Sub-pixel Edge Detection Based on Curve Fitting

XU Guo-Sheng
Weifang university, Weifang 261061，China
e-mail: xuguosheng666666@163.com

Abstract—**Aimed at the problem that it s difficult to improve the identify precision of the linear CCD scan image, a novel fast sub-pixel edge detection method for image measurement is proposed. According to the step jump characteristic of the image edge gray degree and grads, it can determine the pixel boundary of the CCD image through edge automatic detecting algorithm. Based on this, we can use the curve fitting method to make sub-pixel subdivision of the edge position of the image, and carry out curve fitting of the edge signal. Finally, use the least square method to compare the second order curve which is obtained by fitting with the threshold level, and then use it to get the formula. We can use the formula to work out the accurate position of the edge point, thereby achieve the sub-pixel edge positioning precision. The experimental results and analysis show that, compared with the threshold level comparison method, the straight line fitting method has more advantages, such as high repeated precision, good stability and so on. It can restrain the influence of random noise effectively, so it can detect the edge position of one-dimensional image effectively.**

Keywords- curve fitting; edge detection; least square method; CCD

I. INTRODUCTION

The image measurement aims at obtaining the geometric parameters or positional parameters of the object through dealing with the edge of the image of the measured object. So in the image detecting system, the image edge detection is the basis and key point of the measurement, and the sub-pixel subdivision technology is the effective route to improve the precision of the CCD detecting system. With the gradual improvement of the precision requirement in industrial detection, some traditional edge detecting methods can't satisfy the practical needs, so more and more attention has been widely paid on sub-pixel edge detecting and positioning problem. At present, there has been many sub-pixel edge extracting methods[1-3], such as interpolation method, geometric quadrature method, space quadrature method and so on. Most of these methods have principle errors or some deficiencies, such as large computation and weak anti-noise capability. The CCD sensitive pixel can not only receive the light which photosensitive pixels on itself, but also receive the light which photosensitive pixels on neighboring sensitive pixels. Especially for the edge points, they make the CCD device have a gradually changing progress from bright to dark on the response signals of the step jump edge. The sub-pixel position of the edge points just exists in the transitional gradually changing phase, and it can make us use the curve fitting method to obtain the sub-pixel positioning of the edge points[3-5]. This paper integrates the threshold level comparison method, and introduces the application of the curve fitting method based on the least square principle in the edge detecting of the one-dimensional image of line-matrix CCD. It can achieve a sub-pixel positioning precision, and it also has strong anti-noise capability.

II. EDGE SIGNAL OF ONE-DIMENSIONAL IMAGE

In the line-matrix CCD detecting system, the detected object images on the CCD photosensitive pixels, and use the line-matrix CCD as the photoelectric sensor to receive image signals of the detected object. The CCD sensor changes the optical image signals of the detected object into discrete voltage signals, the rest, the size of each discrete voltage signal is corresponding to the light intensity received by the photosensitive pixels, while the output sequence of the signals is corresponding to the position sequence of the CCD photosensitive pixels. We should pretreat the discrete voltage signals outputted by the CCD, and then through low-pass filtering, amplifying, and high-pass filtering, the signals can convert to continuous video signals.

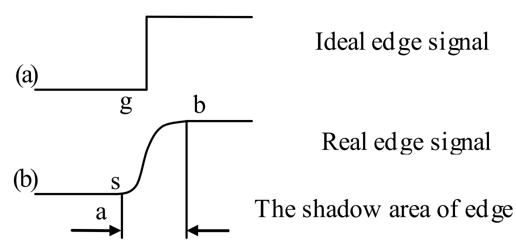

Figure 1. Edge signal of one-dimensional image

The CCD continuous video signals through A/D sampling can convert to digital image. The edge signals of one-dimensional image of the CCD video signals are corresponding to the physical boundary parts of the detected object, as is shown in figure (1). The low level of the output signals of line-matrix CCD is corresponding to the shadow area blocked by the detected object, while the high level is corresponding to the bright area which is not blocked. The ideal edge signal is a step jump signal, as is shown in figure 1(a), and it is also a ideal jump. In the practical system, the practical edge signal is a gradually changing one, and it increases gradually, as is shown in figure 1(b), the rising transitional area from point a to b is the edge transition of the image.

III. THE PRINCIPLE OF THRESHOLD LEVEL COMPARISON METHOD

As for the ideal edge signal shown in figure 1(a), point g is the edge point of one-dimensional image, and it is corresponding to the edge position of the detected object. As for the practical edge signal, to detect the edge point of the image is more complex. Point a, s, and b are practical edge

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signals, just as shown in figure 1(b), the rest, point a and b are the jumping-off point and end point respectively. Commonly, we make point s in the middle part of the edge transitional area of the image as the edge point of the image. Commonly, the threshold level comparison method is adopted to detect the edge points of the one-dimensional image of line-matrix CCD. The dark level V_L and bright level V_H of the one-dimensional image are corresponding to the shadow area and bright area respectively. Choose a threshold V_0, and then make the point whose amplitude V in the edge transitional area of the signal is equal to the threshold V_0 as the edge point of the signal, the rest, the threshold is determined by the dark level V_L and bright level V_H,

$$V_0 = V_L + k(V_H - V_L) \tag{1}$$

Commonly, we choose 0.5 as the proportional coefficient k in the formula, and at this moment, V_K lies between the dark level V_L and the bright level V_H, i.e.

$$V_0 = (V_L + V_H)/2 \tag{2}$$

In normal cases, the point whose amplitude V is equal to the threshold lies between point N and N+1, i.e.

$$V_N \le V_0 \le V_{N+1} \tag{3}$$

Now, the position x_s of the edge point s is not corresponding to the integer n, we can obtain the position of the edge point s through linear interpolation method,

$$x_s = N + (V_K - V_N)/(V_{N+1} - V_N) \tag{4}$$

Simply adopting the threshold comparison method to detect the edge position of the image is interfered by the noise easily, because the noise on the signals V_N and V_{N+1} which are corresponding to point N and N+1 close to the threshold affects the detecting results directly, and the stability of the detecting algorithm is restricted. Therefore, this paper proposes the curve fitting method based on the least square principle, and combine the threshold comparison method with the curve fitting method to detect the edge point of the image.

IV. CURVE FITTING METHOD

The curve fitting method is to fit the curve of the measuring data. Sometimes, the chosen curve passes through the data points, but on other points, the curve closes to them rather than passing through them. In most cases, we choose the curve to make the square error of the data points minimum, which is called the least square curve fitting. As for the output signals of one-dimensional CCD, we can use a second order polynomial to progress the curve fitting, and its principle is shown in figure 2. Based on the threshold comparison method, we can set a lower threshold V_c and a upper threshold V_d, and intercept the edge signals between V_c and V_d to progress the straight line fitting, the rest

$$V_c = V_a + 0.3(V_b - V_a) \tag{5}$$

$$V_d = V_a + 0.7(V_b - V_a) \tag{6}$$

Search along the edge from point a to b to find the first point x_c which is more than V_c. Then search along the edge from point b to a to find the first point x_d which is less than V_d, so $V_{x_c} \ge V_c$, $V_{x_d} \le V_d$. Choose the point from x_c to x_d as fitting window, i.e. using the edge signal from x_c to x_d to carry through the second order curve fitting.

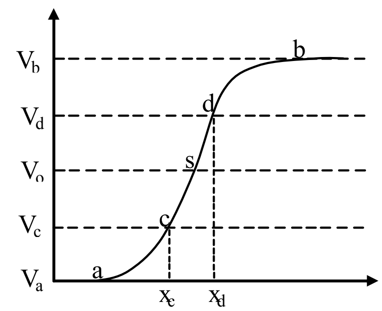

Figure 2. Edge detecting principle figure of the curve fitting method

The curve equation which is used to fit the edge signal can be set as $V(x) = ax^2 + bx + c$. From the least square principle we can obtain the parameters a, b, c, which make the total square error minimum.

$$e^2 = \sum_{x_c}^{x_d} (V(x) - ax^2 - bx - c)^2 \tag{7}$$

Make the partial differential coefficient of e^2 versus a, b, c respectively, and make their partial differential coefficient zero respectively, i.e.

$$\frac{\partial}{\partial a} \sum_{x_c}^{x_d} (V(x) - \mathrm{a}x^2 - \mathrm{bx} - \mathrm{c})^2 = 0 \tag{8}$$

$$\frac{\partial}{\partial \mathrm{b}} \sum_{x_c}^{x_d} (V(x) - \mathrm{a}x^2 - \mathrm{bx} - \mathrm{c})^2 = 0 \tag{9}$$

$$\frac{\partial}{\partial \mathrm{c}} \sum_{\mathrm{x_c}}^{\mathrm{x_d}} (\mathrm{V(x)} - \mathrm{ax}^2 - \mathrm{bx} - \mathrm{c})^2 = 0 \tag{10}$$

We can obtain three parameters a, b, c of the fitting equation $V(x) = ax^2 + bx + c$ of the edge fitting window through the formulas (8) (9) (10), and then use the threshold comparison method we can obtain the intersection x_s by using the threshold V_0 to intercept the fitting curve, and the intersection is the edge point. The signal in the position of x_s is $V(x_s) = V_0$, and V_0 is shown in formula (2), therefore,

$$a{x_s}^2 + bx_s + c = (V_a + V_b)/2 \tag{11}$$

And then we can obtain the position of the edge point x_s, i.e. The comparison of the waveform before and after the curve fitting figure 3 below.

$$x_s = \frac{-b \pm \sqrt{b^2 - 4ac + 2a(V_a + V_b)}}{2a} \tag{12}$$

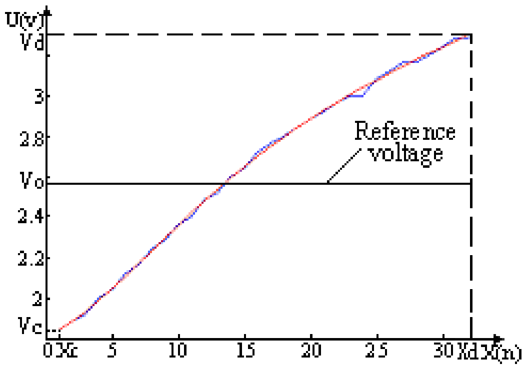

Figure 3. The comparison of the waveform before and after the curve fitting

V. EXPERIMENTAL RESULTS AND ANALYSIS

This system makes the point tungsten light as the light source. The light sent by the light source permeates the XLPE cable material with 20mm width and 1mm thickness, and then pass through a lens onto the photoelectric detector. The detecting principle of the system is shown in figure 4. The impurity particles pass through the lens according to a certain proportion, and then image onto the surface of the pixel array of the CCD device. The photosensitive pixel arrays on the CCD device convert to discrete distributing charge, and then through the CCD device, the outputs of the stimulant shift register become the discrete voltage signals of time series. Finally, through the demodulation of the low-pass filter, they become smooth time domain signals which contain impurity information. Using the virtual oscilloscope we can transform the signals into digital signals which can be processed in the computer.

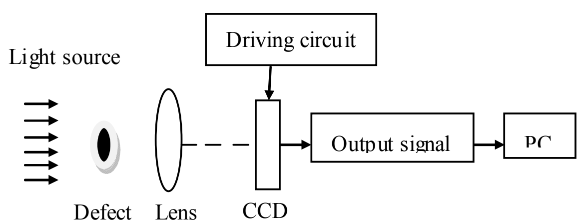

Figure 4. The detection principle for system

The system adopts the virtual oscilloscope DSO2902 to gather and process the signals. The virtual oscilloscope chooses a storage depth of 8k and a real-time sampling rate of 10 MHz, so the sampling cycle is 100 ns. While the clock pulse of CCD is 2 MHz, and its cycle is 500 ns, so each pixel point is corresponding to 1/5 of the pixel. Use the threshold level comparison method and curve fitting method respectively to carry through the edge detection of the pre-calibrated impurities of 185 μm for five times. The experimental results are shown in table 1. The measurement data in the table denotes the number of pixels, and it is proportional to the size of the impurity particles.

TABLE I. THE RESULT FOR THE IMAGE DETECTION SYSTEM

Position	Defect size (μm)	Measurment(μm)
1	*76*	*76.88*
2	*78*	*74.64*
3	*75*	*74.6*
4	*73*	*75.9*
5	*74*	*76.39*
square error	*1.84*	*0.67*
pixel error	*5*	*2.24*

From table 1 we can see that, in the two edge algorithms, as for the impurities of 185 μm, the variance measured by the curve fitting method is 0.67. Compared with the data measured by threshold level comparison, its volatility is improved greatly. The pixel error is 2.24, and the repeatable accuracy and errors of the edge detection also improve greatly, and then achieve the edge positioning accuracy of the sub-pixels.

VI. CONCLUSION

In the detecting system of one-dimensional line-matrix CCD, the hardware circuit of the detecting system has already been perfect, to improve the measuring accuracy, the edge detecting method of one-dimensional image is usually adopted. The quality of the edge points of the CCD image affects the fitting accuracy greatly, so how to choose the edge points is very important. The polynomial curve fitting method uses many pixel points in the edge signals to carry through the computation, therefore, it reduces the impact of random signals on the measuring results, and then improve the reputable accuracy of the system. The method of using polynomial to fit the edge of one-dimensional image has good anti-noise capability. The polynomial fitting edge integrating the threshold comparison method can detect the position of the edge of the image effectively. This paper integrates the threshold level comparison method, and introduces the application of the curve fitting method based on the least square principle in the edge detecting of the one-dimensional image of line-matrix CCD. It can achieve a sub-pixel positioning precision, and it also has strong anti-noise capability.

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