ISSN: 2472-3703 DOI: 10.6911/WSRJ.202001_6(1).0016

Research on Industrial Robot Calibration System

Qian Deng[1, a], Xiumin Shi[1, b] and Sanpeng Deng[1, c]

[1]Institute of robotics and intelligent equipment, Tianjin University of Technology and Education, Tianjin 300222, China

[a]892402358@qq.com, [b]37003739@qq.com, [c]84139814@qq.com

Abstract

In view of the fact that the current industrial robot calibration system is time-consuming, expensive and requires a lot of manual operation, a robot control system using two PSD (position sensitive detector) optical method is proposed to make the calibration process fast and accurate. This paper proposes the control methods needed for realizing system automation. Simulation and experimental results verify the feasibility of the calibration system.

Keywords

Industrial robot, Calibration system, Dual PSD.

1. INTRODUCTION

Industrial robots have high repeatability but low precision. With the passage of time, without an appropriate robot calibration system, the accuracy of any robot system will decrease [1]. Because of this fact, robot calibration has been used to improve the work of industrial robots. Researchers have designed many calibration methods to calibrate industrial robots. Some of them use high-precision equipment, such as CNC machine tools, inclinometers, theodolites, coordinate measuring machines (CMMS) and laser tracking systems, to collect accurate position data of robot tool centers (TCP)[2]. In this study, the position and attitude of the robot are measured by matching the TCP pin with a hole in a corner. In addition, a vision-based system is developed to perform calibration tasks. However, inadequate resolution in wide field of view is a major problem in these systems, as are low frame rate cameras, but because these devices are very expensive or their programs are very time-consuming, it is difficult to be widely used in manufacturing plants.

In this paper, an optical robot control system based on two PSDs (position sensitive detectors) is proposed to improve the time, reliability and cost of other methods. Emphasis will be placed on control methods. In the calibration process, the process of aligning the laser beam to each sensor center can only be repeated twice, so this method is faster and simpler than our previous method. Experiments and simulations are carried out on the ABB industrial robot IRB120 to verify the feasibility of the proposed control method and the newly developed calibration system.

2. ROBOT CONTROL METHOD

Robot control system is one of the most critical and important components of the proposed calibration system[3]. In the calibration process, the controller needs to automatically move the robot TCP to the center of one of the two PSD sensors. Then, the reflection of the PSD sensor must be controlled to reach the center of other sensors. In order to make the whole calibration system an automatic and fast process, it is a challenging problem that must be overcome.

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202001_6(1).0016

To solve this problem, we use hybrid vision and PSD-based servo controller. First, the robot TCP will be controlled by image-based visual servo. In this case, the control task will be limited to determining the approximate value of one of the two sensors, and then determining the length of the laser line, as shown in Figure 4. The camera is tilted.

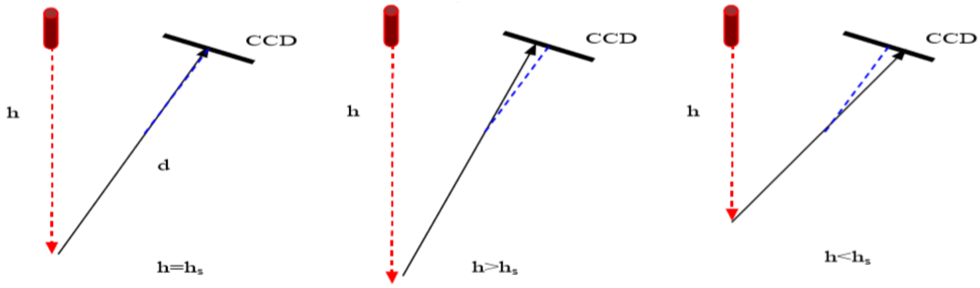

Fig 1. Principle of Laser Length Measurement Control

Laser spot captures images of triangles formed on the surface. Depth triangles can be calculated accurately by using triangular relations[4]. After the laser pointer hits the active area, the controller uses psdbased servo control to switch to the second stage to achieve accurate positioning. When the laser spot reaches the center of psd1, the length information of the laser line is obtained and used to modify the kinematic model of the robot. After completing this step, the direction of the point can be controlled so that it can be repositioned at the center of PSD2 without changing the position of PSD1. At this stage, a similar method is used to move it to the center of the psd2, but this time only the direction is controlled.

2.1. Visual Servo Control

The control method is realized by visual servo control (IBVS). In traditional IBVS system, Jacobian matrix is often used to transform the error of image characteristic speed into the error of robot TCP speed. That is to say

$$\dot{f} = J(u, v, z)\dot{r} \tag{1}$$

$$J=\begin{bmatrix} \frac{\lambda}{z} & 0 & -\frac{u}{z} & -\frac{uv}{\lambda} & \frac{\lambda^2+v^2}{\lambda} & -v \\ 0 & \frac{\lambda}{z} & -\frac{v}{z} & -\frac{\lambda^2+v^2}{\lambda} & \frac{uv}{\lambda} & u \end{bmatrix} \tag{2}$$

f = $(u, v)^T$ is the current image coordinate matrix. w =$[w_x, w_y, w_z]$ for angular velocity vector. v = $[v_x, v_y, v_z]$ for translation velocity vector. The common control laws are given by using the Jacobian matrix relation, and the image Jacobian matrix is a full rank square matrix.

$$\dot{U}=\dot{r} = \Gamma J^{-1}(u, v, z)\dot{f} \tag{3}$$

Among them, U is the control input and Γ is the gain matrix.

2.2. Laser Line Length Control

To avoid the singularity problem in the image Jacobian matrix, the equation (1) can be decomposed into its rotation and translation components, that is:

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202001_6(1).0016

$$\dot{f} = J(u, v)w + J(u, v, z)v \quad (4)$$

Therefore, we can completely remove the direction and translation control, that is to say, when the translation control is carried out, there is no direction control, and vice versa. In the case of directional control only, directional control is expressed as directional control.

$$W = \Gamma J^{-1}(u, v)\dot{f} \quad (5)$$

Where f = fd - f denotes the error of ledsfeature on the image. However, in the translation control process, the feature is the coordinates between two beams on the vertical image plane. Based on height control, the coordinates of the laser beam should not be changed, and the error is based on the coordinates between the laser spot and the two PSD centers.

2.3. Servo Control Based on PSD

In the second stage, the servo control based on PSD is adopted. Similar to IBVS, the image Jacobian matrix is used to transform the error from the image feature speed to the robot TCP speed. In this case, the image is represented by the feedback obtained by the PSCD. For example, let's write the homogeneous transformation matrix of the base coordinate system {B} as ${}_{0}^{P}\mathrm{T}_{B}$.

$${}_{0}^{P}\mathrm{T}_{B} = \begin{bmatrix} R & d \\ 0 & 1 \end{bmatrix} \quad (6)$$

R represents the rotation matrix of base coordinate system {B} relative to PSD coordinate system {P}. Similar to the way we perform translation control in IBV, the direction will remain unchanged. The amount of movement of the CPs representing the laser pointer will be equal to the amount of movement on the PSD surface. Therefore, we only need to get the velocity relationship between the two coordinate systems to control the robot in the task space coordinate system.

Let these three components, translational velocity and angular velocity be expressed in ξ;

$$\xi = [\mathrm{v} \quad \mathrm{w}]^{T} \quad (7)$$

Since the PSD coordinate system {P} is fixed relative to the base coordinate system {B}, the relationship between them is constant and can be written.

$$\xi_p = \begin{bmatrix} R_1 & O_{3x3} \\ O_{3x3} & R_2 \end{bmatrix} \xi_B \quad (8)$$

Here, ξ_p denotes the speed of TCP relative to the PSD coordinate system, while ξ_B denotes the speed of TCP relative to the robot base. We have ξ_B for equation (8).

$$\xi_B = \begin{bmatrix} {R_1}^{T} & O_{3x3} \\ O_{3x3} & {R_2}^{T} \end{bmatrix} \xi_P \quad (9)$$

If s(t) represents the vector of the position value obtained by psd. Then, $\dot{s}$(t) will represent the position velocity.

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202001_6(1).0016

$$\dot{s}(t)=\begin{bmatrix}\dot{X}\\ \dot{Y}\end{bmatrix}=R_{1VB} \tag{10}$$

Where $V_B=[V_x,V_y,V_z]$ represents the component of the translation vector relative to the robot base. Using PSCD feedback, the desired position is eliminated by the center of the sensor, so the image feature error can be represented by the image.

$$e(t)=s(t)-s^d \tag{11}$$

In order to use PSD feedback to control the position error of TCP, we need to calculate the required TCP speed V_B and use it to design the controller. The solution formula is V_B.

$$V_B=-K_p R_1^{-1} e \tag{12}$$

3. CALIBRATION SYSTEM

The method of calibration system is one of the key links to achieve precise calibration of robots [5]. At this stage, we hope to use the encoder information of the robot after the successful completion of the controller stage, so that we can accurately determine the actual TCP location. There are two main and independent methods for calibrating industrial robots. They are equally useful in calibration tasks, namely, joint offset calibration and robot workpiece frame calibration.

3.1. Kinematics Error Model Analysis

The D-H model is used to represent the reference coordinate system in the forward kinematics model of the robot manipulator, as shown below;

$$^B_0\mathrm{T}_E=\prod_{i=1}^{n} A_i \tag{13}$$

Among them, $^B_0\mathrm{T}_E$ is a transformation matrix representing the position and direction of the robot TCP coordinate system relative to the robot base {B} and A_i is a homogeneous transformation matrix. According to D-H model, each homogeneous transformation matrix A_i can be written.

$$\widetilde{A_\iota}=\begin{bmatrix} c\widetilde{\theta_\iota} & -s\widetilde{\theta_\iota}c\alpha_i & s\widetilde{\theta_\iota}s\alpha_i & \alpha_i c\widetilde{\theta_\iota} \\ s\widetilde{\theta_\iota} & -c\widetilde{\theta_\iota}c\alpha_i & -c\widetilde{\theta_\iota}s\alpha_i & \alpha_i s\widetilde{\theta_\iota} \\ 0 & s\alpha_i & c\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{14}$$

Where $c\widetilde{\theta_\iota}$ denotescos$(\widetilde{\theta_\iota}+\widetilde{\delta_\iota})$ and $s\widetilde{\theta_\iota}$ denotes $\sin(\widetilde{\theta_\iota}+\widetilde{\delta_\iota})$ Combined with joint offset, forward kinematics and offset can be written;

$$^B_0\mathrm{T}_E=\prod_{i=1}^{n} A_i=\widetilde{A_1}\widetilde{A_2}\widetilde{A_3}\widetilde{A_4}\widetilde{A_5}\widetilde{A_6} \tag{15}$$

Joint 1 depends on the robot base. So there are five unknown parameters in (15), which are the last five offsets, delta$\delta_i=(i=2,3,4,5,6,)$.

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202001_6(1).0016

3.2. Joint Migration Calibration

Joint offset correction is a process of calculating individual joint errors of robots so as to compensate in the motion model later. In our proposed system, this process is accomplished by locating TCP and laser pointers at four different locations multiple times. Therefore, the robot controller can record four sets of joint angles. The main idea is to determine the square error of each two laser lines. Therefore, by minimizing the sum of squared errors, unknown parameters, i.e., the final offset of delta_$\delta_i = (i = 2,3,4,5,6,)$ are found.

$$\psi = \text{argmin} \sum_{k=1}^{2} \psi_k \tag{16}$$

3.3. Calibration of Robot Workpiece Frame

Robot workpiece frame calibration refers to the process of calculating the relationship between the robot chassis and the robot workpiece frame, usually in the form of transformation matrix, so that the whole motion model can be compensated in the future [7].

R and T are translation vectors of rotation matrix of ${}_{0}^{B}\text{T}_D$, respectively. It is deduced that;

$$R = \begin{bmatrix} R_{11} & R_{12} & R_{13} \\ R_{21} & R_{22} & R_{23} \\ R_{31} & R_{32} & R_{33} \end{bmatrix} \tag{17}$$

The calibration matrix is obtained;

$${}_{0}^{B}\text{T}_D = \begin{bmatrix} R_{3X3} & t_{3X1} \\ O_{1X3} & 1 \end{bmatrix} \tag{18}$$

4. SIMULATION AND ANALYSIS

The PSD based controller moves the laser spot to the center of PSD 1 accurately. This process takes about 15 seconds. Using the length of laser line found in the servo control process, the kinematics model of the robot is modified so that the direction control can be carried out around the points found in the PSD1 center. With directional control, we can not only find the center of psd2 accurately, but also keep the original position of psd1. The same process will be repeated three times to complete the calibration process. Figure 8 shows that the servo control based on PSD reaches the center of PSD1 and can reach the center of PSD2 without changing the position of PSD1. The experimental results basically verify the feasibility of the control system, and finally realize the automation of the whole calibration system, eliminating the need for human-computer interaction.

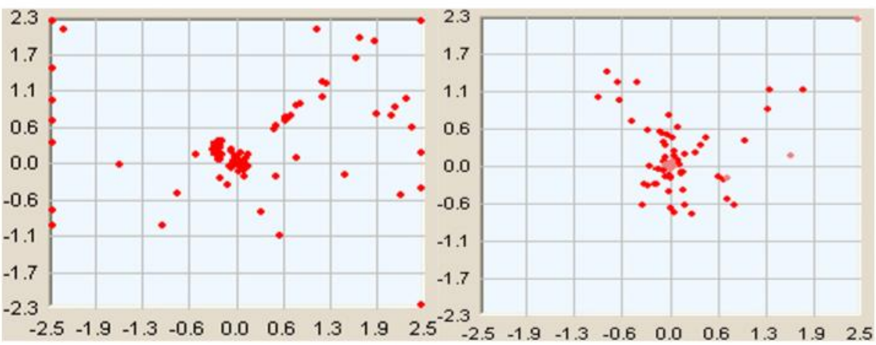

Figure 2. Robot controller results after all phases are completed

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202001_6(1).0016

5. CONCLUSION

This paper presents a new calibration system for industrial robots, which is a fast, economical and reliable calibration solution. In order to make the system faster, a control system is created, which can guide the multi-position alignment of the tool center point of the robot. The proposed controller is simulated and the stability of the control system is proved successfully. The experimental results in this paper essentially verify the feasibility of the proposed control system and prove that the final automation of the whole calibration system is possible.

REFERENCES

[1] Liu Zhanji. Robot based on space coordinate measuring system [D]. Guangdong: Guangdong University of Technology, 2017.

[2] He Xiaoxu. Kinematic calibration of industrial robots based on spatial correlation [D]. Nanjing: Nanjing University of Aeronautics and Astronautics, 2017.

[3] Xue Yanru. Design of Fuzzy Control System for Mobile Robot Based on Embedded System [D]. Shandong: China Ocean University, 2006.

[4] Zhang Tie, Dai Xiaoliang. Robot kinematics calibration based on distance error [J]. Journal of South China University of Technology: Natural Science Edition, 2011, 39 (11): 98-103.

[5] Xiong Shuo, Ye Bosheng, Jiang Ming. Research on Calibration Algorithms of Robot Tool Coordinate System [J]. Machinery and Electronics, 2012 (6): 60-63.

[6] Huang Yankai, Xu Chenglin, Zhou Yongfei, et al. Robot Target Location and Manipulator Control Based on Binocular Vision [J] Computer Technology and Development, 2013, 23 (7): 6-19.

[7] Ren Yongjie, Hao Jigui, Yang Xueyou, and other methods of calibrating robots using laser trackers [J]. Journal of Mechanical Engineering, 2007, 43 (9) 195-200.