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Performance Investigating of Several Classical Edge Detection Operator for Segmentation

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Abstract. Edge detection is an important method in digital image segmentation. It also plays an important role in various research fields. It can obtain the important structural attributes of the object, greatly reduce the amount of the data of the source image. This article mainly studies the basic theory of edge detection and commonly used classical operators such as: Sobel, prewitt, Roberts, Laplacian of Gaussian (Log) and Canny operators. Then do experimental research on each operator and analyze the corresponding experimental results. Especially for the common Canny operator, the paper do a research of automatic threshold improvement based on the Otsu algorithm, and compare and analyze the processing effects between the original canny and the improvement .The experimental results of this article verify the characteristics of theoretical analysis and provide rich learning and reference materials for subsequent researchers.

Keywords. Edge detection, classical operator, canny, theoretical analysis

1. Introduction

Images are a tool for humans to communicate with each other and understand the objective world. As an effective method for expressing the boundary of the object, edge detection is an important part of digital image processing and a key link in the processing process[1]. The purpose is to extract the edge contour information of the image, eliminate information that is irrelevant to the object, retain the important structural attribute, and greatly reduce the amount of data of the source image. Edge detection can be used in the fields of computer vision, robotics, autonomous driving, face recognition, medical assistance and other fields[2]. It can extract important information of object in the image, such as the contour, edges, and texture of the object, so that further processing and analysis can be performed[3].For example, in autonomous driving, edge detection can help vehicles recognize the edges and obstacles of the road, thereby controlling vehicles more accurately. The object edge means that the pixel region value in the picture suddenly changes. If each row pixel and each column of the image are described as a function about the grayscale, the object edge corresponds to the grayscale value function at the area where the function value suddenly becomes larger. Digital images are discrete two dimensional signals. They are generally implemented using differential gradient operator of integer order or image convolution. Thus the common first order differential gradient operators include: Sobel operator, Prewitt operator, Roberts operator, etc.[4-6];

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The common second-order differential gradient operators include: LOG operator[7]. In addition to the classic methods mentioned above, there are also currently popular deep learning methods. Deep learning algorithms can automatically extract features and patterns in images by learning a large amount of image data, thus realizing tasks such as edge detection and image segmentation[8]. The commonly used deep model is CNN[9]. This paper focuses on analyzing and comparing the performance of several classical methods .This article mainly contains the following parts: the basic principle of detection, several classical detector operators, improved canny operators, the analysis of the detection experiments results and conclusion.

2. Basic Theory of Edge Detection

The edge means there is a sudden change in the local region brightness, and the gray scale profile of this region can generally be regarded as a step[10]. This step can produce two derivative cases. One type is the first-order differential edge operator, also known as the gradient edge operator. It is a vector which has direction θ and mode |ΔI|. The gradient is defined as follows Eq.1：

$$\nabla f = \begin{bmatrix} g_x \\ g_y \end{bmatrix} = \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \end{bmatrix} \quad (1)$$

The amplitude of this vector is defined as Eq.2：

$$mag(\nabla f) = \sqrt{(\frac{\partial f}{\partial x})^2 + (\frac{\partial f}{\partial y})^2} \quad (2)$$

To simplify the calculation, in practice the value can sometimes be approximated by omitting the square root or by using the absolute value approximation. Eq.3 and Eq.4 are as follows:

$$\nabla f \approx g_x^2 + g_y^2 \quad (3)$$

$$\nabla f \approx |g_x| + |g_y| \quad (4)$$

The phase angle θ is defined as follows Eq.5：

$$\theta = \arctan\left[\frac{g_y}{g_x}\right] = \tan^{-1}\left(\frac{\partial f / \partial y}{\partial f / \partial x}\right) \quad (5)$$

The other is the second-order derivative edge detection operator. It utilizes the property that the step of the picture at the edge causes the second-order derivative of the image to appear as a zero value at the edge , therefore, the method is also known as the over-zero operator and the Laplace operator. Although the edge detection method using second-order differential operators is simple, it has the disadvantage of being very sensitive to noise and also not being able to provide directional information about the edges. In order to suppress noise, Marr et al propose the method of Gaussian Laplacian. The Laplace operator is commonly used to compute second-order derivatives. The Laplace operator of a function f(x,y) is defined as Eq.6:

$$\nabla^2 f(x,y) = \frac{\partial^2 f(x,y)}{\partial x^2} + \frac{\partial^2 f(x,y)}{\partial y^2} \tag{6}$$

To find the locations where the gray level is changing rapidly, the two rules for edge detection are:

(1)Find the locations where the magnitude of the first-order derivative is greater than some specified threshold value.

(2)Find the position that the second-order difference of the pixel is zero.

3. Several Classic Edge Operator

The basic theory of gradient difference has been described in the previous section. Therefore the practical use is to design the corresponding templates according to the theory, and different operators produce different detection templates. Since the principles and methods of various detectors are not exactly the same, many different edge detection methods have emerged. We often choose a reasonable operator according to the actual situation, and next we will discuss various types of operators in depth.

3.1. Roberts Operator

Robert's operator is one of the most classic and simplest edge detectors proposed by Robert in 1965[11]. This operator uses the template of Eq.7 to make the value of the first-order derivative equal to the difference between neighboring pixels:

$$h_1 = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix} \quad h_2 = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} \tag{7}$$

The Roberts operator is one of the simplest operators and uses a 2×2 template. It uses the difference between two contiguous pixels in the diagonal direction to approximate the gradient magnitude to detect edges. It detects vertical edges better than diagonal edges. It is characterized by high positioning accuracy, sensitivity to noise, but cannot suppress the effect of noise.

3.2. Prewitt Operator and Sobel Operator

The Prewitt operator and the Sobel operator use the discrete deviation of pixel value in 3 × 3 matrix neighborhood to calculate the gradient. The only difference is that the Sobel has doubled the intermediate element. So these two operators can be introduced together. The Prewitt operator is defined as Eq. 8：

$$G_x = \begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix} \quad G_y = \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix} \tag{8}$$

The Sobel operator is defined as Eq. 9：

$$G_x = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix} \quad G_y = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \tag{9}$$

Prewitt operator is a first-order difference operator, using the gray level difference between the upper and lower, left and right neighbors of a pixel point to reach an extreme value at the edge[12]. It can remove some pseudo edges, and has a smoothing effect on noise. Its principle is to use two directional templates to do convolution with the neighbor pixels. The two directional templates detect horizontal edges and vertical edges respectively. The Sobel operator adds the notion of weights to the Prewitt operator. It believes the various distance between the contiguous pixels has unlike effects on the current pixel. The closer the pixels, the greater the impact of the front pixel. So the picture is sharp and highlights the boundary of the edge.

3.3. Canny Edge Detector

Although the Canny detection operator is also a first-order derivative operator[13], it extends operator: It is mainly based on the original operator, adding two improvement measures of non-great value suppression and double threshold. Non-maximum values can not only effectively suppress multi-response edges, but also improve the localization accuracy of the edges; Double thresholds can effectively reduce the leakage detection rate of edges. The steps to run the Canny Edge operator are as follows:

(1) The noise is reduced by a Gaussian filter.
(2) The gradient direction and magnitude is processed.
(3)Spurious response is removed by NMS method.
(4) Apply Twice thresholds method is utilized to identify real borders.
(5) Complete edge detection with suppressing isolated short boundary.

3.4. LoG Operator

Although the second-order differential operator is a simple method for edge detecting, it has the disadvantage of being sensitive to noise and also does not provide directional information about the edges. In order to realize the suppression of noise, Gaussian Laplacian method is proposed by Maar et al[14]. The basic idea of the Laplacian of Gaussian operator: The image f(x,y) is first filtered with Gaussian function G(x,y) and then the filtered image is subjected to Laplace operation. The position where the result is zero is the edge position. Filtering improves the ability to resist noise, but it can also smooth out edges or even cant detect edge out. The Log operator and the extended Log operator are defined as Eq.10:

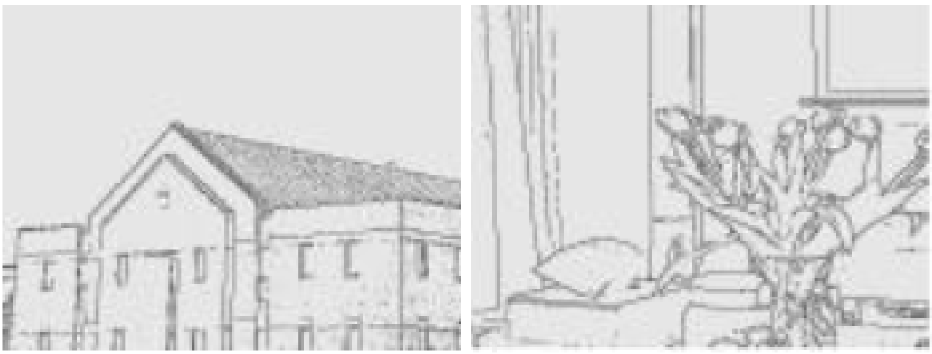
$$G_1 = \begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix} \qquad G_2 = \begin{bmatrix} 1 & 1 & 1 \\ 1 & -8 & 1 \\ 1 & 1 & 1 \end{bmatrix} \tag{10}$$

4. Comparative Experiment of Different Operators

In order to better analyze and compare the detection performance and effectiveness of each operator. Two different pictures are used to test the operators. One picture is a house which is a classic image in the field of digital image processing, and the other one is a picture of tulips flower obtained from the website.

(a)Original house image (b) Original tulip flower

Figure 1. Original image



(a)Detection result of house (b) Detection result of tulip

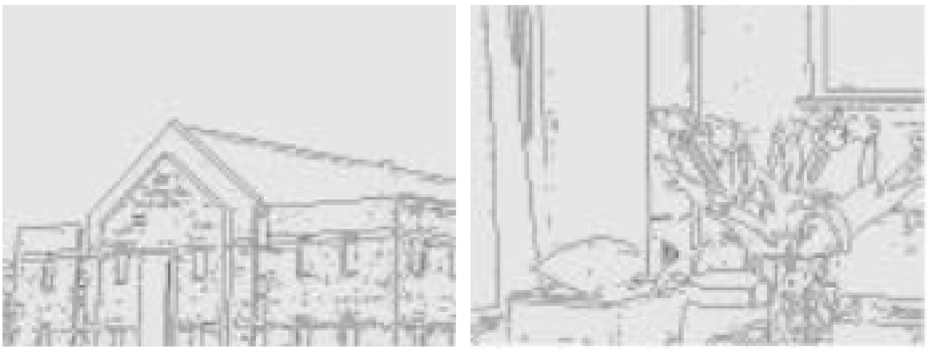
Figure 2. Result of Roberts operator

(a)Detection result of house (b) Detection result of tulip

Figure 3. Result of Prewitt operator

(a)Detection result of house (b) Detection result of tulip

Figure 4. Result of Sobel operator



(a)Detection result of house (b) Detection result of tulip

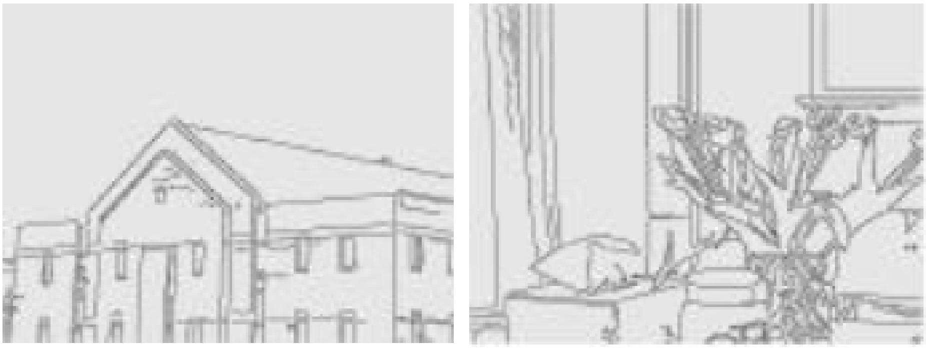
Figure 5. Result of Log operator

(a)Detection result of house (b) Detection result of tulip

Figure 6. Result of Canny operator

Figures 1~6 contain the original grayscale picture and the detection results of each operator. For better detection results, the threshold T of Prewitt, Roberts, Sobel operators are set at 0.05.The thresholds of the other operators are not uniform for multiple parameter values, so determined automatically with edge function default value. Figure 1 is original image and Figures 2~6 are detection results of different operators. Figure 2 shows the detection results of the roberts operator. There is a lot of unnecessary edge information detected such as tiny textures on walls and roofs and also a lot of long straight lines that are not continuous. Figure 3 and Figure 4 show the detection results of Prewitt and Sobel operators respectively. The two operators can detect the image edge information well, but there are still a few places containing certain unwanted details, such as the excess noise line segments on the curtains of the tulip flower. Figure5 shows the detection results of Log operator. The results are generally similar to the Sobel operator. However, the LOG has a little more unnecessary noise information, mainly due to the effect of Sobel threshold. Such as the dotted lines on the exterior walls of the house and some vertical segments on the background curtains. Figure6 shows the detection results of canny operator. Compared with the previous operators, the Canny detector has much more effective. It is a compromise between object detail and outline, detecting the object outline while retaining some detail. The lines of the main contour are more complete. For instance, the edges of the flower and the contour lines of the house in tulip are significantly better than those of several other algorithms.

5. Edge Detector of Otsu-Canny



(a)Detection result of house (b) Detection result of tulip

Figure 7. Detection results of Otsu-Canny

The Canny operator mainly include the parameters of double thresholds vector T and sigma[15]. The vector T primary influences the visibility of edge boundary. They are positively correlated. In general, the default thresholds that come with the edge function don't work very well. The Otsu method is a classical algorithm for image threshold segmentation which was proposed by Japanese scholar Otsu in 1979. The method is based on the grayscale histogram and determines the optimal threshold value by maximizing the inter-class variance to achieve image segmentation. Thereby the image is segmented into foreground and background parts. When the threshold increases, the number of foreground pixels decreases and the number of background pixels increases; Conversely, when the threshold decreases, the number of foreground pixels increases and the number of background pixels decreases. So the Otsu method is chosen to determine the threshold size of the Canny edge detector for better effect[16]. The automatic threshold is always smaller than that generated by the Otsu method. The smaller the threshold, the more detail information detected, and the worse the noise immunity. Table 1 shows the comparison of the two thresholds. As can be seen from Table 1, the Otsu thresholds are bigger than the automatic thresholds for both the house image and the tulip image. Figures2~6 always has more details than Figure 7. For example, there are many textures on the house walls, and also there are many residual noise lines segments on the tulip leaves. The more details there are, the more susceptible it is to interference.

Table 1. Canny threshold selection

Image from left to right	auto threshold	Otsu threshold
House image	[0.0188,0.0469]	[0.0553, 0.1106]
Tulip flower	[0.0313,0.0781]	[0.0490, 0.0980]

6. Conclusion

This article first elaborates the definition, purpose, application scope of edge detection, and then study the basic principles of edge detection. Analyze the common templates and characteristics of several classic operators. Then the experimental design and edge detection experiments are performed on each operator. The corresponding effects and characteristics of each operator are analyzed and compared. Next analyzes and compares the effects and characteristics of each operator. Especially for the Canny operator also provided the Otsu-canny improvement method experiment. Experiment research provides important references for the study and research of the edge detection of subsequent scholars. Although the improved canny method can automatically get better effect, it is still necessary to choose the appropriate method for different application scenarios. In terms of future research, more second-order differential operators should be studied. Alternatively, more detection methods of deep learning could be researched and verified, especially compared with different conditional operators in application scenario.

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References

[1] N. Tariq, R. A. Hamzah, T. F. Ng, S. L. Wang, and H. Ibrahim, "Quality Assessment Methods to Evaluate the Performance of Edge Detection Algorithms for Digital Image: A Systematic Literature Review," *IEEE Access,* vol. 9, pp. 87763-87776, 2021.

[2] S. P. Singh, Shivam, I. Kumar, and J. Lingala, "Edge Detection Based Medical Denoising using Wavelet Domain," in *2nd IEEE International Conference on Intelligent Technologies, CONIT 2022, June 24, 2022 - June 26, 2022*, Hubli, India, 2022: Institute of Electrical and Electronics Engineers Inc.

[3] M. Chen, J. Wang, L. Zhu, H. Deng, H. Wu, and Z. Zhang, "Research on contour extraction and edge detection of sugarcane image based on MATLAB," in *3rd IEEE International Conference on Power, Electronics and Computer Applications, ICPECA 2023, January 29, 2023 - January 31, 2023*, Shenyang, China, 2023, pp. 1784-1787: Institute of Electrical and Electronics Engineers Inc.

[4] R. Zhang, Q. Xiao, Y. Du, and X. Zuo, "DSPI Filtering Evaluation Method Based on Sobel Operator and Image Entropy," *IEEE Photonics Journal,* vol. 13, no. 6, pp. 1-10, 2021.

[5] A. Sharma, R. Dronawat, and A. Jhapate, "Automatic Diabetic Retinopathy Detection using Roberts Cross Edge Detection in DIP," in *2021 10th IEEE International Conference on Communication Systems and Network Technologies (CSNT)*, pp. 363-368. 2021

[6] M. Tiwari, A. Bhargava, V. Chaurasia, M. Shandilya, E. A. Siddiqui, and S. Bhardwaj, "Automated Lung Cancer Detection using Prewitt Gradient Kernel & SVM from CT-Lung Images," in *2023 1st International Conference on Innovations in High Speed Communication and Signal Processing (IHCSP)*, pp. 508-513. 2023

[7] H. Zhang, J. Zhou, Q. Wang, C. Zhu, and H. Shao, "Classification-Detection ofMetal Surfaces under Lower Edge Sharpness Using a Deep Learning-Based Approach Combined with an Enhanced LoG Operator," *CMES - Computer Modeling in Engineering and Sciences,* vol. 137, no. 2, pp. 1551-1572, 2023.

[8] V. Felt, S. Kacker, J. Kusters, J. Pendergrast, and K. Cahoy, "Fast Ocean Front Detection Using Deep Learning Edge Detection Models," *IEEE Transactions on Geoscience and Remote Sensing,* vol. 61, pp. 1-12, Art. no. 4204812, 2023

[9] N. R. Billa, B. P. Das, M. Biswal, and M. Okade, "CNN based image resizing forensics for double compressed JPEG images," *Journal of Information Security and Applications,* vol. 81, 2024.

[10] R. Xian, X. Xiong, H. Peng, J. Wang, A. R. de Arellano Marrero, and Q. Yang, "Feature fusion method based on spiking neural convolutional network for edge detection," *Pattern Recognition,* vol. 147, 2024.
[11] P. Vajpayee, C. Panigrahy, and A. Kumar, "Medical image fusion by adaptive Gaussian PCNN and improved Roberts operator," *Signal, Image and Video Processing,* vol. 17, no. 7, pp. 3565-3573, 2023.
[12] S. Balochian and H. Baloochian, "Edge detection on noisy images using Prewitt operator and fractional order differentiation," *Multimedia Tools and Applications,* vol. 81, no. 7, pp. 9759-9770, 2022.
[13] N. Liu, Y. Ma, L. Shao, and H. Wang, "Rapid Extraction of Clothing Sample Profile Based on the Improved Canny Algorithm," *Advances in Multimedia,* vol. 2022, 2022.
[14] F. Ding and B. Ji, "Level set method by using local entropy and enhanced LoG operator for image segmentation," in *2022 Global Conference on Robotics, Artificial Intelligence and Information Technology, GCRAIT 2022, July 30, 2022 - July 31, 2022*, Chicago, IL, United states, 2022, pp. 252-255: Institute of Electrical and Electronics Engineers Inc.
[15] N. Tao, "Enhanced Canny Algorithm for Image Edge Detection in Print Quality Assessment," *Traitement du Signal,* vol. 40, no. 3, pp. 1821-1827, 2023.
[16] S. Gayathri Monicka, D. Manimegalai, and M. Karthikeyan, "Detection of microcracks in silicon solar cells using Otsu-Canny edge detection algorithm," *Renewable Energy Focus,* vol. 43, pp. 183-190, 2022.