Lens Distortion Correction Method of Linear Array Camera

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Abstract

The imaging technology basing on binocular stereo vision of linear array camera can effectively detect foreign bodies existing in automobile chassis so that ensure the safety of people. However, the distortion of camera lens can influence the precision of system measurement and three-dimensional reconstruction. Because of the difference between the imaging principle of linear array camera and the imaging principle of plane array camera, this leads that the lens distortion correction algorithm applying to plane array camera cannot be directly used in linear array camera. Infer the distortion model of linear array camera by means of studying the distortion model of plane array camera and according to the characteristics of linear array camera. Establish a system of equations in accordance with the distortion mathematical model of linear array camera, then utilize cross ratio invariability and spacing ratio invariability to obtain the radial distortion coefficient and distortion center. This method should be used before the calibration of linear array camera, because it can effectively eliminate the influence of lens error to the whole calibration results.

Keywords

Linear array camera, lens distortion, distortion coefficient, cross ratio invariability camera calibration.

1. Introduction

With the development of science and technology, the development of machine vision industry is becoming more and more mature. Nowadays, car bombing occurred frequently all over the world and terrorist activities increased, so the problem of security has become a top priority. Using binocular stereo vision system for automobile chassis for the needs of on-line detection is stronger and stronger. The linear array camera becomes the key of binocular stereo imaging technology, because it has the advantages of high resolution, good measuring precision and strong anti-jamming. However, it can produce the lens distortion because of camera lens manufacturing precision of the high and low. In practical application, the lens distortion can make the system acquisition quality of images low, the geometry precision of image bad and the error of measurement system increased. Thus, in order to improve the measuring accuracy of binocular stereo vision system and the linear array camera imaging quality, the correction to the lens distortion of linear array camera must be done.

Although the linear array CCD camera correction method is rarely, the linear array CCD camera can be looked as a special case of plane array CCD camera imaging [1]. Then the imaging model of linear array CCD camera is derived via the imaging model of plane array CCD camera. It is worth noting that although the linear array camera can be used as a special case of plane array camera, the imaging principle of linear array camera has essential distinction to the imaging principle of plane array camera [2], the former is more complex than the latter. For linear array CCD camera, it acquires the same image distortion in the same column of pixels, but the plane array camera to get the amount of image distortion in the same column of pixels is different. Linear array camera scanning motion object only one line at a time, if an image has n line pixels, its image will have the n main points. Plane array camera scanning motion object is an image plane, it is always only one main point. Hence, the distortion correction method of plane array camera is not suitable for the distortion correction method of linear array camera. At present, linear array camera correction method have two methods, which are polynomial fitting [3] and precision angle measuring method [4, 5]. Both are not suitable for automobile chassis foreign body's detection based on binocular stereo vision system because of the complexity of polynomial fitting method and the high requirements for the equipment of precision angle measuring method.

For the above problems, this paper introduced a kind of approach of the linear array camera lens distortion correction based on the cross ratio invariability according to the binocular stereo vision measurement system and the plane array camera distortion model. Last, the method was carried out to solve through the experiment.

2. Measuring Principle of Dual CCD Camera Intersection Measurement System And the Derivation of Lens Distortion Model

2.1 Measuring Principle of Dual CCD Camera Intersection Measurement System

The structure of dual CCD camera intersection measuring system is shown in Fig. 1, its main parameters include: the angle of two cameras optic axis and their baseline L, namely (θ_1, θ_2); the focal length that is (f_1, f_2) of the two cameras and object distance. For the convenience of measurement, two camera imaging range of convergence can be into the intersection of plane as a plane coordinate system in the Z = 0 of the world, that is X -0- Y plane. The world coordinates of the object can simplify in this way, set the world coordinates of a point to P (X, Y, 0). Place the two cameras in the same level and they are imaging each other. The point P on the left and right in the camera lens into the image point is respectively said P_1 (x_1, y_1) and P_2 (x_2, y_2).

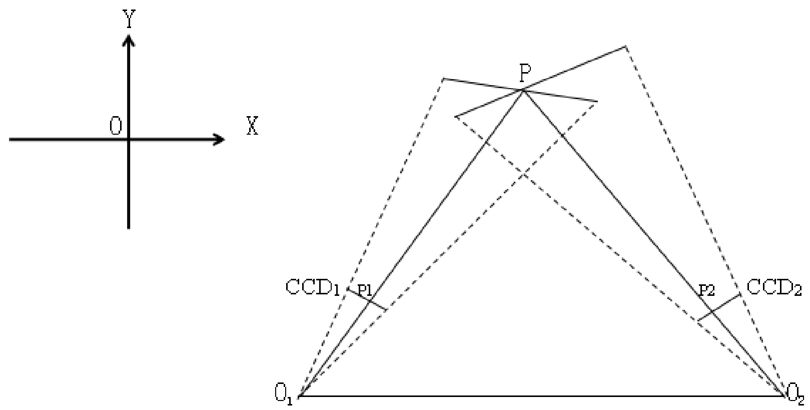

Fig. 1Measuring principle of dual CCD camera intersection

2.2 Derivation of Lens Distortion Model

The derivation of linear array camera lens distortion model can be divided into two steps, the first step is the derivation of space geometry model and the second step is the derivation of mathematical model.

Mentioned earlier, the model of linear array camera distortion can be obtained from the model of plane array camera distortion. The model of plane array camera distortion is shown in Fig. 2.

In Fig. 2, the point S is the actual coordinate of space object, (x, y) is an ideal image point for point S and (x ', y ') is the actual imaging point due to the lens distortion causing the deviation from the ideal position.

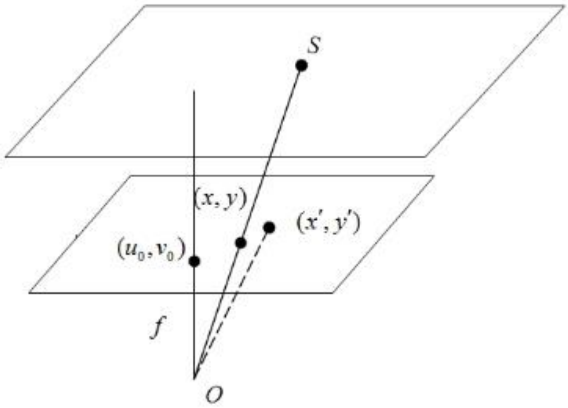

Fig. 2 The space distortion model of plane array image

In the same way, the model of linear array camera distortion is shown in Fig. 3.

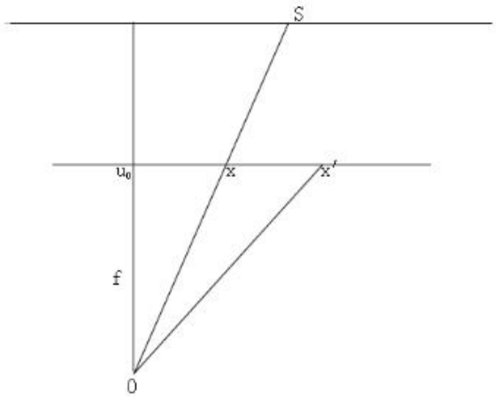

Fig. 3 The space distortion model of linear array image

The lens distortion of plane array camera include the radial distortion caused by radial curvature defects, the centrifugal distortion caused by a light heart not collinear and the thin prism distortion caused by camera assembly problems. The three distortion cause that the actual camera imaging is not ideal, the actual imaging point and the ideal imaging point exist some deviation. Set the center of the camera coordinates to (u_0, v_0), so the ideal imaging point (x, y) and the actual image point (x ', y ') have the following relations:

$$\begin{cases} x = x' + \delta_x \\ y = y' + \delta_y \end{cases} \tag{1}$$

In formula (1) , δ_x and δ_y represent the nonlinear distortion value of X direction and Y direction. Then the mathematical expressions of the plane array camera distortion are [6]:

$$\begin{cases} \delta x = k_1 x(x^2+y^2) + p_1(3x^2+y^2) + 2p_2xy + s_1(x^2+y^2) + o[(x,y)^4] \\ \delta y = k_1 y(x^2+y^2) + p_2(3y^2+x^2) + 2p_1xy + s_2(x^2+y^2) + o[(x,y)^4] \end{cases} \tag{2}$$

In formula (2), x and y represent the abscissa and ordinate of image plane coordinate system each other, k_1 is the first order radial distortion coefficient, p_1 and p_2 are centrifugal distortion coefficients, s_1 and s_2 are thin prism distortion coefficients and O [(x, y) ^{4}] is the lens distortion of high order small amount.

For linear array camera, the y in formula (2) is fixed, which can be written as y_0.The y_0 signifies the distance of the main point to the linear array CCD. Omit the high order small amount at the same time [7], so there are:

$$\begin{cases}\delta_x = k_1 x(x^2+y_0^2) + p_1(3x^2+y_0^2) + 2p_2 x y_0 + s_1(x^2+y_0^2) \\ \delta_y = k_1 y_0(x^2+y^2) + p_2(3y_0^2+x^2) + 2p_1 x y_0 + s_2(x^2+y_0^2)\end{cases} \tag{3}$$

Transform the formula (3), there are:

$$\begin{cases}\delta_x = (p_1+s_1)y_0^2 + (2p_2 y_0 + k_1 y_0^2)x + (3p_1+s_1)x^2 + k_1 x^3 \\ \delta_y = k_1 y_0^3 + (3p_2+s_2)y_0^2 + 2p_1 y_0 x + (k_1 y_0 + p_2 + s_2)x^2\end{cases} \tag{4}$$

In formula (4), constant term and one degree term represent the pan and zoom of one image respectively, so they have no effect on the distortion of linear array image. If omit constant term and one degree term, the simplified mathematical model of linear array camera is:

$$\begin{cases}\delta_x = (3p_1+s_1)x^2 + k_1 x^3 \\ \delta_y = (k_1 y_0 + p_2 + s_2)x^2\end{cases} \tag{5}$$

In practical application, there is less image distortion in the y direction according to the characteristics of linear array image imaging. Only the distortion in the pixel x has an impact on linear array camera imaging. Considering that the centrifugal distortion and thin prism distortion image distortion have less impact on the distortion of linear array image, they can be neglected. Finally, simplify formula (5), there are:

$$\begin{cases}\delta_x = k_1 x^3 \\ \delta_y = 0\end{cases} \tag{6}$$

3. Lens Distortion Correction of Linear Array Camera

As is shown in Fig. 4, there are three points that are A, B and C on the straight line L. A and B are the basic points while C is the point of division. Determined by separated point and basic points of the ratio of the two directed line segment calls simple ratio, that is:

$$SR(A,B;C) = AC/BC \tag{7}$$

Four points on a straight line than the ratio of the two simple ratio called cross ratio, that is:

$$CR(A,B;C,D)=\frac{SR(A,B;C)}{SR(A,B;D)}=\frac{AC}{BC}\Big/\frac{AD}{BD} \tag{8}$$

In formula (8), A and B are basic points while C and D are separated points. It can be proved that there are the following relations:

$$CR(A,B;C,D)=CR(A_1,B_1;C_1,D_1) \tag{9}$$

This is the cross ratio invariability of perspective projection [8].

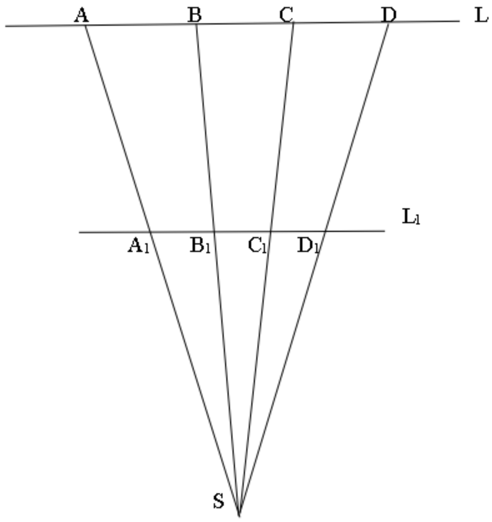

Fig. 4 The schematic diagram of cross ratio invariability

Aiming at the situation that the lens can produce distortion when the linear array CCD camera is calibrated, set up the lens distortion correction function via cross ratio invariability principle of perspective projection.

Place some sampling points in the space in the same interval. Keep the X coordinate of sampling point unchanged and get a group of calibration points in the same interval on the Y axis. Make these points move a distance along the X axis, then continue to obtain some points in the same way and use a camera to get the corresponding pixels. By using cross ratio invariability respectively to obtain the cross ratio of actual points and the cross ratio of corresponding pixels. In the end, set up the lens distortion correction function of linear array CCD camera and obtain distortion function and distortion values after correcting through the lens distortion function into the resulting cross ratio relationship.

Taking four actual points in the space, they are A (X_a, Y_a), B (X_b, Y_b), C (X_c, Y_c) and D (X_d, Y_d). They are shown in Fig. 5.

There are four actual points A,B,C and D on a line in the space, Their online array camera imaging plane of the corresponding image points of them in the imaging plane of linear array camera are a, b, c and d. The cross ratio about A, B, C and D is:

$$CR(A,B;C,D)=\frac{SR(A,B;C)}{SR(A,B;D)}=\frac{(X_a-X_c)(X_b-X_d)}{(X_b-X_c)(X_a-X_d)} \tag{10}$$

The cross ratio about a, b, c and d is:

$$CR(a,b;c,d) = \frac{SR(a,b;c)}{SR(a,b;d)} = \frac{(S_a - S_c)(S_b - S_d)}{(S_b - S_c)(S_a - S_d)} \tag{11}$$

According to the cross ratio invariability, there are:

$$\frac{(S_a - S_c)(S_b - S_d)}{(S_b - S_c)(S_a - S_d)} = \frac{(X_a - X_c)(X_b - X_d)}{(X_b - X_c)(X_a - X_d)} \tag{12}$$

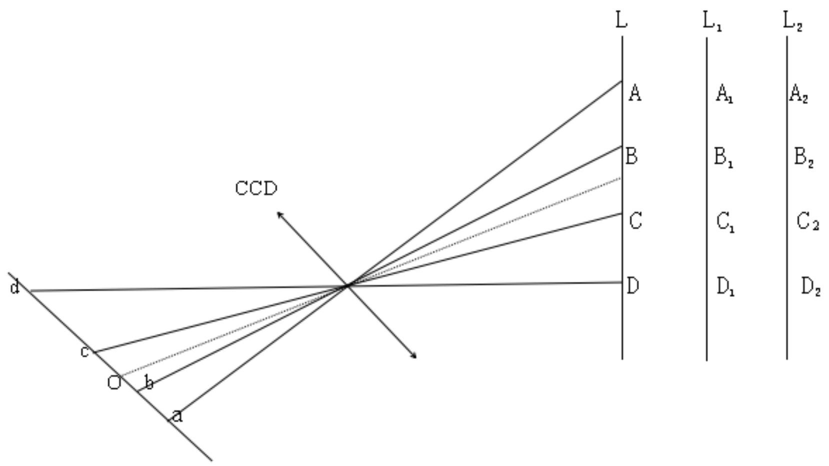

Fig. 5 The actual points and imaging points in the space

The imaging model of linear array camera can be seen as an approximation of the pinhole imaging model. But the actual image of lens can produce distortion. The existence of lens distortion makes the coordinate of imaging point obtained from the camera offset the ideal position of imaging point coordinate. Through formula (1) and formula (6), there are:

$$\begin{cases} x = x' + k_1 x^3 \\ y = y' \end{cases} \tag{13}$$

In formula (13), $x = x' - u_0$, it means the actual distance to the center coordinate. U_0 is unknown in the process of the camera calibration.

From the model of lens distortion and the cross ratio relationship which were derived, the final mathematical expressions of lens distortion correction are:

$$\begin{cases} x_a = x'_a - u_0 + k_1 (x'_a - u_0)^3 \\ x_b = x'_b - u_0 + k_1 (x'_b - u_0)^3 \\ x_c = x'_c - u_0 + k_1 (x'_c - u_0)^3 \\ x_d = x'_d - u_0 + k_1 (x'_d - u_0)^3 \end{cases} \tag{14}$$

Take the experimental data into formula (12) and formula (14), we can find out the first order distortion coefficient k_1 and the center coordinate u_0.

4. Experimental Solution

This paper uses the linear array scanning camera produced by DALSA company is P2-22-04K30 mode. The physical size of this camera is 7 μm, the line of resolution is 4096, the maximum frequency of line scan is 14kHZ, the output format is 8 bit and F - mount lens mount is the center. There is also an image acquisition card.

Set up the experimental platform according to the mathematical model mentioned above. Place the template in the view field of the linear array CCD camera, on which some calibrated points. Keep the horizontal coordinate of these points unchanged, collect 16 points vertically, then move a distance horizontally, continue to collect points. The experimental platform is shown in Fig. 6.

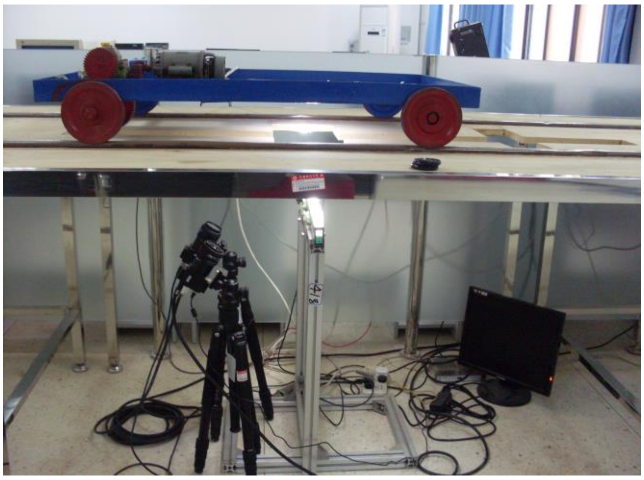

Fig.6 The experimental platform

Use these data in Table 1 to solve the two parameters.

Table 1 The original experimental data

Number	X coordinate of actual points/mm	Actual pixel value of actual points
1	2400	942
2	2600	1012
3	2800	1083
4	3000	1155
5	3200	1230
6	3400	1305
7	3600	1381
8	3800	1458
9	4000	1537
10	4200	1616
11	4400	1697
12	4600	1779
13	4800	1963
14	5000	1948
15	5200	2034
16	5400	2121

Take four experimental data values from Table 1 as the X coordinate of A, B, C and D, for example, make X_a=2400,X_b=2600,X_c=2800 and X_d=3000, so the cross ratio of them is:

$$CR(A,B;C,D)=\frac{(2400-2800)(2600-3000)}{(2600-2800)(2400-3000)}=4/3 \tag{15}$$

According to spacing ratio invariability, if the four actual points have the relation that X_a-X_c=X_b-X_d, their corresponding ideal imaging points also have the relation. We get a binary system of equations according to the cross ratio invariability and the relationship mentioned above. Figure out the binary system of equations, the first order distortion coefficient k_1 and the center coordinate u_0 were derived. In the end, $k_1=7.902\times10^{-9}$ and $u_0=2.752\times10^3$ were obtained.

5. Conclusion

Aiming at the situation that the lens can produce distortion when the dual CCD camera intersection measurement system is imaging, this paper presents a complex mathematical model which contains the radial distortion, the centrifugal distortion and the thin prism distortion. In order to consider the actual situation and the convenience for calculating, only the radial distortion coefficient and the center coordinate were carry out. On the whole, the method of lens distortion correction in this paper is simple, convenient for experimenting, less known conditions are needed, easy to implement and better stability. In practical application, please select some calibrated points that are near the edge of the image when using the method in this paper in order to improve calibration precision, because the amount of distortion in the edge of lens is bigger. If the second order radial distortion coefficient is also taken into account, the lens distortion correction of linear array camera may be better.

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