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Harris Corner Detection Algorithm Based on Improved Contourlet Transform

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Abstract

According to multi-resolution analysis theory, this paper constructed a new Harris multi-scale corner detection algorithm based on contourlet transform. The algorithm can be decomposed by contourlet under different scales, and extract feature points on the edge direction, obtain the corner. The new algorithm can also overcome phenomenon caused by the single-scale Harris corner detection such as the loss information of corners, the corner position offset and extract false corners disturbed by noise. Experimental results show that the new corner algorithm detected more uniform distribution and reasonable, can be well applied in many fields such as image stitching.

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Key words: Multi-scale corner detection;Contourlet;Harris corner detection

1. Instruction

Corner is the point which testing function energy is very intense in any direction changes, it is one of the most important feature of the data information. The accuracy and quality of the corner detection directly affect the results of image processing, and can determine the outline features and important information of the image. Corner detection are used for camera calibration, optical flow velocity measuring,motion estimation, measurement and positioning etc, and has become an important tool for image processing. Corner detection can not only keep the useful image information but also can reduce data redundancy and improve the detection efficiency [1].

At present, the corner detection algorithm can be divided into two types: one is based on the image gray data; the other is based on image edge data. The former algorithm firstly compared the size of the template region's gray values with the image region's, and then matches. The accuracy of the algorithm is relatively higher, but it has some drawback such as complex calculations, precision positioning is not high and real-time processing of image data is poor. While the latter algorithm need to encode the image edges, and has great dependence on the edge of the image, the corner detection information will be lost if the image can not provided completely [2] [3].

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In order to take full advantage of the corner information in different scales, this paper obtained the different frequency components of the image by wavelet decomposition. And then, extracts the corner information on each sub-band. Simulation results show that the algorithm can improve the corner accuracy and the extraction efficiency effectively, and has strong anti-noise ability [4] [6].

2. Characteristics of the contourlet decomposition coefficient

2.1. the directionality of contourlet

Here, we set low-pass filter for Laplace filter (pyramid filter), high-pass filter for directional filter. First of all, the image is decomposed into a low frequency signal (and the sub-sample) and a high frequency signal by using contourlet decomposition. Then the high frequency signal decomposed in different directions by directional filter, while the low frequency signal decomposed by Laplace filter. And iterate the algorithm above subsequently. In high-dimensional circumstances this algorithm only produces one band-pass image which can avoid the spectrum aliasing phenomenon. Contourlet decomposition scheme is shown in Fig.1. [8]

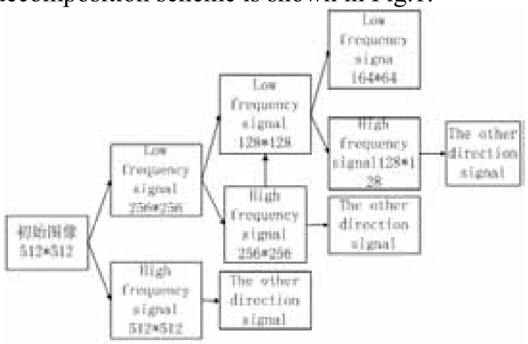

Fig.1. Contourlet decomposition method schemes

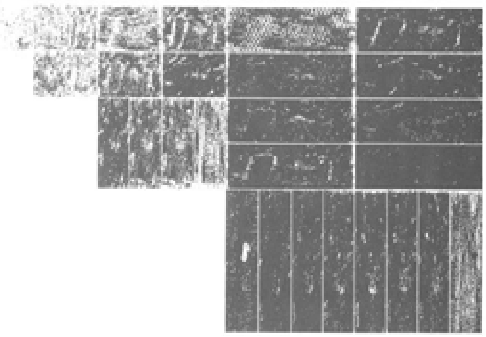

Fig.2. Contourlet decomposition coefficient schemes

3. Harris corner detection principle and inadequate[5]

Harris corner detection is a kind of extraction algorithm based on signal point feature, the principle is as follows. When the image window w (general for rectangular area) move small displacement (x, y) in any direction, the gray variation can be defined as:

$$\begin{aligned} E_{x,y} &= \sum W_{u,v}\left[I_{x+u,y+v} - I_{u,v}\right]^2 = \sum_{u,v} W_{u,v}\left[xX + yY + o\left(x^2 + y^2\right)\right]^2 \\ &= Ax^2 + 2C(x,y) + By^2 = (x,y)M(x,y)^T \end{aligned} \tag{1}$$

Where, X and Y are first order grads, which reflect the gray scale change of the elements, $W_{u,v}$ is the coefficient of the Gaussian window at (u,v).

Harris corner detection algorithm is a kind of effective feature point algorithm, but also have insufficient: (1) algorithm can only detect corner feature in a single scales, the effect of the corner detection will be entirely dependent on the threshold set while implement the non –maxima suppression and determine the local maximum value. The corner information will be loss when threshold set too large, and also will extract pseudo-corner on the counterpart. (2) Although Harris corner detection adopted adjustable window of the Gaussian smooth function, the width of the Gaussian window can not be easily controlled in practical application. If choose smaller window of the Gaussian smooth functions, there will be brought numerous pseudo corner effect by the noise; on the contrary, the greater deviation will be brought by the convolution corner radius of chord effect. Also the computation will be greatly increased. (3) Smoothing filtering the image with infinite Gaussian function will loss the corner information because of the too smooth image. (4) Harris operator does not have the feature of scale invariance [9].

3.1. Harris corner detection on multi- frequency domain and on multi-scale

We take a two-dimensional circle symmetrical, dimension normalized Gaussian function G as an example, the expression in Cartesian coordinates is: $G(x,y)=e^{-\left(x^2+y^2\right)}$,and its direction gradient operator is controllable. We set the n-th order derivative of G at the X-axis direction is G_n , θ is an angle operator, and then any rotated function $f(x,y)$ can be represented as $f^{\theta}(x,y)$. The grads expression in X-axis direction is:

$$G_1^x=\frac{\partial}{\partial x}e^{-\left(x^2+y^2\right)}=-2xe^{-\left(x^2+y^2\right)} \tag{2}$$

The grads expression in Y-axis direction is:

$$G_1^y=\frac{\partial}{\partial y}e^{-\left(x^2+y^2\right)}=-2ye^{-\left(x^2+y^2\right)} \tag{3}$$

Then, we obtained the expression available for any grads θ as follows:

$$G_1^{\theta}=cos(\theta)G_1^x+sin(\theta)G_1^y \tag{4}$$

Since G_1^x and G_1^y can be regarded as decomposition components of G_1^{θ}, we call them as base filter of G_1^{θ}. $\sin(\theta)$ and $\cos(\theta)$ are base filter interpolation functions correspondingly.

According to Eq. (1), we obtain the following equation:

$$\begin{aligned}E_{(u,v)}&=\sum \mathrm{W}_{(\mathrm{u,v})}[I_{x_i+u,y_i+v}-I_{u,v}]^2=\sum_{u,v} W_{u,v}[u\cos(\theta)G_1^x+v\sin(\theta)G_1^y]^2\\&=Au^2+2Cuv+Bv^2=(u,v)M(u,v)^T\end{aligned} \tag{5}$$

So, correlation matrix with angle of θ in each pixel (x, y) of the image is as follows:

$$M_{\theta}=\begin{bmatrix}A & C\\ C & B\end{bmatrix} \tag{6}$$

It should be emphasized that Eq.(6) reflects each pixel grayscale intensity change of the image and the change of scale space information, so that the corner detection can be detected in different frequencies domain and different scales.

In Matrix M: $A=\cos^2(\theta)\left(G_1^x\right)^2$, $B=\sin^2(\theta)\left(G_1^y\right)^2$, $C=\sin(\theta)\cos(\theta)G_1^xG_1^y$.

4. Harris detection algorithm based on Multi–frequency domain and multi-scale

According to the analysis above, we extract feature of the corner points and its rotated image based on contourlet decomposition coefficient. Take the size of the sub-band and the "energy" of each directional for each scale as corner's feature vector, the detailed steps is as follows:

1. Normalized the image and remove its direct-current (DC) component, because the DC component existed in each decomposed layer during the contourlet decomposition process.

2. Decompose the pretreated image with contourlet decomposition. Decomposition method is: according to the order of high to low image resolution , the first layer is decomposed into 16 direction sub-band and second is decomposed into 8 , the third and fourth layer is decomposed into 4 and 3 directions sub-band respectively (excluding the low-frequency decomposition coefficients).

3. Obtain the corner response function of each pixel on each scale ,the response function is as follows:

$$C_\theta(x,y) = \det M_\theta - k\left(trace(M_\theta)\right)^2 \quad (7)$$

where, k is a constant.

4. Non-maxima suppress in each frequency domain on scale θ, obtain the local maxima value, and remove noised pseudo corner points (x, y) by threshold method, which must meet $C_\theta(x,y) > T$, and T is a nonnegative threshold and $C_\theta(x,y)$ is local maximum value.

5. The angle of the image decomposition can be set arbitrarily, so we can from 0 ° by decomposition scale to 180 ° according to certain numerical increments, find the image in which angle the energy reaches the maximum value, the point which meet $C_\theta(x,y) > T$ will be considered as candidate corner points, and then observed whether exist the local maxima under the neighbourhood closest, there are determined the point as corner point if exist the local maxima, otherwise, excluding the point.

5. Experimental results

Here, we obtain the corner position by corner response function (Eq.8) [7, 10].

$$C_\theta = \frac{\det(M_\theta)}{trace(M_\theta) + \varepsilon} \quad (8)$$

Compared with the response function referred in Harris corner detection (Eq.9),

$$C_\theta(x,y) = \det M_\theta - k\left(trace(M_\theta)\right)^2 \quad (9)$$

the function we used in this paper can avoid the eigenvalue decomposition calculation of M, and do not need to select the parameter k, which reduced the randomness of choosing k. Therefore, the response function adopted in this paper has more practical.

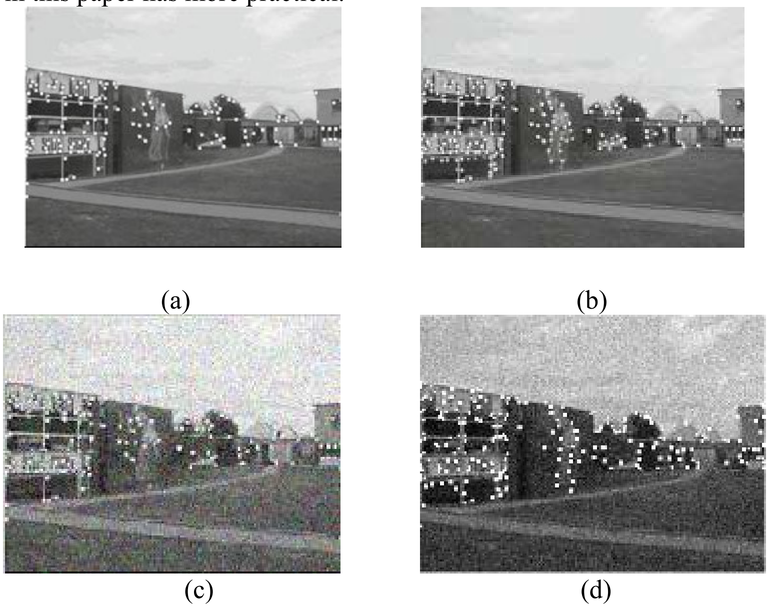

Fig.3. Corner points extracted by different algorithms

Table 1. Extracted number of the original image corners points

Detection algorithm	Accurate points	Undetected corner points	Pseudo corner points
Harris algorithm	180	42	25

Algorithm of this paper	203	4	10

Table 2. Extracted number of the noised image corners points

Detection algorithm	Accurate points	Undetected corner points	Pseudo corner points
Harris algorithm	198	31	32
Algorithm of this paper	212	3	18

The extracted corner point is shown in Fig.3 (a) according to Harris algorithm, while the new algorithm in this paper is shown in Fig.3 (b). The experimental results showed that the proposed algorithm in different frequency domain and different scale has accurate positioning and anti-noise ability. We can see clearly from (a), (b) and Table1 that many important corner points have lost by Harris algorithm, and the new algorithm in this paper can extract more effective corner point and accurate positioning. Then, we noised the image by Gaussian noise (σ =0．01), and extract the corner points by using the two methods mentioned above, the result are shown in Fig.3 (c), (d) and Table 2. Obviously, the new algorithm in this paper has strong anti-noise ability.

6. Conclusion

In order to overcome insufficient of single-scale Harris corner detection method, based on the multi-resolution analysis of the contourlet transform, this paper describes the direction features of the corner by using the contourlet decomposition. Adjust the number of iterations of the directional filter can control the detected angle easily.

Meanwhile, the paper defined a new image gray intensity formula, which can reflect the gray intensity change of the image in different frequencies and different scales, and obtain the corresponding autocorrelation matrix subsequently. Based on theory above, a new corner detection algorithm framework is built, namely Harris corner detection based on multi-scale.

At last, in order to take full advantage of the corner information in different scales, this paper put forward corner filter method on multi-scale. Simulation results show that the algorithm can accurately detect corners and precise positioning, and has better anti-noise ability.

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