Machine Fault Detection under the Background of Strong Interference Based on Line Learning Music Algorithm

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Abstract. First, this article introduces the importance of fault diagnosis in social production, and analyzes many existing machine fault detection methods. Considering the use conditions of the algorithm, these methods may be complicated and may not be suitable for online applications. Especially for the background of strong interference, this phenomenon occurs in the early stage of machine failure, and the traditional weak signal detection method loses its function. The characteristics of random noise modulation are given, and then an improved online learning evolutionary MUSIC algorithm is designed. First, it constructs a data array based on the sampling sequence, and then analyzes the signal spectrum under the condition that the number of signals is underestimated. Because traditional analysis methods are limited to current data, it is difficult to obtain stable analysis results under strong interference. Finally, some historical analysis data is weighted to obtain the true spectrum. The effectiveness of the algorithm can be seen through simulation. For weak fault signals under strong interference background, this method has better detection performance than FFT algorithm.

1. Introduction
With the development of large-scale industrial production, industrial equipment has become more complex, and the relationship between various components has become closer. Especially in the case of machine failure, it will have a huge impact on the production of enterprises, and even bring huge social harm. The purpose of fault diagnosis is to find out the abnormal phenomena of the components during the operation of the machine, and to further analyze the causes, and to predict the development trend of the fault. Vibration monitoring, noise monitoring, performance trend analysis and non-destructive testing are the main diagnostic methods. In order to diagnose a system failure, it must first be detected. In the event of a system failure, it is necessary to diagnose the type, location and cause of the failure, and finally provide a solution for the realization of failure recovery. In fault diagnosis, noise signal processing is of great significance. How to eliminate noise interference has always been a research hotspot in weak signal detection. However, most research attempts to analyze the statistical characteristics of weak signals and noise based on information theory, electronics and physical methods, and construct filters to extract weak signals. However, when the signal and noise frequency bands overlap, the filtering method based on the idea of noise elimination will be hit by the enemy: First, it is difficult to detect weak signals with a low signal-to-noise ratio. Secondly, detection will inevitably lead to signal damage or loss of information [1-6].

Most fault diagnosis methods are restricted by algorithm application conditions. Under the interference of strong noise, the performance of the fault diagnosis method is reduced, which greatly affects the detection of early faults.
2. Music Algorithm
It is well known, for a signal of noise pollution, all the detection methods of real signal are limited by noise power or SNR. Equation (1) shows the sampling is consist of many harmonics, while the actual signal harmonics are only a small part. If the actual signal does not represent the signal salient feature of the sequence, it cannot be distinguished. All the detection methods are limited by their characteristic. They are different from other methods because they can improve the salient features in the frequency domain.

For data $Y = X + W$, its eigenvalue decomposition of self-correlation matrix can be written as:

$$R_{yy} = U \sum U^H = \begin{bmatrix} U_1 & U_2 \end{bmatrix} \begin{bmatrix} \Sigma_1 & 0 \\ 0 & \Sigma_2 \end{bmatrix} \begin{bmatrix} U_1^H \\ U_2^H \end{bmatrix}$$  \hspace{1cm} (1)

where $R_{yy}$ is self-correlation matrix of $Y$, $U_1$ and $U_2$ are signal eigenvector and noise eigenvector, $\Sigma_1, \Sigma_2$ are diagonal matrix. The power of gauss white noise is $\sigma_w^2$ in equation (1),

$$\Sigma_1 = \Sigma_2 + \sigma_w^2 I_1 \quad \text{and} \quad \Sigma_2 = \sigma_w^2 I_2$$  \hspace{1cm} (2)

Obviously, the signal is modulated by noise. The spectrum can be got by (3):

$$P_{\text{MUSIC}} = \frac{a^H(\theta) a(\theta)}{a^H(\theta) U_2 U_2^H a(\theta)}$$  \hspace{1cm} (3)

The core idea of the MUSIC algorithm is to decompose the covariance matrix of the output data, and then construct the orthogonal spatial spectrum function of the noise subspace, so as to detect the signal frequency by searching for the peak of the spectrum. As a non-parametric estimation method, this algorithm is easy to use and has strong noise suppression capabilities.

3. Improved MUSIC Algorithm

3.1. Influence of Signal Number in Music Algorithm
It can be seen from equations (2) and (3) that the noise suppression of the MUSIC algorithm depends on the orthogonality of the noise feature space and the signal vector. It can be written as

$$a^H(\omega) U_2 = 0^T, \quad \omega = \omega_1, \omega_2, \cdots, \omega_r$$  \hspace{1cm} (4)

When signal number is under-estimation, it is still calculated by (3)

$$a^H(\omega) [U_{1n}, U_2] = 0^T, \quad \omega = \omega_1, \omega_2, \cdots, \omega_r$$  \hspace{1cm} (5)

Obviously in (5), more noise space is applied on the condition of signal number under-estimation, so that the actual signal may not be estimated. Because the method uses more noise information, it takes on stronger noise restrain [6].

3.2. Construct Data Array
In the algorithm, data array $X$ is constructed by signal sampling sequence

$$X = [X_1, X_2, \cdots X_M]^T \quad \text{and} \quad X_M = [x_{M+1}, x_{M+2}, \cdots x_M]$$  \hspace{1cm} (6)

where $X_M$ denotes a sampling sequence including $L$ sampling $x_n$. Different data sequences represent different patterns and are used to modulate useful signals. In the machine operation fault detection, as time passes, data will be continuously acquired for corresponding spectrum analysis.
3.3. Weak Signal Detection Method Based on Line Learning

There are many methods for machine failure detection. The FFT algorithm based on non-parametric estimation is simple and fast, and has always been the first choice of people. However, in a noisy environment, the performance will be greatly reduced. So a new method is designed for solving the problem of fault detection in strong interference environment, which is shown in figure 1.

Step 1: Sample the nth time data sequence; select consecutive m points and construct data arrays;
Step 2: Do MUSIC analysis for the data arrays;
Step 3: Weight and sum;
Step 4: Renew and fault record.

Figure 1. Improved MUSIC algorithm.

In this algorithm, weighting historical data can weaken pseudo spectrum and enhance real spectrum. Spectrum out is given by (7).

\[ P(N)_L = \sum_{J=1-M}^N W_j * P(J)_L \]  \hfill (7)

In equation (7), M is weighting length of adjacent M-times historical analysis. It’s equally important to consider every analysis, \( W_j = 1/M \).

4. Simulation

According to the method proposed in the article, Assuming a fault signal:

\[ x(n) = \exp(0.2 \cdot 2\pi n) + \exp(0.3 \cdot 2\pi n) + \exp(0.5 \cdot 2\pi n) + w(n) \]

When the data window is 200, the direct FFT analysis and the improved MUSIC method are simulated respectively. The results are shown as figures 2-5.

Figure 2. Spectrum analysis by FFT and general MUSIC algorithm.
Figure 3. Spectrum analysis by FFT and general MUSIC algorithm (noise variance \( \sigma^2=20 \), Signal number N=2).
In figure 2, when there is no noise interference, FFT algorithm and MUSIC algorithm can detect the real signal. Figures 3 and 4 show the influence of different signal sources on signal detection, and show the better noise suppression ability of MUSIC algorithm with underestimated signal sources. In figure 5, when there is strong noise interference, FFT algorithm can not observe the real signal, but the improved MUSIC algorithm can clearly observe the real signal spectrum.

Obviously, the signal source underestimated MUSIC algorithm has strong noise suppression ability.

5. Conclusion

Weak signal detection is an important content of early machine operation fault detection, and has important application value to product quality, enterprise development and personnel safety. There are many signal detection methods, including methods based on parameter estimation or non-parametric detection. They have their own superior performance under certain conditions. Taking into account the insufficient prior conditions of the machine fault signal, according to the powerful noise suppression characteristics of the MUSIC algorithm in the case of signal source underestimation, this article synthesizes the noise modulation and fully integrates the historical analysis data, which has a good application effect.

References

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