Proceedings of the 2013 International Conference on Wavelet Analysis and Pattern Recognition, Tianjin, 14-17 July, 2013

Image Edge Detection Algorithm Based on Improved Canny Operator

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Abstract:

The traditional Canny operator does not have the adaptive ability in the selection of the variance of the Gaussian filtering. Filtering requires human intervention, and the selection of the variance of Gaussian filtering affects the edge preserving and denoising effect. An improved edge detection algorithm is proposed in this paper. The Gaussian filtering is replaced with the morphological filtering. Experimental results show that the improved Canny operator can filter the salt & pepper noise effectively, improve the accuracy of edge detection, and achieve an ideal effect of edge detection. The experiment results show that the objective evaluation and visual effect are good.

Keywords:

Canny operator; morphology filtering; edge detection

1. Introduction

Image edge is the most basic feature of image. The edge is the set of pixels which has step change in pixel gray value. Image edge reflects most of the image information. Therefore, edge detection is an important part of image processing, and the detection algorithms are studied extensively[1]. Most classical edge detection methods take operation on the neighbor region pixels, and obtain the gradient with templates approximation, such as Robert, Sobel, and Prewitt[2], which are relatively simple and easy to implement, and have good real-time performance, but these operators are sensitive to noise, poor anti-interference performance[3], and the edge accuracy needs to be improved. So these operators are not ideal in the practical application. In contrast, the Canny operator based on optimization algorithm with high SNR and detection precision, has been widely used in practice. There have been extensive study and application of Canny operator in recent years. The actual image is easily affected by all kinds of noise. In this case, on one hand, it is very difficult to set a Gauss filtering parameter if using the traditional Canny operator, and the Canny operator is lack of adaptability for different images[4]. On the other hand, it cannot eliminate the local noise and false edge might be detected. Based on the traditional Canny operator and the many existing improved Canny operators, combined with the advantages of the algorithm mentioned in literature[5], an improved edge detection algorithm is proposed in this paper, in which the Gaussian filtering is replaced by the morphological filtering. The experiment results show that this given method has satisfactory results compared with the traditional Canny operator.

2. The basic principle of tradition Canny operator

The basic idea of Canny operator is to use the first order derivative of 2-D Gaussian function in any direction as a noise filter. The filter acts on the image by the convolution operation, then the local gradient maximum value for the filtered image can be found, and thus the image edge can be determined[6]. The specific steps of algorithm are as follows.

2.1 Gauss filtering

Design a filter and calculate an appropriate mask. Convolve a raw image with the mask. Here, standard deviation σ of the Gauss filtering function controls smooth degree, where Gauss filtering function is

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

2.2 Calculate the gradient amplitude and direction of image

$P_x(i,j)$ and $P_y(i,j)$ are respectively the first order partial derivative of x direction and y direction.

The gradient amplitude can be determined as

$$M(i,j)=\sqrt{P_x(i,j)^2+P_y(i,j)^2} \tag{2}$$

The gradient direction is

$$\theta(i,j)=\arctan[P_y(i,j)/P_x(i,j)] \tag{3}$$

2.3 Non-maxima suppression

Apply the non-maxima suppression to the gradient amplitude, the pixel that has maximal value in the gradient

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direction will be remained as the edge pixel, and delete the other pixels. Gradient maximal value usually appears in the center of the edge, with the increase of the distance in the gradient direction, the gradient value will decrease.

2.4 The determination of double threshold and the connection of edges

The images are made double thresholds processing after non-maxima suppression, the false edges are eliminated and the discontinuous edges are connected. That is, through a given high threshold coefficient and the image histogram, the high threshold is calculated, and then, through the given low threshold coefficient, the low threshold value is calculated. Compare high threshold with the image after non-maxima suppression, and the edge points are recorded. For all the edge points, iteratively search for the points whose pixel value is greater than the low threshold in 8 neighborhoods, and mark them as edge points.

3. The defect of the traditional Canny operator

The purpose of image filtering is to weaken the influence of noise on image and improve signal-to-noise ratio. When using of Gaussian filtering, the selection of the variance σ (smoothing parameter) plays an important role in the smoothing effect. The Gaussian filtering is a low pass filter. When the σ is bigger, the band will be more narrow, and the high frequency signal has a great inhibition. Although the emergence of the false edge point can be avoided, due to the signal frequency in the edge is relatively high, the target edge becomes blurred and loses detail information. On the contrary, if the σ is smaller, the band will be more wide. Although it can keep detail information of the edge, it can not get an ideal effect of noise reduction[7]. However, the parameter σ of the classical Canny operator is set by people, it is hard to find appropriate value in the actual processing, and different images use a fixed parameter[8], so the image edge detection has some limitations.

4. The improved Canny detection algorithm

4.1 Morphological filtering

Mathematical morphology is composed of a set of the algebraic operators of the morphology. Its basic operation has four, which are expansion, corrosion, open and close operations. Assume that the image $F(x,y)$ is gray image, $B(s,t)$ is structural element, the basic operations of gray morphology are defined as follows.

1) The expansion operation

$$F\oplus B = \max\{(F(x-s,y-t)+B(s,t)\} \quad (4)$$

2) Corrosion operation

$$F\Theta B = \min\{(F(x+s,y+t)-B(s,t)\} \quad (5)$$

3) Open operation $F\circ B = (F\Theta B)\oplus B \quad (6)$

4) Close operation $F\cdot B = (F\oplus B)\Theta B \quad (7)$

Open-close filtering is the alternate application of open operation and close operation filtering. One of the forms of open-close filtering is to use a series of increasing structural elements to implement[9]. In this paper, use two diamond structure elements. Here, two selected structure elements are the 3×3 diamond element and the 5×5 diamond structure, which are shown below

$$A=\begin{pmatrix}0&1&0\\1&1&1\\0&1&0\end{pmatrix}, B=\begin{pmatrix}0&0&1&0&0\\0&1&1&1&0\\1&1&1&1&1\\0&1&1&1&0\\0&0&1&0&0\end{pmatrix}$$

So the open-close filtering operation of the image is given as follows.

$$F_{disnoise} = F\circ A\cdot B$$

Where, $F_{disnoise}$ expresses the result after removing the noise.

A is the small scale structure element, so its denoising ability is relatively weak, but at the same time it can keep the detail information of the image edge; B is large scale structure element, so its denoising ability is relatively strong, but at the same time it will blur lots of the detail information[10]. Therefore, structure element A and B are used sequentially to make open-close filtering, which can eliminate image noise and keep the detail of the image information.

The traditional Canny operator only extracts the gradients of x direction and y direction, which lose some important edge information, especially some information in the bevel edge. Therefore calculate gradient information in two oblique directions, and finally synthesize original gradient information and oblique direction information to get the final edge image[5]. Use two diagonal forms as shown below, and get gradient in two diagonal directions.

$$\begin{pmatrix}0&1&2\\-1&0&1\\-2&-1&0\end{pmatrix} \qquad \begin{pmatrix}-2&-1&0\\-1&0&1\\0&1&2\end{pmatrix}$$

Corresponding to the first diagonal form, the gradient is

$$G_1'(x,y)=f(x,y-1)+2f(x+1,y-1)-f(x-1,y)+f(x,y-1) +f(x+1,y)-2f(x-1,y+1) \quad (8)$$

Corresponding to the second diagonal form, the gradient is

$$G_2'(x,y) = -2f(x-1,y-1) - f(x,y-1) - f(x-1,y) + f(x+1,y) + f(x,y+1) \quad G'(x,y) \tag{9}$$

The gradient in oblique direction is

$$G'(x,y) = (G_1'^2 + G_2'^2)^{\frac{1}{2}} \tag{10}$$

Suppose the image extracting from x direction and y direction is G_1, and the image extracting form oblique direction is G_2. The gradient image is $G = \max\{G_1, G_2\}$.

4.2 The improved Canny detection algorithm

By above analysis, the specific procedures of the improved Canny edge detection algorithm are as follows.

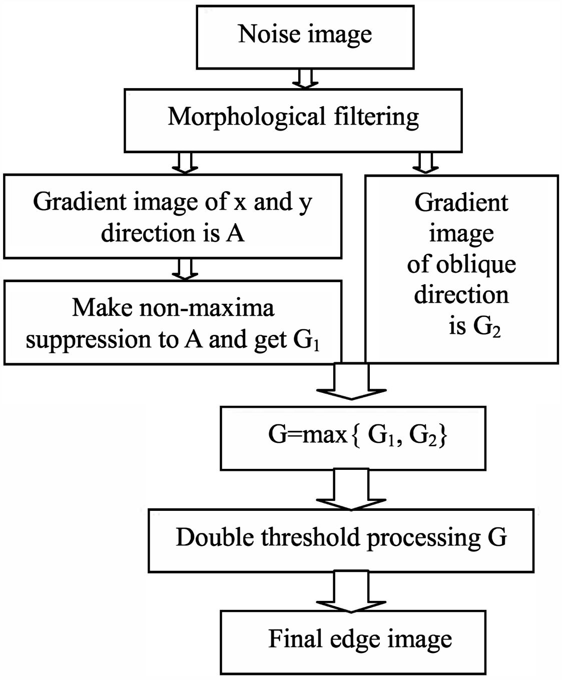
Step1:Add the salt & pepper noise to the original image.

Step2:Use morphological filtering of open and close to smooth noise.

Step3:Extract gradient image of x direction and y direction and make non-maxima suppression. Then extract gradient image of oblique direction.

Step4:Take the maximum of the two gradient images as the final gradient image.

Step5:Process image with double threshold.



5. Experimental analysis

Now we validate that the improved Canny detection method is better than the traditional Canny detection algorithm. Lena image and trees image are used for simulation.

In contrast to the experimental results, it can be seen that the traditional Canny detection loses a lot of information and contains many noise points, especially in image of lena(see Figure(c) and (g)). While the improved Canny edge detection method effectively removes noise and makes edges clearer, and more detail information is shown(see Figure(d) and (h)).

Now, we make quantitative analysis. The information entropy, the Peak Signal to Noise Ratio (PSNR), the average gradient, the correlation coefficient and the distortion degree are selected in paper [11].

The information entropy is an important indicator for measuring the rich degree of image information. The definition is as follows

$$H = -\sum_{i=0}^{L-1} P_i \cdot \log_2(P_i) \tag{11}$$

Where, P_i expresses the probability when the grey values of image pixels equal to i. The higher the information entropy is, the more information the image has.

The PSNR of the image is an important indicator for measuring the image quality, which is the ratio of the video signal and the noise signal. Its formula is as follows

$$PSNR = 10 \times \lg\left(\frac{255^2}{MSE}\right) \tag{12}$$

$$MSE = \frac{1}{M \times N} \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} \| I(i,j) - K(i,j) \|^2 \tag{13}$$

Where, MSE is the mean square error of the two images I and K, usually, for a given image, the higher the PSNR is, the higher quality the image has.

The average gradient is also known as definition, which reflects the contrast of minute details and texture variation characteristics of the image. Its definition is shown below

$$\bar{g} = \frac{1}{M \times N} \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} \sqrt{\frac{I^2{}_x + I^2{}_y}{2}} \tag{14}$$

Where, I_x and I_y are the differences of x and y direction, respectively.

The distortion degree directly reflects the distortion degree of the image. The definition is the following formula.

$$D = \frac{1}{M \times N} \sum_{i=1}^{M} \sum_{j=1}^{N} |I_G(i,j) - I(i,j)| \tag{15}$$

Where, $I_G(i,j)$ and $I(i,j)$ are respectively the grey values of the improved image and the standard image at the point (i, j). The smaller the distortion degree is, the closer to the standard image the improved image is.

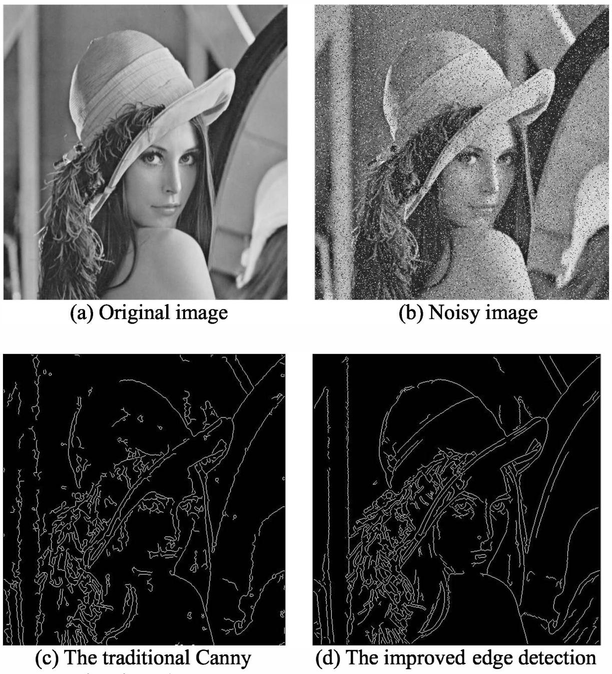
The correlation coefficient reflects the relevance degree of the two images, whose definition is the following statement.

$$corr(A,B)=\frac{\sum_{i,j}\left[(A(i,j)-\overline{A})\times(B(i,j)-\overline{B})\right]}{\sqrt{\sum_{i,j}[(A(i,j)-\overline{A})]^2\times\sum_{i,j}[(B(i,j)-\overline{B})]^2}} \quad (16)$$

$$\overline{A}=\frac{1}{M\times N}\sum_{i=0}^{M-1}\sum_{j=0}^{N-1}A(i,j)$$

$$\overline{B}=\frac{1}{M\times N}\sum_{i=0}^{M-1}\sum_{j=0}^{N-1}B(i,j)$$

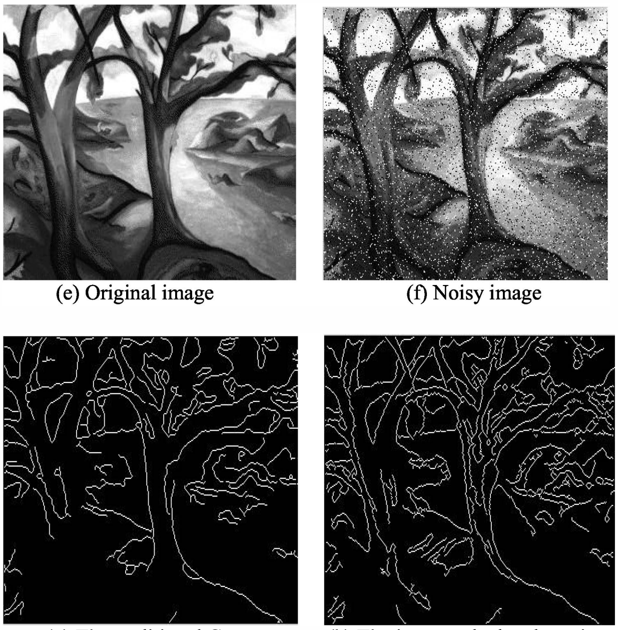
Where, $A(i,j)$ and $B(i,j)$ are the gray values of the two images. $\overline{A}$ and $\overline{B}$ express mean values, respectively. The closer to 1 the correlation coefficient is, the better approximate degree the image has.



(a) Original image (b) Noisy image

(c) The traditional Canny edge detection (d) The improved edge detection

Figure 1. Edge detection results of lena

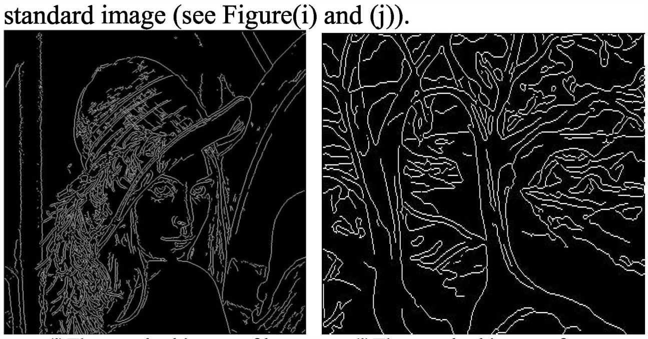


(e) Original image (f) Noisy image

(g) The traditional Canny edge detection (h) The improved edge detection

Figure 2. Edge detection results of trees

The experimental results of the performance evaluation are listed in Table 1 and Table 2. We use the traditional Canny operator to detect the original image so as to obtain the standard image (see Figure(i) and (j)).



(i)The standard image of lena (j)The standard image of trees

TABLE1. THE OBJECTIVE EVALUATION COMPARISON OF IMPROVED CANNY OPERATOR OF LENA

Evaluation indicators	*The standard image*	*The traditional Canny algorithm*	*The improved algorithm*
Entropy	0.9788	0.9645	0.9705
PSNR		5.6167	13.7497
Average gradient	22.3747	10.3327	15.6222
Corr	1	0.8988	0.9137
Distortion degree	0	12.5679	10.7539

TABLE2. THE OBJECTIVE EVALUATION COMPARISON OF IMPROVED CANNY OPERATOR OF TREES

Evaluation indicators	*The standard image*	*The traditional Canny algorithm*	*The improved algorithm*
Entropy	0.9834	0.9720	0.9773
PSNR		7.8118	13.1829
Average gradient	25.7077	15.8334	21.3641
Corr	1	0.8981	0.9015
Distortion degree	0	12.7318	12.2531

From Table 1 and Table 2, the statistical results of the improved algorithm are better than the traditional Canny operator and the improvement effect is obvious. It is well known that the effect of improved algorithm is better, compared with the standard image in the entropy, the PSNR, the average gradient, the approximate degree, or the distortion degree. The improved algorithm can provide a better image, which contains more information and better clarity. The reason is that open and close morphology filter can remove noise, at the same time, remain the image edge strength and important detail information. Consequently, the improved algorithm is very effective.

6. Conclusions

The traditional Canny algorithm has difficulty in treating images which contain the salt & pepper noise, and it does not have the adaptive ability in the variance of the Gaussian filtering. For this reason, a new Canny algorithm is presented in this paper, in which open-close filtering instead of Gaussian filtering. In this paper, the traditional Canny operator is improved by using morphology filtering to pretreat the noise image. The final edge image can reduce effectively the influence of noise, keep the edge strength and more complete details, get a more satisfactory subjective result. And by using objective evaluation standards, compared with the traditional Canny operator, information entropy, average gradient, peak signal to noise ratio, correlation coefficient and the distortion degree also have increased significantly. So, the new algorithm is an effective and practical method of edge detection.

Acknowledgements

The paper is supported by Science and Technology Research Project of Heilongjiang Province Education Department（No.12531100）.

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