Linear Array CCD Image Sub-pixel Edge Detection Based on Wavelet Transform

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***Abstract*—In order to increase accuracy of the linear array CCD edge detection system, a wavelet-based sub-pixel edge detection method is proposed, the basic process is like this: firstly, according to the step gradient features, automatically calculate the pixel-level border of the CCD image. Then use the wavelet transform algorithm to devide the image's edge location in sub-pixel level, thus detecting the sub-pixel edge. In this way we prove that the method has no principle error and at the same time possesses a good anti-noise performance. Experiments show that under the circumstance of no special requirements, the accuracy of the method is greater than 0.02 pixel, thus verifying the correctness of the theory.**

Keywords-Wavelet transform; Sub-pixel; Edge detection; CCD

I. INTRODUCTION

The purpose of image measurement is to obtain the object's geometric and location parameters. so in the image measurement system, image Edge detection is the basis and key to the measurement. and the technology of Sub-pixel division is one of the effective ways to increase the accuracy of CCD measurment system. With the increasing demand for accuracy in the industrial detection, some of the traditional ways of edge detection have been difficult to meet the actual needs of sub-pixel edge detection[1][2].wavelet analysis is a multi-resolution analysis which highlight the local features in the time-frequency domain. At present, the edge positioning based on wavelet transform can not meet the high-precison measurements in the field for it's accuracy can only reach pixel level. In this paper, a sub-pixel based edge detection method is presented. The positioning accuracy can reach the sub-pixel and has a better anti-noise performance[3][4].

II. SUB-PIXEL EDGE DETECTION PRINCIPLE

A one-dimensional wavelet function is as follows:

$$\psi_s(x) = \psi(x/s)/s \tag{1}$$

The s-scale wavelet transform can be obtained through the following convolution

$$Wf(s,x) = f^*\psi(x/s) \tag{2}$$

For some special wavelet functions $\psi_s(x)$ the wavelet transform modulus maxima corresponds to the mutating point. Suppose $\psi(x)$ is a smooth function defined as the first derivative of $\theta(x)$, namely, $\psi(x) = d\theta(x)/dx$ and $\theta(x) = \theta(x/s)/s$,so we get the wavelet transform in the s-scal:

$$Wf(s,x) = f^*\psi(\frac{x}{s}) = s\frac{d}{dx}(f^*\theta(x)) \tag{3}$$

Wavelet transform is proportional to the first derivative of the smoothed fuction f(x). Hence the greatest value of the wavelet transform corresponds to the maximum of the first derivative of $f^*\theta(x)$, which is exactly the signal's mutating point of in the s-scal. Thus the Wavelet transform modulus maxima can be used for image's edge detection.

The priciple of the wavelet transform modulus maxima edge detection has been given in the introduction. However, from the references we know the accuracy of wavelet transform modulus maxima edge detection can only reach pixel-level. The sub-pixel positioning method based on the wavelet transform modulus maxima edge detection is presented in the following discussion. For one-dimensional model of an ideal edge:

$$f(x) = Au(x) \tag{4}$$

where

$$u(x) = \begin{cases} 1 & x \ge x_0 \\ 0 & x \le x_0 \end{cases} \tag{5}$$

Theorem 1: Suppose $Wf(s,x)$ as the wavelet transform coefficient of f(x) in the s-scale, and p(x) refers to the probability of wavelet transform coefficient which is greater than the threshold value T. Then we get the mathmatical expectation $E = \int_{-\infty}^{\infty} xp(x)dx = x_0$, proving that the mathematical expectation is the exact location of the ideal edge.

Because CCD is a integral device, in the actual imaging system, its output gery value is influential to the light distribution of the photographic surface. For a piont spread fuction in the information system, it's usually represented by a Gaussian function.

$$G(x) = \frac{1}{2\pi\sigma} e^{-x^2/(2\sigma^2)} \tag{6}$$

so the noise-free ideal image obtained in the imaging system is

$$f_1(x) = Au(x) * G(x) = A\int_{-\infty}^{x_0} G(x+\alpha)d\alpha \tag{7}$$

where x_0 refers to the exact location of the edge, as is shown in Figure 2.

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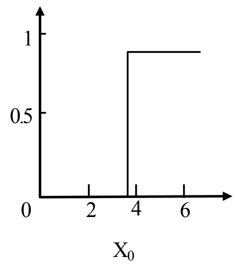

Figure 1. Ideal edge location

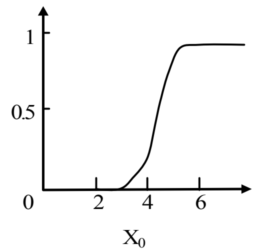

Figure 2. Exact edge location

Theorem 2: Suppose $Wf(s,x)$ as the wavelet transform coefficient of f(x) in the s-scale, and p(x) refers to the probability of wavelet transform coefficient which is greater than the threshold value T. So the mathematical expectation $E=\int_{-\infty}^{\infty} xp(x)dx = x_0$ is the exact location of the edge which has passed through the imaging system.

From the theorem 1and theorem 2, we can see that using the mathematical expectation of the wavelet transform coefficient in the s-scale, it's desirable to determin the exact location, no matter for the ideal edge or the edge passed through the CCD. That is to say, the approach itself has no principle error. Since the expectation has nothing to do with the scale, we can do the signal with large-scale wavelet decomposition and then caculate the expectation to get the exact location. By the multi-resolution analysis theory we know that signal after the large-scal wavelet decomposition reflects the profile information, thus the detailed information such a noise can be effectively removed. It said that the theorem 1 and theorem 2 guarantee by theory that the sub-pixel based edge detection method possesses a ppd anti-nois performance.

The theorem 1 and theorem 2 are based on continous signal, while in practice, sampled signals are all discrete ones. Theory and experiment prove that the theorem 1 and theorem 2 also apply to the discrete signals. Here we only present the processing method.

For an discrete signal. Suppose $Wf(s,x)$ as the wavelet transform coefficient of f(x) in the s-scale, and p(x) refers to the probability of wavelet transform coefficient which is greater than the threshold value T. E refers to the expectation of the edge location, so the formula is as follows:

$$p(k)=\frac{Wf(s,x)}{\sum_{k=1}^{n} Wf(s,x)} \tag{8}$$

$$E=\sum_{k=1}^{n} kp(k)=\frac{\sum_{k=1}^{n} kWf(s,i)}{\sum_{k=1}^{n} Wf(s,x)} \tag{9}$$

The obtained expectation is the edge's exact location. Although the derivation is performed in the ideal case that has no noise, it also applies to the cases with noises.

III. SUB-PIXEL EDGE DETECTION REALIZING METHOD

Specific steps are given as follows:
(1) Select a scale s, implement the wavelet transform.
(2) Find out the modulus maxima of the wavelet transform coefficient in the s-scale.
(3) Remove the modulus maxima whose modulus maxima coefficient decreases with the scale increasing, for the coefficients are generated by noises.
(4) O set a threshold value T, filter out the modulus maxima generated by the tiny details.
(5) In the vicinity of the modulus maximum, find the fiels where the modulus maxima coefficient the same symbols with the modulus maxima. calculat the expectation by (9)and we get the edge's sub-pixel coefficient.

IV. EXPERIMENT

In the experiment, we firstly squeeze the sampled plastic film material into a strip like continous sample with a small extruder or rheometer. Then in the melt state the sample undergo a cold-roll calendar which is 200mm wide, 0.5mm thick with great transparency. Using a linear light source to light the sample ,then CCD camera systerm scan the sample in one-dimension perpendicular to the sample's marching direction to determin the data rate of CCD device, scanning frequency and detection speed.

The principle of the detection system is shown in Figure 3. Passing through the lens, The particle defects fall onto the pixel array of the CCD device in a certain proportion. Then the micro-million photo array transformed into the discrete distributed charge, which becomes the time series discret voltage signal after the CCD model shift register device. After demodulated through the low pass filter, it becomes smooth time-domain signal with defects. Then use a virtual oscilloscope to convert it into a digital one for computer processing .In order to effectively verify the accuracy of the method ,efforts should be made to minimize other source errors, thus making edge detection accuracy the major factor, so that the accuracy of the measurement system can effectively reflect the accuray of the method.

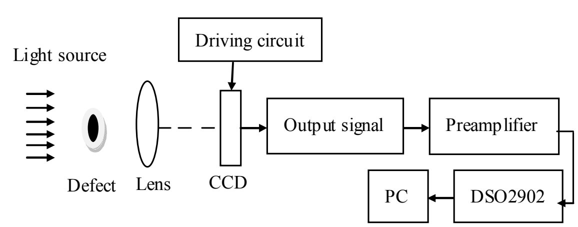

Figure 3. The detection principle for system

A. Calibration and repetitive testing

He equivalent pixel 0.4918 mm/pixel can be obtained through calibration. In order to verify the stability of the measurement system, we carry out the repetitive testing to get the standard deviation σ 0.0053mm.

B. The accuracy of the measurement system

20 calibrated defects are detected in the experiment, with the standard deviation 0.0184 pixel, The tenth defect possesses the biggest deviation as 0.0342 pixel. The graph 1 lists the first 5 defects's measurements. In practice, after several measurements, the standard deviation can reach less than 0.02 pixel.

TABLE I. THE RESULT FOR THE IMAGE DETECTION SYSTEM

positio n	**Defect size(mm)**	**measurment (mm)**	**Error (pixel)**
1	***0.5988***	***0.5940***	***0.0098***
2	***0.9688***	***0.9623***	***0.0132***
3	***0.6012***	***0.6067***	***-0.0112***
4	***0.4924***	***0.4984***	***-0.0122***
5	***1.0038***	***0.9957***	***0.0165***

V. CONCLUSION

In this paper ,we first introduced the structure ,principle and algorithm of the image measuring system. The CCD sub-pixel division algorithm based on wavelet transform is major illustrated. Firstly we prove by theory that the method proposed has no principle error and possesses a good anti-noise performance. Then the experiments show that without the special requirments for light source, the accuracy of the position detect can be achieved within 0.02 pixels, thus verifying the correctness of the method. In conclusion, the method proposed in this paper can greatly improve the accuracy and speed of the measurement systems and at the same time lay foundation to the development of the high-speed , high-precision measuring systems.

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