The Improved Harris Operator based on Steerable Filter

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Abstract: The conventional Harris corner detection operator is improved to enhance the missing rate and the detection capability of false corners in this paper. With the materials recognition on automated logistics and packaging line as an example, the acquired images were firstly pretreated to achieve the grayscale images. The rotations of four different angles were performed by the steerable filter based on the grayscale and the corner points were detected. Finally the authenticity corner points were determined through the integrated logic operations. The image data pre-processed was detected using the improved Harris corner operator and compared with the data by the traditional corner detection operator. The false detection rate was decreased to 1.3 % and the missing rate reduced to 2.9% in the experiment. The results show that the improved operator has a strong capability of discerning authenticity angular point and this method can effectively improve the recognition accuracy of corner detection operator.

1 INTRODUCTION

Angular point is generally defined as the area in which the grey value of image changes the most. By detecting the angle point, the image can be abstracted and replaced only through the typical points. The image data volume is greatly reduced and the speed and efficiency of image processing were improved considerably (Chen, Lyu and Ding, 2005). Corner detection is a method of image features extraction for computer vision system and is used widely in the motion detection, image matching, video tracking, 3D modelling and target recognition, etc.

At present the corner detection algorithm can be classified into two categories: the corner detection based on image edge (Lee, Sun and Chen, 1995; Beus, Steven and Tiu, 1987) and based on gray image (Barbara, Jaroslav and Gabriele, 1999). The corner detection based on image edge to a large extent depends on image edge detection and image segmentation. But the two operations have a great deal of difficulty to achieve the good results. For example, it is difficult to detect the complete edges when it subjects to the local shelter or overlapping situations, so that the scope of application is restricted. The corner detection based on gray image avoids this problem tactfully, and the corner is detected by checking the gray variation of neighborhood, and mainly by computing the gradient and curvature. A successful corner detection operator should be able to detect all the real angular point. Harris operator is a recognized corner detection algorithm for gray image, but the choice of its threshold has a great deal of uncertainty due to without clear theory regulation, just according to the experience or the experiment (Harris and Stephens, 1988). Harris corner detection algorithm is widely used in various fields. Yang et al. (Yang, Ning and He, 2011) used Harris operator to study grains with characteristics of tips such as corn, squash and pumpkin for identifying tips. Wang et al. reflected precisely the geometry quality changes of the remote sensing image before and after compression through Harris corner detection algorithm (Wang, Yang and Wu, 2011). Various cases proved that Harris corner detection operator had good angular point recognition, but it still exist some shortage and need to be improved.

Liu et al. put forward an improved Harris corner detection algorithm based on image edge for fault detection and residual angular point. The experiment results proved that the corner detection algorithm

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had higher accuracy (Liu, Zhao and Sun, 2013). Fang et al. used double mask to set the local scope of the non-maximum inhibition combined with k-means clustering method for the non-maximum inhibition. This method overcame the lost or redundancy of angular point caused by uncertainty of the traditional Harris corner detection algorithm which selected the threshold value based on the experience and improved the precision of corner detection (Fang, Wang and Niu, 2011). Wang et al. put forward a similar angular point algorithm for the T shape and inclined T shape whose positions were not accurate with low arithmetic speed. The experimental results showed that the improved algorithm was more suitable for real-time demanding (Wang, Tang, Ren and et al., 2008). Zhang et al. built a new Harris multi-scale corner detection algorithm based on the wavelet transform for defect of Harris operator without scales change (Zhang, Li and Yang, 2007).

The paper proposed a corner detection algorithm with improved Harris operator based on steerable filters with material identification on the automatic logistics packaging line as example. The improved Harris operator, traditional Harris operator and classical Susan operator were compared on error detection rate and miss rate. The experiments proved that the improved Harris operator was a good way to reduce the error detection rate and the miss rate of angular point.

2 HARRIS OPERATOR

The logic behind the Harris corner detection algorithm (Harris and Stephens, 1988; Beis and Lowe, 1997) is that, the image intensity will change significantly in multiple directions at a corner, while the image intensity will change greatly in a certain direction at an edge. This phenomenon can be formulated by examining the changes in intensity resulting from shifts in a local window. Around a corner point, the image intensity will change greatly when the window is shifted in an arbitrary direction. While around an edge point, the image intensity will change greatly when the window is shifted in the perpendicular direction. Following this intuition, the Harris detector uses a second order moment matrix as the basis of its corner decisions. Unless otherwise specified, all corner points and edge points detected by the Harris corner detector are hereafter referred to Harris corner interest points.

For a given image I, its autocorrelation matrix M at point (x, y) can be calculated as:

$$\mathrm{M}(x,y)=\sum_{x,y}\omega(x,y)\begin{bmatrix}\mathrm{I}_x^2(x,y) & \mathrm{I}_x\mathrm{I}_y(x,y)\\ \mathrm{I}_x\mathrm{I}_y(x,y) & \mathrm{I}_y^2(x,y)\end{bmatrix} \quad (1)$$

Where I_x and I_y is the respective derivative of pixel intensity in the *x* and *y* direction at point (*x, y*). That is,

$$\mathrm{I}_x = \mathrm{I}\otimes\left[-1,0,1\right]\approx \partial \mathrm{I}/\partial x \quad (2)$$

$$\mathrm{I}_y = \mathrm{I}\otimes\left[-1,0,1\right]^T\approx \partial \mathrm{I}/\partial y \quad (3)$$

Where the operator $\otimes$ denotes convolution.

The off-diagonal entries are the product of I_x and I_y, while the diagonal entries are squares of the respective derivatives. The weighting function $\omega(x, y)$ can be uniform, but it is more typically an isotropic, circular Gaussian:

$$\omega(x,y)=g(x,y,\sigma)=\frac{1}{2\pi\sigma^2}\exp(-\frac{x^2+y^2}{2\sigma}) \quad (4)$$

It assigns more weight to those values near the center of a local region. As it turns out, the matrix M(x, y) describes the shape of the autocorrelation measure as a result of the shifts in window location (Harris and Stephens, 1988; Beis and Lowe, 1997). Let α and β be the eigenvalues of M(x, y), and then these values can provide a quantitative description of how the autocorrelation measure changes in space, its principal curvatures. According to the eigenvalues of the autocorrelation matrix, the image regions can be divided into three categories as follows (Harris and Stephens, 1988; Beis and Lowe, 1997):

1. Plain regions: $\alpha\approx 0$ and $\beta\approx 0$. Both eigenvalues are small, thus the intensity variation is negligible in any direction. In this case, the region can be considered almost plain;
2. Edges: $\alpha \gg \beta$. The difference between the two eigenvalues is large, which implies that the intensity variation is noticeable only in one direction, i.e., the edge gradient direction;
3. Corners: $\alpha\approx\beta$, with $\alpha\beta \gg 0$. Intensity variation is strong along all directions, which is usually achieved by 'small spot' regions.

The (α, β) space can be divided into three regions by the heavy lines (Harris and Stephens, 1988; Beis and Lowe, 1997). However, aside from the corner and edge classification regions, a measure of their quality or response is also needed. Note that the product $\alpha\beta$ is sensitive to corners, while the sum

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$\alpha+\beta$ is sensitive to both edges and corners. Besides, the determinant and the trace of a general diagonalizable matrix agree with the product and the sum of its eigenvalues, respectively, i.e.,

$$\mathrm{tr}\left(\mathrm{M}\left(x,y\right)\right)=\alpha+\beta=\mathrm{I}_x^2(x,y)+\mathrm{I}_y^2(x,y) \quad (5)$$

$$\det\left(\mathrm{M}\left(x,y\right)\right)=\alpha\beta=\mathrm{I}_x^2(x,y)\cdot\mathrm{I}_y^2(x,y)-(\mathrm{I}_x\mathrm{I}_y(x,y))^2 \quad (6)$$

Therefore, it is attractive to use $\mathrm{tr}(\mathrm{M}(x,y))$ and $\det(\mathrm{M}(x,y))$ to measure the corner response since it avoids the explicit eigenvalue decomposition of M(x, y). The corner response can be measured using Eq. (7) (Harris and Stephens, 1988; Beis and Lowe, 1997).

$$R(x,y)=\det(\mathrm{M}(x,y))\text{-}k\cdot\mathrm{tr}^2(\mathrm{M}(x,y))=\alpha\beta-k\cdot(\alpha+\beta)^2 \quad (7)$$

Where k is a scalar value empirically chosen from the range [0.04,0.16]. Corner points have large positive eigenvalues and hence a large Harris measure response. Thus, corner points that are greater than a specified threshold are identified as local maxima of the Harris measure response, i.e.,

$$\{(x_c,y_c)\}=\{(x_c,y_c)\,|\,R(x_c,y_c)>R(x_i,y_i),\forall(x_i,y_i)\in W(x_c,y_c),R(x_c,y_c)>t_{th}\} \quad (8)$$

Where $\{(x_c,y_c)\}$ is the set of all corner points, $R(x_c,y_c)$ is the Harris measure response calculated at point (x, y); $W(x_c,y_c)$ is an 8-neighbor set centered around the point (x_c,y_c), and t_{th} is a specified threshold. Obviously, the number of detected Harris corner points depends on the threshold t_{th}.

Above all, Harris operator is a kind of efficient point feature extracting operator with simple algorithm and low time-consuming(Harris and Stephens, 1988; Beis and Lowe, 1997). The operator only needs to calculate the first-order difference and filtering on the basis of gray level and the operation is simple. The point feature information is relatively uniform, and the Harris operator calculates the interested values for all points in the image, and then performs the optimal selection in the neighborhood. The algorithm process is relatively stable, and involves only a derivative operator calculation, not affected by the image rotation, noise and perspective transformation easily (Harris and Stephens, 1988; Beis and Lowe, 1997). But it has also some irremovable drawbacks. It is very sensitive to the changes of scale, and does not have scale invariance. Extraction of angular point level is pixel level. The positioning accuracy is poor and is easy to miss some practical angular point. It is necessary for the maximum inhibition, and the extraction accuracy of angular point depends on the set threshold. If the threshold setting is too big, it will cause the loss of angular point information. If the threshold setting is too small, it will cause a lot of false corners extracted (Harris and Stephens, 1988; Beis and Lowe, 1997).

3 STEERABLE FILTER

Steerable Filter was put forward as a filter design method of Fourier series expansion in 1991 by Freeman (Stephen and Smith, 1997) based on polar coordinates (r, θ). It is adopted as a linear calculation of convolution. The basic idea is that the filter along arbitrary direction can be expressed as a linear combination of a set of base filter functions. Image after responded by filter in one direction can be showed by a set of linear combination of the base filter response. This can avoid the repeated convolution operation, thus reducing the computational complexity.

Steerable filter has the function of arbitrary rotation and can be represented by a linear combination of the fixed base filter for any direction. Therefore it can accurately detect the target features such as edge, texture and singular point. The base filter corresponding to the steerable filter is a set of filters having certain overlap between each other in the frequency domain. And each filter can be expressed as the form of the angle rotating to a certain way for steerable filter. The basic idea is to produce a rotating steerable filter based on a linear combination of filter from a fixed set. The structure of a universal steerable filter was shown in Figure 1.

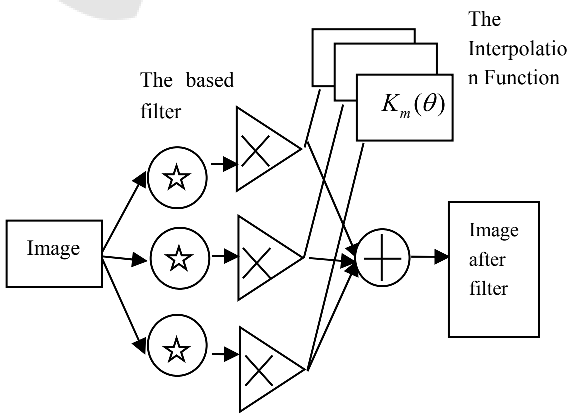

Figure 1: The basic structure of the filter steerable

It is defined as the following form: if a filter

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$f^{\theta}(x,y)$ can rotate, the rotation $f^{\theta}(x,y)$ in any direction θ is as Eq. (7).

$$f^{\theta}(x,y)=\sum_{m=1}^{M}K_m(\theta)f^{\theta_m}(x,y) \tag{9}$$

Where $f^{\theta}(x,y)$ - based filter, M – the number of filter, $K_m(\theta)$ - the interpolation function.

A given function f is determined in the polar coordinate ($r=\sqrt{x^2+y^2}, \theta=\arg(x,y)$). And f after the rotation can be expressed as the function of a Fourier series in the polar angle ψ .

$$f(r,\psi)=\sum_{n=-N}^{N}a_n(r)e^{jn\psi} \tag{10}$$

Where j=-1, N-discrete distance.

This method has a certain requirements on the direction angle of the directional derivative filter with a rotation angle. The filter function must be continuous, otherwise this method will not be applied. The solution process for the algorithm is complex, and the computation is larger. It cannot be directly used in industrial automation geometry image identification and is usually combined with other operator for application, such as combining pyramid algorithm for face recognition (William and Edward, 1991). In the paper, the angle corner in any rotation direction can be expressed as a linear combination of the same group of base filter by using steerable filter.

4 THE IMPROVED HARRIS OPERATOR

For the uncertainty of image rotation due to selecting threshold of Harris operator, the paper improved the Harris corner detection operator using rotation invariance of steerable filter. The rotation of different direction by steerable filter was increased during the detection of Harris operator, and the Harris test was. Finally the authenticity angular point of all directions was determined by logic operations.

4.1 The algorithm process

Harris corner detection needs to set the threshold for the non-maximum inhibition, and the accuracy of extracting angular point depends on the setting threshold (Xie, Zhan and Jiang, 2003; Du, Wen and Chen, 2009). If the threshold setting is too large, the angular point information will be lost; if the threshold setting is too small, it will cause a lot of false corners extracted, such as some image noise (Xie, Zhan and Jiang, 2003; Du, Wen and Chen, 2009). The traditional Harris operator sets threshold according to the experience and there is large uncertainty so that it causes some false detection of non-angular point and leak detection of actual angular point.

This paper proposed an improved Harris corner detection algorithm by steerable filter which can change the selection algorithm for threshold artificially to a great degree and improve the accuracy of the corner detection algorithm. The algorithm structure was as shown in Figure 2.

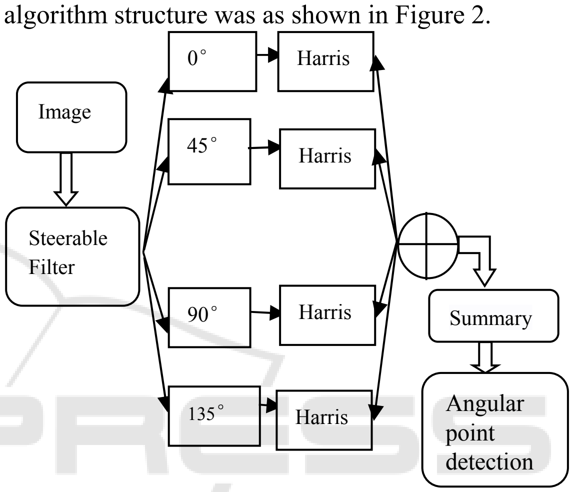

Figure 2: The structure of the improved Harris algorithm

By image collecting of CCD camera, the binary image of experiment was achieved by preprocessing steps such as enhancement and smoothing. Each pixel of binary image was regarded as pixels of discrete grey value. And for each pixel, its four neighbourhoods which constituted the cross point group were calculated, as shown in Figure 3.

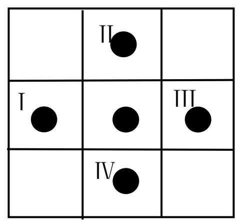

Figure 3: Cross point model

The brightness of the center point was judged by detecting the four points Ⅰ, Ⅱ, Ⅲ and Ⅳ around the cross point group, and then its gradient was judged according to the brightness value. If the higher

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accuracy needs to be achieved, the gradient value of the center point can be detected by the brightness values of 8 points surrounding. For case of the real-time packing line system, the brightness values of four points surrounding were selected for the experiment considering factors such as shape and material.

1) At first, the image was rotated by the steerable filter of different direction.

From the figure 4 it can be seen that the position relations between the four points of cross point group and the center point were four rotation angles of 0 °, 45 °, 90 ° and 135 °. According to the brightness of the cross point, the brightness of the center can be judged, so the four rotation angles of 0 °, 45 °, 90 ° and 135 ° were chosen. The gray image processed was rotated according to the four angles respectively.

2) According to the image clarity (focusing degree), Laplace energy function was evaluated. The brightness values of cross point model was calculated respectively and then the gradient value of the center point was judged.

3) The corners of each direction were detected using Harris operator. The angular corner information of image processed by the steerable filter for four directions was detected using Harris operator respectively.

4) All the authenticity corners detected were performed by the logical "or" operation. The real corners were selected and the false corners were removed.

4.2 The examples

The experiment was based on Microsoft Visual C++ 6.0 programming environment and Open CV. And the classic image of corner detection operator and the material on automatic packaging line were selected. In this paper, all of the processing images were gray images after the early pretreatment. The Susan operator, the classical Harris operator and the Harris operator improved by steerable filter were performed by corner detection on the basis of grayscale. The test results were analyzed and compared as shown in Table 1.

It can be clearly observed that the extraction of different operator for corner point information had a large difference, especially for distinguishing authenticity corner point. The error detection rate and the miss rate were analyzed and compared as shown in Table 2 and Table 3.

The false detection rate is

$$\omega = \frac{k}{N} \tag{11}$$

Where k –the non-corners false detection point which is regarded as a corner point, N-the number of real corner points.

Table 1: The results with different algorithms of Sample 1, 2, 3

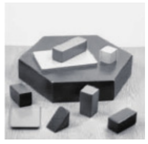
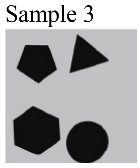
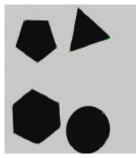
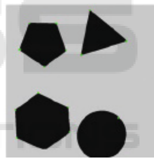
	Sample 1	Sample 2	Sample 3
Original image			
Susan operator			
Harris operator			
The improved Harris operator			

Table 2: The comparison of false detection rate

Algorithm	The number of angular point for false detection			The false detection rate/%
	Sample 1	Sample 2	Sample 3	
Susan	8	6	7	20.34
Harris	4	5	4	7.2
The improved Harris	4	2	1	1.3

Table 3: The comparison of undetected rate

Algorithm	The number of angular point for false detection			The false detection rate/%
	Sample 1	Sample 2	Sample 3	
Susan	8	7	2	5.2
Harris	19	4	3	14.4
The improved Harris	3	1	1	2.9

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The average error detection rate is

$$\overline{\omega} = \frac{1}{n}\sum_{i}^{n}\omega_i \qquad (12)$$

Where n -the total numbers of subjects.

It can be seen from table 1 that for the error detection rate, the evaluation of the Susan operator was the highest, the traditional Harris operator was the second place and the improved Harris operator was the lowest.

The miss rate is

$$\eta = \frac{1}{N} \qquad (13)$$

Where L-the numbers of the missed real corner points, N-the numbers of the real corner points.

The average miss rate is

$$\overline{\eta} = \frac{1}{n}\sum_{i}^{n}\eta_i \qquad (14)$$

Where n-the total numbers of subjects.

From table 3 it can be seen the miss rate of Susan operator was the highest, traditional Harris operator was middle-level, and the improved Harris operator miss rate was the lowest.

In conclusion it can be seen that the traditional Harris operator was superior to Susan operator in detecting the image error detection rate and the miss rate, and the improved Harris operator was better than traditional Harris operator.

5 CONCLUSIONS

The paper put forward an improved Harris operator algorithm based on steerable filter which enhanced the leak detection and mistakenly identification for Harris operator during the corner detection. The gradient of the four different rotation angles for the suspected corner pixels were further tested by steerable filter so as to confirm whether it was really a corner point. The experiment proved that the method was a good way to improve the detection accuracy of the real corner point and reduce error detection rate of the false corner point containing the noise. But for some high-speed case, the algorithm program took too much time and need to be further improved.

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