Application Of A Template Matching Algorithm In The Detection Of The Railroad Track

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Abstract. As the most important part of urban public transportation system, railway and subway are undertaking extremely important tasks. Manual inspection is sometimes difficult to detect track damage in time. Based on the impulse excitation of the rail, the undamaged rail and the damaged rail are distinguished according to the characteristics of its vibration signal. In the process of feature extraction, the pulse signal is intercepted, and the threshold is taken after gaussian smoothing filter. After multiple processing, the feature template is formed. Through the template matching algorithm proposed in this paper, the rail excitation pulse signal can be identified and the rail damage state can be determined. And the simulation display and control platform based on real object is made. After many tests, the method is proved to be effective.

1. Introduction
The rail joint, curve and switch are three weak areas of rail transit. In the curve and switch, due to the asymmetry of its own structure, under the action of temperature load and long-term cyclic load, it is easy to produce such diseases as conversion jamming, component damage, rail break and stress over limit, which directly affect the safe operation of the line. On the other hand, in the subway track, the operation is closed, the maintenance period of the skylight is limited, the working environment is poor, and the existing management and monitoring means cannot timely and comprehensively understand the service status of the key components such as the switch. Therefore, in order to improve maintenance efficiency and timely grasp the service status of rail structure, it is very necessary to carry out the implementation of track health monitoring system.

In this paper, a template formation and template matching algorithm is proposed for the weak link of track, and the non destructive and destructive rails are identified.

2. Pulse signal feature extraction
When analyzing the track vibration characteristics, the pulse signal can more easily reflect the rail vibration characteristics. Therefore, in this paper, the acceleration sensor is adopted to collect signals by means of small hammer striking the rail, and the natural frequency is inferred by analyzing the spectrum characteristics of the pulse signal, so as to form a template for screening.

2.1 Pulse signal detection
When the sensor collects rail vibration data, if there is no external force excitation, the acceleration signal collected by the sensor will be converted into the corresponding voltage signal after the sensor signal conversion, and the result is the white noise state that tends to be stable near the 0 value.
The pulse signal is extracted by means of endpoint detection in speech recognition. The pulse data segment is detected and taken out according to the short-time energy and the short time average zero-crossed rate of the signal [1].

The time-domain signal is set as \( x(n) \), and the windowed function \( w(n) \) is used to process the frame-\( i \) so as to get the voice signal \( y_i(n) \), then the signal \( y_i(n) \) satisfies as follows:

\[
y_i(n) = w(n) \ast x((i-1) \ast inc + n)
\]

(1)

In the formula above, \( y_i(n) \) is the signal of one frame after framing, \( n=1,2,...,L \), \( i=1,2,...,k \), \( L \) is the frame length. \( k \) is the number of frames after framing. \( w(n) \) is the window function, which generally takes hamming window or rectangular window, \( inc \) as the frame shift length.

Then the short-time energy calculation formula of the signal in frame-\( i \) is

\[
E(i) = \sum_{n=0}^{L-1} y_i^2(n), 1 \leq i \leq k
\]

(2)

The short-time average zero crossing rate represents the number of times that the speech signal waveform crosses the horizontal axis (zero level) in a frame of speech [2]. According to the short-term average zero crossing rate, useful signals can be found from the background signal.

When the signal \( x(n) \) is divided into \( y_i(n) \) and the frame length is \( L \), the calculation formula of short-time average crossing rate is as follows:

\[
Z(i) = \frac{1}{2} \sum_{n=0}^{L-1} \text{sgn}[y_i(n)] - \text{sgn}[y_i(n-1)]
\]

\[\begin{align*}
1 & \leq i \leq k
\end{align*}\]

(3)

Where, \( y_i(n) \) and \( k \) are defined as formula (1) and (2).

According to the joint judgment of short-term energy and short-term average crossing rate, a certain threshold value can be taken to detect whether the pulse signal exists. If so, the data segment of the pulse signal exists can be taken out [3].

As shown in FIG. 1, the data of one second between 1000 points before the pulse point and 31999 points after the pulse point is intercepted as the pulse signal.

2.2 Feature extraction

Three criteria can be used to extract spectral line features in frequency domain [4]. (1) its frequency domain amplitude (relative) exceeds a certain threshold;(2) extremely large in the adjacent area; (3) step exists in and outside the immediate domain;

The Fourier transform is applied to the signal to get the result of frequency domain, and the power spectrum is obtained by squaring the amplitude. In order to reduce the misjudgment or missing
judgment caused by the trend of continuous spectrum, gaussian smoothing filter was used to estimate the background of smooth continuous spectrum, as shown in figure 2. By subtracting the background trend spectrum from the original spectrum and taking the fixed threshold $q=20\text{dB}$, the characteristic spectral lines of the pulse signal can be preliminarily extracted with the addition of the maximum condition of the adjacent region.

3. Template formation and identification
In order to more accurately detect the vibration spectrum characteristics of the rail, it is necessary to strike the rail several times with a hammer at different positions and further analyze and process the collected signals so as to obtain more comprehensive information and form the characteristic template based on the rail in a certain way.

3.1 Use adjacent area criteria to extract the frequencies
Analyze the data containing multiple percussion pulse signals, extract each percussion signal according to the method in section 2.1, and obtain the spectral characteristics of each percussion signal. When the spectral line is extracted by multiple calculation of signal features, the result may be the composition of the main peak of width and the side lobe of small amplitude. In the sample signal analysis of finite length signal, the spectral frequency of line spectrum will drift to a certain extent, causing the phenomenon of spectral peak broadening. Therefore, it is necessary to set a neighboring region $\varepsilon$. When the detected spectral line is within the range of $f_i \pm \varepsilon$, it is considered to be the same characteristic spectral line.

Take the adjacent domain bandwidth $\varepsilon = 2\text{Hz}$, divide the spectrum into multiple sub-bands $f_i$, $i=1,2,\ldots,N$, among which $N*(2\varepsilon +1)=fs/2$, conduct sliding window discrimination on the spectrum lines in the frequency domain, and count and summarize the spectral lines that meet the conditions of the adjacent range. After induction and statistics, the random spectral lines are removed and the ones with higher frequency are retained. The characteristic spectral lines can be further arranged, as shown in figure 5.
3.2 Dynamic distribution of weights

Use non-destructive rail. Collect 80 seconds of data with acquisition instrument with a sampling frequency of 32Khz. The data consists of continuous taps, which are struck in different locations to ensure the complexity and diversity of the data. The frequency characteristic template based on the non-destructive rail is obtained after feature extraction, segmental domain induction and statistical sorting of the signal generated by percussion.

Similarly, the template was collected for the rail with big crack in the middle, and a total of 55 knocks were counted. After the template was obtained, the spectral lines whose occurrence times were lower than a certain threshold were screened and considered as random excitation spectral lines, which were removed. Get the template and save it.

The template obtained from the collected sample data is shown in table 1.

| Serial Number | Spectral Lines (Hz) | Number of Occurrences | Serial Number | Spectral Lines (Hz) | Number of Occurrences |
|---------------|--------------------|----------------------|---------------|--------------------|----------------------|
| 1             | 33                 | 11                   | 1             | 1448               | 11                   |
| 2             | 4213               | 11                   | 2             | 9253               | 13                   |
| 3             | 5343               | 11                   | 3             | 13403              | 13                   |
| 4             | 1413               | 12                   | 4             | 598                | 16                   |
| 5             | 5338               | 12                   | 5             | 11288              | 20                   |
| 6             | 6503               | 12                   | 6             | 93                 | 21                   |
| 7             | 5178               | 13                   | 7             | 603                | 29                   |
| 8             | 133                | 14                   | 8             | 1623               | 29                   |
| 9             | 5393               | 18                   | 9             | 1522               | 31                   |
| 10            | 1368               | 22                   | 10            | 5248               | 32                   |
| 11            | 93                 | 24                   | 11            | 80                 | 36                   |
| 12            | 1883               | 30                   | 12            | 1120               | 42                   |
| 13            | 1653               | 33                   | 13            | 2621               | 48                   |
| 14            | 968                | 34                   | 14            |                    |                      |
| 15            | 68                 | 48                   | 15            |                    |                      |
| 16            | 2308               | 52                   | 16            |                    |                      |

As shown in table 1, when the total number of percussion is 55 and the percussion position varies irregularity, the spectral lines with a statistical amount of more than 40 times are generated, which indicates that the rail determines its own vibration characteristics in its shape and material, and its influence on external excitation is limited.
It is found that the deformation of the rails will affect the spectral characteristics of the rails. According to the above, the characteristics of rail can be identified based on the template.

After obtaining the template, weights of each spectral line should be assigned. In this paper, matching weights of each spectral line should be assigned based on the frequency of occurrence of the stimulated spectral line. That is, the more times it appears, the higher its weight; The lower the number of occurrences, the lower the weight.

There is a modal frequency due to the force generated by striking the steel structure. This frequency characteristic is related to its material and shape, and there are usually several frequencies with obvious characteristics, which represent its own natural frequency. Therefore, it is not reasonable to assign the weights of the spectral lines linearly.

In this paper, the spectral line characteristic template of non-destructive rail is dynamically weighted by exponential function, and then:

$$w_i = \frac{C_i^{(1+i/k)}}{\sum_{i=1}^{k} C_i^{(1+i/k)}}, \quad i = 1, 2, ..., k$$

(4)

Where, I is the serial number of characteristic spectral line, k is the maximum serial number, and $C_i$ is the number of occurrence of spectral line.

Because in train or subway operation, the quality of the rail changes from good to bad logically, and its quality problems may be cracks, cracks, sharp track crawling, abnormal abrasion, etc., all of which can be classified as destructive rails, and their characteristic templates cannot be unified. But theoretically, there is only one kind of non-destructive rail, so the template of non-destructive rail can be used as the test sample and benchmark to complete the track flaw detection. After the distribution weight value of formula (4), the new template is generated as follows.

| serial number | Spectral Lines(Hz) | Number of occurrences | The Weight |
|---------------|-------------------|-----------------------|------------|
| 1             | 33                | 11                    | 0.011      |
| 2             | 4213              | 11                    | 0.011      |
| 3             | 5343              | 11                    | 0.011      |
| 4             | 1413              | 12                    | 0.013      |
| 5             | 5338              | 12                    | 0.013      |
| 6             | 6503              | 12                    | 0.013      |
| 7             | 5178              | 13                    | 0.016      |
| 8             | 133               | 14                    | 0.018      |
| 9             | 5393              | 18                    | 0.030      |
| 10            | 1368              | 22                    | 0.045      |
| 11            | 93                | 24                    | 0.054      |
| 12            | 1883              | 30                    | 0.084      |
| 13            | 1653              | 33                    | 0.102      |
| 14            | 968               | 34                    | 0.108      |
| 15            | 68                | 48                    | 0.215      |
| 16            | 2308              | 52                    | 0.253      |
3.3 Flaw detection based on template identification

Set the collection period as 10 seconds, input the collected data into the program, calculate the characteristic spectral lines of the pulse signal according to sections 2.2 and 3.1, and obtain the matching degree of the signal and the template by the template matching weighted algorithm.

\[ v = \sum_{p=1}^{k_p} w_p \]  

Where \( p \) is the serial number, \( k_p \) is the total number of spectral lines matching the upper template, and \( w_p \) is the weight of spectral lines matching the upper template.

According to the engineering requirements, the pulse detection and flaw detection program matching the template protocol is made, and its system is shown in figure 6.

![Flow chart of subway flaw detection system](image)

Figure 6. Flow chart of subway flaw detection system

4. Detection system platform

According to the flow shown in section 3.3 and figure 6, the corresponding detection system display and control interface is made, as shown in Figure 7.

![General system displays](image)

Figure 7. General system displays

5. Test and the performance

5.1 Test method
The realization of the above algorithm and platform is tested. Two steel rails of the same material and shape and size are selected, and there is a crack in the middle of one rail, as shown in figure 8.

Multi-channel sensor acquisition is adopted (figure 9), and the data is continuously knocked with a small hammer at different positions of the non-destructive rail, and the data flows into the system to collect and generate templates.

![Figure 8 Non-destructive rail and the cracked rail](image1)

![Figure 9 Sensor placement](image2)

In FIG. 9, knock five times from point 1 to 7, and generate thirty-five knock pulses as the test data. Time domain waveform is shown in FIG. 10.

![Figure 10. A channel time domain diagram](image3)

5.2 Test performance
The striking data is detected through the system, and the threshold of matching degree is selected as 0.3. If the matching degree is lower than the threshold, it is determined as lossy steel, and the detection output is 1. The detection results of one channel are shown in table 3.

| Knock number | Matching degree | Test results | Matching degree | Test results |
|--------------|-----------------|--------------|-----------------|--------------|
| 1            | 0.48            | 0            | 0.10            | 1            |
| 2            | 0.79            | 0            | 0.10            | 1            |
| 3            | 0.75            | 0            | 0.10            | 1            |
| 4            | 0.43            | 0            | 0.08            | 1            |
| 5            | 0.44            | 0            | 0.03            | 1            |
| 6            | 0.83            | 0            | 0.03            | 1            |
| 7            | 0.89            | 0            | 0.08            | 1            |
| 8            | 0.83            | 0            | 0.05            | 1            |
| 9            | 0.85            | 0            | 0.03            | 1            |
| 10           | 0.80            | 0            | 0.03            | 1            |
| 11           | 0.85            | 0            | 0.00            | 1            |
| 12           | 0.45            | 0            | 0.00            | 1            |
| 13           | 0.85            | 0            | 0.05            | 1            |
| 14           | 0.76            | 0            | 0.06            | 1            |
| 15           | 0.50            | 0            | 0.00            | 1            |
| 16           | 0.48            | 0            | 0.10            | 1            |
According to the above table, 35 pulse signals were detected, and the matching degree of non-destructive rail was obviously higher, while the matching degree of cracked rail was difficult to reach. In this experiment, with the matching threshold of 0.3, there were two false alarms, and the false alarm rate was 5.71%.

6. Conclusion
Simulation and experimental results show that the rail detection algorithm based on feature extraction and template formation has good detection performance. When the rail is stable and the pulse is obvious, the damage characteristics of the rail can be detected effectively.

The disadvantage is that it relies more on pulse signal detection. If it is the actual signal of subway or train running over the track, its performance needs to be verified.

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