vision system.

The object of research in this work is the process of sorting parts on the production line.

The subject of the research is methods of sorting and recognizing the shape of parts using a computer vision system.

2. ANALYSIS OF THE CURRENT STATE OF AUTOMATION OF THE TECHNOLOGICAL PROCESS AT THE INTELLIGENT FACTORY USING CONVEYORS

The process of sorting parts on the assembly line, automated with the help of a control system, not only makes this process simple and accurate, but also reliable when using machine vision. This is because the automatic sorting machine replaces human vision and thinking with algorithms and software.

There are various methods of managing the sorting system [1-5]. The most common basic controller for this purpose can be an Arduino controller, a Peripheral Interface Microcontroller (PIC), a Raspberry Pi mini PC, or even a Programmable Logic Controller (PLC).

Computer vision systems are now considered an integral part of many industrial processes because they can offer fast, precisely reproduced control capabilities [1]. The implementation of automated systems for quality control of products produced by a manufacturing enterprise is a very urgent task, especially in the case of the implementation of the concept of Industry 4.0. Various additional software and hardware tools are used for this. For example, the use of a computer vision system to perform the tasks of monitoring assembly operations is currently very popular.

There are different types of sorting mechanisms. For example, there is a sorting mechanism that uses a pneumatic or hydraulic mechanism to separate parts using a robot with Delta kinematics and a sorting tray driven by a stepper motor or a servo motor (Fig. 1) [16].

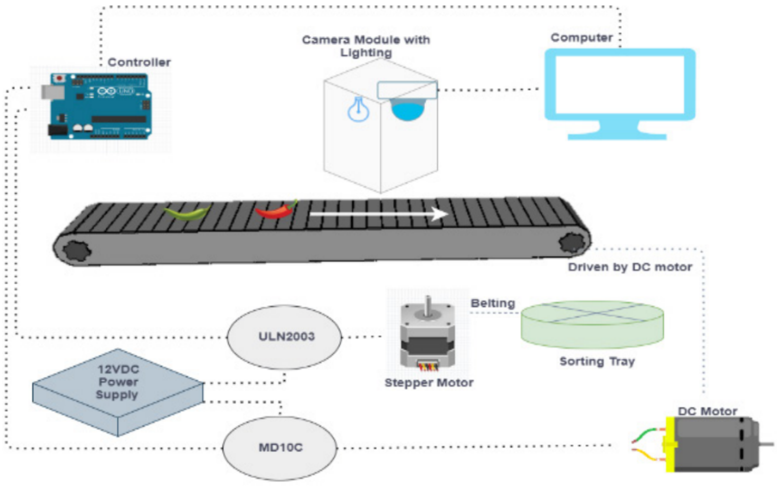


Figure 1. Structural diagram of the automated parts sorting system

A stepper motor is chosen for this circuit because it can be moved accurately and precisely according to the design requirements. The 12V stepper motor is driven by a ULN 2003 motor driver, which is commonly used as a driver circuit for relays, LED lights, and stepper motors.

Robotic goods sorting machines have begun to replace human operators in material recovery facilities (MRFs) and other processing centers. These machines rely on computer vision to identify the class of goods based on RGB images from specialized cameras. Advances in deep learning allow for the identification and separation of up to 95% of the target material on the assembly line. Fast robot manipulators are used to grab goods directly from the flow on the conveyor.

Parallel mechanisms are used to meet these needs. Thanks to the actuators located on the base of the robot, the dynamics of these designs are particularly high with reduced energy consumption compared to serial robots. In particular, Delta robots are among the fastest, cheapest and lightest robots for pick and place operations [17]. They are also easy to repair and dustproof.

A typical configuration for waste sorting is a Delta robot from ABB or Omron equipped with a suction cup. This solution is suitable for collecting light and flat waste (Fig. 2).

Figure 2. An example of a parallel manipulator robot

However, suction systems are far from energy efficient. In addition, for sorting heavy goods and objects with complex geometry or uneven surfaces, it is better to use grippers than suction cups. For example, heavy pickers from ZenRobotics can sort construction goods with a 3 DoF gantry robot equipped with a large gripper. In general, grippers are mounted on Cartesian or articulated robots, resulting in higher power requirements, lower speed and lower pick-up rates, typically 30 ppm, but also shorter life due to dusty environments.

3. ARCHITECTURE OF THE AUTOMATED SYSTEM

The general diagram of an automated system for sorting parts on a production line using a manipulator with a pneumatic gripper is shown in Figure 4.

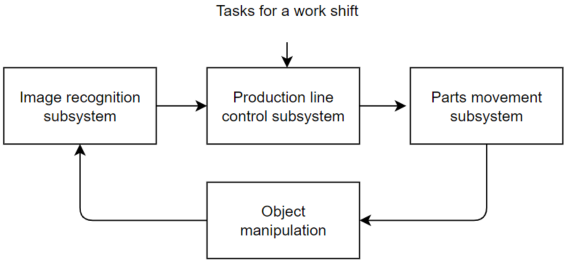


Figure 4 – The general scheme of the automated system for sorting parts on the production line using a manipulator

The automated system is a closed system with feedback built on the basis of the computer vision subsystem. The production line control subsystem receives the work shift task and issues commands to the parts movement subsystem.

The parts moving subsystem is built on the basis of a manipulator with a pneumatic gripper [6]. A computer vision subsystem is used to orient the links of the manipulator and position the working tool in the location of the part on the production conveyor. Figure 4 shows a detailed diagram of the construction of an automated system for sorting parts on a production line.

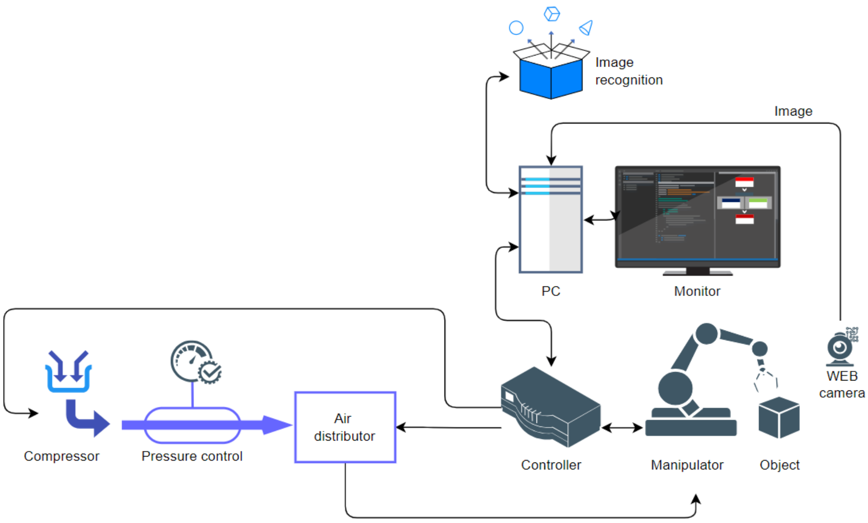


Figure 4. Automated system for sorting parts on the production line

The upper part of the diagram in Fig. 4 describes the image recognition subsystem based on the computer vision system. A WEB camera is used as an image input module. It is connected to a personal computer running a program for image analysis and contour selection of objects moving along the conveyor belt.

If the desired part is detected, the program displays the type of the found part and the coordinates of its center [7]. This information is used by the main controller to form commands to move the manipulator links.

The structural diagram of the manipulator control module is shown in Figure 5.

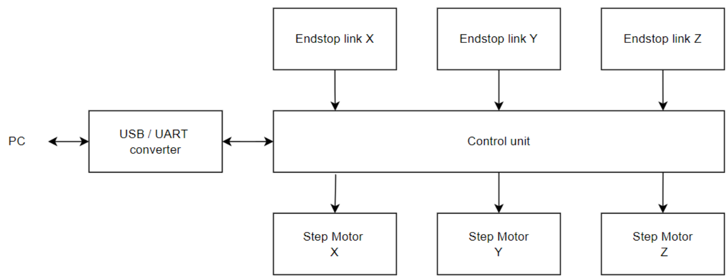


Figure 5. Structural diagram of the manipulator control module

In the automated system, a manipulator with three degrees of freedom is used, but it can be used with more [8, 9, 10]. Each link is controlled by its stepper motor:

– link X performs rotational movements around its axis;

– link Y is the middle lever of the manipulator responsible for moving forward, relative to the center of the device;

– the Z link moves up and down.

Each link has a limit switch. It is used during the initial calibration and during operation of the device. If the specified coordinates exceed the maximum permissible values, the program automatically turns off the device to avoid the destruction of structural elements.

The part is gripped using a gripper based on a pneumatic suction cup. It works thanks to compressed air. The lower part of the scheme (Fig. 4) is responsible for controlling the gripper operation.

Figure 6 shows the structural diagram of the subsystem of pneumatic gripping of parts.

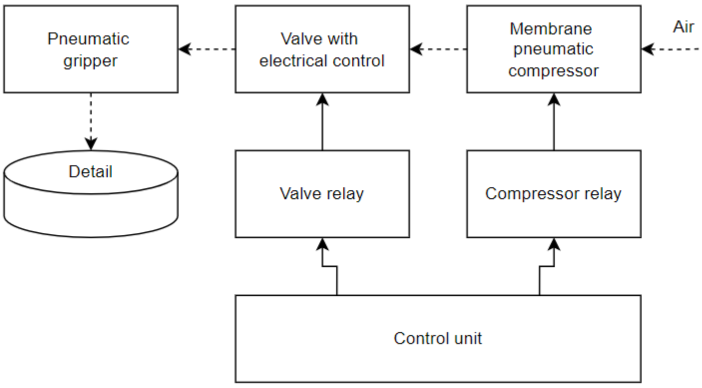
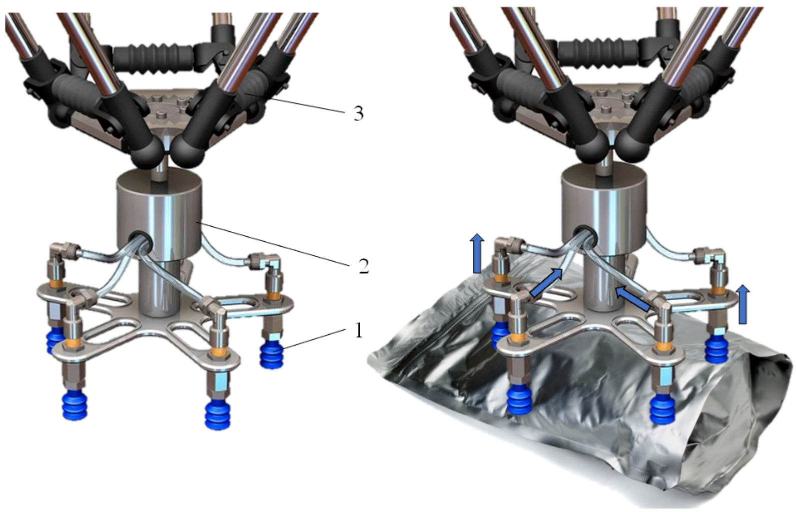


Figure 6. Structural diagram of the pneumatic parts gripping subsystem

With the help of a compressor, compressed air is generated, which enters the main line and further on the executive device of the automated system. Compressed air is controlled by a special distributor with a built-in DC relay.

The control unit sends commands to turn on the operation of the pneumatic compressor through the appropriate relay. After that, the compressed air enters the electric valve. The valve is also controlled by commands from the control unit, depending on the program embedded in it. When the relay is activated, air passes through special channels of vacuum capture and creates a discharged environment. Thanks to this, the gripper can hold the parts when moved. Fig. 7 shows an example of the implementation of a pneumatic gripper based on suction cups.



a) b)

1 – bellows suction cup with 2.5 corrugations; 2 – housing for placing the ejector;
3 – kinematic tripod links

Figure 7. General view of the output functional unit of the tripod manipulator: a) non-working position;

b) conditions during the technological operation

4. HARDWARE IMPLEMENTATION OF THE LAYOUT FOR PARTS SORTING ON THE PRODUCTION LINE

Figure 8 shows the assembled part of the layout responsible for the production and distribution of compressed air.

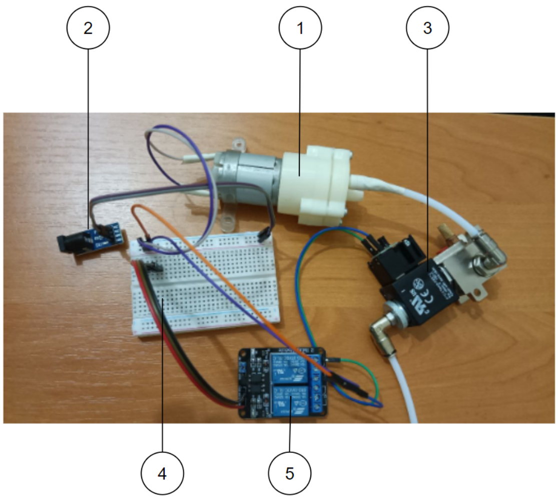


Figure 8. The assembled part of the layout responsible for the production and distribution of compressed air

Figure 8 shows the following layout components:
– membrane compressor (1);
– connector for connecting the 12V power supply voltage (2);
– electropneumatic distributor with relay (3);
– breadboard (4);
– compressor switch-on relay (5).

The ARC145 diaphragm pump was chosen as the compressed air compressor. This device is designed for pumping liquid, but it can also create compressed air in small volumes. The approximate power is 100 kPa, which is enough to solve the given problem. The device uses a DC motor with a supply voltage of 12 V. The minimum voltage at which the pump starts to work is 6-7 V.

An example of attaching a vacuum gripper to a manipulator is shown in Fig. 9 [12].

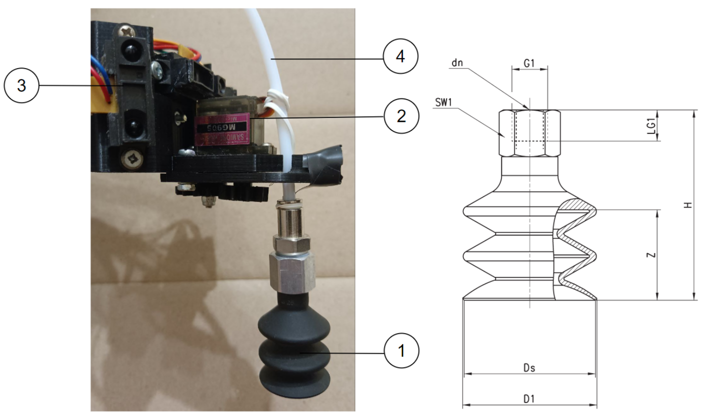


Figure 9. An example of attaching a vacuum gripper to a manipulator

The dashed line shows the following layout components:
– vacuum suction cup (1);
– gripper servo motor (2);
– sensors of the intelligent obstacle avoidance and part detection system (3);
– compressed air supply tube (4).

Fig. 10 shows the general view of the assembled layout of the automated parts sorting system on the production line [11].

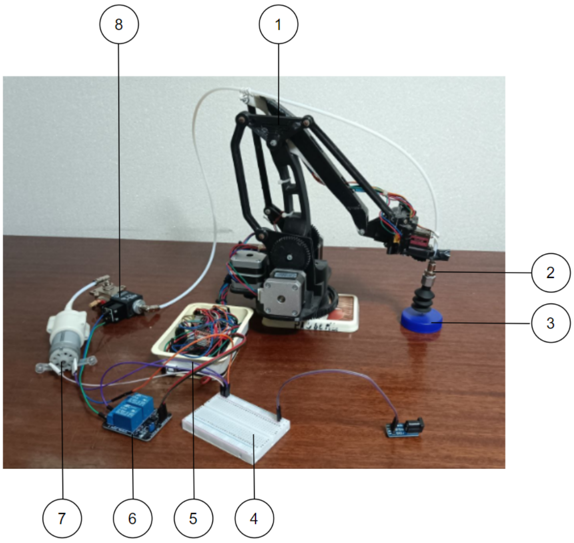


Figure 10. General view of the assembled layout of the automated parts sorting system on the production line

The layout includes the following components:
– layout of an industrial manipulator (1);
– vacuum gripper in the form of a suction cup (2);
– detail (3);
– mock-up circuit board (4);
– layout control unit (5);
– compressor relay (6);
– compressor (7);
– electropneumatic distributor (8).
The layout control unit is made on the basis of an Arduino Uno board using three A4988 stepper motor drivers with a cooling radiator.

5. EXPERIMENTAL STUDIES OF THE PERFORMANCE OF THE PROPOSED METHOD

The Python programming language was chosen for the development of the program for recognizing the shape of parts on the production line. OpenCV [13] is used as an image recognition library. OpenCV and the numpy library can be used to recognize the shape of parts using a webcam and determine the center of the part on a gray background. In the program example below, the parts are recognized by their shape (triangle, quadrilateral or circle) and their center is also displayed.
At the beginning of work, it is necessary to initialize the web camera to receive a video image. The generated code uses a webcam to read frames and display the results of part shape recognition. Fig. 11 shows the beginning of the function of recognizing the shape of parts on the conveyor.

```
def recognize_shape(img):
    # Перетворення зображення у відтінки сірого
    gray = cv2.cvtColor(img, cv2.COLOR_BGR2GRAY)

    # Виділення синього кольору
    lower_blue = np.array([100, 0, 0])
    upper_blue = np.array([255, 70, 70])
    mask = cv2.inRange(img, lower_blue, upper_blue)

    # Знаходження контурів на зображенні
    _, threshold = cv2.threshold(mask, 240, 255, cv2.THRESH_BINARY)
    contours, _ = cv2.findContours(threshold, cv2.RETR_EXTERNAL, cv2.CHAIN_APPROX_SIMPLE)
```

```
for contour in contours:
    # Інтерполяція контуру для знаходження апроксимації
    epsilon = 0.02 * cv2.arcLength(contour, True)
    approx = cv2.approxPolyDP(contour, epsilon, True)

    # Знаходження центру масиву точок
    M = cv2.moments(contour)
    if M["m00"] != 0:
        cx = int(M["m10"] / M["m00"])
        cy = int(M["m01"] / M["m00"])

        # Визначення форми
        if len(approx) == 3:
            shape = "Triangle"
        elif len(approx) == 4:
            shape = "Rectangle"
        else:
            shape = "Circle"

        # Виведення форми та центру на зображенні
        cv2.drawContours(img, [approx], 0, (0, 255, 0), 2)
        cv2.putText(img, shape, (cx - 20, cy - 20), cv2.FONT_HERSHEY_SIMPLEX, 0.5, (255, 255, 255), 2)
        cv2.circle(img, (cx, cy), 5, (0, 0, 255), -1)
```

Figure 11. An example of a function for recognizing the shape of a part

At the beginning of work, the received image is converted into shades of gray:

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```
gray = cv2.cvtColor(img, cv2.COLOR_BGR2GRAY).
```

The image is converted to grayscale using the cv2.cvtColor function. For testing the program, the condition is accepted that the details to be sorted should be blue in color. Highlighting the blue color is done using a mask:

```
lower_blue = np.array([100, 0, 0])
upper_blue = np.array([255, 70, 70])
mask = cv2.inRange(img, lower_blue, upper_blue)
```

A mask is created that selects areas of blue color in the image. cv2.inRange defines the pixels that fall within the specified color range. Finding contours on the image is as follows:

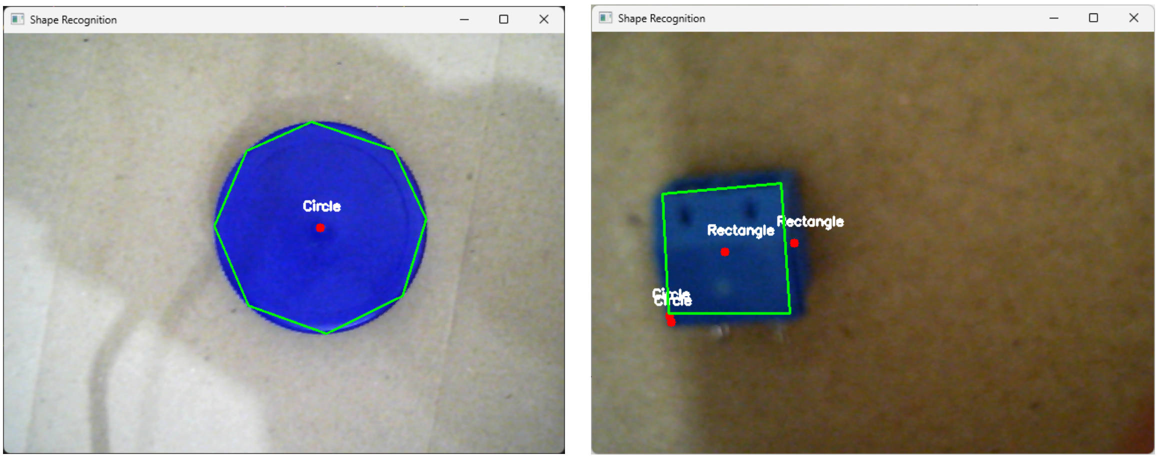
```
_, threshold = cv2.threshold(mask, 240, 255, cv2.THRESH_BINARY)
contours, _ = cv2.findContours(threshold, cv2.RETR_EXTERNAL, cv2.CHAIN_APPROX_SIMPLE)
```

The mask image is passed through a threshold function and then the cv2.findContours function is used to find the contours of the regions that exceed the threshold.

As a result of the work of this code fragment, we get an indication of the shape of the part (triangle, rectangle or circle) and the determined coordinates of the center of the part [14, 15]. The coordinates are necessary for positioning the working tool of the manipulator with a vacuum suction cup.

Fig. 12 shows an example of the part shape recognition program. In the case shown in Fig. 12, it is determined that the shape of the part is round. In this way, the manipulator control program gives the command to grip the part with a pneumatic gripper and transfer it to the corresponding zone on the conveyor.

The detail in Fig. 12, b has the shape of a rectangle. In this technological process, this is a connector. Thus, the control program gives the command to transfer the specified part to another area of the conveyor line.



a) b)

Figure 12. Determination of the part in the shape of a circle (a), and Determination of the shape of the connector (b)

Thus, the conducted experimental studies showed the correctness of the developed program.

6. CONCLUSION

Similar solutions were analyzed and the structural diagram of the automated parts sorting system based on the Arduino controller was considered. Also, as an analogue, the principle of operation of the automated production module for the distribution of parts with the use of pneumatic grippers is considered. An analysis of the pneumatic scheme of the parts distribution station is carried out, the main pneumatic units of the production line are shown. Selected components for building a layout of an automated system for sorting parts on a production conveyor.

On the basis of the acquired knowledge, the design of an automated system for sorting parts was carried out; an algorithm for determining the shape of parts and a computer vision system were developed, and a program for automated recognition of parts on an industrial conveyor was developed.

Experimental studies were conducted to confirm the correctness of theoretical solutions. Experimental studies have shown the correctness of the developed program. However, in the process of research, the shortcomings of the developed model were revealed. One of the main disadvantages is insufficient and unique lighting parameters. This leads to the impossibility of using pre-selected filter parameters in the program. It is necessary to carry out calibration anew at the beginning of each experiment.

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