

A Classification Algorithm for Steel Bar in Coil using Wavelet Transform

Yeon Tak Kim, Jong Pil Yun, Boyeul Seo, Youngsu Park, and Sang Woo Kim

Abstract—There are many ways for detecting defects and classification and these methods have been applied to many areas of industry such as fabric or steel or etc. This paper proposes a method to classify defects of steel Bar In Coil (BIC) which has cylindrical shape. The wavelet transform has been used to detect or classify defects of images recently and the proposed classification algorithm uses wavelet transform to extract features of defect. The performance of classification using wavelet transform is closely related to the selection of the wavelet. A kind of standard wavelet is selected on the base of defect analysis and the selected wavelet decomposes the first order derivative of defects into wavelet function space according to the frequency. The wavelet transform is based on subband coding method and it separates frequency of input data. There are three defects which could affect the quality of BIC severely and each defect class has different frequency concentration. The proposed classification algorithm uses detail coefficients through one to three level 2D wavelet transform as a feature of distinguishing each defect. The result shows 94.8% classification accuracy.

Keywords—Bar In Coil (BIC), Classification, Wavelet Transform.

I. INTRODUCTION

MANY areas of industry have been automated by vision system today. Automating a process is quite important because it enables corporation to save producing cost and to supply products at a low cost to buyer. Overall process of the steel rolling production has been automated or is in a process of automation also. However much of quality assurance process is done manually because there are many kinds of defects and the criterion to discriminate the defects largely depends on inspector's experience. The target of this paper is high-speed steel bar in coil (BIC). The inspection process of BIC is done manually since the process has a similar problem like above. The BIC has a shape of cylinder and there are some defects on the shape. It is important to extract the features of defects reducing the effect of background. The wavelet transform is a good tool to solve detection and classification.

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The wavelet transform is widely used in many areas. Especially, it has been remarkably used to detect and classify defects in fabric area recently. There are some different ways to solve the detection and classification problem. Adaptive wavelet is used to classify defects each other [1]. Classification is done by evaluating DFR (Defect-to-Free Ratio) of coefficient which is well matched to a specific wavelet. The author of [1] also proposed wavelet frame as a discriminative factor which can be obtained by undecimated wavelet transform [2]. On the other hand, someone showed a different approach to the detection problem [3]. They separated 2D-image to vertical and horizontal 1D-signal and compared each SNR using optimized wavelet.

This paper proposes a classification algorithm to discriminate classes of BIC using wavelet transform. There are three major defects on BIC image. They are crack, dark spot and sharp mark. Each of these is serious defect that can harm quality of product relatively and it is important to detect these defects on the process of production. The wavelet transform is a key tool to extract features of each defect and we classify it using Euclidean distance classifier. However, each BIC image has different brightness and each defect has different shape though it is same kind of defect. So we find each derivative of x and y orientation of the image as a preprocessing and take on the wavelet transform with a wavelet that has similar shape comparing to the derivative information.

This paper is organized as follows. In Section 2, Overall description of BIC and wavelet selection and process of classification is explained. Section 3 shows experimental results. Finally, Section 4 is conclusion

II. BIC IMAGE AND CLASSIFICATION

A. BIC Image Analysis

The target of this paper is the steel BIC whose moving speed is up to 18.5m/s. The representative images are shown in Fig 1. Each (a), (b), (c) shows a sample image of crack, dark line and spot. Fig. 1 shows not only each defect but also a characteristic of BIC image. BIC has cylindrical shape and the defects are located on the shape. So we need a detection and classification algorithm that does not be affected by background.



Fig. 1 BIC image (a) Crack (b) Dark line (c) Spot

B. Preprocessing and Selection of Wavelet

Each image has different brightness and each defect has different shape even though they are in a same kind of defect. So we have suffered difficulties to find adequate threshold value and to extract features of them after wavelet transform. However, their variation rate according to vertical and horizontal orientation shows similar trend if they are same kind of defect because they have common characteristic. Therefore, we have found the first order derivative of images according to x and y orientation and selected a wavelet that has similar shape of defect. Fig. 2 shows example signals of crack and dark line.

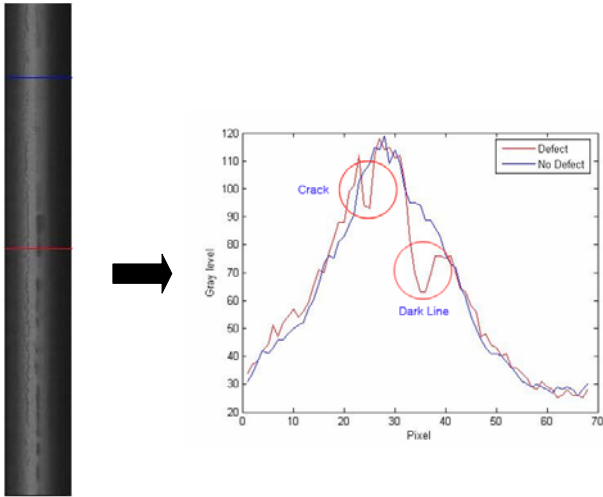
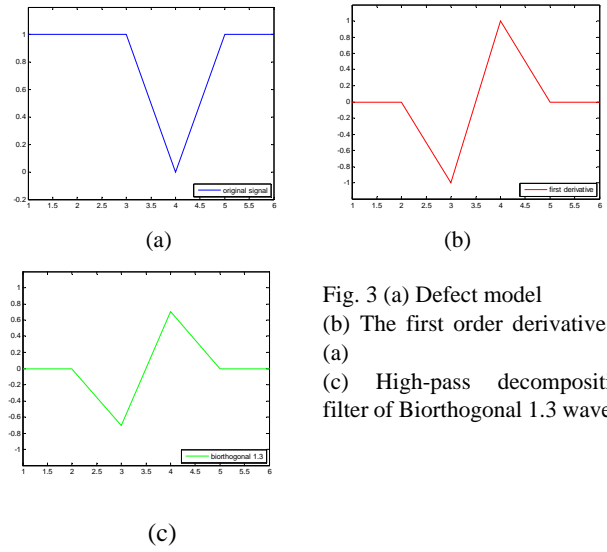


Fig. 2 Examples of crack and dark line defect

Each defect has different width and height. The inclinations at starting and ending point are different also. In other words, their frequency intensity is different. However, they have a common characteristic that they are valley-shaped pattern. The spot defect has this characteristic also.


 Fig. 3 (a) Defect model
(b) The first order derivative of (a)
(c) High-pass decomposition filter of Biorthogonal 1.3 wavelet

To characterize each defect, we have made a simple defect model that can be used for wavelet transform like Fig 3 (a). The major three defects have common trend like (a). Fig. 3 (b) is the first derivative of (a) and Fig. 3 (c) is high-pass decomposition filter of Biorthogonal 1.3 wavelet. The figure shows the wavelet resembles the first derivative of reference defect.

C. Feature Extraction

The wavelet transform is based on subband coding which decomposes signal into a set of band-limited components. They are called subband. The scaling function space which is spanned by scaling function φ is V_j and the wavelet function space which is spanned by wavelet function ψ is W_j .

$$V_j = \overline{\text{Span}\{\varphi_{j,m,n}(x)\}}_{m,n} \quad (1)$$

$$W_j = \overline{\text{Span}\{\psi_{j,m,n}(x)\}}_{m,n} \quad (2)$$

The scaling and wavelet function have dyadic scale according to j which means scaling factor and m, n means dyadic integer transition along vertical and horizontal orientation. The approximation coefficient W_φ which has low frequency information is expressed by the inner product between signal and scaling function. The detail coefficient W_ψ which has high frequency information is expressed in the same manner. The coefficients in 2D are shown below.

$$W_\varphi(j_0, m, n) = \frac{1}{\sqrt{MN}} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x, y) \varphi_{j_0, m, n}(x) \quad (3)$$

$$W_\psi(j, m, n) = \frac{1}{\sqrt{MN}} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x, y) \psi^i_{j, m, n}(x), i = \{H, V, D\} \quad (4)$$

Each defect has different shape but its frequency characteristic of first order derivative of the defect shows similar trend if it belongs to same kind of defect. The wavelet transform is used to find frequency characteristic and it halves

the frequency of signal which matches well with the selected wavelet. Instead of using decimating wavelet transform, undecimated wavelet transform is implemented for a shift-invariant representation and more precise result. The filter bank implementation of 2D undecimated wavelet transform is depicted in Fig. 4. The h_ϕ is scaling function coefficient and the h_ψ is wavelet function coefficient.

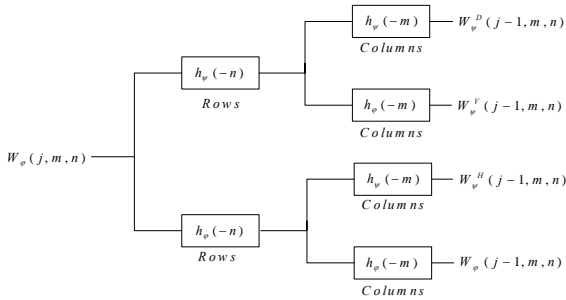


Fig. 4 Filter bank implementation of 2D undecimated wavelet transform for one level

Classification uses response rate to the selected wavelet for each frequency band. Fig. 5 shows separated frequency band from the first level to the third level.

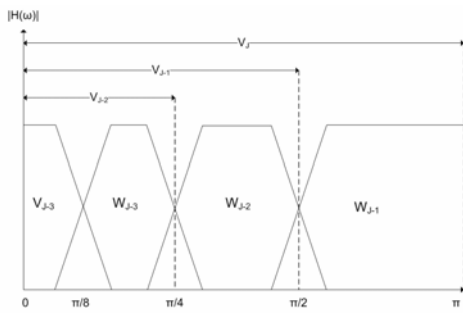


Fig. 5 Frequency separating characteristic

The key features to discriminate classes are wavelet coefficient W_ψ for each level which represents response rate of wavelet function space $W_{J-1}, W_{J-2}, W_{J-3}$ in Fig. 3. The scaling function and wavelet function should be replaced by their dual functions because the selected wavelet is biorthogonal.

D. Classification Process

Based on the undecimated wavelet transform, the block diagram of BIC classification is depicted in Fig. 6.

- 1) BIC Image: Original image of BIC has more broad width than the image below the first block. It contains redundancy region which is whole black. The region is a margin for large BIC and it should be cut off in the first block.
- 2) Segmentation: Each defect should be segmented to extract features using wavelet transform. Determination of window which segments each defect in the image below Segmentation block is based on the power information of the laplacian of smoothed image on specific region. Fig. 6 is moving average of power in windows having size of all

vertical length by eight pixels of horizontal orientation as shown in the image below Segmentation block. The laplacian is useful to find edges which vary fast when it is mixed with slow varying signals such as background.

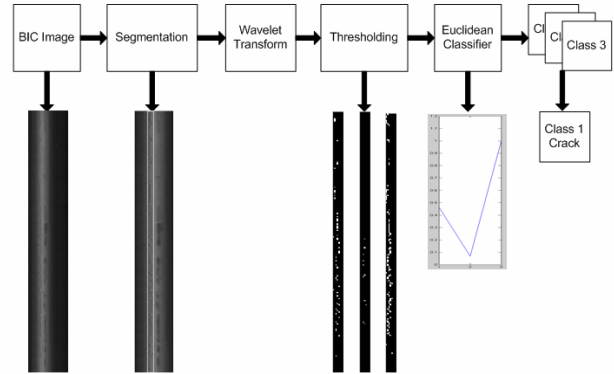


Fig. 6 The block diagram of classification

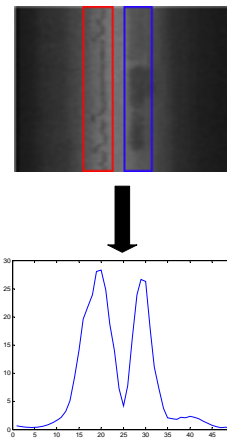


Fig. 7 Average power of local region of laplacian

- 3) Wavelet Transform & Thresholding: Three images under the Thresholding block in Fig. 6 means wavelet coefficients for each level after thresholding. The coefficients represent responses according to wavelet function space $W_{J-1}, W_{J-2}, W_{J-3}$ in Fig. 3. The plot which is on the right of three response image shows response rate for each level. It is used as an input data for euclidean distance classifier.
- 4) Euclidean Distance Classifier: Euclidean distance classifier is used for classification in the module. Equation (5) is discriminant function $g_l(\mathbf{F}, \mathbf{\Lambda})$.

$$g_l(\mathbf{F}, \mathbf{\Lambda}) = \|\mathbf{F} - \mathbf{m}_l\|^2 = \sum_{i=1}^l (F_i - m_{li})^2 \quad (5)$$

The l is an identifier for classes and $\mathbf{\Lambda} = \{m_{li}\}$ is reference vector which represents each class. The i is an index for each component in the vector which means response rate at each level. \mathbf{F} is a feature vector of segmented defect. F_i and m_{li} means i^{th} element of \mathbf{F} and \mathbf{m}_l . The class identifier l which minimizes $g_l(\mathbf{F}, \mathbf{\Lambda})$ for the input vector \mathbf{F} is the class that the defect belongs to.

III. EXPERIMENTAL RESULT

We have tested classification algorithm for 69 defects of 52 BIC images. Table I shows detail result.

TABLE I
CLASSIFICATION RESULT

Defects	Number of defects	Reference defects	Validation defects	Success percentage
Crack	22	10	12	100%
Dark Line	18	10	8	87.5%
Spot	29	10	19	94.7%
Total	69	30	39	94.8%

Ten defect images per each class were used as reference data for euclidean distance classifier. The classifier determined all 12 validation defects of the crack correctly. One defect of 8 dark line validation defects was misclassified as spot. The misclassified image has line shaped defect like other dark lines but the width and depth of it resemble crack and spot defects. The key point of classification algorithm is using the frequency information which is decomposed by a specific wavelet. This kind of misclassification owing to different frequency concentration is inevitable. Then, spot defects have one misclassified data. The misclassified image has a defect looks like a spot and it is classified as a crack. The reason of misclassification is that wavelet transform could not extract sufficient information of the defect because the size of the defect was too small.

IV. CONCLUSION

In this paper, a classification algorithm using wavelet transform for Bar In Coil (BIC) is proposed. The wavelet transform is a good tool for detection and classification problem. There are three defects which could affect the quality of BIC severely and each defect class has different frequency concentration. We made a model of defects which have common characteristic of defects and selected a kind of standard wavelet which can decompose effective information of the first order derivative of defects into wavelet function space according to the frequency. The proposed classification algorithm uses detail coefficients through one to three level 2D wavelet transform as a feature of distinguishing each defect. The classification algorithm is applied to the 69 defects of 52 BIC image. The classification result shows reasonable accuracy of 94.8%. However, there are problems such as inaccurate segmentation which is based on power of laplacian along vertical and horizontal orientation and need of robustness for many kinds of defect. The future work is developing systematic and robust segmentation algorithm for accuracy and modeling various kinds of defect for generalization of classification algorithm.

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