

RFID-Based Intelligent Storage and Retrieval Systems in Automated Warehouse

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Abstract—In order to improve the storage/retrieval efficiency of automated warehouse, robot technology was applied into the design of warehouses. Firstly, the RFID system is used to locate the target roughly and to obtain the attributes of the target. Then the vision mounted on the robot is used to recognize and locate the target precisely. Finally, the teaching mode and remote mode are used flexibly to assist robot to grasp the target. The combination of these two modes can not only reduce the complexity of robot control, but also can make full use of the results of image processing. Experiments demonstrate the feasibility of the proposed system.

Index Terms—automated warehouse, intelligent storage and retrieval systems, RFID, robot vision, robot control

I. INTRODUCTION

The warehouse, which can improve the efficiency of storage and transportation of goods, is widely used in different kinds of corporations. The current warehouses which are often operated manually usually include palletizing robots, carton flow order picking systems, automated guided vehicles, rotary storage cabinets, and automated storage and retrieval systems (AS/RSs) [1,2,3]. The main shortcoming of the current warehouse is that the efficiency of its storage and retrieval systems is very low, which is also a bottleneck to restrict the development of automated warehouse. Therefore, how to improve the efficiency of AS/RSs, and realize intelligent control without manual intervention becomes a very important issue.

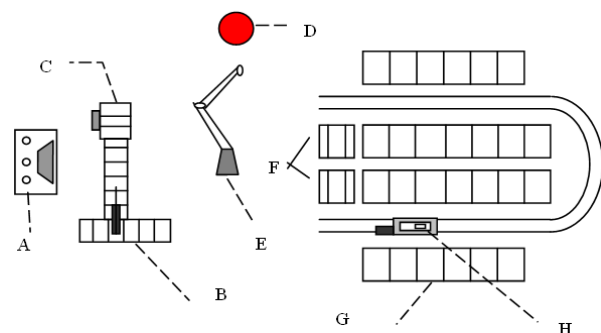
In recent years, because of its ubiquity, radio frequency identification (RFID) technology has becoming the hotspot in the field of object location [4,5]. RFID systems use radio transmissions to send energy to a tag which, in turn, emits a unique identification code back to a reader linked to an information management system. If

the RFID tags with unique codes are embedded in objects, the identification of the objects can be greatly simplified. Furthermore, RFID has a lot of advantages, such as contactless communications, long lived, high data rate, non line-of-sight readability, and low cost [6,7]. For the above reasons, RFID technology has been often employed to recognize objects for navigation, manipulation, etc.

Based on the above analyses, a kind of new RFID based AS/RSs is proposed in this paper in order to realize target recognition, automatic localization and AS/RS, which can not only improve the precision and speed of the automated warehouse, but also be suitable to the management of modern corporation.

II. CONSTRUCTION OF AUTOMATED WAREHOUSE

Figure 1 shows the composition of automated warehouse. There are four rows of automated shelves including 120 cargo spaces divided into two tunnels, an automated stacker, two storage and retrieval platforms, and a SK6 manipulator with six-freedom, etc.



A. Operating platform B. Conveyor C. Weighing platform D. Rotary platform
E. Manipulator F. Storage and retrieval platform G. Shelves H. Stacker

Figure 1. The construction of automated warehouse.

SK6 produced by Yaskawa is used in the warehouse. The controller of SK6 is YASNAC MRC II, which adopts interactive programming language INFORM II. There are two programming ways: teaching and remote

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control. In this paper, we combine the two ways together to simplify the system design.

The RFID system mainly includes three parts: reader, antenna, and RFID tag, as shown in Figure 2. Because of the uniqueness of the RFID tag, the reader can locate and track the target once it is attached on an RFID tag. Passive tags are used to attach on the target object because they are much cheaper, long lived, lightweight and have a smaller foot print. The reader can communicate with host computer through RS232. The CCD camera is mounted on the end of the arm, which can distinguish the target using color and shape of the object.

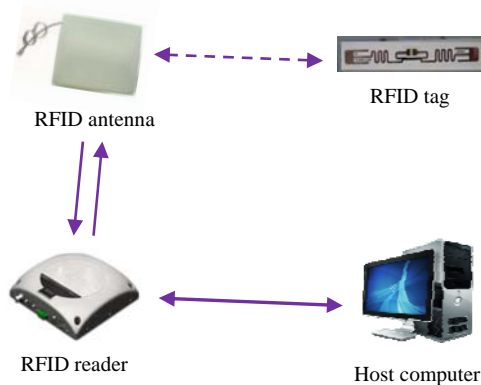


Figure 2. Principle of the RFID system.

The control system of the automated warehouse include management/monitor computer, master PLC and lower PLC, which are connected by Modibus and wireless networks and can build up a complete multi-level computer monitoring system, as shown in Figure 3. The whole automated warehouse system integrated cargo storage, retrieval, distribution and transportation together, realizes intelligent operations in the whole system, and is an intelligent warehouse without any manual operation.

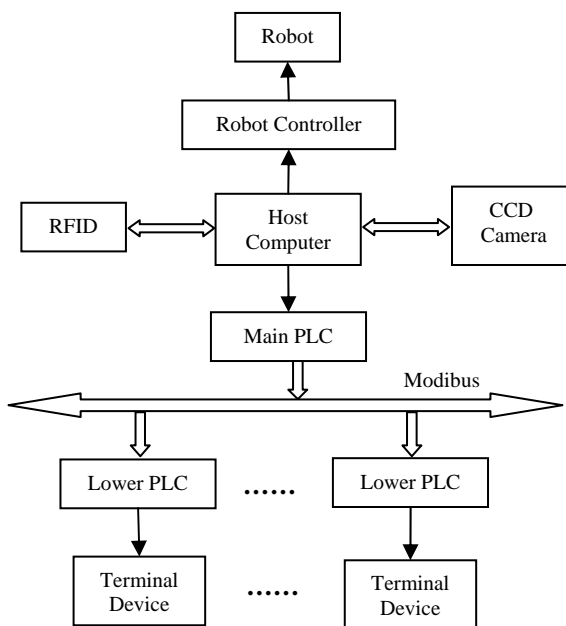


Figure 3. The control system of automated warehouse.

III. INTELLIGENT STORAGE AND RETRIEVAL SYSTEMS

A. Structure of Intelligent Storage and Retrieval Systems

RFID based intelligent storage and retrieval systems are shown in Figure 4. The system mainly includes two parts: RFID and vision systems. RFID technology is used to localize the target roughly, and onboard vision is used to localize the target precisely.

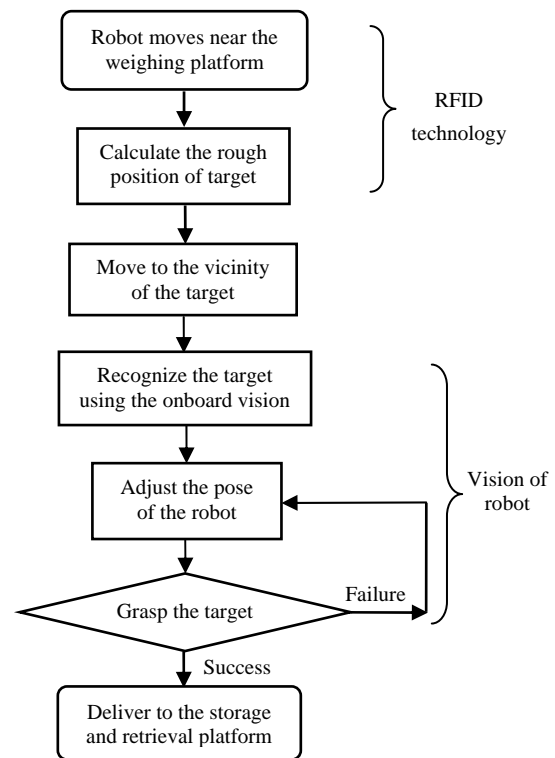


Figure 4. Flowchart of intelligent storage and retrieval.

B. RFID Localization System

Inspired by LANDMARC positioning system [8], the conference tags are introduced in the paper. The conference tags divided into 5 rows 6 columns are distributed on the bottom of a tray, shown in Figure 3. The real position of each conference tag is recorded in it. Furthermore, each of the considered target objects of the database is also attached to an RFID tag, which is called as target tag. When the reader detects the conference tag and the target tags, the robot can know the name and count of real targets in its detecting field, which can reduce the number of matching items in the database, and the rough position in Figure 5, the green box indicates the conference tag, and the red circle represents the detection range of the RFID antenna. The other colored shapes mean different targets.

From Figure 5, we can conclude that there are 6 conference tags and 3 targets in the detection range of RFID, so the rough position of the target can be calculated as:

$$(X_T, Y_T) = \left[\sum_{i=1}^N (X_i, Y_i) \right] / N \quad (1)$$

where N is the number of conference tags.

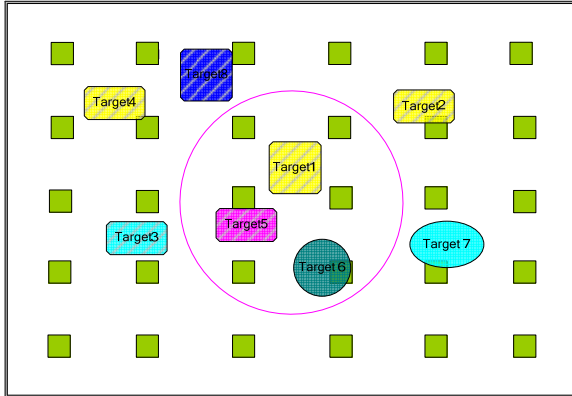


Figure 5. Distribution of reference tags.

C. Robot Vision System

When the rough position of target is determined, the manipulator recognizes the target using the onboard camera. In this paper, the color and shape information are used to recognize the target [9,10,11].

(1) Target Recognition

The video provided by camera is in RGB space. In order to reduce the influence of light, we transform the RGB space to YCbCr space which can separate the illumination from hue. Gaussian model is used to color detection because the parameters are easily to calculate and the detection rate is high. For the image transformed to YCbCr space, the similarity degree to the target is calculated as:

$$p(CbCr) = \exp[-0.5(x - m)^T C^{-1}(x - m)] \quad (2)$$

where $x = (CbCr)^T$, $m = E(x) = (\overline{Cb}, \overline{Cr})$, \overline{Cb} and \overline{Cr} are the means of Cb and Cr , C is the variance matrix and $C = E[(x - m)(x - m)^T]$.

Next, the similarity image is transformed to a binary image, and the white regions are the interesting areas where the target may exist. The interesting areas still include some other regions whose color is similar to the target, so the shape information is used to extract the target accurately. Moment function is global invariant, less sensitive to noise, and could be used to identify the target successfully whether the target is closed or not. Therefore, moment invariants have been widely used in shape recognition and identification. In this paper, Hu invariant moments [12,13] is used to deal with the interesting area image after image segmentation, and the nearest area is selected as the target area.

(2) Target Tracing

The target recognition is not very stable due to the image processing is influenced by sunlight. A kind of target tracing algorithm based on Kalman Filter is designed in the paper in order to forecast and trace the

target. Kalman Filter [14,15] is used to predict the position of the target, and the center coordinate values, the area of the target, the ratio of length and width, and one dimension HSV histogram are used as the features of the target. The main process is shown as follows:

$$\begin{aligned} X_v(k | k - 1) &= F_v(k)X(k - 1 | k - 1) \\ P_{vv}(k | k - 1) &= F_v(k)P_{vv}(k - 1 | k - 1)F_v^T(k) + Q \\ X_v(k | k) &= X_v(k | k - 1) + K(k)(Z(k) - H(k)X_v(k | k - 1)) \\ P_{vv}(k | k) &= P_{vv}(k | k - 1) - K(k)S(k)K^T(k) \\ S(k) &= H(k)P_{vv}(k | k - 1)H^T(k) + R \\ K(k) &= P_{vv}(k | k - 1)H^T(k)S^{-1}(k) \end{aligned} \quad (3)$$

The experiments demonstrate that the algorithm can trace the target stably, and can solve the occlusion problem to some extent.

IV. ROBOT CONTROL SYSTEM

YASNAC MRC II is used as the controller of SK6, which is composed of Playback Box, Main Power Switch, Door Lock, and Programming Pendant [16,17].

A. Teaching Programming

The flow chart of Teaching Programming is shown in Figure 6.

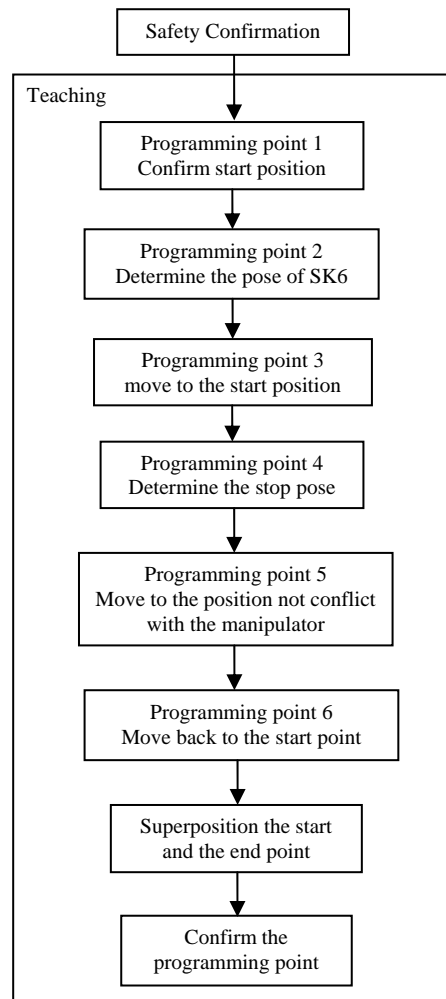


Figure 6. Flow chart of Teaching Programming.

Teaching Programming is an important mode in robot control, and it is simple and can be used to plan path.

B. Remote Control

(1) Transmission characters

The transmission characters and their meanings are shown in Table 1.

TABLE I.
THE TRANSMISSION PROCESS OF A COMMAND

| Control Character | Code (hex) | Character meanings |
|-------------------|------------|---------------------------------|
| DLE | 10 | Data Link Escape |
| SOH | 01 | Start of Header |
| STX | 02 | Start of Text |
| ETX | 03 | End of Text |
| EOT | 04 | End of Transmission |
| ENQ | 05 | Enquiry |
| NAK | 15 | Negative Acknowledgment |
| ETB | 17 | End of Text Block |
| ACK0 | 10. 30 | Even Affirmative Acknowledgment |
| ACK1 | 10. 31 | Odd Affirmative Acknowledgment |

(2) Transmission format

The transmission format is shown in Figure 7.

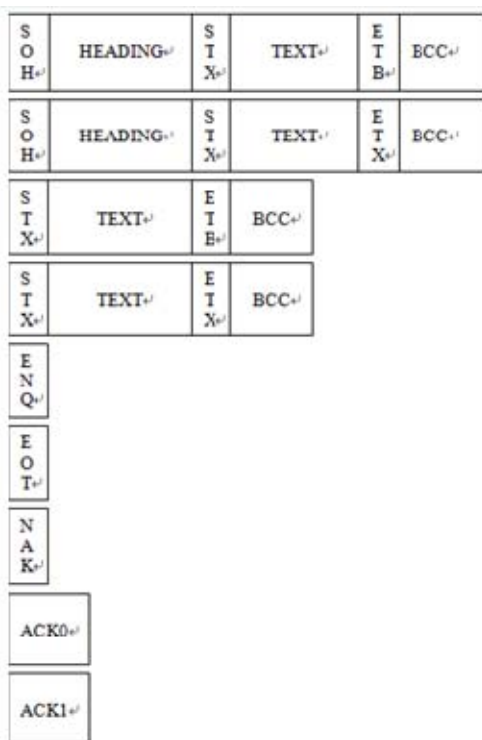


Figure 7. Transmission format

(3) Error check system

First calculate the sum of all the characters from SOH/STX to ETB/ETX, and then decide the error control based on the checksum. The calculation of checksum is shown in Figure 8.

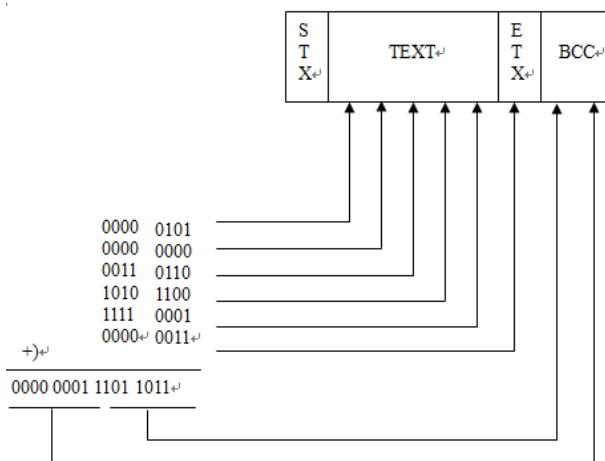


Figure 8. Calculation of checksum

(4) File data transmission and command transmission

YASNAC MRC II support host computer control function. According to different commands sent by the host computer, it can be divided into two classes: file data transmission and command transmission.

File data transmission function

File data transmission function can realize data exchange between the user's memory data stored in YASNAC MRC II and the data stored in host computer. The transmission process is shown in Figure 9.

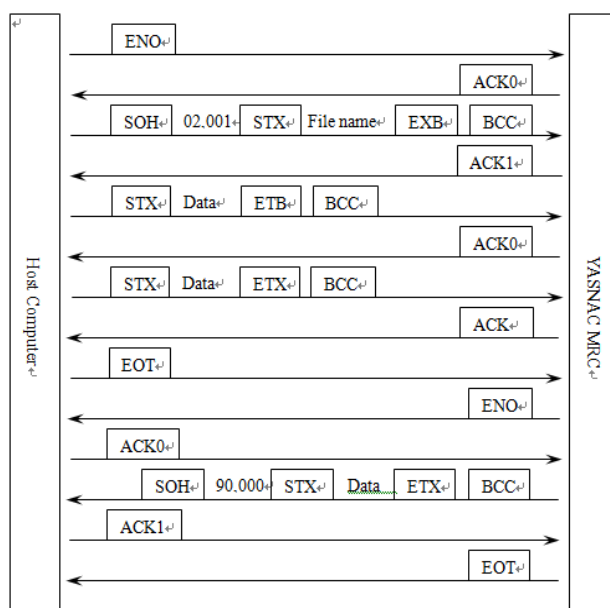


Figure 9. The transmission process of a file

Command transmission

Figure 10 shows the command (DELETE WORK-A) transmission process from the host computer to YASNAC MRC II

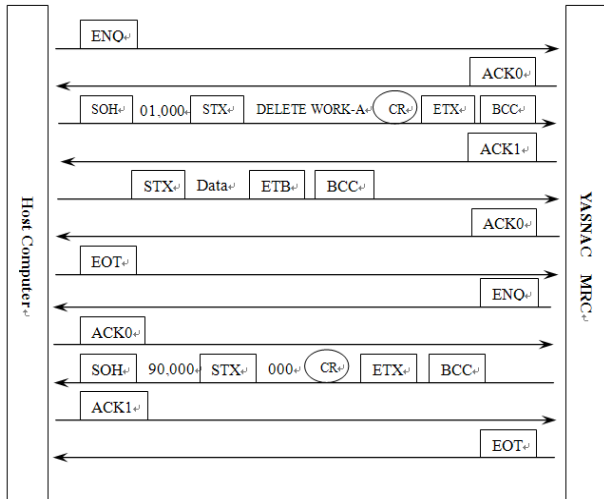


Figure 10. The transmission process of a command

V. EXPERIMENTS AND ANALYSES

A. Intelligent Storage and Retrieval Experiment

Taken automated retrieval operation as an example. The target is placed on the rotary platform, the manipulator first localize the target using RFID, then recognize and trace the object using onboard vision, finally grasp the target and place on the weighing platform. The procedure is shown below:

(1) The manipulator move to the stat point which is near the rotary platform.

The coordinate values are: 829.461 , 29.261 , 517.968, 175.50, 2.24, -176.78.

The first three data (mm) are the coordinate values of X, Y, and Z axis, respectively. The latter three data are the degrees of TX, TY, and TZ angles.

(2) Adjust the end of the actuator to make it perpendicular to the rotary platform.

The coordinate values are: 1139.372 , 35.096 , 567.047, 39.48, 87.38, 41.30.

This position should meet the requirements of object recognition using RFID and vision.

(3) Delay 3 seconds.

First the RFID is used to localize the target roughly, and then the target is recognized precisely using onboard vision. Finally, the coordinate values of the center point is calculated and written to the position variable P000 in YASNAC MRC II.

The coordinate values are: 1175.012 , 50.227 , 371.339, 68.18, 87.63, 69.44.

(4) The manipulator is adjusted slightly to be close to the target.

The coordinate values are: 1185.014 , 70.222 , 371.341, 68.18, 87.63, 69.42.

(5) The manipulator grasps the object, and then delay 1 second.

The coordinate values are: 1185.014 , 70.221 , 361.341, 68.18, 87.63, 69.42.

(6) The manipulator moves to the top of the rotary platform.

The coordinate values are: 1109.141 , 46.776 , 687.747, 78.18, 84.76, 81.98.

(7) The manipulator moves to the top of the weighing platform.

The coordinate values are: 317.513 , 1063.751 , 687.747, 78.18, 84.76, 152.98.

(8) The manipulator places the object on the weighing platform.

The coordinate values are: 317.652 , 1084.249 , 424.544, 79.19, 84.69, 151.69.

(9) The manipulator moves to the top of the weighing platform.

The coordinate values are: 286.537 , 990.862 , 721.899, 44.33, 82.64, 119.31.

(10) The manipulator moves near the starring point, and the task is ended.

The coordinate values are: 737.606 , 26.728 , 496.366, 175.50, 2.24, -176.78.

From the experiments, we can conclude that:

(1) The manipulator can trace the planned path accurately.

(2) The host can read the data file and generate the command sequence correctly, and can save the data to the variable to control the robot grasping the target.

(3) The teaching and remote modes are used flexibly in the paper, which can not only simplify the programming, but also can improve the flexibility of the automated storage and retrieval system.

B. Performance Evaluation

The system is valued mainly form the following two aspects: positioning accuracy and efficiency of storage and retrieval system.

(1) Positioning accuracy

Figure 11 shows the positioning error of one typical target in different conditions. We can see that in conventional pattern, the robot only used vision to localize the target. When the distance between robot and target exceeds 1.2 meters, it is difficult to distinguish the target. Even if the distance is below 1.2 meters, the positioning error is higher and fluctuates largely. While in our method, the robot can not only obtain the rough position of the target, but also the information stored in target tag in advance, such as color and size, which are both helpful to localize the target precisely. So the positioning precision based on multi-pattern (RFID and vision) is higher and the positioning system is more stable, too.

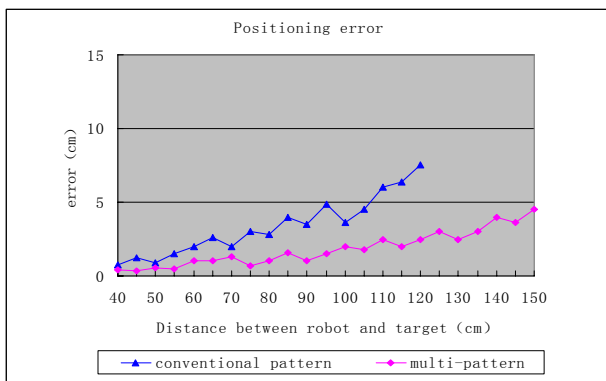


Figure 11. Positioning error

(2) Efficiency of storage and retrieval system

Figure 12 shows the efficiency in different methods. We can conclude that our method adopts multi-mode information provided by RFID and vision, and can improve the efficiency about 50%.

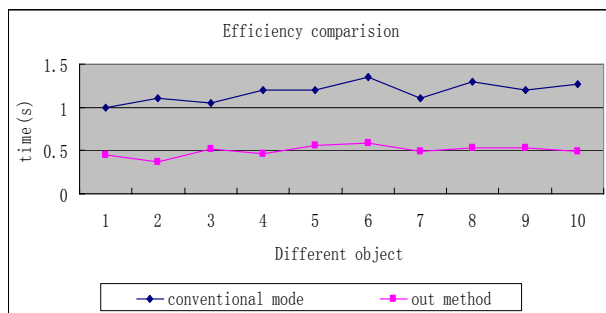


Figure 12. Efficiency of retrieval system

VI. CONCLUSIONS

The robot technology is introduced into the automated warehouse in the paper aiming to improve the storage/retrieval efficiency in the warehouse. The RFID system is used to localize the target roughly, and then the onboard vision system is used to recognize and localize the target precisely. Finally, the teaching and remote control modes are used together to assist the robot to grasp the target and deliver to the warehouse. The combination of the two modes can not only reduce the complexity of robot control, but also can make full use of the results of image processing. The experiments demonstrate the feasibility of the system.

In the future, we will improve the structure of AS/RSs, design more suitable object recognition and localization algorithms, and build a more practical system for the warehouse.

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