

Design of a Waste Wire Sorting Control System

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Abstract: This paper presents a waste wire and cable sorting system based on machine vision and PLC control. An industrial camera is used to capture images of waste wires, and an OpenCV-Python program is used to recognize four wire colors, including red, yellow, blue, and black. After the color is identified, the PLC sends the control signal to a three-axis robotic arm, which picks up the wire and places it in the corresponding area. An intelligent mobile vehicle is then used to transport the sorted wires. The system combines image recognition, PLC control, robotic sorting, and material transportation to reduce the amount of manual work involved in wire sorting. Experimental tests were carried out to check the recognition and sorting performance of the system. The results show that the system can recognize the four target colors and complete the corresponding sorting operations under the test conditions. The system is divided into four parts: wire detection and recognition, PLC control, robotic sorting, and transportation. The experimental results also show that the machine vision method can be used together with PLC control for waste wire sorting, and the system can provide a basis for further improvement and practical application.

Keywords: Machine vision; waste wire sorting; PLC control; intelligent mobile vehicle.

1. Introduction

In recent years, more and more waste electrical wires and cables have been produced. Sorting these materials by hand takes a lot of time, and mistakes can easily occur when there are many wires to deal with. To solve this problem, this study designs a waste wire sorting system that combines a camera, PLC control, and an intelligent transport vehicle. The system is used to recognize four colors of waste wires, namely red, yellow, blue, and black. After the wires are identified, they are sorted and sent to different areas. The main purpose of the system is to reduce the amount of manual work and make the sorting process faster and more consistent. It is mainly intended for small- and medium-sized recycling applications.

The basic idea of machine vision sorting is to let a camera obtain information from the waste materials and then use a computer to process the captured images. In the case of waste wires, color and shape can be used as important features for recognition. After the image has been processed, the sorting equipment uses the recognition result to decide where the wire should be sent [1]. Compared with a person checking the wires one by one, this method can process the image automatically and can also provide the position information needed for the following sorting operation.

Research on this type of system in China started later than in some other countries, but it has developed quite quickly. Since around 2010, the use of machine vision in waste sorting has received more attention with the development of environmental protection and automated production. Existing studies in China have mainly looked at image recognition, sorting machines, PLC control, and automatic transportation [2]. Chen Yu, for example, studied a sorting method based on color and used image processing to recognize the color and shape of waste wires [3]. Qiao Jianping developed a PLC-controlled color sorting system and combined it with an industrial robot [4]. Chen Yuanyuan et al. studied an AGV controlled by a PLC for automatic material transportation [5]. These studies cover different parts of the sorting process. They also show that the research is gradually moving from a

single sorting device toward a system that can complete recognition, sorting, and transportation together.

Research in other countries began earlier. Since the 1990s, machine vision has been used in industrial automation and some waste sorting applications in Europe and the United States [6]. In some systems, cameras are used together with infrared or ultrasonic sensors so that more information about the material can be obtained. Deep learning methods have also been used in some recent studies for automatic classification [7]. Pitney Bowes developed a sorting robot system that combines visual recognition with industrial robots and scheduling functions [8]. Siemens has also carried out work related to industrial automation, including improvements in energy use and system operation efficiency [9].

From the existing studies, it can be seen that waste sorting systems are gradually using more automatic recognition and control methods. At the same time, the equipment used for sorting is becoming more closely connected with transportation and other parts of the system. However, a system does not always need a complicated structure to complete a relatively simple sorting task. For this reason, this study focuses on a more straightforward combination of machine vision, PLC control, robotic sorting, and intelligent transportation. The aim is to develop a system that can complete the required wire sorting work while keeping the overall structure and control process relatively simple.

2. Scheme Design and Selection

2.1. General Design Principles and Approach

The main purpose of this design is to develop an integrated control system for automatic waste wire identification, sorting, and transportation. The system is divided into four main parts: a detection and recognition module, a control module, a sorting and execution module, and a transfer module. These modules work together to complete the processes of wire color identification, accurate sorting, and classified transportation. The overall operating process of the system is illustrated in Figure 1.

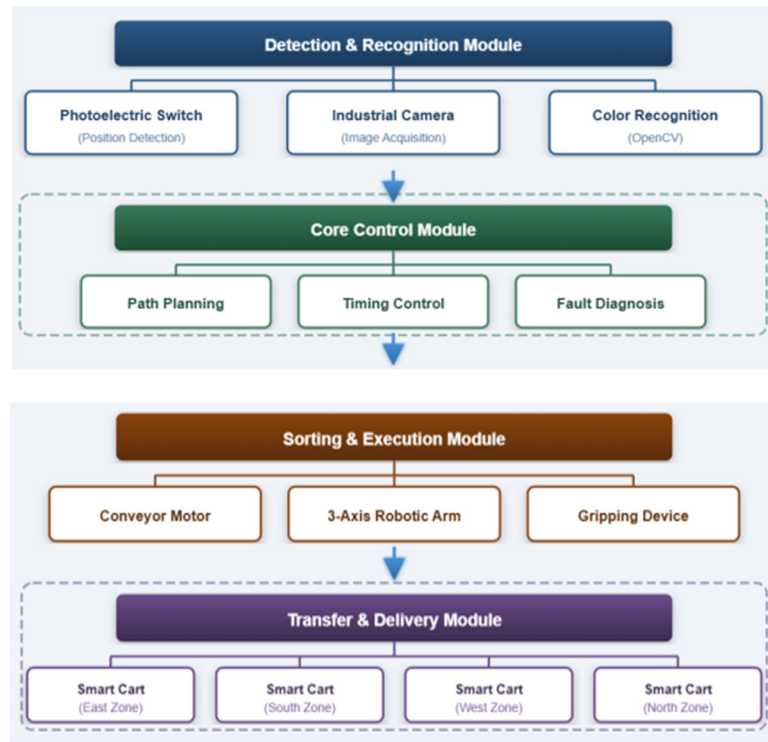


Figure 1. Overall System Workflow Diagram

2.2. Design and Selection of Control Scheme

Since waste wire sorting equipment usually works in industrial environments with considerable electromagnetic interference, the control system needs to have good stability and reliability. Therefore, PLC is selected as the main controller in this design. Its strong anti-interference performance and reliable operation make it suitable for industrial applications. In addition, the modular structure makes maintenance and future expansion more convenient, while ladder logic simplifies the implementation of control programs. PLCs also have good compatibility with other industrial devices, which facilitates system integration [10].

This design adopts the Siemens S7-300 series PLC, which is a classic modular medium-sized PLC. It features extremely high reliability, strong anti-interference capability, modular design for easy expansion, rich communication protocols (supporting PROFIBUS-DP, PROFINET, Modbus, etc.), and abundant accessories and reference cases for convenient maintenance.

2.3. Color Recognition Scheme Selection

Python and OpenCV were chosen for the vision part of the system mainly because they can meet the recognition requirements of the experiment. The system needs to tell the difference between red, yellow, blue, and black wires. Among these colors, red and yellow can sometimes be difficult to separate when the lighting changes, so the image needs to be processed rather than relying only on a simple color sensor. Another reason for using a camera is that the system needs to know not only the color of a wire but also where it is located on the conveyor belt. This information can then be used to determine the position at which the robotic arm should pick up the wire. OpenCV also provides many image processing functions, which makes it possible to make further changes to the recognition method if the current system needs to be improved. For the requirements of this project, the Python and

OpenCV combination is therefore sufficient for completing the basic wire recognition task and provides some room for later modification.

2.4. Sorting and Transfer Scheme Selection

After comparing the different parts of the system, the sorting and transportation method was finally decided.

A three-axis Cartesian robotic arm is used for sorting. A pneumatic gripper is installed at the end of the arm to pick up the waste wires. The arm moves in three directions and can reach the required position on the conveyor belt. Servo motors are used to control its movement. Compared with a six-axis robotic arm, the three-axis arm has a simpler structure and is easier to control. It also costs less. For the wire picking and placing work in this project, the three-axis arm is enough to complete the required actions [11].

Four intelligent vehicles are used to move the sorted wires. They are assigned to four storage areas in the east, south, west, and north directions. Magnetic strips are placed on the floor, and the vehicles follow these strips to move along the planned routes. This method does not require a complicated navigation system and is relatively easy to set up and adjust [11].

The sorting process is carried out in several steps. First, the robotic arm picks up a waste wire after its color has been recognized. It then puts the wire onto the vehicle assigned to that color. After receiving the loading signal from the control system, the vehicle starts moving and carries the wire to the corresponding storage area. When the wire is unloaded, the vehicle returns to its original position and waits for the next instruction.

The four vehicles are controlled by the PLC. When more than one vehicle needs to move at the same time, the PLC uses a preset priority order to arrange their movements and reduce the chance of vehicles meeting on the same route. The main structure and working process of the whole system are shown in Figure 2.

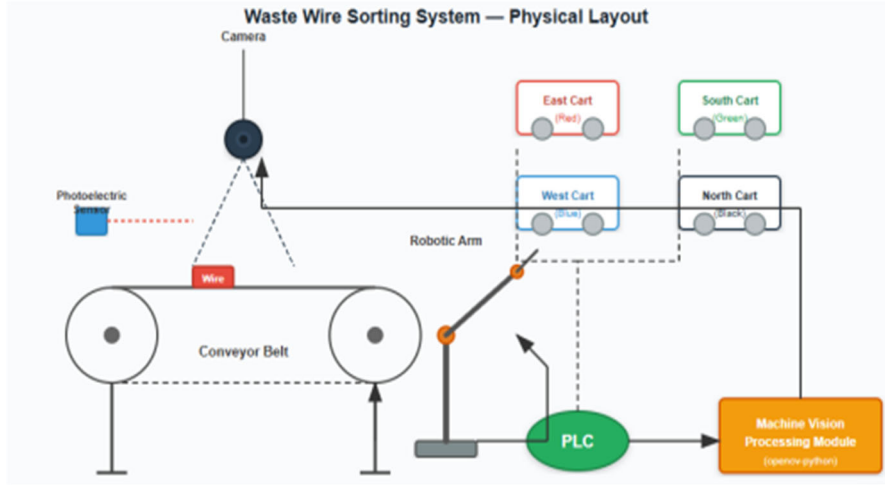


Figure 2. Sorting System Schematic Diagram

3. Machine Vision Recognition Module

3.1. Camera Calibration

Camera calibration is an important step in a machine vision system because it affects the accuracy of target positioning. Its main purpose is to reduce lens distortion and establish the coordinate relationship between image pixels and the robot workspace [12].

In this design, a nine-point calibration method is used. Nine reference points are arranged on the sorting table, as shown in Figure 3. The robotic arm moves to each point in sequence and records its physical coordinates, while the camera obtains the corresponding pixel coordinates. These two sets of coordinates are then used to calculate the transformation parameters and generate the calibration file. The calibration error must remain within the required range to ensure reliable positioning accuracy [13].

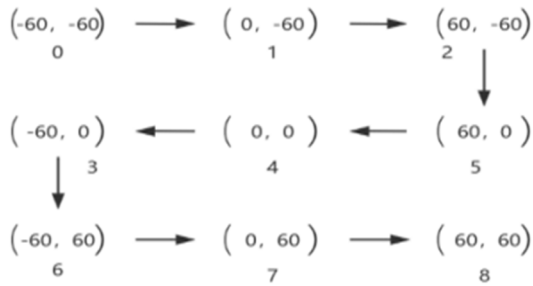


Figure 3. Schematic Diagram of 9-Point Calibration Positions

3.2. Color Space Conversion

Image quality can be affected by camera characteristics and changes in ambient lighting, resulting in noise and color deviations. Therefore, image preprocessing is necessary before visual recognition. In this design, the preprocessing procedure mainly includes color space conversion, Gaussian filtering, image segmentation, and morphological processing.

RGB is widely used for image representation, but its color components are strongly affected by brightness. Changes in illumination can therefore cause significant variations in RGB values, reducing the reliability of color recognition [14]. To improve this problem, the HSV color space is adopted. HSV separates color information from brightness through Hue, Saturation, and Value components. The Hue component is

relatively less affected by illumination, making HSV more suitable for color-based wire recognition under different lighting conditions [15].

3.3. Image Segmentation Processing

In the vision part of the system, color thresholding is used to separate the waste wires from the background. The captured image is first converted into the HSV color space. The cv2.inRange function is then used to keep the pixels that fall within the selected color range. A binary mask is obtained after this operation. Some small unwanted areas may still remain in the mask, so erosion and dilation are performed using cv2.erode and cv2.dilate. After this processing, the wire regions are easier to distinguish and the shape of the detected area is more complete.

The threshold values in Table 1 were selected according to the samples used in the experiment. They were not simply taken from standard values found in other examples. During the adjustment process, the four kinds of wires were placed on the sorting platform several times. Their positions and directions were changed so that the images would not all have the same appearance. More than 50 images were collected with the industrial camera under the normal working light. These images were converted to HSV, and the H, S, and V values of the different wire colors were observed. The observed ranges were then used to set the first group of threshold values.

The first set of values was not used directly as the final result. Several segmentation tests were carried out, and the binary images were checked after each adjustment. If part of a wire was missing, the corresponding threshold range was increased. If too much of the background was detected, the range was reduced. Reflections and shadows on the wire surface were also considered during this process. The parameters were adjusted repeatedly until the four colors could be separated with relatively little overlap. Red and yellow required more adjustment because their segmentation results changed more noticeably under different lighting conditions.

Finally, the selected parameters were checked with another 30 groups of samples. The results were compared visually to determine whether the same thresholds could be used for samples at different positions. After the parameters were confirmed, they were added to the recognition program. Red was handled separately because its hue is located at both ends of the HSV scale. Therefore, the program uses two ranges, 0–

10° and 170–180°, to detect red. This helps retain red pixels that would otherwise be excluded when only one continuous

hue range is used.

Table 1. HSV Color Threshold Ranges

color	H_min	H_max	S_min	S_max	V_min	V_max
red	0/170	10/180	120	255	70	255
yellow	20	30	100	255	100	255
blue	90	120	100	255	100	255
black	0	180	0	255	0	46

3.4. Edge Feature Extraction

Several operators can be used for edge detection, including the Roberts, Sobel, and Canny operators. Considering the requirements of this system, the Canny operator is selected because it can effectively detect the boundaries of waste wires while maintaining relatively good noise resistance [16]. The main processing procedure consists of the following five steps:

(1) **Gaussian Filtering:** The input image is smoothed with a Gaussian filter to reduce noise and suppress small fluctuations that may interfere with subsequent edge detection.

(2) **Gradient Calculation:** The Sobel operator is used to calculate the first-order derivatives of the image in the horizontal and vertical directions. Based on these results, the gradient magnitude and direction of each pixel are obtained [17].

(3) **Non-Maximum Suppression:** The pixels along the gradient direction are examined, and only local maximum points are retained. This step removes redundant pixels and makes the detected edges thinner and clearer.

(4) **Double Threshold Processing:** A high threshold and a low threshold are introduced to classify the detected pixels.

Pixels above the high threshold are regarded as strong edges, while those below the low threshold are removed. Pixels between the two thresholds are temporarily treated as weak edges.

(5) **Edge Linking:** Weak edges connected to strong edges are retained, while isolated weak edges are discarded. In this way, relatively continuous and complete edge contours can be obtained.

In the OpenCV-Python environment, the Canny algorithm can be implemented directly using the `cv2.Canny()` function, which simplifies the development of the image processing program.

3.5. Recognition Process and Results

The program flow of the machine vision recognition module includes: image acquisition, image preprocessing (color space conversion, Gaussian filtering), image segmentation (threshold segmentation, morphological processing), color judgment (comparison with HSV ranges), contour detection, and coordinate calculation (centroid computation using `cv2.moments`). The flowchart is shown in Figure 4.

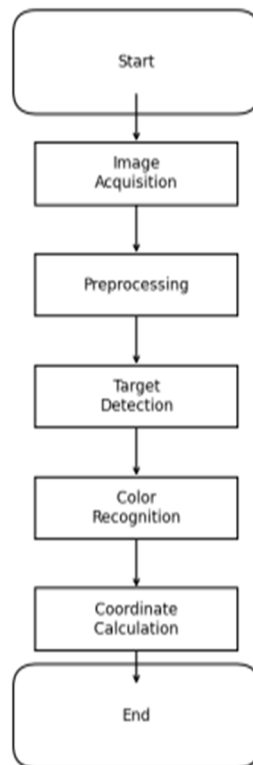


Figure 4. Machine Vision Recognition Flowchart

(1) Image Acquisition: Real-time video frames are captured via an industrial camera or DroidCam.

(2) Image Preprocessing:

Gaussian Filtering: A 5×5 Gaussian kernel is used to eliminate image noise.

Color Space Conversion: The RGB image is converted into

the HSV color space.

(3) Target Detection:

Contours are searched within the mask image using the `cv2.findContours()` function.

The area of each contour is calculated; noise contours with an area smaller than the threshold (`MIN_CONTOUR_AREA = 500`) are excluded. For contours meeting the criteria, their geometric center coordinates are computed.

(4) Color Recognition:

For each target color, a mask image is generated based on the preset HSV threshold range.

Morphological processing (erosion + dilation) is performed on the mask image to remove noise.

The Canny operator is used to extract contour edges.

(5) Coordinate Calculation:

The `cv2.moments()` function is used to calculate the moments of the contour, from which the centroid coordinates are derived. Centroid coordinate calculation formulas:

$$cx = M10/M00 \quad (1)$$

$$cy = M01/M00 \quad (2)$$

(6) Result Output:

The recognition results (bounding box, center point, and color label) are drawn on the original image. The color code and coordinate information are transmitted to the PLC; the code recognition results are shown in Figure 5.

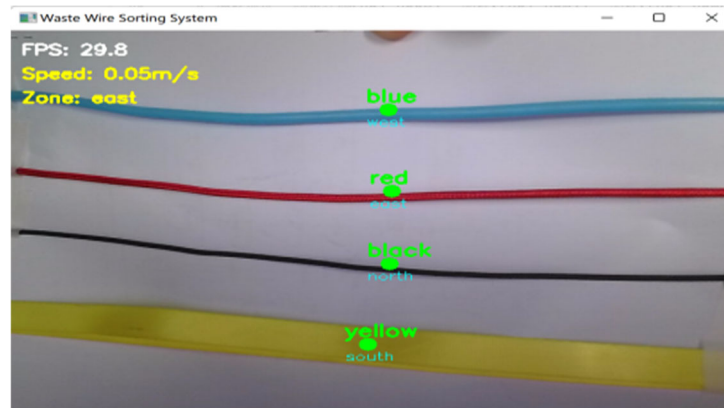


Figure 5. Schematic Diagram of Code Recognition Results

4. Experiments and Results Analysis

4.1. Experimental Objectives

An experimental test was carried out to evaluate the performance of the waste wire sorting system in a working environment. The test mainly examined three aspects: the recognition of different wire colors, the success of robotic arm picking and sorting, and the transportation of sorted wires to the designated areas. These results were used to assess the overall operation of the automatic sorting process.

The experimental system uses a Siemens S7-300 PLC as the main controller. An OpenCV-Python program is responsible for color recognition, while a three-axis robotic arm performs the picking and sorting operation. After sorting, intelligent vehicles transport the wires to the corresponding storage areas. Through the cooperation of these units, the complete process from wire image acquisition and color identification to grasping, sorting, and transfer can be tested under the same experimental conditions.

4.2. Experimental System Composition

The experimental platform is mainly composed of four functional modules: the detection and recognition module, core control module, execution and sorting module, and transfer and distribution module. The detection and recognition module includes an industrial camera, photoelectric sensors, and an image acquisition unit. It is mainly used to detect the arrival of waste wires and obtain their color information.

The core control module uses a Siemens S7-300 PLC as the main controller, which coordinates the operating sequence and timing of the different devices. The execution and sorting module consists of a three-axis robotic arm and a gripper for

picking up and placing the waste wires. The transfer and distribution module contains four intelligent vehicles, which transport the sorted wires to their corresponding storage areas. Through the cooperation of these four modules, the main functions of detection, recognition, sorting, and transportation can be completed.

4.3. Experimental Methods

The hardware test is mainly used to check whether the different devices can work together as expected. During the test, waste wire samples are transported to the detection area by the conveyor belt. When the photoelectric sensor detects the arrival of a sample, it sends a signal to trigger image acquisition by the industrial camera. The captured image is converted into the HSV color space, after which OpenCV performs color segmentation and determines the wire category. According to the recognition result, the PLC sends the corresponding control commands to the three-axis robotic arm. The arm then picks up the wire and places it in the assigned sorting area, after which the corresponding intelligent vehicle transports it to the target location.

The software test is mainly concerned with the reliability of color recognition and the response of the control program. The visual processing program is developed with OpenCV-Python and includes image denoising, HSV conversion, threshold segmentation, and contour extraction to identify the wire color. The PLC program is developed and debugged in STEP 7. Communication between the vision processing system and the PLC is established through PROFINET, allowing the recognition results to be transmitted to the control system in time and supporting the coordinated operation of the entire sorting process.

4.4. Experimental Parameters and Test Conditions

The experiment used four colors of waste wires: red, yellow, blue, and black. For each color, at least 30 sets of samples were prepared, giving a total of 120 sets for the tests. During the experiment, the conveyor belt was operated at a speed of 0.2 m/s, and the robotic arm performed the picking operation according to a fixed working cycle. The intelligent vehicles moved along their preset routes to complete the transportation of the sorted wires. The main experimental parameters are given in Table 2.

The experiments were carried out indoors, where the surrounding conditions were kept as stable as possible. A Basler acA2440-75uc industrial camera was installed above the sorting platform. The camera has a 5-megapixel sensor, a resolution of 2448×2048 pixels, and a maximum frame rate of 75 fps. Its optical axis was set nearly perpendicular to the surface of the conveyor belt. The distance from the camera lens to the belt was kept at approximately 60 cm throughout the experiment.

Lighting was also considered because changes in ambient light can affect the recognition of wire colors. An XX W white LED strip was placed above the sorting area as an additional light source. The position of the LED strip and its lighting conditions were kept unchanged during the tests as much as possible. This helped reduce the effect of changes in the surrounding light on the camera images.

The test samples were waste wires and cables collected from recycling stations and separated according to their colors. Each cable had an outer diameter of about 6 mm and a length of 24 cm for a single section. The outer sheath was made of polyvinyl chloride (PVC), while the conductor inside was copper. There were at least 30 sample sets for each color, resulting in 120 sets in total. Before testing, wires with serious surface damage or a large amount of oil contamination were removed. This was done to avoid large differences in the surface color of the samples. The conveyor belt speed was set to 0.2 m/s. At this speed, the cables showed no obvious motion blur in the camera's field of view when the photoelectric sensor triggered image acquisition.

Table 2. Main Experimental Parameter Settings.

Parameter Name	Parameter Value
Recognition Object	Red, yellow, blue, and black waste wires
Sample Quantity	30 groups or more per category
Control Core	Siemens S7-300 PLC
Vision Platform	OpenCV-Python
Actuator	Three-axis robotic arm + gripper
Transfer Method	Four intelligent vehicles for zoned transfer
Communication Method	PROFINET

4.5. Experimental Results and Analysis

The experimental statistical results show that the system achieves high recognition accuracy for all four categories of waste wires, and the robotic arm grasping process is stable with no obvious missed or mis-grasping phenomena. In the

overall experiment, the system can complete automatic identification and sorting according to color categories, with continuous sorting process and coordinated actions, indicating that the linkage between visual recognition and PLC control is relatively reliable. Table 3 presents the experimental result statistics.

Table 3. Waste Wire Sorting Experimental Result Statistics.

Color Category	Recognition Accuracy	Sorting Success Rate
Red	96.7%	95.0%
Yellow	95.0%	93.3%
Blue	98.3%	96.7%
Black	96.7%	95.0%
Average	96.7%	95.0%

The experimental results indicate that the sorting system operated relatively steadily throughout the tests. The HSV-based color recognition method was able to distinguish the four types of waste wires under the given experimental conditions. At the same time, the cooperation between the three-axis robotic arm and the intelligent vehicles completed the subsequent sorting and transfer tasks, showing that the proposed system can be applied to small- and medium-scale waste wire sorting.

The test results show that machine vision, PLC control, and the robotic arm can work together in the same sorting system. The control process does not require a complicated structure, which is enough for the sorting tasks used in this study. Compared with manual sorting, the system can run continuously and keep the sorting process more consistent. A three-axis robotic arm was selected instead of a six-axis arm. Since the wires mainly need to be picked up and placed in

different positions, the extra degrees of freedom of a six-axis arm are not necessary for the tasks in this system. The three-axis arm therefore meets the basic requirements of the experiment.

There were also some problems during the tests. Changes in the surrounding light had an effect on the recognition results, especially when strong light was reflected from the surface of the wires. In these situations, the detected color could change and lead to incorrect recognition. This shows that the vision part of the system is still sensitive to the lighting conditions. In further work, the position and intensity of the auxiliary light can be adjusted. The image preprocessing and color segmentation methods can also be improved. These changes may help the system obtain more stable results when the lighting conditions are different from those used in the current experiment.

5. Conclusion

This study developed a waste wire sorting system using machine vision and PLC control. The system consists of an industrial camera, an OpenCV-Python color recognition program, a three-axis robotic arm, and an intelligent vehicle. The camera is used to collect images of waste wires on the conveyor belt, and the OpenCV program identifies the wire colors based on HSV color segmentation. After the color is identified, the PLC sends the corresponding control signal to the robotic arm. The arm then picks up the wire and puts it into the assigned area, while the intelligent vehicle is used to transfer the sorted wires. The system mainly deals with four wire colors: red, yellow, blue, and black.

The experimental results showed that the average recognition accuracy was 96.7%, and the sorting success rate was 95.0%. During the tests, the HSV method was able to distinguish the four wire colors under normal lighting conditions. The robotic arm also completed the picking and placing operations according to the recognition results. However, changes in lighting and reflections on the wire surface sometimes affected the recognition results. These problems caused a small number of errors during the experiments. Therefore, the system still needs further improvement. In future work, the lighting conditions and image preprocessing method can be adjusted to improve recognition stability. More types of waste wires can also be tested to make the system more suitable for practical sorting environments.

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