Edge Connection Based Canny Edge Detection Algorithm[1]

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Abstract—Double threshold method of traditional Canny operator detects the edge rely on the information of gradient magnitude, which has a lower edge connectivity and incomplete image information. Aiming at this problem, we proposed an edge detection algorithm based edge connection—the Hough Transform based Canny (HT-Canny) edge detection algorithm. HT-Canny algorithm guided by high threshold image, which obtains edge direction through calculating edge endpoint gradient and connects the edge by using the Hough Transform instead of traditional double threshold method. It avoids the limitation of traditional Canny algorithm, which must set the double threshold manually and protect the low intensity edge especially. The experimental results show that HT-Canny algorithm has stronger edge connectivity and can distinguish edge points and non-edge points effectively, which not only retain the advantages of the traditional Canny algorithm but also make the detection result more complete and comprehensive.

Keywords: edge detection, Canny operator, gradient direction, Hough transform

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1. INTRODUCTION

Image edge is the collection of gray value dramatic change pixel in image, which is the basic characteristic of the image [1]. Edge detection is the first step of image processing, its detection result will affect the image analysis and recognition directly, therefore edge detection research has the vital significance [2]. Traditional edge detection operators are the Roberts operator, the Prewitt operator, the Sobel operator and the LOG operator [3, 4]. These operators view the maximum value of the first derivative or zero crossing of the second derivative as candidate edge point, then set the gradient magnitude value as threshold to extract the edge information. But differential operation is very sensitive to noise, besides the edge position accuracy is poor and rarely used in the practical engineering. In 1986, Canny proposed the Canny edge detection algorithm and has been widely used [5].

Compared with other conventional edge detection algorithm, the Canny operator based on the optimization algorithm has the best performance, but the defect has not yet been entirely solved. Because the double threshold method of Canny algorithm has poor adaptability, so the edge detection information is incomplete. In recent years, various scholars proposed many revised Canny algorithm. For example, Chao et al. [6] use Qtsu method to set high and low thresholds automatically in the process of edge detection and connection. Danyang et al. [7] proposed a new edge linking method based on edge contrast features and edge direction. Zhi et al. [8] divided image into sub-images and detect them with adaptive threshold value according to the whole image edge information. But these improved algorithm do not solve the low intensity edge detection problem, and the continuity and integrity of the edge detection is not satisfied. Therefore, we proposed the Hough transform based Canny (HT-Canny) algorithm for edge detection. HT-Canny algorithm designed an edge connection method based on gradient direction and Hough transform, improved the edge connectivity of Canny algorithm and distinguished real edge points effectively. Experiment results also verify the feasibility and effectiveness of the HT-Canny.

The rest of paper is structured as follows. Section 2 discusses traditional Canny edge detection algorithm, Section 3 describes the HT-Canny operator and Section 4 demonstrates its performance. Finally, Section 5 summarizes the conclusions.

2. TRADITIONAL CANNY EDGE DETECTION ALGORITHM

Traditional Canny algorithm use Gaussian function firstly to smooth the image, calculate image gradient magnitude and direction for de-noising image, then non-maxima suppression according to gradient direction to get unilateral edge response, finally use double threshold method to detect and connect edge [9, 10].

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2.1. Image Smooth

In order to reduce the noise influence, the first step of traditional Canny algorithm is to smooth image. Canny operator carries on the filtering to image with two-dimensional Guassian function. Guassian function is defined as:

$$G(x,y) = \frac{1}{2\pi\sigma^2}\exp\left(-\frac{x^2+y^2}{2\pi\sigma^2}\right), \quad (1)$$

where σ is the space scale coefficient of Guassian filter, and it controls the extend of smoothing image. Filter whose σ is smaller has higher position accuracy, but lower signal-noise ratio. Filter whose σ is bigger is just the opposite. Therefore, we should select appropriate Gaussian filter parameter according to the need.

2.2. Gradient Calculation

The second step is to calculate the gradient magnitude and gradient direction. Canny algorithm adopts finite difference of 2×2 neighbouring area to calculate gradient magnitude and gradient direction, getting the corresponding gradient magnitude image G and gradient direction image θ. For pixel $I(i, j)$, the first order partial derivatives in the directions of x and y can be got from following formulas, respectively:

$$G_x(i,j) = (I(i+1,j) - I(i,j) + I(i+1,j+1) - I(i,j+1))/2, \quad (2)$$

$$G_y(i,j) = (I(i,j+1) - I(i,j) + I(i+1,j+1) - I(i+1,j))/2. \quad (3)$$

At this time, the gradient magnitude and gradient direction are:

$$G(x,y) = \sqrt{G_x^2(i,j) + G_y^2(i,j)}, \quad (4)$$

$$\theta(i,j) = \arctan\left[\frac{G_y(i,j)}{G_x(i,j)}\right]. \quad (5)$$

2.3. Non-maxima Suppression (NMS)

After acquired the gradient magnitude image G and gradient direction image θ, in order to get accurately position and unilateral edge, it's need to perform non-maximum suppression. Canny algorithm uses 3×3 neighboring area which consists of eight directions to execute interpolation to the gradient magnitude along gradient direction. The non-maximum suppression process select edge point through judging whether the gradient magnitude of every point along gradient direction is maximum within its eight neighboring area. If the magnitude $G(i, j)$ is bigger than the two interpolation results on the gradient direction, it will be marked as candidate edge point, otherwise it will be marked as non-edge points.

2.4. Edge Detection and Connection

After carrying on non-maximum suppression, the Canny algorithm adopts double threshold method to detect and connect edge points. The double threshold method has high threshold and low threshold. The pixels whose gradient magnitude is above the high threshold will be marked as edge point, and those whose gradient magnitude is under the low threshold will be marked as non-edge points. The edge detection result is discontinuous after this process. In order to get continuous edges, the rest points which are connect with edge points will be marked as edge points.

3. HOUGH TRANSFORM BASED CANNY OPERATOR

Traditional Canny operator uses the gradient magnitude to identify edge, when edge contrast ratio of the detected image is weak, it is easily to loss low intensity edge. For instance, the grads histogram of the Lena image is shown in Fig. 1. From the grads histogram, we can see that image gradient magnitude is mostly concentrated in the 0 to 50. If using traditional double threshold method to detect and connect edge, we unable to set appropriate threshold to distinguish edge points availably, and lose low intensity edge. Therefore, the traditional double threshold method becomes the performance bottleneck of Canny algorithm. Therefore, we proposed Hough transform based Canny (HT-Canny) operator to image edge detection.

The HT-Canny algorithm introduced edge connection method based on gradient direction and Hough transform to replace the double threshold method. Firstly, we use the high threshold image as guide. Then we use the edge direction of high threshold image to connect the edge. When the gray difference between pixel and endpoint are less than fixed value and, in the same time, Hough transform determine those pixels are collinear, we connect those pixels as edge points.

3.1. Edge Endpoint

In the traditional Canny edge detection algorithm, if the gradient magnitude of one point is greater than the high threshold, the point will be regarded as the edge point. Therefore, in the HT-Canny, the points whose gradient magnitude is larger than the high threshold are also marked as edge point. After this process, we get the high threshold image.

The edge endpoint is defined as eight neighboring area has only an edge point or two adjacent edge point in high threshold image [7]. For instance, in Fig. 2, the eight neighboring area of point A has only an edge point, so point A is an endpoint. The eight neighboring area of point B has two adjacent edge point, so point B is also an endpoint. Because endpoint is the

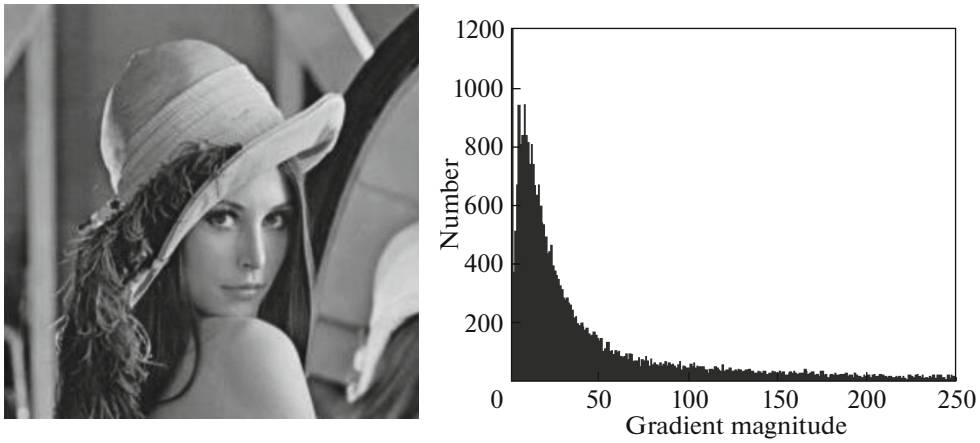

Fig. 1. Grad histogram.

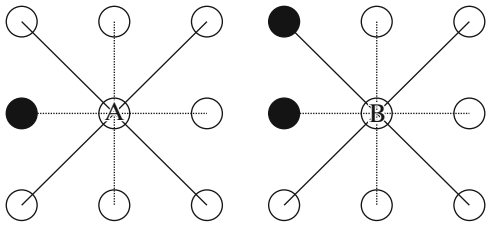

Fig. 2. Example of edge endpoints.

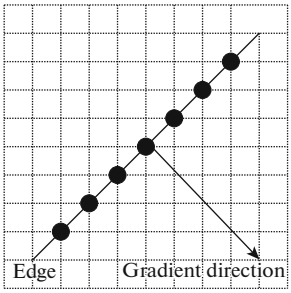

Fig. 3. Gradient direction.

gap of the edge, so we connect the edge based on endpoint information.

3.2. Edge Connection

Pixel gradient direction refers to the violent direction of the gray change. As shown in Fig. 3, the gradient direction perpendicular to the edge direction, so we can get the edge direction according to the gradient direction.

Because there are two possible directions for each edge, so we determine edge connection direction according to the location of edge points in the 8 neighbouring area of edge endpoint. We define the opposite direction of edge points in the neighbouring area as edge connection direction. The selection of edge connection window selection is shown in Fig. 4, the black points are the edge points and the dots are the edge connection window for Hough transform. If current endpoint gradient direction complies $-10° \le \theta(i, j) \le 10°$, we view current edge as vertical, so we select horizontal edge connection window. If current endpoint gradient direction complies $-90° \le \theta(i, j) \le -80°$ or $80° \le \theta(i, j) \le 90°$, we view current edge as horizontal, so we select vertical edge connection window. When excess points participate in the calculation, Hough transform will detect the fake edge, so we all select 5 × 5 edge connection window.

Because the adjacent edge points have the similar edge direction, while noise points do not have the feature. So, same direction points in edge connection window represent current edge direction and those points can be connected as edge. In this paper, we use Hough transform to look for the collinear points. The Hough transform has been the most popular detection method to geometric figure, such as straight lines, circles, ellipses [11–13]. Because the collinear points in image space mapped into intersecting curve in the parameter space after Hough transform, so we can transform the line detection into point detection. In the xy plane, the straight line equation of the point (x, y) in slope-intercept form is:

$$y = kx + b, \tag{6}$$

where k is the slope of the straight line, b is the intercept of the line on the y axis. Due to the vertical line slope problem, the parameter equation in polar coordinates form is expressed as:

$$\rho = x\cos\theta + y\sin\theta, \tag{7}$$

where ρ is the distance from the origin of the image to the line, θ is the angle between the linear normal and x axis.

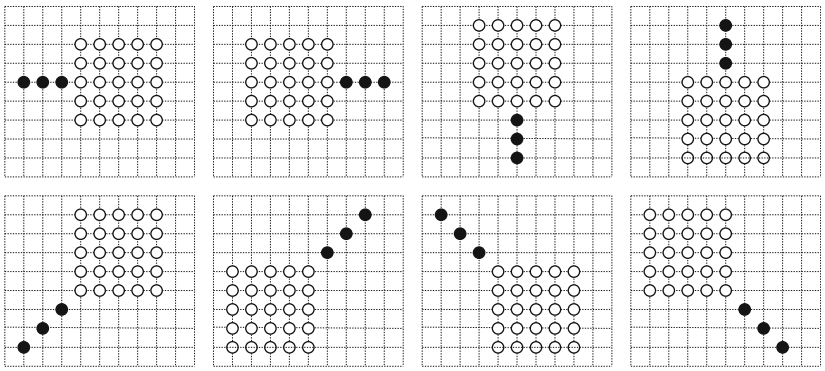

Fig. 4. Edge connection window selection.

The process of Hough transform. Discretize the scope of θ and ρ value, and set a corresponding 2D accumulator array in parameter space. To each pixel, using the equation expressed in Eq. (7) to calculate p value with a change in the succession of 9 in the parameter space, then looks for the accumulator's cells that the (ρ, θ) value fall into and let the cell value increase 1. After all pixels have been accumulated, find the local maxima (ρ, θ) value in accumulator array. The local maxima (ρ, θ) value represent the most likely straight line in image space, so we can obtain the collinear pixels and connect as edge points. Due to the adjacent edge points have the similar gradient magnitude, so HT-Canny algorithm only let the points whose the gradient magnitude difference with edge point less than fixed value to participate in Hough transform.

The process of HT-Canny. (1) Set the point of high threshold as the edge point and get the high threshold image. (2) Look for the edge endpoints in the high threshold image. (3) Select edge connection window according to the gradient direction of edge endpoint and the location of edge point in 8 neighboring area. (4) Do Hough transform to edge connection window, and set the pixel value of collinear point as 255 to link it as edge.

4. EXPERIMENT

We evaluate the performance of HT-Canny by comparing HT-Canny with the traditional Canny operator and the algorithm in literatures [6, 7]. The algorithm in [6] uses Qtsu method to get double thresholds automatically. The algorithm in [7] links edge according to the similarity of edge contrast features and edge direction. Edge detection experiments were carried out on the Lena image, cameramen image and transmission line image.

4.1. The Edge Detection Result and Analysis

The traditional Canny operator, algorithms in literatures [6, 7] and the HT-Canny operator were employed as the edge detection algorithm, respectively. The simulation results are shown in Figs. 5 and 6. From Figs. 5 and 6, we make the following conclusions:

(1) Traditional Canny algorithm lost a lot of edge information. In Lena image, people contour are missed and the left line appeared jagged. In Cameraman image, the right edge of building is missed.

(2) From Figs. 5b–5e we can see that, although the algorithms in literatures [6, 7] also obtained more edge information than traditional Canny algorithm, but the HT-Canny algorithm gained more complete edge (as red ellipses show in Fig. 5).

(3) From Figs. 6b–6e we can see that, the simulation results of the algorithms in literatures [6, 7] and HT-Canny algorithm are almost the same. HT-Canny was verified more continuity and has better unilateral edge response by the edge detection statistical criterion in [16].

In general, high voltage transmission lines are far away from traffic towns. In order to ensure the security operations of high voltage transmission lines, conducting transmission lines detection in images is necessary [14, 15]. In this paper, HT-Canny algorithm is used in transmission line image detection. The detection result is shown in Fig. 7. From the detection results, we can conclude that HT-Canny algorithm gained more clean and complete edge information than the rest of three algorithms.

4.2. The Statistical Criterion of Edge Detection Algorithms

Lin et al. [16] proposed an edge detection statistical criterion. Firstly, the criterion count the total number of detected edge points A, four connection component B and eight connection component C, then calculate the ratio of C/A and C/B. Finally, the ratio is compared with the original algorithm to give the evaluation results. The smaller C/A value, the more continuity. The smaller the C/B value, the better unilateral edge

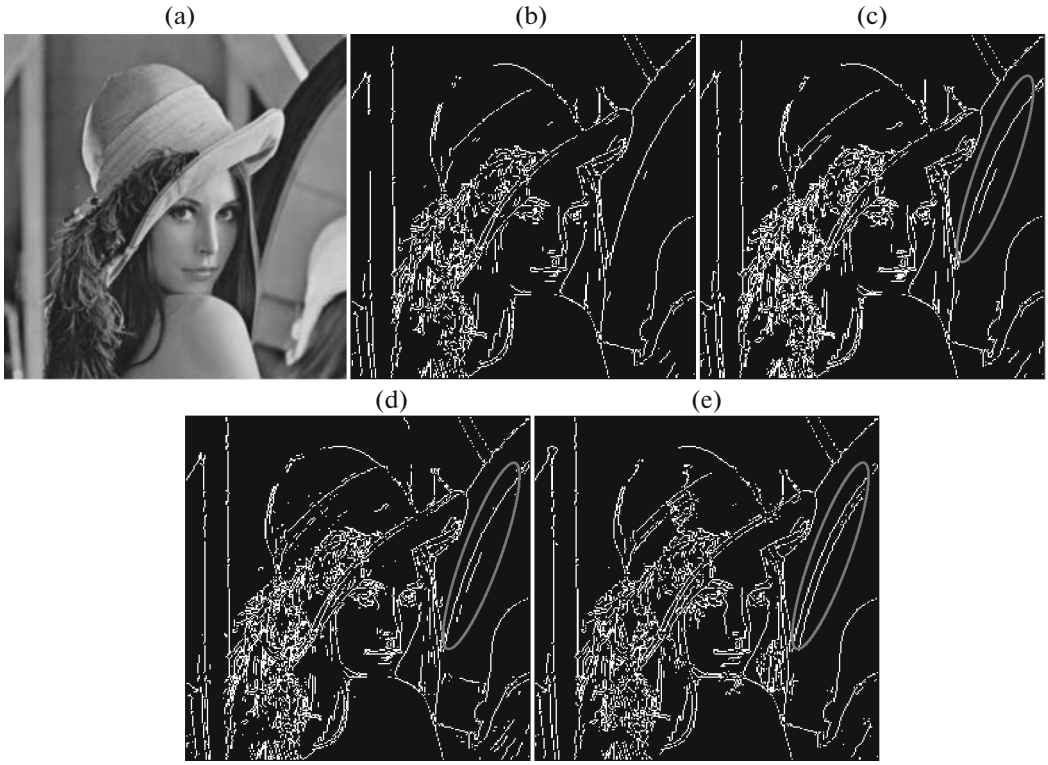

Fig. 5. Edge detection results of Lena image: (a) Lena image, (b) traditional Canny, (c) algorithm in [6], (d) algorithm in [7], (e) HT-Canny.

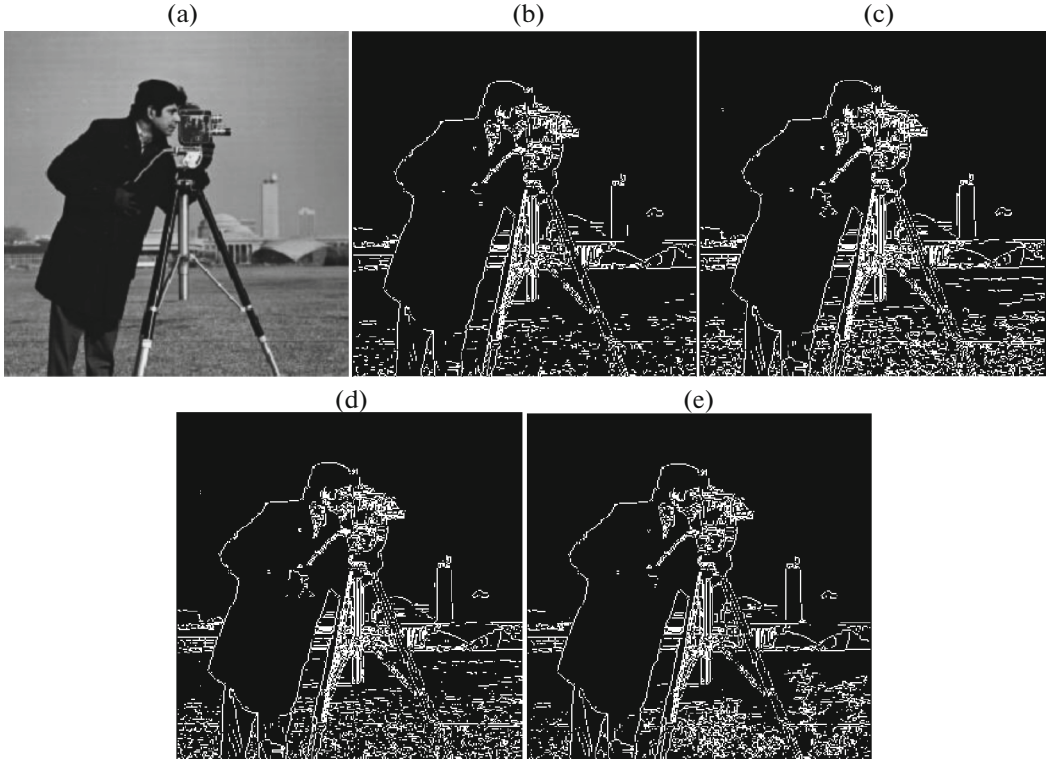

Fig. 6. Edge detection results of Cameramen image: (a) Lena image, (b) traditional Canny, (c) algorithm in [6], (d) algorithm in [7], (e) HT-Canny.

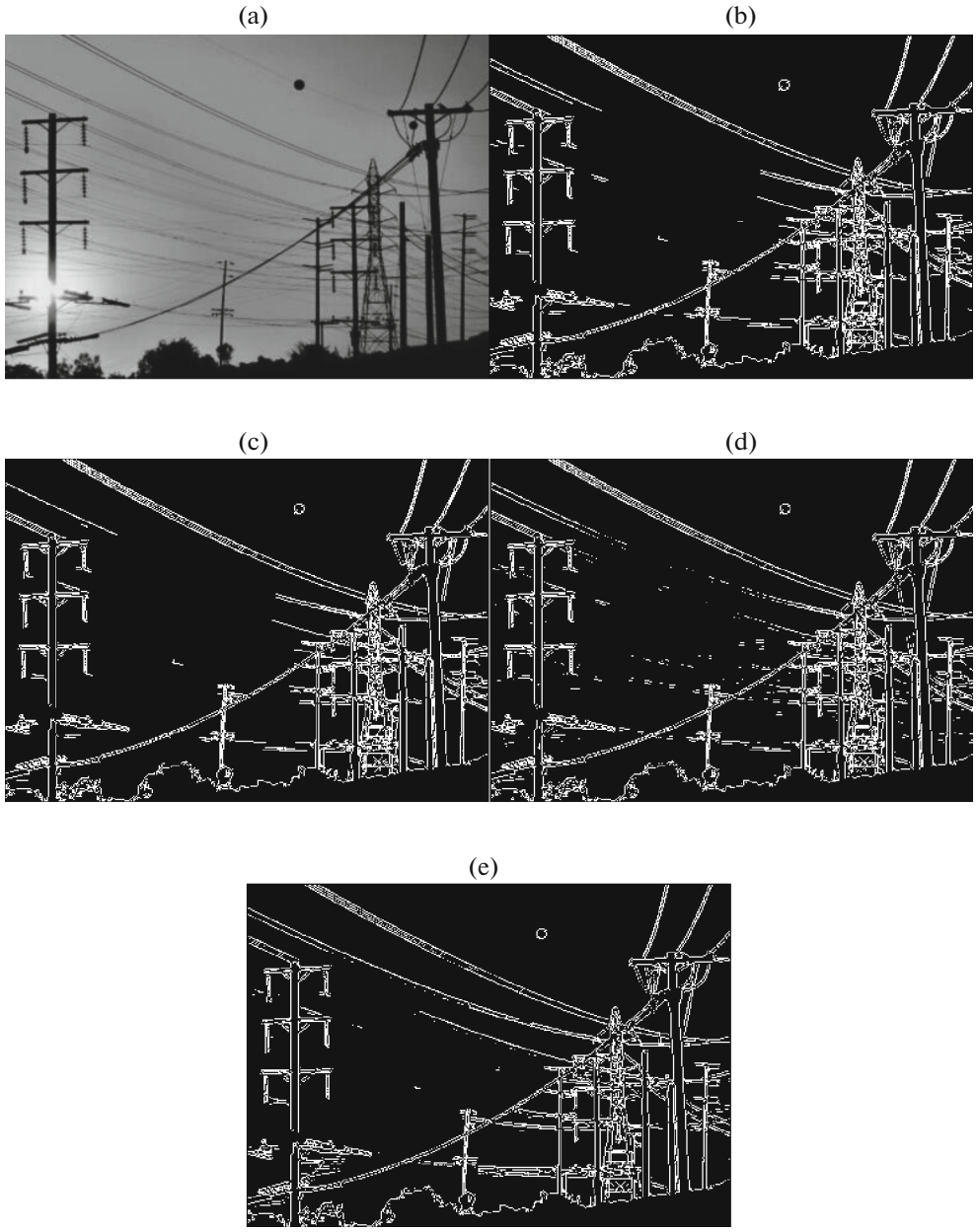

Fig. 7. Edge detection results of transmission line image: (a) transmission line image, (b) traditional Canny, (c) algorithm in [6], (d) algorithm in [7], (e) HT-Canny.

response. The statistical results of the four algorithms are shown in Tables 1–3.

From Tables 1–3, we can see the following.

(1) The C/A, C/B value of the HT-Canny algorithm is less than the rest of algorithm's C/A and C/B value.

(2) Because the smaller C/A value, HT-Canny algorithm has obvious improvement in edge connectivity and gets more comprehensive edge information, and it can distinguish edge points and non-edge points effectively.

(3) In the case of better detection results than algorithms in [6, 7], edge points detected by the HT-Canny less than edge points detected by algorithms in [6, 7] (Tables 1–3 C/B value) due to the HT-Canny has better unilateral edge response.

5. CONCLUSIONS

In this paper, we proposed an edge connection based edge detection algorithm—the Hough transform based Canny (HT-Canny) algorithm. HT-Canny algorithm introduced gradient direction and Hough

Table 1. Statistical results of Lena image

Algorithm	A	B	C	C/A	C/B
Canny	5176	398	65	0.0126	0.1633
Ref. [6]	6426	778	156	0.0243	0.2004
Ref. [7]	6425	616	114	0.0177	0.1851
HT-Canny	6257	418	55	0.0088	0.1316

Table 2. Statistical results of Cameramen image

Algorithm	A	B	C	C/A	C/B
Canny	6390	947	320	0.0501	0.3379
Ref. [6]	9004	1458	474	0.0526	0.3251
Ref. [7]	8394	1238	412	0.0491	0.3328
HT-Canny	7798	1074	318	0.0408	0.2961

Table 3. Statistical results of transmission line image

Algorithm	A	B	C	C/A	C/B
Canny	11466	2014	656	0.0572	0.3257
Ref. [6]	11193	2011	656	0.0586	0.3262
Ref. [7]	11552	1759	552	0.0478	0.3138
HT-Canny	10685	1143	315	0.0295	0.2756

transform replaced traditional double threshold method to detect and connect the edge image. Experimental results show that HT-Canny not only maintain the advantages of traditional algorithm but also detect more low intensity edge and reflect the image details comprehensively. Especially, HT-Canny algorithm has stronger practicability for transmission line image detection.

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