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Edge Connection based Canny Edge Detection Algorithm

Renjie Song[1], Ziqi Zhang[2*], Haiyang Liu[3]

[1,2]Department of Information Engineering, Northeast Electric Power University, Jilin 132012, China
[3]State Grid Jilin Electric Power Co.,Ltd. Jilin power company, Jilin 132012, China
*Corresponding Author: 975312621@qq.com
[1]1939811347@qq.com

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Abstract. *The traditional Canny operator's double threshold method only detects the edge based on the gradient magnitude information, which causes the poor edge connectivity, and the 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. The HT-Canny algorithm takes the high threshold image as the guide, obtains the edge direction by calculating the edge endpoint gradient, and then uses the Hough transform instead of the traditional double threshold method to connect the edge, which effectively protects the low intensity edge and avoids the limitations of the Canny algorithm that must manually set the double threshold. The experimental results show that the HT-Canny algorithm can effectively distinguish the edge point and the non-edge point, not only retains the superiority of the traditional Canny algorithm, but also make the detection results more complete and comprehensive.*
Keywords: Edge detection, Canny operator, Gradient direction, Hough transform.

1. **Introduction.** The edge of image is a collection of pixel points where the gray scale of the image changes dramatically, which is one of the basic characteristic of the image[1]. Edge detection is the first step in image processing, its detection result will directly affect the image analysis and recognition, therefore the edge detection research has the vital significance[2]. The traditional edge detection operator has Roberts operator, Prewitt operator, Sobel operator and LOG operator[3,4]. These operators view the maximum value of the first derivative or the zero crossing of the second derivative as candidate edge point, then set the gradient magnitude value as threshold to extract the edge information. However, the difference operator is more sensitive to noise, and the edge location is not accurate enough to make it used in practical engineering. Therefore, Canny in 1986 proposed the Canny edge detection algorithm, and has been widely used[5].

Compared with the conventional edge detection algorithm, Canny operator based on the optimization algorithm has better performance, but its shortcomings have not yet been entirely solved. Because the Canny algorithm's double threshold method has poor self-adaptability, so the edge detection information is incomplete. In recent years, various scholars have proposed many revised Canny algorithms. For example, Liu et al. used Otsu method to automatically obtain high and low thresholds in the process of edge detection and connection[6]. Qi et al. proposed a method of edge connection based on edge contrast features and edge direction[7]. When edge points and candidate edge points have the similar edge contrast features and edge direction, connect them as edges. Wang et al. divided image into several regions and then use adaptive threshold to detect the edge according to the image information[8]. However, the above algorithm does not solve the problem of low intensity edge detection, the continuity and integrity effect is not ideal. 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. Compared with the traditional algorithm, HT-Canny algorithm can effectively detect low intensity edge, and do not need to manually set the double threshold, improve the edge connection capability of Canny algorithm. 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 firstly uses Gaussian function to smooth the image, and then calculates image gradient magnitude and direction of the de-noising image, performs the non-maxima suppression according to gradient direction to obtain unilateral edge response, and finally uses double threshold method to detect and connect edge[9-10].

(1) Image smooth

To reduce the effects of noise, Canny operator first uses Guassian function to convolve to smooth the image. The Guassian function is defined as:

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

Where σ is the space scale coefficient of Guassian filter, and it controls the extension of smoothing image. When the value of σ is small, the filter has high positioning accuracy, but the signal-noise ratio is low. When the value of σ is large, it is just the opposite. Therefore, we should select appropriate Gaussian filter parameters according to the need.

(2) Gradient calculation

The traditional Canny algorithm adopts finite difference of 2×2 neighbouring area to calculate gradient magnitude and gradient direction to obtain the corresponding gradient magnitude image G and gradient direction image θ. The first order partial derivatives in the directions of x and y can be got from following formulas respectively:

$$G_x(i,j) = (I(i+1,j) - I(i,j) + I(i+1,j+1) - I(i,j+1))/2 \tag{2}$$

$$G_y(i,j) = (I(i,j+1) - I(i,j) + I(i+1,j+1) - I(i+1,j))/2 \tag{3}$$

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

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

$$\theta(i,j) = arctan[\frac{G_y(i,j)}{G_x(i,j)}] \tag{5}$$

(3) Non-maxima Suppression (NMS)

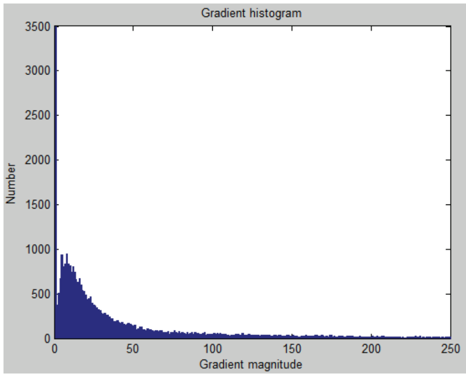
In order to get accurately position and unilateral edge, the smoothed image requires non-maximum suppression. Canny algorithm uses 3×3 neighboring area which consists of eight directions to execute interpolation to the gradient magnitude along gradient direction. The non-maximal suppression process selects the edge points by determining whether the gradient magnitude of each pixel is the maximum of its 8 neighboring area in the gradient direction. If the gradient magnitude G(i,j) is greater than the two interpolation in the gradient direction, the pixel will be marked as candidate edge point, otherwise it will be marked as non-edge points.

(4) Edge detection and connection

The Canny algorithm adopts double threshold method to detect and connect edge after carrying on non-maximum suppression. The double threshold method first sets the high and low thresholds. If the gradient magnitude of the pixel is greater than the high threshold, the point will be treated as edge point, and if the pixel gradient magnitude is less than the low threshold, the point will be treated as non-edge points. The edge detection results are 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 algorithm only determines the edge point based on the gradient magnitude information. When the edge contrast ratio of the detected image is weak, the low intensity edge is easy to leak. For instance, the gradient histogram of the Lena image is shown in Figure 1. From the gradient histogram, we can see that gradient magnitude is mostly concentrated between 0 and 50. If using traditional double threshold method to detect and connect edge, we unable to set appropriate threshold to effectively distinguish edge points, and easy to lose low intensity edge. The traditional double threshold method has become the performance bottleneck of Canny algorithm. Therefore, we propose Hough Transform based Canny (HT-Canny) operator for image edge detection.

(a)



(b)

FIGURE 1. Gradient histogram

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 the guide, and then select the edge connection window according to the gradient direction of the edge endpoint. When the gradient magnitude of the pixel is close to the endpoint, in the same time, Hough Transform determines it is collinear, we connect the pixel as edge point.

3.1. **Edge Endpoint.** The traditional Canny edge detection algorithm regards the point where the gradient magnitude is greater than the high threshold as the edge point. In the HT-Canny, we use Otsu method to automatically obtain high threshold. The points whose gradient magnitude is greater than the high threshold are marked as edge points. The points whose gradient magnitude is less than the high threshold are marked as candidate edge points.

For edge points, if there are only one edge point or two connected edge points in its 8 neighboring area, we see it as edge endpoints[7]. For instance, in Figure 2, the black

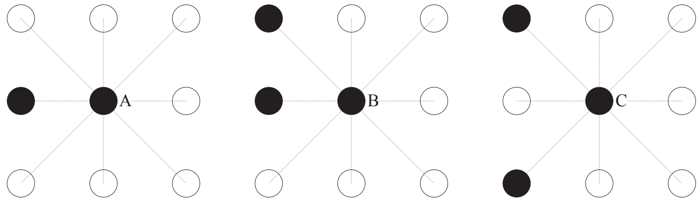


FIGURE 2. Example of edge endpoints

points represent the edge points and the dots represent the candidate edge points. The 8 neighboring area of point A has only one edge point, so point A is the edge endpoint. There are two connected edge points in the 8 neighboring area of point B, while point C has two non-connected edge points, so the point B is the edge endpoint and the point C is not the edge point.

3.2. **Edge Connection.** Because edge endpoint is the gap of the edge, so we connect the edge relies on endpoint information. Pixel gradient direction refers to the direction in which the gradient direction changes drastically. As shown in Figure 3, the gradient direction is perpendicular to the edge direction, so we can get the edge direction according to the gradient direction.

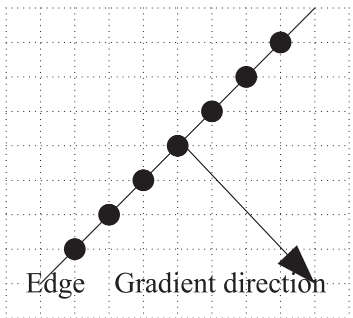


FIGURE 3. Gradient direction

Since each edge has two possible directions, we determine edge connection direction according to the position of edge points in the edge endpoint's 8 neighbouring area. The opposite direction of edge points is regarded as the edge connection direction. The edge connection window selection is shown in Figure 4, where the black points are the edge points and the dots are the edge connection window for Hough Transform. If current endpoint gradient direction complies $-10^\circ \leq \theta(i,j) \leq 10^\circ$, the edge direction is considered vertical and the horizontal edge connection window is selected. If current endpoint gradient direction complies $-90^\circ \leq \theta(i,j) \leq -80^\circ$ or $80^\circ \leq \theta(i,j) \leq 90^\circ$, the edge direction is considered horizontal and the vertical edge connection window is selected. When excess points in the calculation, the Hough transform will detects fake edge, so we chose 5×5 edge connection window.

Because the adjacent edge points have the similar edge direction, while noise points do not have this feature. So, the points in the 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 of the Hough Transform, the collinear points in image space mapped into intersecting curve in the parameter space, so we convert the line

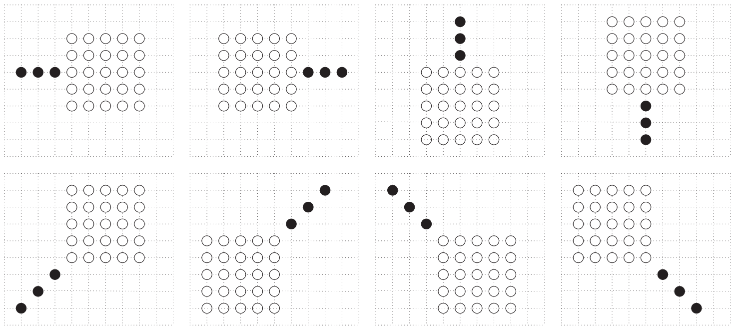


FIGURE 4. Edge connection window selection

detection to point detection. The general equation of a straight line in the image space is:

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

Since the vertical line slope is infinite, the parameter equation is expressed as:

$$\rho = xcos\theta + ysin\theta \tag{7}$$

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.

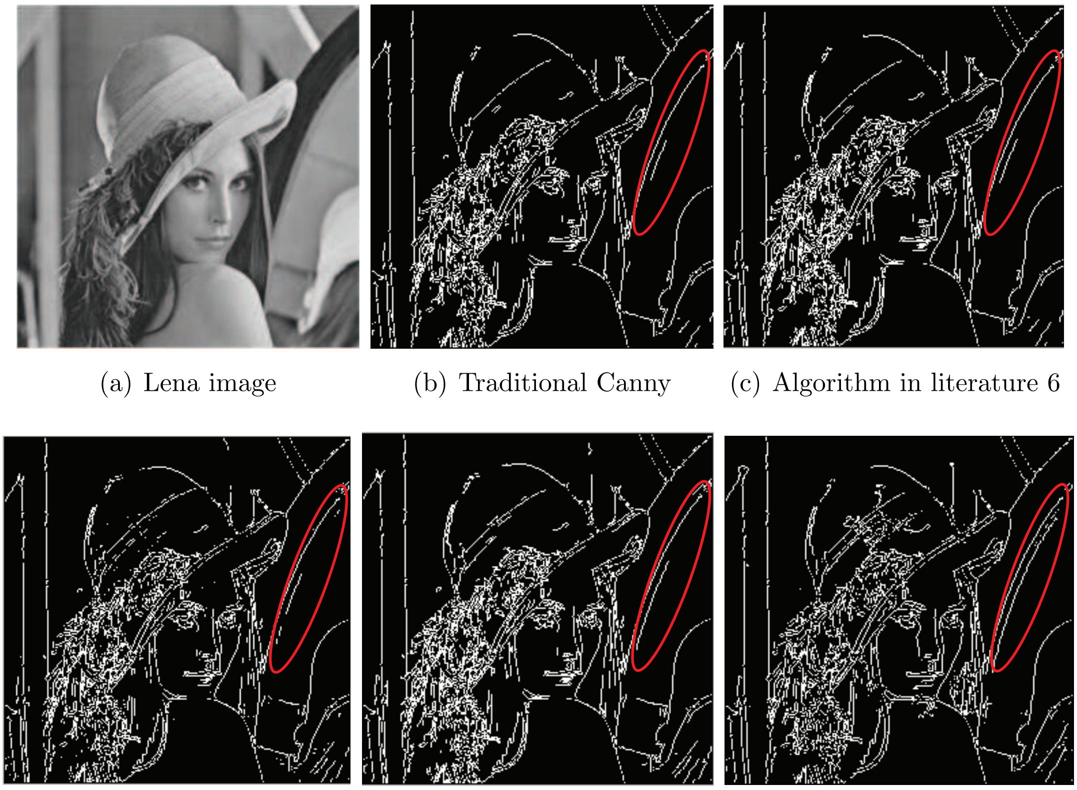
The process of Hough Transform: Discretize the scope of θ and ρ value, and set a corresponding 2-dimension accumulator array in parameter space. For each pixel, using the equation expressed in equation (7) to calculate ρ value with a change in the succession of θ in the parameter space, then looks for the accumulator's cells that the (ρ,θ) value fall into and the cell value is incremented by one. When 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 it as edge points. The adjacent edge points in the image have similar gradient magnitudes, while the isolated noise points do not have this characteristic. According to this feature, an additional condition is added to the candidate edge points in the edge connection window: the gradient difference of the endpoint gradient is less than the fixed value. In the experiment, when the gradient difference is 10, the detection effect is better, so we set the fixed value as 10 according to experience.

The process of HT-Canny: (1) Use Otsu method automatically get high threshold, the pixels are divided into edge points and candidate edge points. (2) Look for the edge endpoints. (3) Select edge connection window according to the gradient direction of edge endpoint and the position of edge point in 8 neighboring area. (4) Do Hough Transform to edge connection window, and the collinear point pixel value is set to 255, connected to the edge.

4. **Experiment.** We evaluate the performance of HT-Canny by comparing HT-Canny with the traditional Canny operator and the algorithm in literatures [6-8]. The algorithm in [6] uses Otsu method to automatically get double threshold. The algorithm in [7] links edge according to the similarity of edge contrast features and edge direction. The algorithm in [8] divides image into sub-images and detects them with adaptive threshold value. Edge detection experiments were carried out on the Lena image, Cameramen image and Transmission line image. In the experiment, the high threshold of the traditional Canny algorithm and the HT-Canny algorithm is automatically generated by the Otsu algorithm.

4.1. **The edge detection result and analysis.** The traditional Canny operator, algorithms in literatures [6-8] and the HT-Canny operator were employed as the edge detection algorithm, respectively. The simulation results are shown in Figure 5 and Figure 6. From Figure 5 and Figure 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.



(a) Lena image (b) Traditional Canny (c) Algorithm in literature 6

(d) Algorithm in literature 7 (e) Algorithm in literature 8 (f) HT-Canny

FIGURE 5. Edge detection results of Lena image

2. From Figure 5 (b)-(f) we can see that, although the algorithms in literatures [6-8] also obtained more edge information than traditional Canny algorithm, but the HT-Canny algorithm gained more complete edge (As red ellipses show in Figure 5).

3. From Figure 6 (b)-(f) we can see that, the results of the algorithms in literatures [6-8] 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 literature [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 Figure 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. proposed an edge detection statistical criterion[16]. Firstly, the criterion count the total number of

(a) Lena image (b) Traditional Canny (c) Algorithm in literature 6

(d) Algorithm in literature 7 (e) Algorithm in literature 8 (f) HT-Canny

FIGURE 6. Edge detection results of Cameramen image

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 response. The statistical results of the five algorithms are shown in table 1-3.

From table 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.

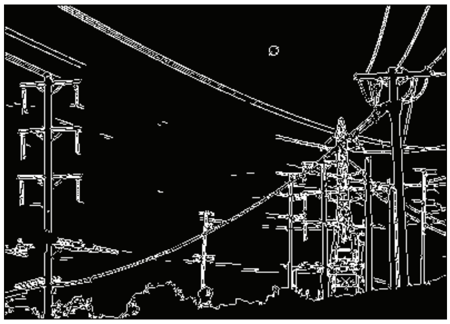
2. Because the smaller C/A value, HT-Canny algorithm has obvious improvement in edge connectivity and gets more comprehensive edge information, and it can distinguish edge points and non-edge points effectively.

3. In the case of better detection results than algorithms in literatures [6-8], edge points detected by the HT-Canny less than edge points detected by algorithms in literatures [6-8](Table1-3 C/B value) due to the HT-Canny has better unilateral edge response.

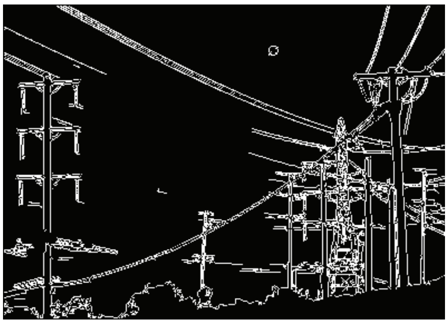
TABLE 1. Statistical results of Lena image

algorithm	A	B	C	C/A	C/B
Canny	5971	612	114	0.0191	0.1863
Paper[6]	6426	778	156	0.0243	0.2004
Paper[7]	6425	616	114	0.0177	0.1851
Paper[8]	6572	756	152	0.0231	0.2011
HT-Canny	6752	470	60	0.0089	0.1277

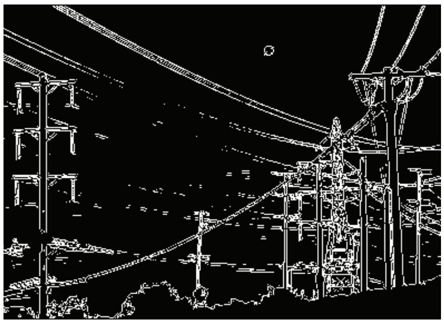
(a) Transmission line image



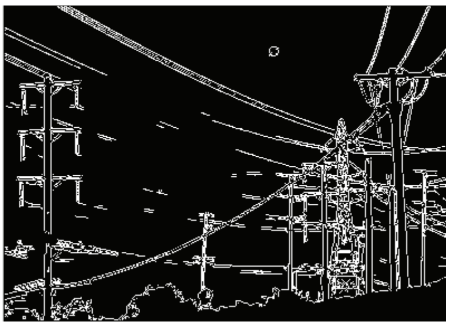
(b) Traditional Canny



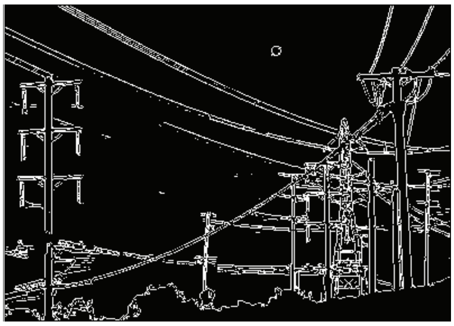
(c) Algorithm in literature 6



(d) Algorithm in literature 7



(e) Algorithm in literature 8



(f) HT-Canny

FIGURE 7. Edge detection results of Transmission Line image

TABLE 2. Statistical results of Cameramen image

algorithm	A	B	C	C/A	C/B
Canny	7586	1230	411	0.0542	0.3341
Paper[6]	9004	1458	474	0.0526	0.3251
Paper[7]	8394	1238	412	0.0491	0.3328
Paper[8]	8942	1374	465	0.0520	0.3384
HT-Canny	8800	1257	367	0.0417	0.2919

5. **Conclusions.** In this paper, we propose an edge connection based edge detection algorithm-the Hough Transform based Canny (HT-Canny) algorithm. HT-Canny algorithm introduces gradient direction and Hough Transform to replace 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 has

TABLE 3. Statistical results of Transmission Line image

algorithm	A	B	C	C/A	C/B
Canny	10923	1757	552	0.0505	0.3142
Paper[6]	11193	2011	656	0.0586	0.3262
Paper[7]	11552	1759	552	0.0478	0.3138
Paper[8]	11690	1809	571	0.0488	0.3156
HT-Canny	11504	1328	342	0.0297	0.2575

stronger edge connectivity and makes the detection result more complete and comprehensive. Especially, HT-Canny algorithm has stronger practicability for transmission line image detection.

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