An X-corner Detection Algorithm Based on Checkerboard Features

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Abstract—The paper presents an X-corner detection algorithm based on the neighborhood features of the X-corner. It makes use of the features in the neighborhood of X-corners to detect X-corners, which include the black or white area occupying half of the neighborhood area and a large gray difference between black and white, as well as the grayscale symmetry of the pixels in the neighborhood. Experiments show that the algorithm can detect the real X-corner effectively and fast, so it is suitable for the X-corner real-time detection.

Keywords-X-corner features; corner detection; black and white area; gray difference; gray symmetry

I. INTRODUCTION

The checkerboard image is used as a typical pattern image in camera calibration, the X-corner detection of which is a hot issue in computer vision. According to the calibration coordinates of X-corners and known world coordinates, we can obtain internal and external camera parameters to establish the relationship between image coordinates and the world coordinates[1], so the X-corner detection can directly affect the camera calibration.

At present, the X-corner detection algorithm can be mainly divided into two categories: the detection methods based on edge and the detection methods based on gray. The methods based on edge mainly include two kinds, one is the method that firstly obtain image edges and get smooth continuous curves by connecting the discontinuous edges, and then calculate the curvature of every point on the edges and the points which have local maximum curvature would be regarded as corners; the other is that determine the coordinates of corners by calculating the intersection of two edge lines; Both methods are time-consuming and complex in operation. Once considering the distortion of camera lens, performance on image acquisition is that the detected edges will bend, and the result will be a great error[2]; the methods based on gray need to operate the gray levels of nucleus and its neighborhood pixels. The methods commonly used are Harris algorithm[3] and SUSAN algorithm[4]. Harris algorithm needs Gaussian filter and gradient operation, so it needs large amount of calculation; SUSAN algorithm does not need gradient calculation, has high anti-noise ability, fast operation and high accuracy, but it always confuse the edge points and corners easily. Many scholars have been made a lot of improvement based on these algorithms. For example, a checkerboard corner detection algorithm based on SUSAN and multi-direction restriction of symmetry and uniformity was proposed in Ref. [5]. In Ref. [6] it used the sobel algorithm to detect image edges and then the gray symmetry degree was defined to distinguish the corner from the edge according to the characteristics of the SUSAN template. A new algorithm for X-corner detection can be found in Ref. [7], which used symmetry operator S and variance operator V to locate X-corners.

According to the analysis and experiment of X-corner features, this paper presents an algorithm based on the study of SV algorithm, which makes use of checkerboard features to detect X-corners. The method has small calculation and it is robust to rotation and image noise, so it has a large application value.

II. THE ANALYSES OF THE CHECKERBOARD IMAGE AND REGIONAL FEATURES

The checkerboard image is made up of alternate black squares and white squares, as shown in Fig. 1. The areas occupied by the black and white squares are defined as flat areas. The intersection lines of the adjacent squares are edges. The intersection points of black squares and black squares (white squares and white squares) are X-corners, as the point O shown in Fig. 1.The area surrounded by circle is the neighborhood of the X-corner O and the area covers the interlaced black and white areas. So we can divide it into two areas, which are the black area and the white area. Each area occupies half of the neighborhood area, and the gray-level values of the pixels have symmetrical relationship about the X-corner O in the neighborhood area. So the X-corner has the below three features: the feature 1 is the black or white area occupying half of the neighborhood area; the features 2 is the large grey-level difference between black and white in the neighborhood area; the features 3 is all of the gray-level values of the pixels having symmetrical relationship about the nucleus in the neighborhood area.

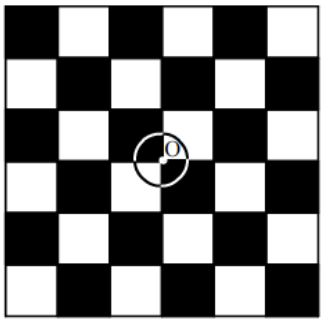

Figure 1. Image of the X-corner

So, this paper presents a new X-corner detection algorithm based on the above three features. The method only needs the statistics of gray features in the neighborhood of nucleus and does not have to calculate gradient and variance, therefore it will be rapid and easy to implement..

III. THE PRINCIPLE OF THE X-CORNER DETECTION ALGORITHM BASED ON THE CHECKERBOARD FEATURES

Firstly, according to the two features of the black or white area occupying half of the neighborhood area and the large grey-level difference between black and white, we can filter out the pixels in flat area and obtain edges and corners in checkerboard image. Then according to the gray-level values of the pixels having symmetrical relationship about nucleus in the neighborhood area, we can reject the pixels on edges and get the X-corners. However, the pixel level corners can not satisfy the request of camera calibration, so this paper uses gray square centroid method to achieve the sub-pixel level corners and implement precise location of the X-corners.

A. The X-corner location based on checkerboard features

Feature 1 need to calculate the difference of the black and white areas. When the difference value is less than a certain threshold value, we believe each of the two areas occupies separately half of the neighborhood area. At the beginning we divide the neighborhood area of nucleus into two areas: the "black area" and "white area". Separately count the numbers of the pixels in the two areas and calculate the difference value. That is,

$$ND(r_0) = | n(r_0) - m(r_0) | \quad (1)$$

where $n(r_0)$ is the number of the pixels in "black area" and $m(r_0)$ is the number of the pixels in "white area". Their equations can be defined as:

$$n(r_0) = \sum_{r \in W(r_0)} C_1(r, r_0) \quad (2)$$

$$m(r_0) = N - n(r_0) \quad (3)$$

where $W(r_0)$ is the neighborhood window of nucleus r_0, N is the number of the pixels in the window. $C_1(r, r_0)$ is a function for dividing areas, which we can use to put pixel r into different areas through comparing the gray levels of pixel r and nucleus, defined as

$$C_1(r, r_0) = \begin{cases} 1 & if\ I(r) < I(r_0) \\ 0 & if\ I(r) \geq I(r_0) \end{cases} \quad (4)$$

where $I(r)$ is the gray level of pixel r and $I(r_0)$ is the gray level of nucleus. Through adding the values of $C_1(r, r_0)$ for every pixel in the window, we can get the number of the pixels in the "black area".

Substituting Eq. (3) in Eq. (1) we get

$$ND(r_0) = | 2 \times n(r_0) - N | . \quad (5)$$

Hence, in fact we can get the difference value just by computing the number of the pixels in the "black area".

The computing of the feature 2 needs to add the gray levels of pixels in the two areas and get the averages respectively. When the difference of the averages is greater than a threshold, we can believe that the gray levels of pixels in the two areas have a large deference. This will correspond with the feature of black squares and white squares in checkerboard images. So, we can divide the neighborhood into two areas and get the gray levels of the pixels in "black area" through Eq. (6). $C_2(r, r_0)$ is the gray function of "black area", according to the result of comparing the gray levels of pixel r and nucleus r_0 ,if r is belong to the "black area", return its gray value, defined as

$$C_2(r, r_0) = \begin{cases} I(r) & if\ I(r) < I(r_0) \\ 0 & if\ I(r) \geq I(r_0) \end{cases} \quad (6)$$

The sum of the gray levels of pixels in "black area" can be shown as follows:

$$g(r_0) = \sum_{r \in W(r_0)} C_2(r, r_0) \quad (7)$$

Then the gray sum of "white area" $h(r_0)$ is the value that the sum of all the gray levels in the window subtracts the gray sum of "black area", that is,

$$h(r_0) = \sum_{r \in W(r_0)} I(r) - g(r_0) \quad (8)$$

Separately compute the two averages and the difference of the averages is the result of the feature 2. Given by the expression

$$GD(r_0) = \left| \frac{g(r_0)}{n(r_0)} - \frac{h(r_0)}{m(r_0)} \right| \quad (9)$$

According to the feature 1 and feature 2, when we divide the window into "black area" and "white area" and each of the two areas occupies half of the window and they have a large gray deference, we can determine that there are black areas and white areas in the neighborhood and their areas divide equally the area. That is, the nucleuses are the edges or corners in the checkerboard image. Then by computing the symmetry of these points through the features 3, we can get the corners.

The computing of the feature 3 needs to judge whether the gray level of every point is symmetrical about nucleus or not, and then count the number of symmetrical points in the neighborhood. When the number is greater than a certain threshold, we can think that the pixels have gray

symmetrical relationship in the neighborhood area. In the neighborhood area of nucleus, compute the difference of the gray levels of pixel r and symmetrical pixel r' about nucleus. If the difference is small, this pixel has gray symmetrical relationship about nucleus; otherwise, it has not. The function $S(r)$ which judge whether the gray level of pixel r is symmetrical about nucleus or not can be defined as:

$$S(r)=\begin{cases}1 & if\ |I(r)-I(r')|\le t\\ 0 & if\ |I(r)-I(r')|>t\end{cases} \tag{10}$$

where pixel r and pixel r' is symmetrical about nucleus; t is a set threshold. Count the number of symmetrical points in the neighborhood area of nucleus, the equation $GS(r_0)$ can be shown as follows:

$$GS(r_0)=\sum_{r\in W(r_0)} S(r) \tag{11}$$

In fact, we just need to compute half of the window.

We can distinguish the X-corner according to the above three features: in the neighborhood area of the X-corner, the number difference of the black and white areas is small; the gray difference is big; and the area has gray symmetry relationship about nucleus. Therefore, the response function of the algorithm R can be defined as Eq. (12), and when the point has local maximum R value, it will be the X-corner.

$$R=k\times(GD+GS)-ND \tag{12}$$

Where GD is the gray average difference of the two areas; ND is the pixel number difference of the two areas; GS is the value of the symmetry relationship in the window. Usually k ranges from 0.1 to 0.5 on the basis of computer experiment.

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B. The sub-pixel level location of the X-corner

In camera calibration, we need to make the pixel level X-corner to be accurate to the sub-pixel level. At first the applied sub-pixel algorithm is centroid method. Later the different methods have been developed, such as probability theory, polynomial interpolation, filter reconstruction, moment method and so on[8]. The moment method requires images to be binary images, but its positioning accuracy is lower. The precision of the filter reconstruction method is the highest. However, the centroid method is most simple and easy to execute. It is known that the checkerboard image belongs to gray symmetrical distribution target and gray contrast strongly. Therefore, this paper adopts gray square centroid method[9] in sub-pixel corner detection.

IV. EXPERIMENTAL RESULTS AND THEIR ANALYSES

In order to verify the correctness and effectiveness of this algorithm, we took a tilted checkerboard image as the experiment image, which has 10×12 squares and incomplete grids. The experiment results of this algorithm and Harris algorithm will be given and contrasted. The results of corner detection will be shown as fig. 2 and fig. 3. From these figures, we can see that the algorithm can accurately detect corners with checkerboard features in the image and does not exist the phenomenon of missing detection and false detection; although Harris algorithm can also detect X-corners, it has the phenomenon of false detection.

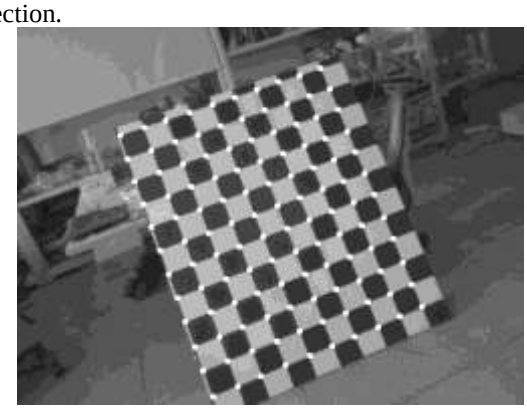


Figure 2. The experiment result image by proposed algorithm

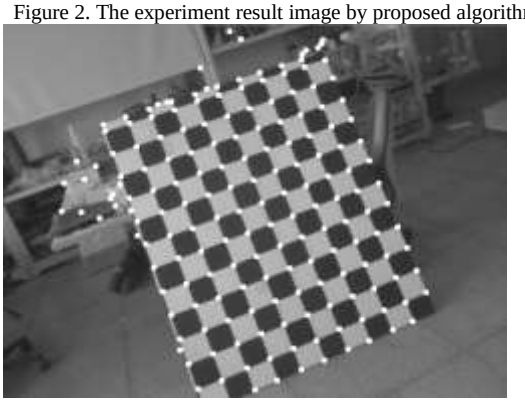
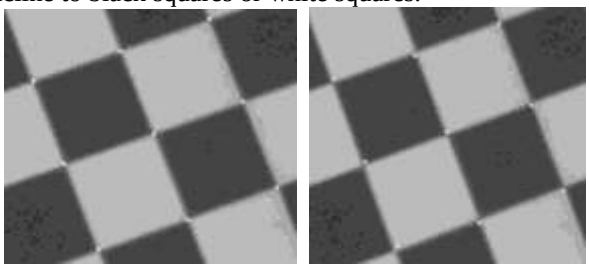


Figure 3. The experiment result image by Harris algorithm

In order to validate the accuracy of the algorithm proposed in this paper, the result images are magnified 4 times and the same local images are obtained as shown in Fig. 4. As can be seen from the Fig. 4, the positions of X-corners detected by this algorithm mostly are in the center of the intersections of black squares and black squares (or white squares and white squares). But the positions detected by Harris algorithm are not in the center and incline to black squares or white squares.



(a) This algorithm (b) Harris algorithm

Figure 4. The experiment result image of partial enlargement

Table 1 gives the gray levels of local image from the upper left coordinate (174,369) to the lower right coordinate (183,378) and the positions of the corners detected by this algorithm and Harris algorithm. The ideal corner position is in the center of two bold numbers in table 1. The position detected by this algorithm is the

position of the bold underlined number and the position detected by Harris algorithm is the position of the number in the box. Therefore, we can see that the position detected by this algorithm is more close to the real X-corner position. When doing the sub-pixel level location, we can obtain more accurate position.

TABLE I. THE GRAY LEVELS OF THE LOCAL IMAGE

x	*Y*									
	369	370	371	372	373	374	375	376	377	378
174	180	176	163	101	73	69	64	61	66	69
175	182	179	175	128	73	75	71	69	77	86
176	181	182	178	155	92	77	81	104	133	155
177	182	180	176	167	**114**	121	151	170	175	175
178	176	168	145	114	**<u>121</u>**	167	177	178	178	175
179	125	95	81	$\boxed{75}$	98	158	178	179	178	178
180	75	73	69	73	81	137	175	180	178	178
181	66	66	64	66	73	106	167	176	182	180
182	64	66	66	69	71	83	152	177	180	179
183	61	61	66	66	66	77	125	170	180	183

Through the above experiments we can see that this algorithm has better recognition ability of X-corner. In terms of computational speed, this algorithm requires only the comparison and statistics of pixels in neighborhood window, so it is not necessary to calculate gradient and variance, less computation and faster. Therefore this algorithm has a certain speed and accuracy and can be used for the checkerboard corner detection in real-time processing.

In this paper the window of the algorithm can be circular, square or regular polygon and the window should be the appropriate size. Large window will improve the accuracy of detection, but that will increase the amount of calculation. Generally, its size is 5×5 or 7×7, and can be adjusted according to the specific situation of the image in actual calculation. By utilizing the symmetry of the neighborhood of the X-corner, the algorithm has rotation invariance; by making use of gray information statistics in the neighborhood window, it has some noise immunity.

V. CONCLUSION

Aim at the X-corner detection of checkerboard image template for camera calibration, the paper proposes an X-corner detection algorithm based on neighborhood features of the X-corner. The algorithm makes use of the three features in the neighborhood of nucleus to detect corners, which are the black and white areas, gray difference and gray symmetry. Through the tow features of the black or white area occupying half of the neighborhood area and the large gray difference between black and white, we can eliminate pixels in flat areas effectively. Then on the edges using the feature of the pixels having symmetrical relationship about nucleus in the neighborhood area of X-corner, we can get the positions of X-corners. In order to meet the need for camera calibration, the paper uses the gray square centrobaric arithmetic with precise location to do sub-pixel level corner detection. The algorithm proposed by this paper is smart, less computation and easy to execute, not only has rotation invariance, but also has a certain anti-noise performance. Experimental results show that compared with Harris algorithm, it is faster and more accurate to detect X-corners, so it is suitable for the X-corner fast detection of checkerboard images in camera calibration.

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