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Application of Subpixel Edge Detection in Laser Spot Image Detection and Control

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Abstract

The low accuracy of pixel-level edge detection leads to large errors in the measurement of light spots. For this reason, a high-precision measurement method for light spots based on sub-pixel edge detection is proposed. The method assumes that the grey value of the pixel unit through which the edge of the object passes is discontinuous, and builds a model in the rectangular neighbourhood of each edge pixel unit, which is positioned by the improved grey moment sub-pixel algorithm, which makes the accuracy improve again. The experimental results show that the detection accuracy of the improved grey moment sub-pixel algorithm is high which verifies that the method has high stability and accuracy.

Keywords

Edge Extraction; Image Preprocessing; Metal Parts; Quality Control; Subpixel Algorithms.

1. Introduction

In the current industrial era environment, laser perforation has been a lot of widespread applications, and in the process of laser perforation, the need for strict control of laser power. The size of the laser power can be measured by the size of the laser spot, so there is an urgent need to use the method of machine vision for measurement, in the industrial field, there have been a lot of products using machine vision technology to improve detection efficiency, such as glass products [1], Gear inspection [2],leather inspection [3]etc. In terms of software development, Zhu [4]et al. developed a machine vision development framework for product quality inspection, which can be adapted to different hardware devices for secondary development. [5]et al. developed a vision system with deep learning classifiers for automatic inspection. While in vision inspection systems, sub-pixel edge detection [6]positioning accuracy is the key element of its final measurement accuracy. However, through the previous research results, it was found that most of the current inspection techniques for laser spots are measured by calipers, which cannot provide real-time feedback, resulting in low efficiency, while the use of machine vision inspection is faster and more accurate, therefore, this study innovatively proposes a simultaneous online inspection method for two different metal parts based on sub-pixel edge technology.

2. Related Work

As a big industrial manufacturing country, although China has many metal parts processing enterprises, most of these enterprises are small and medium-sized enterprises, and there are many deficiencies in laser spot extraction and measurement, which can easily lead to out of place. In the research of sub-pixel edge detection algorithm, many experts have done some research work.

Guzhov [7]et al. investigated a new method to improve the resolution of optical microscopes using the spatial sub-pixel offset method, i.e., the spatial resolution was improved using the sub-pixel offset

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technique.Poyraz [8]et al. investigated a subpixel counting based diameter measurement algorithm for industrial machine vision, which classifies image pixels into whole pixel images and transition pixel images, and the accuracy of the proposed algorithm was improved by 3-10% compared to existing methods.In terms of sensitivity measurements, the operational sensitivity of the proposed method was quantified to be 1/20 of the pixel size, with an average uncertainty of 1 μm.In addition, the baseline calculation time of the proposed method was at least 12% higher than that of existing work. time is at least 12.5% to 35% higher than the existing work.Xie [9]et al. investigated a sub-pixel measurement method for metallic materials, which resulted in a difference between the measured values of the characteristic dimensions of bearing housings and shims and the investigated method in the range of 4-5 μm. Xu [10]et al. investigated an experimental displacement measurement experiment of a shaker based on binocular vision and subpixel optimization.A binocular vision algorithm based on ellipse fitting to accurately extract the subpixel centre of a circular target was proposed.An improved subpixel optimization method based on the Zernike moments and Canny operator was used to accurately locate the three-dimensional coordinates of the extracted target points.The results show that the proposed algorithm achieves highly accurate The results show that the proposed algorithm achieves high accuracy of displacement measurement and overcomes the problems of traditional methods. The common sub-pixel algorithms have an accuracy of about 0.01 pixel level, and the need to detect light spots requires an improvement in the detection accuracy of the algorithms. In this paper, a grey scale gradient method is used to determine the sub-pixel level edges.

3. Methodology

3.1 Scharr Edge Detection

To study subpixel algorithms, the first step is to improve on top of whole-pixel algorithms, and the Sobel [11]operator excels in gradient magnitude edge detection, it has a simple structure, wide applicability and is relatively easy to implement. However, it has some limitations in dealing with weaker edges, so some researchers developed the Scharr [12]operator, which can greatly improve the difference between pixel values and thus greatly improve the accuracy of edge detection. In Scharr operator, the convolutional template can be classified into two types i.e. horizontal and vertical.

$$S_1 = \begin{bmatrix} -3 & 0 & 3 \\ -10 & 0 & 10 \\ -3 & 0 & 3 \end{bmatrix}, S_2 = \begin{bmatrix} -3 & -10 & -3 \\ 0 & 0 & 0 \\ 3 & 10 & 3 \end{bmatrix} \quad (1)$$

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It can be seen that using traditional edge detection there may be a situation where the edge information is lost, this is due to the presence of gradients in the image in more than one direction, so the edge detection operator has to be increased to make the edges clearer.

The operator in each direction detects edges in different directions, because there are multiple edges in the image, so one operator cannot detect the edges of the image completely, so it is necessary to consider the sum of the detected edges in each direction. The following is an explanation of the principle for images in both directions, as shown in Figure 1:

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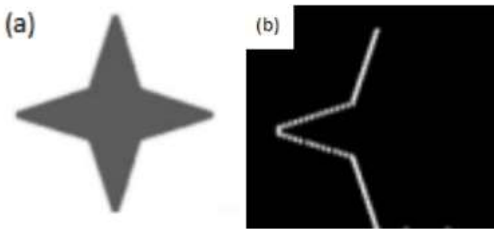


Figure 1. Principle of edge detection by Scharr operator: (a) original image; (b) image after edge detection

3.2 Sub-pixel Edge Detection

Since some edges remain discontinuous after edge detection, a curve fitting operation is required. The accuracy of the fitting depends on the accuracy of the edge detection algorithm; first-order differential and second-order differential edge detection algorithms can only identify pixel edges, and then there is a risk that subsequent positioning will be inaccurate. In order to improve the accuracy, there are two possible ways, one is to use higher resolution industrial cameras, which can obtain clearer edges. The second is to further improve the accuracy through algorithms that increase the positioning accuracy to sub-pixel [13]. This section focuses on the study of fitting algorithms at the sub-pixel level, starting from the improvement of the algorithms.

Because there is a situation that the edge of the object does not fall on the edge of the whole pixel when the camera shoots, which will cause errors in the positioning accuracy, subpixel is the basic pixel points in the image are divided again, and re-localisation is carried out on the basis of the traditional edge detection as shown in Fig. 2:

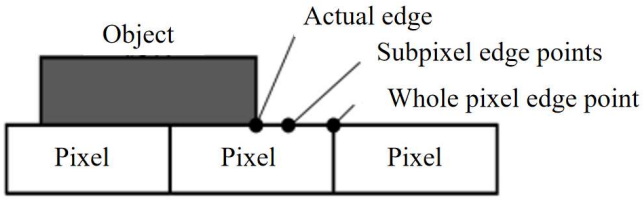


Figure 2. Schematic diagram of sub-pixel edge detection

3.3 Grey Moment Sub-pixel Positioning Algorithm

This section uses the grey moment method [14]. For localisation: there are two types of grey moment methods, one dimensional image grey moment method and two dimensional image grey moment method.

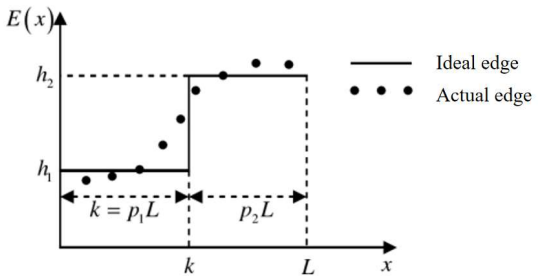


Figure 3. Schematic diagram of a 1D edge

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According to Fig. 3, h1 and h2 represent the theoretical and actual grey values, and k represents the step height of the one-dimensional image; therefore, Eq. 1 can be used to estimate the characteristics of the one-dimensional image more accurately, thus obtaining more accurate results:

$$\mathrm{E(x)} = (h_2 - h_1)\mu(x - k) \tag{2}$$

$\omega 1$and $\omega 2$ represent the proportions of grey value pixel points of h_1 and h_2, respectively, which form a complete grey moment when + $\omega 1 \omega 2$ = 1, and are expressed in the form:

$$\overline{\mathrm{m}} = \sum_{j=1}^{2} w_j h_j^i = \frac{1}{n}\sum_{j=1}^{n} g_j^i \tag{3}$$

Where: n denotes the total number of actual image edge images, i.e. $\omega_j = \frac{k}{n}$; g_j denotes the actual image grey value.

Therefore, it can be concluded that the position of the edge and its orientation parameters are as follows:

$$\omega_1 = 0.5\left[1 + \overline{s}\sqrt{1/\left(4 + \overline{s}^2\right)}\right] \tag{4}$$

$$h_1 = \overline{m}_1 - \overline{\sigma}\sqrt{\omega_2 / \omega_1} \tag{5}$$

$$h_2 = \overline{m}_2 - \overline{\sigma}\sqrt{\omega_1 / \omega_2} \tag{6}$$

$$\overline{\sigma} = \overline{m}_2 - \overline{m}_1, s = \frac{1}{n}\sum_{i=1}^{n}\frac{\left(x_i - \overline{m}_1\right)^3}{\overline{\sigma}^3} = \frac{\overline{m}_3 + 2\overline{m}_1^3 - 3\overline{m}_1\overline{m}2}{\overline{\sigma}^3} \tag{7}$$

Then the image sub-pixel edges are localised:

$$k = np_1 - \frac{1}{2} = \frac{n}{2}\sqrt{\overline{s} / \left(4 + \overline{s}^2\right)} + (n-1)/2 \tag{8}$$

(2) 2D edge positioning

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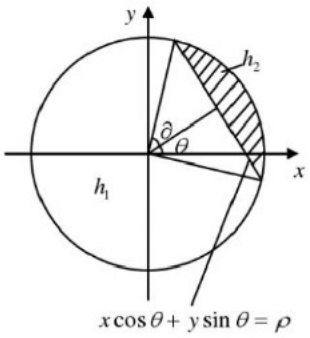


Figure 4. Schematic diagram of 2D edges

As can be seen from Fig. 4, the basic principle of the 2D edge model is:h_1 andh_2 represent the grey values on both sides of the edge, respectively, while ρ denotes the position of the edge and θ denotes the direction of the edge. A complete 2D edge model can be derived from these four parameters to achieve an accurate description of the edge:

$$E(x, y, \rho, \theta) = \begin{Bmatrix} h_1, x\cos\theta + y\cos\theta \le \rho \\ h_2, x\cos\theta + y\cos\theta > \rho \end{Bmatrix} \tag{9}$$

The first three orders of grey moments of the edge are denoted as:

$$\bar{m}_k = h_1^k \omega_1 + h_2^k \omega_2, k = 1, 2, 3 \tag{10}$$

$$\bar{m}_k = \sum_{i=1}^{N} \omega_i G_i^k \tag{11}$$

Style:

ω_i-Weight occupied by the ith pixel point;

G_i-The grey value of the ith pixel is tagged with that name;

N-Formwork area.

Therefore, the formula for solving the sub-pixel contour coordinates can be expressed as:

$$\rho = \cos\alpha, \sin\theta = \frac{y_0}{\sqrt{x_0^2 + y_0^2}}, \cos\theta = \frac{x_0}{\sqrt{x_0^2 + y_0^2}} \tag{12}$$

Style:

x_0, y_0-Position of the neutral point of the unit circle.

Therefore, the formula for solving the sub-pixel contour coordinates can be expressed as:

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$$\begin{bmatrix} x_s \\ y_s \end{bmatrix} = \begin{bmatrix} x \\ y \end{bmatrix} + \frac{N}{2}\rho \begin{bmatrix} \cos\theta \\ \sin\theta \end{bmatrix} \tag{13}$$

Since there are two accuracies for the image pixels, this paper decides to use the 2D grey moment method to achieve higher accuracy. Since the value ofθ can only be determined by traversing the value of the complete pixel point and the division of the pixel point is not very clear, therefore, in this section, the grey value of the pixel point will be carefully divided and the related formula will be optimised.

3.4 Determination of the Grey Scale Gradient

In order to locate subpixels accurately, one starts with a complete pixel point and then constructs a space within a rectangle along7×7 as shown in Fig. 4, where each of the four directions a, b, c, and d corresponds to a grey scale gradient, and the angle between them is 45° .

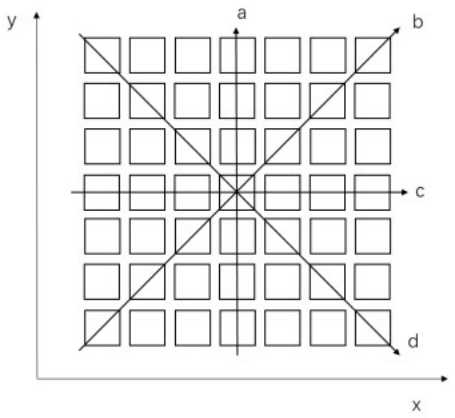


Figure 5. Schematic representation of the four gradient directions

By summing the difference of the absolute values of the four grey values noted asE_i , the maximum value ofE_i is the grey gradient direction of this pixel point, which can be expressed by the following equation:

$$E_i = \sum_{j=1}^{7} \left| p_{j+1} - p_j \right|, (i = a,b,c,d) \tag{14}$$

For the gradient direction of the grey value is presented decreasing and the largest change, the joint grey moment algorithm and this paper to improve the edge detection to find the coordinates, that is, the coordinates are composed of integer part and fractional part, the above formula is changed to:

$$\begin{bmatrix} x_s \\ y_s \end{bmatrix} = \begin{bmatrix} x \\ y \end{bmatrix} + \frac{N}{2}\rho \begin{bmatrix} \cos\theta \\ \sin\theta \end{bmatrix} \tag{15}$$

Where θ is determined by the grey scale gradient and N is the template area.

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After determining a gradient direction, edge positioning is carried out according to the two-dimensional grey moment method, taking a certain coordinate of the laser spot as an example, as shown in Figure 6 below for the laser spot picture.

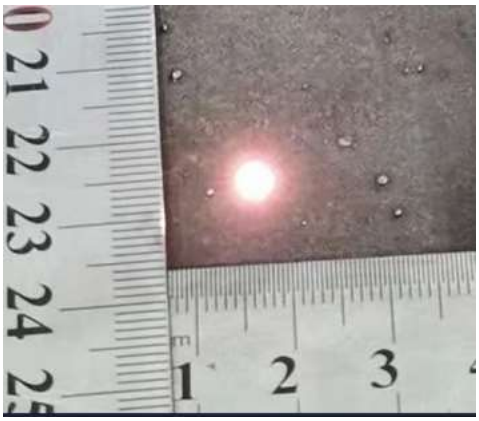


Figure 6. Laser spot image

The pixel grey values of the 7×7 matrix region centred on this point are shown in Fig. 7.

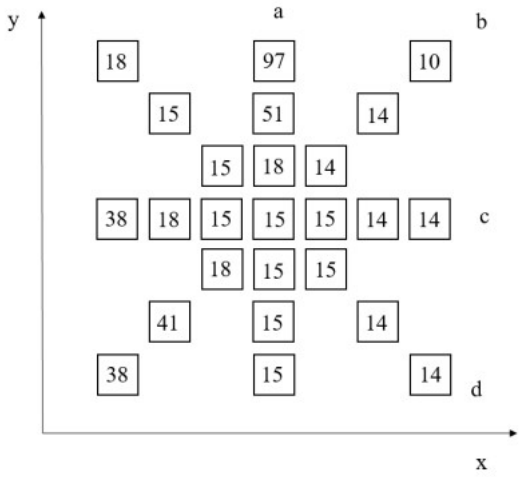


Figure 7. Pixel grey values in each direction

According to the gradient direction direction formula, find $E_a = 82, E_b = 34, E_c = 4, E_d = 24$. The obtained gradient direction in this direction is direction a direction. The grey scale moment algorithm fine positioning of the grey scale values of the points on the direction a can determine $\theta = -90^{\circ}$ in Eq. The coordinates of the sub-pixel coordinate points can be obtained from Eq. $(29 \quad 23.8037)$.

It is summarised as follows: the approximate direction of the grey scale gradient is determined and the value ofθ is determined, then the grey scale method of moments is used to compute the finely positioned contour points, cycling through the individual pixel points and then calculating the coarsely positioned contour points for the next image until all the pixel points have been taken.

So far, the flow of sub-pixel edge detection is shown in Figure 8:

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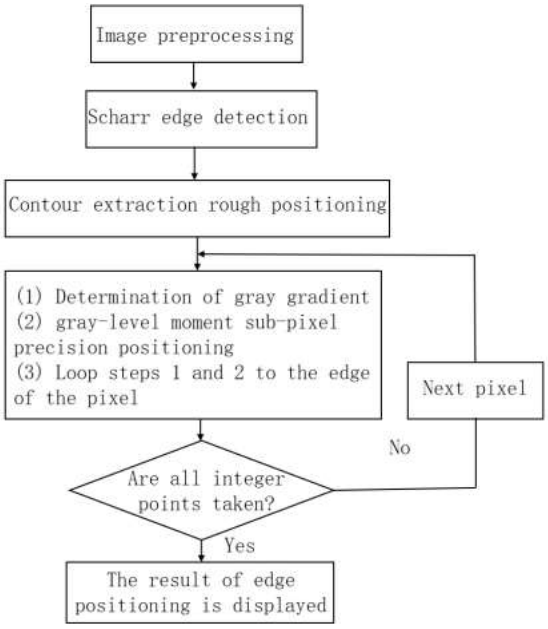


Figure 8. Subpixel detection flow

3.5 Comparative Analysis of Image Processing Effect

In order to verify the degree of fine positioning of the algorithm, a comparative analysis with the original algorithm is carried out. As shown in Figure 8 below, the blue line in the figure is the result obtained by the above improved edge detection coarse positioning, and the red line is the result obtained by the grey moment algorithm fine positioning, it can be found that in the sub-pixel edges, the grey moment fine algorithm is also able to carry out the edge recognition, and by obtaining a more comprehensive edge feature, it can improve the detection accuracy.

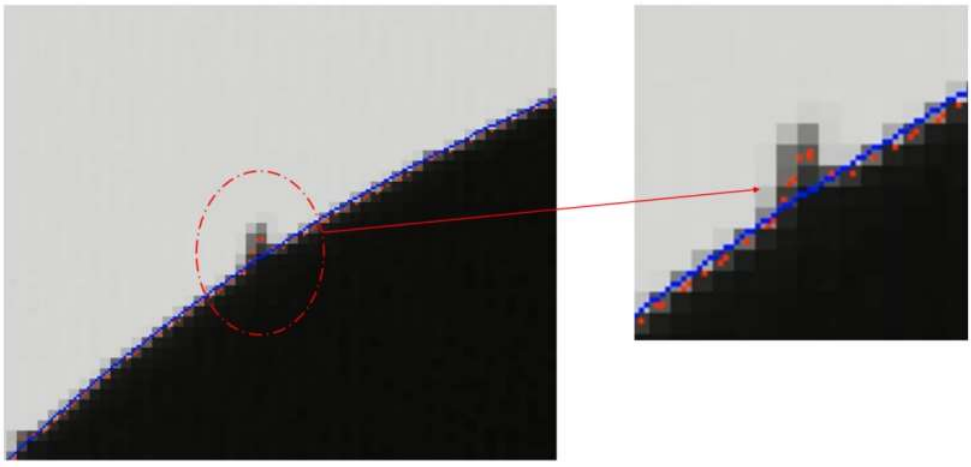


Figure 9. Positioning of circular grey moments

The detection accuracy of the two types of edge detection can be clearly seen by taking five random samples for the experiment in Fig. 8.

The two algorithms are compared with the actual coordinate values by establishing a coordinate system and obtaining the actual coordinate system by tracing the points with the software. From Table 1, the improved edge detection algorithm has high accuracy, but it is limited to the pixel level, compared to the sub-pixel level algorithm, which is more accurate and has an extraction accuracy of

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up to 0.1 to 0.2 pixels. Therefore, the modified grey moment algorithm is used in this paper to achieve accurate detection of edges and is applied in future research and detection.

Table 1. Actual and algorithmic detection of detection values

actual coordinates(x,y)		Improved Edge Detection Operator(x,y)		Grey moment sub-pixel(x,y)	
2.65	42.92	3	43	2.6429	42.9137
7.51	38.90	8	39	7.5035	38.8737
8.57	37.84	9	38	8.572	37.8232
12.70	34.57	13	35	12.682	34.5622
43.27	14.48	43	15	43.2733	14.4756

4. Conclusion

This chapter briefly describes how images restored using the improved grey scale gradient algorithm still retain edges more clearly compared to other filtering algorithms. Around the edge detection algorithm to carry out research, around the grey moment algorithm for sub-pixel fine positioning research, the grey gradient determination algorithm and the traditional grey moment algorithm for the combination of the grey gradient determination algorithm in a single direction to reduce the traditional grey moment algorithm of the amount of computation, as can be seen in Table 1, after the computation of the resulting coordinate value has reached four decimal places.

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