A Chinese Chessboard Calibration Method in Chess-Playing Robot by Machine Vision Sensing

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A Chinese Chessboard Calibration Method in Chess-Playing Robot by Machine Vision Sensing

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Abstract. In view of Chessboard calibration in Chess-Playing Robot by machine vision sensing, a new Chinese chessboard calibration method based on external aided planar pattern is given. Introducing the advantages of the international chessboard calibration technology, which can overcome the difficulties of lens distortion imaging and non-orthographic projective imaging in which cases the former calibration methods can't be used. This method aligns the planar calibration pattern to the chessboard in such a way that we can get the chessboard grid points' Image-Coordinate-System coordinates by detecting the planar pattern's corners and obtain the mapping of a group of points' s World-Coordinate-System coordinates and Image-Coordinate-System coordinates, which is easy to operate and robust to noises. Workpiece location by machine vision methods in industrial application also faces the problems of lens distortion imaging and non-orthographic projective imaging, so it would be beneficial to introduce this method's idea into industrial areas.

1. Introduction

Chess-playing robot (CPR) based on machine vision [1] uses camera to obtain the image of chessboard and chess piece, furthermore, the game algorithm of artificial intelligence is further analyzed to the position of situation on the chess board, and determine the position of piece placement. The machine vision target positioning, robot control and other core technologies can be widely used in industry, information and other industries.

Machine vision as a link in CPR which has two core technologies: chessboard calibration and chess pieces position. Chess pieces position is to identify the position of the pieces in the image by machine vision algorithm. Chessboard calibration refers to finding the match between the actual position of the chessboard and the image position. With this correspondence, after finding the position of the chess pieces in the image, the position of the chess pieces in the actual chessboard can be known.

Chinese chessboard includes go chessboard, Chinese chessboard, gobang chessboard, et al., all of which are vertical and horizontal crossing, middle hollow square lattice structure. The Chinese chess board consists of 9*8 square lattices, except for the diagonals of individual squares, the rest are hollow. The go chessboard is composed of 18*18 hollow lattices. In order to calibrate it, the mark point interpolation algorithm and the line detection intersection algorithm are usually used. The mark point interpolation algorithm is easy to implement, but it's difficult to overcome the camera imaging distortion and the positioning offset caused by the non orthographic projection of the image. It's also

difficult to solve the problem of camera distortion by finding intersection point by line detection. Distortion correction has been reported in the literature, but the optical principle of distortion should be modeling compensation, at the same time, the compensation precision needs to be considered according to the computational complexity and the compensation parameters are nonlinear variables in the calibration model, this's difficult to obtain the global optimal solution. If correction of nonorthographic projection is used, the relationship of conversion relation between camera coordinate system and world coordinate system should be calibrated in advance, moreover, if the lens distortion is considered in the calibration process, more complex nonlinear optimization is needed.

This paper focuses on a new calibration method for Chinese chessboard. By mechanical positioning for the target, which avoids the computational complexity and compensation approximation of optical distortion modeling compensation, it also avoids the nonlinear optimization problem in the calibration process with lens distortion. Provided that the mechanical positioning reaches a certain precision, the problem of lens distortion and non orthographic projection can be solved, it's easy to implement and easy to operate.

2. Chessboard Calibration

In machine vision chess robot system, the purpose of chessboard calibration is to find out the correspondence between the actual position and the image position of the chessboard, that is to find the pixel coordinates of each position of the chessboard in the image. Suppose that the world coordinate system of the spatial location where the chessboard is located is (x, y, z) ,the world coordinate of the chessboard points are (x_{ij}, y_{ij}, z_{ij}) ; Suppose that the image coordinate system is (u, v) after Chessboard imaging, the coordinates of the checkerboard points in the image are (u_{ij}, v_{ij}) , $i = 1,2,3,\cdots M$, $j = 1,2,3,\cdots N$. The task of chessboard calibration can be transformed into the mapping relation between the world coordinate system and the image coordinate system of chessboard grid points, that is:

$$f : (x_{ij}, y_{ij}, z_{ij}) \rightarrow (u_{ij}, v_{ij}) \tag{1}$$

As long as the world coordinate of the grid points and the corresponding image coordinates are obtained, and the mapping relation of formula (1) is obtained, the chessboard calibration task is completed. (x_{ij}, y_{ij}, z_{ij}) can be obtained by locating the mechanical origin and calculating the offset after the establishment of the world coordinate system, the corresponding image coordinates (u_{ij}, v_{ij}) needs to be extracted by machine vision algorithm. Because the chessboard grid size is fixed, so as long as access to the world coordinate chessboard corner point, according to the two-dimensional array subscript position chessboard lattice point, we can calculate the coordinates of each lattice point of the world coordinate. This paper mainly discusses the acquisition method of grid point image coordinate (u_{ij}, v_{ij}) based on machine vision.

3. Calibration Analysis

3.1. Calibration Method

Point interpolation algorithm is in the four corners of the board set markers, and detect the image coordinates of the mark points, once the detected image coordinates of the four corners of the Chess board, if the imaging process is a positive projection, the grid points inside the chessboard can be calculated by the uniform linear interpolation algorithm. (u_{ij}, v_{ij}) is represented by I_{ij} here, the image coordinates of four corners (u_{11}, v_{11}) , (u_{1N}, v_{1N}) , (u_{M1}, v_{M1}) , (u_{MN}, v_{MN}) are represented by C_1 , C_2 , C_3 , C_4 Separately. Corresponding to four red star markers in clockwise direction, the grid point image

coordinate which lie the first column on the left is evenly interpolated as:

$$I_{i1} = C_1 + \alpha_1(i-1) \tag{2}$$
$$\alpha_1 = \frac{C_3 - C_1}{M}$$

The grid point image coordinate which lie the last column on the right is evenly interpolated as:

$$I_{iN} = C_2 + \alpha_N(i-1) \tag{3}$$
$$\alpha_N = \frac{C_4 - C_2}{M}$$

By the evenly interpolated of the first column lattice coordinate I_{i1} and the last column lattice coordinates I_{iN}, the coordinates of the grid points for each row can be obtained as:

$$I_{ij} = I_{i1} + \beta_i(j-1) \tag{4}$$
$$\beta_1 = \frac{I_{iN} - I_{i1}}{N}$$

Formula(2) to (4) represent the whole process of uniform linear interpolation algorithm for marker points.

However, lens distortion is a common phenomenon in the imaging process. Especially for barrel distortion of wide-angle lens[2], If it isn't corrected, it will not be used in precision measurement or camera calibration, which also affects the chessboard calibration technique based on marker points.

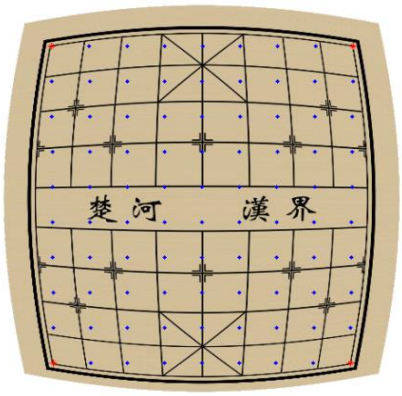

Figure 1. Interpolation effect of marker points in barrel distortion image.

As shown in figure 1, a Chinese chessboard with a barrel distortion is formed, and the straight line becomes a curved curve. The red points on the four corners are marked points, the linear interpolation points are blue dots, and the blue dots are not matched with the grid points (the intersection points of the straight lines).

If the imaging process isn't a positive projection, that means the optical axis of the camera isn't perpendicular to the chessboard plane, it will also cause the projective mapping of the change of the length ratio of the line segment. At this point, the chessboard of the image is no longer evenly divided into the line segments, and the mark point method can not work, as shown in figure 2.

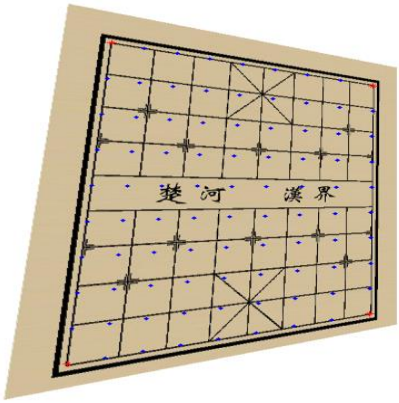

Figure 2. Interpolation effect of non orthographic image marker points.

Another Chinese chessboard calibration technology is based on line detection algorithm for intersection point, it can't be applied in the case of barrel distortion similar to Figure 1.

As shown in Figure 3, there is an image without distortion which requires to detect the boundary line region of middle green, but the boundary line becomes a curve in the case of barrel distortion. Figure4 is a straight line detected by Hough transform; it can be seen that the detected straight line has seriously deviated from the image that should have a "straight line" position, it's impossible to complete the chessboard calibration task in this case.

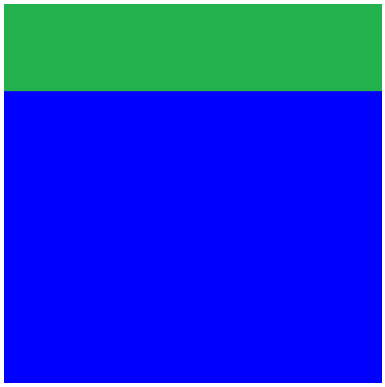

Figure 3. Edge of image without distortion.

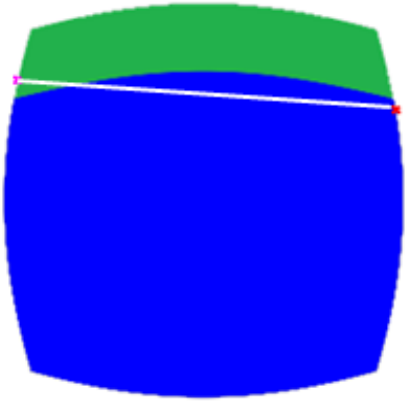

Figure 4. Straight line detection result of distorted edge.

Although the international chessboard is made up of 8*8 squares, but the squares are filled with solid black and white or other colors.

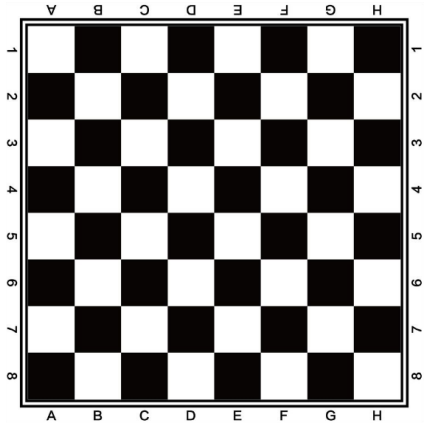

Figure 5. International chessboard.

As shown in Figure 5, because the square lattice is solid, the corner feature is obvious, therefore, the calibration method based on corner detection is usually used.

Corner detection such as the most classic Harris method, the algorithm based on local region gray information is used to detect the property of the change surface of the gray value of the pixel in a local region; if the point corresponds to the minimum value of the change surface of gray value, the movement of any direction will lead to the increase of the gray change value, and then the point is a corner. If (u,v) is the coordinate position of one pixel in the local region of an image, $I(u,v)$ is the pixel gray value at the (u,v), the tiny movement of each coordinate position changes is $\Delta x,\Delta y$, when the position of each position in the local area is moved slightly, the sum of the square of the gray value of the pixel is equal to the sum of the square of the change of the gray value of the pixel:

$$E(\Delta x,\Delta y) = \sum_u \sum_v w(u,v)(I(u+\Delta x,v+\Delta y)-I(u,v))^2 \tag{5}$$

Where $w(u,v)$ is weighted average coefficient of (u,v). $I(u+\Delta x,v+\Delta y)$ is expanded by first order Taylor approximation:

$$I(u+\Delta x,v+\Delta y) \approx I(u,v)+I_x(u,v)\Delta x+I_y(u,v)\Delta y \tag{6}$$

Where $I_x(u,v)$ and $I_y(u,v)$ are the first derivative of x direction and y direction separately, then put them into formula (5):

$$E(\Delta x,\Delta y) \approx \sum_u \sum_v w(u,v)(I_x(u,v)\Delta x+I_y(u,v)\Delta y)^2 \tag{7}$$

Express in the form of a matrix:

$$E(\Delta x,\Delta y) \approx (\Delta x,\Delta y)A\begin{pmatrix}\Delta x\\ \Delta y\end{pmatrix} \tag{8}$$

$$A = \sum_u \sum_v w(u,v)\begin{bmatrix} I_x^2 & I_xI_y \\ I_xI_y & I_y^2 \end{bmatrix} = \begin{bmatrix} \langle I_x^2\rangle & \langle I_xI_y\rangle \\ \langle I_xI_y\rangle & \langle I_y^2\rangle \end{bmatrix} \tag{9}$$

Where the symbol "$\langle\ \rangle$" stands for "mean". If the two eigenvalue of the matrix A is a larger positive number, the change of each direction will lead to the increase of gray value in this local

region, there is a corner point in the local region.

Therefore, corner detection only change information associated with the local gray value of the image, the image distortion will not affect local properties, so the corner detection algorithm has the capability of anti lens distortion. Because the international chessboard has black and white gray change obviously, the corner feature information rich features, robustness and corner detection can guarantee, therefore, the plane calibration board is also the style of international chessboard; (Zhang, Z., 2000); according to the obvious feature of corner feature of the chessboard pattern, the corner points are extracted to calculate the internal and external parameters of the camera.

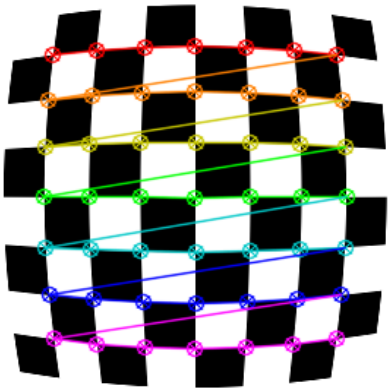

Figure 6. Bucket distortion chessboard corner extraction.

In figure 6, each corner of the chessboard has a small ball of color. The center of the circle of the small ball represents the position of the extracted corner; although the bucket distortion is serious, corner extraction algorithm still works.

3.2. New Calibration Method

A method is proposed here, the international chessboard calibration technology is applied to Chinese chessboard calibration, which will have remarkable effect to overcome the drawbacks of the existing methods.

To Chinese chess board as an example, The position of the chess pieces on the chessboard is locked by 9*8 square lattices. Make a black and white plate with 10*9 squares as the calibration board. The size of the grid is equal to the size of the squares on the chessboard, as shown in figure 7.

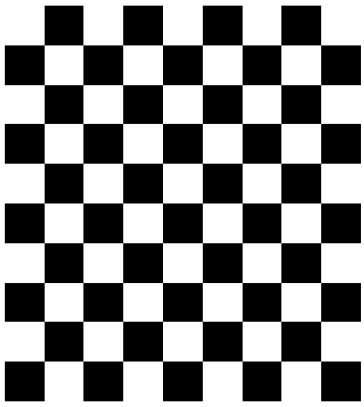

Figure 7. Chinese chess board calibration board.

Obviously, the calibration plate removes the outermost circle square lattice, which is consistent with the overall size of the chessboard size and the size of the inner square lattice is equal. Through

mechanical positioning, the calibration plate removes the outermost part of the plate and aligns with the chessboard; the calibration plate removes each inner square of the outermost circle and is aligned with the square corresponding to the chessboard. After alignment, the world coordinates of each corner point of the calibration board are the world coordinates of each grid point of the chessboard:

$$(x_{ij}, y_{ij}, z_{ij}) = (x'_{ij}, y'_{ij}, z'_{ij}) \tag{10}$$

Where $(x'_{ij}, y'_{ij}, z'_{ij})$ is the world coordinates of corner calibration board. Therefore, the chessboard calibration can be achieved by getting the correspondence between the corner coordinate of the calibration board and the image coordinates.

$$f : (x'_{ij}, y'_{ij}, z'_{ij}) \to (u_{ij}, v_{ij}) \tag{11}$$

The world coordinate $(x'_{ij}, y'_{ij}, z'_{ij})$ of the corners of the calibration plate is the world coordinate (x_{ij}, y_{ij}, z_{ij}) of the chessboard grid points, which can be obtained by the calculation of the origin mechanical positioning and the two-dimensional array subscript offset calculation, because the feature of the corner image coordinate (u_{ij}, v_{ij}) of the calibration board is obvious, it can be acquired robustly. After calibration, take the index board down, you can machine vision robot chess.

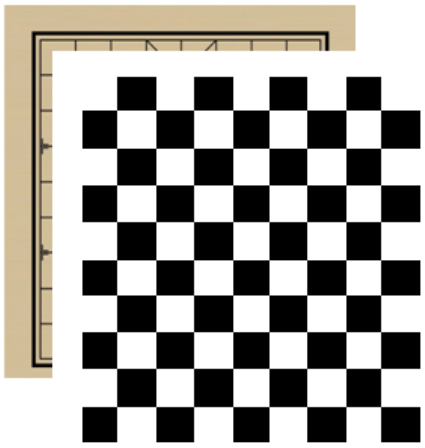

Figure 8. Alignment diagram of calibration board and chessboard.

Similarly, the chess board (18*18 square number) the plane calibration board just to create a 19*19 squares the number of black and white as the calibration plate, square lattice equal square lattice size and the chess board, you can follow the above method of the same.

The calibration board is one more square than the actual chessboard, it provides the feature information that can detect the corner points for the local area of the grid on the outermost part of the chessboard, in order to make the outermost point of the checkerboard image coordinates can also be obtained.

4. Simulation

Taking the go chessboard as an example, the calibration is carried out according to the method described above. The calibration of orthographic projection is carried out first.

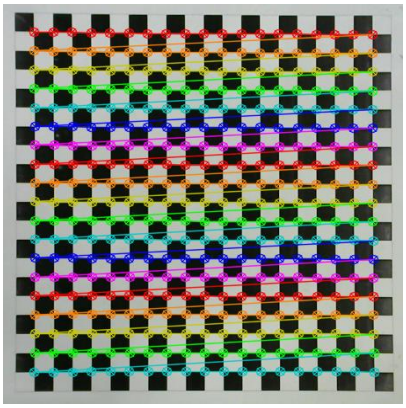

Figure 9. Corner extraction effect of calibration plate.

Figure 9 is a corresponding, aligned calibration board, corner extraction using corner detection library function in OpenCV: the calibration of corner plate of each internal department has a color of small ball, corner position of small ball center representative to extract; visible extracted to 19*19 corner points successfully. The calibration board is removed to obtain the image of the chessboard, the extracted 19*19 corners are drawn into the chessboard image. If the corners are aligned with the chessboard grid points, the calibration is successful. The orthographic projection template data are compared with the calibration data, as shown in table 1. As shown in Figure 10 of the red dot, i.e. 19*19corner points plotted on the chessboard image in the corresponding and checkerboard points coincide well.

Table 1. Comparison of original projection template data and calibration data

Raw template data (pixels)		Calibration data (pixels)	
u_{ij}	v_{ij}	u_{ij}	v_{ij}
128	35	126.786	34.71629
149.444	35.0556	148.534	35.00293
170.889	35.1111	170.2682	35.48389
192.333	35.1667	191.7842	35.87283
……	……	……	……
493.389	439	492.4495	438.4564
515	439	514.306	438.8669
average error：1.3381，mean square error：0.4482			

The chessboard distortion and non orthographic chessboard image of go chessboard are calibrated respectively by using the same method.

Figure 11 is the corresponding calibration board image and corner extraction effect, all corner points can be extracted, the blue point is the effect of the uniform linear interpolation of the marker points which deviate from the checkerboard point obviously in figure 12; the red point is the result obtained by new calibration method in this paper, which is significantly better than the mark point method.

In the projection mapping of non orthographic projection, the nature of the chessboard's physical lattice length is no longer existing in the image.

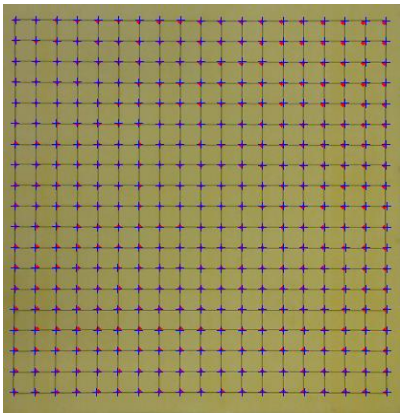

Figure 10. Calibration effect.

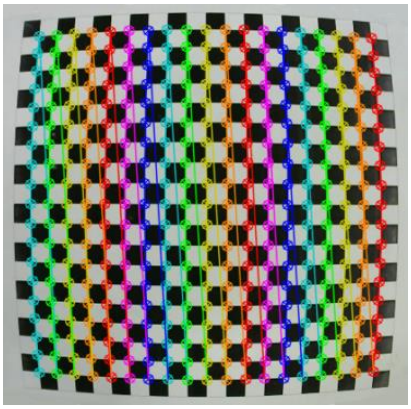

Figure 11. Corner extraction effect chart of barrel distortion calibration plate.

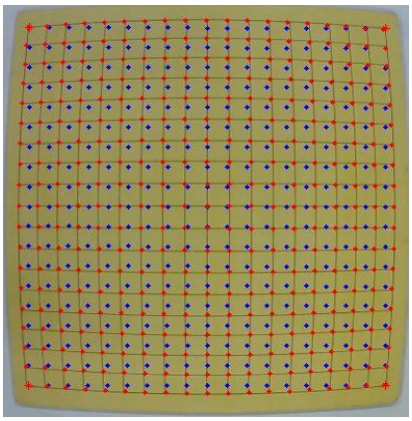

Figure 12. Comparison with mark point method.

Figure 13 is the corner extraction effect of the non orthogonal projection subscript plate, and it is not affected by the non orthographic projection. Figure 14 shows that new calibration method is better than the mark point method in the non orthographic imaging condition.

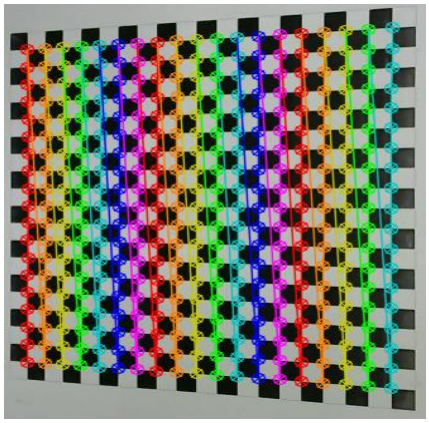

Figure 13. Corner extraction effect of non orthographic projection calibration plate.

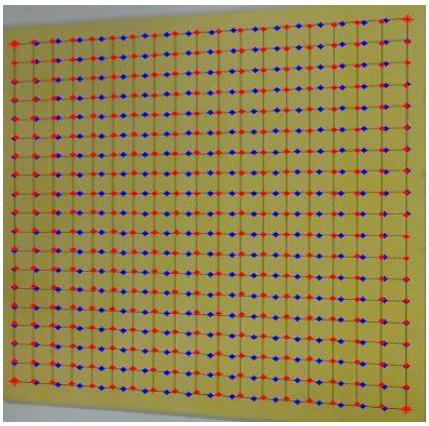

Figure 14. Compares with mark point method.

5. Conclusions

Image distortion will make straight line into curve, but non orthographic projection will change the isometric character of chessboard square, which will lead to the failure of existing Chinese chessboard calibration technology. The corner detection method is usually used in international chessboard calibration, however, the Chinese chessboard can not be directly applied to the Chinese chessboard because there are only straight lines intersecting vertically and horizontally, and there are not enough obvious corner features. In this paper, a new calibration method is proposed, which is based on the classical method of camera calibration, and relies on the calibration object, the calibration technique of the international chessboard is introduced into the Chinese chessboard calibration. The experimental results show that the method can resist the interference caused by image distortion and non orthographic projection, and overcome the disadvantages of the existing calibration techniques.

Machine vision positioning technology is widely used in machine vision[3] positioning technology in the industrial field, such as circuit board solder joint precision positioning[4], mobile phone glass cutting precision positioning[5].The main advantage of this method is that it can eliminate the influence of image distortion and non orthographic projection, therefore, if the idea and idea are introduced into the machine vision positioning in the industrial field, it will be a valuable research direction.

6. References

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