Research on the Laser Calibration Method for the Image Plane Center of the Visual Sensor

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Abstract. This paper explains the principle and method to calibrate the image plane center of the camera by use of laser in the pre-calibrate process of the intrinsic parameters of the visual sensor. The laser facula image has been disposed properly, so the accurate position has been located by calculating the center of mass. Consequently, the image plane center can be calibrated accurately. After the calibration, the guiding experiments show that the precision of the system is quite good which proves that camera calibrated by the method presented by this paper can satisfy the requirement of the whole system.

1 Introduction

Human beings always apperceive the out world by the sense apparatus such as vision, feeling, ear, or nose and so on. It is estimated that about 80% information is obtained by vision. So visual sense technique is always the hot research topic, and it is used widely in the industry because it is rapid response, high level automatization and information plenty[1]. As the kernel of the visual sense system, the parameter calibration of the camera is very important to the whole system.

There are two parts of the CCD camera parameter that are intrinsic parameters and extrinsic parameter. Intrinsic parameters include imagine plane center (principle point), effective focus, lens aberration parameter and the ratio of the vertical length to the transverse length of the image plane. Extrinsic parameter is the transition matrix of the camera coordinate system to the world coordinate system. There are several method to calibrate the camera parameters, while most of the method have to pre-calibrate the optical camera center and the transverse-vertical ratio of the imagine plane. But most of calibration methods of the CCD image plane center are low precision and large amount computation [2-4]. This paper studies how to calibrate the image plane center by use of laser.

2 Calibration Principle

2.1 CCD Imaging Model

The CCD image plane center is the intersection point of the main optical lens axis and the CCD imaging plane. Fig.1 is the camera imaging model with radial aberration,

T.-J. Tarn et al. (Eds.): Robot. Weld., Intellige. & Automation, LNCIS 362, pp. 295–302, 2007.
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where Z_c is the main optical axis of the lens, $O_i - X_iY_i$ is the image coordinate system of the CCD imaging plane, and O_i is the imaging plane center of the CCD whose pixel coordinate is (c_x, c_y). In most cases, all of the intrinsic and extrinsic CCD parameters including 6 intrinsic parameters as (c_x, c_y), s_x, s_y, k, f and 8 extrinsic parameters like CCD rotation matrix *R* and transferring matrix *T* need to be calibrated before CCD working.

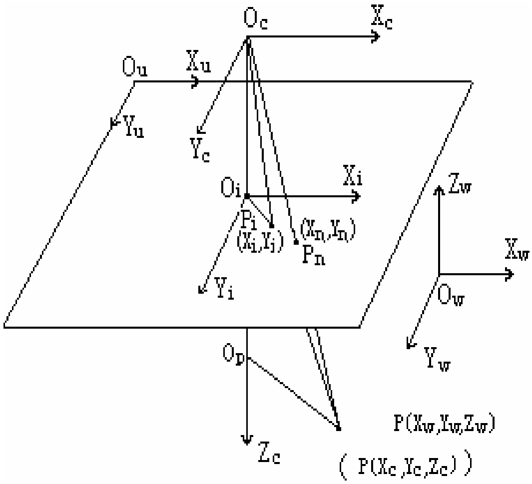

Fig. 1. Camera imaging model with radial aberration

In the computer visual system, the image plane center is the origin point of the image coordinate system, which is also the center of the radial and tangent aberration calibration model for some high level precision cases. This point should be the center of the imaging target plane. But because of the manufacture and installing error and the lens aberration, the image center does not locate at the target plane center exactly [5]. So it is very necessary to calibrate the CCD image center exactly which is a very important part for the CCD parameter calibration. But also, in the stereo visual system, it is the precondition for the transition from the CCD image plain coordinate system to the world coordinate system.

2.2 Principle for the Image Center Calibration by Use of Laser

The principle to calibrate the image center of the CCD by use of laser is shown as Fig.2. The laser beam passes through a small hole on the diaphragm and shoots on the lens. Based on the optical principle, a part of the light passes though the lens and creates the image point on the image plane but the other part is reflected by the lens to shoot on the diaphragm to create the reflecting image facula (when the reflecting angel is small). When the incident beam coincides with the main axis of the lens, it also coincides with the reflecting beam on the lens, so the reflecting beam also passes though the hole on the diaphragm. At this time, the laser image facula on the image plane is the CCD image plane center. So the CCD image plain center can be obtain by observing the position of the reflecting image facula on the diaphragm and adjusting the CCD position and pose to make the reflecting beam pass through the hole.

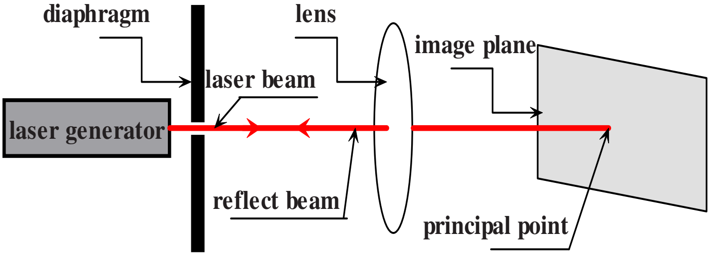

Fig. 2. Sketch map of calibration theory

3 Experiment Results and Analysis

3.1 Experiment

The camera used in the experiment is like a pen which is very small and whose target plain is about 1/3 inch. Experiment collection imagine, whose dimension is 768×582 pixel, is 8bit BMP image collected by image collection card. To observe the reflection beam better, the experiment is operated in the darkroom and both the camera and the laser generator are fix on the precision experiment platform which can be adjusted in 3 dimensions. Fig.3 shows the experiment process. At the beginning, the reflect beam doesn't coincide with the laser beam. And then the camera position and pose is adjusted carefully to make the laser beam coincides with the reflect beam exactly as Fig.4. Now the point created by the laser beam on the image plain is the center of the image plain. For every time of the new experiment, the camera and the laser generator are moved far away from the calibrating position of the previous experiment first, and then their position and pose are adjusted carefully to get the satisfying imagine.

3.2 To Obtain the Exact Position of the Principle Point

Because the incident beam is very strong, the image on the CCD image target is a large facula whose center is incident beam center (Fig.4). In this paper, the real pixel position of the image center is determined by the real position of the facula centroid. After the

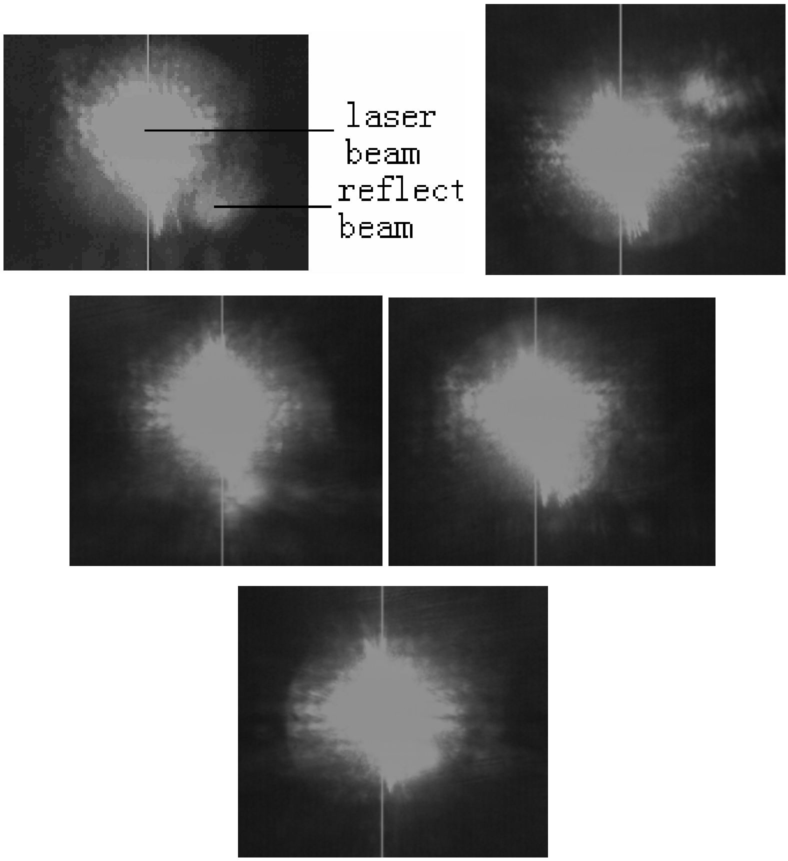

Fig. 3. Diagram of experiment process

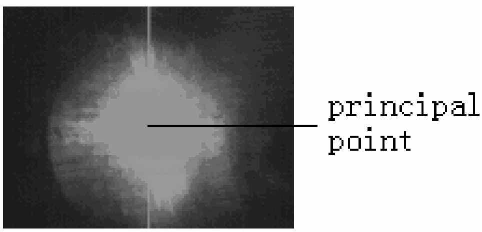

Fig. 4. Diagram of the experiment result

pretreatment of the emanative image, the exact pixel position of the laser beam can be obtained by Equation 1.

$$X_g = \frac{1}{N}\sum_{i=1}^{i=N} X_i \quad Y_g = \frac{1}{N}\sum_{i=1}^{i=N} Y_i \tag{1}$$

To repeat the process many times, the experiment data is shown as table 1.

Table 1. Experiment data of the coordinate of the image plane center

Num.	X	Y
1	364.67	283.81
2	365.83	282.18
3	365.17	282.99
4	364.85	283.12
5	365.30	282.53
6	365.14	282.37
7	365.21	283.04
8	365.18	282.58
Mean value	365.17	282.83

So the pixel coordinate of the image plane center is $(365.17, 282.83)$ which is the mean value of 8 experiment data. From table 1, we can also see that the experiment error is very small for every time (<1pixel), so the pre-calibration of the image plane of the visual sensor is finished.

4 Validation of the Laser Calibration Method

Based on the result, the other intrinsic and extrinsic parameters of the visual sensor can be calibrated useing the method mentioned in [4]. The visual guide test shows that the guide error in the local area is smaller than 5mm which means the method present by this paper is high precise and very useful.

4.1 Calibration of the Hand-Eye Relationship

After acquiring the extrinsic parameters of the camera, the hand-eye relationship of the robot, namely the relationship between the camera installing position and the robot controlling point (last arthrosis), can be determined by use of the control point coordinates read from the robot controller at the imaging moment. Given the robot coordinates {A} with the origin of A_0, the last arthrosis coordinates {B} with the origin of B_0 and the camera coordinates {C} with the origin of C_0, the coordinates of P at camera coordinates is ${}^{C}P$ which can be obtained by use of the following equation:

$$ {}^{C}P = {}^{C}_{A}R\,{}^{A}P + {}^{C}A_0 \tag{2} $$

Where ${}^{A}P$ is coordinates of P at the robot coordinates, ${}^{C}_{A}R$ is the rotate matrix of A to C, ${}^{C}A_0$ is the translation matrix. Both the ${}^{C}_{A}R$ and ${}^{C}A_0$ can be determined by those calibration of the camera extrinsic parameters[6].

According to the robot last arthrosis (control point) data that been read from the robot controller, and the rotation and translation equation between different coordinates, the parameters ${}^{A}_{B}R$ and ${}^{A}B_0$ can be determined.

$$ {}^{C}_{A}T = \begin{bmatrix} {}^{C}_{A}R & {}^{C}A_0 \\ 0 & 1 \end{bmatrix} \quad {}^{A}_{B}T = \begin{bmatrix} {}^{A}_{B}R & {}^{A}B_0 \\ 0 & 1 \end{bmatrix} \tag{3} $$

So, the robot hand-eye relationship can be educed directly.

$$ {}^{C}_{B}T = {}^{C}_{A}T \, {}^{A}_{B}T \tag{4} $$

where R is the 3×3 rotation matrix, A_0 and B_0 is the position vector,0 is the 1×3 0 vector.

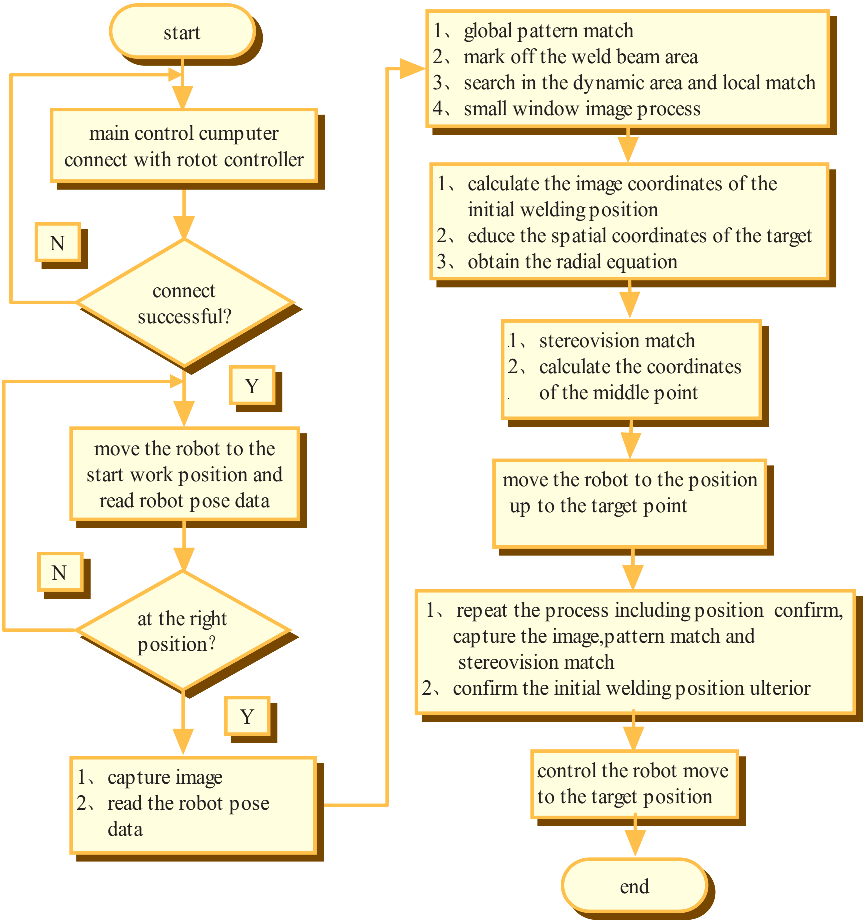

Fig. 5. Flow chart of the vision guiding experiment

4.2 Vision Guiding Experiments

All the experiments are performed on the ordinary industrial robot named MOTOMAN UP6. The used camera is ARONIX MCC-2510 micro CCD camera whose dimension of the target plane is 1/3 inch. Images are captured by the PCI-1409 image capture card produced by National Instrument Corporation. The flow chart of experiments is shown as fig.5.

Vision guiding experiments are performed under the nature sunshine. The experiments are repeated ten times. Error in X direction is less than 3.22mm, error in Y direction is less than 3.11mm, and error in Z direction is less than 5mm.

When the robot is in operation, the system guides the robot to the initial welding position and then tracks the welding line while the allowable error is $\pm 10mm$. The guiding experiments show that the precision of the system is quite good which proves that camera calibrated by the method presented by this paper can satisfy the requirement of the whole system.

5 Conclusions

(1) This paper presents a method how to calibrate the CCD camera image plane center of the visual sense system by use of laser, whose principle is simple and whose precision is very high, can calibrate the image plane center alone in one operation and does not mention the other parameters. This method doesn't need the complicated computation as the other method.
(2) The calibration result of this method provides the precondition for the calibration of the other CCD parameters.
(3) By fixing the camera calibrated by the laser calibration method at the end of the robot arm, the hand-eye relationship of the robot, namely the relationship between the camera installing position and the robot controlling point (last arthrosis), is determined. The guiding experiments show that the precision of the system is quite good which proves that camera calibrated by the method presented by this paper can satisfy the requirement of the whole system.

Acknowledgements

The authors would like to thank Prof. S. B. Chen and Mr. T. Lin for their support in numerous discussions. Thanks are also due to the Robot and Intelligent Welding Lab, Shanghai Jiaotong University, P. R. China for providing the equipments for the experiments.

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