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An Improved Canny Algorithm for Edge Detection

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Abstract

Edge detection is an important part of digital image processing. This paper discusses the basic theory of edge detection, its method based on the traditional Canny operator, and proposes an improved algorithm based on the eight neighborhood gradient magnitude to overcome the disadvantages of being sensitive to noise in the calculation of the traditional canny operator gradient. The two thresholds of the traditional Canny operator need manual setting, so there are some defects to different images. This paper puts forward an adaptive threshold calculation by OTSU method. The experimental results prove that this improved method can effectively detect the edge of the image. And the continuity of the edge is strong, and positioning accuracy is high. .

Keywords: Edge Detection; Canny Operator; Adaptive Threshold

1. Introduction

Edge detection is an important part of the digital image processing. The edge is the set of the pixel, whose surrounding gray is rapidly changing. The internal characteristics of the edge-dividing area are the same, while different areas have different characteristics. The edge is the basic characteristics of the image. There is a lot of information of the image in the edge. Edge detection is to extract the characteristics of discrete parts by the difference in the image characteristics of the object, and then to determine the image area according to the closed edge. Edge detection is widely used in computer vision, image analysis, etc.

Edge detection methods are mainly as follows:

1) Edge detection based on gradient operator.

The edge is the place where image gray value is changing rapidly, so the method based on the derivation of the gradient operator is most widely used. The classical gradient operators are Sobel operator[1], Prewitt operator[2], Roberts operator, Laplacian operator.

2) Edge detection based on the optimum operator.

The gradient of the image edge is the maximum value, that is, the inflection point of the gray image is the edge. From the mathematical point of view, inflection point of the second derivative of the function is 0. Detecting this point, whose second derivative is 0 is a way of edge detection, for example, Marr-Hildreth operator[3], Canny operator[4,5].

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3) Multiscale edge detection.

Wavelet transform is particularly suitable for signal mutation detection and edge detection. Rosenfeld [6] suggested a combined consideration on the edge detected by multiple dimensions operator; Marr advocated applying multiple scales of different operators, and put forward some combination rules.

4) Some other methods.

The adaptive smooth filter method. The iterative computation of the smoothing filtering sharpens the signal edge. And then to detect the edge can get a high positioning accuracy. There are also methods based on integral transform and based on tensor.

The rest of this paper is organized as follows:

1) Discuss the digital representation of the image and the Canny's three optimal criteria.

2) Have a research on the edge detection algorithm based on the traditional Canny operator

3) Discuss the deficiency of the traditional Canny operator, propose the improved algorithm in terms of the gradient magnitude, gradient direction and the threshold setting.

4) Talk about the traditional Canny algorithm and the implementation of improved Canny algorithm by C#. Analyze the experimental results and the future work.

2. Digital Representation of the Gray Image And Canny Optimal Criteria

2.1. The Digital Representation of the Gray Image

A continuous black and white gray scale image, after equal interval sampling can be expressed as a discrete magnitude matrix:

$$f(x,y)=\begin{bmatrix} f(1,1) & f(1,2) & \dots & f(1,n) \\ f(2,1) & f(2,2) & \dots & f(2,n) \\ \dots\dots & \dots\dots & \dots\dots & \dots\dots \\ f(n,1) & f(n,2) & \dots & f(n,n) \end{bmatrix} \tag{1}$$

Each element in the matrix is called pixel or image elements, f (x, y) represents the light intensity of the pixel, also known as the gray values (ie the brightness value) of f (x, y). It is a form of energy, f (x, y) values range from 0 (black) to 255 (white). Different figures from 0 to 255 stand for different gray level.

2.2. Canny Optimum Criteria

Canny believed that a well-performing edge detection operator should have the following three characteristics:

a) Low probability on mismarking non-edge points and low probability on nonmarking the real edge points.

b) The pixel marked as the edge point should be as close to the center of the real edge as possible.

c) The result of applying the operator is that there is only one pixel marked as the edge point.

According to these characteristics, Canny put forward that the edge detection operator should satisfy three optimal criteria: signal to noise ratio (SNR) criterion, location accuracy criterion and single-edge response criterion. And then he suggested the optimal edge detection algorithm.

a) SNR criterion: It means the important edges should not be missed. And there should be no spurious responses. A maximal signal-to-noise ratio means a real edge is not missed, while the non-edge point is not detected as the edge. The mathematical expression is:

$$SNR = \frac{\left| \int_{-w}^{+w} E(-x) f(x) dx \right|}{\delta \sqrt{\int_{-w}^{+w} f^2(x) dx}} \tag{2}$$

$f(x)$ is the filter impulse response of the edge $[-w,+w]$. $E(-x)$ is the edge function. δ is the root mean square of Gaussian noise. The greater value SNR is, the higher quality the edge detection has.

B) Location accuracy criterion: Distance between the actual and located position of the edge should be minimal. It means the location of the detected edge shall be as close to the real edge as possible. The mathematical expression is:

$$Loc = \frac{\left| \int_{-w}^{+w} E'(-x) f'(x) dx \right|}{\delta \sqrt{\int_{-w}^{+w} (f'(x))^2 dx}} \tag{3}$$

The greater value Loc is, the higher quality the detection has.

C) 0ne response criterion : It minimizes multiple responses to a single edge. And spurious edge response should be maximum suppressed. f stands for response to noise. The distance between adjacent maxima in the noise response to f, is $x_{\max}(f)$:

$$x_{\max}(f) = 2x_{zc}(f) = 2\pi \left[\frac{\int_{-\infty}^{+\infty} (f'(x))^2 dx}{\int_{-\infty}^{+\infty} f''(x) dx} \right]^{\frac{1}{2}} \tag{4}$$

Meeting this criterion ensures that there is only one response to the single edge.

3. Canny Edge Detection

Canny operator is the optimum-approaching operator of the product of SNR and the location. Canny algorithm smoothes image by Gaussian filter, calculates the magnitude and direction of gray level gradient, has the non-maxima suppression on gradient magnitude, and detect and connect the edge from the candidate points by the high and low thresholds. Figure 1 shows the basic steps of Canny algorithm.

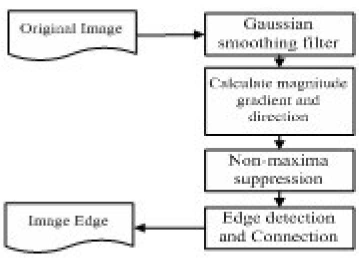

Fig. 1 Basic Steps of Canny Algorithm

3.1. Gaussian Filter Smoothes Image

Smoothing image by Gaussian filter [7,8,9] means removing image noise. Have image convolution on Gaussian function, whose variance is 1.4 and the image. Gaussian function is :

$$G(x, y) = \frac{1}{2\pi\sigma^2} \exp\left[-\frac{x^2 + y^2}{2\sigma^2} \right] \tag{5}$$

Gradient vector is

$$\nabla G = \begin{bmatrix} \partial G / \partial x \\ \partial G / \partial y \end{bmatrix} \tag{6}$$

$$\frac{\partial G}{\partial x} = kx \exp(-\frac{x^2}{2\sigma^2}) \exp(-\frac{y^2}{2\sigma^2}) = h_1(x) h_2(y) \tag{7}$$

$$\frac{\partial G}{\partial y} = ky \exp(-\frac{x^2}{2\sigma^2}) \exp(-\frac{y^2}{2\sigma^2}) = h_1(y) h_2(x) \tag{8}$$

Parameters σ stands for the width of the Gaussian filter, meaning smoothness. The larger σ is, the wider the frequency band of Gaussian filter is. Parameters σ can be adjusted according to the different images.

3.2. Calculate the Gradient Magnitude and Direction

Canny operators, by first-order differential operator, calculate the gradient magnitude and direction of individual point after being smoothed out. The partial derivatives of the two directions of the point (x, y) are

$$P_x(i, j) = \left[I(i, j+1) - I(i, j) + I(i+1, j+1) - I(i+1, j) \right] / 2 \tag{9}$$

$$P_y(i, j) = \left[I(i, j) - I(i+1, j) + I(i, j+1) - I(i+1, j+1) \right] / 2 \tag{10}$$

The gradient magnitude and direction of the point (i, j) are:

$$M(i, j) = \sqrt{P_x^2(i, j) + P_y^2(j, j)} \tag{11}$$

$$\theta(i, j) = \arctan \frac{P_x(x, y)}{P_y(x, y)} \tag{12}$$

$M(i, j)$ stands for the edge strength. And the direction angle, at which $M(i, j)$ has the local maximum reflects the direction of the edge. Then gradient magnitude should be normalized to get a global gradient magnitude.

3.3. The Non-maxima Suppression on the Gradient Magnitude

In order to determine the edge of the image, the roof ridge of gradient magnitude image shall be refined. Only the local maximum of the magnitude shall be kept, that is, non-maxima shall be suppressed to get the refined edge. Canny operator has the interpolation, along the gradient direction, in the gradient magnitude image G in the 2×2 neighborhood of the center point (i, j). If the gradient magnitude of the point $M(i, j)$ is greater than the two adjacent interpolation in the direction of $\theta(i, j)$, the point (i, j) will be marked as the candidate edge point, Otherwise marked as non-edge point.

3.4. Dual Threshold Algorithm Detection and Edge Connection

The traditional Canny operator, by dual threshold method, detects and connects edge points from the candidates points. It is more robust. The steps are:

Step 1. Set manually the high threshold T_h and low threshold T_l;

Step 2. Scan image. Choose any pixel (i, j) in the candidate edge image M. calculate its gradient magnitude $M(i, j)$.

if (gradient magnitude $M(i, j) >$ T_h*)* , the point will be marked as the edge point;

if (gradient magnitude $M(i, j) <$ T_l *)* , the point will be mark as non-edge point.

if ($M(i, j)$ *is between* T_h *and* T_l*)* , the point will be marked as suspect, it should be further decided based on the connectivity of the edge. If the adjacent pixels are the edge points, the point will be marked as the edge points. Otherwise, as non-edge points.

Step 3. Connect , through the marked Edge points and the domain relations to get the final edge detection image.

4. Improved Canny Algorithm

4.1. Improved Method of Gradient Magnitude and Direction

The traditional Canny operator calculates, in the neighborhood of 2×2, the difference the gradient magnitude, the gradient directions are horizontal, vertical, left diagonal and right diagonal zones. This method is more sensitive to noise. The non-edge could be detected and the real edge could be missed. We presents a gradient magnitude in the 8 neighborhood, which can effectively suppress noise and precisely locate the edge.

First of all, calculate the first order partial derivatives of x direction and y direction of. The mathematical formula is:

$$M_x(i, j) = \frac{[I(i, j+1) - I(i, j-1) + I(i-1, j+1) - I(i-1, j-1) + I(i+1, j+1) - I(i+1, j-1)]}{2} \tag{13}$$

$$M_y(i, j) = \frac{[I(i+1, j) - I(i-1, j) + I(i+1, j-1) - I(i-1, j-1) + I(i+1, j+1) - I(i-1, j+1)]}{2} \tag{14}$$

Then calculate the gradient magnitude and direction of the point. The mathematical formula is:

$$M(i, j) = \sqrt{M_x^2(i, j) + M_y^2(j, j)} \tag{15}$$

$$\theta(i, j) = \arctan \frac{M_x(x, y)}{M_y(x, y)} \tag{16}$$

4.2. Improved Method of Gradient Magnitude and Direction

There is some deficiencies of the dual thresholds [10] of Canny operator, though they are more flexible than one threshold. A too-high-setting threshold may miss important information, while a too-low-setting one may put too much importance on the minor matters. It is Difficult to set a general threshold. Otsu [11], a Japanese scholar, put forward an adaptive method of determining the threshold, referred to his name OTSU. The main idea is to select a threshold, which minimize the within-class variance or maximize the between-class variance. This threshold can both suppress noise and keep the fine edge.

Set the number of image pixels as N, the range of gray scale as $[0, L-1]$, the corresponding pixel number of gray level i as n_i , the probability is:

$$p_i = n_i / n \quad i = 0,1,2,\cdots,L-1 \tag{17}$$

The image pixels, by gray level are divided into two groups: C_0 and C_1. C_0 is composed of the pixels, whose gray level value is between $[0,T]$. C_1 is composed of the pixels, whose value is between $[T+1, L-1]$. The mean of the gray level distribution probability of the whole image is :

$$u_T = \sum_{i=0}^{L-1} ip_i \tag{18}$$

The mean of C_0, C_1 are

$$u_0 = \sum_{i=0}^{T} ip_i / w_0 \quad u_1 = \sum_{i=T+1}^{L-1} ip_i / w_1 \tag{19}$$

$$w_0 = \sum_{i=0}^{T} p_i \qquad w_1 = 1 - w_0 \tag{20}$$

Thus

$$u_T = w_0 u_0 + w_1 u_1 \tag{21}$$

Between-class variance is defined as:

$$\sigma_B^2 = w_0 (u_0 - u_T)^2 + w_1 (u_1 - u_T)^2 \tag{22}$$

Let T take values in turn in the range of $[0, L-1]$. The best threshold of this method is the T-value, which makes σ_B^2 e maximum. The threshold is applied in Canny operator to determine T_l by the formula $T_l = 0.5T_h$.

5. Experiment Result and Analysis

We select two image files. And put in 0.2 salt-pepper noise, as shown in Figure 2a, 3a. First by traditional Canny algorithm, set Gaussian smoothing parameter σ = 2, high threshold as 0.10 and low as 0.04 to detect edge. The results are shown in Figure 2b, 3b. Then by the improved method, applying the adaptive strategies to do edge detection, calculate gradient magnitude in the 8 neighborhood directions. The results are shown in Figure 2c, 3c.

Fig. 2a Image 1

Fig. 2b Edge Detection by Canny Algorithm

Fig. 2c Edge Detection by Improved Canny Algorithm

Fig. 3a Image 2

Fig. 3b Edge Detection by Canny Algorithm

Fig. 3cEdge Detection by Improved Canny Algorithm

Compared to the traditional Canny operator, the improved Canny method can automatically determine high and low threshold parameters according to the actual feature of the image, to get more integrated information. The continuity of the edge is strong, and positioning is accurate.

From table 1, we can see the improved algorithm is relatively slow, due to the neighborhood expansion, and adaptive threshold calculation and others.

Table 1 Parameter Settings and Time of 2 Methods

Algorithm		Image 1	Image 2
The traditional Canny algorithm	Parameters	σ =2 T_h =0.10 T_l =0.04	σ =2 T_h =0.10 T_l =0.04
	Time	36ms	48ms
Improved Canny algorithm	Parameters	σ =2 Adaptive threshold	σ =2 Adaptive threshold
	Time	41ms	51ms

6. Conclusion and Future Work

Canny operator can be applied to different situations. Canny operator can detect the edge clearly. In order to improve its performance, we propose the calculation of gradient magnitude and gradient direction based on 8 neighborhood, and make the adaptive calculation of the threshold of Canny operator by OTSU method. The experimental results show that the edge detected by the improved Canny operator has more continuity, and greater signal to noise ratio.

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