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Subpixel edge detection algorithm based on improved Gaussian fitting and Canny operator

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Abstract: *In image processing, image edge is often used as a basic feature in higher-level image processing. Edge detection technology is the basis of image processing technologies such as image measurement, image segmentation, image compression and pattern recognition. It is one of the important research topics in digital image processing. In this paper, we explore the image edge and pixel data, and propose an optimization model for sub-pixel edge extraction, image distortion correction and image edge segmentation. We preprocess the image with Gaussian filter, median filter and morphological close operation to reduce the impact of lighting environment and noise on the image. After edge detection with Canny operator, we use two-dimensional interpolation to Gaussian fit the edge points in the gradient direction to obtain the sub-pixel edge, and then search the pixel points to obtain the pixel order of the graphic outline and display it with different colors. Finally, we summarize the model, adjust the search range and extend it to the case of low definition of the original image. We can obtain high-precision contour edges of low pixels through technical means.*

Keywords: *Canny operator; Gaussian interpolation; Sub pixel; Distortion correction; Edge fitting and segmentation*

1. Introduction

With the development of science and technology, the requirements for the measurement accuracy of various workpieces and parts are higher and higher, and the requirements for measuring instruments are also higher and higher[1]. Various image measuring equipment such as digital image size measuring instrument is gradually replacing the traditional manual caliper measurement application. Generally, after the camera is calibrated, the distortion of the image is corrected according to the lattice or checkerboard feature information of the calibrated image, and the mapping relationship between the image coordinate space and the world coordinate space is calculated[1].

The edge of object is very useful in image recognition and computer analysis. Image edge is the reflection of the discontinuity of image local features. The edge can outline the outline of the target object so that the observer can see it at a glance. Edge contains rich internal information (such as direction, step attribute, shape, etc.)[2], which is an important attribute for extracting image features in image recognition. Contour extraction is a very important processing problem in image boundary segmentation. The purpose of contour extraction and contour tracking is to obtain the external contour features of the image[2]. When necessary, some methods are applied to express the features of the contour, preparing for image shape analysis, and having a significant impact on the implementation of advanced processing, such as feature description, recognition and understanding. This paper mainly solves the problem of image edge detection, segmentation and extraction, and accurately extracts the complete edge information of the target image[2].

2. Model assumptions and symbols description

2.1 Model assumptions

(1) assume that the contour line for edge detection has no external interference.

(2) it is assumed that the connecting parts of straight line segment, arc segment and elliptical arc segment are tangent.

(3) it is assumed that the measured sub-pixel contour edge data is accurate without error.

(4) assume that the edges are only composed of single-layer pixels, and there is no overlap at any place.

2.2 Symbols description

Table 1: Description of symbols

Symbol	Description
σ	Parameters of Gaussian filter, standard deviation of Gaussian function, variance threshold[3]
M	The gradient amplitude of the pixel
θ	The gradient direction of a pixel, the angle between the normal and the positive direction of the x-axis
μ	Subpixel edge coordinates
k	Amplitude of Gaussian function
x_c、y_c	Horizontal and vertical coordinates of main point C
k_1、k_2、k_3	Gradient magnitude of pixels
ρ	Distance from main point C to line
h	The number of fitted straight lines
R_s、R_m、R_e	Radius of curvature near the beginning, midpoint and end of the curve
t_{ij}	Distance between any two points in three points
σ_1	Fitting variance
n	Number of points on the fitting curve
percent	Percentage threshold

3. Model establishment and solution

We compared the traditional edge detection operators and get the following results (Figure 1). Various operators are greatly affected by noise and image brightness, so it is necessary to preprocess the image before edge extraction[4].

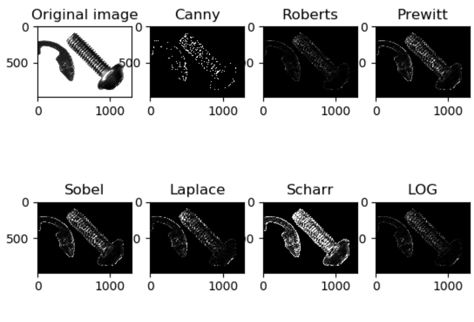

Figure 1: Comparison of various edge detection operators

3.1 Data preprocessing

In order to highlight image shape features, reduce noise interference and protect signal edges, we preprocess the image, mainly including image graying, adjusting image contrast, median filtering, Gaussian filtering, image binarization and morphological processing;

(1) adjust the light and dark contrast of the image, and change the difference between the maximum gray level and the minimum gray level of the image. Especially for pic1 taken under relatively complex lighting conditions_ 3 image, reducing the interference information on the image.

(2) image morphological processing uses the closed operation of expansion before corrosion to process the image morphologically. The purpose of expansion is to find the local maximum value, that is, to calculate the maximum value of the pixel in the area covered by the structural element in the image, and assign this maximum value to the pixel specified in the center of the current structural element. Corrosion is a dual operation of expansion, which calculates the minimum pixel value of the area covered

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by the structural element in the image, and sets the pixel where the center of the current structural element is located as the minimum value[5]. After the completion of the closed operation, the black spots in the image that are misjudged as edges can be effectively suppressed, so as to get a better extraction effect.

(3) Gaussian filter and median filter noise is caused by the sudden change of the gray value of some pixels in the image, which makes it inconsistent with the surrounding area.

Gaussian filtering is to find Gaussian filtering kernel first and then convolute. It is a process of weighted average of the whole image. The value of each pixel is obtained by weighted average of itself and other pixel values in the neighborhood. Eliminate the noise generated or mixed in the process of image digitization.

Median filtering algorithm is a filtering technology proposed by Tukey[5]. Image median filtering is a non-linear image processing method based on statistical sorting. This algorithm is simple and fast, and can effectively suppress the random impulse noise of the image. Its advantage is to filter out the image noise while maintaining the original contour and details of the image, especially for impulse noise and salt and pepper noise[6].

In the process of preprocessing, the image is first processed for contrast, and then perform morphological opening and closing operations, and use Gaussian filter and median filter to remove noise and reduce the influence of shadow part. The gray value of noise pixels in the image is not so abrupt.

3.2 Model introduction

3.2.1 Canny operator

Canny algorithm first uses Gaussian filter to smooth the image[7], then uses window to calculate the amplitude and direction of gray gradient, then suppresses the non maximum value of gradient image, and finally uses double threshold method to detect and connect edges from candidate edge points[8]. We use Canny algorithm to locate the edge of the image roughly, which provides data support for further fitting to get sub-pixel points.

3.2.2 Image smooth processing

During preprocessing, the image has actually been smoothed, and its principle is the neighborhood average method[9]. The Gaussian function is shown in the formula:

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

σ is a parameter of Gaussian filtering, and the selection of σ will directly affect the filtering effect. If σ is large, it will cause serious edge offset and greatly increase the amount of computation; If σ is small, although the edge detection accuracy is high, the image smoothing effect is weak, resulting in poor noise reduction effect.

3.2.3 Calculation of gradient amplitude and direction

Canny edge detection algorithm using 2 × 2. Calculate the gradient amplitude and direction of the sequence matrix I (x, y) by the finite difference of partial derivatives in the neighborhood. The specific calculation method is as follows.

Find the partial derivative P in two directions at point (x, y)_ X (I, J) and P_ Y (I, J) are respectively:

$$P_x(i,j) = \frac{I(i,j+1)-I(i,j)+I(i+1,j+1)-I(i+1,j)}{2} \quad (2)$$

$$P_y(i,j) = \frac{I(i,j)-I(i+1,j)+I(i,j+1)-I(i+1,j+1)}{2} \quad (3)$$

Using formula (4) and formula (5), the gradient amplitude m (I, J) and direction θ (I, J) of the pixel are obtained.

$$\mathrm{M(i,j)} = \sqrt{P_x(i,j)^2 + P_y(i,j)^2} \quad (4)$$

$$\theta(\mathrm{i,j}) = tan^{-1}\frac{P_x(i,j)}{P_y(i,j)} \quad (5)$$

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3.2.4 Non maximum suppression of gradient amplitude

Since the ridge zone will be generated near the maximum value of gradient amplitude, the principle of non maximum suppression is to better determine the position of the edge by thinning the ridge zone in the amplitude map the non maximum suppression process is to take each point in the gradient amplitude matrix M (I, J) as the central pixel and compare the gradient amplitudes of two neighborhoods along the gradient direction of the central point in its surrounding 8 directions[10]. If the amplitude of the central pixel is less than the gradient amplitude of the neighborhood in the two directions, the value of the edge flag bit of the central pixel is 0. After non maximum suppression, not only the ridge width of the gradient amplitude matrix is replaced by the width of one pixel, but also the gradient amplitude of the ridge is retained[11].

3.2.5 Double threshold detection and connection edge

After the above processing, there are many false edges. It is necessary to filter the noise and eliminate the false edges by thresholding.

The specific steps of thresholding are as follows:

(1) Set two thresholds, i.e. a high threshold and a low threshold, and regard the gray value corresponding to the pixel with gradient amplitude less than the low threshold as 0;

(2) Set the image extracted by low threshold as A, and the image with gradient amplitude greater than high threshold as B. since A is the image extracted by low threshold, its edge continuity is good, but it will contain more false edges. B is the image with gradient amplitude greater than high threshold, so it does not contain false edges, but its edge continuity is poor;

(3) Based on image B and supplemented by image A, edge information is obtained by recursive tracking method.

To sum up, the selection of high threshold and low threshold is greatly affected by human factors, with poor adaptability, and there are obvious defects in practical engineering applications. Therefore, it is necessary to propose a method that can adaptively determine the high and low thresholds according to different images to eliminate the interference of human factors[12] we have coarse positioning of image edges through Canny algorithm to provide data support for further fitting to obtain sub-pixel points.

3.3 Sub pixel edge position calculation

After obtaining the rough edge location information, the algorithm uses Gaussian fitting to further improve the pixel level location information to sub-pixel level. Because the image generation process has fuzzy effect, and Canny edge extraction algorithm also has Gaussian filtering operation on the image, fitting using Gaussian model is more suitable for the actual situation of edge extraction[13]. As shown in Figure 2, the dotted grid represents the integer pixel points in the image. Let G be the gradient function, and the origin of the coordinate system coincides with the canny edge points. In the gradient direction, the algorithm obtains 2n+1 sampling points g (- n). G (0).G (+ n) by interpolation. Then the 2n +1 sampling points are used to fit the one-dimensional Gaussian function, and the position of the center point of the Gaussian function is the updated sub-pixel edge point coordinates.

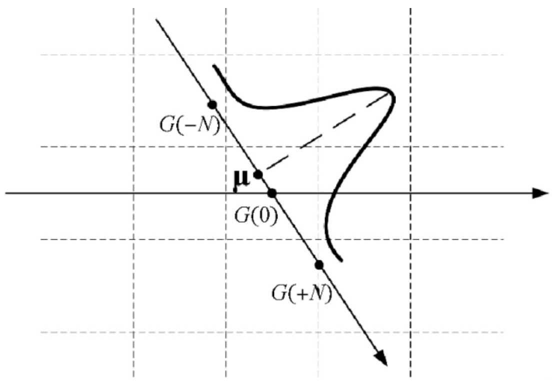

Figure 2: Sub-pixel edge detection based on Gaussian fitting

Specifically, the fitted Gaussian function is:

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$$\Omega_{\sigma,\mu,k}(x) = k\frac{1}{\sqrt{2\pi\sigma^2}}exp - -\frac{(x-\mu)^2}{2\sigma^2} \quad (6)$$

μ is the sub-pixel edge coordinate; σ is the standard deviation of Gaussian function; k is the amplitude of the Gaussian function. The fitting process uses the least square method to solve the Gaussian function μ、 σ、 k parameter value[14].

For the image contour edge tracking algorithm, the classic algorithm is based on Freeman chain code. The basic idea of the algorithm is to detect the image edge, then refine and connect the image edge, and finally track the image edge. Such algorithms need to detect four or eight connections of image edges. (citing sub-pixel edge detection and automatic recognition of geometric features. NIU) however, some edges are difficult to achieve four or even eight connections after processing, so for the part of graphic edge extraction, we use the chain search method to refine the image edge and obtain the pixel order of the image contour[15]. The specific steps are as follows:

(1) Select a pixel as the starting point;

(2) Add it to the output list and establish a 3*3 pixel matrix centered on it;

(3) Traverse the eight pixels except the center in the specified order.

If there are pixels with a binary result of 255 and not added to the output list, point the pointer to the point and jump to (2), otherwise the search ends.

The following points should be noted:

(1) Manually obtain the first pixel, so it is required to know the specific coordinates of at least one edge pixel;

(2) The traversal order problem after obtaining the pixel matrix. In order to obtain the next edge point as accurately and quickly as possible, we propose to comprehensively consider the gradient of the point and the binary results of the eight pixel points except the center, and obtain the next pixel point with the gradient as the dominant factor, so as to complete the edge search of the overall image.

(3) The image contour is as thin as possible to reduce the time consumption for non edge point judgment, so we first carry out the rough positioning of the image contour and a certain degree of thinning before extracting the edge.

3.4 Analysis of the model

Through the above steps, we get the final orderly segmented contour data (see the attachment) and the edge contour, as shown in the following figures (Figure 3,Figure 4). It can be seen that the edge features of each image are well preserved, and the effects of burrs and shadows are eliminated. Especially for pic1_3. The white spots formed under complex lighting conditions did not form an inner contour within the contour[16].

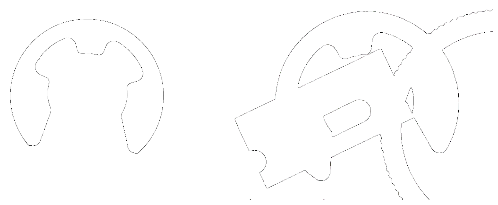

Figure 3: Edge graph of contour of pic1_1 and pic1_2

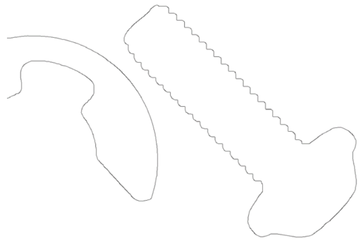

Figure 4: Edge graph of contour of pic1_3

Using this model, we combine canny, which has poor edge extraction effect in the light environment and more burrs, with a variety of filters and two-dimensional interpolation fitting to extract the edge contours of different shapes[17]. Canny operator provides us with the basic image edge, which has a good effect on the gray image and the image with clear edge, but for the image with complex illumination and fuzzy edge, it will not detect the edge points or make the edge points float and deviate from the edge position[18]; We use a variety of filtering methods to solve the problems of complex illumination and noise interference, and restore the original image as much as possible by eliminating the impact of the external environment to a great extent[19]; For the burr phenomenon of image edge caused by pixel loss or other reasons, we use binary pixel and two-dimensional interpolation to realize Gaussian fitting to further restore and supplement the edge[20]. From the comparison between the experimental results and other operator results, it can be seen that this algorithm is more suitable than the traditional algorithm for edge detection with complex illumination and compressed image.

4. Conclusion

Gaussian fitting can not only improve the blur effect in the process of image generation, but also the Gaussian filtering operation in the preprocessing. Therefore, using Gaussian model for fitting is more suitable for the actual situation of edge extraction. Canny uses two different thresholds to detect strong edges and weak edges respectively. Canny is not easily disturbed by noise and can detect real weak edges. Compared with curvature and slope, curvature angle can better distinguish straight line segment, arc segment and elliptical arc segment in edge curve. And the algorithm is easy to implement.

References

[1] Du Huimin, Jiang Yan, Chang Libo, et al. The improvement and parallel implementation of expansion and corrosion algorithms [J]. Journal of Xi'an Post and Telecommunications University, 2017, 22 (01): 88-93.

[2] Yu H, Lu Y, Yu C, et al. Co-Occurrence Morphological Edge Detection[C].//2019 International Conference on Internet of Things (iThings) and IEEE Green Computing and Communications (GreenCom) and IEEE Cyber, Physical and Social Computing (CPSCom) and IEEE Smart Data (SmartData). IEEE, 2019: 395-402.

[3] Zhang Z, Zhang J, Yue M, et al. High-temperature thermal expansion behaviour of C/SiC studied using an in-situ optical visualisation method and numerical simulations in a quartz lamp array heating environment[J]. Ceramics International, 2021, 47(9): 12547-12556.

[4] Wang Z, Huang X. Visual positioning of rectangular lead components based on Harris corners and Zernike moments[J]. Journal of Central South University, 2015, 22(7): 2586-2595.

[5] Ding Dengfeng. Intelligent edge detection technology research and application based on hybrid filtering algorithms [D]. Wuhan Textile University, 2021.

[6] Lu X, Zhang Y. Human body flexibility fitness test based on image edge detection and feature point extraction[J]. Soft Computing, 2020, 24(12): 8673-8683.

[7] Guo Y, Chen G, Zhang J. Measurement of Road Slope based on Computer Vision[C].//Journal of Physics: Conference Series. IOP Publishing, 2021, 1802(3): 032063.

[8] BISWAS R, ROY S, PURKAYASTHA D. An efficient content-based medical image indexing and retrieval using local texture feature descriptors [J]. International Journal of Multimedia Information Retrieval, 2019, 8(4): 217-231.

[9] Yu Songyu, Zhou Yuanhua, Zhang Rui, et al. Digital image processing [M]. Shanghai: Shanghai Jiaotong University Press, 2007.

[10] Li Mu, Yan Jihong, Li Ge, Zhao Jie. Adaptive Canny operator edge detection technology [J]. Journal of Harbin Engineering University, 2007 (09): 1002-1007.

[11] Dong Yu, Gao Yunbo, Liu Xiang. The application of improved genetic algorithms in the selection of Canny Occupation [J]. Lanzhou Jiaotong University Journal, 2014, 33 (6): 1-5.

[12] Han Dong, Li Yuqi, Wu yanhui. Sub pixel edge detection algorithm based on Gaussian fitting [J]. Computer applications and software, 2018,35 (06): 210-213+229.

[13] Shang Yaceng, Chen Jing, Tian Junwei. Gaussian fitted sub-pixel edge detection algorithm [J]. Computer application, 2011,31 (01): 179-181.

[14] Niu Ben. Sub-pixel edge detection and automatic geometric feature recognition [D]. Hefei University of Technology, 2014.

[15] Hu Junping, Song Feifei, Luo Chunlei, et al. A non-quantitative correction method based on adaptive corner detection [J]. Laser and optoelectronic progress, 2021,58 (12): 175-181.

ISSN 2616-5775 Vol. 5, Issue 7: 33-39, DOI: 10.25236/AJCIS.2022.050706

[16] Santana- Cedres D, Gomez L, Aleman-Flores M, et al. Invertibility and estimation of twor parameter polynomial and division lens distortion models [J]. SIAM Journal on Imaging Sciences, 2015, 8 (3): 1574- 1606.
[17] Ahmed M,Farag A. Nonmetric calibration of camera lens distortion: differential methods and robust estimation[J]. IEEE Transactions on Image Processing, 2005,14(8): 1215-1230.
[18] Liu Lianxiong, Hu Changhua, He Chuan, waiting. An improvement of non -quantitative correction method based on linear characteristics [J]. Journal of Optical Studies, 2017, 37 (9): 0915001.
[19] Devernay F, Faugeras O. Straight lines have to be straight[J]. Machine Vision and Applications, 2001, 13(1): 14-24.
[20] MoreJJ. The Levenberg -Marquardt algorithm: implementation and theory[M]. Heidelberg: Numerical Analysis, 1978: 105-116.