An Image Edge Feature Extraction Method Based on Multi-operator Fusion

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Abstract
Image edge is the most fundamental image feature and it includes the position and contour of the image. Image edge feature extraction has been widely applied in the image analysis and processing such as feature description, image segmentation, image enhancement and pattern recognition. This paper studies the characteristics of Sobel operator, Prewitt operator, Laplacian operator and other conventional operators in edge detection in details, processes the same image with these operators respectively, compares the strengths and weaknesses of these traditional operators in edge detection and proposes a multi-operator fusion method for image edge feature extraction according to the characteristics of change of local gray-level difference along the image edge, namely that gray-level changes slightly along edge direction while it changes greatly along the direction vertical to the edge. The experiment proves that the method of this paper improves the ability to extract detail information of the image edges and to suppress false edges and provides an effective approach for the practical image processing.

Key words: Edge Detection, Feature Extraction, Multi-operator Fusion

1. INTRODUCTION

The so-called edge refers to the part with the most significant local intensity changes of the image and it can outline the contour lines of the target objects in the image. It exists between region and region, target and target, target and background as well as primitive and primitive and it includes the key information used for image recognition. Edge always exists in the form of abrupt changes, as presented by the discontinuity of local image features such as the saltation of gray level, texture structure and colors. As for gray-level image, the edge is the part with drastic gray-level changes in the image, namely where strange changes happen to the signal (Xue-Feng and Xu-Ri et al., 2015; Xi et al., 2015). This paper studies the rules of each gradient operator in edge detection and combines them for edge feature detection.

The detection of edge information in the image is firstly proposed in 1959, but the systematic research on edge feature detection can be dated back to the famous Roberts algorithm raised by the scientist, L.G.Roberts in 1965. When analyzing the frequency-domain characteristics of digital image signal, people have found that the frequency-domain signal is presented in the form of high-frequency component in the edge regions, step regions and noise points of the image while the frequency-domain signal presented in the form of low-frequency component in the background (Bouchet and Quiros et al., 2015; Haojie and Fuming et al., 2015). Most of the early edge detection algorithms take the high-frequency components of the image as the breakthrough points. By using the change law that the pixel value of the edge approximates first-order or second-order directional derivative, the edge feature extraction methods based on gradient operators, including Roberts operator, Sobel operator, Kirsch operator and Prewitt operator have been proposed under the main idea that edge is located as the zero point and that one-pixel-wide image edge can be obtained, therefore, there is no need to perform refining processing on the edge image and the edge detection accuracy has been improved (Siqiang and Junping et al., 2012). However, as the response produced with the image edge feature region is quite wide, its positioning accuracy for edge feature is quite bad. So, how to apply these techniques to image edge extraction and improve the existing edge detection algorithms has become the research focus of the field of image processing (Changyi and Lihua, 2015).

This paper firstly studies the laws and characteristics of image edge distribution and the changes reflected by the discontinuity of pixel gray-level value. Then, it analyzes such operators as Roberts operator, Prewitt operator, Sobel operator and Canny operator, provides their respective advantages and disadvantages and proposes a multi-operator method to extract the image edge features. This method is the feature extraction...
algorithm based on multiplying edge classification and gradients. Finally, it is the experiment and it proves the method of this paper is an effective edge detection method.

2. IMAGE EDGE EXTRACTION

Image edge extraction refers to the processing on the image contour in the digital image processing. For the boundaries, the place with dramatic gray-level changes is defined as the edge. Inflexion is the point where function has concavity and convexity. The part with the second-order derivative as 0 is not a first-order derivative because the fact that the first-order derivative is 0 is the extremum point. Generally, when people see an object with edge, they first feel that it is the edge. The saltation of gray-level, structure or other information is referred to the edge. The edge is not only the end of a region, but also the start of another region. This feature can be used to segment image. It needs to be pointed out that the detected edge is no equal to the real edge of the practical object as the edge of the image target is the reflection of the discontinuity of the gray level (Hongjin and Shengjen, 2015). The edge can be divided into the following two kinds: 1) step edge, the gray-level values of the pixels of its two sides are significantly different; and 2) roof edge, it is located in the turning point where the gray-level value decreases, as indicated in Fig.1 and Fig.2.

Figure 1. Step edge

Figure 2. Roof edge

Edge feature extraction is aimed to detect the edge with significant changes or the discontinuous regions in the digital image and capture the regions with rapid changes in brightness. Those regions are usually the ones we pay attention to. In an image, the regions which have discontinuous brightness are usually the places with discontinuous depth, discontinuous (gradient) direction and discontinuous lighting (intensity) and texture changes. The traditional edge extraction methods explore the changes of the pixel gray levels in a certain image region and the image edge point usually corresponds to the point with maximum first-order difference magnitude. The conventional edge detection methods construct edge detection algorithm for a certain neighborhood of the pixel in the original image (Xiangzhi and Fugen et al., 2012; Zhuang and Xingbao, 2016). The edge feature extraction process is shown in Fig.3.

Figure 3. Flowchart of conventional edge feature extraction

3. COMPARISON OF SEVERAL TRADITIONAL EDGE DETECTION OPERATORS

3.1. Sobel Operator

Sobel operator is a method which combines direction difference operation and local mean and it believes that the neighborhood pixels play a non-equivalent impact on the current pixel; therefore, the pixels at different
distances will have different weights and play different influence on the operator result. Generally, the longer the distance is, the lesser impact it will have. As the brightness near the image edges changes quite great, the pixels in the neighborhood with the gray level over a certain value can be taken as the edge points.

Move two direction templates along the image from one pixel to another and overlap the pixel center with a certain pixel of the image, multiply the coefficient within the template with the corresponding pixel value in the image, add all the products together, give the maximum value of two convolutions to the pixel in the corresponding template center as its new gray-level value.

The templates of Sobel operator in vertical and horizontal directions are indicated in Fig.4. The former template can detect the image edges along the horizontal direction while the latter can detect those along the vertical direction. In practical applications, each image pixel will have convolution operation with these two convolution kernels and take the maximum value as the output. The operation result is the image which shows the edges(Iain and Muge et al., 2012).

![Figure 4. Sobel operator template](image)

### 3.2. Prewitt Operator

Prewitt operator is the edge detection of first-order differential operator. It uses the gray-level difference of the upper and lower as well as right and left pixels, detects the edge with the fact that it reaches the extremum at the edge and removes some false edges. Prewitt edge detection operator can suppress the noises through pixel averaging. However, equivalent to low-pass filtering of the image, pixel averaging is completed by performing neighborhood convolution between the two direction templates and the image in the image space and one of these two direction templates detect the horizontal edges while the other detects the vertical edges. We can seek the averaging first and then the difference, namely to seek the gradient with the so-called averaging difference. Replace difference with first-order partial derivative and obtain the following operator form.

\[
\begin{bmatrix}
\Delta_x f(x, y) &= \left[ f(x+1, y+1) + f(x, y+1) + f(x-1, y+1) \right] - \left[ f(x+1, y-1) + f(x, y-1) + f(x-1, y-1) \right] \\
\Delta_y f(x, y) &= \left[ f(x+1, y-1) + f(x-1, y) + f(x-1, y+1) \right] - \left[ f(x+1, y+1) + f(x, y+1) + f(x-1, y-1) \right]
\end{bmatrix}
\]  

(1)

The two templates of Prewitt edge detection operator are demonstrated as Fig.5. It is used in the same way as Sobel operator. Each point of the image will use these two kernels in the convolution and take the maximum value as the output. Prewitt operator will also produce an edge image.

![Figure 5. Prewitt operator template](image)

The typical Prewitt operator thinks that any pixel with new gray-level value bigger than or equal to the threshold pixel is the edge point. In other words, select the proper threshold \( T \), if \( P(i, j) \geq T \), then point \( (i, j) \) is the edge point and \( P(i, j) \) is the edge image. This is not very reasonable and it will cause misjudgment because many noise points usually have big gray-level value and for the edge point with smaller magnitude will lose its edge(Xiangzhi and Fugen et al., 2011).

### 3.3. Canny Operator

Canny operator is constituted by the first-order derivatives of Gaussian function, which is in circular symmetry, therefore, Canny operator is symmetrical in the edge direction and anti-symmetrical in the direction vertical to the edge. It means that this kind of operator is quite sensitive in the edges with the most dramatic changes and not sensitive along the edge direction(Sonya and Shanmugalingam et al., 2010).

Assume that the two-dimensional Gaussian function is as follows:
Here, $\sigma$ is the distribution parameter of Gaussian function and it can be used to control the smoothness of the image.

The gradient of the smooth $g(x,y)$ can use $2 \times 2$ first-order finite differential approximation to calculate the two arrays $f'_x(x,y)$ and $f'_y(x,y)$ of $x$ and $y$ partial derivatives.

$$f'_x(x,y) \approx G_x = [f(x+1,y) - f(x,y) + f(x+1,y+1) - f(x,y+1)] / 2$$

$$f'_y(x,y) \approx G_y = [f(x,y+1) - f(x,y) + f(x+1,y+1) - f(x+1,y)] / 2$$

The template of Canny operator is shown as Fig.6.

![Figure 6. Canny operator template](image)

### 3.4. Roberts Operator

The operator proposed by Roberts is a kind of operator which uses local difference operator to search the edges. The sharpness of the edge is determined by the gray-level gradient of the image. Gradient is a vector and $\nabla f$ points out the direction and quantity with the fastest gray-level changes. Edge detection operator uses the vertical and horizontal differences of the image to approximate gradient operator. Assume that $f(x,y)$ is the gray-level distribution function of the image and $g(x,y)$ is called as Roberts edge detection operator, then

$$\nabla f = (f(x,y) - f(x-1,y), f(x,y) - f(x,y-1))$$

Calculate the vector of the above formula for every pixel, seek its absolute value, compare it with the threshold and obtain Roberts crossover operator with this idea.

$$g(i,j) = |f(i,j) - f(i+1,j+1)| + |f(i,j+1) - f(i+1,j)|$$

The corresponding two $2 \times 2$ templates to the above operator is indicated in Fig.7. In the practical applications, every image pixel performs convolution operation with these two templates and to avoid negative value, its absolute value is usually taken in the edge detection(Barnabás and Emil et al., 2009).

![Figure 7. Roberts operator template](image)

### 3.5. Laplacian Operator

Laplacian operator is a second-order difference operator and it is isotropic, namely that it is irrelevant to direction of the coordinate axis and the gradient result remains the same even if the axis is rotated. Laplacian operator is point, line and boundary extraction edge and it is also referred to as boundary extraction operator. Besides, Laplacian operator is also the simplest isotropic difference operator with rotation invariance. Laplacian transform of a two-dimensional image function is an isotropic second-order derivative and it is defined as follows.

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

In order to be more suitable for digital image processing, Laplacian operator is represented in the discrete form.
\[ V^2 f = [f(x+1,y) + f(x-1,y) + f(x,y+1) + f(x,y-1)] - 4f(x,y) \]  \hspace{1cm} (7)

The template of Laplacian edge detection operator is indicated as Fig.8. The basic characteristics of the templates are that the coefficients at the central positions are positive while the rest coefficients are negative. Take one of the two dot matrices of the image as the convolution kernel and perform convolution operation with the original image. As a second-order derivative, Laplacian operator is unacceptably sensitive to noises (Xudong, 2007).

\[
\begin{array}{ccc}
0 & -1 & 0 \\
-1 & 4 & -1 \\
0 & -1 & 0 \\
\end{array} \quad \begin{array}{ccc}
-1 & -1 & -1 \\
-1 & 8 & -1 \\
-1 & -1 & -1 \\
\end{array}
\] 

(a) \hspace{1cm} (b)  

**Figure 8. Laplace operator template**

### 3.6. Kirsch Direction Operator

Kirsch operator uses eight templates to perform convolution on every pixel of the image and seeks the derivatives. These eight templates confirm the gradient magnitude and direction. They represent eight directions and makes maximum response to the eight specific edge directions of the image. The maximum value of the operations will be taken as the edge output. Actually, Kirsch operator uses eight templates, which are shown in Fig.9.

\[
\begin{array}{ccc}
5 & 5 & 5 \\
3 & 0 & -3 \\
-3 & -3 & 3 \\
-3 & 3 & 5 \\
-3 & 0 & 5 \\
-3 & -3 & 5 \\
-3 & -3 & -3 \\
5 & 5 & 5 \\
\end{array} \quad \begin{array}{ccc}
5 & 5 & 5 \\
3 & 0 & 5 \\
-3 & 3 & 3 \\
-3 & 0 & 5 \\
-3 & 3 & 5 \\
-3 & 3 & 3 \\
5 & 5 & 5 \\
5 & 5 & 3 \\
\end{array}
\] 

\[ \begin{array}{ccc}
5 & -3 & -3 \\
5 & 0 & 3 \\
5 & 5 & 3 \\
\end{array} \quad \begin{array}{ccc}
5 & 5 & 3 \\
5 & 0 & 3 \\
-3 & -3 & -3 \\
\end{array}
\] 

**Figure 9. Eight direction templates of Kirsch operator**

It can be seen from the above eight direction templates that the included angle of every two convolution kernels (templates) is 45 degrees. Each point in Fig.9 will use eight masks in the convolution and every mask makes maximum response to a certain specific edge direction. The maximum value of all eight directions will be taken as the output of the edge magnitude image and the number of the mask with the maximum response forms the coding of the edge direction. The gradient magnitude of Kirsch operator is sought with the following formula (Peter and Kristof, 2009).

\[
\begin{align*}
G(x, y) &= \max(\{|M_0|, |M_1|, |M_2|, |M_3|, |M_4|, |M_5|, |M_6|, |M_7|) \\
G(x, y) &= \max\{1, \max\{5s_k - 4t_k : k = 0,1,\ldots,7\}\} \\
s_k &= a_{k1} + a_{k2} + a_{k3}, \quad t_k = a_{k1} + a_{k2} + \cdots + a_{k7}
\end{align*} \hspace{1cm} (8)
\]

If the above subscripts exceed 7, divide the subscript by 8 and take the remainder. Please note that \(k = 0,1,\ldots,7\) and it means that eight templates have been used. Process the original image lena with the above-mentioned operators and see the results in Fig.10.
4. MULTI-OPERATOR FUSION IMAGE EDGE EXTRACTION

Roberts operator can better eliminate the false edge with accurate positioning. Its performance on the vertical edge is better than that on the diagonal direction. To extract edge with Roberts operator will result in rough edge, therefore, it is not very accurate in positioning the edge.

Sobel operator detection method does well in the processing of the images with gray-level gradations and many noises, however, Sobel operator obtains rough edges and false edge may occur. Besides, Sobel operator doesn’t strictly simulate the visual physiological features of humans, therefore the image contour it obtains may not be very satisfactory.

Prewitt operator is a kind of edge detection based on first-order difference operator. It detects the edge with the gray-level differences between the upper and lower as well as left and right pixels which reaches the extremum at the edge, removes some of the false edges and smoothen the noises, however, the edge is quite wide and there are many discontinuity points.

Laplacian operator is quite sensitive to noises, so this kind of operator is rarely used in edge detection, instead, it is usually used to determine whether the edge pixel is in the bright or dark region of the image. Laplacian operator is the simplest isotropic difference operator and it has rotation invariance, so it is more suitable to be used in the image templated caused by the diffuse reflection of the light.

Canny operator is not easy to be affected by noises and it can detect the true weak edge. Moreover, when the weak edge connects the strong one, Canny operator will include the weak one into the output image. However, Canny operator is too refined in the image edge detection, so it is not good for the extraction of the image texture features, either.
Kirsch operator can better get rid of the impact of noises, however, this method only takes the gray-level information of the pixel point into consideration and it doesn’t consider the space information of that point.

The edge detection operators based on first-order derivative include Roberts operator, Sobel operator and Prewitt operator. In the realization of the algorithm, perform convolution and operation between \( n \times n \) template (as the kernel) and every pixel point of the image and then select the proper threshold to extract the edge. In order to realize the edge fusion, it is necessary to analyze the relationship of the multi-scale edges in the position, intensity and direction. Firstly, the closer the scales of two spaces are, the closer the edge positions detected in the two scales will be. Assume that the correlative block of the local modulus maxima \((i, j)\) in scale \(s\) is the \(3 \times 3\) neighborhood centered by \((i, j)\) in the scale of \(s+1\); \(f_{s+1}(i, j)\), \((m,n)\) is any point in \(f_{s+1}(i, j)\) and the set of the local modulus maxima in \(s\) is \(M_s\).

\[
C_{s+1}(i, j, m, n) = \begin{cases} 
1 & \exists (m, n) \in F_{s+1}(i, j) \text{ and } \exists (m, n) \in M_s \\
0 & \text{Others}
\end{cases}
\]  

(9)

If \(C_{s+1}(i, j, m, n) = 1\), the maximum point \((i, j)\) of scale \(s\) is correlated with the point \((m, n)\) in scale \(s+1\) and \((i, j)\) is considered to be transferred from a certain pixel \((m, n)\) in \(3 \times 3\) of \(s+1\). It reflects the same edge of the image in different scale space.

In order to describe the image edge point more accurately, reduce the impact of noises in the detection result and improve the anti-noise capacity of the operator, reconstruct the template and the weight of each position of the template will be determined by the distance from this position to the central position and the direction of this position in the template. The points with equal distance will have the same weight. In the algorithm of this paper, we have used the edge gradient value with the corresponding maximum output template as the edge gradient intensity of the pixels.

5. EXPERIMENT TEST AND ANALYSIS

The development environment used in this experiment is Matlab2012 and the test images come from Matlab image database. Extract the edge features of the test images with Sobel operator, Prewitt operator, Canny operator, Roberts operator, Kirsch operator and the multi-operator fusion method of this paper respectively. Multi-operator fusion is not equal to the simple addition of the edges in different scales. As the edge detection operators of different scales do not have the same response on the same edge, the positions of the edge enhanced image in different scales are not the same and the edge addition will inevitably cause edge redundancy. See the experiment results in Fig.11 - Fig.14.

Figure 11. Peppers original image and it’s three dimensional view of RGB image

(a) Original image  (b) Three dimensional view of RGB image

(a) Sobel operator  (b) Prewitt operator  (c) Canny operator
It can be seen from the above experiment results that with the characteristics of variable scales and directions, multi-operator fusion method is effective in the edge detection from different perspectives. Its edge accuracy is better than each conventional gradient operator method and it has better image edge segmentation effect. The segmentation is quite refined, the entire image edge segmentation is quite clear-cut and it can better reflect the image texture. Therefore, multi-operator fusion method can perform better positioning segmentation on the image and its segmentation is quite accurate. Because multi-operator fusion method has combined the strengths of Sobel operator, Prewitt operator, Canny operator, Roberts operator and Kirsch operator, it can take the advantages of the output edge with different scales, ensure the accuracy of the edge positioning and have perfect adaptability.
6. CONCLUSIONS

This paper has proposed an image edge detection method based on multi-operator fusion. This method has overcome the influence of noises, simulated the visual physiological features of humans strictly according to gray-level gradient and extracted the image edge. This multi-operator has combined the strengths of Sobel operator, Prewitt operator, Canny operator, Roberts operator and Kirsch operator and each operator will take the union set and finally obtain the corresponding image edge. The simulation experiment proves that the algorithm of this paper is effective.

ACKNOWLEDGEMENTS

This work was supported by KJ2016A304.. Research on relationship recommendation based on link prediction.

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