Research on the optical image edge detection based on the improved LOG operator

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Abstract: - Edge detection has been a hot issue in image processing field for many years. This paper focuses on the LOG operator and its improvement methods. Firstly, a new edge detection template is proposed, which increases the detect direction for the original Laplace template and re-allocation of the weight reasonable. Secondly, this paper proposes an adaptive selection strategy of threshold for edge extraction based on the pixel neighborhood correlation. Experimental results show that the proposed algorithm significantly improved with better detection effect compared to traditional LOG operator and others, and very suitable for practical engineering.

Key-Words: - Image, Edge detection, LOG operator, Template, Threshold selection, Neighborhood correlation

1 Introduction

There are a lot of photoreceptor cells in human eyes, so the optical image which generated based on the principle of light's transmission and refraction is most likely to be recognized and remembered by the human eyes. Now, the image people often said in image processing field generally means the image is the optical image. For the study of optical image processing has been carried out for a long time, in which the optical image edge detection has been one focus of research [1]. The edge of the image actually is a series of points with discontinuous brightness or grayscale, which is an important feature of the image. It depicts the contour feature information of the image in the foreground entities, which is very important for subsequent processing of the image meaning, so the image edge detection technology has been widely used in the aerospace, communications, geographic exploration, health and other fields, and is playing an important role [2-3]. For example, in the traffic control system, the image edge detection needs to be performed firstly for the car, and then the license can be positioned.

Image edge contains a wealth of information, which is an important basis for image segmentation, feature extraction and other analysis process. Currently, the most commonly edge detection operators include Robert operator, Sobel operator, Kirsch operator, Prewitt operator, Laplace operator and so on. The basic idea of these detection algorithms is to construct edge detection operator in small neighborhood of the original image, and then run first-order or second-order differential operation to obtain maximum gradient or the zero-crossing point of second-order derivative, and finally select the appropriate threshold to extract the boundary [4-5]. Generally, the image generated by various instruments may be contains the noise, so the processing for noise must be considered simultaneously when detected the image edge. Marry and Hildreth combine the Gaussian filter and Laplacian edge detection to form the LOG (Laplacian of Gaussian) algorithm. Laplace operator with advantages of rotational invariance and shift invariance, but it also has the disadvantage of losing the edge direction information and increased noise. For this case, the literature [6] studied the statistical characteristics of Laplace operator with posture-invariant condition, the detection effort is good, but it is not suitable for the image within noise; while the literature [7] studied the use of gray correlation to improve LOG algorithm, the detection performance is enhanced greatly, but the complexity of the algorithm is too high, which limits its application; literature [8] proposed an adaptive LOG algorithm based on energy differential and applied it to the infrared video processed, simulation results show that the algorithm can achieve good edge detection result, but this algorithm is affected by the detection template, if the template is selected inappropriate, the detection result will become so bad. These researches improve the shortcomings of traditional LOG algorithm to some extent, but with limited effect, and the scope for improvement is not comprehensive enough.

Based on the analysis above, this paper will improve the traditional LOG algorithm in two ways. Firstly, a new detection template is proposed according to the disadvantages of losing edge direction information and noise strengthen; secondly, the fixed threshold is often used in traditional LOG algorithm when extracted boundaries, which is given generally based on human experience. This paper presents an adaptive selection strategy of threshold based on the pixel neighborhood correlation, which can make edge extracting with adaptive features. The innovation of this paper is to improve the traditional LOG algorithm from these two aspects simultaneously, and the simulation results show that the detection effect of improved algorithm is significantly improved, while the detection time not increases significantly, and the overall efficiency of the algorithm improved obviously.

2 Definition and characteristics of Laplace operator

For an image, the edge means the boundary of the region where image gray changes dramatically. So it can reflect these changes by the gradient of gray distribution, that is, the edge of image can be examined by the differential of the image [9]. If the gradient of an image is $\nabla f(x,y)=\frac{\partial f}{\partial x}i+\frac{\partial f}{\partial y}j$, and the mode gradient is $|\nabla f|=\sqrt{f_x^2+f_y^2}$, then for a continuous function with two variables $f(x,y)$, the Laplace operator can be defined as:

$$\nabla^2 f=\frac{\nabla^2 f}{\partial x^2}+\frac{\nabla^2 f}{\partial y^2}$$

(1)

It can be known from equation (1) that the Laplace operator is defined according to the second order partial derivatives in the sum direction. So the first-order partial derivatives of image edge have the local extreme value when the gray of edge changes obviously, and the second order partial derivatives will across the zero points at the edges. For practical applications, Laplace operator is achieved by second-order differential. There are three kinds of common Laplace templates as shown is figure 1.

0	1	0
1	-4	1
0	1	0

a

1	0	1
0	-4	0
1	0	1

b

1	1	1
1	-8	1
1	1	1

c

Fig.1 Laplace operator templates

We can see from the definition and templates of the Laplace operator that its advantage is rotational invariance, shift invariance and sharpen edges, but its disadvantage is also very distinct. Firstly, due to the Laplace operator is second-order differential operation, although the influence of edge blur is decreased by sharpening operation, the affect of noise increased simultaneously, result in the losing of edge information; secondly, a fixed threshold is used by LOG algorithm to extract the boundary commonly, that is also the disadvantage of the most common edge detection algorithms [10]. If the threshold is too high, many edges can not be detected; while if the threshold is too low, many of the non-edge pixels will be erroneously detected as edge. In particular, when the structure of prospects is more complex and the texture changes more dramatically, the effect of boundary extraction using the fixed threshold is often poor.

3 Improvement of LOG algorithm

3.1 Improvement of Laplace templates

It can be seen from figure 1 that the template in figure 1a can only detect the edge in horizontal and vertical directions, including 0°, 90°, 180°, 270°; the template in figure 1b can only detect the edge in diagonal directions, including 45°, 135°, 225°, 315°; figure 1c can detect more directions and its detection effect is a little better, it only consider 8 main directions, failed to consider some other directions, so the overall detection accuracy is not high.

There are two problems need to be considered when improves the Laplace template. Firstly, the detection directions should be added in order to increase the detection accuracy, and allocates weights rationally; secondly, increases the directions will result in the expending of template size, which can further increase the complexity of algorithm and the efficiency of algorithm will drop.

Considering the impact of these two aspects, this paper will increase the size of the original Laplace template to 5×5. This change can increase the detection directions, while the complexity of the algorithm will not too high. When allocating the weights, the directions of 0°，90°，180° and 270°

as the main detection directions, their weights is 1; the directions of 45°, 135°, 225° and 315° as the secondary detection directions, their weights is 1/2; the directions of 22.5°, 67.5°, 112.5°, 157.5°, 202.5°, 247.5°, 292.5° and 337.5° as the assistant detection directions, their weights is 1/4. So the center of the template is -8, the improved Laplace template is shown in Figure 2.

0	1/4	0	1/4	0
1/4	1/2	1	1/2	1/4
0	1	-8	1	0
1/4	1/2	1	1/2	1/4
0	1/4	0	1/4	0

Fig.2 Improved Laplace template

3.2 The adaptive method of threshold selection for boundary extraction

Image sharpening by the Laplace template can be seen as the first step of LOG algorithm. After this step, we can get a new pixel point in the center of template window, but weather the newly obtained pixel point is an edge need to be compared with the threshold. It is the edge point if the pixel value is greater than the given threshold, otherwise it may be the non-edge point or noise. The threshold of boundary extraction often given according to the human experiences when using the traditional LOG algorithm, it is hard to deal with the problem of edge detection in many situations. Therefore, this paper presents an adaptive strategy for threshold selection. Firstly, calculates the neighborhood correlation of each pixel in the template window; then calculates the mean and standard deviation of neighborhood correlation for all the pixels; finally, estimates the degree of noise infection according to the mean and standard deviation, which is used as boundary extraction threshold.

Here's how to get the neighborhood correlation and its mean and standard deviation of each pixels.

The characteristic of neighborhood information relation exists among all the adjacent pixels, so the difference between adjacent pixels can reflect their degree of association. This characteristic is used to calculate the neighborhood correlation in this paper [11-12]. For the convenience of description, the 3×3 window is as an example, shown in Figure 3, how to calculate the neighborhood correlation definite in this paper is as follows.

$f_1(x,y)$	$f_2(x,y)$	$f_3(x,y)$
$f_4(x,y)$	$f_5(x,y)$	$f_6(x,y)$
$f_7(x,y)$	$f_8(x,y)$	$f_9(x,y)$

Fig.3 3×3 window

Firstly, calculates the neighborhood correlation of each pixel. For example, the pixel point 1 is calculated as follows. In fact, the neighborhood correlation is the gray difference between one certain pixel and the neighboring pixels of all.

$$r_1 = \frac{\sum_{j=2,4,5} \left| f_1(x,y) - f_j(x,y) \right|}{3} \quad (2)$$

The neighborhood correlation of other pixels $r_i, i = 2, \cdots, n$ calculated follows this method. Then calculates the mean of neighborhood correlation in the window by the equation (3),

$$r_{avg} = \frac{\sum_{i=1}^{n} r_i}{n} \quad (3)$$

Next, calculates the standard deviation of neighborhood correlation by the equation (4).

$$\sigma_r = \sqrt{\frac{\sum_{i=1}^{n} (r_i - r_{avg})^2}{n-1}} \quad (4)$$

The final step is how to determine the threshold. The mean r_{avg} reflects the average condition of neighborhood correlation in the template, that is, the associated degree among all the pixels should close to it. In accordance with the law of 3σ, a reasonable range of neighborhood correlation should be $r_{avg} - 3\sigma_r < r_i < r_{avg} + 3\sigma_r$. If the neighborhood correlation of one pixel beyond this range, it shows that the associated degree among this pixel and other pixels within the template is not high enough. Therefore, we select the lower bound $r_{avg} - 3\sigma_r$ as the threshold for boundary extraction, the pixel point processed by the template is edge if it smaller than the threshold, as shown in equation (5). Because the template of the traditional LOG algorithm is improved in this paper, the detection directions are added and the weights are allocated rationally, so the law of 3σ is easy to achieve for practical application.

$$\begin{cases} edge & f(x,y) \le r_{avg} - 3\sigma_r \\ not\ edge & f(x,y) > r_{avg} - 3\sigma_r \end{cases}$$
(5)

4 Implementation steps of improved LOG algorithm

Assume that the size of image want to be detected is M×N, its structure as shown in the following matrix:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}$$
(6)

The implementation process as follows:

Step1: process all the pixels in image X using the template in figure 2, that is, $Y_i = T \times X_i$, we can get a new image Y, where X_i is a 5×5 neighborhood of the original image, Y_i is a 5×5 neighborhood of the new image, and T is the template;

Step2: select the size of calculation window is 3×3, calculates the neighborhood correlation of each pixel in image Y according to the equation (2);

Step3: calculates the mean and standard deviation of neighborhood correlation by the equation (3) and (4) respectively, the threshold $th = r_{avg} - 3\sigma_r$ can be got simultaneously;

Step4: determine whether the pixel within the window is the image edge by the equation (5);

Step5: iterates Step2 ~ Step4 until the image Y is detected completely.

5 Simulation analysis

In order to test and verify the efficiency of the improved LOG algorithm for image edge detection, the image Lena in the photo library of Matlab software is selected as the test example. The first simulation is the situation without noise; perform image edge detection for image Lena using the templates in figure 1 and the template proposed in this paper, and the adaptive selection strategy of threshold is also applied. At the same time, it is also compared with Sobel operator, Robert operator and Prewitt operator, the detection results as shown in figure 4.

As seen form figure 4, the detection results of the improved LOG algorithm proposed in this paper is better than others. Where, the result of Sobel operator exists the phenomenon of edge weak; the result of Robert operator exists the phenomenon of image rupture in the person's chin and shoulders; the result of Prewitt operator better than the previous two, but the image color is too dark; the result of traditional LOG operator is also not ideal, obviously missing some details of the image in the person's eyes and mouth; While the detection results using the improve LOG operator is so good, image edge detected more complete, no image rupture, and the image detail maintained more intact.

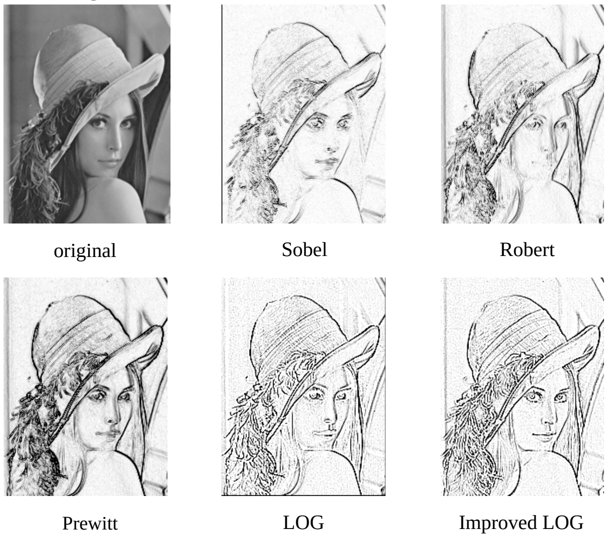

Fig.4 Detection results without noise

The image lena is also used in the next test, but the difference is we join some noise with the intensity 0.3, including Gaussian noise and salt and pepper noise. The purpose is to compare the detection results between traditional LOG algorithm and the improved algorithm in this paper when noise exists.

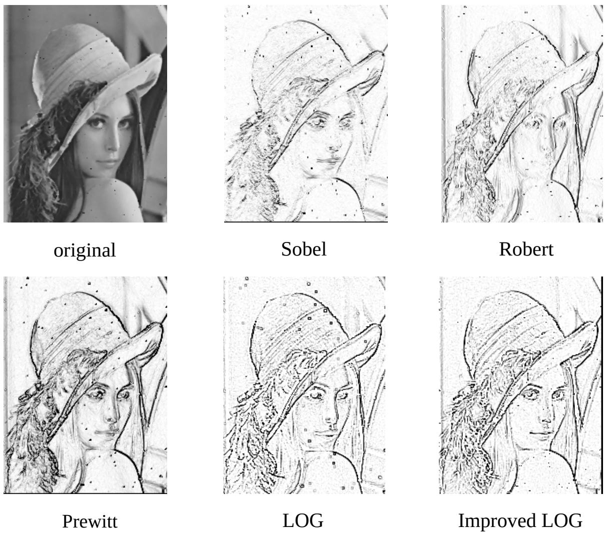

Fig.5 Detection results within noise

To evaluate an edge detection algorithm good or not, the detection of image with the noisy is very important. The reason is we need the algorithm not only detects the image edge, but also have the ability of noise filtering. As the analysis mentioned above, because the traditional LOG algorithm is second-order differential operator, although the image edge is sharpened, while the intensity of noise is redoubled. The test results in figure 5 can clearly prove this view, the noise is not filtered so well whether using the traditional LOG algorithm. Simultaneously, the detection result of Sobel operator, Robert operator and Prewitt operator are also not good. In contrast, the image edge is detected so well by the improved LOG algorithm presented in this paper, and largely eliminates the noise, only left a few noises in person's shoulder and hat. This is mainly due to the improved template of the algorithm proposed in this paper enhances the accuracy of edge detection, and the difference between noise and edge more accurate and effective when using the adaptive threshold selection algorithm based on the neighborhood correlation of pixels. Therefore, the overall effect detected far better than other algorithms.

To further validate the detection performance of the improve LOG algorithm, we selects 20 images with the size of 256×256 to compare the time consuming between these algorithms mentioned in this paper, where the configuration of computer hardware and software are same with the previous test, the result is shown in figure 6.

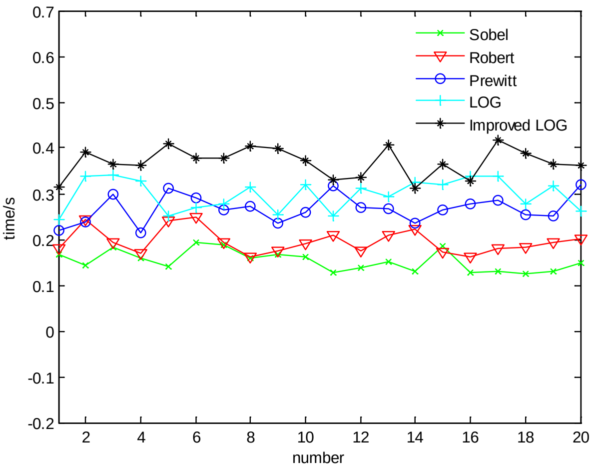

Fig.6 Comparison result of time consuming

It can be known from figure 6 that the time consuming of the algorithm in this paper is a little higher than other algorithms. The average of these 20 images is 0.3693s, while the results of other algorithms are 0.1532s, 0.1950s, 0.2672s and 0.2985s. With the improvement of the image size and the complexity of structure, the time consuming of the algorithm in this paper will increase significantly. That is mainly due to the increase of the detection template size and the threshold needs to be calculated real-time. From the point of view of practical application, however, the average time 0.3693s is desirable for the image size of 256×256. Therefore, considering the two aspects of detection accuracy and time consuming, the algorithm in this paper is much better than other algorithms common used, which also proves the proposed improved Laplace template and the adaptive selection method of threshold based on the neighborhood correlation of the pixel is correct and effective.

6 Conclusion

Edge detection is a very important foundation step of image processing, which play a key role for subsequent job. The LOG algorithm based on the principle of second-order differential operation is focused on in this paper. For its shortcomings that the templates with less detection directions and the edge extraction threshold relatively fixed, some very effective improvements are proposed in this paper. Firstly, we increases eight detection directions based on the traditional Laplace templates, and re-allocates the weights reasonable according to the importance of the direction; secondly, an adaptive selection strategy of threshold based on the pixel neighborhood correlation is proposed in this paper, which can make edge extracting with adaptive features. The simulation tests show that the edge detection results of the improved algorithm in this paper obviously better than the traditional LOG algorithm and other algorithms whether the image within the noise or not, and the edge information is maintained so well. Although the last test shows that the time-consuming of the proposed algorithm is a little higher, it can meet the needs of practical applications. Future research will focus on how to optimize the method reasonable and improve its efficiency.

ACKNOWLEDGMENT

This work is supported by the National Science Foundation for Young Scholars of China (Grant No. 61301021).

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