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Improvement of Correlation Identification Method Based on Non-Negative Periodic Autocorrelation Function

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Abstract

The correlation identification algorithm is a system identification method that can effectively suppress stochastic noise. However, since the auto spectrum of m-sequence has zero amplitude points, it will seriously affect the result of identification. Based on this problem, this paper proposes advanced method: we only take the non-negative part of the autocorrelation function and the cross correlation function, the spectrum of non-negative period autocorrelation function does not exist zero points. Compared with the auto spectrum of m sequence, the spectrum of non-negative period autocorrelation function has obvious advantages. In order to solve the conventional zero problem and improve the identification accuracy, this paper uses this method. Experiments showed that the improved correlation identification method had a higher identification accuracy and had achieved better identification results.

Keywords

Correlation Identification, Autocorrelation Function, Non-negative Period, M-sequences

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1. Introduction

The conventional correlation identification can suppress the noise in some degree [1]. It uses Pseudo Random Binary Signal (PRBS) as input signal and obtains the impulse response and frequency response of the system under identification [2]. In the correlation identification, m-sequence is often used as PRBS. However, the auto spectrum of m-sequence has zero amplitude points [3], which will make the result of identification unsatisfactory. In order to solve this problem, the conventional method is Iterative Method. In addition, ShuQin [4] used the method of Lobbattas, and QiuLishan [5] used the method of adding a small amount. However, these methods only reduce the impacts of zero points.

The spectrum of non-negative period autocorrelation function does not exist zero points. This will be a good solution to the conventional zero problem. Therefore, this paper applies this method to the correlation identification field and propose an improved algorithm: we use the non-negative periodic autocorrelation function and cross-correlation function instead of the autocorrelation function and cross-correlation function, then conduct the correlation identification experiments. Using this method, the spectrum of the impulse response is more accurate. Compared with the MATLAB simulation results, the improved correlation correlation had a better result than the conventional correlation correlation.

2. Methods

2.1. Model Assumptions

In the correlation identification, the transmission model of the system to be tested is [6]: the transmitting device sends the PRBS to the second-order system, the PRBS transmits in the

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second-order system, adds the noise interference, and the receiving device receives the output signal. The model of correlation identification of subsurface is illustrated in Figure 1.

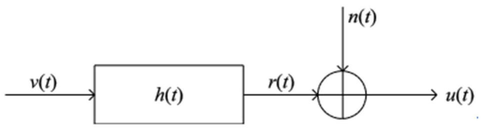

Figure 1. Pseudo-random signal transmission model in correlation identification.

in which the impulse response of the subsurface to be identified is $h(t)$, the input PRBS signal is $v(t)$, the output signal is $r(t)$, the noise is $n(t)$, and the final output voltage signal acquired by the receiver is $u(t)$.

In this paper, m-sequence is used as PBRS signal. The m-sequence is usually generated by feedback shift registers. The principle is shown in figure 2:

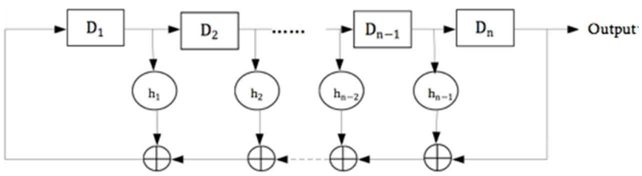

Figure 2. The production of m-sequence.

Since it has a sharp autocorrelation property like random noise and easy to create and copy, m-sequence is widely used in communications, radar and other aspects. The autocorrelation function of m-sequence is shown in the figure 3.

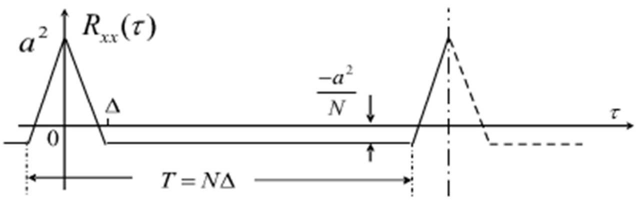

Figure 3. The autocorrelation function of m-sequence.

in which α is the amplitude of m-sequence, N is the length of m-sequence.

2.2. Correlation Identification

As is shown in Figure 1, the relation between the input and output signals is given by the following equation:

$$u(t) = v(t) * h(t) + n(t) \tag{1}$$

Correlation operation is carried out with the input signal $v(t)$ on both sides of the equation (1), the result is:

$$R_{vn}(t) = R_{vv}(t) * h(t) + R_{vn}(t) \tag{2}$$

Since the input signal is m-sequence, it has excellent correlation characteristics and is independent of noise [7], so $R_{vn}(t)$ is approximately equal to 0 and the noise is suppressed [8]. Then, performing the Fourier transform on both sides of the equation, and the result is:

$$H(w) = FFT\big(h(t)\big) = \frac{FFT(R_{vu}(t))}{FFT(R_{vv}(t))} \tag{3}$$

2.3. Zero Problem

The m-sequence autocorrelation function and the power spectral density constitute a pair of Fourier transforms [9]. the power spectral of m-sequence is:

$$\Phi_{vv}(w) = \frac{2\pi a^2}{N^2}\delta(w) + \frac{2\pi a^2(N+1)}{N^2}\sum_{\substack{n=-\infty \\ n\neq 0}}^{\infty}\left[\frac{\frac{\sin(n\omega_0)}{2}}{\frac{n\omega_0}{2}}\right]^2 \delta(\omega - n\omega_0) \tag{4}$$

The amplitude spectrum of power spectral density is illustrated in Figure 4.

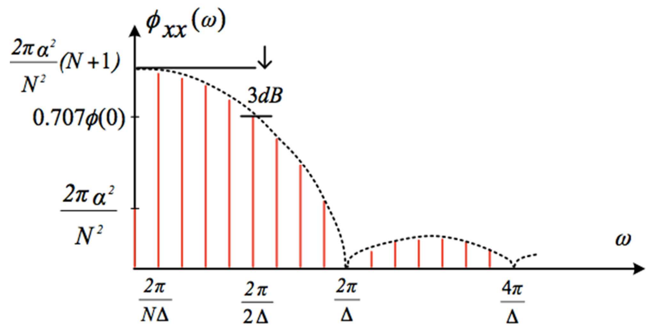

Figure 4. Power spectral density of m sequence.

From the figure, it is clearly that the power spectrum of m-sequence has zero points.

In the method of correlation identification, the solution of $H(w)$ is inaccurate due to the zero points. Therefore, when using the method of correlation identification, various methods are usually adopted to solve this problem.

2.4. The Traditional Solution to the Zero Problem

In order to solve this problem, many methods were used. QiuLishan used the method of adding a small amount. According to his method, the equation (3) became equation (5):

$$H(w) = FFT\big(h(t)\big) = \frac{FFT(R_{vu}(t))}{FFT(R_{vv}(t))+\alpha} \tag{5}$$

Since the value of α was small, the influence on the power spectrum of the m-sequence could be minimized and the points at which the amplitude of the m-sequence was zero could be slightly increased.

However, the value of α was not clearly defined. In the experiments, the effect of identification was very sensitive to the value of α.

2.5. Improvement of Correlation Identification Method

Through the above analysis, the traditional method to solve the zero problem is not ideal. Therefore, this paper proposes an improved method.

Multiply both sides of equation (2) by $u(t)$, the result is:

$$R_{vn}(t)u(t) = R_{vv}(t) * h(t)u(t) + R_{vn}(t)u(t) \quad (6)$$

The Fourier transform of $u(t)$ is [10]:

$$U(w) = \frac{1}{jw} + \pi\delta(w) \quad (7)$$

Since $R'_{vv}(t)$=$R_{vv}(t)u(t)$, the Fourier transform of $R'_{vv}(t)$ is:

$$R'_{vv}(w) = \Phi_{vv}(w) * U(w) \quad (8)$$

According to equation (4) and equation (7), the Fourier transform of $R'_{vv}(t)$ is:

$$\mathrm{R}'_{\mathrm{vv}}(\mathrm{w}) = \frac{1}{\mathrm{jw}} * \Phi_{\mathrm{vv}}(\mathrm{w}) + \frac{2\pi \mathrm{a}^2}{\mathrm{N}^2} + \frac{2\pi \mathrm{a}^2(\mathrm{N}+1)}{\mathrm{N}^2} \quad (9)$$

In the equation (9), $\frac{1}{jw} * \Phi_{vv}(w)$ is non-negative, and $\frac{2\pi a^2}{N^2} + \frac{2\pi a^2(N+1)}{N^2}$ is a positive value, so $R'_{vv}(w)$ does not exist zero point.

Since $R_{vn}(t)$ is nearly equal to 0, performing the Fourier transform on both sides of the equation (6), and the result is:

$$H(w) = FFT(h(t)) = \frac{FFT(R'_{vu}(t))}{FFT(R'_{vv}(t))} \quad (10)$$

in which $R'_{vu}(t)$=$R_{vn}(t)u(t)$,$R'_{vv}(t)$=$R_{vv}(t)u(t)$.

Based on the above analysis, the spectrum of $R'_{vu}(t)$ compares to the spectrum of $R_{vv}(t)$ has the following two characteristics:

(1) The imaginary part of the spectrum is not equal to zero;

(2) The spectrum does not exist zero point.

Based on these characteristics, zero problem can be solved very well. Then, certification will be shown in next part.

3. Experiment and Result

Based on the simulation of typical second-order system for earth system identification in MATLAB, given a second-order system to be tested, the impulse response of the system is:

$$h(t) = \frac{250}{8e^{-375t}} \quad (11)$$

The parameters of the input signal are a=1, q=5, N=16383, where N is the cycle length, q is the number of periods and a is the amplitude of m-sequence.

First, traditional correlation identification was used, the result was shown in figure 5:

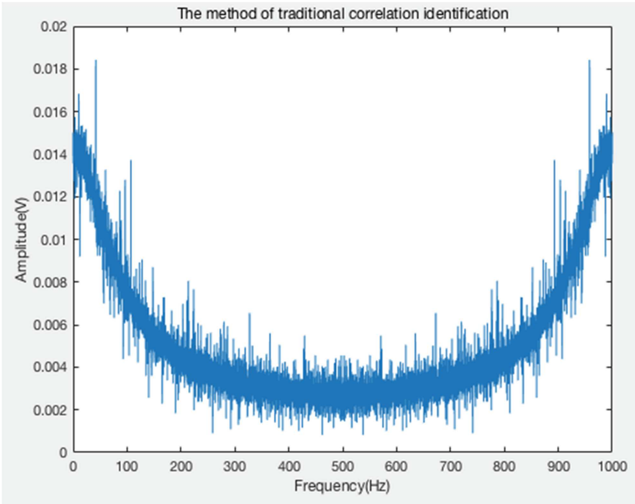

Figure 5. The spectrum of traditional correlation identification.

From Figure 5, the effect of zero problem on the identification effect was obviously, some points existed errors due to the zero points. Therefore, this paper used different methods to solve this problem.

3.1. The Method of Adding a Small Amount

In this part, the method of adding a small amount was used to solve the zero problem. However, determining the value of α was not easy. The experiment results of different α were showed in figure 6.

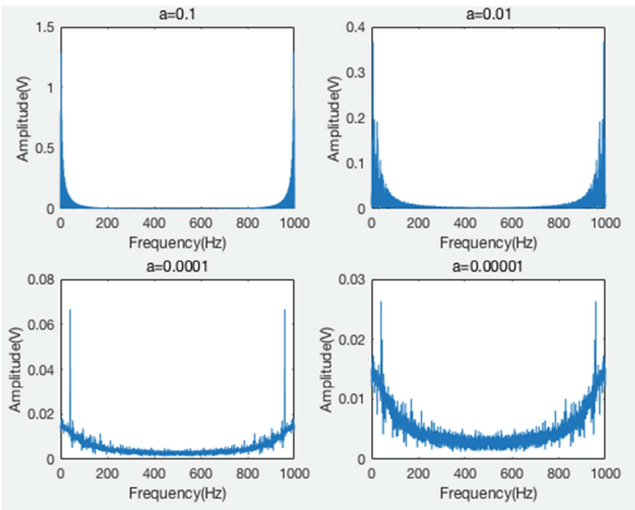

Figure 6. The identification effect of different α.

From the figure 6, comparing the effects of different α on the correlation identification effect, it could see that α has huge effects on the results. A large value had a big impact on the identification effect. However, too small value would not solve the zero problem.

After many experiments, the identification effect was the best when α is equal to 0.001.

3.2. Improvement of Correlation Identification Method

In this part, Improvement of correlation identification method was used to solve the zero problem.

First, the spectrum of the non-negative periodic autocorrelation function and the auto spectrum of the m-sequence were shown in figure 7 and figure 8:

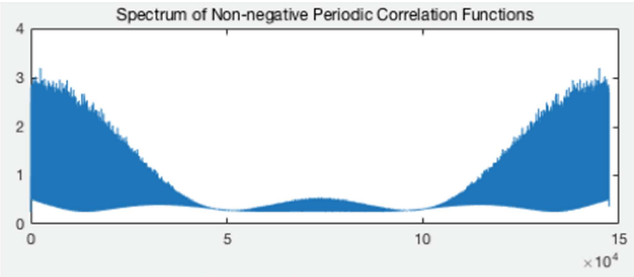

Figure 7. The spectrum of the non-negative periodic autocorrelation function.

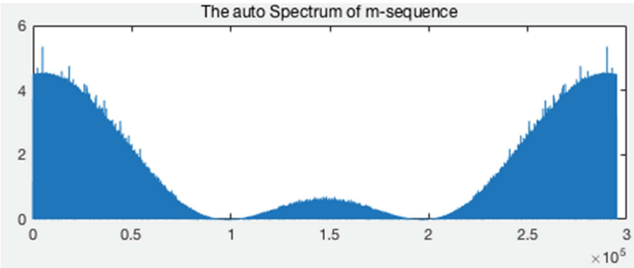

Figure 8. The auto spectrum of m-sequence.

The difference between the two spectrums was that the spectrum of the non-negative periodic autocorrelation function didn't exist zero point, it proved the conclusion mentioned in 2.5.

Second, two different methods were used to solve the zero problem, and the results were shown in Figure 9 when no noise was added:

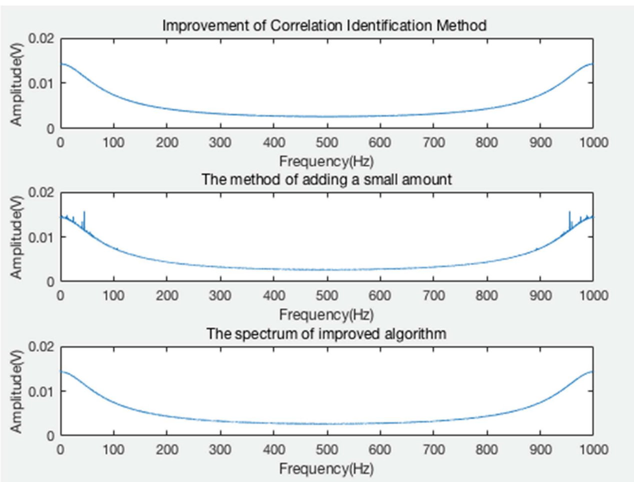

Figure 9. Comparison of spectrum.

When 1V random noise was added, the results were shown in Figure 10:

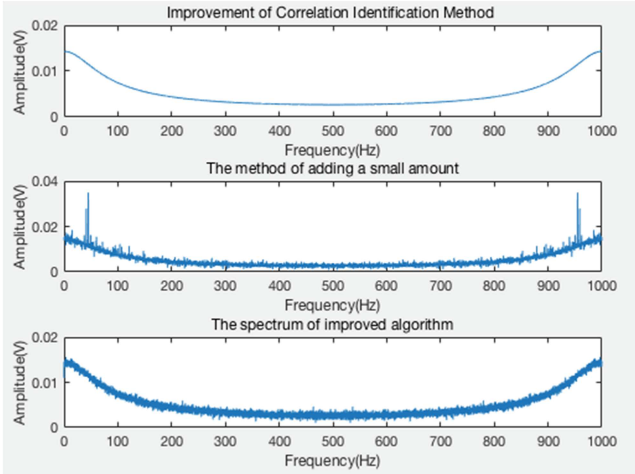

Figure 10. Comparison of spectrum (add 1 V random noise).

From Figure 9 and Figure 10, comparing the two results between Improvement of correlation identification method and the method of adding a small amount, it could be seen that the effect of Improvement of correlation identification method was better than that of the other. Since the spectrum of the non-negative periodic autocorrelation function didn't exist zero point, zero problem was solved. What's more, the method of adding a small amount reduced the effects of zero problem by changing the amplitude of the auto spectrum of m-sequence, it would affect the accuracy of identification to some extent. On the contrary, Improvement of correlation identification method did not exist this problem. However, since the cross-correlation function between the noise and the m-sequence was not exactly equal to 0, the result of identification still existed error.

4. Conclusions

This paper presented the principle of correlation identification, analysed the causes of the non-ideal identification results, and two improved methods were used to solve this problem.

In the method of adding a small amount, α played a great role in the result of correlation identification, and the identification result was not accurate due to the existence of α. In contrast, Improvement of correlation identification method could not only solve the zero problem but also ensure the accuracy of identification. Comparison of the two methods, Improvement of correlation identification method had better identification result. Obviously we could acknowledge that the latter was better than the former.

Owing to the discusses are only in the frequency domain, the identification effect in the time domain deserves further study.

Acknowledgements

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