

An Algorithm for Detecting Seam Cracks in Steel Plates

Doo-chul Choi, Yong-Ju Jeon, Jong Pil Yun, Sung Wook Yun, and Sang Woo Kim

Abstract—In this study, we developed an algorithm for detecting seam cracks in a steel plate. Seam cracks are generated in the edge region of a steel plate. We used the Gabor filter and an adaptive double threshold method to detect them. To reduce the number of pseudo defects, features based on the shape of seam cracks were used. To evaluate the performance of the proposed algorithm, we tested 989 images with seam cracks and 9470 defect-free images. Experimental results show that the proposed algorithm is suitable for detecting seam cracks. However, it should be improved to increase the true positive rate.

Keywords—Defect detection, Gabor filter, machine vision, surface inspection.

I. INTRODUCTION

QUALITY control is an important part of the steel manufacturing process. Therefore, production inspection should be carried out to evaluate the quality of products. Currently, human workers carry out product inspection of steel plates manually. However, since their standards vary, the reliability and accuracy of their inspection are poor. Moreover, conducting inspections that guarantee that 100% of all products are defect-free is a time-consuming task. To overcome these limitations, an automated inspection system should be developed.

Recently, automatic inspection has become an important issue in the steel manufacturing industry. A real-time defect detection algorithm using the Laplacian and edge-preserving filter has been developed for a bar in coil [1]. A defect detection algorithm based on an optimized Gabor filter has been suggested for steel billets [2], and one using wavelet transform has been reported for periodic defects in steel wire rod production [3]. An algorithm for detecting pinholes using Gabor filters and morphological features has been developed for steel slabs [4].

In this paper, the target of detection is a seam crack. Seam cracks are generated in the edge region of a steel plate. Because the width of a seam crack is very small, it is difficult to detect with the naked eye. Therefore, we used a high-resolution

line-scan camera to acquire images of seam cracks. In this paper, we propose an algorithm for detecting seam cracks using a Gabor filter and a feature extraction method.

This paper is organized as follows. In Section II, we explain the system configuration and analysis of the surface images. In Section III, we present the algorithm proposed for detecting seam cracks. In Sections IV and V, we discuss the experimental results and conclusions, respectively.

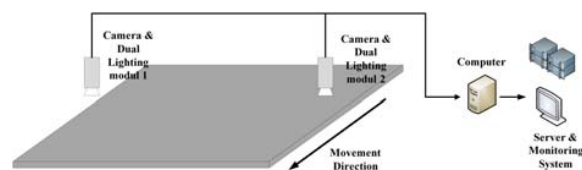


Fig. 1 Structure of the automated inspection system

II. SYSTEM CONFIGURATION AND IMAGE ANALYSIS

The surface defect detection system is shown in Fig. 1. The components of the system are a camera, lighting, a frame grabber, and a PC. Because the seam cracks are generated in the edge of a thick plate, two line-scan cameras were placed, one each on the left and right sides. The line-scan camera scans the edge region of a thick plate every 0.5 mm movements. One frame consists of 2000 scan-lines captured by the frame grabber. The size of one frame is 4096×2000 pixels with an 8-bit resolution. The images are sent to the PC, which runs the seam crack detection algorithm. The detection results and original images are sent to a monitoring system and stored at the main server.

The surface image of a thick plate with seam cracks is shown in Fig. 2. The width of the seam crack is approximately 10 pixels in the horizontal direction, but its length is not uniform. The gray-levels of the seam crack are only 20-30 gray-levels lower than that of the background. Because of these properties of seam cracks, they are difficult to detect.

In this study, we used a Gabor filter to detect seam cracks. In addition, features were used to remove pseudo defects. Finally, a machine learning method was used to enhance the performance.

Doo-chul Choi and Yong-Ju Jeon are with the Department of Electrical Engineering, Postech, Pohang, Korea (e-mail: {dooshe, jjeon83}@postech.ac.kr).

Jong Pil Yun, Sung Wook Yun are with System Research Group, Engineering Research Center, Pohang Iron and Steel Company (POSCO), Pohang 790-300, Korea (e-mail: {rebirth, swyun}@posco.com).

Sang Woo Kim is with Department of Creative IT Excellence Engineering (CITE) and Department of Electrical Engineering (EE), Pohang University of Science and Technology, Pohang, 790-784, Korea (e-mail: swkim@postech.ac.kr).



Fig. 2 Surface image of a steel plate with seam cracks

III. PROPOSED ALGORITHM

A. Segmentation

Because seam cracks are generated in the edges of thick plates, segmentation was performed to remove unnecessary information from the image. First, we found an edge point of a thick plate. The change in the gray-value is at its maximum or minimum at an edge point. Therefore, we could find it using a vertical projection profile as shown in Fig. 3. The vertical projection profile is obtained as follows:

$$P(x) = \frac{1}{N} \sum_{y=1}^N I(x, y), \quad x = 1, \dots, M \text{ and } y = 1, \dots, N \quad (1)$$

where $M = 4096$ and $N = 2000$ are the width and height, respectively.

From the edge point, we extracted a segmentation image as shown in Fig. 3. The width of the segmentation image is 800 pixels.

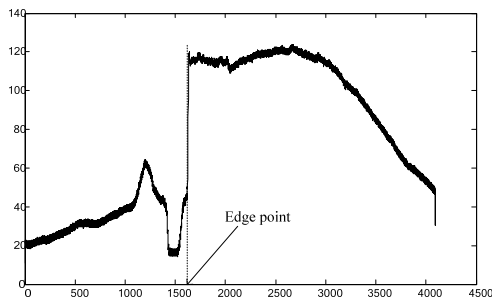


Fig. 3 Vertical projection profile of the image in Fig. 2

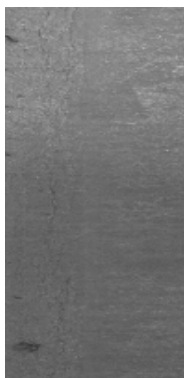


Fig. 4 Image after segmentation

B. Gabor Filtering

Gabor filters have been widely used for defect detection in the fabric, LCD, and steel industries [5]. The Gabor function is the product of a complex valued sinusoidal function and Gaussian function. The real part of a 2D Gabor filter is used as a blob detector, and the imaginary part is used as an edge detector [6]. To detect seam cracks, we used the real part of the 2D Gabor filter, whose general form is:

$$g(x, y) = \exp \left[-\frac{1}{2} \left\{ \left(\frac{x'}{\sigma_x} \right)^2 + \left(\frac{y'}{\sigma_y} \right)^2 \right\} \right] \cos(2\pi f x') \quad (3)$$

where

$$\begin{aligned} x' &= x \cos \theta + y \sin \theta \\ y' &= -x \sin \theta + y \cos \theta \end{aligned}$$

The Gabor filter has four parameters: f , θ , σ_x , and σ_y . The parameter f is the frequency of the sinusoidal function, and θ is the rotation angle. σ_x and σ_y are the Gaussian envelopes along the x and y axes, respectively [7]. The Gabor-filtered image $R(x, y)$ is calculated as:

$$\begin{aligned} R(x, y) &= I(x, y) * g(x, y) \\ &= \sum_{m=1}^{M'} \sum_{n=1}^{N'} I(x-m, y-n) g(m, n) \end{aligned} \quad (4)$$

where $*$ is the convolution operator. M' and N' are the width and height of the Gabor filter, respectively. The Gabor-filtered image $R(x, y)$ is shown in Fig. 5 (a).

C. Adaptive Double-Thresholding

After Gabor filtering, a binarization process was performed to obtain a binarized image of seam cracks. An adaptive double thresholding method was used in this study. The high and low threshold values are determined adaptively as follows:

$$\begin{aligned} T_{high} &= \text{mean} \{R(x, y)\} + \alpha_{high} \times \text{std} \{R(x, y)\} \\ T_{low} &= \text{mean} \{R(x, y)\} + \alpha_{low} \times \text{std} \{R(x, y)\} \end{aligned} \quad (2)$$

where mean is a mean value and std is a standard deviation of $R(x, y)$. α_{high} and α_{low} are weighting factors. The high- and low-threshold images are shown in Fig. 4 (b) and (d), respectively. To remove the noise component, size filtering was applied to the high-threshold image as shown in Fig. 3 (c). The double threshold image is shown in Fig. 4 (e).

D. Feature Extraction

After the binarization process, we obtained the binarized image of seam cracks. To distinguish seam cracks from pseudo defects, we used the features of continuity, orientation, eccentricity, extent ratio, minor axis length, and gray value difference. Continuities are the ratios of seam cracks taking possession along the horizontal and vertical direction.

Orientation is the rotation angle of the seam crack. Eccentricity is the ratio of the distance between the foci of the ellipse to its major axis length. Extent ratio is the ratio of pixels in the blob to those in the bounding box. The minor axis length is the length of the minor axis of the ellipse that has the same second-moments as the blob. The gray value difference is the difference between the gray values of the edge seam crack and the background. We calculated the mean value and standard deviation of these features except for continuities. Therefore, the length of the feature vector is 12.

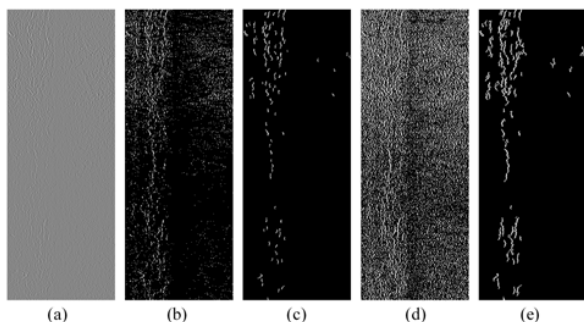


Fig. 5 Step images of the proposed algorithm: (a) Gabor-filtered image, (b) High threshold image, (c) High threshold image after size filtering, (d) Low threshold image, and (e) Double-threshold image

IV. EXPERIMENTAL RESULTS

The performance of the proposed algorithm was evaluated using images of thick plates that were directly obtained from a production line. We tested the proposed algorithm on 989 images with seam cracks and 9470 defect-free images. The parameters of the Gabor filter, f , θ , σ_x , and σ_y , were set to 0.1, 0° , 5, and 2, respectively. The experimental results are summarized in Table I. We could detect seam cracks easily using the Gabor filter and adaptive double-thresholding method. However, many pseudo defects are also detected. To reduce the number of pseudo defects, we used a feature extraction method, and a support vector machine to classify seam cracks in the binarized images after Gabor filtering. The resultant images are shown in Fig. 6.

V. CONCLUSION

In this study, we developed an algorithm for detecting seam cracks in steel plates using a Gabor filter and a feature extraction method. We tested the performance of the proposed algorithm using images directly obtained from a production line. The width of a seam crack is very small and the difference in the gray values of a seam crack and the background is not significant. Therefore, we applied a Gabor filter to detect seam cracks, and low threshold values were used to binarize the region of seam cracks. However, because of the low threshold values, many pseudo defects were also detected. To solve this problem, a feature extraction method was used. The experimental results show that the proposed algorithm can detect seam cracks. The false alarm rate was satisfactory.

TABLE I
CLASSIFICATION RESULT

	Training set		Test set		Total	
	Defect	Pseudo	Defect	Pseudo	Defect	Pseudo
Gabor filtering	370/38	1890/401	554/60	1613/545	934/98	3503/947
Feature extraction	3	2	6	8	9	0
n	375/38	115/4012	464/60	6/5458	839/98	121/9470

However, improvements in the proposed algorithm to increase the true positive rate will be addressed in future work.

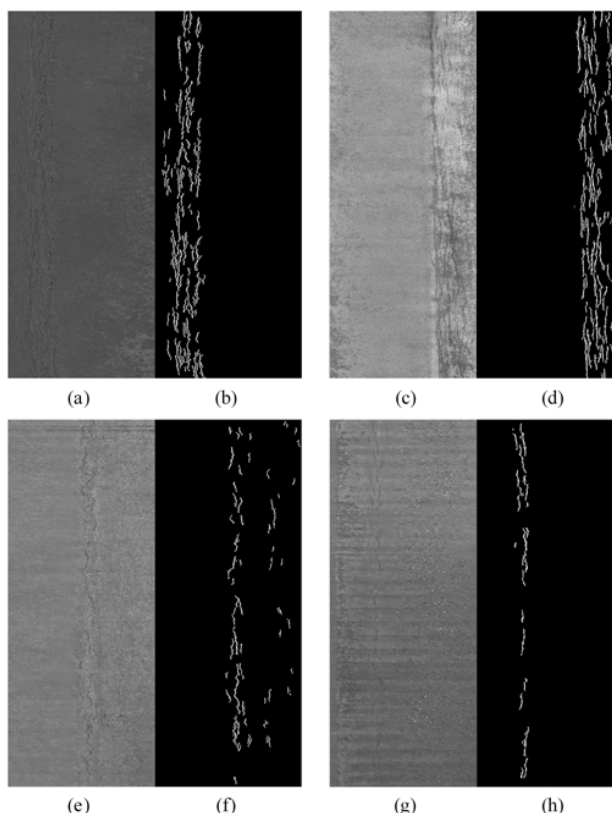


Fig. 6 Resultant images: (a),(c),(e), and (g) Input images; (b),(d),(f), and (h) Detection results

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