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RESEARCH ON VIBRATION SIGNAL NOISE SUPPRESSION METHOD BASED ON SMOOTHING FILTERING

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ABSTRACT

In order to effectively remove the noise interference in the vibration response signal, Smoothing Filtering, a filtering method commonly used in the field of geophysical data processing for improving data signal-to-noise ratio is introduced. The method is mainly realized by triangular filtering, and the triangular filter is constructed by two rectangular filters, which has high computational efficiency. Meanwhile, triangular filtering can also be regarded as a good approximation method of Gaussian filtering. When the trigonometric function is multi-convolved with itself, mathematically, it can approximate the Gaussian function. After multiple iterations, it can also implement an approximate Gaussian filter. Through the processing of the measured vibration signal, the de-noising performance of the median filtering method and the smoothing filtering method is compared. And the advantages of the smoothing filtering method are further testified by using time-frequency analysis. The results show that the smoothing filtering method can better preserve the details of the effective signal while suppressing the noise interference, and effectively improve the data signal-to-noise ratio. The effectiveness and feasibility of the smoothing filtering method applied to the noise suppression of vibration response signals are verified.

Keywords: vibration signal, noise suppression, smoothing filtering

1. INTRODUCTION

Engineering structures may be damaged by different loads and sudden factors during long-term service. If the damage cannot be found and the corresponding measures are taken in time, it will cause catastrophic consequences and cause huge losses. Therefore, it is important to identify the damage of the engineering structure. Structural damage detection is the core content of structural health monitoring. Traditional damage identification methods based on modal parameters identify structural damage by comparing changes in modal parameters before and after damage, however, this method is computationally intensive and complicated, which is not conducive to long-term monitoring of the structure. The structural damage identification method based on vibration signal analysis directly analyzes the test signal and extracts the damage information. Compared with the traditional damage identification method, this method is simple and efficient, and is widely used in engineering structure damage identification [1].

However, in actual projects, vibration signals are often subject to noise interference during transmission, acquisition, and pre-processing, resulting in a decrease in the signal-to-noise ratio of the vibration signal [2]. The reduction in data quality seriously hinders the use of vibration signals for damage identification and extract the changing characteristics of the structures. Therefore, how to extract effective signal characteristic information from a large number of vibration signals and suppress noise interference is particularly important.

2. MATERIALS AND METHODS

Smoothing filtering is a commonly used method to improve data signal-to-noise ratio in the field of geophysics. Claerbout [3] proposes the concept of smoothing filtering in seismic data processing. Smoothing filtering is mainly realized by triangular filtering, and triangular filter is constructed by two rectangular filters. The filtering method has higher computational efficiency because it only needs to multiply the input data of length N by N times. Triangular filtering can also be seen as a good approximation of Gaussian filtering. When the trigonometric function is convolved multiple times with itself, mathematically, the Gaussian function can be approximated. Therefore, the triangular filter can also implement an approximate Gaussian filter after repeated iterations, and this method is simple and efficient. For noisy target data, smoothing filtering can achieve the purpose of suppressing noise by selecting the appropriate smoothing radius and number of iterations according to the target data.

2.1 Smoothing Filtering

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An ideal filter should be able to pass all signals at the frequencies in the passband without loss, and signals above or below the cutoff frequency should be quickly attenuated to zero. The general rectangular filter is in the form of a Z transform (take a five-point filter as an example):

$$\frac{1-Z^5}{1-Z}=1+Z+Z^2+Z^3+Z^4 \tag{1}$$

A rectangular filter is a basic smoothing filter that performs a moving average under a rectangular window. The shock response of the moving average filter is a filtering process that convolves the input signal and the rectangular pulse. When the width of the selected response function is long, the calculation time will also increase, but the recursive algorithm will greatly reduce the time cost. When applied, a rectangular filter moves a rectangular window by adding a new value at one end and discarding an old value at the other end. When the filter smooths the input data, it appears as a convolution of the filter with the input signal in the time domain and as a product of the filter and the input signal in the frequency domain, marked in the Z transform as

$$Y(Z)=X(Z)(1-Z^5)/(1-Z) \tag{2}$$

where $X(Z)$ is input signal, $Y(Z)$ is the output signal after the input signal and the filter are convolved.

Triangular smoothing is achieved by completing two times rectangle smoothing, marked in the Z transform as:

$$T_k(Z)=B_k(1/Z)B_k(Z) \tag{3}$$

where $B_k(Z)$ is a rectangle filter, $T_k(Z)$ is a triangular filter obtained by convolution of two rectangular filters.

$$B_k(Z)=\frac{1}{k}(1+Z+Z^2+\cdots+Z^k)=\frac{1}{k}\frac{1-Z^{k+1}}{1-Z} \tag{4}$$

where k is the smoothing radius of the rectangular filter.

The mathematical description of the triangular filter can be simply considered as the square of the formula (1). The effect of repeating the triangular smoothing can quickly approximate Gaussian smoothing. This is because although the top of the trigonometric function is an acute angle, its shape approximates the Gaussian function. When the trigonometric function is convolved with itself multiple times, the shape at the top of the trigonometric function will be closer to the shape of the Gaussian function (according to the central-limit theorem). Therefore, the repeated application of triangular smoothing can converge the impulse response to a Gaussian curve and has a fast convergence speed. Compared with Gaussian smoothing, the iterative triangulation algorithm is simple, efficient and easy to implement.

2.2 Median Filtering

Median filtering is a nonlinear signal processing method, and its corresponding median filter is a statistical sorting filter [4]. In this paper, the median filtering method is used as a method to compare with smoothing filtering and is applied to the processing of measured noisy signals. When the median filter processes the target data, the data is replaced by the median of the data sorted in the neighborhood of the data volume. Its mathematical expression is:

$$y_i=Med\left\{f_{i-v},\dots,f_i,\dots f_{i+v}\right\}\quad i\in N,\, v=\frac{m-1}{2} \tag{5}$$

where $f_1, f_2 \dots f_n$ is a one-dimensional sequence, take the window length to m (m is odd), applying Median filtering to it, which is to extract m numbers $f_{i-v},\dots,f_i,\dots f_{i+v}$ from the input sequence.(where f_i is the mid-point value of the window $v=(m-1)/2$), then, the m points are sorted according to their numerical values, and the sorted number in the center point is taken as a filtered output.

2.3 Experimental Setup

The test uses hand-power hammer to apply excitation to the reinforced concrete simply supported beam and uses the acceleration sensor to collect the vibration response signals under different load conditions. The test used concrete with a strength of C20. The reinforced concrete test beam has a length of 1000 mm, a section size of 100 mm × 150 mm, and a net span of 900 mm. The longitudinal section of the compression zone is 2φ6, the longitudinal section of the tension zone is 2φ10, and the stirrup ratio is φ6@100. Supports are placed at both ends of the simply supported beam, and the support is 50 mm from the beam end. The tapping point of the hand-power hammer is located 50mm above the left support of the simply supported beam, and there is an acceleration sensor is placed on the right side of the simple support beam for receiving the vibration response signal. The accelerometer is located above the right-side support. There is a loading instrument just above the middle of the simply supported beam that can apply concentrated loads of different force.

3. RESULTS AND DISCUSSION

The experiment was carried out in a relatively open environment. During the experiment, the experimental data will be affected by environmental noise and the noise generated by the internal electrodes and amplifiers of the instrument, thus reducing the quality of the test data. In this experiment, the effective excitation force selected is 140kN. Due to the large amount of the overall test data, in this paper, only two data volumes under the uncrack and cracked state of the simply supported beam are taken as examples for processing and analysis.

Figure 1a and Figure 1b show the vibration response signal received by the accelerometer in the non-destructive state and the damage state of the simply supported beam, respectively. It can be seen from the signal in the time domain that under the instantaneous impact of artificial excitation, the amplitude instantaneously reaches a maximum value and then rapidly decays. However, there are relatively serious random noise interferences and some large amplitude impulse noise interferences in the signal. It can be found in their time frequency spectrum that the amplitude of the noise is spread over the entire frequency band, which brings certain difficulties for the subsequent damage identification work.

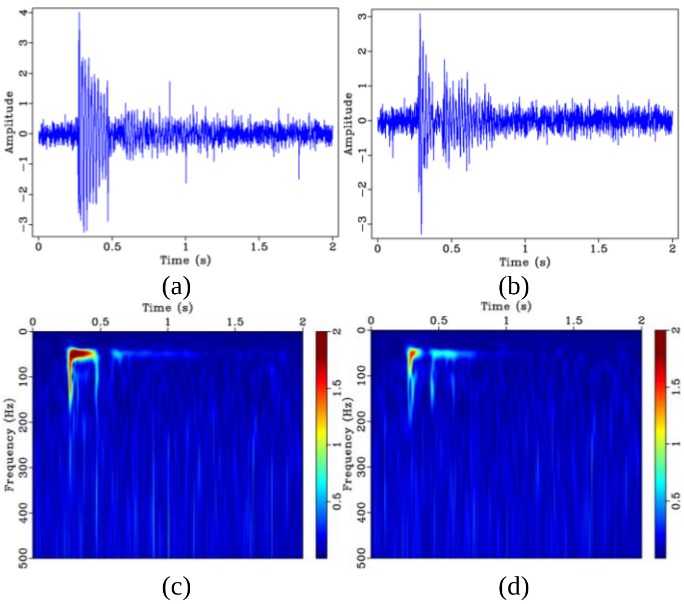

FIGURE 1: Noisy vibration signal under uncrack and cracked state and their time frequency spectrum.

Median filtering denoised data displayed in Figure 2, after the median filtering method, the impulse noise interference in the time domain signal is effectively suppressed, but in the time-frequency domain, it can be seen that the strong random noise interference still exists.

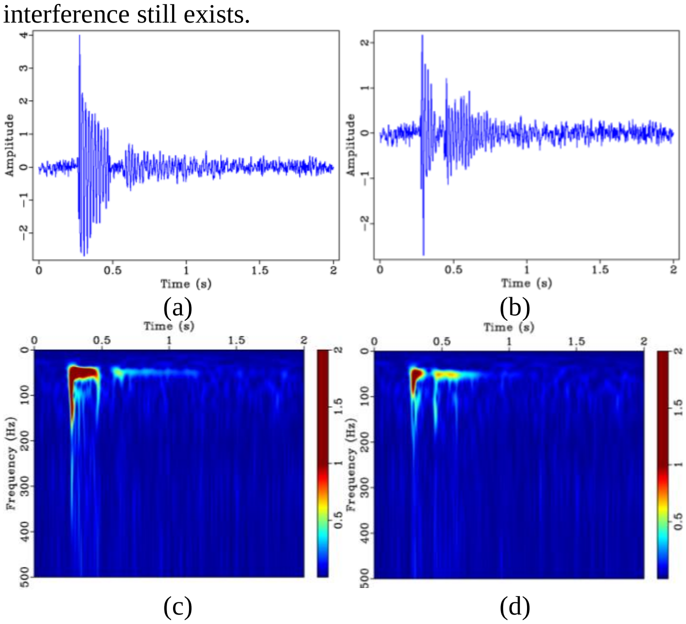

FIGURE 2: Median filtering denoised vibration signal under uncrack and cracked state and their time frequency spectrum.

The result after applying smoothing filtering as shown in Figure 3, the denoising result in the time domain is not significantly different from the result of the median filtering. However, in the time-frequency domain, after using smoothing filtering, noise amplitude interference greater than 200Hz has been completely removed. At the same time, the phenomenon that the high-frequency signal attenuates faster when it propagates in the crack is also well reflected in the time frequency spectrum.

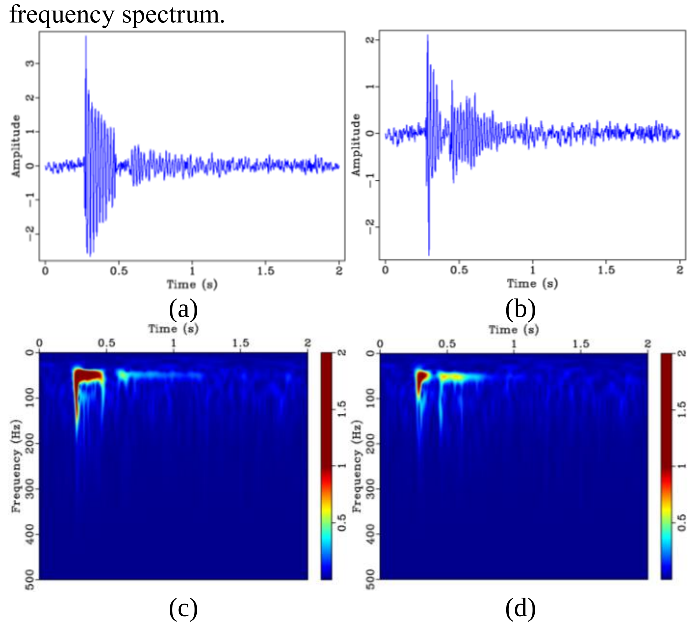

FIGURE 3: Smoothing filtering denoised vibration signal under uncrack and cracked state and their time frequency spectrum.

4. CONCLUSION

Base on the simply supported beam damage detection experiment, this paper combines the signal noise suppression problem with the structural damage identification problem. By applying the median filtering method and the smoothing filtering method to the measured signal for processing and analysis, the following conclusions can be drawn: (1) Compared with the median filtering method, the smoothing filter can better preserve the detailed information in the signal while suppressing the signal noise, and the data error caused by the noise suppression process is smaller. (2) It can be seen from the time-frequency spectrum of the signal processed by the smoothing method that the high-frequency noise is effectively suppressed, and the noise amplitude in the spectrum range is significantly reduced, which effectively improves the data signal-to-noise ratio and provides an effective solution for the quality of data used for subsequent damage identification work.

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