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An improved adaptive threshold canny edge detection algorithm

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Abstract: It has proposed an adaptive threshold edge detection algorithm in this paper, which applies the bilateral filtering that has the advantages of edge-preserving and noise-removing firstly. Then it uses OTSU, which is based on gradient magnitude to maximize the separability of the resultant classes, to determine the low and high thresholds of the canny operator. Finally, the edge detection and connection are performed. The experimental results show that this algorithm is practical and reliable.

Keywords: bilateral filtering; edge detection; canny operator; OTSU

I. INTRODUCTION

Edge detection is one of the most fundamental operations in the field of image analysis and computer vision, and is being and will be being the focus of research. The conventional edge detection operators, such as Roberts, Sobel, Prewitt, Kirsch, LOG and canny etc, obtain unsatisfying outcome in practice because of their drawbacks. In 1986, John Canny proposed the three performance criteria of optimal edge detection operator and had deduced an approximate implementation of the optimal edge detection operator—Canny operator[1]. Canny operator has been mostly put into practice because of its excellent performance. However, when applying canny operator to detect the edge, on one hand, Gaussian filter has to be used, although it can smooth the image and suppress the noise, at the same time, it has also smoothed the edge of the image, making the loss of the edge. On the other hand, the low and high thresholds have to be set manually when selecting the edge pixels, once the scene or illumination changes, the thresholds have to be reset manually, making the canny operator inconvenient and un-adaptive.

Given the problems mentioned above, a series of researchers have proposed their own improved algorithm. Firstly, with regard to the loss of edge when applying Gaussian filter to smooth the images, it introduced median filter to replace the Gaussian filter, and obtained rather good outcome from the image with pepper & salt noise in [2]. In [3], it proposed adaptive spatial domain to remove the pepper & salt noise of the images, and reached satisfying result of removing noise. Secondly, concerning to the settings of low and high thresholds, in [4], it introduced the adaptive threshold algorithm based on the gradient magnitude histogram and maximizing the separability of the resultant classes, and proved it was practical through examples for different images. In [3], it used variance of gray-scale to auto-adjust Gaussian space coefficient and edge detection threshold and automatically detected the edge, but it was performed under a rigorous condition. All mentioned above, in [2, 3, 4,5], to some extent, they had solved the problem of loss the edge when smoothing or the threshold determined adaptively. However, a lot of work still should be done to further improve the performance of canny operator. In this paper, the proposed improved algorithm based on bilateral filtering and maximizing the separability of the resultant classes of gradient magnitude, in some degree, can solve the problems mentioned above, and proving its practice and reliability from a series of experiments.

II. THE CONVENTIONAL CANNY OPERATOR

A. *The introduction of the conventional canny operator*

In [1], John Canny thought an optimal edge detection operator should meet the following three performance criteria:

1) Maximum of signal-noise ratio (good detection), that is to say, there should be a low probability of failing to mark real edge points, and low probability of falsely marking non-edge points. This criterion makes the output signal-noise ratio of the edge maximum.

2) Good localization, that is to say, the points marked as edge points by the operator should be as close as possible to the center of true edge.

3) Only one response to a single edge, that is to say, only one response output for a single edge, and the faint edges should be suppressed greatest.

In the procedure of edge detection, noise suppression and edge accurate locations can not meet the requirements simultaneously. While the edge detection operator smoothes

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the image to remove the noise, the uncertainty of the edge increases. In contrast, when the sensitivity of edge detection increases, the noise does. Canny operator has made a tradeoff between the noise suppression and good localization [2], and deduced an approximate implementation of the optimal edge detector. The implemented steps as follows:

1) Smooth the image with Gaussian filter

Canny operator, firstly, smoothes the original image with the 1st derivation of 2-D Gaussian function, and obtains the smoothed image g(x, y). Assuming the 2-D Gaussian function as:

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

Where σ indicates the standard variance of Gaussian function, and it determines the width of the Gaussian filter and outcome of smoothing.

2) Compute the gradient magnitude and direction of the smoothed image

Computing the data array of smoothed image with the means of finite difference in the neighborhood of 2×2, denoting the partial derivation of the x-direction and y-direction as G(x), G(y), then its gradient magnitude and direction can be computed respectively:

$$M[i,j] = \sqrt{G(x)^2 + G(y)^2} \quad (1\text{-}2)$$

$$Q[i,j] = \arctan(G(y)/G(x)) \quad (1\text{-}3)$$

3) Perform non-maximum suppression and determine the candidate edge points

In the image of gradient magnitude, it produces the multi-points appearance surrounding the point M [i, j], which should be thinned to obtain the accurate positions by the means of single pixel. Namely, the procedure of this is called non-maximum suppression. During the processing, the canny operator performs the interpolation along its gradient direction surrounding its 8 neighborhoods, and then the center pixel M [I, j] is compared with its adjacent two pixels along its gradient direction. If it is less than any of the two, it is marked as 0; otherwise, it is marked as 1. When finishing this procedure, the multi-points are thinned as one pixel width, and the accurate gradient magnitude is preserved [3].

4) Perform edge detection and edge connection with double thresholds

Canny operator produces the final edge from the candidate edge points with double thresholds. Firstly, it selects the high threshold Th and the low threshold Tl ; Secondly, it scans the whole image to detect any pixels that are marked as candidate edge points. If the gradient magnitude G(i,j) of Point(i, j) is greater than the high threshold Th, then it is absolutely determined as edge point; It is completely not edge point when the gradient magnitude G(i,j) of point(i,j) is less than Tl. For these points whose gradient magnitudes range from Tl to Th, they are considered as the suspected edge points and examine their connectivity. If their adjacent pixels have edge pixels, then they are also considered as edge pixels, otherwise, they are non-edge pixels. [6]

B. the drawback analysis of the conventional canny algorithm

Canny operator, although, is deduced based on the optimization theory, in practice, it does not often presents optimally. Firstly, this operator smoothes the image with Gaussian filter, which has also smoothed the high frequent signals that may the edge pixels present, making the loss of edge information while suppressing the noise. In addition, the high and low thresholds are set manually requiring prior empirical knowledge, and it is possible to get a proper threshold after many experiments. However, in practice, the high and low thresholds often change because of the scenes and illumination change frequently. The conventional canny operator lack of the capability of self-adaptation, in many cases, it can not obtain a satisfying detection results.

III. THE IMPROVED CANNY ALGORITHM

A. The introduction of Bilateral Filtering

The conventional canny algorithm smoothes the image with Gaussian filter, while suppressing the noise, the edge pixels are also smoothed. In 1988, C.Tomasi and R.Manduchi proposed bilateral filtering. The traditional low-pass filter considered the center pixel similar to its neighborhood and unconcerned with the noise. However, the pixels on the edges of the images greatly differ from its bilateral pixels, thus when smoothing, the edge pixels are unavoidable to be smoothed, making the loss of the edge pixels. Fortunately, when processing the neighbor pixels, the bilateral filtering not only has considered the closeness of the space, but also the range of the intensity. By the means of non-linear combination of these two, a new filter is born, which can smooth the image adaptively. For image f(x), after applying low-pass filter, the filtered image can be denoted as h(x), namely:

$$h(x) = k_d^{-1}(x)\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(\xi)c(\xi,x)d\xi \quad (2\text{-}1)$$

Where $c(\xi,x)$ denotes the geometric closeness between the neighborhood center x and a nearby point ζ . Assuming $x=(x1,x2), \xi=(\xi1,\xi2)$ as the spatial coordinate, if the low-pass filter preserve the direct currency of the signal, then

$$k_d(x) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} c(\xi,x)d\xi \quad (2\text{-}2)$$

If the filter is shift-invariant, $c(\xi, x)$ is the vector difference $\xi - x$. Range filtering is similar, accordingly, it can be defined as:

$$h(x) = k_r^{-1}(x)\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(\xi)s(f(\xi), f(x))d\xi \quad (2\text{-}3)$$

Where $s(f(\xi), f(x))$ indicates the photometric similarity between the center pixel x and its neighborhood point ξ . At this moment:

$$k_r(x) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} s(f(\xi), f(x)d\xi \quad (2\text{-}4)$$

Contrary to what occurs with the geometric closeness, the photometric similarity is determined by the difference $f(\xi) - f(x)$. According to the formula (2-1) and formula (2-3), the combined filtering by spatial filtering and range filtering can be described as follows:

$$k(x) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} c(\xi, x)s(f(\xi), f(x))d\xi \quad (2\text{-}5)$$

This combined filtering through the spatial domain and range domain is called bilateral filtering. Its advantages are that it replaces the pixel value at x with an average of similar and nearby pixel values. In smooth regions, pixel values in a small neighborhood are similar to each other, and approximating to a constant. At this moment, the bilateral filtering is degraded into a standard domain filter. In a sharp region, the filter replaces the bright pixel at the center by an average of the bright pixels in its vicinity, and essentially ignores the dark pixels. Conversely, when the filter is centered on a dark pixel, the bright pixels are ignored instead [6]. Thus, the bilateral filtering can not only filter the noise, but also preserve the edge details, which is practical method that can be put into practice to a greet extent.

B. OTSU adaptively determine the thresholds

OTSU is an approach that makes the separability of the resultant classes maximum to automatically determine the thresholds. Its basic ideas are according to the gray characteristics of images, the image is separated into background and foreground, making their variances of inter-class maximum, finally obtaining the optimal thresholds. For an $M \times N$ image $I(x, y)$, the segmented threshold of foreground and background denotes as T, the rate of foreground is $\omega 1$, its average value is $u1$; the rate of the background is $\omega 2$, and the average value is $u2$, the mean of the image is u , the variance of the inter-class is g. Then we can get the following formulas:

$$\omega_1 = \frac{N_1}{M \times N} \quad (2\text{-}6)$$

$$\omega_2 = \frac{N_2}{M \times N} \quad (2\text{-}7)$$

$$N_1 + N_2 = M \times N \quad (2\text{-}8)$$

$$\omega_1 + \omega_2 = 1 \quad (2\text{-}9)$$

$$u = u_1 \times \omega_1 + u_2 \times \omega_2 \quad (2\text{-}10)$$

$$g = \omega 1 \times (u - u_1)^2 + \omega_2 \times (u - u_2)^2 \quad (2\text{-}11)$$

From the formula.(2-10) and formula. (2-11), the following formula can be obtained:

$$g = \omega_1 \times \omega_2 \times (u_1 - u_2)^2 \quad (2\text{-}12)$$

Finally, applying traversed approach to obtain the threshold which makes g maximum, and then T is the optimal threshold. As a sequence, we consider T as the high threshold, and the low threshold can be got as:

$$T_h = k \times T_l \quad (2\text{-}13)$$

Where k is a constant (recommend as 2-3), its default value is 2.

C. Steps of improved algorithm

1) Smooth the image with bilateral filtering

Applying bilateral filtering to smooth the image and remove the noise, when the bilateral filtering smoothed the image, it considers not only the domain relation, but also the range relation, by the non-linear combination of these two, it can adaptively smooth the image and obtain the smoothed image. After this step, not only much noise has been removed, but the edge information has been preserved.

2) Compute the gradient magnitude and direction

After processing from (1), in this step, the gradient, direction and magnitudes are computed. The details can refer to the description of the conventional canny operator.

3) Perform non-maximum suppression

This step is same as the conventional canny operator, and more details can refer to the related contents of the introduction of the conventional canny operator in section 2.

4) Adaptively determine the double thresholds and perform edge detection and connection

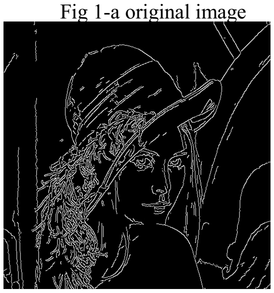
Calculating the histogram of gradient magnitudes, and then the OTSU algorithm is applied to determine the double thresholds Th and Tl. After this, it scans the whole image to detect any pixels that are marked as candidate edge points. If the gradient magnitude G(i,j) of Point(i, j) is greater than the high threshold Th, then it is absolutely determined as edge point; It is completely not edge point when the gradient magnitude G(i,j) of point(i,j) is less than Tl. For these points whose gradient magnitudes range from Tl to Th, they are considered as the suspected edge points and examine their connectivity. If their adjacent pixels have edge pixels, then they are also considered as edge pixels, otherwise, they are non-edge pixels. [6]

IV. RESULTS AND ANALYSIS

The proposed improved algorithm in this paper is implemented under the platform Visual C++ 6.0 with the open source library Opencv 1.0. And a series of images have been tested. Compared with the conventional canny algorithm, the results show as follows:


Fig 1-a original image


Fig 1-b conv-canny 1



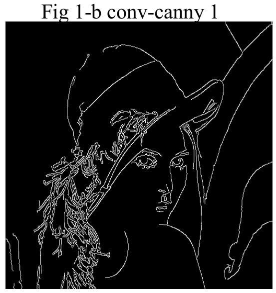


Fig 1-d proposed in this paper

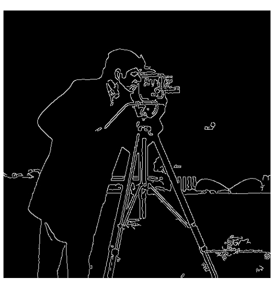


Fig 2-a original image


Fig 2-b conv-Canny 1


Fig 2-c conv-canny 2

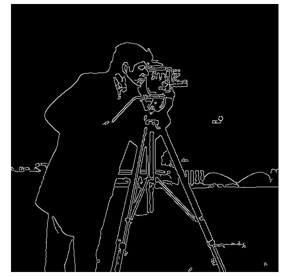


Fig 2-d proposed in this paper


Fig 3-a original image

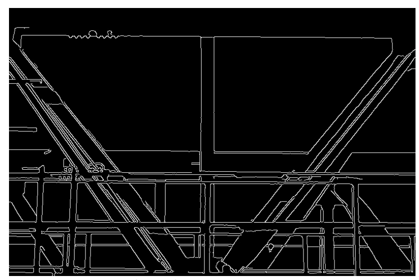


Fig 3-b conv-canny 1

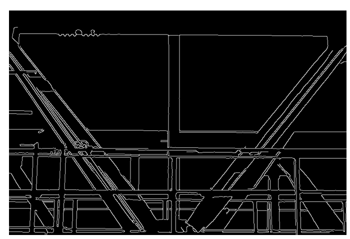


Fig 3-c conv-canny 2

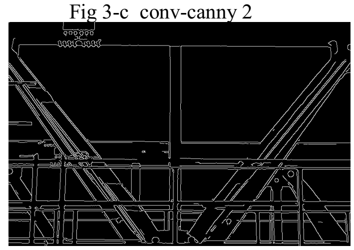


Fig 3-d proposed in this paper

Note: there are totally 3-groups experimental images marked as a, b, c. (i=a, b, c) i-1 denotes the original images, i-2 denotes the image performed with conventional canny with low threshold, and i-3 denotes the image performed with conventional canny with higher threshold than i-2, i-4 denotes the image performed with the algorithm proposed in this paper.

V. Conclusion

In this paper, it has described the conventional canny in details and analyzed its drawbacks, and proposed the improved adaptive threshold canny algorithm based on the bilateral filtering and the maximum of the separability of the resultant classes based on the gradient magnitudes. Firstly, this algorithm applies bilateral filtering to smooth the image, which not only has suppressed the noise of the image, but also has well preserved the edges. Secondly, OTSU is performed to adaptively determine the low and high thresholds. The experimental results show that this improved algorithm can well solve the drawback analyzed above, as well as, it have the capability of self-adapting the changes of scenes and illumination, and extended its use.

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