An Automated X-corner Detection Algorithm (AXDA)

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***Abstract*—According to the central symmetry and bright-dark alteration of the four peripheral regions at the X-corner, an automated X-corner detection algorithm (AXDA) is presented to camera calibration problem. By detecting the gray changes of the image, the algorithm can locate the position of X-corner accurately using the minimum correlation coefficient of the symmetry regions. Cross points of intersection are calculated using the detection points and the least square straight line fitting algorithm. The method can not only realize the sub-pixel X-corner extraction, but also resolve the low automation degree problem of the present detection algorithm under complex background. Experiment results show that the algorithm is an easily-realized, highly-automated and robust method for rotation transform and brightness transform of the X-corner image.**

***Index Terms*—chessboard, corner detection, camera calibration**

I. INTRODUCTION

Camera calibration[1,2] based on the chessboard planar template consists of corner detection and parameter calculation. Calibration is to create the constraint between the world coordinates and the image coordinates of the chessboard feature points. So X-corner detection is the essential technology for camera calibration.

At present, X-corner detection algorithm can be classified as follows. One is the traditional corner detection algorithm, such as Harris operator [3,4]and SUSAN [5,6]. These algorithms are versatility and straightforward but are invalid for the vagueness of the image. The idea of Harris corner detection is simple and the corners extracted by this algorithm distribute uniformly. Besides, this algorithm is insensitive to the rotation of the image and the alteration of the image gray. However, in the X-corner image, the image blurring in the corner area usually causes a high Harris respond value of one or several points, which makes it difficult to determine the position of the corner exactly. SUSAN operator is proposed by Smith and Brady. The operator is a completely different corner detection method, which mainly based on light contrast. Do not have to calculate image difference. The calculation speed is so fast that the SUSAN are widely used in the higher requirements of real-time areas. The other is the curve fitting based algorithm. Algorithms based on the two times Radon transform [7] are the representative ones. But there will be a great error if image distortion exists. And there are some other detection algorithms [8,9] aimed at the characteristics of the chessboard image. But [8] is computational expensive. Although [9] is straightforward in computation, great error will generate after binarization processing. All the above algorithms are liable to be influenced by light and background image in practical applications and will inevitably result in missing error, detection error or false error, which leads the automation detection hard to realize. Although the calibration toolbox in Matlab[10] resolves these problems, the automation level for camera calibration decreases greatly since four points should be selected manually before the corner extraction.

An automated X-corner detection algorithm (AXDA) is provided by studying the present methods carefully. This algorithm can detect the corner using the unique feature of X-corner so as to avoid detection error, false

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error as well as the influence of complex background. Meanwhile, detection result could achieve sub-pixel level with the help of least square straight line fitting and the missing error is resolved. This algorithm is straightforward, computational cheap and robust for rotation and gray alteration. Besides, it can resist the edge vagueness and significantly improve the automation level.

II. X-CORNER DETECTION METHOD FOR CHESSBOARD IMAGE

Chessboard image is shown as Fig. 1. Chessboard is made up of black and white square boxes, where the connection of two black boxes or two white boxes is the X-corner. In order to detect corners in complex background without false error, algorithm suitable for the characteristic of chessboard image should be used. Image at the X-corner is shown as Fig. 2. In Fig.2, there are two features. First, brightness of the four regions around the X-corner changes alternately. There are gray changes in the adjacent regions of part I、II、III and IV. Besides, they are light and dark alternation. Second, in the corner centered regular region, image is central symmetry. X-corner can be detected accurately in complex background using the above two exclusive features of the X-corner.

A. Corner Detection

Chessboard image is easy to be affected by the brightness of the light and the angle of shooting in the time of acquisition, which proposed higher requirements for the automated detection algorithm. Taking into account various aspects, such as the impact of complex background on the chessboard image, it is required that the number of extracted corners is not excess. All the corners should be extracted with a certain accuracy. So the detection algorithm is necessarily required a certain specific. In the absence of human intervention, the common corner detection algorithms can not meet the above requirements. To solve the above problem, we should choose the algorithm based on the characteristics of chessboard images. The algorithm is described as follows:

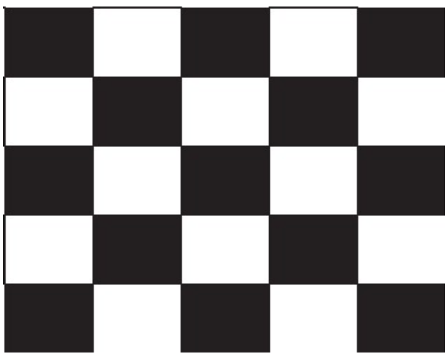


Figure 1. Chessboard Image

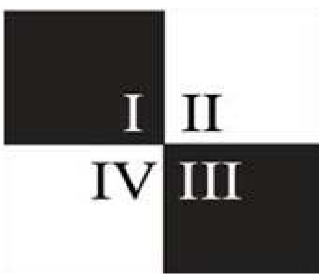


Figure 2. Features of Chessboard Image

Firstly, crude extract. Corners can be roughly extracted by using the first features. After the crude extract, the point at the region between two Haig rectangular can be obtained.

Secondly, filter the results. Corners extracted by using above method should be filtered by using the second features, which aim to look for the regional center of symmetry as the corner.

Finally, Corners should be classified by the row (column). The corners in the same row (column) are used to get curve fitting. The intersection can be calculated by the curve fitting. In this way, the final corners can be obtained. Further more, there is no missing error.

B. Algorithm Implementation

First, roughly extract the X-corner using the light and dark alternation characteristic of the four regions around the corner. Since there is gray difference between the adjacent regions, in the window W(7*7), gray summation of this region can be defined as follows:

$$F(I)=\sum_{r}\sum_{c} f(r,c) \quad x_0\text{-}3<r<x_0 \quad y_0\text{-}3<c<y_0 \tag{1}$$

$$F(II)=\sum_{r}\sum_{c} f(r,c) \quad x_0\text{-}3<r<x_0 \quad y_0<c<y_0+3 \tag{2}$$

$$F(III)=\sum_{r}\sum_{c} f(r,c) \quad x_0<r<x_0+3 \quad y_0<c<y_0+3 \tag{3}$$

$$F(IV)=\sum_{r}\sum_{c} f(r,c) \quad x_0<r<x_0+3 \quad y_0\text{-}3<c<y_0 \tag{4}$$

Where *F(X)* is the gray summation of the region *X*, $X \in \{I, II, III, IV\}$. (x_0,y_0) is the current detection point. *f(r,c)* is the gray value of the point *(r,c)* in the image.

The gray difference threshold is set as *T* so as to judge whether the gray differences of the adjacent regions are all greater than T. That is whether |*F(I)-F(II)*|, |*F(II)-F(III)*|, |*F(III)-F(IV)*| and |*F(IV)-F(I)*| are all greater than *T*. It is possible for the point to be a corner if the values of the four polynomials are all greater than T. Otherwise, it is not a corner. Since there are vague areas in the image, many false errors will be included in the extracted points and the extracted points will distribute in the small region where two black boxes join together. Therefore, in order to extract the X-corner from the extracted points, central symmetry characteristic of the X-corner should be used.

Central symmetry has the following characteristic:

$$f(x_0-x, y_0-y)=f(x_0+x, y_0+y) \tag{5}$$

So there is high correlation in the symmetrical regions of the image. Concretely, there are high correlations between I and III, between II and IV. Extracted points can be filtered with this characteristic and the real X-corner can be selected. The correlation coefficient can be calculated as follows (Take a 20 ×20 window as an example):

$$P=\frac{\sum_{r=1}^{20}\sum_{c=1}^{20}(f_X(x_0-r,y_0-c)-\eta_1)(f_{\bar{X}}(x_0+r,y_0+c)-\eta_2)}{\sqrt{\sum_{r=1}^{20}\sum_{c=1}^{20}(f_X(x_0-r,y_0-c)-\eta_1)^2\sum_{r=1}^{20}\sum_{c=1}^{20}(f_{\bar{X}}(x_0+r,y_0+c)-\eta_2)^2}} \quad (6)$$

Where (x_0,y_0) is the current detecting point. $f_x(x_0-r,y_0-c)$ is the gray value of (x_0-r,y_0-c), $x\in\{I,II\}$. $\bar{X}$ is the central symmetrical region of x. η_1 and η_2 are the average gray values in the region.

In the small region where real corner is included, only the real corner has the maximum correlation coefficient. So the extracted points can be filtered with this characteristic so as to get the real corner. In practical calculation, it only needs to compute half of the correlation coefficients. Namely, compute the region of I and III or II and VI is enough.

C. Missing error solution and sub-pixel corner detection realization

Corner detection algorithms are often influenced by image brightness and shooting angle in practical application, which would inevitably cause the missing error and is inconvenient for automated calibration. Besides, in order to pursuit more accurate camera calibration, sub-pixel corner coordinates are required. Aimed at the above problems, first of all, pattern classification is implemented on the extracted points to classify those points by rows and columns. Points in the same row or in the same column are fitted by least square method to solve the intersection point. This approach can avoid the missing error and achieve the sub-pixel precision corner detection. Meanwhile, it lays the foundation for resolving the coefficient automatically in the next step since the sequence information of corner position is included in the intersection point. It should be noted that if there is a strict requirement on precision, points in the outside rows and columns should be rejected before straight line fitting since they would sometimes cause the performance decline of the detection due to image distortion. In addition to the above method to improve the precision of the corners to sub-pixel level, there are also other methods. The most common method is gray-scale interpolation and then extracts corners on sub-pixel level using the algorithm provided by this paper. Another method is proposed in [11]. The main idea is that the vector starting from the real corners (q) to any other adjacent points (p_i) is vertical to the gray gradient at the point p_i.

$$\varepsilon_i=\nabla(I)_{p_i}^{T}.(q-p_i) \quad (7)$$

Where $\nabla(I)p_i^T$ is the gray gradient at the point p_i . ε_i should be zero in theory, but because of the noise, ε_i may not be zero. Therefore, q is the point where ε_i gets the minimum value. We build the iterative function according to (7) and calculate the coordinate of the corner on sub-pixel level. Results show that this is a precise algorithm.

The whole algorithm is as shown in Fig.3.

Where A is the set, which contains the points detected by using the first character. B is the set that contains the final pixel level corners. W is the detection window. C is the set that contains the final sub-pixel corners.

III. EXPERIMENTAL ANALYSIS

In order to test the correctness of the above algorithm, a series of experiments were conducted. Images involved in the experiments can be obtained on the website of http://www.vision.caltech.edu/bouguetj/calib_doc/htmls/calib_example/index.html. Image resolution is 640×480. The chessboard template consists of 14×13 boxes, where 156 internal corners are included. The size of each box is 30mm×30 mm.

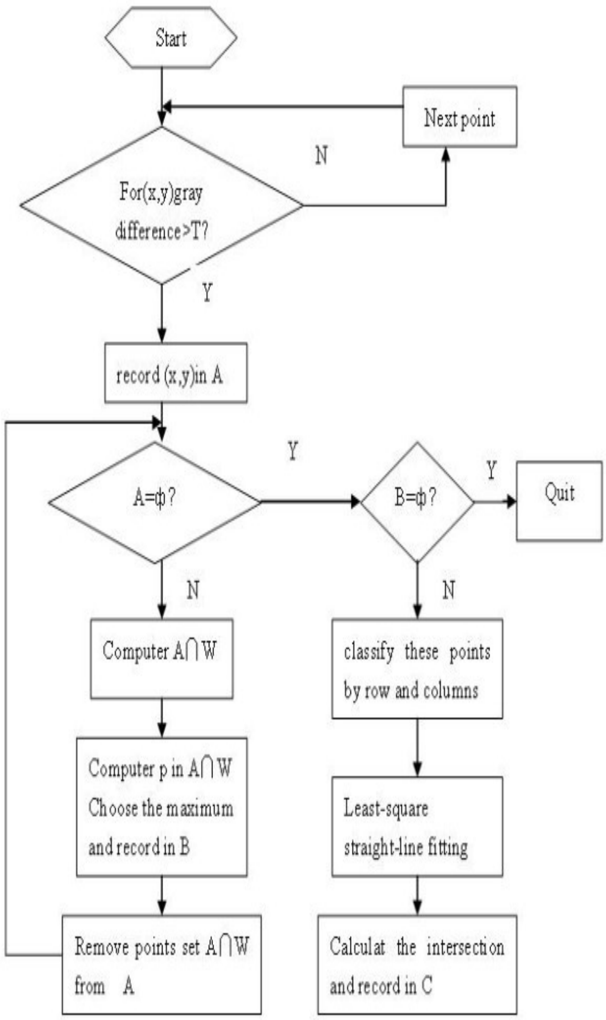


Figure 3. Program Flow Chart

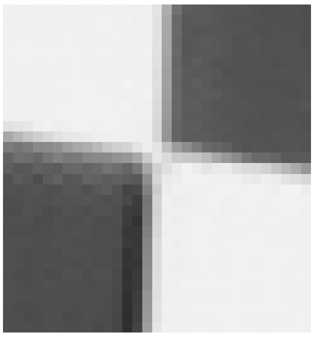
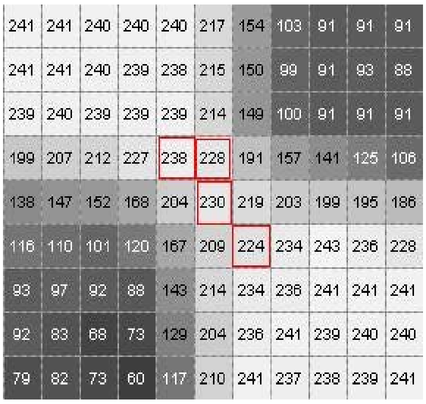


Figure 4. Image fragment



241	241	240	240	240	217	154	103	91	91	91
241	241	240	239	238	215	150	99	91	93	88
239	240	239	239	239	214	149	100	91	91	91
199	207	212	227	238	228	191	157	141	125	106
138	147	152	168	204	230	219	203	199	195	186
116	110	101	120	167	209	224	234	243	236	228
93	97	92	88	143	214	234	236	241	241	241
92	83	68	73	129	204	236	241	239	240	240
79	82	73	60	117	210	241	237	238	239	241

Figure 6. Pixel-level image and results

First, process Fig. 4 using the first method mentioned in II where T is equal to 400.The results are marked with red box as shown in Fig. 5.. It can be seen that these points are distributed in a 3 × 3 small areas.

Second, we use the second method in II to filter the above results. The correlation coefficient of points between I and III is shown in Table 1.

From Table I we can see that the maximum value of the correlation coefficient is at (16,15). So we define (16,15) as the corner we want. In Fig. 6, the red cross indicates the final extracted result. It show that algorithm is correct and has a high accuracy

TABLE I.
EXTRACTED RESULTS

Point	Extracted Results				Corner
Coordinate	(15,14)	(16,14)	(16,15)	(17,16)	(16,15)
P	0.1632	-0.1085	0.6497	0.4043	

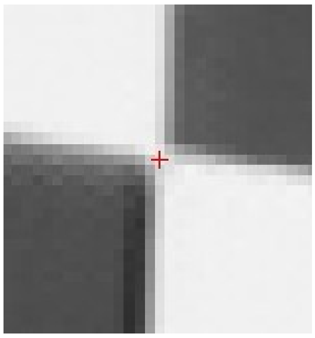
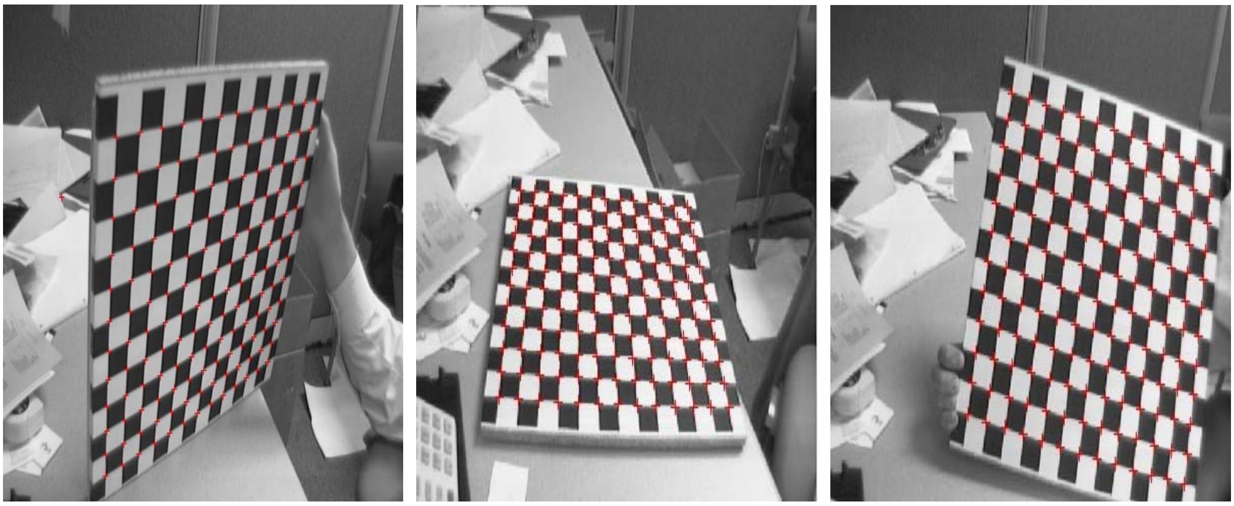


Figure 8. Extracted Result

A. Comparison with Harris corner detection algorithm

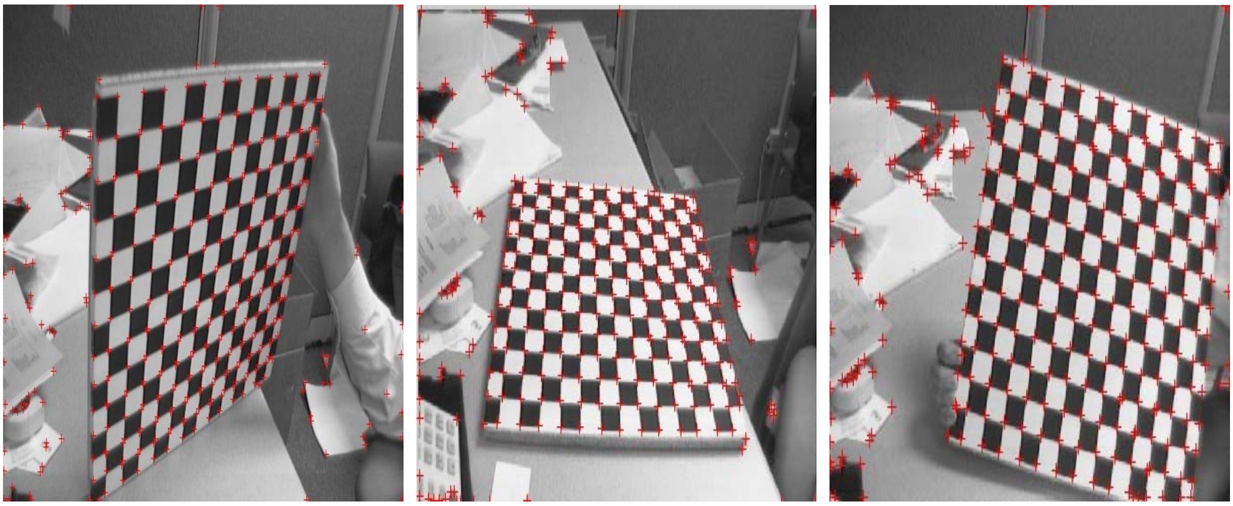
Red labels in Fig. 7, Fig. 8, Fig. 9and Fig. 10 are detection results processed by AXDA and Harris operator respectively. Numbers of detected corners are listed in Table II.

From Fig. 7, Fig.8 and Table II we can see that the performance of the AXDA is much better than that of the Harris operator. The AXDA detects only one corner outside the chessboard. As the general algorithm however, Harris detects large numbers of non-X-corners in the background. These points distribute disorderly and will cause great trouble in the automated calibration.



A B C

Figure 7. Results extracted by AXDA



A B C

Figure 8. Results extracted by Harris

TABLE II.
NUMBER OF POINTS

Algorithm	Number of Corners		
	Image A	Image B	Image C
Harris	443	382	393
AXDA	157	156	156

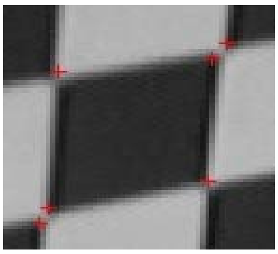


Figure 9. Results extracted by Harris

Fig. 9 and Fig. 10 are the local enlargement result images of AXDA and Harris operator respectively. It can be seen clearly that the performance of the AXDA outweighs the Harris operator. Corners detected by Harris in Fig. 9 shifts from the real position and false corners are detected. But in Fig. 10 the results are more accurate.

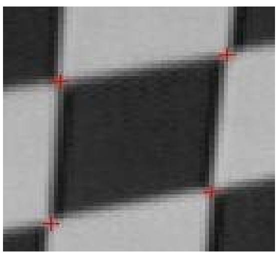


Figure 10. Results extracted by AXDA

TABLE III.
SUB-PIXEL CORNERS

Corners	AXDA	Camera Calibration Toolbox for Matlab
1st	（287.5431，116.2525）	（287.1477，114.9688）
2nd	（282.3183，152.3035）	（281.4477，151.0909）
3rd	（277.3627，186.4973）	（276.3348，185.5046）
4th	（272.6387，219.0928）	（271.3617，217.9590）
5th	（268.1781，249.8713）	（267.0234，248.7857）
6th	（264.0387，278.4330）	（262.5504，277.8376）
7th	（260.0439，305.9974）	（258.6074，305.3773）
8th	（256.3077，331.7771）	（254.5650，331.1984）
9th	（252.7597，356.2584）	（251.3006，355.5708）
10th	（249.4266，379.2563）	（247.6796，378.6948）
11th	（246.2785，400.9786）	（244.7730，400.3725）
12th	（243.3301，421.3226）	（241.7335，420.8897）

B. Precision comparison on sub-pixel level

Corners detected by intersection of straight line fitting and corners detected by Matlab calibration toolbox are compared on the sub-pixel level. Take the detection results of the fourth column in Fig.7.A as an example, comparisons from the top to the bottom are shown as Fig.11 and Tab.III.

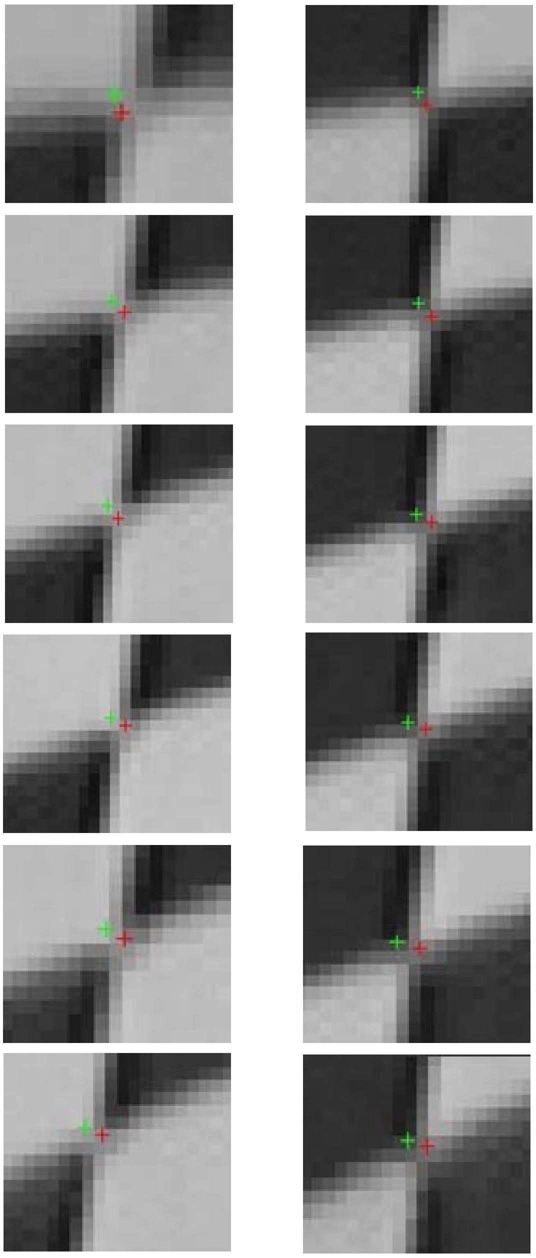


Figure 11. Image fragment Sub-pixel level results contrast

In Table III, the sub-pixel corner coordinates, detected by AXDA and Camera Calibration Toolbox for Matlab were listed. There are about 1-2 pixels difference in the results. Those points are projected on the test image, shown as in Fig.11.In Fig. 11, red corners are extracted by the AXDA and green corners are detected by the Matlab calibration toolbox. It can be seen from Fig. 11 that compared with green labels, red labels marked more accurately on the connection of two black boxes. So the performance of the AXDA is much better than that of the Matlab calibration toolbox. Besides, the AXDA does not need human intervention and has a higher degree of automation.

To sum up, it is show that the proposed algorithm can not only detected corners accurately, but also has a low algorithm complexity .In the process of coarse extraction, which uses the first feature, a lot of points are excluded. The computation can be reduced effectively in the subsequent Essence extracted. In addition to, it is feasible for obtaining the missing corners. Furthermore, the proposed algorithm can automatic acquisition corner position sequence information, which can provide coordinates sequence information for further automatic camera calibration.

IV. CONCLUSIONS

By analyzing the current X-corner detection algorithms, a new X-corner extraction approach is provided using the characteristic of the central symmetry of the gray image as well as the characteristic of the bright and dark alteration of the four regions around corner. First of all, roughly extract the corners using the characteristic of the bright and dark alteration of the four regions around corner. Second, accurately extract the coordinates of the corner with the symmetry characteristic. Then, classify the extracted corners by rows and columns. Fit the points with least square straight line fitting algorithm. Calculate the intersection of the fitting straight lines and finally obtain the precise corners. The proposed method effectively settles the false error and missing error in practical application and is robust for rotation transformation and brightness variation. Besides, our algorithm is computational cheap and has a high degree of automation, which is beneficial to the real-time camera calibration.

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