FIXED CONTROL SYSTEM OF ASSEMBLY ROBOT BASED ON VISION CONTROL

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ABSTRACT: For exploring the application of assembly robot with vision function in the industrial field, in terms of vision control, a three-stage vision control strategy based on cross ratio invariant and motion displacement is put forward. The target motion is calculated by using cross ratio invariant and the moving route. First of all, the reference image is used for the alignment, and then the target point is calculated by using the cross ratio invariant and moving route. After the image coordinate difference is obtained, the PID control is adopted for adjustment and control approach, and for each image, a new constraint can be re established. In allusion to the target assembly task of vision robot applied in micro parts assembly, a fixed vision control system is designed. And then, from two aspects of hardware and software, the sub millimeter assembly robot prototype system is set up. At last, through the micro parts target guidance experiments and visual control contrast experiments based on the location, the feasibility and accuracy of the system are verified. The experimental results showed that, compared with other systems, especially the monocular vision system, this system has advantages in accuracy. In a word, the fixed control system has high feasibility and accuracy that it can be widely applied.
KEY WORDS: Assembly robot, vision control, control system.

1 INTRODUCTION

Robot is a comprehensive system which combines mechanical, electronic, automatic control, information processing, material and dynamics and so on disciplines. There is a great prospect in the aerospace industry that is beneficial to the people's livelihood, agriculture, medical and military fields. In some extreme or dangerous situations, such as space exploration, deep-sea exploration, rescue and EOD and so on, it plays a role that cannot be replaced. As a result, it gains the attention all over the world, and enormous human and material resources deployment studies are carried out. In the foreseeable future, the robot will become an indispensable human helper, and even in some fields, it can completely replace human beings [1].

Since the birth of robots, its application and category are continuously expanded, in which the assembly robot has been widely used in the field of industrial manufacturing, which mainly completes the assembly task of electrical appliances, automobile, electronic products and the components. With the rapid development of computer, communications, materials and other technologies, assembly robots have also made considerable progress, from remote control and demonstration kind in the past to program-controlled, and to the intelligent one at present. Fine and intelligent degree is higher and higher, so the application scope has been greatly expanded. For instance, with the help of electron microscope, the micro assembly robot is capable of operating MEMS components, and achieving the assembly task of large-scale components through coordinated multi machine. However, in terms of the core technology, key parts, and industrial scale in the field, there is still not a small gap between our country and the advanced countries in the world, so it has great practical significance to carry out research on the visual assembly robots. In this paper, the vision assembly robot system is studied from three aspects of vision control, image processing and camera calibration. In addition, a new type of assembly robot system [3] is designed from software and hardware aspects.

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2 METHOD

2.1 Principle of the end executor and target part detection

Visual control takes image as the input, which acquires image through optical sensing device, then transmits it to the host computer for image processing, segmentation and so on, so as to obtain relevant data such as feature points. The centroid coordinates projection detection of the vacuum adsorption clamp end and small parts is mainly introduced. For the vacuum adsorption clamp at the end, in allusion to the conical structure and taking into account the fuzzy case caused by exceeding the camera depth of field blur, the Hough transform is used to detect the line edge and calculate the coordinates of the intersection. For the small parts, due to the location, the projection is the irregular shape. And the method based on moment invariant is used to obtain the centroid coordinates [4].

2.2 Visual control strategy analysis

Visual control system structure model diagram is shown in Figure 1. After the vacuum adsorption clamp and the end part centroid image pixel coordinates are obtained, a visual control principle based on cross ratio invariant and motion process is used to control.

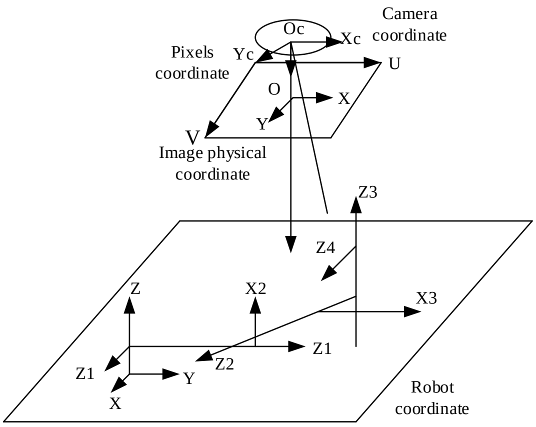

Figure. 1. Schematic diagram of camera and actuator

2.3 Visual controller design

The visual controller takes the image features obtained by image processing as the input, which outputs the motion instructions of the actuating mechanism, so each joint performs the corresponding movement, thus realizing the visual control [5]. The image features obtained by the image processing is in the image pixel coordinate space, and joint motion is in 3D coordinate space. As a result, the visual controller needs to establish the correlation between the spatial coordinates of image pixels and the 3D coordinates space, so as to obtain the relationship between the image pixel coordinates difference of the executor end and the part centroid and three-dimensional space position. Then, after the desired pose of the next cycle is obtained, according to the inverse kinematics of the actuator, the motion amount of each joint can be calculated. In consequence, the visual controller can be built through the camera projection model and the manipulator kinematics model [6].

The camera model has positive and weak perspective, parallel perspective, affine projection and so on kinds. The ideal linear perspective projection model is shown as the bold dashed lines in Figure 2. All the lights, through the optical axis of the camera center, are projected OC to the imaging plane 2, and become the image with smaller scale and in opposite direction. In order to simplify the model and facilitate the processing, the light is projected to the imaging plane 1, and becomes the image with smaller scale and in the same direction. XcYcZc is the camera coordinates, Oc is the camera optical center, OcO is the camera focal length f, and Zc is the camera optical axis. The optical axis is perpendicular to the imaging plane and the intersection of O is the origin of the image physical coordinates. XOY refers to the image physical coordinate, UOV indicates the image pixel coordinates, and the projection of the scene point PW in the imaging plane is PC.

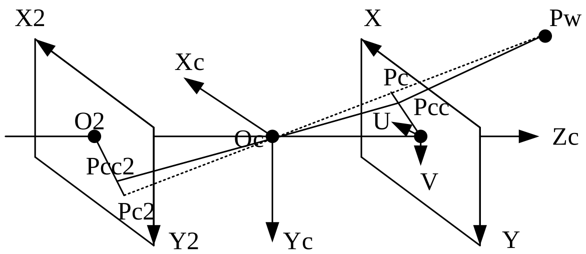

Figure. 2. Perspective projection imaging model

3 PARAMETER CALCULATION OF VISUAL CONTROLLER BASED ON MONOCULAR IMAGE

For this chapter, it mainly carries out the calculation of parameters in the visual controller. In that this method is not based on the visual control of the location, it is unnecessary to make use of external camera parameters. As a result, it requires only linear and nonlinear camera internal parameters calibration. Through the perspective of the camera projection model, and three times translational motion of the camera, self-calibration of linear parameters and the nonlinear distortion coefficient is achieved, so as to obtain the parameters of the camera model needed for the visual controller. The main contents include: to conduct the weak calibration of the basic matrix of moving camera for a translation, to get the linear internal parameters of the camera through the basic matrix obtained, and by the longitudinal twice translation, to make use of RAC constraint to obtain the nonlinear distortion coefficient of the camera. And the parameters of the controller sets up a block diagram of control system and adjusts the control parameters setting. What's more, the linkage parameters design of parabola transition based on joint space is implemented to realize three axis smooth linkage, so as to provide the basis for the follow-up guiding task based on the prototype system.

3.1 Weak calibration principle and analysis of for fundamental matrices

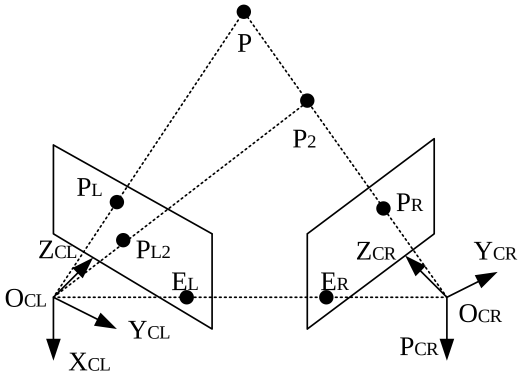

Figure. 3. Binocular vision imaging model

The imaging model of the scene point in the dual camera imaging planeis shown in Figure 3. Taking the linear model of the left camera as an example, OcL-XClYClZcL refers to the camera coordinate, OcL indicates the camera optical center, ZcL represents the camera optical axis, P suggests the field attractions, and its projections in two camera imaging plane are PL and PR.

3.2 Internal parameter motion self calibration method for camera

In that there is a distortion of the three types of radial, centrifugal and thin prism in the nonlinear optical perspective projection camera model, in the actual situation, the camera will not satisfy the linear imaging geometry. Based on fundamental matrix weak calibration methods based on epipolar constraint mentioned above, the linear internal parameters and the nonlinear radial distortion coefficient calibration method based on the moving camera are mainly studied. Because this system does not need to consider the external parameters. the camera can be moved first of all. A translation as mentioned above, used for the weak calibration of basic matrix, so as to get the linear internal parameters. The other two translations are used to obtain the nonlinear radial distortion coefficient, and the distortion projection point is corrected to the ideal projection that can meet the linear imaging geometric relationship.

According to the plane equation:

$$U_R^T \bullet M_{nR}^{-T} \bullet T \bullet R \bullet M_{mL}^{-1} U_L = 0 \quad (1)$$

In the above formula, R is the rotation conversion matrix between the two camera coordinates, T refers to the anti symmetric matrix of the translation transformation vector t between the two camera coordinates, Min indicates the camera intrinsic parameters matrix, and U suggests the image pixel coordinate vector. The fundamental matrix can also be expressed as:

$$F = M_{nR}^{-T} \bullet T \bullet R \bullet M_{mL}^{-1} \quad (2)$$

Because of the camera transition, the rotation matrix R means the unit matrix. The transition distance is measured, and the transition vector t is [tx ty 0]-T, so the anti symmetric matrix is:

$$T = \begin{bmatrix} 0 & 0 & t_y \\ 0 & 0 & -t_x \\ -t_y & t_x & 0 \end{bmatrix} \quad (3)$$

As a result, the above formula can be expressed as:

$$F = M_{\text{in}}^{-T} \bullet T \bullet M_{in}^{-1} \quad (4)$$

Then, we get:

$$M_{\text{in}}^{T} \bullet F \bullet M_{in} = T \quad (5)$$

According to the definition of internal parameter matrix Min:

$$M_{in} = \begin{bmatrix} k_x & 0 & u_0 \\ 0 & k_y & v_0 \\ 0 & 0 & 1 \end{bmatrix} \quad (6)$$

In (6), u0 and v0 can be replaced by the center of the image pixel coordinates. F and T obtained previously are substituted into (5), kx and ky can be solved, so as to obtain the linear internal parameter matrix Min of the camera.

4 RESULTS AND DISCUSSION

4.1 Hardware structure of prototype system

The hardware structure of the assembly robot consists of four parts: optical sensing mechanism, control mechanism, driving amplifier structure and the implementation structure. The optical sensing structure includes a high resolution CCD camera, image acquisition card, SDI (Serial Digital Interface) digital component serial interface data line, lens and auxiliary light source; the control mechanism adopts the structure of computer control; the driving amplifier structure is mainly composed of permanent magnet synchronous servo drive; the implementation structure includes AC servo motor, the Cartesian coordinate manipulator and vacuum gripper as the end executor. The overall scheme of the hardware structure is shown in figure 4:

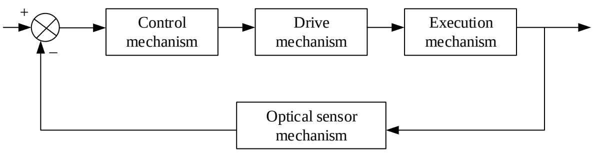

Figure. 4. Schematic diagram of hardware structure

Optical sensing mechanism: the optical sensing mechanism consists of CCD (Charge Coupled Device) photosensitive element and lens, auxiliary light source, image acquisition card interface, coaxial cable and so on. CCD charge coupled device is a semiconductor device using a photosensitive diode array to convert the images and other optical signals to the analog signals, and after being amplified, it is converted to digital signal. It is widely used in cameras, digital cameras, scanners and other devices. Compared to the low cost CMOS (Complementary Metal Oxide Semiconductor) complementary metal oxide semiconductor camera, the imaging effect is better and the quality is better. As a result, it is widely applied in the fields of image sensing and non-contact measurement.

Control and drive mechanism: the control mechanism adopts an industrial personal computer (IPC) structure, and the IPC is connected with the servo driver through the RJ-45 interface. AC permanent magnet synchronous servo drive is a high precision controller for servo motor control, mainly composed of position loop, speed loop, current loop control unit, power driving unit, communication interface unit and feedback receptors. The servo driver consists of two major parts: the control unit and the power driving unit. The control unit realizes the complex control algorithm; and the power driving unit is used for driving motor and providing power for the whole system. The rectifier part is divided into three-phase full bridge rectifier circuit. The inverter part is three-phase sine PWM (Pulse Width Modulation) voltage inverter. And it is used for the rectified DC inverter through PWM to output the inverter frequency so as to drive three-phase permanent magnet synchronous AC servo motor.

Implementation mechanism: the actuator is composed of a rectangular coordinate configuration mechanical arm and a vacuum absorbing gripper. The end actuator uses the vacuum gripper, adopts the air for absorbing the small target, and releases the target by using target gravity. For small targets with viscous force less than the target's own gravity, the way of changing the direction of flow can also be used to release the target. It includes: air compressor is used for generating flow, the electromagnetic valve is applied for controlling the size of pressure generated, and glass straw is adopted for sucking the target. In addition, the hose is used for connecting each part, and the filter is used for filtering the impurities in the air to protect the holder's safety and service life. The system adopts the vacuum suction gripper developed by SMC company.

4.2 Target guidance experiment of small parts

In order to verify the feasibility and accuracy scope of the designed small target visual assembly robot system, the prototype system designed is adopted. The vacuum gripper end is guided to the metal ball target parts with the diameter of 1.0mm. Considering the characteristics of the end executor, we should make the spatial distance error less than 5.0mm, and the experiment is divided into three stages.

The experimental results show that the system has high precision in the planes X and Y direction. The average error in the image is within 5 pixels, while the actual error is 0.3mm. And there is a big error of 3.5mm in the depth, and the spatial distance error is 3.514mm. But considering that the suction can still complete the task, so on the whole, the system can achieve the predetermined target.

The main causes of errors in X and Y directions are: the control parameters are non optimal parameters. In that the control parameters obtained from calibration are non optimal parameters, when using Simulink, it is necessary to obtain more accurate control parameters. That is to say, the response curve can conduct fast convergence, and the convergence value is equal to the target value. The end executor and the target image pixel coordinates have extraction error. Due to the camera resolution and precision of image processing, the error exists in the image pixel coordinate. As a result, it can be replaced by a higher resolution camera and in the image processing algorithms, it can use better filtering algorithm to restore clear images.

The main reason for error generated in Z direction is: when the end actuator coincides with the target, although the end does not reach the target plane, it still meets the cross ratio invariant (threshold δ). The error range is controlled by changing the value of δ. If the size of δ is too large, it may result in that the end cannot absorb the target, while if the size of δ is too small, the number of movement steps required will be more, and the time spent will be longer. As a result, on the occasions of different real-time requirements and accuracy requirements, and in the accuracy range that the selected actuator allows, the appropriate δ value can be set to complete the task.

4.3 Comparison with location based fixed monocular vision guidance experiments

P3P three point perspective method is a commonly used method that makes use of monocular vision for the camera coordinate system coordinate measurement. As shown in Figure 5, using the known camera of the internal parameters, the image of three spatial points is acquired and the image pixel coordinates are obtained. By the camera internal parameters, the unit vector is solved. In addition, the absolute distance m, n, and t between the spatial three points. A four order equation is obtained by using spatial geometrical principle, and the distances da, db, and dc of three points to the space imaging plane are solved, and thus the coordinates of the three points in the camera coordinate system are obtained. By using the principle, fixed monocular vision control based on the camera coordinate position can be carried out. That is to say, the end point, the target point and another middle point are taken as the spatial three points, and the distance between the three points is measured. In addition, its coordinate in the camera coordinate system is obtained by using P3P principle. The translation vector of the end point and the target point in the camera coordinate system is the displacement required for the robot coordinate system.

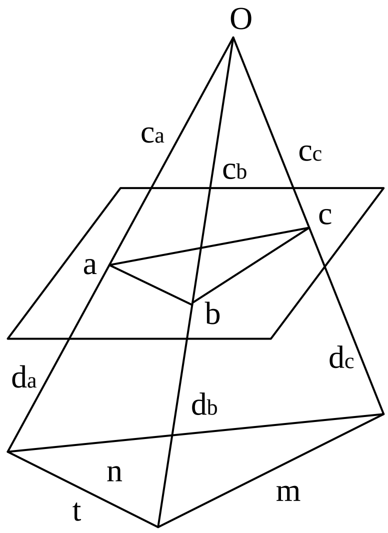

Figure. 5. P3P principle

The same conditions are used and the target and end are placed again to carry out the experiment, so the internal parameters are:

$$M_{in} = \begin{bmatrix} 2983.70077 & 0 & 1664 \\ 0 & 2983.53796 & 936 \\ 0 & 0 & 1 \end{bmatrix} \quad (7)$$

Table 1. The image pixels coordinates and the coordinates of the camera coordinates system of three spatial points

Points	Image pixel coordinates	Camera coordinate system
A	（1040，2529）	（9.853152，81.874327，282.325265）
B	（1525，2378）	（28.754359，50.84987，244.030952）
C	（1254，1942）	（56.838017，68.896310，287.787429）

Therefore, the displacement coordinate is shown in Table 1. Compared with the results of the contrast experiment, it can be seen that, the error range of the system designed in this paper in the horizontal direction is smaller, which proves the feasibility and the accuracy range of the system.

5 CONCLUSION

Robot vision control refers to that the robots, through the vision system receiving and processing the images, and the feedback information of the visual system, do the corresponding operations. Robots are generally divided into Cartesian plane configuration, SCARA plane joint configuration, spherical coordinate configuration, cylindrical coordinate configuration and chain configuration in terms of the configuration. In allusion to the image detection, the camera calibration, and vision control of the visual assembly robot system, some studies and discussions are carried out, and the theoretical verification is conducted through lots of experiments. And then, from two aspects of hardware and software, the assembly robot fixed visual control system based on monocular image is achieved. At last, the metal ball guide assembly task is performed and compared with visual control experiments of the position. More importantly, the feasibility and precision of the vision control system discussed in this paper are verified.

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