Image Edge Detection Based on Rotating Kernel Transformation

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***Abstract*—An edge detection algorithm based on improved Rotating Kernel Transformation, IRKT edge detection method (IRKTE), is proposed in this paper. The algorithm adopt the line detection approach RKT, and defines a new model of edge detection according to the direction difference between edge and smooth regions. Simultaneously, an accurate edge location approach based on edge normal direction is presented to overcome the wide width caused by a large scale kernel in IRKT. Furthermore, the improvement of previous IRKT with weight edge detection (IRKTEW) is proposed to improve the ability to resist the noise effectively. A series of experiments are carried out through the picture libraries with ground truth and the performance is analyzed with ROC curves. The experimental results show that the proposed method can effectively detect the edge under the strong noises, and the performance of edge detection is improved with the proposed approach.**

Keywords: RKT，Edge detection，ROC

I. INTRODUCTION

Image edge detection is one of the hot issues in the field of image processing, the current classic methods of image edge detection include Roberts operator [1], Sobel operator [2], Prewitt operator [3], Kirsch operator [4], Log operator [5], Canny operator [6], and so on. These methods are all utilizing the maximum value of image gradient or the value of zero-crossing point in second derivative to detect edge, and then the convolution is performed by differential operator templates. But the classic image edge detection methods are sensitive to noise, and detecting the image edges is affected by noise interference meanwhile. Many novel methods have emerged in the area of edge detection technology, including the method based on the multi-scale wavelet [7], fractal theory method [8], the artificial intelligence algorithm [9], and so on. These methods are robust to noise and can detect the edges well, but they take a long time in the process of image edge detection.

In 1990, Lee and Rhodes proposed the rotating kernel transformation technique, which operates by filtering an image through multiple direction kernels, and retaining the largest filter output at each pixel [10]. Subsequently, they applied this method to the linear edge enhancement of noise images in 1995. The image is processed by this multi rotating kernels, effectively suppressing the image noises and preserving the linear image edges [11]. In 1999, the application of RKT for edge enhancement in medical ultrasonic image with noise was found by Czerwinski *et al* [12]. Jadwiga Rogowska *et al* utilized the rotating kernel technology for edge enhancement of OCT image [13] in 2000.And then, in 2013, Guo Qing *et al* redefined the model of rotating kernel, which makes RKT can be applied for edge detection [14]. Inspired by this multi direction kernel, an edge detection method is proposed based on IRKT In this paper. In order to strengthen the edge detection effect of the direction kernel, we put forward the rotating kernel based on weighted processed.

II. RKT LINE DETECTION AND EDGE ENHANCEMENT METHOD

The RKT technique works by convolving an image with a series of kernels, and selecting the maximum convolved result as output at each pixel. The convolution formula can be written as

$$D_\theta(x,y) = I(x,y) \bullet \mathrm{k}_\theta(x,y) \tag{1}$$

where I is the input original image, and k_θ is the kernel oriented at rotation angle θ. The maximum values can be computed over all the rotating kernels, and the output of image is defined as

$$P(x,y) = \text{maximum}\{D_\theta(x,y): 0 \le \theta < 360°\} \tag{2}$$

This RKT algorithm is inspired by the "rotation kernel min–max transformation" (RKMT) [11]. The difference is that the output of image in RKMT is defined as the arithmetic

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formula between the minimum and the maximum of D_θ, while it is only the maximum in RKT algorithm.

From the kernel form of RKT and the process of algorithm, the kernel model can be in response with a higher value based on the line in the image. When the image is proceed by RKT algorithm, the image can be enhanced while the noises get suppressed to some extent.

III. THE EDGE DETECTION BASED ON IRKT

The IRKT algorithm is inspired by the RKT technique which uses several direction kernels. It overcomes the problem that the RKT algorithm can only enhance the linear edge. According to the pixel's direction information, the IRKT algorithm can also solve the problem that the edge response range is large caused by the large scale kernel. Firstly, starting from the difference in the direction among the edge, the smooth regions and the noise points, the directional characteristic of the edge point is defined. Then, after rotation kernel transformation, the response value and variance of each pixel corresponding to each direction kernel can be obtained. The response values determine the direction of each pixel and the variance determines the edge point. Finally, according to the direction of each pixel, an edge detection result of single pixel response is obtained.

A. The definition of image edge based on the direction

In order to detect the image edge effectively, the definition of the difference between the edge and the non-edge must be clear. Based on the small scale kernel, the traditional gradient edge detection methods, results in a poor edge detection because of the similar response to the noise points and edges. From the point of view, the pixels on the edge have a specific direction in the local, and non-edge region including flat areas and the noise points does not have the direction. From this, the image edge can be defined as follows:

$$I_{edge}(x,y)=\begin{cases}1 & if\ I(x,y)\in Dir_i \\ 0 & if\ I(x,y)\notin \mathrm{Dir}_{\forall i}\end{cases} \tag{3}$$

where $I(x,y)$is the original image. And the different image direction is given a number, Dir_i refers to the Direction i. The equation (3) implies that, if a pixel in the original image can be classified in certain direction, it can be judged as an edge point; otherwise it can be judged as a non-edge point. In fact, there is some noise on the image edge, but it has little affect on judging the edge points from the local information. Also, it is related to the window size, which will be discussed later.

B. The edge detection method based on IRKT

The edge detection method based on IRKT as an example, to illustrate the process of edge detection algorithm. The direction number needing to count is known as $Ndir$; K is the size of kernel, here $K=(Ndri+2)/2$. In order to explain the process, look at $Ndir=8$, for example.

Step 1): generate the multi direction kernels according to the $Ndir$. Each kernel [14] is defined as $k_i(\mathrm{i}=1,2,\dots,8)$.

Step 2): execute convolutions to I with $k_i(\mathrm{i}=1,2,\dots,8)$ and get eight matrixes $M_i(\mathrm{i}=1,2,\dots,8)$ which have the same size with I. So each pixel of I know as $I(x,y)$ corresponds to eight values $M_i(\mathrm{i}=1,2,\dots,8)$ in the eight matrices.

Step 3): for the edge pixels, the value of response in one direction must be larger than the others, for example, Point A and B which are shown in Fig. 1.(b); for the non-edge pixels, the value in each direction has little difference, for example, Point C in Fig.1.(b). According to this characteristic, calculate the standard variation $\sigma(x,y)$ of the eight values $M_i(x,y)(\mathrm{i}=1,2,\dots,8)$, then obtain a standard variation of direction image S, which is shown in Fig.1(c). At the same time, select each pixel of the largest value among the eight values $M_i(x,y)$ corresponding to the eight direction kernels as the direction of this pixel. For example, the Point A in Fig. 1(b) is defined the direction for Dir_8.

Step 4): use maximum between-class distance to obtain the threshold T_σ of the variation image. Then the edge equation can be defined, as shown in equation (4).

$$I_{edge}(x,y)=\begin{cases}1 & if\ \ S(x,y)>\mathrm{T}_\sigma \\ 0 & if\ \ S(x,y)\le \mathrm{T}_\sigma\end{cases} \tag{4}$$

C. Based on the edge normal direction of single pixel response

Fig.1(d) shows that the edge detection method introduced in 3.2 has better anti-noise performance. This thanks to two aspects: 1) defined the edge in subsection *A*, to distinguish between edge and noise better. 2) Template with large scale kernel effectively reduces the noise affection. However, the large scale kernel causes large corresponding range of the edge. A method based on the edge normal direction of single pixel response is proposed to solve this problem.

According to the above definition of the direction kernel, the edge pixels on the corresponding direction kernel should have the largest response value and the corresponding standard deviation also be the largest. However, because of using the large scale direction kernel, there is a higher response in the neighborhood of the edge pixel. The result is shown in Fig.2. The Fig.2(a) is the direction standard variation image. Here, the standard variation of each pixel in the yellow box is shown in Fig.2(d); according to subsection *B*, Fig.2(b) is the edge detection result of the yellow box; Fig.2(c) is the defined direction of each pixel in (b),for example, 5 refers to the corresponding of the pixel direction is Dir_5.

At the confirmed image edge, the pixel that has the maximum standard deviation in the edge normal direction can be taken as the actual edge point, which is shown in Fig.2(d). The gray boxes are the final determination of the edge points. For example, the Dir_5 in those edge points, the vertical direction is Dir_1, and the brown line is its range. It is clear to that the edge points are always the maximum value in the range of normal direction. Through this method, the single pixel response result of edge detection can be obtained based on subsection *B*.

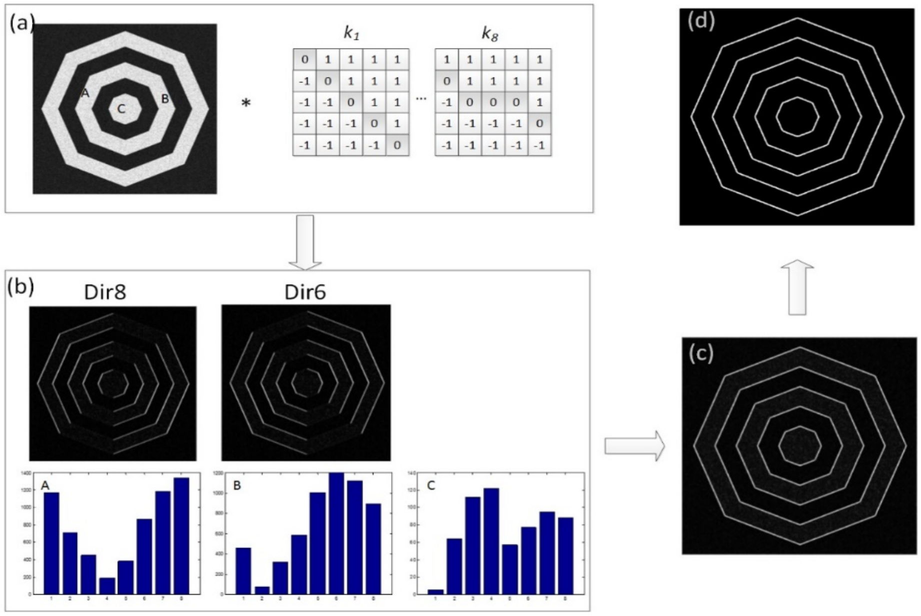
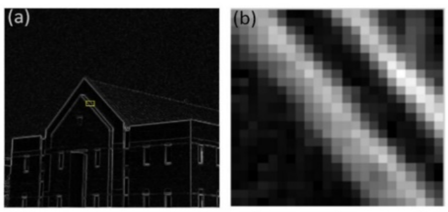


Fig. 1 The process of the edge detection based on IRKT, where (a) is the convolution between input image I and the eight kernels; (b) are the pixels corresponding to eight values from the result of convolution, using the points A, B, C as examples; (c) is the obtained standard variation of direction image S; (d) is the preliminary results of edge detection by setting a threshold for S.



(c)

5	5	0	0	0	0	0	0
5	5	0	0	0	0	0	0
6	5	5	0	0	0	0	0
5	5	5	5	0	0	0	0
0	4	5	5	5	0	0	0
0	0	5	5	5	5	0	0
0	0	6	6	6	5	0	0
0	0	0	6	6	6	6	0
0	0	0	0	6	6	5	6

(d)

252.36	190.27	102.39	37.52	26.83	20.39	38.39	74.66
238.99	218.45	164.50	75.02	32.87 Dir1	24.18	22.19	34.58
186.08	241.00	247.38 Dir5	166.89	74.29	35.09	18.67	19.94
190.78	211.62	273.09	234.55	151.67	89.90 Dir1	16.98	22.67
141.73	182.95	217.30	239.90 Dir5	212.37	130.56	34.75 Dir1	12.61
115.42	156.51	194.33	241.60	258.76 Dir5	212.89	119.18	81.54
80.88	120.18	176.28	218.92	254.28	227.72	138.02	75.51
43.91	80.78	149.49	186.16	226.31	257.21 Dir6	212.29	136.31 Dir2
44.39	75.15	129.25	161.79	185.58	232.15	237.04	185.49

Fig.2 (a) the direction of standard variation image; (b) the edge detection result of the yellow box; (c) the defined direction of pixels in (b), 5 refers to the corresponding of the pixel direction kernel is Dir_5; (d) the standard variation in the yellow box. Here, the gray boxes are the final determination of the edge points, the brown lines are the range of the corresponding normal direction.

D. The edge detection process based on weighted IRKT

It is similar to the method of defining the direction kernel in [14] that needs define the image direction using the multi-direction kernels. If we need to define Ndir directions, K is the size of kernel, then $K = (Ndir + 2)/2$. T is the weight of kernel, $T_{max} = (K - 1)/2$. In order to better explain the whole process, we take the $Ndir = 8$ as example. The size of kernel is $K = 5$ and the weight $T_{max} = 2$. The eight direction kernels are defined as shown in Fig.3. The more defined direction of the image, the larger size of the window. At the same time, the vertical direction of the defined direction Dir_i is $Dir_{(i+\frac{Ndir}{2})}$. For example, in Fig.3, Dir_1 and Dir_5 are orthogonal.

k_1

1	1	1	1	1
2	2	2	2	2
0	0	0	0	0
-2	-2	-2	-2	-2
-1	-1	-1	-1	-1

k_2

2	1	1	1	1
0	2	2	2	1
-2	0	0	0	2
-1	-2	-2	-2	0
-1	-1	-1	-1	-2

k_3

0	2	1	1	1
-2	0	2	2	1
-1	-2	0	2	1
-1	-2	-2	0	2
-1	-1	-1	-2	0

k_4

-2	0	2	1	1
-1	-2	0	2	1
-1	-2	0	2	1
-1	-2	0	2	1
-1	-1	-2	0	2

k_5

-1	-2	0	2	1
-1	-2	0	2	1
-1	-2	0	2	1
-1	-2	0	2	1
-1	-2	0	2	1

k_6

-1	-1	-2	0	2
-1	-2	0	2	1
-1	-2	0	2	1
-1	-2	0	2	1
-2	0	2	1	1

k_7

1	1	1	2	0
1	2	2	0	-2
1	2	0	-2	-1
2	0	-2	-2	-1
0	-2	-1	-1	-1

k_8

1	1	1	1	2
1	2	2	2	0
2	0	0	0	-2
0	-2	-2	-2	-1
-2	-1	-1	-1	-1

Fig.3 when $Ndir = 8$, the eight defined direction kernels

The process of edge detection is similar to the description in subsection B. The only different is that convolution kernel in subsection B replaced by the weighted rotating kernels above.

IV. EXPERIMENTS AND ANALYSIS

This section illustrates the size or orientations of selected kernels' influence on extracting edge information from an image. Then we utilize the most commonly used test images to make a comparison between IRKT and weighted IRKT.

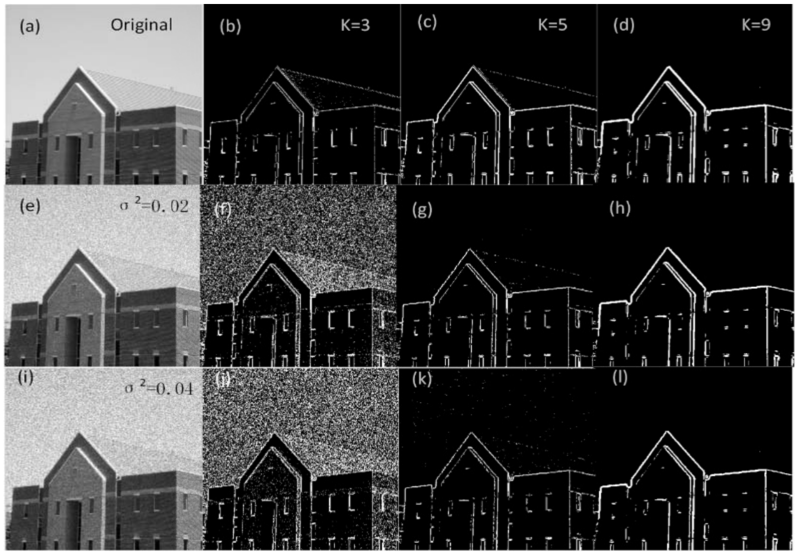


Fig.4 results of edge detection using different kernel size under different variance of noise. (a)~ (d) shows the detection results with unpolluted image using multi-scaled oriented kernels. (e) ~ (h) and (i) ~ (l) shows the detection results using multi-scaled oriented kernels under speckle noise with variance of 0.02 and 0.04 respectively.

A. Selection of kernel size

A standard test image is polluted by speckle noise of different degree. Then three kernels of different size are used to handle these polluted images, the experiment results is shown in Fig. (4). From these results, it is obvious that when an image is not polluted, IRKT algorithm can always get a superior detection result from a single pixel's response, no matter what the kernel's size is. But since the size becomes large, partially of the detailed information was missed, see from Fig.4(a) ~ (d). For a polluted image, the robustness to noise is improved with the increasing kernel size, see from Fig.4(e) ~ (l). So, when the image is seriously polluted, large scale kernel is needed to get a more reasonable result. This is cause by the fact that under serious pollution, some edge information is covered by noise, and this is unrecoverable. The goal is to get effective edge information from the seriously polluted image.

B. Comparison between IRKT and weighted IRKT algorithm

Variant images are used for a visual and quantitative comparison between IRKT algorithm and weighted IRKT algorithm [15].

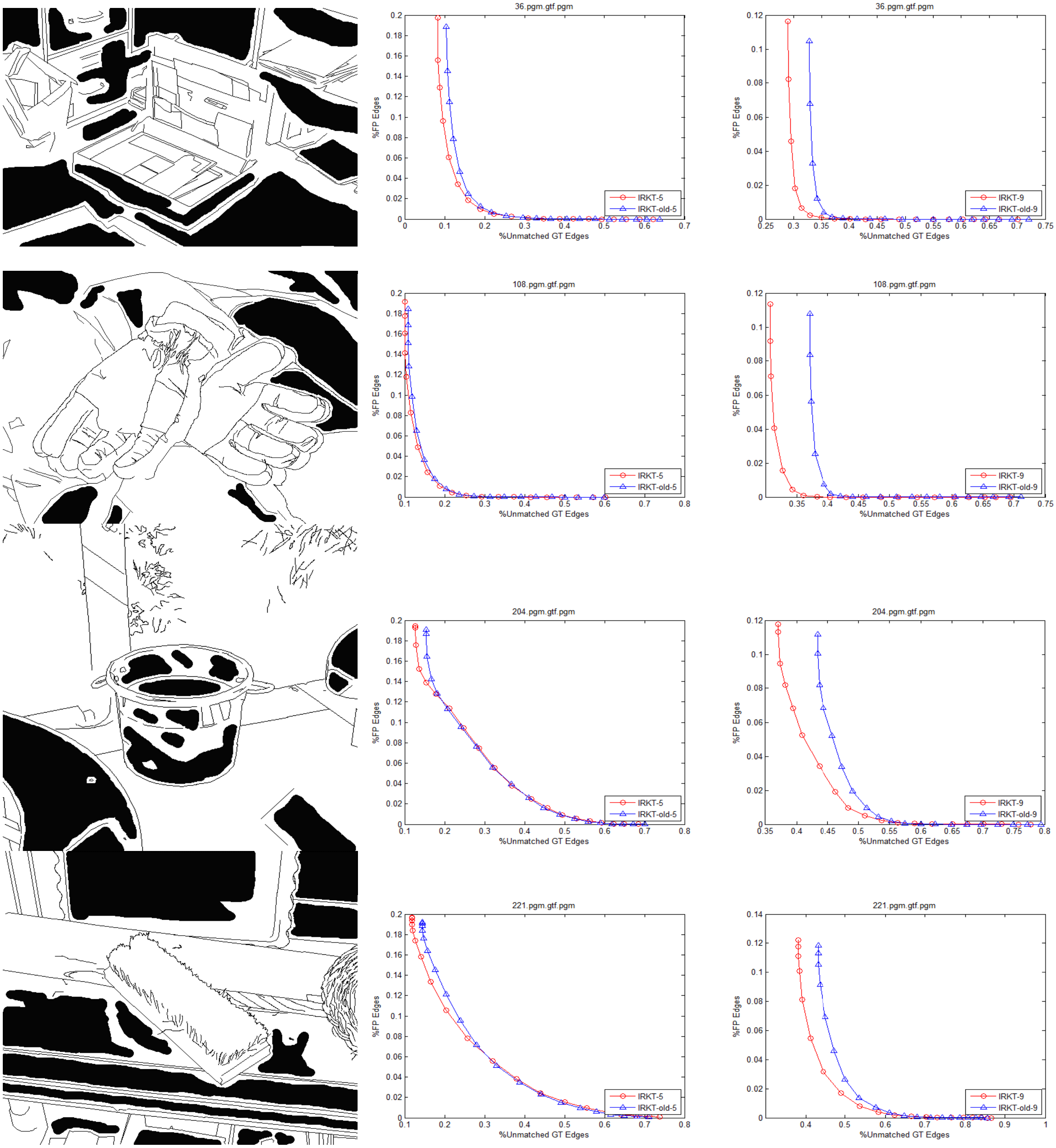
The visual comparison is shown in Fig.5. Fig.5(a) depicts an image polluted by speckle noise with a variance of 0.04. The edge detection results illustrate that both IRKT and weighted IRKT can find the edge of test image under serious pollution. And the detected edge is smooth and the response width is narrow.

Quantitative comparison is carried out by plotting ROC curves to evaluate the algorithm's performance [15], the results is shown in Fig.6. As is depicted in Fig.6, IRKT algorithm has a superior in edge detection, while weighted IRKT outperforms in the accuracy of detection results.

Fig 5. edge detection results of IRKT and weighted IRKT. (a) shows the image polluted by speckle noise with a variance of 0.04. (b) is the detection results of IRKT with K=9. (c) is the detection results of weighted IRKT with K=9.

V. CONCLUSION

A new idea of edge detection based on orientation is proposed in this paper, by utilizing multi-orientated and large scale oriented kernels, a new edge detection model is formed. The problem of large response scope of edge detection when using large kernels is solved by seeking for the maximal



(a) (b) (c)

Fig. 6 ROC curves of edge detection using IRKT and weighted IRKT. (a) shows the truth image. (b) (c) shows the edge detection using IRKT and weighted IRKT with K=5 and 9, respectively. The red circle represents weighted IRKT, and the blue triangle stands for IRKT.

transformation response on the law direction of edge. Experiment results illustrate the relationship between the selected kernel scales and the image noise, and the weighted IRKT algorithm is more accurate on the edge detection.

However, there still exist some drawbacks which can be improved in the future. Firstly, the computation of algorithm is slow, this is mainly caused by adopting multiple large scale kernels to convolve with the image, and by using maximal space method to determinate the threshold of oriented standard deviation chart. Secondly, the orientation information of pixel is not fully used, we can still use orientation information to restrain non-edge pixel and noisy pixel, and connect the disconnected edge.

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