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Real-Time Defects Detection Algorithm for High-Speed Steel Bar in Coil

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***Abstract*—**This paper presents a real-time defect detection algorithm for high-speed steel bar in coil. Because the target speed is very high, proposed algorithm should process quickly the large volumes of image for real-time processing. Therefore, defect detection algorithm should satisfy two conflicting requirements of reducing the processing time and improving the efficiency of defect detection. To enhance performance of detection, edge preserving method is suggested for noise reduction of target image. Finally, experiment results show that the proposed algorithm guarantees the condition of the real-time processing and accuracy of detection.

***Keywords*—**Defect detection, edge preserving filter, real-time image processing, surface inspection.

I. Introduction

IN steel manufacturing industry, as many advanced technologies increase manufacturing speed, fast and exact products inspection gets more important. Most parts in the steel production rolling process are automated, but the quality assurance of a steel BIC (Bar in Coil) is mainly carried out by manual. This manual inspection can't cover overall surface of a steel BIC. Due to the different criterion of inspectors, the reliability and the accuracy of this inspection can't be guaranteed. If the defects of the product are reliably inspected, it is also possible to grade the product for the needs of the customer. Moreover, if the defects are detected at early stage of the process, it is possible to improve the production process and to reduce product damage [6].

In this paper, in order to detect BIC defects effectively, the detection algorithm should solve four issues as follows. First, the target of defect detection is the steel BIC whose moving speed is up to 18.5 m/s. Because BIC speed is very high, to process such a large amount of image data on real-time, the processing time of detection algorithm should be small. Second, the performance of defect detection decreases due to noise such as camera thermal noise, digitizing noise, and so on. Hence defect detection algorithm should reduce the noise effect efficiently. Third, since BIC is in the form of long cylindrical stick, the image which, by the lightening, is brightest in the center and gets gradually dark towards sides. So it is essential to reduce the effect of lightening. Finally, because the width of crack defect is only one or two pixel, it is difficult to discriminate noise from the image.

There have been many approaches for the defect detection in many kinds of manufacturing industry. For instance, the neural network technique, Gabor filter technique, Wavelet transform technique and etc. have been used to detect defects of many kinds of products [7]-[12]. Although good performance can be expected, it is impossible to apply these techniques to this real time system because of too much processing time. Therefore, this paper proposes an effective real-time defect detection algorithm that can solve above four problems. To get good performance and fast processing time for real-time processing, we propose edge preserving filter technique and we employ the double threshold method.

Section II introduces the proposed real-time defects detection algorithm. The performance of the algorithm is evaluated in Section III. Finally, Section IV gives conclusion.

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II. Real-Time Defects Detection Algorithm for High-Speed BIC

The target of defects detection is the steel BIC whose moving speed is up to 18.5 m/s. The BIC image is acquired from a line scan camera that has 512 pixels per one line with 50KHz line rates. Fig. 1 (a) shows an acquired BIC image. The image data should be processed at a speed of about 100 frames per second and each image has a size of 512 by 512. Therefore, to process such a large amount of image data on real-time, the processing time of detection algorithm should be small. So we proposed simple defects detection algorithm which has fast processing time.

A. The Proposed Edge Preserving Smoothing Method

In general, gradient or 2^{nd} derivative information is used to separate images with different gray levels. But these pieces of information are very sensitive to noise. Therefore to reduce noise effects, image smoothing must precede the main defection processing. Smooth filtering method has been suggested in many different ways such as averaging filters, Gaussian low-pass filter, etc. However, most of the smoothing filters are implemented uniformly across the image and thus tend to modify both noise and defects pixel. Consequently, the effective reduction of noise is often accomplished at the expense of blurring and distorting features [1]. Fig. 2 shows gray level of a horizontal line in BIC image. The black line represents gray level of original image and the red line represents gray level of averaging filtered image. This figure shows that the smoothing filter tends to blur detail of defect as well as noise. The edge preserving smoothing should preserve significant changes in image intensity, while it smooth down random noise fluctuations. To solve this problem, many methods have been studied in many different ways [1]-[5]. One of many different methods improves the performance of filtering based on median filter. These decision-based median filters realized by threshold operations have been introduced in some recently published works [1]-[4]. In general, the decision-based filtering procedure consists of the following two steps: an impulse detector that classifies the input pixels as either noise-corrupted or noise-free, and a noise reduction filter that modifies only those pixels that are classified as noise-corrupted [1]. Because the BIC image has much Gaussian noise than impulse noise, these methods which are fit the impulse noise can not be expected to have a good performance. Moreover, impulse detectors need amount of processing time, so these methods can not be applied to defect detection for BIC which should operate in real-time. Another method of filtering blends recursively the linearly smoothed versions [5]. However the recursive scheme is not in accord with our demand of the fast processing time. So we propose the simple edge preserving filter method. The algorithm can be expressed as follows. The proposed edge preserving filter method can be expressed as follows:

$$\hat{f}(x,y) = \alpha(x,y) f(x,y) + (1-\alpha(x,y))\tilde{f}(x,y)$$

$$\alpha(x,y) = \frac{\dfrac{\partial^2 \tilde{f}(x,y)}{\partial x^2}}{\max\left(\dfrac{\partial^2 \tilde{f}(x,y)}{\partial x^2}\right)} \qquad (1)$$

where $f(x,y)$ is an original image at x, y and nonlinear smoothed version of $f(x,y)$ denoted by $\hat{f}(x,y)$.

$\tilde{f}(x,y)$ represents a smoothed image by a weighted averaging filter. The $\alpha(x,y)$ is smoothing rate parameter. The proposed edge preserving filtering method consists of two operations. First, the original image smooth down by using weighted averaging filter. And then the laplacian filtering is used to the smoothed image. The calculated laplacian value of smoothed image has maximum value in defect region. The smoothing rate $\alpha(x,y)$ is derived by dividing laplacian value to the maximum laplacian value. The $\alpha(x,y)$ controls smooth rate in the range $0 \le \alpha(x,y) \le 1$. In other words, as the value of α approaches 1, there is more probability that the pixel is defect. So the edge of defect can be maintained while noise is removed.

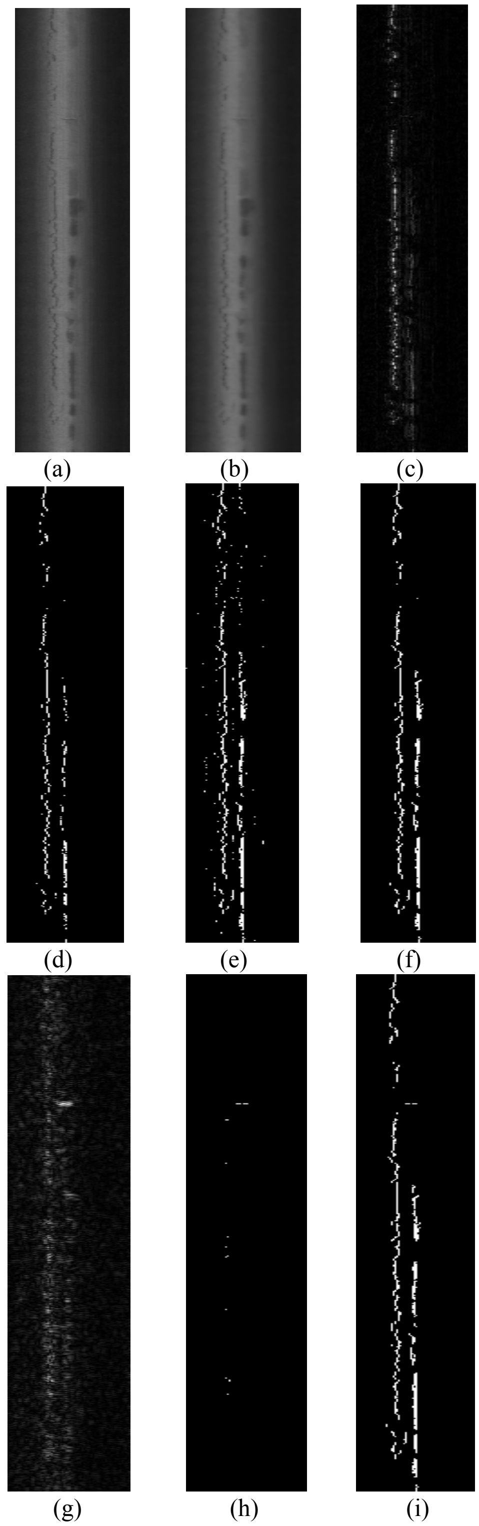


Fig. 1 Result images for step-by-step precessing (a) original, (b) edge preserving filtering, (c) x-axis laplacian, (d) x- axis high threshold, (e) x-axis low threshold, (f)double threshold, (g) y-axis laplacian, (h) y-axis threshold, (i) final result

Fig. 4 (a) shows general weighted filter and proposed edge preserving filter result. And Fig. 4 (b) shows gaussian smooth filter (σ =1.5) and proposed edge preserving filter result. Both figures verify that the proposed method preserves significant defect edge while it removes noise.

B. Laplacian Filter (2nd Differential)

In general, gradient information of the image is used to separate images with different gray level. However, BIC is in the form of long cylindrical stick as seen in Fig. 1 (a). This

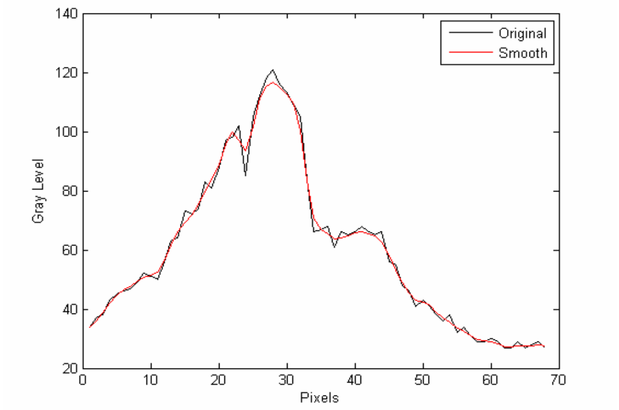


Fig. 2 Gray level of a horizontal line in original image and weighted averaging filter image

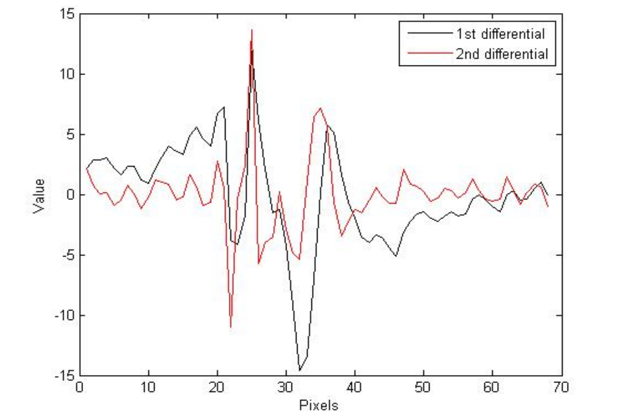


Fig. 3 Magnitude plot with gradient and laplacian

shows the image which, by the lightening, is brightest in the center and gets gradually dark towards sides. Gradient on the horizontal direction is shown in the Fig. 3. Due to the smooth filter, the gradient magnitude in defect parts is smaller than that of original image. This causes a serious difficulty in the threshold level decision which discriminates between the effect from the noise and that from the defect. Moreover, brightness change by the lightening from the center to the right side affects the gradient value, which gets bigger than the value resulted from defect. Therefore, we applied laplacian filter which is appropriate to the character of the BIC image.

Generally, the laplacian uses templates in the form of convolution masks having the following values:

$$\begin{bmatrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{bmatrix}, \quad \begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix} \tag{2}$$

The first mask considers only change of gray level to the horizontal and vertical directions and the second mask reflects change of gray level to diagonal direction in addition to horizontal and vertical direction. In BIC image, dominant gray level change is shown to the horizontal direction. If all directions are considered, more noise will be added and the difference between defect image and no defect image will be reduced. It is also more difficult to distinguish defect from image. So the laplacian mask needs to divide into vertical and horizontal direction. After analyzing various methods, we concluded that in the process of laplacian, it is the most appropriate to separate a x axis from y axis and then use a laplacian operator as shown below.

$$L_x = \begin{bmatrix} 0 & 0 & 0 \\ 1 & -2 & 1 \\ 0 & 0 & 0 \end{bmatrix}, \quad L_y = \begin{bmatrix} 0 & 1 & 0 \\ 0 & -2 & 0 \\ 0 & 1 & 0 \end{bmatrix} \tag{3}$$

The laplacian response for the typical defects is shown Fig. 6.

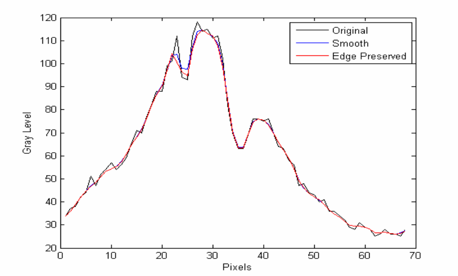
C. Double Thresholding

After the laplacian filtering, it follows the threshold operation to binarize the image. If threshold which has a high value is applied to an image, only real defect parts are detected as a defect without noise. But it can make the defect looks like a dashed or broken shape.

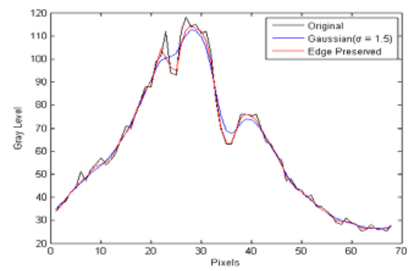
On the other hand, applying low threshold can detect all defects with keeping shape. But it also has a problem that noise can be detected as a defect. Therefore, we used double threshold method to take both merits in two threshold values.

All the pixels that have a laplacian value above the high threshold will be retained. Similarly, all the pixels that have a laplacian value below the low threshold will be rejected. The pixels with laplacian values in between the high and low thresholds are retained only if the pixel is connected to another pixel with a laplacian value above the high threshold. This double threshold method is applied only to horizontal direction. As a result of experiment, we concluded that it is enough to use single threshold method for vertical direction. Fig. 1 (f) shows the result of double thresholding. It is clear that double threshold method detects the shape of detect better than single threshold method.

The threshold level is updated for the image with no defect and is not updated for the image with any defect. In this way, we can change the threshold level and improve the detection efficiency on the noise change depending on images and time. The next threshold value is determined by calculating the moving average of previous threshold values in the fixed size buffer.



(a)



(b)

Fig. 4 Result of filtering (a) weighted averaging filter (b) Guassian filter and proposed method

In this paper, we fix 125% of max laplacian value of no defect image as the high threshold level, and 60% as the low threshold level. There are only a few defects oriented to the vertical direction, and the laplacian value to this direction is relatively different between defect and noise. Therefore double thresholding to vertical direction is just waste of time without enhancing the result compared to the single threshold. And, we fix 180% of max laplacian value to the vertical direction of no defect image as the vertical threshold level.

TABLE I
DETECTION PERFORMANCE OF EACH DEFECT

Operation	Number of Defects	Number of Processing	Detection Ratio
Crack	74	72	97.29 %
Spot	81	77	95.06 %
Dark Line	20	18	90.00 %
Total	175	167	95.42 %

TABLE II
PROCESSING TIME

Operation	Number of Processing	Processing Time
Smooth Kernel Convolution	1	0.334 ms
Laplacian Kernel Convolution (x)	2	0.208 ms
Max Calculation	2	0.410 ms
Arithmetic (division by constant)	1	0.611 ms
Arithmetic (subtraction)	1	0.108 ms
Arithmetic (multiplication)	1	1.125 ms
Arithmetic (addition)	1	0.108 ms
Laplacian Kernel Convolution (y)	1	0.194 ms
Binarization	3	0.306 ms
Arithmetic (addition between binary images)	1	0.127 ms
Double Threshold	1	4.8 ms
Total	15	8.331ms

The entire defect detection algorithm block diagram is shown as Fig. 5.

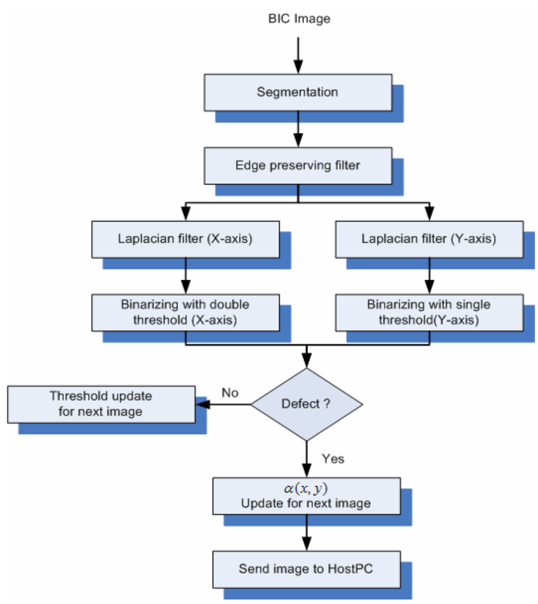


Fig. 5 The block diagram of proposed defect detection algorithm

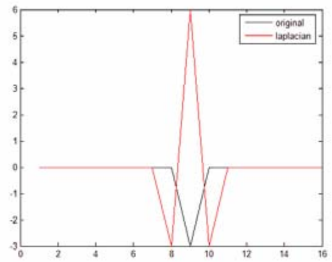
III. EXPERIMENT RESULTS

The vision inspection system consists of a line scan camera module, a image processing board that grabs image and operate proposed defect detection algorithm and a HostPC that classifies and saves the defect image. The image processing board inspects the defects in real-time and sends the image data to the HostPC when defect is detected. In this paper, we only deal with the defect detection in real-time parts. The operating system consists of Pentium 4 XEON 3G CPU, 2GB memory, Odyssey Xpro image processing board of the Matrox Company.

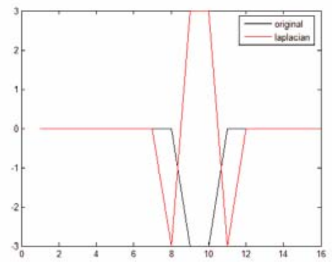
To measure the performance of the proposed algorithm, we measured the processing time and the detection efficiency. The proposed defect detection algorithm is implemented in vision inspection system using C programming with MIL(matrox image library).

To evaluate the efficiency of the detection, 73 images which include 175 defects were analyzed in this paper. Most defects are successfully detected but 13 defects were failed. This failure is caused due to the low contrast between defect and background. The detection rate of the proposed algorithm is 95.42% as shown Table I.

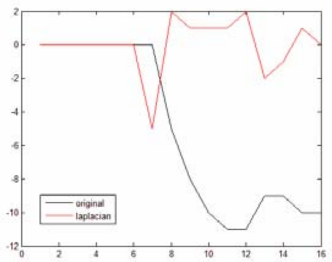
The processing time was evaluated as the average value of the processing time by repeating 1000 times. The necessary operations are convolution, binarization, arithmetic operations such as division, subtraction, multiplication and addition, etc. The demand processing time is within 10 ms because the BIC image is acquired from a line scan camera that has 512 pixels per one line with 50 KHz line rates. The measured processing time of the proposed algorithm is shown in Table II. The pure processing time of detection algorithm is 8.331 ms. It is enough to guarantee the condition of the real-time processing. Even if additional operations are allowed to segment the image, allocate child buffer, send the image from image processing board to HostPC, it can satisfy the real-time processing condition.



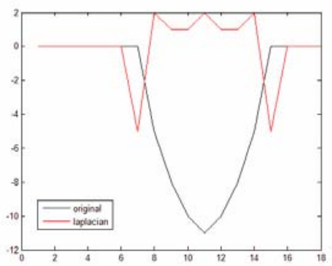
(a)



(b)



(c)



(d)

Fig. 6 The various laplacian response (a) 1 pixel defect (b) 2 pixel defect (c) like dark line defect (d) defect of sinusoidal shape.

IV. Conclusion

This paper deals with a real-time defect detection algorithm for high-speed steel BIC. Since the BIC moving speed can be as fast as 18.5m/s, the defect detection algorithm should satisfy two confliction requirements of reducing the processing time and improving the efficiency of defect detection.

This paper proposed defect detection algorithm based on laplacian operation. And we proposed edge-preserving filter. In addition to removing noise, this edge preserving filtering keeps the defect edge. And the double thresholding method was introduced to detect defect more accurately.

Experiment results show that the proposed algorithm guarantees the condition of the real-time processing and accuracy of detection.

We expect that if successful, the system will help the steel industry to improve the consistency of product quality and lower production costs.

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