Improved canny edge detection operator

Chuan Xu
Guangxi University of Science and Technology
No.19 Guantang Avenue, Yufeng District, Liuzhou City, Guangxi Province, China
xc2645352076@163.com

Jianhuan Su
Hechi University
No.42 Longjiang Avenue, Yizhou District, Hechi City, Guangxi Province, China
sujianhuan@126.com

Teng Wang
Guangxi University of Science and Technology
No.19 Guantang Avenue, Yufeng District, Liuzhou City, Guangxi Province, China
wt_970528@163.com

Yinguang Zhang
Guangxi University of Science and Technology
No.19 Guantang Avenue, Yufeng District, Liuzhou City, Guangxi Province, China
zhangyinguang111@163.com

Ao Yu
Guangxi University of Science and Technology
No.19 Guantang Avenue, Yufeng District, Liuzhou City, Guangxi Province, China
2750684179@qq.com

***Abstract*—Edge detection is an important method in image processing, which can not only extract the important contour features of the image, but also greatly reduce the workload of the computer in processing. Among them, the canny operator has been widely used among many algorithms with its certain advantages, but the processing effect is easily affected by the noise. In order to remove the Gaussian noise in the image and to retain the edge information better, this paper proposes an improved canny edge detection algorithm. The algorithm discards the previous Gaussian filtering and adopts bilateral filtering to improve the smoothing process, replaces the original gradient template in the gradient calculation, and adds 45 angle and 135 angle gradient templates to reduce the problem of missed detection and false detection, then uses linear interpolation to calculate the sub-pixel gradient value in the non-maximum suppression to makes the non-maximum suppression result more accurate. At last, the Otsu is used for threshold selection in the dual-threshold screening stage to achieve its adaptivity. After comparison, it is found that the improved canny operator has some advantages in processing images with Gaussian noise compared with the traditional canny operator.**

Keywords—Canny operator, bilateral filter, multi-gradient direction, linear interpolation, Otsu

I. INTRODUCTION

It is very important to extract the edge information of the detection region in the recognition and processing of the image target region, Edge detection plays an important role in image processing, image 3D measurement, image analysis and image recognition. Traditional edge detection operators include Sobel, Prewitt, Roberts, Laplacian, LOG and so on, but they are all very sensitive to noise in edge detection, and the image processing is not ideal. In 1986, John Canny[1] proposed a multilevel edge detection Canny operator, its signal-to-noise ratio, positioning accuracy and edge response have certain advantages compared with other edge detection algorithms, it can achieve ideal results in edge detection, so it is favored by many users. But Its disadvantage is that it is not ideal for image processing with more noise, it is easy to cause omission or false detection. In recent years, more and more scholars have put forward their own improvement methods for Canny operator, such as Liu Guodong[2] used Discrete Wavelet Transform(DWT) decomposition and weighted reconstruction to smooth filter the image and optimize the filtering effect. However, the effect of edge extraction remains to be improved; Liu Lixia[3] et al. proposed to use guide filter instead of Gaussian filter for image filtering processing, then combined with Otsu algorithm, the influence of human factors on threshold selection is reduced, it improved the adaptability of the algorithm, but the edge determination and extraction are also ineffective; Wang Jun[4] preprocessed images by an improved adaptive median filter, he proposed three threshold segmentation method instead of the original threshold segmentation method to make the image edge information more complete and accurate, but it's not adaptive enough; Liu Suxing[5] replaced the original 2×2 gradient template with a 3 × 3 one when performing gradient calculation, and added template direction, it effectively improve the continuity of edge detection, but the filtering effect is not good, and easy to be misdetected. Hao Zexing[6] used side-window Gaussian filter instead of traditional Gaussian filter to smooth the image, and used a 3 × 3 template instead of a 2 × 2 template for the calculation of image gradient and amplitude, and added 45 angle and 135 angle direction calculation templates to reduce the problem of false detection and missing detection, but the edge extraction was not exquisite enough.

In order to better filter the Gaussian noise in the image, and preserve marginal information as much as possible, this paper puts forward an improved Canny edge detection algorithm. Firstly, bilateral filtering[7] is used to replace the original Gaussian filtering to improve the filtering effect; Secondly, the original 2×2 gradient template is replaced by 3×3 in the part of gradient calculation. Moreover, the gradient templates in 45 angle and 135 angle directions are added; Then the linear interpolation method[8] is used to calculate the gradient of non-maximum suppression, it reduced the possibility of missed detection and false detection; Finally, Otsu[9] is adopted to determine the optimal threshold in threshold selection, It increased the adaptability of the algorithm. Compared with traditional canny edge detection operator, the improved algorithm in this paper can significantly improve the edge detection effect of images with Gaussian noise.

II. TRADITIONAL CANNY

A. The basic principle of Canny

The traditional canny algorithm is mainly divided into four steps, (1)The gray image is smoothed by Gaussian filter to eliminate part of the noise;(2)The soble operator template is used to calculate the gradient magnitude and direction ; (3)Non-maximum suppression was performed in the same gradient direction；(4）Dual Threshold Screening. The steps as shown in fig.1:

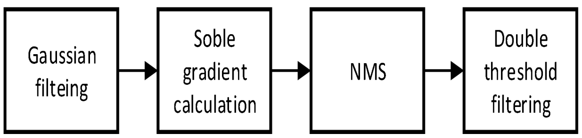

Fig. 1. Traditional canny flow chart

B. The defect of traditional Canny

1) Gaussian filtering：A linear smoothing filter, The step are: performing a convolution operation on the pixel points of the image with a fixed template, and then replacing the value of the central pixel point with the weighted pixel value in the neighborhood obtained by the convolution. Gaussian filtering is only affected by the pixel distance during the calculation, so some edge information may be lost during the processing. It is mainly used to eliminate linear noise.
2) Gradient calculation: Using the template of the soble operator, the gradient values in the x-axis and y-axis directions are calculated by the first-order derivatives to finally find the gradient amplitude and gradient direction. Because the gradient template only has horizontal and vertical directions, the gradient values of other directions are ignored, which will lead to partial loss of edge information.
3) Non-maximum suppression: the gradient amplitude in the same gradient direction is suppressed in a non-maximum way. In the traditional canny algorithm, the non-maximal suppression approximates the gradient direction in four directions: 0° , 45° , 90° , and 135° . However, the gradient direction of the edge pixel points in the actual image is multi-directional, and such approximate processing will make the edge information inaccurate, resulting in missed or false detections.
4) Dual threshold screening: artificially set two thresholds MAX and MIN, the gradient value larger than MAX is retained and smaller than MIN is discarded, and the values between the two thresholds are first judged to be relevant using correlation, and then decided to be retained or discarded. The artificially set thresholds are highly subjective and poorly adaptive. The template is used to format your paper and style the text. All margins, column widths, line spaces, and text fonts are prescribed; please do not alter them. You may note peculiarities. For example, the head margin in this template measures proportionately more than is customary. This measurement and others are deliberate, using specifications that anticipate your paper as one part of the entire proceedings, and not as an independent document. Please do not revise any of the current designations.

III. IMPROVED CANNY

This paper mainly aims at the edge detection of images with Gaussian noise. Based on the traditional canny operator, with bilateral filter to replace the original gaussian filtering; and replace the 2 x 2 soble template with a 3 x 3 template, added 45 angle and 135 angle templates; A linear interpolation calculation method is used to calculate the sub-pixel gradient values in the non-maximal value suppression session； And otsu is used to select the threshold. Fig.2 shows the overall process:

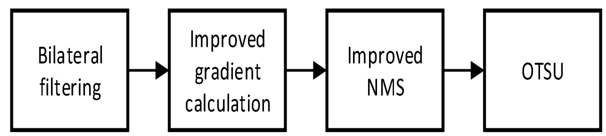

Fig. 2. Flow chart of the improved canny operator

A. Bilateral Filtering

Bilateral Filtering is a nonlinear filtering method, it can maintain the edge, reduce noise and smooth effect. Bilateral filtering also adopts weighted average, but it's different from Gaussian filtering, the weight of bilateral filtering not only considers the spatial Euclidean distance of pixel, but also considers the gray distance of pixel,it makes the filtering effect more reasonable and accurate.The principle is to convolve each pixel with a spatial domain kernel and a pixel domain kernel based on the Gaussian function, respectively, and then obtain the corresponding weight values. Finally, a new pixel value is obtained by multiplying the weight and pixel value to replace the central pixel value of the template. The detailed calculation method is as follows:

P = (i, q) denotes the coordinates of the pixel point at the center of the filter kernel.

q = (k, l) ∈ S (filter kernel) denotes the coordinates of pixel points in the neighborhood (within the filter kernel) of point p, including point p.

Hp and Hq denote the pixel values of pixel points p and q, respectively.

Gσs and Gσr denote the image space domain kernel and the pixel domain kernel, respectively, and are the corresponding parameters

$$G_{\sigma_s} = e^{-\frac{(i-k)^2+(q-l)^2}{2\sigma_s^2}} \qquad (1)$$

$$G_{\sigma_r} = e^{-\frac{[H_p - H_q]^2}{2\sigma_r^2}} \tag{2}$$

Wq is the sum of the weights of all pixel points in the filter kernel:

$$W_q = \sum_{q \in s} G_{\sigma_s} \times G_{\sigma_r} \tag{3}$$

Tp denotes the pixel value of the point to be processed after bilateral filtering:

$$T_p = \frac{1}{W_p} \sum_{q \in s} G_{\sigma_s} \times G_{\sigma_r} \times H_q \tag{4}$$

After the above steps, our bilateral filtering is completed. The noise of the image after the bilateral filtering process is obviously reduced, which lays a good foundation for the edge extraction to be performed afterwards.

B. The improved gradient Calculation

After bilateral filtering, most of the Gaussian noise in the image will be removed, and the sharpness will be somewhat reduced. But the edge of the image is not obvious, and it is not easy to be captured. Therefore, in order to reflecting the size of the edge gray change more accurately, the concept of image gradient is proposed, the magnitude of the gradient is used to indicate the sharpness of the edge grayscale change in order to determine the edge position more accurately.

In this paper, we add 45 angle and 135 angle templates on the basis of the two directions of the traditional canny operator. Fig.3 shows the four templates:

$$T_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \qquad T_y = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix}$$

$$T_{45^\circ} = \begin{bmatrix} 0 & 1 & 2 \\ -1 & 0 & 1 \\ -2 & -1 & 0 \end{bmatrix} \qquad T_{135^\circ} = \begin{bmatrix} 2 & 1 & 0 \\ 1 & 0 & -1 \\ 0 & -1 & -2 \end{bmatrix}$$

Fig. 3. Gradient calculation template

The gradient value calculation:

$$\begin{aligned} G_x = \{&[f(i+1,j-1) + 2f(i+1,j) + f(i+1,j+1)] \\ &-[f(i-1,j-1) + 2f(i-1,j) + f(i-1,j+1)]\} \end{aligned} \tag{5}$$

$$\begin{aligned} G_y = \{&[f(i-1,j+1) + 2f(i,j+1) + f(i+1,j+1)] \\ &-[f(i-1,j-1) + 2f(i,j+1) + f(i+1,j+1)]\} \end{aligned} \tag{6}$$

$$\begin{aligned} G_{45^\circ} = \{&[2f(i+1,j+1) + f(i+1,j) + f(i,j+1)] \\ &-[2f(i-1,j-1) + f(i-1,j) + f(i,j-1)]\} \end{aligned} \tag{7}$$

$$\begin{aligned} G_{135^\circ} = \{&[2f(i-1,j+1) + f(i-1,j) + f(i,j+1)] \\ &-[2f(i+1,j-1) + f(i+1,j) + f(i,j-1)]\} \end{aligned} \tag{8}$$

f (i, j) is the pixel value of the center pixel point to be processed. The gradient amplitude of point f (i, j) is calculated as follows:

$$G = \sqrt{G_x{}^2 * G_y{}^2 * G_{45^\circ}{}^2 * G_{135^\circ}{}^2} \tag{9}$$

Fig.4 shows the relationship between the gradient direction and the edge direction of the center point (x, y), we can know that the direction of the edge is perpendicular to the direction of the gradient of the pixel.

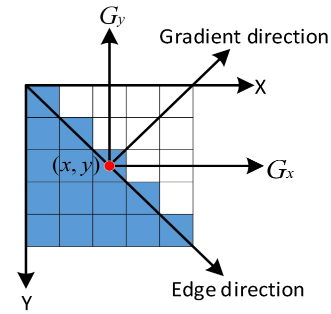

Fig. 4. Gradient vector diagram

Formula for gradient direction calculation:

$$\theta = \arctan \frac{G_y}{G_x} \tag{10}$$

C. Equations Improved non-maximum Suppression

The purpose of non-maximum suppression is to refine the edges, so that we can better show the outline of the image. The principle of non-maximum suppression is to compare the gradient amplitude of adjacent pixels in the same gradient direction of each pixel, if the gradient amplitude is maximal, it is retained. Otherwise, it is set to 0.

In the traditional non-maximum suppression calculation, it was only carried out in the four gradient directions of 0 angle, 90 angle, 45 angle and 135 angle, the gradient direction of each pixel point is approximated by these four directions according to the degree of similarity. The advantage of this process is that it makes the calculation easier, but the disadvantage is that this simplified method is prone to false detection and missing detection. Because in the actual image, the edge gradient direction is not necessarily only along these four directions. The pixel points in the actual image are discrete two-dimensional matrices, and the points on either side of the gradient value at the center position C may not exist， For better observation, we can call these two points sub-pixel points and we set them as q1 and q2, while the gradient values of the pixels adjacent to the central pixel point are g1, g2,g3,g4,g6,g7,g8,g9, and the gradient values of these two sub-pixel points we can get by interpolating with the gradient values of the neighboring pixels of q1 and q2.The analysis shows that there are four cases of gradient direction, for each case, the corresponding q1 and q2 are obtained, and then non-extreme suppression is performed with the central pixel gradient value.In this paper, based on the traditional gradient direction, the linear interpolation method is used to calculate the gradient size of multiple angles, which can make the next non-extreme value suppression cover a wider area and the results are more accurate. The gradient values of the sub-pixel points are calculated as shown in Fig.5:

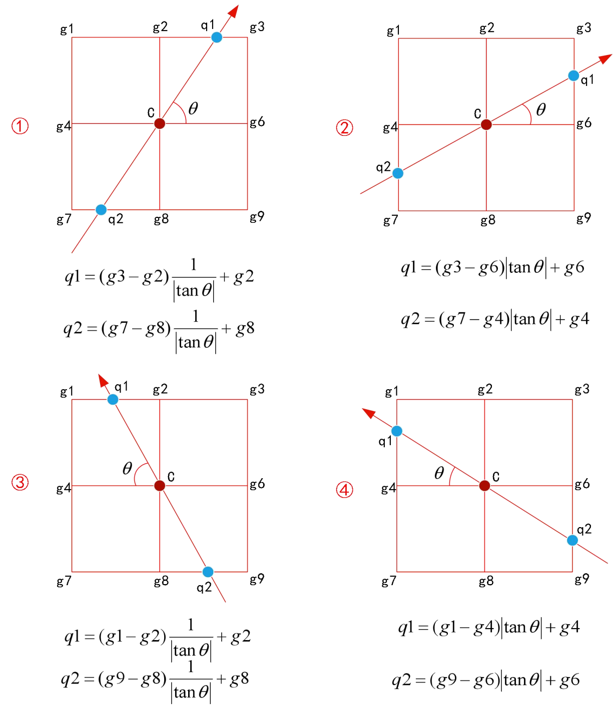

Fig. 5. Interpolation calculation schematic

D. Otsu

After completing the non-maximal suppression, we will get an image composed of local gradient maxima, but there are still some false edges caused by noise or other reasons, so we need to set a suitable threshold to connect the real edge points and remove the isolated noise points at the same time.We set two thresholds: minVal and maxVal respectively, when the pixel gradient value of the image is higher than maxVal, it will be considered as true boundary point, and those values below minVal will be considered as non-boundary points, and then set the pixel point to 0.If The gradient value of the detected point is in between, it is determined whether the point is associated with a real boundary point, and if there is a correlation, it is also determined to be a boundary point, and vice versa. As shown in Fig.6:

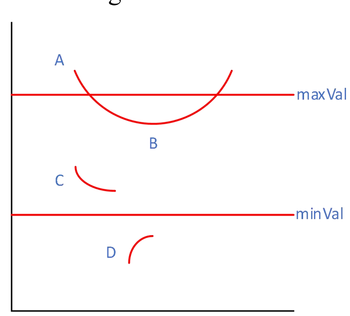

Fig. 6. Dual Threshold screening

Point A is above the threshold maxVal so it is a true boundary point, and point B is below maxVal but above minVal and is related to A, so it is also considered a true boundary point. While C and D are judged as non-edge points.

In the traditional algorithm, the maxVal and minVal values need to be set artificially, while the adaptivity is poor. Otsu algorithm is a binarized threshold segmentation algorithm. Its principle is that the image can be divided into two parts, background and foreground, according to the grayscale characteristics of the image. Based on the Otsu algorithm, setting the segmentation threshold as Th, which divides the pixels on the image into two classes, foreground C1 and hindground C2, the average grayscale of foreground C1 class is m1, and the ratio of these pixels to all the pixels in the image is p1; while the average grayscale of hindground C2 is m2, and the ratio of these pixels to all the pixels in the image is p2.The global gray mean of the image is mG, and the inter-class variance is denoted as σ.

$$P_1 * m_1 + P_2 * m_2 = m_G \quad (11)$$

$$\sigma^2 = P_1(m_1 - m_G)^2 + P_2(m_2 - m_G)^2 \quad (12)$$

E. Over flow Chart

The general flow chart of the algorithm is shown in Fig.7:

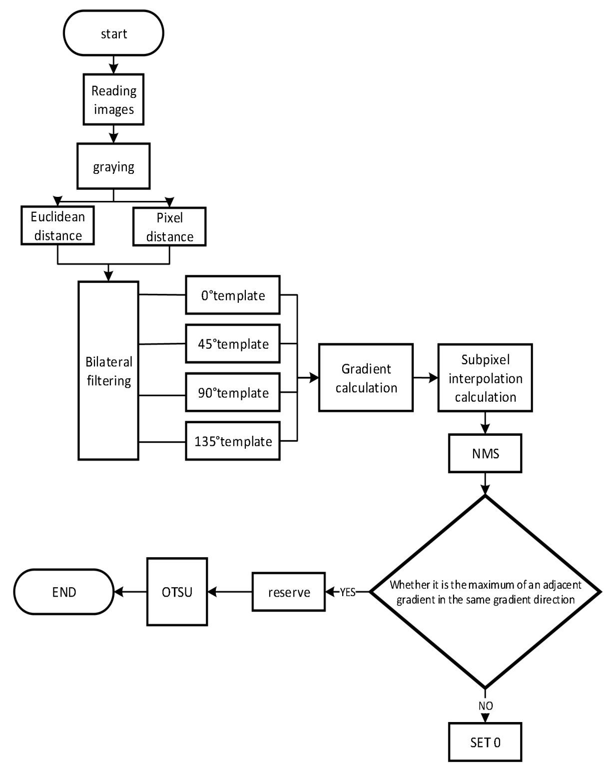

Fig. 7. Flow chart of the improved algorithm

IV. ANALYSIS OF THE RESULTS

The experimental environment for this paper was conducted in a windows 11 cpu, and the IDE chosen was pycharm with version 4.7.0.72 of the opencv library. First we selected a picture of Lena and House respectively, and then added a Gaussian noise with mean of 0 and standard deviation sigma of 0.1 to the two pictures uniformly.Processing of images with added Gaussian noise by using Gaussian filtering and bilateral filtering, The filtering effect is shown in Fig.8. It can be seen that the latter one is more effective in smoothing the noise.

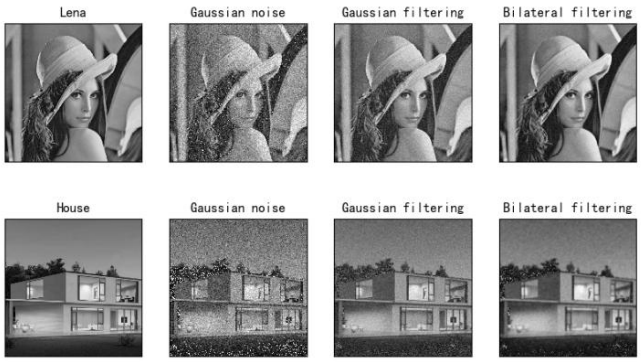

Fig. 8. Filtering effect

In order to make the smoothed effect more scientific and objective, we will use the results of Peak Signal to Noise Ratio (PSNR) [10] and Structural Similarity (SIMM) [11] as the basis for the comparison of the filtering effect of the two image, as shown in Table 1 and Table 2. The larger the PSNR is, the more similar the processed image is to the original image, which means the the filtering effect is better. As for SIMM, the closer the result is to 1, the smaller the change is compared with the original graph, and the larger the difference with the original graph, the more it tends to 0.

TABLE I. PSNR VALUES AFTER SMOOTHING

	Lena		House	
Filter	Gaussian	Bilateral	Gaussian	Bilateral
PSNR	27.9068	31.1029	22.5055	23.3045

TABLE II. SSIM VALUES AFTER SMOOTHING

	Lena		House	
Filter	Gaussian	Bilateral	Gaussian	Bilateral
SSIM	0.6027	0.8422	0.5618	0.7525

We use Laplacian, soble, traditional canny and the improved algorithm in this paper for edge detection of Lena images without artificially added Gaussian noise, respectively, the result is shown in Fig.9:

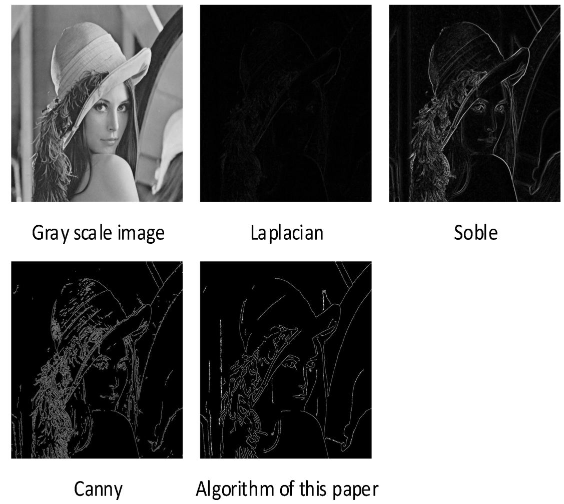

Fig. 9. Grayscale image edge detection result

It can be seen that for ordinary images without artificially added noise, the effect of the traditional edge detection method is goodish, but there are still edges that are not obvious, or redundant edges, or many false detections, and the improved canny algorithm in this paper can achieve more satisfactory results compared to the traditional one.

Then we add Gaussian noise with mean 0 and sigma 0.1 to Lena, House and Car images respectively, and compare the results between using traditional edge detection and algorithm of this paper. The results are shown in Fig.10:

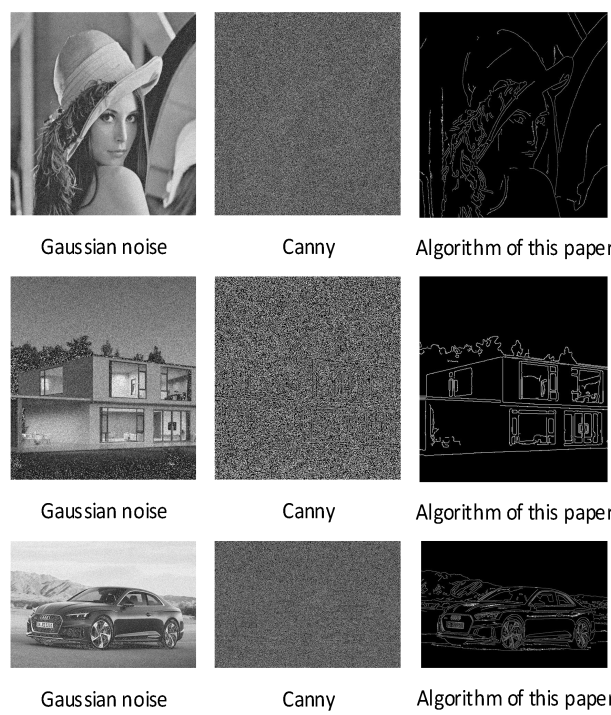

Fig. 10. Edge detection after adding noise

As we can see, for the image with Gaussian noise, the traditional canny edge detection algorithm is affected by the noise and the result is not accurate. And the improved algorithm in this paper can better handle images with Gaussian noise and get more accurate detection results.

In order to show the advantages of this algorithm, we add Gauss noise to Lena image and use the algorithm of Reference and the algorithm of this paper to detect the edge, the results are shown in fig.11.

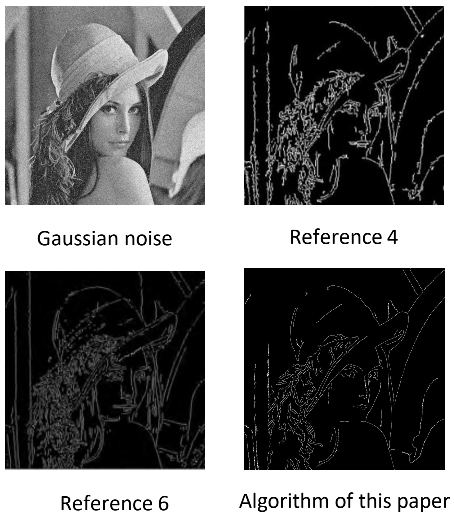

Fig. 11. Reference algorithm comparison of this paper algorithm

As can be seen from the figure above, the effect of noise on the image after edge detection using the algorithms in Reference 4 and Reference 6 is more obvious than that in this paper. In this paper, we use interpolation algorithm to calculate sub-pixel points in non-maximum suppression, which makes the edge extraction more reasonable and accurate, so the final effect is better.

V. CONCLUSION

In this paper, based on the traditional canny edge detection, Gaussian filtering is replaced by bilateral filtering to filter out the noise while preserving the edge information as much as possible and enhancing the noise suppression ability； At the same time, the gradient template is added and the interpolation calculation is used for Non-maximum suppression, so that the rate of edge miss detection and false detection are reduced, while the connectivity is enhanced. Then, the Otsu method is used for threshold segmentation, which increases the adaptiveness of the algorithm. It has been experimentally confirmed that compared with traditional algorithms, this algorithm is more accurate for edge extraction of images with Gaussian noise, However, the shortcoming is that the computation has increased and the speed has become slower, so it is still necessary to continue to study and improve.

REFERENCES

[1] Canny J.A computational approach to edge detection[J].IEEE Transactions on Pattern Analysis and Machine Intelligence,1986,8(6):679-698.

[2] Guodong Liu,Jiulun Fan.An improved Canny edge detection algorithm[J].Microcomputer & Its Applications,2013(22):32-34,37.

[3] Lixia Liu,Baowen Li,Yangping Li,Jingyu Yang.Remote Sensing Image Segmentation with Improved Canny Edge Detection[J].Computer Engineering and Applications,2019,55(12):54-58+180.

[4] Jun Wang,Yuhang Lin,Yutong Li.An image edge detection algorithm with improved Canny operator[J/OL].Journal of Chinese Computer Systems:1-6[2023-04-03].

[5] Suxing Liu,An improved Canny edge detection algorithm[J].Computer Programming Skills & Maintenance,2019(6):64-65.

[6] Zexing Hao, Gaizhi Guo, Yanwei Dai, Feng Ni. An improved edge detection algorithm based on Canny operator [J] . Journal of Inner Mongolia University (Natural Science Edition), 2022,53(05) : 530-537.

[7] Xuefeng Zhang,Pengcheng Wan.Improved rough set bilateral filtering image denoising algorithm[J].Journal of Shenyang University(Natural Science), 2022,34(05):354-362.

[8] Shu Yang,Shoujin Zeng,ZhenLiu.Nickel slice edge extraction algorithm based on Canny and bilinear interpolation[J].Journal of FuJian University of Technology,2022,20(06):567-572.

[9] Javeed Muhammad Awais et al. Lane Line Detection and Object Scene Segmentation Using Otsu Thresholding and the Fast Hough Transform for Intelligent Vehicles in Complex Road Conditions[J]. Electronics, 2023, 12(5) : 1079-1079.

[10] Filzasavitra Priyandanu,Waluyo Purboyo Tito,Erfa Saputra Randy. Analysis of Steganography on PNG Image using Least Significant Bit (LSB), Peak Signal to Noise Ratio (PSNR) and Mean Square Error (MSE)[J]. Journal of Engineering and Applied Sciences,2019,14(21).

[11] Xingtao Deng,Hai Min.Level set texture image segmentation based on texture structure similarity and edge information[J].Journal of Hefei University of Technology(Natural Science),2022,45(01):30-38+124.