Design of Vision Guidance Transferring System for Automobile Hub Manufacturing

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Abstract. In the era of industrial 4.0 intelligent manufacturing, improving product quality and reducing labor costs are important issues in the transformation and upgrading of manufacturing industry. For Automobile Hub manufacturing, first the whole design of software and hardware based on visual guidance is carried out; then, from the perspective of equipment communication and control, the communication between industrial robot and PC host computer is implemented by using Modbus RTU communication protocol, and PLC control frequency converter is selected to complete the control of transmission unit, and finally, the parameters of camera geometric model are obtained by software identification during the wheel hub to be transferred. Now the camera is calibrated, so that the offset can be calculated further to adjust the robot's attitude, and finally the whole process of visual guidance and load transfer can be completed through image recognition. The practice shows that the visual guidance design scheme has been successfully applied to the automatic production line of automobile hub, which improves the production efficiency of the factory and further reduces the cost.

Keywords: Industrial Robot; Automobile Hub Loading; Vision Guidance.

1. Introduction

Machine vision highlights the most important perception ability of robot because of its large amount and real-time information. Therefore, using machine vision to guide robots to complete the cyclic work is still one of the research issues at present, which plays an important leading role in the flexible manufacturing using industrial robots and the intelligent manufacturing in industrial informatics. Generally, for the target object, the initial position and the end position of the industrial robot are mostly obtained by the way of teaching. However, large number of practices show that by using machine vision to recognize the workpiece, estimate the target pose, then perform the specified actions, which will improve the automation accuracy of intelligent manufacturing.

Hence, there exist many researches on the application of visual guidance, which contains the business processes of target recognition, positioning, calibration, and object transfer. Among them, calibration is the key technology to achieve visual guidance, and its accuracy will directly affect the positioning of the robot with respect to the workpiece [1]. In the field of industrial control, robot sensing action is controlled by PLC under Modbus communication protocol. Therefore, communication between PLC and Modbus equipment is equally important [2]. The characteristics of PLC, including its stability,
reliability, anti-interference ability, easy to flexible use the various functions of single-chip microcomputer, the combination of two will better convenient to control the complex system [3]. Generally, the production line for automobile hub uses the support rod on the conveyor belt to transport the hub. As shown the scenario in Figure 1, the polished wheel hub is treated by powder spraying and transferred to the oven for high-temperature baking. For the purpose of ensuring safety and efficiency, an industrial robot with machine vision is used to achieve the two working modes through two gear selection switch. The first mode is to transfer the hub of the powder room on line D, then to the oven transport line for smooth paint leveling chamber of line B; the second mode is to transfer line B from the hub of the smooth paint leveling chamber to the oven transport line for cooling.

Figure 1. Production scenario for hub transferring.

2. Overall Design of Visual Guided Hub Transferring
According to the scenario, a robot is placed among line B, oven and line D. For the first working mode, the default position of the robot is position 0. When line D stops, a digital signal (24V switch signal) should be provided to the robot controller IRC5. After IRC5 receives the signal, it will send a signal to the vision system of industrial control computer through the serial port or Ethernet interface to trigger camera 1 and camera 2 to shoot, the detail process is as shown in Figure 2. Through the simultaneous reading of camera 1 and camera 2, the industrial computer processes the data returned by these two cameras to get the grab coordinates of the wheel hub and simultaneously read and process the diameter of the wheel hub. The industrial computer obtains the center position of the target supporting rod on the oven conveying line through the data processing returned by camera 3, and then sends the reading mark position to the robot controller IRC5. According to the above data, the robot moves to the position above the target support bar of the oven transportation line, such as position 2. Then the robot puts the wheel hub movement on the support surface of the support rod, and controls the fixture servo system to release the fixture. Then the robot retracts and moves back to position 0, waiting for the next D line to stop triggering the next movement process.

Figure 2. Overall framework of visual guidance system.
3. Camera Calibration for Transfer System
Under the joint action of light source and industrial camera, image measurement is carried out by machine vision. In order to better determine the spatial coordinates of a point on the surface of an object in 3D space and its corresponding points in the image, it is necessary to establish a spatial geometric model of camera imaging, and obtain camera parameters through experiments and calculations. This process is camera calibration [6].

The vision system will guide the industrial robot to grab the hub from point A to point B, where point A and B are the top of the strut of the hub transferring system. The stop point at the bottom of the strut is fixed and tightened to the left and right, but there will be an offset within 10 degrees in the direction before and after the movement. As shown in Figure 3, it is necessary to detect the actual stop position of the hub central point by the visual system, same as the thickness of the hub, so as to help the robot grasp the designated part accurately.

![Figure 3. Deviation of strut apex from hub central point.](image)

3.1. Pinhole Imaging Model
As we know, the key of vision measurement and control is camera calibration, and the establishment of coordinate system is an important part of calibration. Here, the machine vision imaging process is mainly to solve the conversion problem of space point from the world coordinate system to the image coordinate [7]. The camera imaging process is shown in Figure 4 as below.

![Figure 4. Transformation process from world coordinate to image coordinate.](image)

The working principle of machine vision is shown in Fig. 5. For point P1 with world coordinate system, its imaging point on plane \( \Pi_2 \) is P2. To maintain the consistency of imaging point direction, set the origin of camera coordinate system \( O_cXcYc \) at the optical axis center, set space point P1 to be \( (x_1, y_1, z_1) \) under camera coordinate system, then the coordinates of image point P2 on imaging plane \( \Pi_2 \) are \( (x_2, y_2, f) \), there is a corresponding proportion relationship

\[
\begin{align*}
\frac{x_1}{x_2} &= \frac{z_1}{f} \\
\frac{y_1}{y_2} &= \frac{f}{f}
\end{align*}
\]

![Figure 5. Principle diagram of pinhole imaging.](image)
3.2. Camera Internal and External Parameter Model

Generally, the internal parameters of camera have been preset before leaving the factory, so the camera can be calibrated by the following model. If the image coordinate \((x_2, y_2)\) of imaging point is \((u, v)\), then

\[
\begin{align*}
\Delta u &= a_x x_2 \\
\Delta v &= a_y y_2
\end{align*}
\]  

(2)

\(a_x, a_y\) represent the axial magnification coefficients between the image plane and the imaging plane \(\Pi_2\), respectively. \((u_0, v_0)\) is the intersection coordinates of the optical axis central line and the imaging plane \(\Pi_2\). Substituting formula (2) into formula (1), and changing it in matrix form as follows,

\[
\begin{bmatrix}
u \\
v_1
\end{bmatrix} =
\begin{bmatrix}
k_x & 0 & u_0 & 0 \\
0 & k_y & v_0 & 0 \\
0 & 0 & 1 & 1
\end{bmatrix}\begin{bmatrix}x_1/z_1 \\
y_1/z_1
\end{bmatrix} = M_{in}\begin{bmatrix}x_1/z_1 \\
y_1/z_1
\end{bmatrix}
\]  

(3)

From Formula (3), we can see that \(k_x = a_x f\) and \(k_y = k_y f\) represent the axial magnification coefficients in the X-axis and Y-axis directions, where \(M_{in}\) is the coordinate matrix representation of the space point parameters in the camera. As shown in Figure 5, the external parameter matrix of the camera is the transformation from the workpiece coordinate system into the camera coordinate system as [6]:

\[
\begin{bmatrix}
x_w \\
y_w \\
z_w
\end{bmatrix} =
\begin{bmatrix}
x_x & 0 & u_0 & 0 \\
y_x & 0 & v_0 & 0 \\
z_x & 0 & 0 & 1
\end{bmatrix}\begin{bmatrix}x_w \\
y_w \\
z_w
\end{bmatrix} = R\begin{bmatrix}p \\
0 \ 1
\end{bmatrix}\begin{bmatrix}x_w \\
y_w \\
z_w
\end{bmatrix} = c_{Mw}\begin{bmatrix}x_w \\
y_w \\
z_w
\end{bmatrix}
\]  

(4)

Where \(c_{Mw}\) is external parameter matrix, \((p_x, p_y, p_z)\) is the coordinate of the origin of the workpiece world coordinate system in the camera coordinate system, which represents a corresponding relationship between the two coordinate systems. Rotation matrix \(R=[n_x, c_{o_w}, c_{w_w}]\) is orthogonal matrix. Thus, the camera model shown in Formula (5), which describes the coordinate relationship between the world coordinate system of the workpiece and the image coordinate system.

\[
\begin{bmatrix}
u \\
v_1
\end{bmatrix} =
\begin{bmatrix}
k_x & 0 & u_0 & 0 \\
0 & k_y & v_0 & 0 \\
0 & 0 & 1 & 1
\end{bmatrix}\begin{bmatrix}x_w \\
y_w \\
z_w
\end{bmatrix} = M_{in}c_{Mw}\begin{bmatrix}x_w \\
y_w \\
z_w
\end{bmatrix} = M\begin{bmatrix}x_w \\
y_w \\
z_w
\end{bmatrix}
\]  

(5)

4. Image Recognition and Guidance

There are two kinds of positioning for workpiece, contains position and posture positioning. The position positioning base on the central positioning, and the posture positioning is determined by the orientation of the long axis of the workpiece. No matter which kind of positioning, image recognition process is needed for workpiece. The image recognition and process is shown in Figure 6.
5. Design of PLC Control
Considering Siemens s7-1200PLC has the characteristics of fast response in real-time mode [12]. Therefore, in field of industrial using Modbus protocol interact directly between the bottom layer and the upper PC. However, in the process of visual guidance and control, besides camera calibration and accurate positioning of the target, target grabbing has to rely on the support of electric cylinder or pneumatic. Especially while the hub is baked in the high temperature oven, the strength of the manipulator shall be considered when it is transferred out to grab and transfer the load, so as to avoid scratches and twist of the hub shape.

Figure 7 describes the interaction process between upper computer PC and Siemens PLC through RS-485 / RJ45. Modbus standard connection is built between the controller of RTU protocol and the RMBA-01 adapter on ABB variable frequency drive unit for external control. The control of IAI electric cylinder is a high-performance electric cylinder equipped with ball screw, linear guide rail and AC servo motor, which is convenient for the manipulator to grasp the target.

![Figure 7. Hardware design of PLC and ABB Inverter.](image)

We design the protocol format of RTU on Modbus, see as Table 1. The message format requires a pause interval of at least 3.5 characters. In the adapter, the control word, status word, parameter and actual address from converter Fieldbus to drive unit are shown in Table 2.

### Table 1. 3.5-character time-address format.

| Star bit | Device address | Function code | data | CRC verification | End bit |
|----------|----------------|---------------|------|------------------|---------|
| T1-T2-T3-TH | 8bit          | 8 bit         | n-8bit | 16bit            | T1-T2-T3-TH |

However, in the parameter mode, the user can view or change the settings so as to complete the communication parameter settings of ABB Inverter. PLCs7-1200 can be programmed with TIA configuration software, and the configuration port is loaded with Modbus RTU protocol communication instruction MB_COMM_LOAD, including enabling, CM1241 port number, transmission baud rate, parity and other parameters.
Table 2. Address table of Modbus control word.

| Fieldbus → Drive unit | Drive unit → Fieldbus |
|-----------------------|-----------------------|
| Address   | Implication  | Address   | Implication  |
| 40001     | Control word  | 40004     | State word   |
| 40002     | Param1        | 40005     | Actual value1|
| 40001     | Param2        | 40006     | Actual value2|
| 40007     | Param3        | 40010     | Actual value3|
| 40008     | Param4        | 40011     | Actual value4|
| 40009     | Param5        | 40012     | Actual value5|

6. Testing and Conclusion

In order to realize the vision guided grabbing system of wheel hub transferring based on the industrial robot, the overall functional architecture including software and hardware is designed according to the system requirements. The system collects the image of the moving target by CCD, in which opencv function library is used to process the image part. After the camera calibration and posture positioning, let PLC to control the 4-DOF robot. Figure 8 shows the results of image recognition for different types of hub. The identified hub model code is pushed to the tooling PLC through serial port or bus, which is convenient to calculate the clamping force required to grab the hub.

![Figure 8. The results of Image recognition for different wheel hubs.](image)

The system can adapt to the electrical environment of the wheel hub production plant. With the help of the electric cylinder control, the system has strong universality in structure, greatly enhanced the anti-interference ability of the manipulator fixture, high reliability and good stability of the system. At present, the robot transfer system has been running safely in the production site for more than one year, and the number of wheel hubs transferred from the conveyor belt reaches 1K + every day, which greatly improves the automation of the wheel hub production line, improves the productivity by 40%, reduces the labor cost of operation, shortens the cost return period of the R & D system to one year, and further improves the product quality and market competitiveness, and created certain economic benefits for the enterprise.

Acknowledgments

This work was partly supported by the Sci. and Tech. project of Huizhou city of Guangdong province of China(No.2016X0423038), the project of Collaborative Education Reform of Education Ministry (No.201802153087), the 2018 provincial project of Higher Education Teaching Reform(No.PX-218603), the project of Higher Education Teaching Reform of HZU(No.ZYRC2017005, PX-8819875), and the project of Cultivation for Research and Innovation Team of HZU(No.HZU201710).

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