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Foreign Detection Based on Wavelet Transform Algorithm with Image Analysis Mechanism in the Inner Wall of the Tube

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Abstract
A method for detecting foreign substances in mould based on scatter grams was presented to protect moulds automatically during moulding production. This paper proposes a wavelet transform foreign detection method based on Monte Carlo analysis mechanism to identify foreign objects in the tube. We use the Monte Carlo method to evaluate the image, and obtain the width of the confidence interval by the deviation statistical gray histogram to divide the image type. In order to stabilize the performance of the algorithm, the high-frequency image and the low-frequency image are respectively drawn. By analyzing the position distribution of the pixel gray in the two images, the suspected foreign object region is obtained. The experiments demonstrate the effectiveness of our approach by evaluating the labeled data.

Keywords
Foreign Substance Inspection, Monte Carlo, Wavelets Transform

1. Introduction

In recent years, it is very important to improve the quality of a foreign substance inspection apparatus, because it could help to determine detecting infinitesimal foreign substances, and to assist industrial production and so on. Products with surface ribs, such as rifled tubes, longitudinally ribbed plates, are more and more widely used in industry and everyday life. In order to ensure the quality of the product, we need to detect the foreign substance in the inner wall of the tube. Many inspection techniques for foreign substance algorithms were presented. Due to the poor resolution and weak contrast, the algorithms are difficult to precisely detect foreign substance, when the image contains noise and artifacts pollute. The object of inspection techniques for foreign substance is to detect all foreign substance. Qin and Wang [1] has study of online inspection technique for foreign substance in ampoule. To enhance the contrast of the background and the foreign substance in ampoule, a reflective lighting method which illuminates in side direction is designed in a vision system. Qin et al. [2] proposed an inspection algorithm based on cascade classifiers is presented for detecting small moving foreign substances with low signal-to-noise ratio (SNR) and low contrast in sequential images.

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The algorithm obtains three features of absolute difference, local difference contrast and neighborhood correlation from the sequential images of an ampoule. But there are not universal algorithms for inspection [3-5]. The wavelet transformation is one of the most popular of the time-frequency-transformations [6]. The wavelet transform can provide us with the frequency of the signals and the time associated to those frequencies, making it very convenient for its application in numerous fields [7,8]. For instance, signal processing of accelerations for gait analysis [9], for fault detection [10,11], for image compression [12], for design of low power pacemakers and also in ultra-wideband (UWB) wireless communications [10]. Singh and Khare [13] have proposed a new multimodal medical image fusion using Daubechies complex wavelet transform (DCWT) at multiple levels which is based on multiresolution principle. The proposed method fuses the complex wavelet coefficients of source images using maximum selection rule. Banerjee and Mitra [14] propose cross wavelet transform (XWT) to analyze and classify electrocardiogram (ECG) signals. Agarwal et al. [15] propose a novel algorithm for image retrieval based on color edge detection and discrete wavelet transform (DWT). This method is different from the existing histogram-based methods. The proposed algorithm generates feature vectors that combine both color and edge features.

Although the wavelet transform method has many advantages over other methods in foreign matter detection. However, the irregularities of threaded pipe image can produce errors so that influence the stability of the wavelet transformation detection. We propose a foreign object detection algorithm based on wavelet filtering. The wavelet transform has a good local property, carrier phase data can be divided into high frequency part and low frequency part by wavelet transform. The wavelet transform is used to decompose the input image into two parts: high frequency and low frequency, and edge detection is performed separately. The foreign substance recognition is performed on the high frequency edge and the low frequency edge by using the local area square-difference principle in the wavelet domain. We can get more effective recognition results than traditional methods.

Organization of the paper is as follows: in Section 2, the wavelet transform is described. Section 3 describes advanced the foreign body detection algorithm based on wavelet transform. Section 4 introduces the image analysis based on Monte Carlo methods. Section 5 shows implementations of our method and the results. Section 6 summarized our work.

2. Wavelet Transform

A function $\psi \in L^2(\mathbb{R})$ is called an orthonormal wavelet, if it can be used to define a Hilbert basis that is a complete orthonormal system, for the Hilbert space $L^2(\mathbb{R})$ of square integrable functions. The Hilbert basis is constructed as the family of functions $\{\psi_{jk} : j,k \in \mathbb{Z}\}$ by means of dyadic translations and dilations of ψ .

$$\psi_{jk}(x) = 2^{\frac{j}{2}} \psi\left(2^j x - k\right) \qquad j,k \in \mathbb{Z} \tag{1}$$

If under the standard inner product on $L^2(\mathbb{R})$,

$$\langle f, g \rangle = \int_{-\infty}^{\infty} f(x) \overline{g(x)} dx \tag{2}$$

This family is orthonormal, it is an orthonormal system:

$$\left\langle \psi_{jk}, \psi_{lm} \right\rangle = \int_{-\infty}^{\infty} \psi_{jk}(x)\overline{\psi_{lm}(x)}dx \tag{3}$$

where σ_{jl} is the Kronecker delta. Completeness is satisfied if every function $f \in L^2(\mathbb{R})$ may be expanded in the basis as formula (4). With convergence of the series understood to be convergence in norm. Such a representation of f is known as a wavelet series.

$$f(x) = \sum_{j,k=-\infty}^{\infty} c_{jk}\psi_{jk}(x) \tag{4}$$

The feature parameters of wavelet multi-scale edges include direction, amplitude, position and scale. It can effectively denoise and remove the false edges. The method detects the edge of the image *F*(*U*, *V*) by looking for the local extrema of the wavelet transform. Let $\theta(u,v)$, meet

$$\iint_{R^2} \theta(u,v)\,d\mu dv = 1, \lim_{\mu,v\to\infty} \theta(u,v) = 0 \tag{5}$$

$$\theta_s(u,v) = \frac{1}{s^2}\theta\left(\frac{u}{s},\frac{v}{s}\right) \tag{6}$$

$$\varphi^1(u,v) = \frac{\partial\theta(u,v)}{\partial\mu}, \varphi 2 = \frac{\partial\theta(u,v)}{\partial v} \tag{7}$$

F(*U*, *V*) in the s scale on the two component of 2D wavelet transform as follows.

$$W^1 f(s,u,v) = \iint_{R^2} f(x,y)\frac{1}{s}\varphi^1\left(\frac{x-u}{s},\frac{y-u}{s}\right)dxdy = \left(f*\varphi_s^1\right)(u,v) \tag{8}$$

$$W^2 f(s,u,v) = \iint_{R^2} f(x,y)\frac{1}{s}\varphi^2\left(\frac{x-u}{s},\frac{y-u}{s}\right)dxdy = \left(f*\varphi_s^2\right)(u,v) \tag{9}$$

Hence,

$$\begin{bmatrix} W^1 f(s,u,v) \\ W^2 f(s,u,v) \end{bmatrix} = s\begin{pmatrix} \left(f*\varphi_s^1\right)(u,v) \\ \left(f*\varphi_s^2\right)(u,v) \end{pmatrix} = s\begin{pmatrix} \frac{\partial}{\partial u}\left(f*\theta_s\right)(u,v) \\ \frac{\partial}{\partial v}\left(f*\theta_s\right)(u,v) \end{pmatrix} = s\nabla\left(f*\theta_s\right)(u,v) \tag{10}$$

$\nabla(f*\theta_s)(U,V)$ is the gradient of the smoothing function.

$$Mf(s,u,v) = \sqrt{\left|W^1 f(s,u,v)\right|^2 + \left|W^2 f(s,u,v)\right|^2} \tag{11}$$

The angle between the gradient direction and the horizontal direction is:

$$Af(s,u,v) = \arctan\left(\frac{W^1 f(s,u,v)}{W^2 f(s,u,v)}\right) \tag{12}$$

Therefore, the maximum value of the smoothing function $\nabla(f*\theta_s)(U,V)$ along the gradient direction is equal to the maximum value of the $\nabla(f*\theta_s)(U,V)$ wave transforming mode.

If $Mf(s,u,v)(U_1,V_1)$ in one-dimensional neighborhood points along the gradient direction $(U,V)=(U_1,V_1)+\lambda f(U_1,V_1)$. The edge of the image is the largest modulus with a wavelet coefficient greater than a certain threshold.

3. The Foreign Body Detection Algorithm based on Wavelet Transform

H_0 filter is a low-pass filter, and the output is the approximate value of the image. H_1 filter is a high pass filter, and the output is high frequency or detail part of the image. When the signal source sends information, it is difficult to identify the signal due to the superposition of noise and interference. So it is necessary to remove the noise and interference components in the signal to effectively analyze the image. When the frequency of the noise is higher or lower than the effective signal, a filtering method is usually used to remove the noise. The filtering method is a frequency domain processing method. When analyzing the frequency characteristics of the signal, the portion where the signal change rate is small corresponds to the low frequency component, and the signal change rate is large corresponds to the high frequency component. Wavelet analysis is time-frequency localization analysis method with a fixed window area, but the window shape is variable, and the time window and the frequency window can be changed. It can use longer time intervals to obtain more accurate low frequency signal rate. Acquire high frequency signal information in short time intervals. In practical engineering applications, the analysis of the signal may contain many spikes or mutation, and the noise is not fixed white noise. For this kind of signal noise reduction processing, with the traditional fast Fourier transform (FFT) analysis, it is impossible to give a signal at a certain point in time. Wavelet analysis is a new signal processing method, the frequency components of various signals were decomposed into different frequency bands, which provides an effective way for signal filtering, denoising and feature extraction. We propose a foreign body detection algorithm based on wavelet transform in Fig. 1.

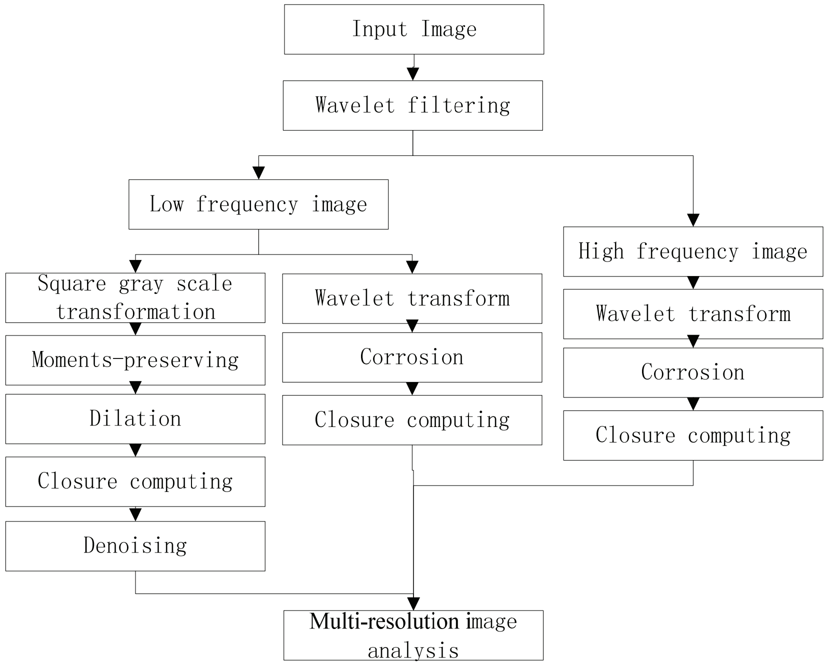


Fig. 1. Foreign body detection framework.

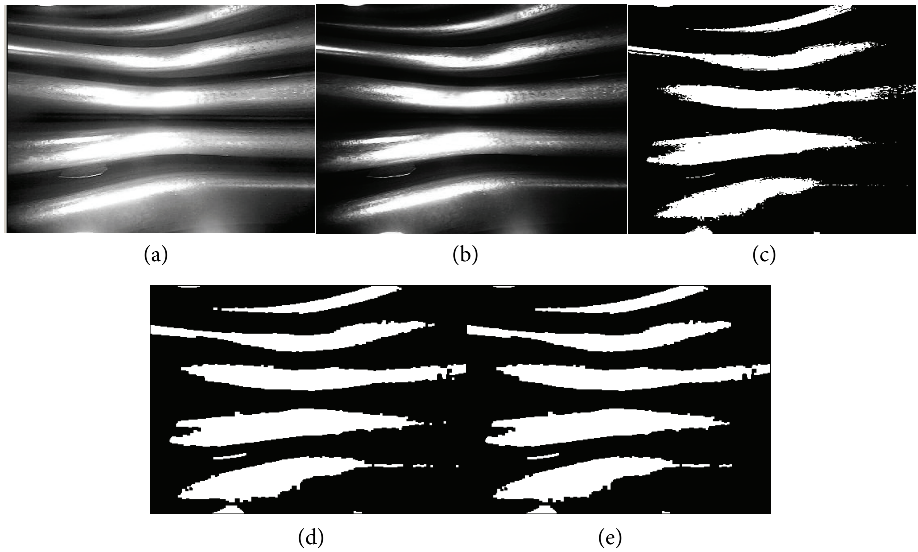


Fig. 2. Background and foreign body image analysis: (a) low frequency image, (b) gray image, (c) binary image, (d) image expansion and closed operation, and (e) image noise reduction.

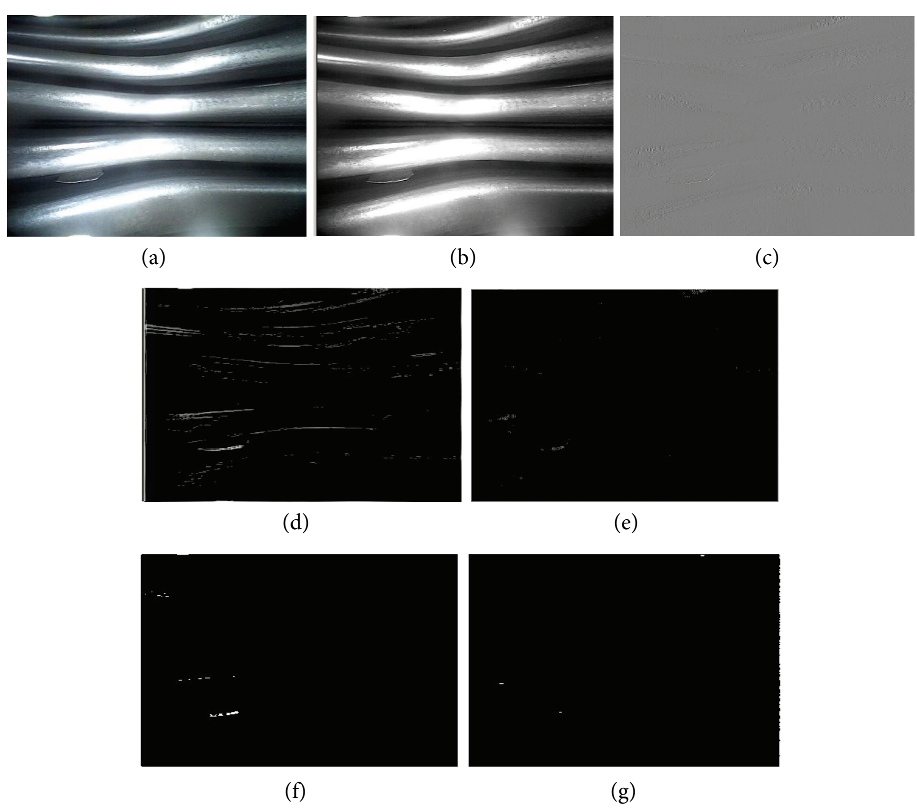


Fig. 3. Foreign body detection: (a) original image, (b) low frequency image, (c) high frequency image, (d) edge detection base on wavelet transform of low frequency image, (e) edge detection base on wavelet transform of high frequency image, (f) corrosion of low frequency image, and (g) corrosion of high frequency image.

The wavelet transform method is to transform the input image into high frequency image and low frequency image. We adopt two kinds of processing methods for low frequency image. The first approach would be to use the square method to transform the low frequency image (Fig. 2(a)) into gray scale (Fig. 2(b)), and then use the moments-preserving method to transform the gray image into the binary image (Fig. 2(c)). In the process of binary image correction, in order to facilitate the acquisition of target edge information, image expansion, closed operation (Fig. 2(d)) and image denoising methods (Fig. 2(e)) are adopted. The image I1 to be analyzed is obtained using the first type of method. The second kinds of low frequency image processing methods (Fig. 3(b)). We use the edge enhancement method to detect the edge of the low frequency image (Fig. 3(d)). According to the results of the edge detection, we can dilation and closed operation the image to obtain the image I2 (Fig. 3(f)). For the high frequency image (Fig. 3(c)), we use the wavelet transform for edge detection (Fig. 3(e)), and then dilation the edge detection results and closed operation to get I3 (Fig. 3(g)). We use I1, I2, and I3 to improve the accuracy of the algorithm. The I1 is used as the input image of the tube to analyze the background area of the tube surface and the suspected foreign object area. The I2 is used to detect suspected foreign object in low frequency images. The I3 is used to detect suspected foreign object in high frequency images. Finally, the Monte Carlo method evaluates suspicious foreign objects in the three images to determine the foreign object area.

4. The Analysis Mechanism based on Monte Carlo

A Monte Carlo simulation is a computerized mathematical technique that allows people to account for the probability in quantitative analysis and decision making. Monte Carlo methods are a class of computational algorithms that rely on repeated random sampling to calculate their results [16,17]. The probability of an event can be estimated by the frequency of the event in a large number of trials, and when the sample size is large enough, it is assumed that the frequency of occurrence of the event is its probability [18]. Monte Carlo simulation furnishes the decision-maker with a range of possible outcomes and the probabilities they will occur for any choice of action. It shows extreme possibilities (the outcomes of going for broke and the most conservative decision) along with all conceivable consequences for middle-of-the-road decisions [19].

Fig. 4 shows the number of simulations is 500 times. The analysis principles are applied to estimate the probability indices for suspected foreign bodies by combining their weights. We select sensitive factors as stochastic variable in the image analysis. The factors consist of two principal events (location and size of suspected foreign bodies). The model follows a particular pattern:

1. Define a domain of possible inputs for the foreign body assessment.
2. Randomly generate inputs from a probability distribution sampled over the domain.
3. Perform a deterministic estimate on the inputs according to distribution characteristics of the random variable.
4. Get the probability value.

The probability distribution is defined using values that are positively skewed, not symmetric like a normal distribution. It is used to represent the values that don’t go below zero but have unlimited positive potential. For a lognormal distribution X, the parameters denoted μ and σ are, respectively, the mean and the standard deviation of the variable's natural logarithm. $X = e\mu + \sigma Z$, and Z is a standard normal variable. Norm = NORMSINV (LAP), NORMSINV is the inverse function of the standard normal distribution function, σi = -Ri/Norm. See Table 1 for the location of the suspected foreign body.

According to the distribution function, we parse the inverse function of the random variable. Then it calculates the results iteratively, each time drawing a different set of random deviates from the probability functions. Five hundred Monte Carlo simulation iterations are used. Finally, we calculate the mean value of each event as the recognition result.

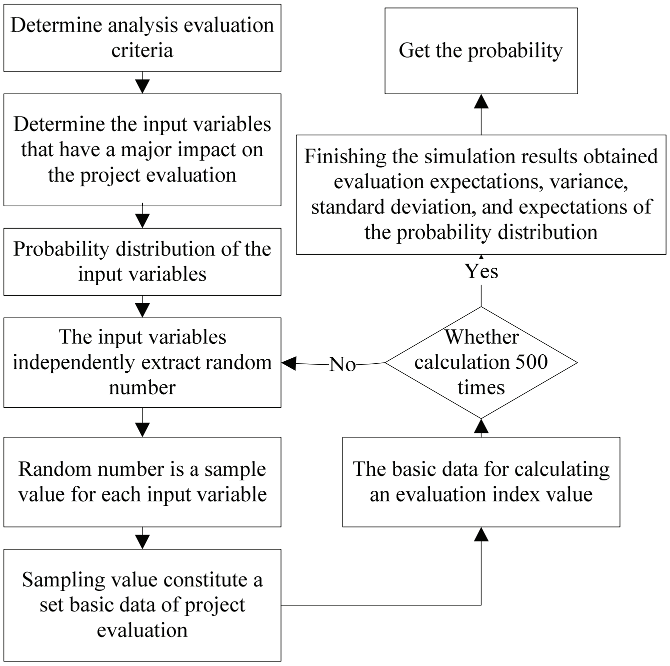


Fig. 4. Monte Carlo algorithm flowchart.

Table 1. The probability distribution function and inverse function

	Min	Max	CP	R	LAP	Norm	μ	σ_i
1	87	97	0.8	4	0.1	-1.28155	2.97025	0.433271
2	85	95	0.85	4.2	0.075	-1.43953	1.19025	0.412706
3	83	96	0.8	4.1	0.1	-1.28155	1.98025	0.433271
4	89	97	0.9	4.2	0.05	-1.64485	2.97025	0.392641
5	90	96	0.85	4	0.075	-1.43953	1.98025	0.412706
6	82	96	0.85	4.1	0.075	-1.43953	1.98025	0.412706
7	81	95	0.85	4.2	0.075	-1.43953	1.19025	0.412706
8	80	96	0.8	4.1	0.1	-1.28155	1.98025	0.433271
9	86	95	0.85	4.1	0.075	-1.43953	1.19025	0.412706
10	87	95	0.9	4	0.05	-1.64485	1.19025	0.392641
Y							9.9225	0.058463809
σ							3.15	0.241792905
cv							3.44%	8.39%

Min = the congestion minimum value, Max = the congestion maximum value, CP = coverage probability.

5. Experiment Result and Analysis

First, the square transform method converts the low frequency image into a gray-scale image. In addition, we choose exponential transformation, piecewise linear transformation, square root transformation and logarithmic transformation as comparison algorithms. Fig. 5(a) is an exponentially transformed image, with the result that too many black pixels cause a lot of trouble for future processing and application. Fig. 5(c) is a piecewise linear transformation, which results in the algorithm detecting more pseudo foreign object regions. In Fig. 5(d) and (e) are square root transformation and logarithmic transform, respectively. Their results indicate that too large a white background makes it difficult to detect foreign objects. Fig. 5(b) is a square transform with a large proportion of black pixels and a uniform distribution.

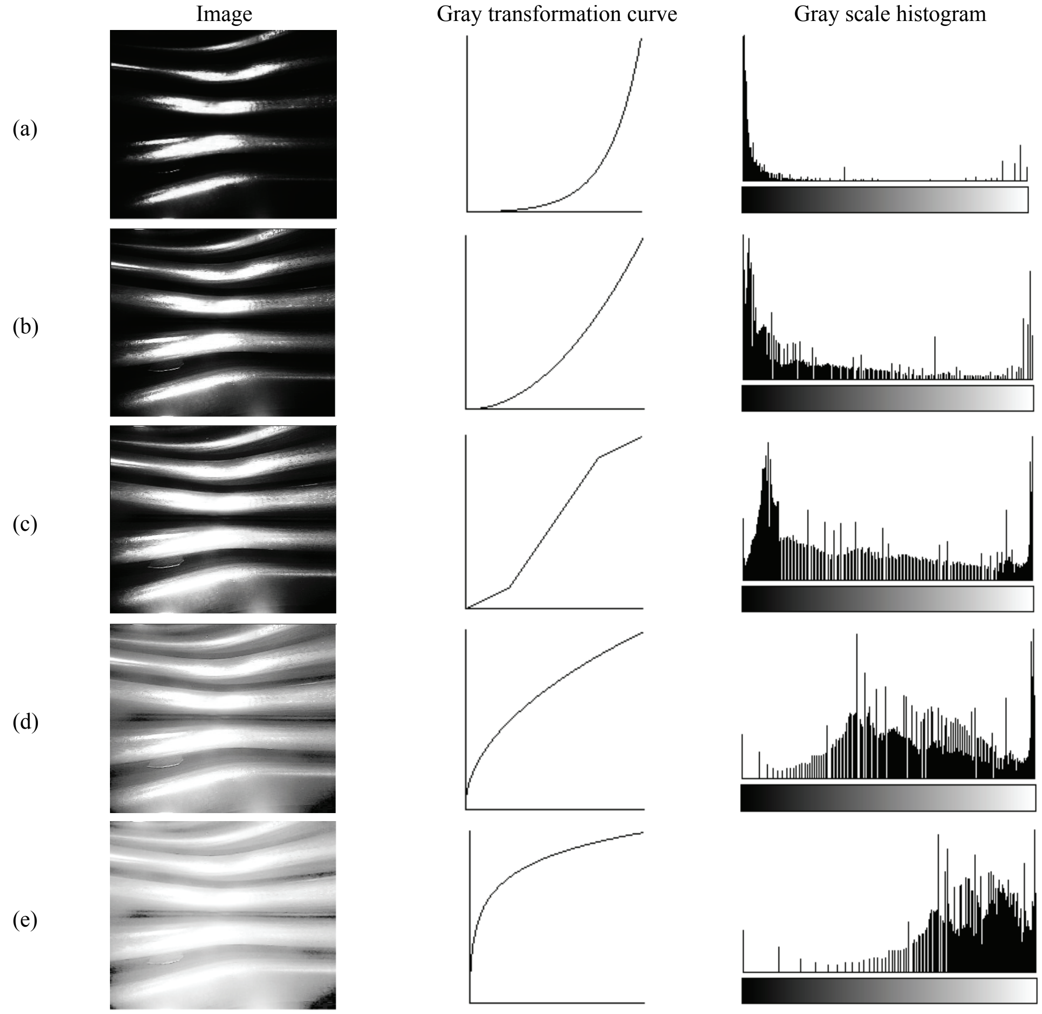


Fig. 5. Statistical analysis of gray scale histogram: (a) exponential transformation, (b) square transformation image, (c) segmental linear transformation image, (d) square root transformation image, and (e) logarithmic transformation image.

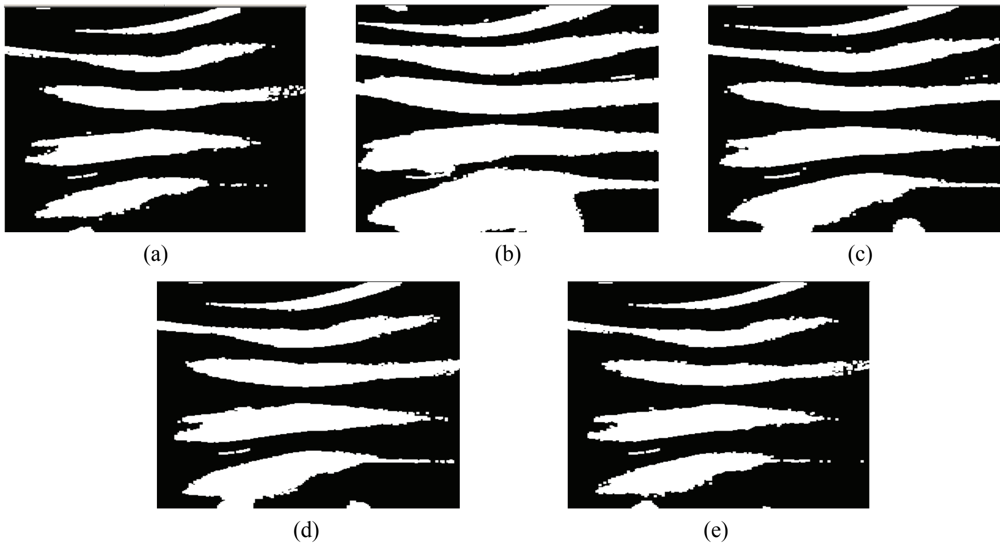


Fig. 6. Binary image of square transformation image: (a) Otsu image, (b) minimum error image, (c) maximum entropy image, (d) minimum bias-normal distribution image, and (e) moment-preserving image.

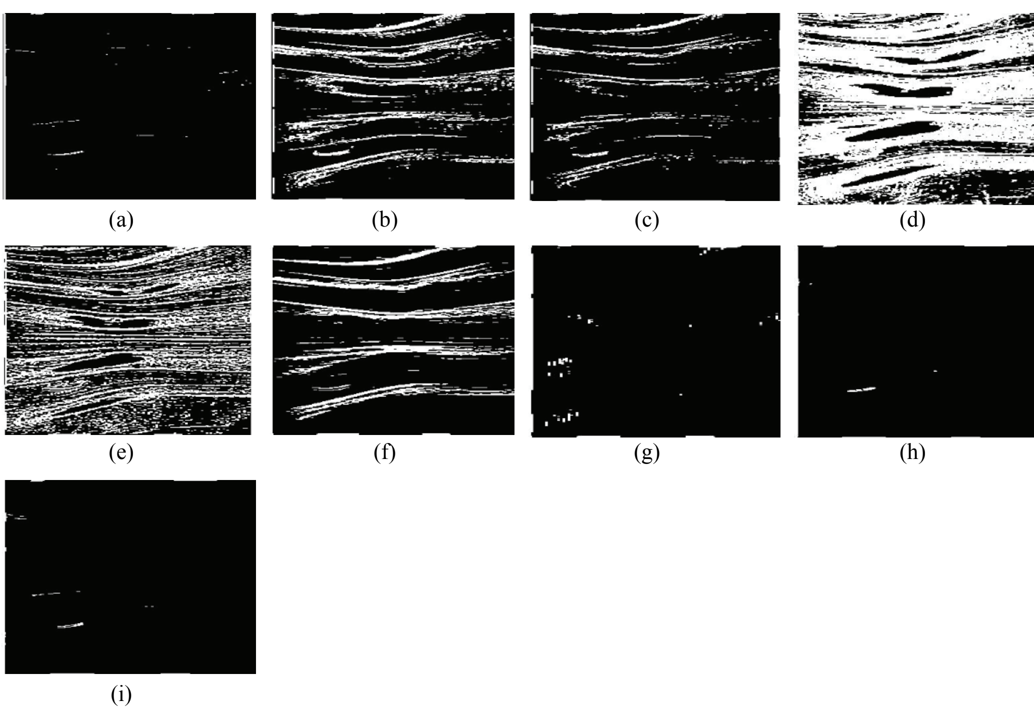


Fig. 7. The edge detection: (a) Roberts, (b) Sobel, (c) Prewitt method, (d) Kirsch, (e) Gauss-Laplacian, (f) level detection, (g) vertical detection, (h) wavelet, and (i) edge equalization.

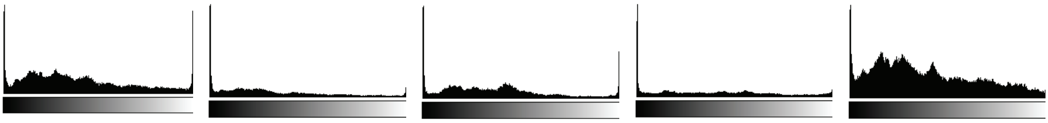
The maximum entropy method which is a low frequency passed image based on wavelet multiresolution filters is proposed for binarization, and the result is satisfactory. Otsu method leads to excessive impurity to influence the recognition of foreign body in Fig. 6(a). The minimum error method mixes the background and foreign matter, making it difficult to identify the foreign matter in Fig. 6(b).

The maximum entropy method (Fig. 6(c)), the minimum bias-normal distribution method (Fig. 6(d)) and the moment preserving method (Fig. 6(e)) can generate a sharp contour image as compared with the above method. But the maximum entropy method is better than the other two methods. The binary image obtained by the maximum entropy method is the basic framework of image analysis. Finally, the detection algorithm uses the basic frame to identify foreign objects based on the low-frequency image and high-frequency image edge detection.

Fig. 7 is a comparison of our proposed method (Fig. 7(h)) with other edge detection methods. Fig. 7(d) and (e) is difficult to identify the edge of foreign bodies. The results of Fig. 7(b), (c), and (f) are too much interference, making it difficult to identify foreign objects effectively. Fig. 7(g) is a vertical edge detection that contains too many discrete points that do not form an effective boundary. Fig. 7(a) and (i) detect more pronounced boundaries than other methods. Compared with these two methods, we propose a wavelet method with smaller interference boundary and higher recognition accuracy.

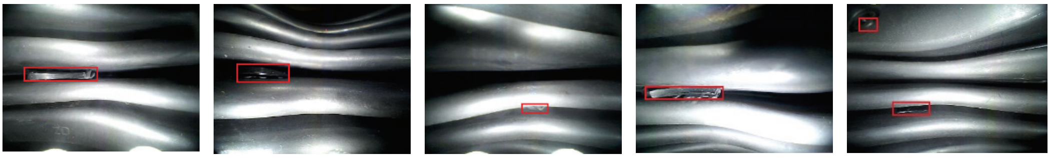
Firstly, the distribution of histogram was used to classify images into five categories (C1, C2, C3, C4 and C5) in Fig. 8.

Our algorithm can effectively identify the location of foreign bodies for the five categories as shown in Fig. 9. The red region is the final result of algorithm analysis.



(a) (b) (c) (d) (e)

Fig. 8. Histogram classification image.



(a) (b) (c) (d) (e)

Fig. 9. The red region is the final result of algorithm analysis.

Table 2. Foreign body recognition of the proposed method

	Precision (%)	Error probability	Proportion of missing
C1	100	0	0
C2	99.0789	0.844	0
C3	99.2	0.8	0
C4	98.6	0.14	0.005
C5	100	0	0

In the five types of input images, we prove that our proposed algorithm can identify foreign objects as shown in Table 2. Each type of image is prepared with 500 test cases to test the performance of the algorithm. The precision indicates the ratio of detected foreign body area (foreign body) and the recognition of the detected foreign body area. The error probability indicates detected foreign object (false foreign object) accounted for the proportion of detected foreign object. The missed rate indicates the proportion of unidentified foreign bodies occupying foreign bodies. The accuracy rate of C1 and C5 is 100%. The recognition accuracy of C2 and C3 is up to 99.0789% and 99.2%, respectively. The C4 recognition accuracy rate is 98.6%, but the reason is the lack of illumination with 4% omission of foreign object detection. The proposed algorithm is more accurate than the traditional wavelet transform algorithm, as shown in Tables 3 and 4. The difference between the two is that the traditional wavelet algorithm will determine the background area (similar to the foreign body) as the foreign object area which leads to decreased the accuracy of recognition. Therefore, with the enhancement of image contrast and the uniform distribution of pixels, the proposed algorithm is more accurate. We propose a foreign detecting algorithm based on wavelet transform to achieve the purpose of practical application.

Table 4 shows that our proposed algorithm improves the accuracy of foreign object recognition. The experimental results are more reasonable than other methods.

Table 3. Foreign body recognition of the traditional wavelet

	Precision (%)	Error probability	Proportion of missing
C1	74.7198	25.2802	0
C2	70.0422	29.9578	0
C3	72.68	27.32	0
C4	69.8	30.2	0
C5	74.776	25.224	0

Table 4. Foreign body recognition precision (%) of comparative method

	This study	Multi-wavelength [20]	Wavelet edge [21]	Wavelet transform [22]
C1	100	89.3	87.3	91.0
C2	99.156	89.0	81.1	89.2
C3	99.2	89.1	82.3	89.3
C4	98.6	86.2	78.5	87.5
C5	100	89.2	88.2	91.0

6. Conclusion

An improved wavelet transform algorithm with image analysis mechanism has been proposed to detect the foreign bodies on the inner wall of a threaded pipe image. We combine the Monte Carlo method to analyze the probability of foreign body. The algorithm chooses typical characteristics (location and size of suspicious regions) as evaluation parameters. The image analysis mechanism can generate a background with the suspected foreign object region to initialize the contours. This mechanism uses the connected domain to separate the background, the clutter, the foreign objects. The wavelet transform is used to detect the edge of foreign object in low frequency and high frequency image, and the foreign object is determined by the background analysis. Experimental results show that the algorithm has a promising recognition effect. Compared with the traditional wavelet transform method, this method can obtain the boundary region closer to the foreign object. However, the intensity of the light affects the accuracy of the algorithm so that our research is continuing in future work.

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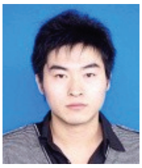

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