Improvement and Implementation for Canny Edge Detection Algorithm

Yang Tao[1, 2], Qiu Yue-hong[1]

([1]*Xi'an Institute of Optics and Precision Mechanics, Xi'an, 710119,* [2]*University of Chinese Academy of Sciences, Beijing, 100049, China*)

ABSTRACT

Edge detection is necessary for image segmentation and pattern recognition. In this paper, an improved Canny edge detection approach is proposed due to the defect of traditional algorithm. A modified bilateral filter with a compensation function based on pixel intensity similarity judgment was used to smooth image instead of Gaussian filter, which could preserve edge feature and remove noise effectively. In order to solve the problems of sensitivity to the noise in gradient calculating, the algorithm used 4 directions gradient templates. Finally, Otsu algorithm adaptively obtain the dual-threshold. All of the algorithm simulated with OpenCV 2.4.0 library in the environments of vs2010, and through the experimental analysis, the improved algorithm has been proved to detect edge details more effectively and with more adaptability.

Key word: improved Canny, bilateral filtering, Otsu, gradient templates

1. INTRODUCTION

Image edge detection is an elementary feature for Image segmentation, Pattern recognition, Motion detection and some corresponding theory. The points at which image brightness changes sharply, such as in step change, are typically organized into a set of curved line segments termed image edge.[1] There are many methods for edge detection, but most of them can be grouped into two categories, search-based and zero-crossing based. These methods detect edges by first-order or second-order derivative expression such as the gradient magnitude and direction, which consist of Roberts, Prewitt, Sobel, LoG [2] operator. Based on the optimization algorithm, with a series of advantages of high SNR and detection accuracy, Canny[3] algorithm has reliable effect. So far, kinds of improved Canny algorithms have been proposed. This paper analyzes the traditional Canny algorithm and improved it. On one hand, the bilateral filter was used to smooth image instead of Gaussian filter, which solves the defects caused by artificial setting Gaussian function variance. On the other hand, to reduce the noise sensitivity in gradient calculating and to promote the detection accuracy, the improved algorithm used a new kind of 4 directions gradient templates. Finally, the application of an improved Otsu algorithm[4] adaptively get the best threshold value which effectively balances the contradiction between the anti-noise function and the retaining of edge details. The improved algorithm flow chart are shown in Fig.1:

Seventh International Conference on Digital Image Processing: ICDIP 2015, edited by Charles M. Falco, Xudong Jiang, Proc. of SPIE Vol. 9631, 96310H · © 2015 SPIE
CCC code: 0277-786X/15/$18 · doi: 10.1117/12.2197080

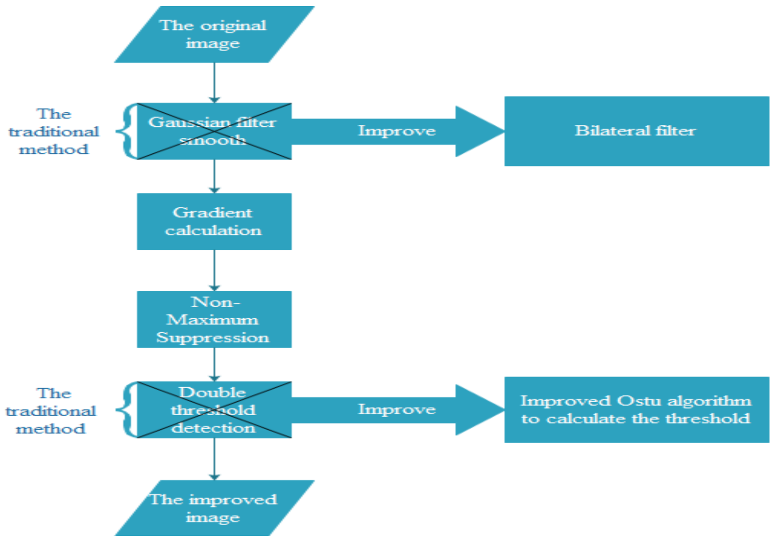


Fig.1

2. THE PRINCIPLE AND ANALYSIS OF TRADITIONAL CANNY ALGORITHM

2.1 Fundamental principles of Canny algorithm

According to the computational theory of edge detection established by John F. Canny, the general criteria for an ideal edge detection includes:[5]

1. Detection of edge with low error rate, which means that the detection should accurately catch as many edges shown in the image as possible.
2. The edge point detected from the operator should accurately localize on the center of the edge.
3. A given edge in the image should only be marked once, and where possible, image noise should not create false edges.

To satisfy these requirements, Canny considered the mathematical problem of deriving an optimal smoothing filter given the criteria of detection, localization and minimizing multiple responses to a single edge.

2.2 Basic process of Canny algorithm and defect analysis

1. Apply Gaussian filter to smooth the image in order to remove the noise, the Gaussian function defined by (1). In the formula, edge location accuracy is proportional to σ. To smooth the image, a Gaussian filter is applied to convolve with the image as function (2). Owing to the σ value determined artificially, the image may be over smoothed and lost edge details. Thus, the traditional Gaussian filtering algorithm has certain limitations

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

$$G(x,y) = f(x,y) * H(x,y) \tag{2}$$

2. Find the intensity gradients of the image with 2×2 traditional gradient template. The edge detection operator returns a value for the first-order derivative in the horizontal direction defined by G_x and the vertical direction defined by G_y. The gradient magnitude and direction can be determined as:

$$M(x, y) = \left(G_x^2 + G_y^2\right)^{\frac{1}{2}} \tag{3}$$

$$\theta(x, y) = \arctan\left(\frac{G_x}{G_y}\right) \tag{4}$$

But the 2×2 neighborhood window is sensitive to noise.[6] In order to calculate a better gradient magnitude values and directions and retain more edge details, various improved gradient templates are introduced.

3. Apply non-maximum suppression (NMS) to get rid of spurious response to edge detection. Each pixel in the gradient image compares the edge strength with pixels in the positive and negative gradient directions. If the edge strength of the current pixel is the largest, the value will be preserved. Otherwise, the value will be set to zero.

4. Apply double threshold to determine potential edges, and track edge by hysteresis. In order to get rid of the spurious responses from these bothering factors, two threshold values are set to clarify the different types of edge pixels.[7] But in traditional Canny algorithm, the two threshold values are empirically determined values, which will need to be defined artificially when applying to different images. Thus, the traditional algorithm is inapplicability now.[8]

3. IMPROVEMENT OF TRADITIONAL CANNY ALGORITHM

3.1 An improved Bilateral filter

Gaussian filter is applied to smooth out the noise, but it will also smooth the edge. A bilateral filter is an edge-preserving and noise-reducing smoothing filter.[9] The model is demonstrated as:

$$\hat{I}(x, y) = \frac{\sum_{(i,j)\in M_{x,y}} w_\varsigma(i, j)\, w_\tau(i, j)\, I(i, j)}{\sum_{(i,j)\in M_{x,y}} w_\varsigma(i, j)\, w_\tau(i, j)} \tag{5}$$

$$w_\varsigma(i, j) = \exp\left(-\frac{|i - x|^2 + |i - y|^2}{2\sigma_\varsigma^{\,2}}\right) \tag{6}$$

$$w_\tau(i, j) = \exp\left(-\frac{|I(i, j) - I(x, y)|^2}{2\sigma_\tau^{\,2}}\right) \tag{7}$$

In the model, let $\hat{I}$ be image after filter; let $w_\tau(i, j)$ be a range kernel for smoothing differences in intensities; let $w_\varsigma(i, j)$ be a spatial kernel for smoothing differences in coordinates. Let σ_τ and σ_ς be the exponential variance. The smooth process influence by both range kernel and spatial kernel. When the σ_ς increase, the number of pixels participating in the weighted process increase too. Image blur, but the limitation of σ_τ can keep more edge character. Thus the bilateral filter preserved more edge details and reduce noise. In this article, we introduce a new improved bilateral filtering method from reference [9]. A compensation function based on pixel intensity similarity judgment in the filter window is introduced in. The improved range kernel defined by:

$$w_\tau(i,j) = \exp\left(-\frac{\left|I(i,j) - I(x,y) - \zeta(x,y)\right|^2}{2\sigma_\tau^2}\right) \tag{8}$$

The compensation function $\zeta(x,y)$ defined by three criteria:

1. If the absolute value of difference from current pixel to the center pixel is less than $\sigma_\tau/3$, then suppose that $I(i,j)$ is similar to $I(x,y)$, and retain the $I(i,j)$ value; Otherwise let $I(i,j)$ be zero;
2. The compensation function defined by the number of similar pixels in the filter window. If less than one-third pixels in filter window is set to zero, then let $\zeta(x,y)$ be zero. Otherwise, we define the compensation function according criterion 3.
3. Let the minimum pixel in window be MIN, let the maximum pixel in window be MAX and let the pixel mean be $MEAN$.Using the formulate $\Delta = I(x,y) - MEAN$. If $\Delta > 0$, suppose that $\zeta(x,y) = MAX - I(x,y)$; if $\Delta < 0$, suppose that $\zeta(x,y) = MIN - I(x,y)$; if $\Delta = 0$, suppose that $\zeta(x,y) = 0$.

We compared the improved bilateral filter with Gaussian filter in smoothing the Lena image with Gauss noise (mean value is 0.003, variance is 0.004) and pulse noise (intensity is 0.01). Let bilateral filter σ_τ and σ_ς be 100.

(a) Original image (b) Gaussian filter (c) Improved Bilateral filter

Fig.2 Comparison of filtering effect

Obviously, the image applied to improved bilateral filter preserved more edge details and reduce noise effectively.

3.2 Improvement of Gradient Templates

To resolve the high sensitivity result from the small-scale window gradient computation, this article introduced a modified 3×3 neighborhood windows. In the 8-connected neighborhood pixels, calculate the first-order derivative. We used 4 gradient templates in x-axis direction, y-axis direction, 45 degree direction and 135 degree direction.[10] The equations are demonstrated as following:

$$\begin{aligned} f_x(i,j) &= f(i+1,j) - f(i-1,j) \\ f_y(i,j) &= f(i,j+1) - f(i,j-1) \\ f_{45^\circ}(i,j) &= f(i-1,j+1) - f(i+1,j-1) \\ f_{135^\circ}(i,j) &= f(i+1,j+1) - f(i-1,j-1) \end{aligned} \tag{9}$$

Then, horizontal difference G_x is:

$$G_x(i,j) = f_x(i,j) + \frac{\sqrt{2}}{2}\left[f_{45^\circ}(i,j) + f_{135^\circ}(i,j)\right] \tag{10}$$

Vertical difference G_y is:

$$G_y(i,j) = f_y(i,j) + \frac{\sqrt{2}}{2}\left[f_{135^\circ}(i,j) - f_{45^\circ}(i,j)\right] \tag{11}$$

Then, by formulate (3), (4), we can calculate the edge gradient magnitude and direction.

4. IMPROVEMENT OF OTSU ALGORITHM

Otsu algorithm is used to automatically perform clustering-based image threshold-classification.[11] The algorithm assumes that the image contains two classes of pixels following bi-modal histogram, target pixels and background pixels, it then calculates the optimum threshold separating the two classes so that their inter-class variance is maximum. In the article, the whole algorithm process is; suppose that {0, 1, 2… L-1} to the gradient-scale, N is the total number of pixels in the image, Set n_i to the number of pixels with gradient magnitude i, compute histogram and probabilities of each intensity level $p_i = \frac{n_i}{N}$. Set up initial high-low thresholds k, m to classify the gradient magnitude image based on non-maximum suppression into three classes: C_0, C_1 and C_2. The class C_0 includes gradient magnitude with $0 \sim k$, represent non-edge pixels; the class C_1 includes gradient magnitude with $k+1 \sim m$, represent potential of weak edge pixels; the class C_2 includes gradient magnitude with $m \sim l-1$, represent edge pixels. Suppose the image gradient magnitude means to: $\mu_T = \sum_{i=0}^{l-1} ip_i$, the class probabilities , the class means and the intra-class variance of each class is

$$
\begin{cases}
\omega_0 = \sum_{i=0}^{k} p_i \quad \mu_0 = \dfrac{\sum_{i=0}^{k} ip_i}{\omega_0} \quad \sigma_0^2 = \dfrac{\sum_{i=0}^{k} \left(i-\mu_0\right)^2 p_i}{\omega_0} \\
\omega_1 = \sum_{i=k+1}^{m} p_i \quad \mu_1 = \dfrac{\sum_{i=k+1}^{m} ip_i}{\omega_1} \quad \sigma_1^2 = \dfrac{\sum_{i=k+1}^{m} \left(i-\mu_1\right)^2 p_i}{\omega_1} \\
\omega_2 = \sum_{i=m+1}^{l-1} p_i \quad \mu_2 = \dfrac{\sum_{i=m+1}^{l-1} ip_i}{\omega_2} \quad \sigma_2^2 = \dfrac{\sum_{i=m+1}^{l-1} \left(i-\mu_2\right)^2 p_i}{\omega_2}
\end{cases}
\tag{12}
$$

The evaluation function based on maximizing inter-class variance defined by:

$$
\sigma^2\left(k,m\right) = \sum_{j=0}^{2} \left(\mu_j - \mu_T\right)^2 \omega_j \tag{13}
$$

According to the iteratively computation, the algorithm obtain the optimum dual-threshold k and m adaptively. In reference [4], the author proposed an improved Otsu algorithm which combine neighborhood pixels information. That is equivalent to a pretreatment process for gradient image. This article introduced this method. Firstly, let the maximum and minimum of the gradient magnitude be $\min Gra$, $\max Gra$. Then, let the gradient magnitude at the first and last peak of histogram be T_0 and T_1. For each gradient magnitude defined by $M(x, y)$, if $M(x, y) > T_0$ and $M(x, y) < T_1$, suppose that:

$$
\begin{aligned}
M(x,y) = 0.25 \times \Big[& \left(\left|M(x-1,y) - M(x,y)\right| + \left|M(x+1,y) - M(x,y)\right|\right) \\
& + \left(\left|M(x,y-1) - M(x,y)\right| + \left|M(x,y+1) - M(x,y)\right|\right) \Big] \\
& + M(x,y)
\end{aligned}
\tag{14}
$$

Finally, instead of gradient-scale defined by [0, 1, 2… L-1], the improved algorithm obtained the optimum dual-threshold k and m in $\left[\alpha, \beta\right]$. And suppose that $\alpha = 2 \times T_0 - \min Gra$, $\beta = 2 \times T_1 - \max Gra$.

5. IMPLEMENT OF ALGORITHM AND ANALYSIS

In order to illustrate the validity of the algorithm in this paper, we contrasted the improved approach performance with the traditional algorithm in three groups of experimental images. The Experiment adopted microcomputer with the Intel Core 2.0 GHz, and simulated with OpenCV 2.4.0 library in the environments of vs2010.

Experiment 1: The pre-detection figure, 256×256 pixels, is adopted to rice image and Japan Temple image which download from Ground truth database of University of Washington. For color images, made gray pretreatment. In traditional Canny algorithm, let the cvCanny[12] function threshold parameters be (40, 120). In the contrasting improved algorithm, set bilateral filter σ_{ς} to 10, and σ_{τ} to 300.

(a) Original image (b) Traditional Canny algorithm (c) Improved Canny algorithm

Fig.3 Detection effect comparison of noise free rice image

(a) Original image (b) Traditional Canny algorithm (c) Improved Canny algorithm

Fig.4 Detection effect comparison of noise free Japan Temple image

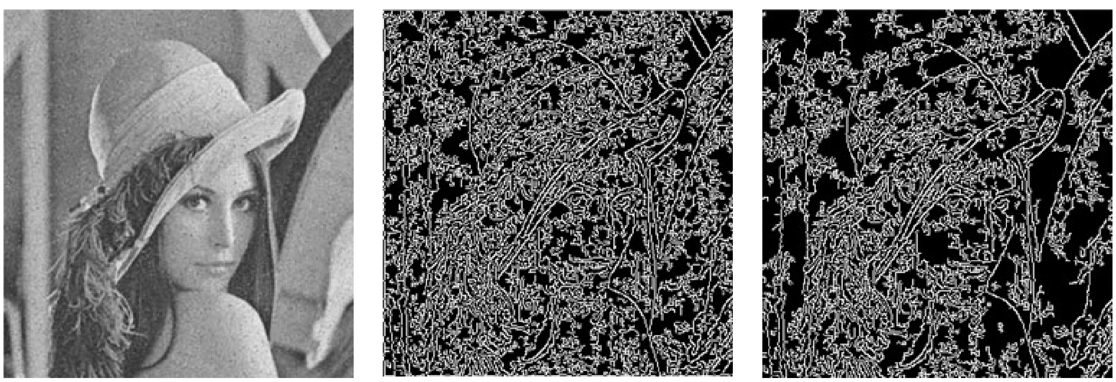
According Fig.3 and Fig.4, obviously, the improved algorithm detected more edge detail, and the performance image has less false edge. For the sake of application of bilateral filter, in Fig.4, the Temple image, the outline of lantern is more complete, and the detail of wire and pole is preserved. The lattice on the window is more distinct too. In addition, to an image with simple and clear edge, as Fig.3, the improvement of the improved algorithm is limited. However, to an image with enormous edge details, the improved algorithm has better effect.

Experiment 2: The pre-detection figure, 256×256 pixels, is adopted to Lena image which added the Gauss noise and pulse noise. Let the mean value of the Gauss noise be 0.003, let the variance be 0.004. Let the intensity of the pulse noise be 0.01. In traditional Canny algorithm, let the cvCanny function threshold parameters be (40, 120) (Fig3. b) and (80, 200) (Fig3. c). In the contrasting improved algorithm, let bilateral filter σ_ς be 100(Fig3. d) and 300(Fig3. e), let σ_τ be 100(Fig3. d) and 300 (Fig3. e). (Let σ_τ and σ_ς be 10-300 usually)

At last, we apply traditional canny algorithm to a median filtering Lena image (Fig3. f), and compare with other edge images. In Fig.5.b and Fig.5.c, with the increasing of high-low thresholds, (the threshold setting empirical formula defined by: $lowthreshold = 0.4 \times highthreshold$) the edge of image tend to be obvious.

Because of the limitation of traditional algorithm, it's hard to obtain more distinct edge image. According Fig.5.d and Fig.5.e, the improved Canny algorithm rejected most of the noise and retained the most of edge details. Although the edge images have false edge and edge loss, we can conclude, the improved Canny algorithm has better performance in the field of noise smooth. Finally, in Fig.5.f, which applied traditional algorithm to a median filtering Lena image. Despite a little noise remain, the effect of improved algorithm has less false edge and more clear face outline.

Reference [8] introduce an evaluation method of edge detection algorithm. According to the number of edge pixels, 4-connected neighborhood pixels, 8-connected neighborhood pixels, we calculate a comparable ratio. For each image, let A be edge pixel, let B be 4-connected neighborhood, let C be 8-connected neighborhood pixel. If the ratio of C/A and C/B has a small value, the continuity of the detected edge is excellent. By the above definitions, the value of C/B has more influence in evaluation.



(a) Lena image with noise

(b) Traditional algorithm with Threshold(40,120)

(c) Traditional algorithm with Threshold(40,200)

(d) Improved Canny algorithm1

(e) Improved Canny algorithm2

(f) Traditional algorithm with Median filtering image

Fig.5 Detection effect comparison of noise-add Lena image

For Fig.4, we compute the parameter of A, B, C as

Table 1: Statistical results of Japan Temple image

Algorithm	Edge pixel A	4-connected neighborhood B	8-connected neighborhood C	C/A	C/B
Traditional Canny	19352	11368	3590	0.185	0.316
Improved Canny	21694	14631	4942	0.228	0.338

According to Table 1, the improved algorithm has advantage in the edge continuity detection also.

6. CONCLUSION

Aim at some disadvantages of traditional Canny algorithm, this paper proposed an improved Canny edge detection algorithm. The bilateral filter is applied to improve the limitation of Gaussian filter. An improved Otsu algorithm replaces the traditional dual-threshold algorithm. Above experimental results shown that, the improved algorithm effectively detect the image edge. While still preserving the advantages of traditional algorithm, it enhance the ability of detecting the details. In the aspect of noise suppression, there is obviously improved.

Acknowledgments

The first author is grateful to thank Yuehong Qiu for his guidance in research. The research work was supported by National Natural Science Foundation of China under Grant No. 61178033 and Natural Science Foundation of China under Grant No.11310301020.

References

[1] Gonzalez R C. Woods R E. Digital Image Processing (Third Edition) [M]. Beijing Publishing House of Electronics Industry. 2011:445-465

[2] Michael D. Heath, Sudeep Sarkar, Thomas A. Sanocki, Kevin W. Bowyer. Comparison of Edge Detectors: A Methodology and Initial Study [J]. Computer Vision and Image Understanding, 1998, 69.

[3] Canny J. A computational approach to edge detection. [J]. IEEE Transactions on Pattern Analysis and Machine Intelligence, 1986, 86.

[4] HU bin, GONG Ning-sheng. An Improved Otsu' Thresholding Segmentation Method [J]. Microelectronics & Computer, 2009, 12:153-155.

[5] ZHANG Bin, HE Sai-xian. Improved Edge-detection Method Based on Canny Algorithm [J]. Infrared Technology, 2006, 03:165-169.

[6] Bao Paul, Zhang Lei, Wu Xiaolin. Canny edge detection enhancement by scale multiplication. [J]. IEEE Transactions on Pattern Analysis and Machine Intelligence, 2005, 279.

[7] LIANG Guang-ming, SUN Ji-xiang, MA Qi, YAO Chun-guang. An Application of Otsu Algorithm on Canny Operator [J]. Journal of National University of Defense Technology, 2003, 05:36-39.

[8] LIN Hui, ZHAO Chang-sheng, SHU Ning. Edge detection based on Canny operator and evaluation [J]. Journal of Heilongjiang Institute of Technology, 2003,02:3-6+16

[9] ZHANG Hai-rong, TAN Jie-qing. Improved bilateral filtering algorithm [J]. Journal of Hefei University of Technology (Natural Science), 2014, 09:1059-1062.

[10] WANG Zhi, HE Sai-xian. An Adaptive Edge-detection Method Based on Canny Algorithm [J]. Journal of Image and Graphics, 2004, 08:65-70.
[11] Otsu N.A threshold selection method from gray-level histograms [J].IEEE Transactions on Systems Man and Cybernetics, 1979, 9(01):62.DOI:10.1109/TSMC.1979.4310076.
[12] LI Song, PING Xi-jian, DING Yi-hong. Application Of Open Source Computer Vision Library [J]. Computer & Information Technology, 2005, 08:134-136