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# Robot precise positioning and interconnection system based on machine vision

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## Abstract

With the continuous advancement of intelligent manufacturing in our country, factories have increasingly higher requirements for intelligent devices. Traditional production technologies can no longer meet the growing needs of enterprises. In order to improve the quality of product production, adapt to complex production scenarios, and achieve intelligent interconnection and flexible production, enterprises combine equipment IoT (Internet of Things) and visual systems to conduct real-time detection and positioning of products. They utilize industrial robots with high precision for rapid sorting, thereby replacing manual labor to complete high-intensity and high-precision work. The integration of this technology is an important driving force for the construction of digital factories and the development of intelligent manufacturing. This article introduces EPSON robots and machine vision systems, and develops a monitoring software APP, realizing the application of an interconnected system for precise positioning and grasping.

## Keywords

Machine Vision; Industrial Robot; Positioning and Grasping; Internet of Things (IoT); Image Processing

## Introduction

In recent years, intelligent manufacturing technology has been widely applied and promoted in the field of industrial production [1][2]. The core of intelligent manufacturing technology lies in using various intelligent technical means to achieve the automation and digitization of the production and manufacturing process. Among them, industrial robots, robot vision, and Internet of Things (IoT) technology are three important components of intelligent manufacturing.

As a mechanical device capable of automatically performing various tasks, industrial robots play an increasingly important role in industrial production. Through the precise operation and efficient production of industrial robots, enterprises can effectively improve production efficiency and product quality while reducing production costs [3][4]. Machine vision, through visual sensors such as cameras and image processing algorithms, endows robots with the ability to perceive and understand the environment. With robot vision technology, industrial robots can automatically perceive and identify objects and scenes in the working environment, thus achieving more precise and efficient operations [5][6][7]. IoT technology connects and interlinks the physical world and the digital world through IoT devices and sensors, enabling real-time monitoring and control of the production process and the production environment. Through IoT technology, enterprises can achieve the digitization and automation of the production process, improving production efficiency and quality [8].

Therefore, industrial robots, machine vision, and IoT technology are important components of intelligent manufacturing, and their applications can bring huge economic benefits and social values to enterprises. This article will be developed from these three aspects to create a robot precise positioning interconnected system based on machine vision.

# 1. Construction of the Camera Detection and Robot Positioning and Grasping System

## 1.1 Overall Hardware Design

This workstation is mainly composed of two major parts, namely the camera detection part and the robot grasping part. The overall system solution block diagram is shown in Figure 1.

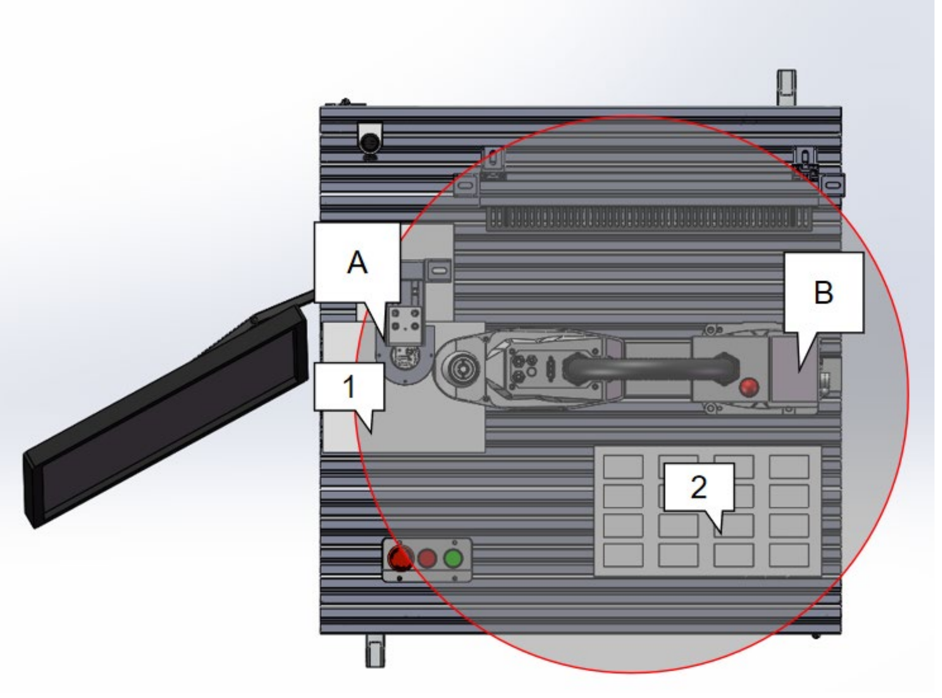



Fig.1 Systems solutions

The camera detection part consists of an industrial camera, a controller, an industrial lens, a light source, etc. The robot grasping part consists of an industrial robot, an end - effector, and a palletizing tray. The camera and the robot are independently fixed (located on the left side of the robot), and the camera does not move with the movement of the robot gripper. The specific parameters of the system hardware are shown in Table 1. In the overall system scheme, the circle within the red frame represents the maximum motion range of the grasping robot. The robot can reach within the red frame, but cannot reach outside the frame.

**Tab.1** Hardware design selection

| Serial No. | Name | Model | Performance Parameters |
|---|---|---|---|
| 1 | Industrial Camera | Hikvision MV-CE050-31GC | The resolution 2592×1944 |
| 2 | Industrial Lens | HikvisionVL-HF1628M-6MPE | The focal length is 16mm |
| 3 | Ring Light Source | YS-R90-50-20 | The color is white light, the illumination angle is 30 degrees |
| 4 | Machine Vision Library | Visionpro | The core algorithm of the system |
| 5 | Secondary Development Environment | Vision studio 2017 | System integration interface design |
| 6 | Industrial Robot | Epson T3-401S | Workpiece grasping and palletizing |

## 1.2 Workflow of Precise Positioning Guided by Machine Vision

Area 1 is the visual inspection area, and Area 2 is the sorting and palletizing area. Camera A captures images of the workpieces in the inspection area 1. The Hikvision VisionMaster software is used to write a vision program to accomplish the tasks of workpiece positioning, identification, and inspection. The vision processing program sends the positioning position information, assembly position information, and workpiece size information of the identified workpieces to the robot program via Ethernet communication. Based on the received position information, the robot program enables Robot B to flexibly and adaptively position and grasp the workpieces, and complete the assembly tasks of the workpieces in Area 2 according to the identification information. After Robot B finishes sorting, it returns a completion signal and the assembly result. The human - machine interaction interface dynamically displays the assembly task data, workpiece information, and positioning data. Moreover, the workstation system can be remotely monitored through an APP program, as shown in Figure 2.

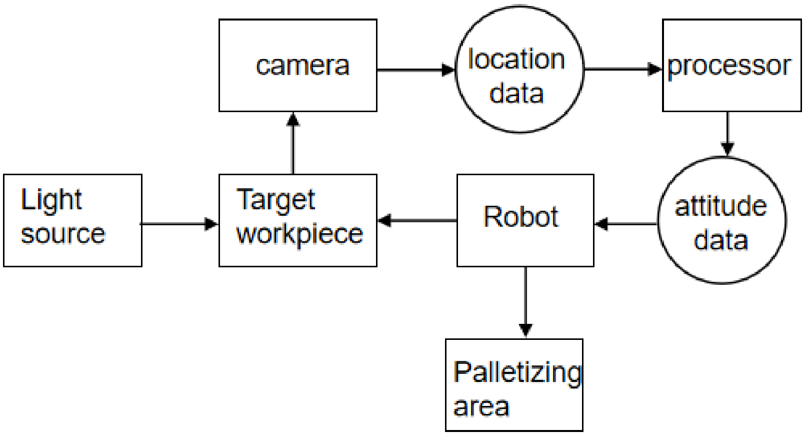



Fig.2 System structure diagram

### 1.3 System Architecture

According to the task objectives of the system solution, the basic structural levels of the system can be roughly divided into three layers: the bottom layer, the data communication layer, and the software application layer. Figure 3 shows a schematic diagram of the system hierarchical classification.

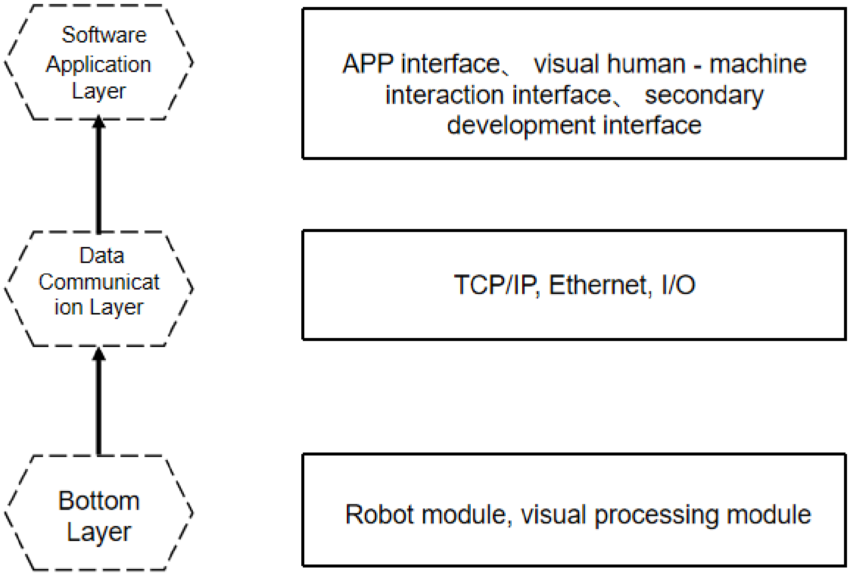



Fig.3 Schematic diagram of system hierarchy classification

1)Bottom Layer

Robot Module: EPSON industrial robot, end - effector tools, other auxiliary equipment, and robot programs.

Vision Processing Module: Industrial camera, optical lens, light source, image acquisition card, computer, and vision processing programs.

2)Data Communication Layer

Ethernet Communication: EPSON robot controller and vision processing programs.

TCP/IP: Vision processing programs and the APP.

I/O: EPSON robot.

3)Software Application Layer:

APP exchange interface, human - machine exchange interface of the vision system, and secondary - development client interface.

Based on the task objectives, select the corresponding hardware to build the workstation, write the corresponding communication codes and the human - machine exchange interface. Finally, control the operation of the workstation through the human - machine interface to achieve the tasks.

## 2 Design of Vision - Guided Robot

### 2.1 Vision Positioning Processing Flow

The vision system first uses a light source to illuminate the target workpiece. The target workpiece reflects the light back to the industrial camera, during which an optical transformation occurs through the industrial lens. The chip sensor of the industrial camera converts the collected light data into electrical data. The camera sends the converted analog - signal data to the image acquisition card. The image acquisition card then converts the data into information that can be processed by a PC. Finally, the PC processes the image data and outputs the positioning and recognition results to the robot. This is shown in the basic positioning process of the machine vision system in Figure 4.

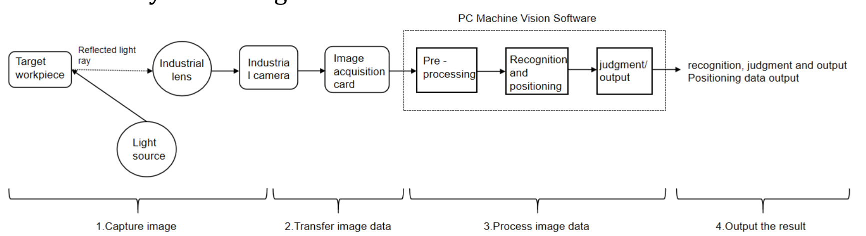



Fig.4 The basic composition of machine vision system positioning process

## 2.2 Flow of Robot Positioning Compensation Algorithm

The camera measurement calibration completes the transformation from the pixel coordinate system to the image coordinate system. It can only perform operations such as measuring the side length of products and the distance between circle centers, but cannot achieve the precise positioning of industrial robots. To achieve the precise positioning of industrial robots, the internal relationship between the pixel coordinate system and the world coordinate system must be obtained.

Suppose there is a random point P in space. If the coordinates of this point are represented by the X, Y, and Z axes, it can be expressed as (XP, YP, ZP). If this point is regarded as a point on the plane of the image coordinate system, it can be expressed as (X1, Y1). Let the focal length of the industrial camera be f, then the matrix can be obtained:

$$\begin{bmatrix} X_1 \\ Y_1 \\ 1 \end{bmatrix} = \frac{1}{Z_P} \begin{bmatrix} f & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & f & 0 \end{bmatrix} \begin{bmatrix} X_P \\ Y_P \\ Z_P \\ 1 \end{bmatrix} \tag{1}$$

According to the above formula, the mutual conversion formula between the pixel coordinate system and the world coordinate system can be obtained, that is, the relationship between the coordinate (X, Y, 1)T and the coordinate system (XP, YP, ZP, 1). The formula is:

$$Z_P \begin{bmatrix} X \\ Y \\ 1 \end{bmatrix} = \begin{bmatrix} G & t \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \frac{f}{dx} & 0 & X_0 & 0 \\ 0 & \frac{f}{dx} & Y_0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} = S_1 S_2 \begin{bmatrix} X_i \\ Y_i \\ Z_i \\ 1 \end{bmatrix} = S \begin{bmatrix} X_i \\ Y_i \\ Z_i \\ 1 \end{bmatrix} \tag{2}$$

Among them, Xi, Yi, and Zi are the shooting coordinates of the industrial camera in the world coordinate system; S1 and S2 represent the internal matrix and the external matrix respectively, and the external matrix S2 is determined according to the position of the industrial camera; S represents the projection matrix of the industrial camera.

For different types of industrial robots, the transformation from the world coordinate system to the end-effector coordinate system also varies. With the transformation formula between the pixel coordinate system and the world coordinate system and the transformation formula from the world coordinate system to the end-effector coordinate system, the relationship between the pixel coordinate system and the robot coordinate system can be finally obtained, and the precise positioning of the industrial robot can be achieved.

The above positioning method is relatively complex and requires obtaining the mutual transformation relationships between various coordinate systems to be realized. It is suitable for the situation where the robot and the vision system are of the same brand, and the manufacturer has already integrated the transformation algorithm.

If the industrial robot cooperates with the vision systems of other brands, positioning can be achieved through the offset amounts △X and △Y from the origin of the graphic coordinate system and the offset of the initial angle △A. The relationship between the coordinates of the industrial robot and the camera coordinate system depends on the relative position relationship between the industrial robot and the industrial camera. The relative position between the industrial robot and the industrial camera is shown as follows.

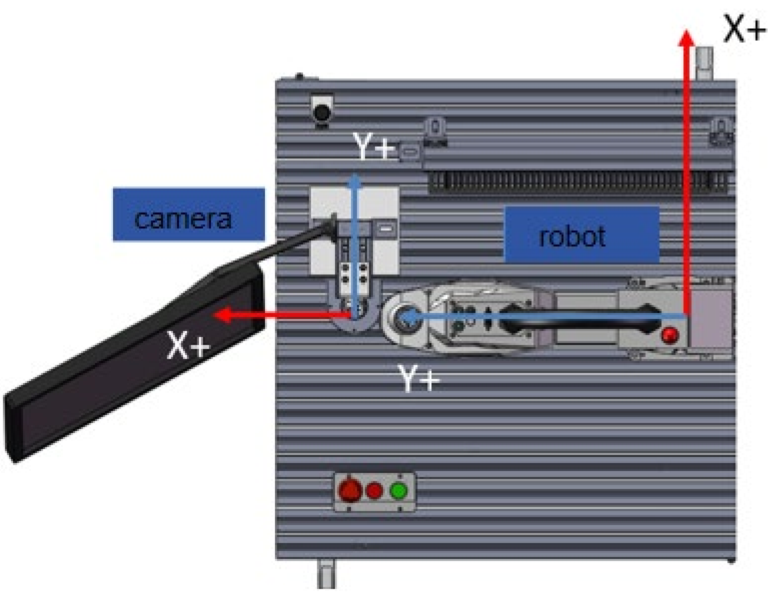



Fig.5 The relative position of industrial robot and industrial camera

In the figure, the X-axis of the image coordinate system is parallel to the Y-axis of the robot coordinate system, and the Y-axis of the image coordinate system is parallel to the X-axis of the robot, with the directions as shown in the figure. The image processing software sends the offset of the origin of the graphic coordinate system to the industrial robot. Since the image coordinate system is different from the robot coordinate system, a certain transformation is required:

$$\Delta_{\text{X camera}} = \Delta_{\text{Y robot}}$$
$$\Delta_{\text{Y camera}} = \Delta_{\text{X robot}} \quad (3)$$

Secondly, use the industrial robot to move the end-effector of the robot to the origin position of the image coordinate system through the teach pendant for teaching, and obtain the default grasping origin (X_default, Y_default) of the industrial robot. Finally, in the robot program, the grasping point position (X_determined, Y_determined) is automatically updated through visual detection using the following formula.

$$X_{\text{determined}} = X_{\text{default}} + \Delta_{\text{X robot}} = X_{\text{default}} + \Delta_{\text{Ycamera}}$$
$$Y_{\text{determined}} = Y_{\text{default}} + \Delta_{\text{Yrobot}} = Y_{\text{default}} + \Delta_{\text{Xcamera}} \quad (4)$$

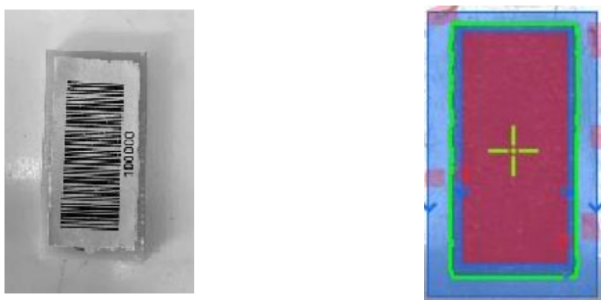
```
Function communicate
    Call clientinit
    String toks$(0)
    String sendstr$
    Print "Port 203 The connection to the server is completed"
    Input #203, receiveStr$
    Print "The data reception is completed"
    ParseStr receiveStr$, toks$(), ";"
    B = InStr(toks$(0), "B")
    D = InStr(toks$(1), "D")
    F = InStr(toks$(2), "F")
    cPianyi$ = Mid$(toks$(0), 2, B - 2)
    xPianyi$ = Mid$(toks$(1), 2, D - 2)
    yPianyi$ = Mid$(toks$(2), 2, F - 2)
    cPianyi = Val(cPianyi$)
    xPianyi = Val(xPianyi$)
    yPianyi = Val(yPianyi$)
    Print "angular offset", cPianyi$, "xaxis offset", xPianyi$, "yaxis offset", yPianyi$
    Print receiveStr$
    receivecount = Val(toks$(3))
    K = Val(toks$(4))
    Print "K", K;
    Call motion
    sendstr$ = Str$(sum) + ";" + Str$(Z(0)) + ";" + Str$(Z(1)) + ";" + Str$(Z(2)) + ";" + Str$(Z(3))
    Print #203, sendstr$
    Print "The data is successfully sent."
    sum = sum + 1
    Print sum
    CloseNet #203 'close203port
    Go baseReleasePoint1 -Y(M(0) * 43.818) +Z(5 * N(0)) ''
```

Fig.6 Robot visual positioning compensation program

### 2.3 Image Preprocessing and Recognition of Sorting Objects

The target workpiece in this paper has the feature of a regular quadrilateral, and the adjacent sides of the quadrilateral are smoothly connected. However, directly collecting the image will be affected by the changes in the surrounding environment (changes in indoor light, differences in workpiece shapes), resulting in a decrease in the imaging quality of the image. Therefore, it is particularly important to enhance and preprocess the characteristic information of the image information.


Fig.7 Pre processing steps



a) Preprocessing b) Template Matching

Fig.8 Preprocessing and template matching

Based on the contour features of the target workpiece, contour matching is carried out first, and a reference template of the workpiece is established. The workpiece is recognized according to the template, and at this time, the coordinate value of the center of the recognized contour in the pixel coordinate system can be obtained. The ROI (Region of Interest) area where the workpiece recognition and positioning are completed serves as the search area for the barcode, and barcode detection is carried out. A reference point is established to obtain the positional relationship between the current workpiece positioning point and the reference point. The coordinate of the positioning center point relative to the reference center point is obtained by subtracting the coordinate of the reference center point relative to the pixel coordinate system from the coordinate of the positioning center point relative to the pixel coordinate system. Unit conversion is performed. Through the calibration data completed by calibration, the image data in pixels is converted into actual data in millimeters, as shown in Figure 9.

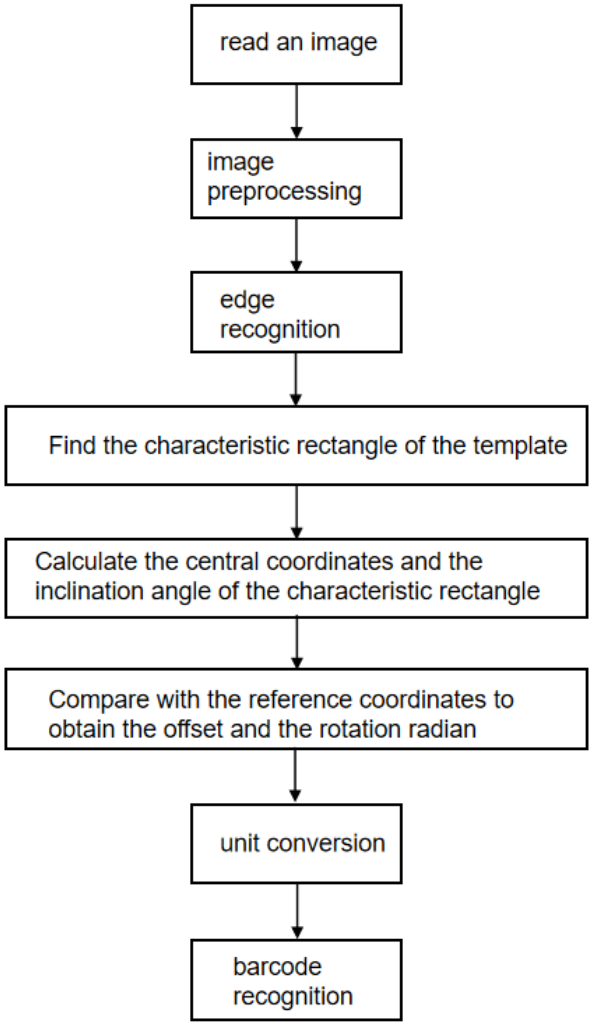



Fig.9 Positioning process

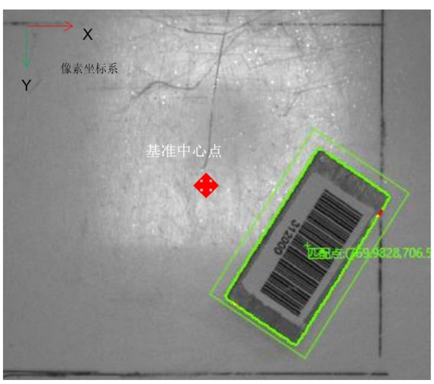



Fig.10 Workpiece identification and positioning

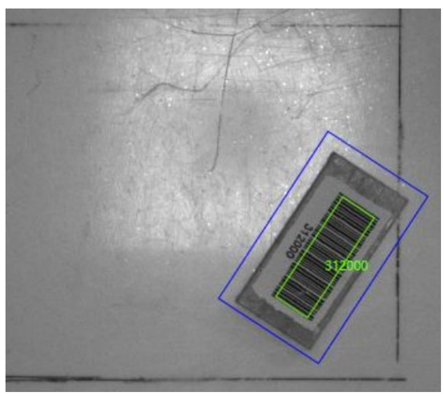



Fig.11 Barcode detection

# 3. Software Development of the Interconnected System

## 3.1 Implementation of the Secondary - Development Client Based on PC

Visual Studio is used for the secondary development of the vision program, as shown in Figure 6. First, import the DLL files provided by the official VM software, reference the VM.Core namespace, and create a VmSolution object using the solution path. At this time, the vision program has been imported. Process 1 in the VmSolution object is the vision program process. Control the operation of Process 1 through the corresponding interfaces and methods, obtain the result data, process and calculate the data, and build the software framework and main functions according to the required functions.

Through camera calibration and template matching, the coordinates of the template center point (X - coordinate, Y - coordinate, rotation angle) are located. Then, through the coordinate relative conversion program, the relative data △X, △Y, and △rotation angle of the positioned product's coordinates relative to the reference center point are obtained. The results of modules such as QR - code detection and measurement are used to obtain the classification information of the palletizing area. Combine the relative data and classification information into a string that meets the custom protocol and send it to the robot, as shown in the vision program client in Figure13.

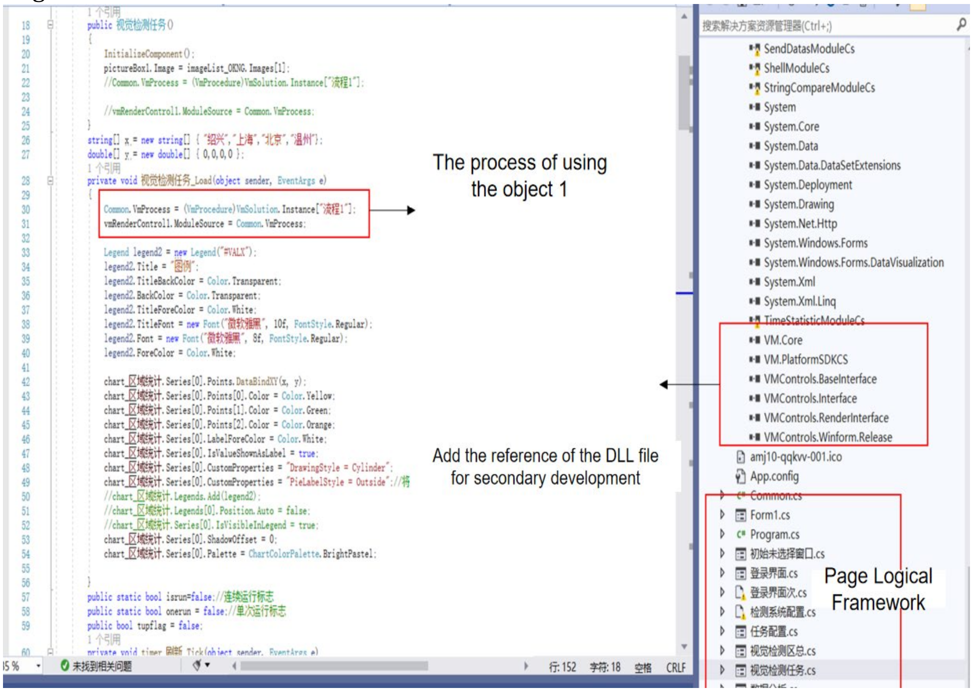
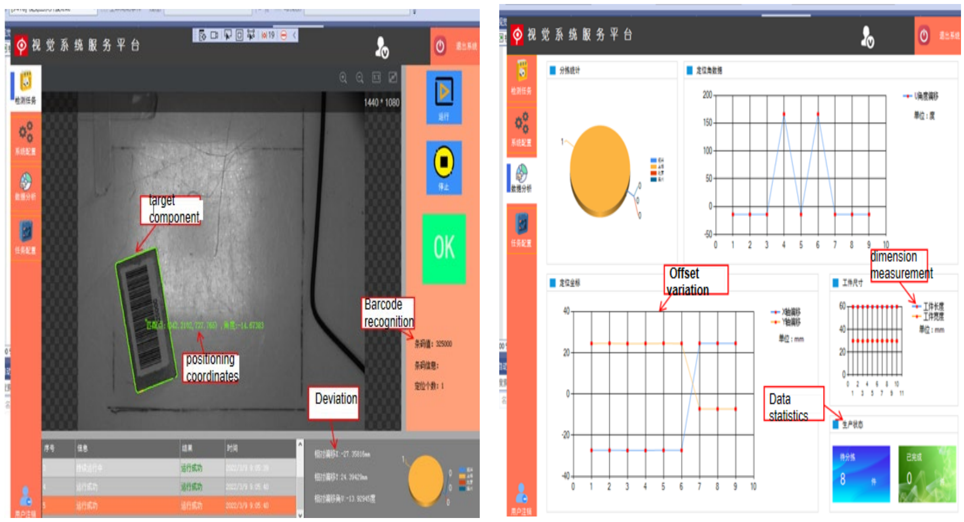



Fig.12 Secondary development design



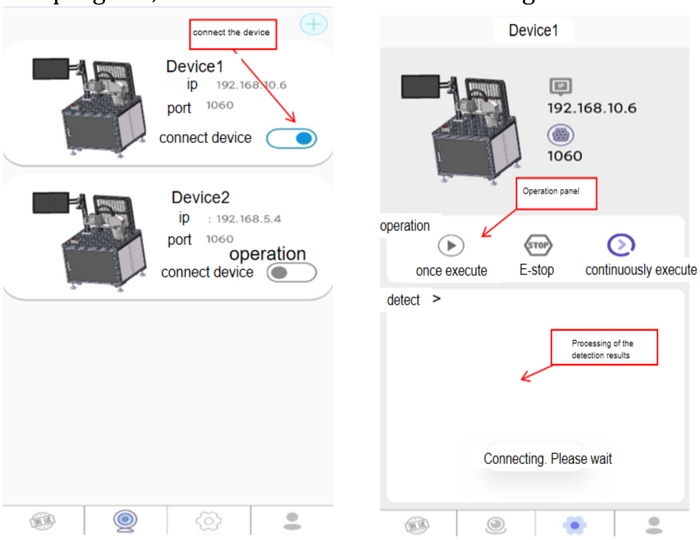

（a）Robot locates the workpiece (b) Data Monitoring Interface

Fig.13 Visual application client

## 3.2 Implementation of the Visual APP

Android Studio is used to write the visual APP. Design the interface layout of the APP, which can achieve cyclic connection of multiple workstations. Write the Android client program to connect to the visual server, which can be used to control the operation of the workstation and remotely monitor the working data of the workstation.

Send data such as detection and measurement results to the mobile phone APP program (it can also control the operation and stop of the VM visual program). At the same time, graphically display the relevant data of the processing results of the visual program, as shown in the visual APP in Figure14.




(a) Connection Interface (b) Monitoring Interface

Fig. 14 Visual APP

# 4. Experimental Verification

## 4.1 Experiment for Detecting Visual Positioning Accuracy

1)Adjust the height of the platform to the same height as during the task operation. Place the chessboard calibration plate on it and perform camera calibration. After the calibration is completed, ensure that the calibration accuracy this time is relatively high and generate a calibration file.

2)Remove the calibration plate, place the detection object on the platform, use the camera to take a photo, and establish a template image of the detection object.

3)Randomly place multiple detection objects on the platform, run the visual processing program, and obtain data such as the angle offset of the detection object relative to the reference template, the coordinate values in the world coordinate system, and the barcode detection values.

4)Use measuring tools such as a ruler to measure data such as the actual angle offset of the detection object and the coordinate values in the world coordinate system.

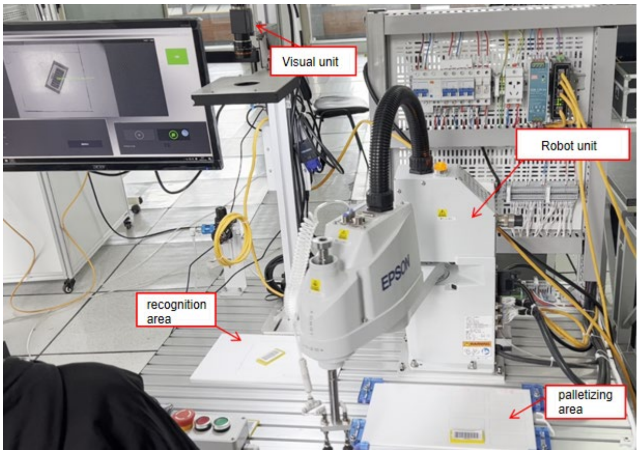



Fig. 15 Experimental verification

We take 4 detection objects as a reference, and the data information currently detected is displayed on each detection object. The theoretical measurement values of these detection objects and the actual values measured in space are statistically shown in the visual positioning and recognition results. From the data in the above table, it can be known that the error between the image positioning coordinates and the actual measurement coordinates is basically within 3mm, the error between the detected angle offset and the actual angle offset is within 3 degrees, and the recognition success rate of the sorting barcode is 100%. Therefore, it can be concluded that both the accuracy of visual positioning and the accuracy of recognition are relatively ideal.

**Tab.2** Visual positioning and recognition results

| Detection Object Serial No. | Pixel Positioning Coor.（pix） | Image Positioning Coor.（mm） | Actual Coor.（mm） | Detected Angle Offset（deg） | Detected Angle Offset（deg） | Barcode Recognition |
|---|---|---|---|---|---|---|
| 1 | （277,392） | (-36,-22) | （-35,-23） | 68 | 66 | 2000 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2 | (788,463) | (35,-11) | (36,-13) | -141 | -140 | 31200 |
| 3 | (348,729) | (-26,25) | (-24,26) | -135 | -133 | 32500 |
| 4 | (845,887) | (43,46) | (41,44) | -107 | -110 | 10000 |

## 4.2 Experiment for Detecting the Given Position of the Robot

1)On the PC side, use the network debugging assistant to open the server and successfully connect to the robot client.

2)Run the robot program and send information such as the position in the actual world coordinate system, the rotation angle, and the sorting flag in the specified protocol to it.

3)The robot moves to the specified position point, and measure the coordinate information of the final position point reached by the robot.

4)The robot performs sorting and palletizing in four areas according to the received sorting flag information.

Taking the four sets of given data as a reference, the statistical information of the actual position where the robot arrives and the given position information is shown in Table 3.

**Tab.3** Statistics of robot positioning and grasping results

| Detection Position Data Serial No. | Given Grasping Position Coor.（mm） | Actual Grasping Position Coor.（mm） | Sorting Flag | Actual Sorting Area |
|---|---|---|---|---|
| 1 | （40,35） | (44,34) | 31200 | Region 1 |
| 2 | (-35,27) | (-31,26) | 32500 | Region 2 |
| 3 | (-43,35) | (-40,-33) | 100000 | Region 3 |
| 4 | (-30,36) | (-34,32) | 2000 | Region 4 |

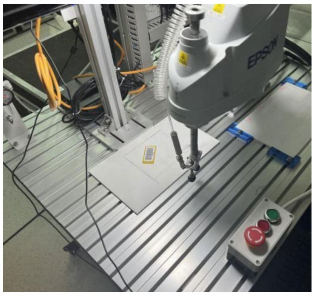
## 4.3 Joint Experiment

1)Preparation steps. Turn on the visual program server, run the robot program, place the workpiece within the detection area, set the number of continuous operation times on the human-machine interaction interface, and click the continuous operation button.

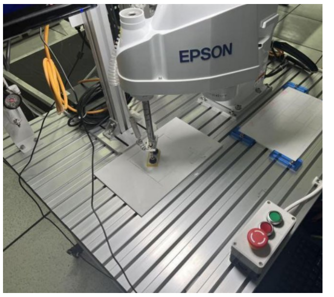
2)The robot automatically operates to achieve positioning, grasping, and classification for palletizing. When there is no workpiece in the detection area, the robot waits.

3)Put the workpiece in again, and the robot executes the operation. This process repeats in turn until the set number of continuous executions is reached, and then the robot stops automatically.

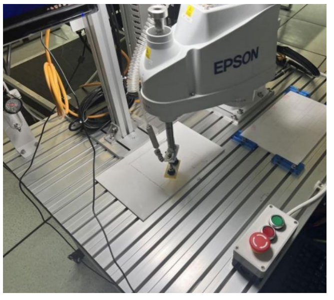
The operation process of the robot is shown in Figure 16.



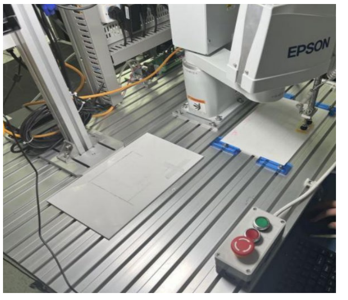

（a）Robot locates the workpiece




（b）Robot picks up the workpiece




（c）Robot transports the workpiece




（d）Robot sorts the workpiece

**Fig. 16** Process Diagram of Robot Grasping and Sorting Workpieces

## 5. Conclusion

In this paper, the traditional industrial robot technology is integrated with the identification and positioning technology of industrial vision robots. A flexible assembly workstation based on a single camera is designed. According to the requirements of the sorting task, the hardware of the workstation is set up, and the theories related to precise positioning, such as robot kinematics and visual positioning, are studied. The visual human-machine interaction software for the PC side of the workstation and the Android application program are developed. Through this software, the robot can be remotely controlled, and functions such as setting the continuous operation times and counting the sorting times are provided.

Finally, an experimental analysis is carried out on the completed flexible assembly workstation based on a monocular camera. The hardware and software design framework is established according to the experimental objectives, and experimental tests on the positioning accuracy and system stability are conducted. It is concluded that this workstation can meet the requirements for the assembly and sorting of high-precision objects and can adapt to different types of workshop environments.

## Acknowledgements

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