Research on Automatic Defect Localization Method for Mobile Wheel Ultrasonic Inspection System

Li WANG, Jianping PENG, Yu ZHANG, Xiaorong GAO, Zeyong WANG, Quanke ZHAO, Zhen WANG, Chaoyong PENG, Kai YANG

WangLi.net@263.net, adams.peng@home.swjtu.edu.cn

NDT Research Center, College of Physical Science and Technology, Southwest Jiaotong University; Chengdu, China

Abstract

In this paper, a new automatic defect localization method for mobile wheel ultrasonic image from a mobile wheel inspection system. This wheel inspection system adopting the phased array ultrasonic technology is widely used in railway industries for detecting all kinds of wheel defects in the wheel rim and disk area. However, the echo wave in the railway wheel is highly complex because of the unregularly wheel geometry, especially with the bore hole in the wheel disk, so that the common evaluation method by the A-Scan and B-scan image fails. The objective of our study is to develop a data processing algorithm for the B-scan image of wheel, to identify the defect echo wave image and assist the processing of the wheel quality evaluation. The research work described in the paper has thus been done with this objective in mind and it concerns a method that we have developed for automatic detection of defects. This method with the morphology processing and region growing can realize the automatic locate the defects image and increase the possibility of defects (POD) in the wheel.

Keywords

Railway wheel, Ultrasonic, automatic defect localization, morphology processing

1 Introduction

In recent years, high speed and heavy load are important symbols of railroad modernization. Since 2007 the speed of CRH train in china has increased quickly, the high speed train needs more strict ways to keep the train safety than before. It’s necessary to test the wheel-set in period times. In China, a mobile wheel-set inspection system named LU is applied to inspecting the wheel-set in stationary train on a maintenance line. Along with rapidly development of CRH trains, the routine inspection data from LU system is increasing every day. In order to supply a more efficient, higher reliability and higher quality service for the CRH wheel set, a method of automatic defect localization is needed to be designed.

Ultrasonic response from a defect depends on the size, shape, orientation and acoustic properties of the defect. On the ultrasonic test of wheels, the bore hole may give rise to high amplitude signal as well as a big flaw, especially for the defects which are near bore holes may disturb the inspective result. In our study, the method can position defects automatically in the inspection image from LU system without any omissive judgement.

2. The inspection principle of LU system

2.1 The typical defects in the wheel

The appearance of defects in the railway wheel may cause the great vibration and shock in high speed
train, which not only produces great uncomfortable noise, but also increases the wheel wear and damage, evermore generate the danger. The defect occurs not only in the tread, but also near the holes which used to fix the brake disk in the wheel disk. It is necessary to check those areas at fixed periods.

2.2 The principle of inspection wheel defect

In Figure 1, the probe carrier in LU system consists of two parts, one locates in the inner surface of wheel rim and the other locates the wheel tread.

2.2.1 The inspection of the wheel rim

The defects in the wheel rim can be inspected by the probes from tread side and the inner surface of rim.

- Defects in the inner of wheel rim always are inspected by conventional TR probes placed on the wheel tread and the inner surface of rim.
- Defects in the outer flank of wheel rim are inspected by phased array probes which are placed on the inner surface of rim.
- Defects in the inner flank of wheel rim and top of flange are inspected by conventional large angle probes which are also on the inner surface of rim.

2.2.2 The inspection of the wheel disk

The probe carrier on the tread has two kinds of probes: the TR and phased array probe. For example, the figure 2 shows the TR probes inspect the wheel rim and disk scheme. The TR probe generates the longitudinal wave and test the axle and circumferential orientation defect in the disk. Our algorithm of automatic defect localization also focuses on those TR probes inspection data firstly.

3. The feature analysis of inspection data

3.1 The inspection data

Once a wheel set is inspected completely by LU system, close to one hundred analysis and views are
generated at the same time, so the data analysts have to do an abundant of repetitive work. An automatic localization method is necessary to be designed to increase efficiency and lighten their work.

Through analysis on plenty of inspection data, the B-scan image views in LU system can be divided into two. One is the view without echo waves from bore holes in the wheel disk, the other one is the view with them. The table 1 shows the feature analysis between them and the red rectangular area references where the disturbing wave are in the B-scan image.

Table 1 the feature analysis for the L-wave inspection result

<table>
<thead>
<tr>
<th>Image type</th>
<th>Image Characteristics</th>
<th>Typical B-scan view</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image without echo waves from bore holes in the wheel disk</td>
<td>Image without any disturbing wave</td>
<td><img src="image1" alt="Typical B-scan view" /></td>
</tr>
<tr>
<td>Image with echo waves from bore holes in the wheel disk</td>
<td>Image inspected by TR probe placed on the wheel tread</td>
<td><img src="image2" alt="Typical B-scan view" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Image type</th>
<th>Image Characteristics</th>
<th>Typical B-scan view</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image without echo waves from bore holes in the wheel disk</td>
<td>The interface geometry echo is like a continuous band in the fixed position</td>
<td><img src="image3" alt="Typical B-scan view" /></td>
</tr>
<tr>
<td>Image with echo waves from bore holes in the wheel disk</td>
<td>The echo waves from bore holes in the disk are main problem. The feature is as follows: 1. The presence of echo wave from one bore hole is characterized by a parabola in the B-scan image. There is a cross-region between echo waves of adjacent bore holes. 2. The first or multiple echo waves from bore holes are in the fixed positions for a same wheel</td>
<td><img src="image4" alt="Typical B-scan view" /></td>
</tr>
</tbody>
</table>

4. The algorithm of automatic defect localization

So far in our work, our work is focus on the TR probe inspection result, automatic defect positioning accuracy is high in any LU inspection channel.

The defect position algorithm flow chart of TR inspection channel is shown in Figure 3.

4.1 Adjust contrast

In the image from TR inspection channel, there are many kinds of interference in it. By an abundance
of practical analysis, some of them can be removed by adjusting contrast based on gray histogram analysis. Linear gray transformation function is one dimensional function that can be written as:

\[ D_B = f(D_A) = f_A D_A + f_B \]  

(1)

Where \( f_A \) the slope of is linear function, \( f_B \) is the y intercept of linear function, \( D_A \) is the gray of input image, \( D_B \) is the gray of output image. In our work, we only need adjust contrast, not overall brightness. Thus in the equation (1), \( f_B \) is zero, \( f_A \) is the only parameter which is needed to change.

We adjust the contrast through the following steps:

- Select a special sample image, which needs no adjusting contrast procedure, its size is \([M, N]\), then calculate every line’s sum of gray values and get the max recorded as \( S \).
- Input other images, calculate the max of every line’s gray value sums and record it as \( s \).
- Compare \( s \) with \( S \), the parameter \( f_A \) in equation (1) is converted as following steps:
  
  \[
  \begin{align*}
  \text{if } s < S & \\
  f_A &= 1 + k(S - s) \\
  \text{Else } & \\
  f_A &= 1 - k(s - S)
  \end{align*}
  \]

\( k \) is a constant coefficient obtained by training large numbers of samples.

A binary image can be obtained by a fixed threshold value, threshold value is 40 percent of the largest gray value in the image. Figure 4(a) shows the binary image before adjusting contrast, and the one after adjusting contrast is shown in Figure 4(b). It can be seen that there is less bore holes coming back echoes interference in the image after adjusting contrast.

![Figure 4](image_url)

**Figure 4** (a) Binary image before adjusting contrast  
(b) Binary image after adjusting contrast

### 4.2 Morphological processing

As shown in Figures5(a), if enlarging region with bore holes in the image after adjusting contrast, we can find that there are some narrow gaps which will influence the next operation seriously. The most common technique used on this issue is morphological image processing, and the most common morphological operations are erosion and dilation. Erosion makes the objects smaller, and can break a single object into multiple objects. Dilation makes the objects larger, and can merge multiple objects into one. So dilation operation is used to fill narrow gaps in the region with bore holes. According to pulse echo method and B-SCAN image’s characteristic, we select structuring elements as shown in equation (2).

\[
\begin{align*}
\text{SE1} &= \begin{bmatrix}
0 & 0 & 0 & 0 & 1 \\
0 & 0 & 0 & 1 & 0 \\
0 & 0 & 1 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0
\end{bmatrix} & \text{SE2} &= \begin{bmatrix}
1 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 1
\end{bmatrix}
\end{align*}
\]

(2)

As shown in Figure 5(b), using the dilation by the structuring elements SE1 and SE2 in turn, gaps in the region with bore holes can be filled.
4.3 Region growing

Region growing is a simple region-based image segmentation method. It is also classified as a pixel-based image segmentation method since it involves the selection of initial seed points. This approach to segmentation examines neighboring pixels of initial “seed points” and determines whether the pixel neighbors should be added to the region. In general, we can separate bore holes region from inspective image, the segmented bore holes region is shown in Figure 6.

![Figure 6 Bore holes region which is segmented by region growing](image)

Figure 7(a) and (b) show 1 defect localization results of two TR inspection images. The results have proven that our algorithm achieves to position all the defects in the detection image without any misjudged or left out.

![Figure 7(a) defect localization result](image)

![Figure 7(b) defect localization result](image)

5. The experimental result

In the daily test work of LU system, there is rarely flaw in the result report. So the algorithm satisfactory has been proven by large quantities of reference wheels inspection data. More than ten artificial defects with different size and type are distributed in the important area of wheel rim and disk. The result from the experiment shows that our method can position all defects automatically in the
allowed channels in different type of wheel. The Table 2 shows defects position results in different inspection channels.

Table 2 defects position results in different inspection channels

<table>
<thead>
<tr>
<th>Image type</th>
<th>Algorithm accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image without echo waves from bore holes in the wheel disk</td>
<td>approximately 100%</td>
</tr>
<tr>
<td>Image inspected by TR with echo waves from bore holes in the wheel disk</td>
<td>&gt;95%</td>
</tr>
<tr>
<td>Image inspected in PC mode with echo waves from bore holes in the wheel disk</td>
<td>&gt;90%</td>
</tr>
</tbody>
</table>

6. Conclusions

In our work, a method of automatic defect position for the ultrasonic detective B-scan image has been put forward. In the processing of dealing with a large amount of on-site data, the result shows that the algorithm can localize defects accurately, improve detection efficiency greatly and lighten data analysts’ workload.

References

1. Peng Jianping, Wang Li, Gao Xiaorong, The design of mobile wheel set ultrasonic inspection system based on the phased array ultrasonic technology. 10th ECNDT, 2010, MOSCOW.