Automated Inspection Algorithm for Thick Plate Using Dual Light Switching Lighting Method

Yong-JuJeon, Doo-chul Choi, Jong Pil Yun, Changhyun Park, Homoon Bae, and Sang Woo Kim

***Abstract*—**This paper presents an automated inspection algorithm for a thick plate. Thick plates typically have various types of surface defects, such as scabs, scratches, and roller marks. These defects have individual characteristics including brightness and shape. Therefore, it is not simple to detect all the defects. In order to solve these problems and to detect defects more effectively, we propose a dual light switching lighting method and a defect detection algorithm based on Gabor filters.

***Keywords*—**Thick plate, Defect, Inspection, Gabor filter, Dual Light Switching.

I. Introduction

IN recent years, automated inspection algorithms are being widely used to ensure high-quality products and achieve high productivity in various industries such as the LCD panel[1], textile[2], and optical fiber[3] industries. However, most inspection steps are still manually performed in the steel industry [4]. Manual inspection cannot guarantee accuracy or reliability because it depends greatly on the experience of the human inspectors. However, automatic inspection systems offer the following advantages as compared to humans: (1) it eliminates the need for human beings to work in hazardous environments; (2) the inspection performance is not limited by human ability; (3) product quality and productivity are improved [5].

In this study, we focus on the detection of various defects on thick plates. A thick plate is a steel product, the thickness of which is 6 mm or more after a hot rolling process. It is characterized by having the form of a large plate, and it used to make vessels, boilers, bridges and other large steel structures. Manufacturing a thick plate involves various processes, including a hot rolling process. Therefore, faulty manufacturing conditions are the cause of different types of defects, such as roller marks, scabs, and scratches. These various defects on a thick plate directly influence the quality of the final products. Therefore, it is important to detect all of them. However, their detection is difficult because they differ in the kind of shape, size, and feature.

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In general, various defect detection methods based on image processing techniques have been developed in the steel industry. The crack detection algorithm with an optimized Gabor filter has been developed to detect cracks in raw steel blocks[6]. Gabor filtering and a morphological approach have been proposed for detecting pin-holes in steel slabs [7]. The undecimated wavelet transform and Fourier analysis have been proposed to defect periodic defects in steel wire rods [8]. Although, these methods have experimentally demonstrated good performance, their application to the detection of an abnormal defect in a thick plate is difficult because they target specific defects.

In this paper, we propose a defect detection algorithm for defects in a thick plate using a dual light switching lighting method. This paper is organized as follows. The dual light switching lighting method and Gabor filtering method are presented in Section II, and experimental results and conclusions are discussed in Section III.

II. Methods

A. Dual Light Switching Lighting

An automatic inspection system consists of three components: a camera module, lighting module, and processing unit. To obtain good inspection performance, high-quality images are essential. In general, inspection cameras can be classified into area cameras and line scan cameras. The area camera has several disadvantages, such as blurring, and a limited frame rate and field of view [9]. These disadvantages make detecting a moving target or high-resolution detection difficult. To solve these problems, we adopted line scan cameras. The line scan camera has a low signal noise, high resolution, and fast acquisition speed.

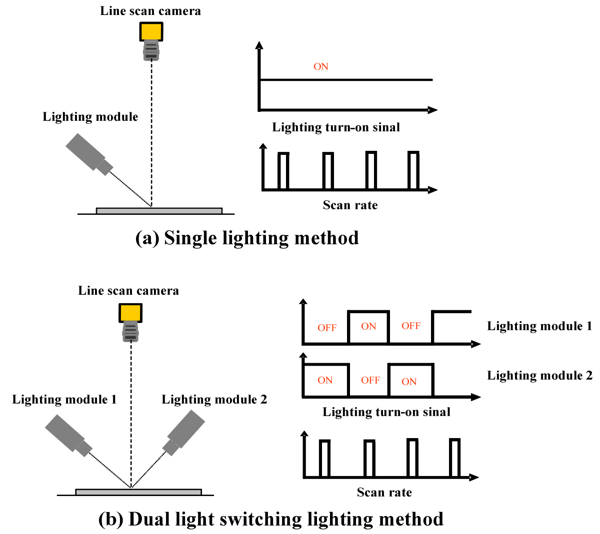

Fig. 1 Architecture of the lighting method

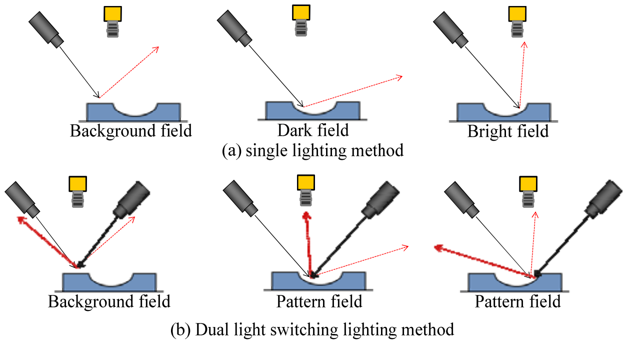

Fig. 2 Illumination patterns depending on different types of lighting methods

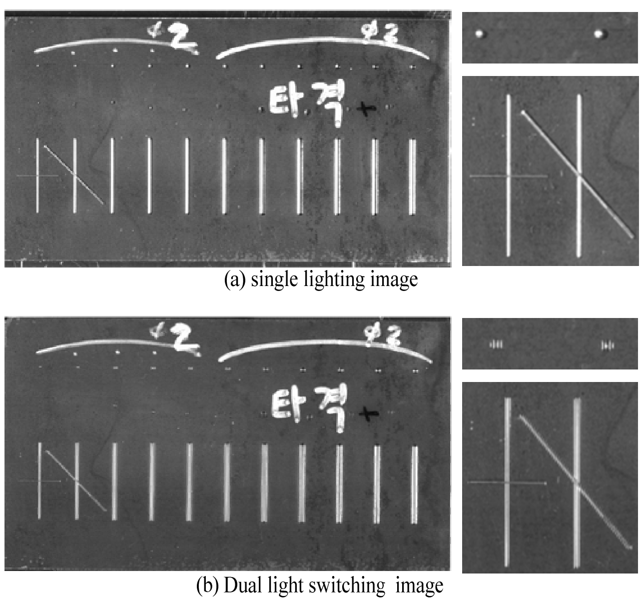

Fig. 3 Artificial defect images acquired in different lighting conditions

The architectures of the single lighting method and dual lighting switching lighting method are presented in Fig. 1. The single lighting method consists of one camera and one lighting module. The lighting modules in single camera methods are always activated, regardless of the scan rate. In this case, objects are always illuminated on one side, which depends on the orientation of the lighting module. Therefore, various defect patterns appear, depending on the direction, size, and thickness of the defects. Fig. 3 (a) shows the artificial defect image acquired using the single lighting method. The illumination patterns on the surface differ depending on the size, shape, and orientation of the defect. It is difficult to detect all the defects using single lighting methods when variously shaped defects exist on the surface. On the other hand, a dual light switching lighting method consists of one camera module and two lighting modules. The dual light switching lighting method is illustrated in Fig. 1(b). The two lighting modules are setup opposite each other on either side of the object, and each lighting module has an inverted form of on off cycle depending on the scan rate. Therefore, odd scan lines are illuminated in lighting module1 and even scan lines are illuminated in lighting module2. Because the two lighting modules are setup opposite each other, as shown in Fig. 2 (b), the appearance of a normal surface does not change, as compared to when single lighting methods are used. However, when the surface is lumpy, a black and white pattern appears. Fig. 3 (b) shows artificial defect images acquired using the dual light switching lighting method. The defect areas manifest the black and white pattern regardless of the shape, orientation, and size of the defects. Therefore, when the dual light switching lighting method is used, the detection problems related to the various shapes of a defect can easily be solved by finding the black and white pattern region.

B. Gabor Filtering

Gabor filters have been widely used in image processing. An important property of Gabor filters is that they achieve the maximum possible joint localization or resolution in both the spatial and spatial-frequency domain [10]. 2D Gabor functions are complex valued sinusoids of given frequencies and orientations modulated by 2DGaussian functions in the space domain and shifted Gaussians in the spatial-frequency domain [11]. The general form of the real part of a 2-D Gabor function *g(x,y)* is expressed as:

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

where

$$x'=x\cos\theta+y\sin\theta$$
$$y'=-x\sin\theta+y\cos\theta$$

In general, the two-dimensional real part of a Gabor function has four parameters: f, θ, σ_x, and σ_y. f denotes the radial frequency of the Gabor function, and θ is the rotation parameter. σ_x and σ_y are the space constants of the Gaussian envelope along the x and y-axes, respectively [12].

For a given input image $I(x, y)$, the image $R(x, y)$ is obtained by using Gabor filter $g(x, y)$:

$$R(x,y) = g(x,y) * I(x,y) = \sum_{m=0}^{M-1}\sum_{n=0}^{N-1} g(m,n)I(x-m, y-n) \quad (2)$$

where * denotes the 2D convolution, and M and N are the size of the Gabor filter mask. The energy of the filtered image, $E(x,y)$, is calculated by the square nonlinear operator $|\cdot|^2$:

$$E(x,y) = R^2(x,y) \quad (3)$$

The defect regions have a gray pattern when dual light switching lighting is used. Therefore, the parameters were chosen on the basis of the pattern. The Gabor filter parameters are listed in Table I. Fig. 4 shows an image obtained using a Gabor filter that amplifies defect pattern. Fig. 4 shows the input image with the defective region and the Gabor filtered output image. Using the energy of the Gabor filtered image, we performed a binarization process to obtain the defect region. The threshold value was calculated using second-order statistics:

$$T = mean[E(x,y)] + \alpha \times std[E(x,y)] \quad (4)$$

where, α is the weighting factor selected in the experiment. The binary image, $b(x,y)$, is obtained as:

$$b(x,y) = \begin{cases} 1, & E(x,y) > T \\ 0, & E(x,y) \le T \end{cases} \quad (5)$$

Fig. 4(d) shows the final defect detection result.

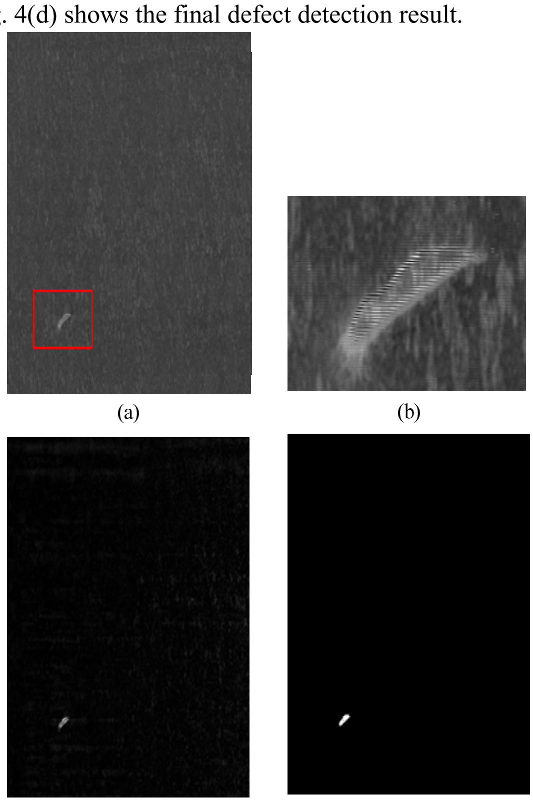

Fig. 4 Thick plate images containing defect: (a) thick plate image, (b) partially enlarged image of defect region, (c) energy of Gabor filtered image, (d) binarized image

TABLE I
GABOR FILTER PARAMETERS

σ_x	σ_y	f	θ
3	3	1/2	π/2

III. EXPERIMENT AND CONCLUSION

In this section, we present the result of our experiments to evaluate the performance of the proposed algorithm. To evaluate the performance of the proposed algorithm, we applied the algorithm to images of thick plates, which were acquired directly from an actual production line. Fig. 5 shows the structure of the surface defect detection (SDD) system.

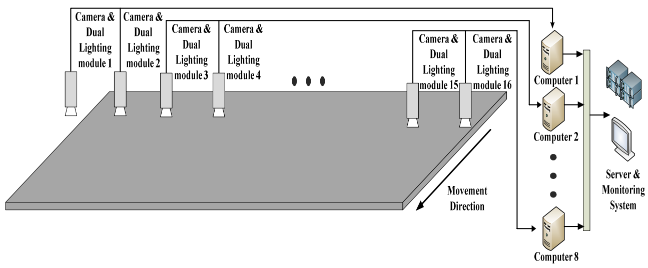

Fig. 5 Surface defect detection system

To guarantee that the upper sides of the thick plates were inspected, 16 cameras and dual lighting modules were set up. The resolution of one frame image is 2048 × 2000 pixels. In this experiment, the target of the detection system was a lumpy defect, such as a scab, scratch, or roller mark. Fig. 6 shows the results of the defect detection system for various defects.

In this paper, a defect detection algorithm for thick plates that uses a dual light switching lighting method is presented. Our objective was to develop a detection algorithm that satisfactorily detects various types of defect. The surface properties of the defect region vary depending on various factors, such as the type of steel, manufacturing conditions, and illumination types. Therefore, different defects have individual characteristics including brightness and shape. To solve this problem, we proposed the dual light switching lighting method. The problems of detecting variously shaped defects can easily be solved by finding the black and white pattern region using a dual light switching lighting method. To improve the detection accuracy, binarization using the Gabor filter method was introduced. To evaluate the performance of the proposed defect detection algorithm, thick plate images from areal steel production line were used. The experiment results show that the proposed algorithm has a good detection performance for various types of defects.

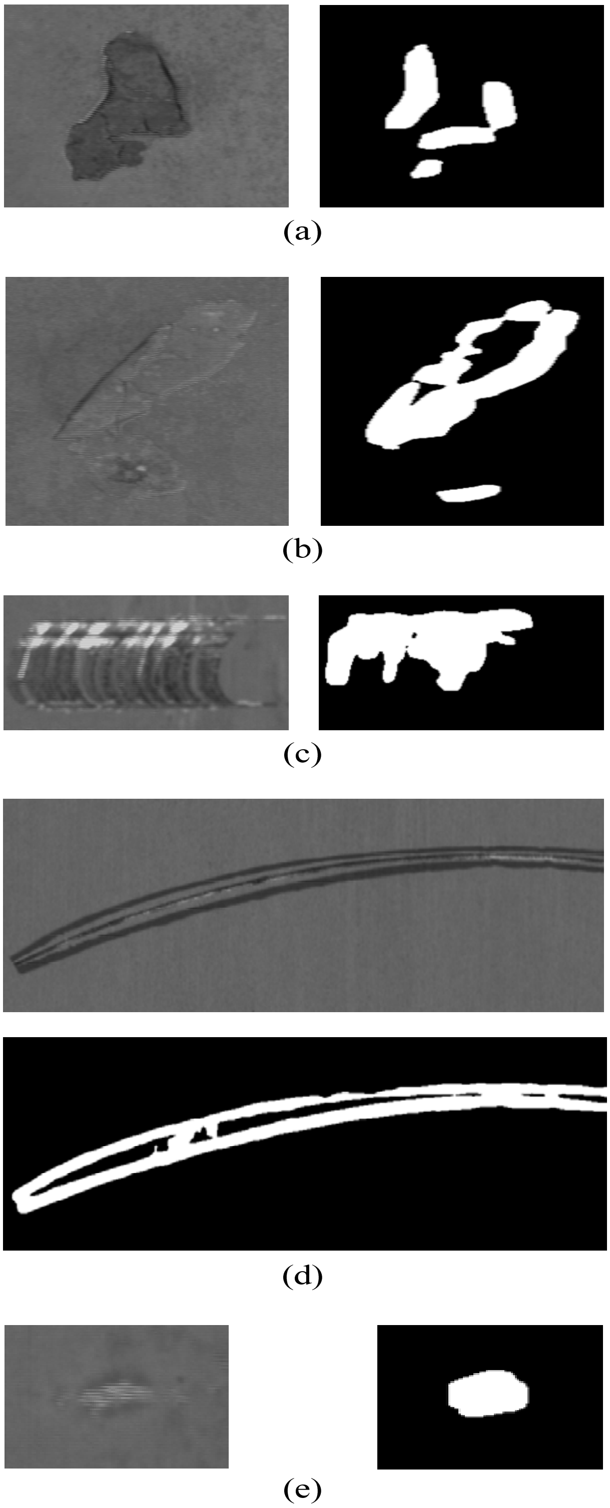

Fig. 6 Defect detection result images: (a), (b) scab; (c), (d) scratch; and (e) roller mark

ACKNOWLEDGMENT

This research was supported by the MKE (The Ministry of Knowledge Economy), Korea, under the ITRC (Information Technology Research Center) support program (NIPA-2012-H0301-12-2002) supervised by the NIPA (National IT Industry Promotion Agency).

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