An Adaptive Edge-detection Method Based on the Canny Operator

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Abstract*—On the basis of analyzing the conventional Canny algorithm, this paper advanced an adaptive edge-detection method based on the canny operator. This method not only keeps the Canny's good performance in good detection, good localization and only one response to a single edge, but also improves the capability of restraining the fake edge and the automaticity of edge-detection based on the Otsu's thresholding method. Through experiments, it is demonstrated that the adaptive edge-detection method in this paper is very effective.

Key words: Canny Operator; Adaptive Threshold; Otsu's thresholding Method ;

I. INTRODUCTION

The edge is not only the basic feature of an image and the important basis for the image segmentation, but also is the important information source of the texture feature and the basis of shape quality analysis. The edge detection is an fundamental and very important research subject, its detection result directly affect the performance of the image comprehension and the discrimination. The classical edge detection algorithms reckon that the edges primarily behave the discontinuities of the local area features on the image, so the algorithms are based on the research of the grey image gradient. Usually the image edge includes three types: the step type edge, the roof type edge, the line type edge. The both sides grey levels of the step type edge varies obviously, the roof type edge locates on the boundary of the grey level increment and the reduction[1]. The representative first order differential operators are the Roberts operator, the Prewitt operator and the Sobel operator, the Laplace operator and the LOG operator are the second-order operators, these operators are very easy to realize, but they are very sensitive to the image noise, the results are not very ideal. By contrast, the Canny operator which is based on the optimized algorithm haves good performance in good detection, and good localization, so it deserves widespread application.

These years, many researchers bring forward the advanced method of the Canny operator, but on the whole they don't resolve the problem of the self-adaptability. In practice, because the noise and illumination condition affect the image quality in the process of the image obtainment, it is necessary to get the high and the low threshold adaptively. This paper advanced an adaptive edge-detection method based on the canny operator, it improves the capability of restraining the fake edge and the automaticity of edge-detection based on the Otsu's thresholding method, through experiments, it deserves good performance.

II. EDGE-DETECTION METHOD BASED ON THE CANNY OPERATOR

Canny brought out the rule that excellent edge-detection method should pleased in 1986：

(1)Fine SNR(Signal-to-Noise)，is that the probability of the edge-point to be mistaked must be low；

(2)Good performance of positioning，is that the detected edge-point should be at the center of real edge to its best possibility；

(3)Single edge response，is that the single edge has only one response，and the false edge should be restrained mostly .

The course of edge-detection by canny operator includes that lowpass filtering with Gauss function、

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calculating the value and direction of grads、non-maxima suppression to grad value and checking and connecting edges [4].

A. image filtering

Canny operator first carried on the filtering to image with two-dimensional Gauss function，and the function is as follow：

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

Its grads vector is：

$$\nabla G=\begin{bmatrix}\partial G/\partial x\\ \partial G/\partial y\end{bmatrix} \quad (2)$$

In above formula：

$$\frac{\partial G}{\partial x}=kx\exp(-\frac{x^2}{2\sigma^2})\exp(-\frac{y^2}{2\sigma^2})=h_1(x)h_2(y) \quad (3)$$

$$\frac{\partial G}{\partial y}=ky\exp(-\frac{x^2}{2\sigma^2})\exp(-\frac{y^2}{2\sigma^2})=h_1(y)h_2(x) \quad (4)$$

k is a constant，σ is the parameter of Gauss filter and control the extend of smoothing image .

B. Calculating the value and direction of grads

Traditional canny operator adopts first order limited difference of 2×2 neighbouring area to calculate the value and direction of grads on image，the first order approximation on x and y directions are got from following formula：

$$P_x=\frac{1}{2}\times\begin{bmatrix}-1 & 1\\ -1 & 1\end{bmatrix} \qquad P_y=\frac{1}{2}\times\begin{bmatrix}1 & 1\\ -1 & -1\end{bmatrix}$$

Following are formulas to calculate the value and direction of grads：

$$M(i,j)=\sqrt{P_x^2[i,j]+P_y^2[i,j]} \quad (5)$$

$$\theta(i,j)=\arctan(P_y[i,j]/P_x[i,j]) \quad (6)$$

C. non-maxima suppression to the value of grads[4]

The value in array M[i,j] is greater，its responding value of grads on images is greater，but this is not enough to ensure edges .In order to accurately position edges，the points whose value changes mostly are observed only through thinning the fastigium strip of images，and this is called non-maxima suppression(NMS) . Canny operator adopts 3×3 neighbouring area which includes eight directions to carry on interpolation to the value of grads along grads' direction aiming to each value in array M[i,j] .If the value m[i,j] of the center of the area is not bigger than the two interpolation results on the grads direction，the edge sign responding to m[i,j] is evaluated as zero .The process thins the fastigium strip，and made its width from M[i,j] to one pixel，at the same time keep its grads value .

D. checking and connecting edges

Canny operator adopts double-threshold method to get two images(T_h[i,j] and T_l[i,j]) after edge extraction with threshold by segment images after carrying on non-maxima suppression . The image T_h [i,j] is gained by high threshold so it includes no false edge but probably brings some gaps into the edge，double-threshold method connects edges on image T_h [i,j] to contour，and when getting to the end points，begins to find edges that can be connected to the contour in the 8×8 neighbouring area on the image T_l [i,j] which is gained by high threshold，keeps imposing recursive tracking method until all the gaps on the image T_h [i,j] are connected .

III. OTSU THRESHOLDING METHOD

There are a lot of image thresholding segmentation methods based on grayscale histogram，and the method brought out by Otsu is one of methods in common use .

The statistical information on two-dimensional images can be expressed by histogram P_i（i=1,2,…,T），Pi can be regarded as an estimation to the mixed probability density function of background and object，for threshold t （1＜t ＜T），

$$\omega_0(t)=\sum_{i=1}^{t}P_i \quad \omega_1(t)=\sum_{i>T}^{T}P_i=1-\omega_0(t) \quad (7)$$

$$\mu_0(t)=\sum_{i=1}^{t}iP_i/\omega_0(t) \quad \mu_1(t)=\sum_{i>T}^{T}iP_i/\varpi_1(t) \quad (8)$$

$$\sigma_0^2=\sum_{i=1}^{t}(i-\mu_0(t))^2P_i/\omega_0(t) \quad (9)$$

$$\sigma_1^2=\sum_{i>t}^{T}(i-\mu_1(t))^2P_i/\omega_1(t) \quad (10)$$

Suppose that，$\mu_T=\sum_{i=1}^{T}iP_i \qquad \sigma_T^2=\sum_{i=1}^{T}(i-\mu_T)^2P_i$

Covariance between classes σ_B^2 and covariance within classes σ_W^2 is separately defined as follow：

$$\sigma_B^2=\omega_0(t)\omega_1(t)(\mu_0(t)-\mu_1(t))^2=\omega_0(t)(\mu_0(t)-\mu_T)^2+\omega_1(t)(\mu_1(t)-\mu_T)^2$$

$$\sigma_W^2=\omega_0(t)\sigma_0^2(t)+\omega_1(t)\sigma_1^2(t)$$

Now that：

$$\mu_T=\omega_0(t)\mu_0(t)+\omega_1(t)\mu_1(t) \quad (11)$$

$$\sigma_T^2=\sigma_B^2+\sigma_W^2 \quad (12)$$

Otsu selects best threshold t through maximizing one of the three formulas：

$$\lambda=\frac{\sigma_B^2}{\sigma_W^2} \qquad \kappa=\frac{\sigma_T^2}{\sigma_W^2} \qquad \eta=\frac{\sigma_B^2}{\sigma_T^2}$$

Usually we obtain threshold through maximizing σ_B^2 or minimizing σ_W^2，the paper carries on thresholding segmentation to grads histogram through minimizing σ_W^2，and then captains the high and low threshold needed in Canny operator .

IV. THE ADAPTIVE CANNY ALGORITHM

A. The improved calculation method of the gradient value

The grads values of the traditional Canny operator are got through calculating the difference in the 2×2 neighborhood. The result of this method is very sensitive to the noise, in allusion to this limitation, we bring forward the method of calculating the first order partial derivative in the 3×3 neighborhood along the x and the y direction. This method considers the requirement of edge localization and the noise suppressing. The results in the experiments are very well, the arithmetic is designed as follows:

The partial derivatives along the x and the y direction are calculated as below:

$$P_x[i,j] = I[i,j+1] - I[i,j-1] + (I[i-1,j+1] - I[i-1,j-1] + I[i+1,j+1] - I[i+1,j-1])/2$$

$$P_y[i,j] = I[i+1,j] - I[i-1,j] + (I[i+1,j-1] - I[i-1,j-1] + I[i+1,j+1] - I[i-1,j+1])/2$$

The grads value is:

$$M(i,j) = \sqrt{P_x^2[i,j] + P_y^2[i,j]} \tag{13}$$

The azimuth of the grads is:

$$\theta(i,j) = \arctan(P_y[i,j]/P_x[i,j]) \tag{14}$$

B. *The adaptive method of getting the threshold*

The high and the low threshold of the traditional Canny operator need to be fixed on artificially, they can't be got according to the features of the image. In allusion to this limitation, we bring forward the method of getting the thresholds adaptively.

- The construction of the gradient histogram

The grads histogram which describes the distributing of the edge grads can be formed by counting the grads value number on the location whose sign parameter is not zero in the image N[i,j] after NMS. The grads histogram of the Lena image is showed below:

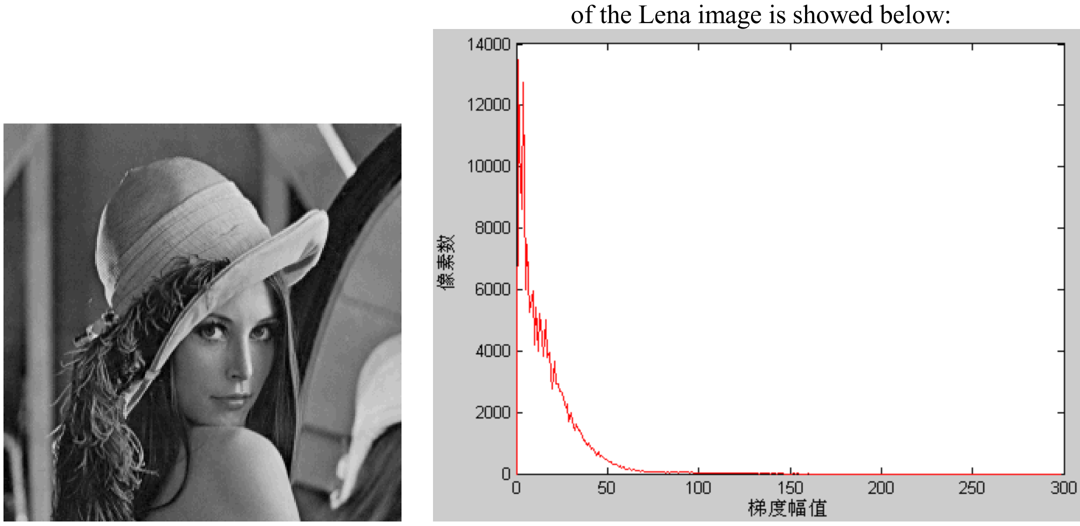

Figure 1. The Lena image and its grads histogramt.

- The obtaining of the high and the low threshold

The grads histogram can delineate the intensity information of the edges, generally the edges in the image accounts for only a little part of the image, so the grads histogram is very different from the image histogram used commonly. The character of the double peaks in the grads histogram is not evident, the peak in the low grads area is very evident. The grads histogram of the Lena image in Fig.1 can illuminate the above theory.

After getting the grads histogram, we can use the Otsu's thresholding method to calculate the best segmentation threshold t which can divide the high grads area and the low grads area, then we can calculate the means($\mu_1(t)$, $\mu_0(t)$) and the variances(σ_1^2, σ_0^2) of the high grads area and the low grads area with the formula (8), (9), (10).

According to the above description about the traditional Canny operator, the high threshold τ_h must be selected outside the non-edge area in the grads histogram, otherwise there will be many fake edges in the result[4]. According the probability statistical meaning of the mean and the variance, we can get the range of the non-edge area with $\mu_0(t)$, σ_0 or with $\mu_1(t)$, σ_1 .Through experiments, we found that the method of getting the non-edge area with $\mu_0(t)$, σ_0 is better and more effective, when the high threshold τ_h is greater than $\mu_0(t)+\sigma_0$, we consider that the high threshold τ_h is beyond the non-edge area, then the fake edges will not occur in the edge image, the formula to calculate the high threshold is as follows:

$$\tau_h = \mu_0(t) + \sigma_0 \tag{15}$$

After experiments, when the low threshold is equal to $\mu_0(t) - 0.3\sigma_0$, the result of the edge extraction is very ideal.

C. *The edge tracing[4]*

The edge tracing process is as follows:

(1)For the image sub-area which contains the edges, if the grads value of one pixel is greater than the high threshold τ_h , then that pixel is considered as the beginning point, tracing begins;

(2)If the grads value of one pixel in the 3×3 neighborhood for the pixel is greater than the high threshold τ_h , then consider that pixel in the neighborhood as one pixel of the edge, tracing begins with this pixel as the beginning point;

(3)If the grads value of any pixel in the 3×3 neighborhood for the pixel is lower than the high threshold τ_h, then searches the pixel whose grads value is greater than the low threshold τ_l, continue the second process with this pixel as the beginning point;

(4)If the conditions of the second and the third process are not matched, end this edge tracing process, and consider the first process for the next pixel.

V. EXPERIMENTS AND ANALYSIS

In the experiments, we use the VC++ programs to test the validity of this paper's method with the computer whose dominant frequency is 2.4GHz and memory size is 512M. We took the experiments on the Lena image(a), the Couple image(d) and the RS image(g) in fig 2 with the traditional Canny operator and the improved Canny operator in this paper separately, thereinto, in the traditional canny operator, the standard deviation of the Gauss filter is 0.3, the ratio of the low threshold and the high one is 0.4, the ratio of the high threshold and the image pixel number is 0.7. The experiments' result, the calculation time and the corresponding parameters are showed in TABLE 1.

(a)Lena image(256×256) (b) traditional method (c)method in this paper

(d)Couple image(256×256) (e) traditional method (f)method in this paper

(g)RS image(560×896) (h)traditional method (i)method in this paper

Figure 2. The experiments results.

TABLE I. CALCULATION TIME AND CORRESPONDING PARAMETERS

		(a)lena image	**(d)Couple image**	**(g)RS image**
The traditional Canny operator	parameters	σ =0.3 τ_h =20 τ_l =8	σ =0.3 τ_h =14 τ_l =6	σ =0.3 τ_h =20 τ_l =8
	Calculation time	47ms	46ms	469ms
The adaptive Canny operator in this paper	parameters	σ =0.3 τ_h =21 τ_l =5	σ =0.3 τ_h =15 τ_l =3	σ =0.3 τ_h =15 τ_l =5
	Calculation time	62ms	62ms	593ms

(In the above table, the σ , τ_h , τ_l separately represents the Gauss filter parameter, the high threshold and the low threshold)

The experiments show that the adaptive Canny operator not only keeps the traditional Canny's merits, but also the connectivity of the detection result is better. Compared with the traditional Canny operator which needs to ensure the high and the low threshold artificially, the adaptive Canny operator can ensure the high and the low threshold adaptively according to the features on the image, whose results have more complete information of the edge. Through the Tab.1, we can see that the adaptive Canny operator needs more time to operate.

VI. CONCLUTIONS

The text brings out an improvement to traditional Canny operator aiming at its disadvantage that it is sensitive to noise， and considers that the double-threshold in traditional Canny operator must be manual setted up， brings the Otsu thresholding method into ensuring threshold of Canny operator .The result indicates that edge contours got from this method have fine SNR and connectivity， and the most important is that it can self-adaptively ensure the high and low threshold according to the characters of real images， so it has higher automatization. Now the results from the two methods only can be evaluated by eyes， and how to judge them impersonally is our direction to study thoroughly .

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