A Camera Calibration Method Based On OpenCV

Ao Wu*
College of Information Science and Engineering
Guilin university of Technology
Jiangan Road 12,Guilin,China
86-17862123205
1021304196@qq.com

Hongxiang Xiao
College of Information Science and Engineering
Guilin University of Technology
Jiangan Road 12,Guilin,China
86-13768916556
xhx0601@qq.com

Fanyong Zeng
College of Information Science and Engineering
Guilin University of Technology
Jiangan Road 12,Guilin,China
86-0773 2537803
2287691541@qq.com

ABSTRACT

Automobile four-wheel positioning refers to the accurate measurement of a specific set of angles of the car wheel. The accuracy of the four-wheel positioning is directly related to the overall performance of the car. Camera calibration as the first step in four-wheel positioning measurement and three-dimensional modeling is of great significance for improving the accuracy of four-wheel positioning measurement based on machine vision. In order to improve the accuracy of four-wheel positioning measurement based on machine vision, this paper based on the imaging model of the camera, based on Zhang Zhengyou calibration method, combined with openCV to calibrate the camera, and calculate the actual internal parameters and distortion parameters of the camera, which lay the foundation for the next four-wheel positioning parameters measurement.

CCS Concepts

• **Computing methodologies→Camera calibration**

Keywords

Camera calibration; four-wheel positioning; OpenCV.

*Corresponding author

1. INTRODUCTION

The traditional four-wheel aligner is complex in design, with many system modules, large measurement error, and difficult to maintain equipment. The 3D four-wheel aligner based on machine vision technology is simple in operation, fast in measurement speed and high in precision [1]. Domestic research on four-wheel positioning technology is relatively late, but in the case of more and more popular vehicles, the application space is also growing. Therefore, it is of great significance to the system construction of four-wheel positioning based on machine vision and the application research of data processing and three-dimensional modeling. While camera calibration is the first step in four-wheel alignment measurement and three-dimensional modeling, the importance of camera-related parameter accuracy is self-evident.

Based on the Zhang Zhengyou calibration method, this paper writes the calibration program under the window 10 system, combined with visual studio 2010 and openCV2.4.10, and then runs the program to get the actual internal parameters and distortion parameters of the camera.

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2. BASIC CONCEPT

Machine vision is a computer system that simulates human visual functions. One of its important functions is to restore the corresponding three-dimensional spatial information in a certain transformation relationship according to the collected two-dimensional image information. Camera calibration plays a key role in computer vision and 3D reconstruction [2], which provides a solid research foundation for 3D reconstruction. The essence of camera calibration is to obtain the internal and external parameters of the camera, find the relationship between the image coordinate system and the actual object space coordinate system, and then calculate the 3D position coordinates of the corresponding matching points according to the 2D coordinate image of the actual image [3].

2.1 Coordinate Transformation Relationship in Machine Vision

The world coordinate system is used to represent the position information of a target in real space， it is represented by $o - x_w, y_w, z_w$ [4], as shown in Figure 1.

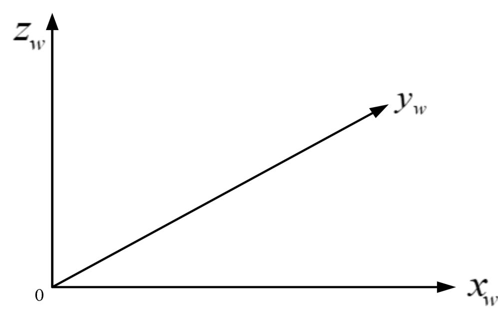

Figure 1. World coordinate system

The camera coordinate system is the coordinate center of the center of the lens, the line passing through the center and perpendicular to the pixel plane is the Z axis, and the X and Y axes are collinear with the axis and the axis in the pixel plane, we are accustomed to using $o - x_c, y_c, z_c$, as shown in Figure 2.

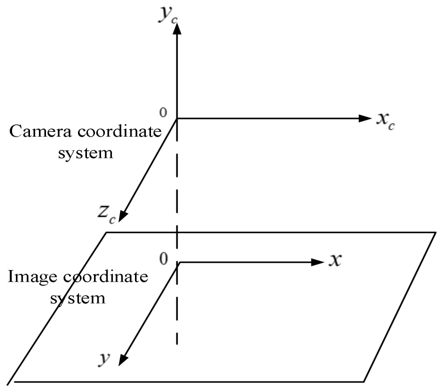

Figure 2. Camera coordinate system

The objects in the three-dimensional space are projected onto the inner photosensitive surface by the imaging model of the camera to form a final image. In order to be able to quantitatively describe the image formed on the photosensitive plane, we establish a two-dimensional coordinate system with two intersecting lines parallel to the X-axis and Y-axis of the camera coordinate system as axes and axes. If the point O is at the upper left of the photosensitive surface, the coordinate system is in pixels. The light passing through the lens center and perpendicular to the photosensitive plane will intersect the photosensitive surface. If the point is used as the coordinate system origin, the image coordinate system is as shown in Figure 3.

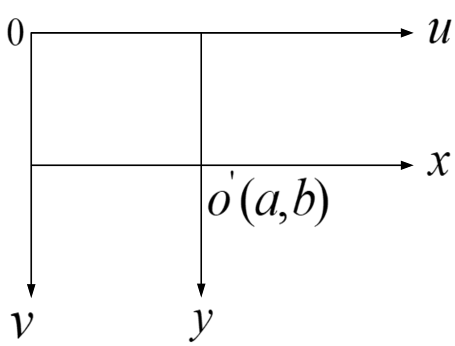

Figure 3. Image coordinate system

If the element on the X-axis is dx and the element on the Y-axis is dy, then the image physical coordinate system is converted into the image pixel coordinate system, as shown in equation (1).

$$\begin{aligned} \mathrm{u} &= \frac{x}{dx} + u_0 \\ v &= \frac{y}{dy} + v_0 \end{aligned} \tag{1}$$

The image coordinate system and the camera coordinate system can be converted by the formula (2).

$$\begin{aligned} \mathrm{u} - u_0 &= fs_x x / z = f_x x / z \\ v - v_0 &= fs_y y / z = f_y y / z \end{aligned} \tag{2}$$

Where f is the focal length of the camera, f_x and f_y are the components of the focal length f on the X and Y axes, respectively. $f_x = fs_x$, $f_y = fs_y$, s_x, s_y is the scaling factor.

The world coordinate system and the camera coordinate system can be converted by the formula (3).

$$\begin{bmatrix} x_c \\ y_c \\ z_c \end{bmatrix} = R \begin{bmatrix} x_w \\ y_w \\ z_w \end{bmatrix} + T \tag{3}$$

2.2 Camera Imaging Model

The linear model of camera imaging is what we usually call a pinhole model, which allows a point P in the target to form an image point on the photosensitive plane inside the camera.

$$\begin{bmatrix} \mathrm{u} \\ v \\ 1 \end{bmatrix} = \frac{1}{Zc} k \begin{bmatrix} R & \mathrm{t} \\ 0 & 1 \end{bmatrix} \begin{bmatrix} Xc \\ Yc \\ Zc \\ 1 \end{bmatrix} \tag{4}$$

Equation (4) is the camera aperture imaging model. (Xc, Yc, Zc) is the coordinate of P in the camera coordinate system， k is only related to the manufacturing process of the camera, we call it the internal parameters of the camera. R and t are used to describe the orientation of the camera and the world coordinate system. So it is called the camera external parameters.

Due to the influence of the processing technology, the camera lens itself is not perfect. It is not an ideal imaging effect in the imaging process, but there is a certain degree of distortion. The imaging and ideal imaging exist at a certain point in the space on the camera coordinate plane. A certain offset. Therefore, it is not enough to consider only the description of the linear model in practical applications, and it is difficult to reasonably describe the imaging system. Therefore, in order to achieve higher accuracy camera calibration, nonlinear distortion factors must also be included. Camera imaging mainly includes three forms of radial distortion, tangential distortion, and thin lens distortion [5] [6], the latter of which is usually the carrier of the former two. As shown in Figure 4.

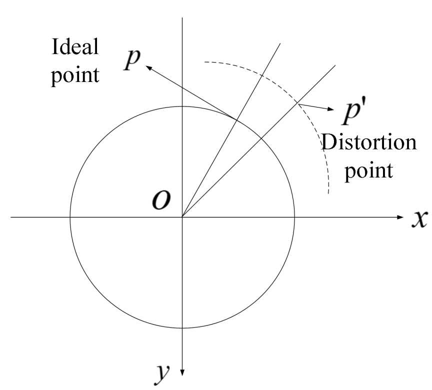

Figure 4. Radial distortion and tangential distortion

Usually, only the radial distortion can be considered to meet the requirements of general visual measurement. Excessive consideration of thin prism distortion will adversely affect the calibration result. If only radial distortion is considered, the nonlinear distortion model of the camera is shown in equation (5).

$$X_u = X_d(1+kr^2)$$
$$Y_u = Y_d(1+kr^2) \tag{5}$$

Where k is the distortion coefficient, $r_2 = {X_d}^2 + {Y_d}^2$, (X_d, Y_d) is the actual coordinate of the image, (X_d, Y_d) is the image coordinate of the object P.

3. CAMERA CALIBRATION

The traditional calibration method requires manual participation in the extraction of corners and other stages, which is time-consuming and labor-intensive, and the accuracy is not guaranteed. OpenCV is an open source computer vision library that integrates a large number of video image processing algorithms [7]. The openCV library can take advantage of the mature algorithms designed by the predecessors, and can be modified and used at will, with good scalability and openness. In OpenCV, the camera calibration method of single-plane checkerboard proposed by Professor Zhang Zhengyou in 1998 is a method for solving the internal and external parameters of the camera for radial distortion and tangential distortion [8]. It is not necessary to use this method for calibration. Special calibration, just print a checkerboard, eliminating the need for expensive and delicate calibration plates, which is very practical. Next, the principle of Zhang Zhengyou calibration algorithm will be introduced in detail.

3.1 Calibration Principle

Let the world coordinate of an object be $\mathrm{M} = [X, Y, Z, 1]^T$, and the corresponding two-dimensional image coordinates be $\mathrm{m} = [u, v, 1]^T$, then the mapping relationship between them is formula (6).

$$\mathrm{sm} = \mathrm{A}[\mathrm{R}, \mathrm{t}]\mathrm{M} \tag{6}$$

Where s is an arbitrary non-zero scale factor and the matrix R, t are external parameters of the camera. Since Zhang Zhengyou is based on the method of planar target calibration [9], all the feature points are in the same plane, so Z=0 can be assumed, and the formula (6) can be expressed as a matrix form.

$$\mathrm{s}\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \mathrm{A}\begin{bmatrix} r_1 & r_2 & r_3 & t \end{bmatrix}\begin{bmatrix} X \\ Y \\ 0 \\ 1 \end{bmatrix} \tag{7}$$

Where, r_2 is the column vector of the rotation matrix. Since Z=0, the formula (7) can be rewritten as the formula (8).

$$\mathrm{s}\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = A\begin{bmatrix} r_1 & r_2 & t \end{bmatrix}\begin{bmatrix} X \\ Y \\ 1 \end{bmatrix} \tag{8}$$

Get the formula (9).

$$\mathrm{sm} = \mathrm{HM} \tag{9}$$

Then there is the formula (10).

$$\begin{gathered} \mathrm{sm} = A[R,t]M = A[r_1, r_2, t]M = HM \\ H = [h_1, h_2, h_3] = \lambda A[r_1, r_2, t] \end{gathered} \tag{10}$$

Where H is a homography matrix, representing the transformation relationship of the point on the three-dimensional image to the corresponding point on the plane template, and λ is the scaling factor, $\lambda = \frac{1}{s}$, then $r_1 = \frac{1}{\lambda}A^{-1}h_1$, $r_2 = \frac{1}{\lambda}A^{-1}h_2$ .According to the orthogonality of the mapping matrix and R, there are two constraints of the internal parameter matrix A: ${r_1}^T r_2 = 0$ and ${r_1}^T r_1 = {r_2}^T r_2$.

$$\begin{cases} {h_1}^T A^{-T} A^{-1} h_2 = 0 \\ {h_1}^T A^{-T} A^{-1} h_1 = {h_2}^T A^{-T} A^{-1} h_2 \end{cases} \tag{11}$$

From the knowledge of linear algebra, the matrix A with 5 unknowns can find the corresponding solution when there are six equations.

$$B = A^{-T}A^{-1} = \begin{bmatrix} B_{11} & B_{12} & B_{13} \\ B_{21} & B_{22} & B_{23} \\ B_{31} & B_{32} & B_{33} \end{bmatrix}$$
$$B = \begin{bmatrix} \frac{1}{\alpha^2} & -\frac{\gamma}{\alpha^2\beta} & \frac{v_0\gamma - u_0\beta}{\alpha^2\beta} \\ -\frac{\gamma}{\alpha^2\beta} & \frac{\gamma^2}{\alpha^2\beta^2} + \frac{1}{\beta^2} & -\frac{\gamma(v_0\gamma - u_0\beta)}{\alpha^2\beta^2} - \frac{v_0}{\beta^2} \\ \frac{v_0\gamma - u_0\beta}{\alpha^2\beta} & -\frac{\gamma(v_0\gamma - u_0\beta)}{\alpha^2\beta^2} - \frac{v_0}{\beta^2} & -\frac{\gamma(v_0\gamma - u_0\beta)^2}{\alpha^2\beta^2} + \frac{{v_0}^2}{\beta} + 1 \end{bmatrix} \tag{12}$$

Where , B is a symmetric matrix, represented by a six-dimensional vector as a formula (13).

$$\mathrm{b} = \begin{bmatrix} b_{11} & b_{12} & b_{22} & b_{13} & b_{23} & b_{33} \end{bmatrix} \tag{13}$$

Let the vector of the ith column in H be $h_i = \begin{bmatrix} h_{i1} & h_{i2} & h_{i3} \end{bmatrix}^T$,then

$$\begin{gathered} {h_i}^T B h_j = {v_{ij}}^T b \\ v_{ij} = \left[h_{i1}h_{j1}, h_{i1}h_{j2} + h_{i2}h_{j1}, h_{i2}h_{j2}, h_{i3}h_{j1} + h_{i1}h_{j3}, h_{i3}h_{j2} + h_{i2}h_{j3}, h_{i3}h_{j3}\right] \end{gathered} \tag{14}$$

Ability to rewrite constraints to formula (15).

$$\begin{bmatrix} {\mathrm{v}_{12}}^T \\ (v_{11} - v_{22})^T \end{bmatrix} b = 0 \text{, that is } \mathrm{vb} = 0 \tag{15}$$

The matrix v is a 2×6 matrix with 6 unknowns. Each picture can get two equations, so you need to create 6 equations. You must collect at least 3 pictures to get a unique solution, that is, determine the parameter size of b, but this is only an initial value and not an optimal solution. We can solve the problem by maximum likelihood estimation [10] and further refine.

Establish a nonlinear minimization objective function based on the actual imaging model of the camera.

$$\sum_{i=1}^{n} \sum_{j=1}^{m} \left\| m_{ij} - m(A, k_1, k_2, R_i, t_i, M_j) \right\|^2 \tag{16}$$

According to this function, the L-M method is used, and the L-M algorithm is expressed as follows.

$$\begin{aligned} x_{(k+1)} &= x_k + \Delta x \\ \Delta x &= -[\nabla^2 E(x)]^{-1} \nabla E(x) \end{aligned} \tag{17}$$

Where x_k represents the weight of the k iterations and the threshold vector, $x_{(k+1)}$ is the updated weight and threshold vector, $\nabla^2 E(x)$ is the Hessian matrix used for the error index function $E(x)$, and $\nabla E(x)$ is the corresponding gradient.

The initial value of H needs to be set when iteratively solves with the L-M method. The following equations are obtained from the relationship between the feature points on the template and the corresponding points of the image [11].

$$\begin{bmatrix} M_i^T & 0^T & -uM_i^T \\ 0^T & M_i^T & -vM_i^T \\ \vdots & \vdots & \vdots \\ M_n^T & 0^T & -uM_n^T \\ 0^T & M_i^T & -vM_i^T \end{bmatrix} \begin{bmatrix} h_1 \\ h_2 \\ h_3 \end{bmatrix} = 0 \tag{18}$$

Solving the equations yields the initial value of H, then iteratively computes the homography matrix H, and then b can calculate A, and then find the corresponding R and t. After the initial solution is found, the value of the variable with the smallest error can be obtained by using the L-M method according to the formula (16).

3.2 Camera Calibration Process

Because the checkerboard pattern is prone to corner blur during the imaging process, the calibration accuracy is affected, and the circular pattern has the characteristics of central symmetry. In the perspective imaging model of the camera, the feature point blurring can be avoided and the calibration accuracy can be improved. Therefore, this paper adopts the circular grid plane template, based on Zhang Zhengyou calibration method, combined with openCV to complete the calibration of the camera. The calibration board is shown in Figure 5:

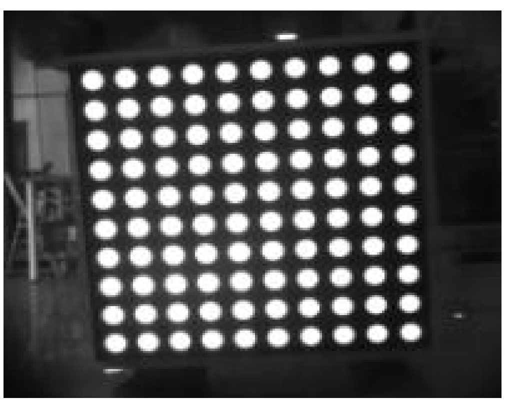

Figure 5. Calibration board

The camera calibration process based on openCV is shown in Figure 6:

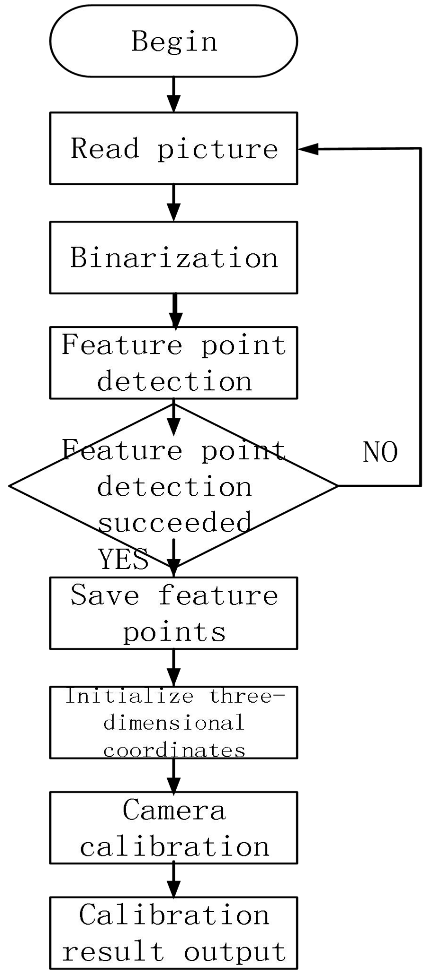

Figure 6. Calibration flow chart

In order to more intuitively see the above process, the detected circle is marked correspondingly, and the aligned center coordinates are connected by a straight line. As shown in Figure 7:

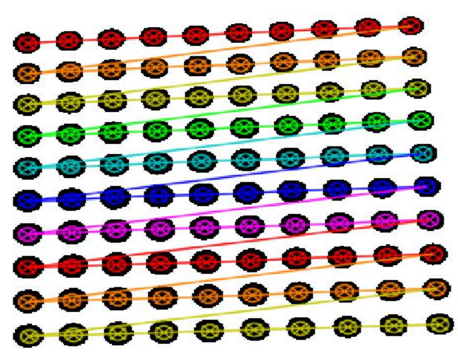

Figure 7. Camera calibration process diagram

4. CALIBRATION RESULTS AND ANALYSIS

According to the camera calibration process, using the calibration algorithm, in the Windows 10 system, combined with visual studio 2010 and opencv2.4.10 to write the calibration program, and then run the program to get the corresponding calibration results.

The calibration results are as follows:

Table 1. Calibration results

opencv-matrix	camera_matrix	distortion_coefficients
rows	3	5
cols	3	1
dt	d	d
Data	[9.8279571285577481e+002, 0., 6.2215222779699263e+002, 0.,9.8240693503011971e+002, 5.2357058161130510e+002, 0., 0., 1.]	[1.5203166846867872e-001, 7.6045697603195528e-001, 1.3078226914917473e-003, 2.7632096383769708e-004, 5.1408018498088168e+000]
avg_reprojection_error	8.5690125631249670e-002	

During the calibration process, the circle in the calibration plate can be accurately detected and the center coordinates extracted, so the corresponding calibration parameters are calculated according to the camera calibration principle. In the calibration result, camera_matrix is the camera matrix, distortion_coefficients is the distortion matrix, avg_reprojection_error is the camera re-projection error, which is about 8.57×10^{-2}, and the re-projection error reaches the order of 0.01, which meets the requirements of camera calibration accuracy in industrial measurement. The camera calibration method in this paper has high calibration accuracy. The camera calibration program developed by this method combined with openCV has high application value.

5. CONCLUSION

At present, the four-wheel locator based on machine vision has high detection accuracy and high speed, but also high cost. Therefore, it is of higher social value to develop a measuring device with high detection accuracy, high speed and higher cost performance.

At present, the four-wheel positioning device based on machine vision is based on binocular vision technology, which can capture the image of the target fixed on the left and right wheels of the car through two cameras mounted on the beam. Based on the current research on four-wheel positioning technology based on binocular vision, a scheme is proposed in this paper. The wheel positioning technology based on monocular vision is studied. A camera is used to capture the image of the target fixed on the left and right front wheels of the vehicle, and then the camera calibration technology is studied.

First introduced knowledge about coordinate transformation, then expounds the pinhole imaging model and emphatically in this paper, the nonlinear imaging model, it is also the camera imaging model of actual use, after ilf calibration method based on planar template is studied emphatically, and combining the openCV2.4.10, through the design of the visual studio 2010 completed the calibration procedure, finally used to extract the image feature point coordinates and initializes the three-dimensional coordinates of feature points to complete the camera calibration experiment, and the corresponding participation within the camera distortion parameters, the experiments show that this calibration method is of high precision, It lays a foundation for the next four-wheel positioning parameter measurement.

In the follow-up work, the image acquisition environment light source can be improved, or a higher precision camera and lens can be used to further improve the accuracy of image acquisition to meet the requirements of four-wheel positioning parameter measurement.

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