Abstract—Corner detection is an important step in the image processing of machine vision. An improved algorithm is proposed in this paper following the analysis on the existing corner detection algorithms and on the localization precision and computation efficiency in the Harris corner detection algorithm. In this algorithm, a large number of irrelevant points are rejected by statistical analyzing the pixel gray level difference around the target pixel, and then the response function of residual points is calculated and compared with the set threshold value to certify the real corner. Finally computation program is programmed, using this program, the synthesize images of five types of corners are analyzed and calculated, which shows that the improved algorithm acquires better efficiency and accuracy in corner detection.

Keywords—Machine Vision; Corner Detection; Harris algorithm

I. INTRODUCTION

Corner point is the point whose gray level changes acutely or the cross-point of outline boundary, which reflects the important information in image. Detecting corner point is beneficial to emphasizing the important information in image and weakening the minor information. Compared with other features, such as line, circle, edge, and so on, the detection of corner feature is easy, steady and has good adaptability. Corner detection methods are widely used in most vision processing, such as image matching, shape analysis and moving object detection, the results of corner detection will influence the remaining works, therefore Corner detection proves to be an important analyzing method in machine vision.

The existing algorithms of corner detection can be divided into two important types: The first one is the detecting method based on the edge contour, in which corners are detected after the detection of edge contour. The second one is direct corner detecting from the gray level image. Since the corner detection algorithm based on the processing of the image pixel’s gray level, it can avoid the errors existing in the algorithm based on the edge contour. In this kind of algorithm, Harris algorithm and SUSAN algorithm are the two most widely-used algorithms. One of the biggest disadvantages of Harris algorithm is that it is very sensitive to scale variation. Those pixels detected as corners in the large scale may turn into the edge points or other feature points in small scale. Therefore the researches are mainly focus on how to achieve the scale invariance. The C.Schmid has proposed an improved algorithm that can get a higher repetition rate. Using the production of K.Mikolajczyk and C.Schmid, Chen Baifan have constructed Harris-Laplacian operators that can get the scale invariance. Wang Zhan has get the scale invariance by the wavelet transformation method. In addition, Li Bo etc have researched Gaussian filter in Harris algorithm and used B-spline function as the smoothing filter, which proves to have better effects.

Most of the existing improved algorithms are concentrating on the improvement of scale invariance, rather than on the detection accuracy and calculation efficiency. To overcome the disadvantages of Harris corner detection algorithm in positioning precision and computation efficiency, an improved algorithm is proposed in this paper on the basis of the Harris corner detection principle, moreover, the accuracy and efficiency of the improved algorithm is verified by experiments.

II. THE PRINCIPLES OF HARRIS CORNER DETECTION

Harris algorithm is based on Moravec algorithm, and the basic principles of Moravec algorithm are as follows: taking a small window centering around the target pixel, and moving the window upward, downward, leftward and rightward, then calculating the change of gray level in the windows of the four directions, taking the minimum value as the corner response function value, if the value of the corner response function is larger than the threshold value, this pixel will be considered as the final corner.

The Harris algorithm calculates the changing value of gray level in any direction and expresses it in analytical form. If the small window that selects the pixel (x, y) as the center moves along X-direction for u and Y-direction for v, the analytical form of gray level change in Harris algorithm are as follows:

\[ E_{x,y} = \sum w_{x,y} \left( I_{x+u,y+v} - I_{x,y} \right)^2 \]

\[ = \sum w_{x,y} \left( u \frac{\partial I}{\partial X} + v \frac{\partial I}{\partial Y} + o(\sqrt{u^2 + v^2}) \right)^2 \]  

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Where $E_{x,y}$ is the gray level change value within the window, $w_{x,y}$ is window function, and its commonly definition is $w_{x,y} = e^{-(x^2+y^2)/\sigma^2}$, $I$ is the image gray level function. Omit the infinite minor items, the equation could be expressed as follows:

\[
E_{x,y} = \sum w_{x,y} \left[ u^2 (I_x)^2 + v^2 (I_y)^2 + 2uv I_x I_y \right] = Au^2 + 2Buv + C
\]

\( A = (I_x)^2 \otimes w_{x,y} \)

\( B = (I_x I_y) \otimes w_{x,y} \)

\( C = (I_y)^2 \otimes w_{x,y} \)

\( \otimes \) denotes convolution:

And transform $E_{x,y}$ into quadratic form as:

\[
E_{x,y} = [u \ v] M \begin{bmatrix} u \\ v \end{bmatrix}
\]

(3)

$M$ is real symmetric matrix as:

\[
M = \sum w_{x,y} \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix}
\]

(4)

After diagonalization processing as:

\[
E_{x,y} = R^{-1} \begin{bmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{bmatrix} R
\]

(5)

Where $R$ is Twiddle Factor, the space surface shape that takes the $u$ and $v$ for the coordinate parameters isn’t changed after diagonalization, and its eigenvalue reflects the image surface curvature in two principal axis directions. If two characteristic values are both small that indicate the areas neighboring target point are flatness area; and if one characteristic value is large, while the other one is small, that indicate the feature point is on the edge; only when two characteristic values are large that any side movement will induce the acute change of the gray level. The expression of Harris corner response function (CRF) is as follows:

\[
CRF(x, y) = \det(M) - k(\text{trace}(M))^2
\]

(6)

Where $\det(M)$ denotes the determinant of matrix $M$, and $\text{trace}(M)$ denotes the matrix trace. When the CRF value of target pixel is larger than the threshold value, the pixel will be considered as the corner.

### III. HARRIS ALGORITHM ANALYSIS

In general, Harris algorithm is a very effective method of image corner detection, and its advantages are as follows: First, the detected corners are equable and rational, after calculating the response value of every point, Harris algorithm will search for the optimum point within neighborhood. Experiment indicates that Harris algorithm can get a mass of useful corners on the area with abundant texture information, but fewer on the destitute area. Second, the detected corners are reliable, so far as the large scale changes does not happen, the steadier corner feature will be detected by Harris algorithm.

But Harris algorithm also has some disadvantages. The first is corner location errors, particularly in some especial corners. Combined with some familiar types of corners, the cause of low location precision of Harris algorithm will be analyzed. The corners within actual image are mainly divided into the types as Fig.1 shows:

![Figure 1. Five types of corners(from left to right: L, T, Y, X, diagonal T)](image)

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According to the comparison between practical detection results and real corners, we can find the location errors by using Harris algorithm in T and diagonal T corners. For T corners, a pixel deviation exists in horizontal direction, while for diagonal T corners, a pixel deviation exists in both horizontal direction and vertical direction. As for the X corner, Harris algorithm can detect four corners, which proves to be reasonable since the four peaks got by the four rectangles overshadowing each other can be considered as corners. Therefore this algorithm is precise in X corner location.

The second disadvantage of Harris algorithm is its low calculation efficiency, as this algorithm calculates every pixel’s corner response function except the edged ones. The larger the image size, the more calculation time is needed. The experiments in this paper shows that it takes 2.584592 seconds when detecting the corners of the image with the size of 960*960, whereas it takes 5.419184 seconds for a image with a size of 1600*1200. Therefore Harris algorithm is not fit for real-time processing.
IV. IMPROVED HARRIS ALGORITHM PRINCIPLE

Since Harris algorithm uses difference directional derivative method to calculate the corner response function value of the irrelevant pixels around the real corners, and errors exist among ideal directional derivative so that the real corners are wiped off in non-maximum suppression. Therefore, the key problem to improve the precision of Harris corner detection algorithm is to explore a rational method that can eliminate the influence of the surrounding pixels.

To the target pixels, consider the pixel points within the 8 neighborhoods and calculate absolute value of the gray level difference of pixel points and the target pixels. If the value is not larger than the threshold value (mark as T), these pixels will be considered as the corners similar to the target pixel points. Count the number of the pixel points within the 8 neighborhoods of the similar corners, and denote them as $K(i,j)$:

$$K(i,j) = \sum_{(x,y)} R(i+x, j+y)$$

$$(-1 \leq x \leq 1, -1 \leq y \leq 1, x \neq 0, y \neq 0)$$

In Eq. (7):

$$R(i+x, j+y) = \begin{cases} 1, & \Delta(i+x, j+y) \leq T; \\ 0, & \Delta(i+x, j+y) > T; \end{cases}$$

From the definition we can see that: 0 ≤ $K(i,j)$ ≤ 8, and the meanings of the value of $K(i,j)$ are as follows.

a) $K(i,j)=8$, it denotes that the 8 neighborhood of the current target pixel is filled in the similar pixels, so the pixel is within the area, therefore, this kind of pixels should be excluded in corner detection.

b) $K(i,j)=0$, it denotes that there is no the similar pixels within the 8 neighborhood of the target pixel, so these pixels are isolated points or noise points, therefore, this kind of pixels should be excluded in corner detection.

c) $K(i,j)=7$, it can be summed up as the following two situations (and all others can be obtained by rotation): To the left image of Fig.2, the possible corner should be the pixel point above the target pixel, and the possible corner should be the pixel point on the top right corner of the target pixel to the right image of Fig.2, therefore, under this condition, the target pixels can not be considered as the candidate points of the corners.

d) $K(i,j)=1$, it can be summed up as the two situations shown in Fig.3, the white areas denote dissimilarity to the target pixel, but the pixels of the white area may be similar or dissimilar, under these two conditions, the target pixels may be corners, or the discrete noise points or two isolated points hanging together. Therefore the pixel gray level distribution over a larger area needs to be investigated. One option is to count the number of the pixels similar to the target pixel within the 24 neighborhood. If the number is still small or the proportion of the similar pixel number is unchanging, these pixels can be considered as the noise points or the discrete isolated points.

e) $2 \leq K(i,j) \leq 6$, although no method can be used to ensure the characteristics of pixels, we can ensure that: if the target pixel is corner, the K value of this point should be the minimal within the 8 neighborhood (as Fig.4 shows). Otherwise, we can’t make such conclusions. Therefore we need calculating the K value of the target pixels and the pixels within the 8 neighborhood, and find the minimum value. If the value equals to the K value of the target pixel, the point will be reserved as the candidate for the next step of Harris algorithm calculation, but if not, the point will be rejected to reduce the calculation of the next step. If meet the condition of the Harris algorithm corner detection, the point will be selected as the corner, in this way the possibility that false corner suppresses the true corner and treats the real corner when in non-maximal suppression will be avoided, and this is also the cause of the corner location deviation on the T and diagonal T corners. If K=5, the K value of any point within the 8 neighborhood is greater than or equal to 5, which denotes that many similar points, most probably the points on the edge, are in the area, so the K value of the pixels on both side of the target pixel will be considered. If the value of both sides is 5, the target pixel is the point on edge, and it shouldn’t be selected as the candidate point. In the same way, the same conclusion will be obtained when we consider the pixels in the sides of the diagonal.

![Figure 2. Two cases when $K(i,j)=7$](image2)

![Figure 3. Two cases when $K(i,j)=1$](image3)

![Figure 4. Comparison of K value of five types corners within 8 neighborhoods](image4)
Having processed the candidate corners by the above steps, the value of the Harris algorithm corner response function is calculated, if the value is larger than the threshold value, these pixels will be considered as the final corners.

V. Capability Analysis of Improved Harris Algorithm

A. Precision analysis

Because of the influence of pixels around the real corners, when detecting the T and diagonal T corners using Harris algorithm, the threshold value of the unreal corner is larger than the value of the real corner, when processing local maximum inhibition or threshold value selection, there will be location errors in real corner location or the neglect of real corner detection.

Improved Harris algorithm resolves the problem of location deviation in Harris algorithm detection on T and diagonal T corners. To the 8 neighborhood of the real corners, the improved algorithm makes the local analysis, and the K value of the real corner should be least in its area. This criterion is effective on avoiding the influence of the pixels around the corners and the location errors, but only by this criterion we can’t ensure whether the pixel is the corner or not. In the next step, according to the K value of the target pixel, the distribution condition of the pixels within the neighborhood can be judged, and the candidate corners are sorted out, and then calculate the real corner by using corner response function value. Improved algorithm can not only locates T corners and diagonal T corners precisely, but also inherit the accurate corner location of Harris algorithm for other types such as L, Y and X corners. The artificial synthesize images of five types of the corners are processed by using the improved Harris algorithm, Tab.1 shows the detection results.

B. Efficiency analysis

Harris algorithm calculates the every pixel’s value of CRF within the image except for the edge points. On the assumption that Harris algorithm uses the circular window whose diameter is 5 (the number of pixel is 21) and use Sobel operators as the directional derivative, the number of multiplication in the calculation course of every pixel is (4+1+2+2+1)*21+4=214 and the number of addition is (3+3+3)*21+2=191. In spite of the edge influence, the algorithm complexity of the image with the N*N resolution may be 214*N*N (multiplication) + 191*N*N (addition). Since multiplying costs more time than adding, the efficiency of Harris algorithm is lower in real time processing.

The improved algorithm makes an initial selection before calculating the CRF which is mostly addition operation and the operation is 8*N*N. Since multiplication is not involved, although operation amount is increased, a mass of the non-pixel points are rejected, we do not have to calculate the CRF of every pixel, which greatly cut down of multiplication, times and the efficiency are obvious showed in the images with high resolution. After pretreatment, the proportion of the rejected pixel in the experiments is higher than 60%, as a result, about half of multiplication amount is commonly reduced. Experiments shows that the improved algorithm only needs 14.3% computation time of the original Harris algorithm and greatly abbreviates the processing time, which is propitious in real time processing.

VI. Conclusion

This paper analyzes the principle and the exiting limitations of Harris corner detection algorithm is analyzed in this paper, moreover, an improved Harris algorithm is proposed. The improved algorithm calculate the distribution of the gray level of the target pixel within 8 neighborhood and calculates the number of the similar pixels (K). By analyzing the selecting of K value, some of the non-corner pixels are rejected and residual pixels are selected as the candidate points, furthermore, the real corners are selected after using the Harris corner response function to calculate the response value. The experiments show that the improved algorithm only needs 14.3% computation time of the original Harris algorithm, and obtains the accurate localization on T and diagonal T corners. So the improved algorithm is fit for the situation of the image detection and treatment with higher real time request.

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