ROLLING ELEMENT BEARING FAULT DETECTION THROUGH ADAPTIVE FILTERING WAVELET TRANSFORM USING VIBRATION & CURRENT SIGNALS

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Abstract
This paper deal with a new scheme for the adaptive filtering algorithm of wavelet transforms. This algorithm is based on localized defects in ball bearing based on wavelet transform at different scales ,bearings are the major components of rotating machinery prone to failure , hence need to monitor their condition and maintain them ,Although various bearings fault detection methods based on different technologies are present and implemented there is a need an accurate fault detection system, In this present work, to eliminate the limitations and merge the advantages of these two techniques an integrated technique based on weak signals(Vibration and Current signature) . For normal ball bearing, bearings with inner race fault, outer race fault and rolling ball fault are acquired from a motor-driven experimental system, The wavelet transform was used to process the accelerometer signals and to generate feature vectors, The weak signal with noise is decomposed by wavelet multi-filtering, the filter filtered out the noise in order to detect the weak signal. The traditional adaptive filter, and adaptive filtering algorithm of wavelet transform were compared and simulated using the MATLAB software, The results show that: adaptive filtering algorithm of wavelet transform for weak signal detection method can more effectively defect weak signal from containing the noise signal than the traditional adaptive filtering algorithm

Keywords: Weak signal detection, Wavelet decomposition, Adaptive filtering

1. INTRODUCTION

At present, no matter in the practical engineering or theory study, week signal detection is an important research topic from the noise signal. When the weak signal is interfered by wide bandwidth noise, setting the parameter of the traditional adaptive filtering algorithm is difficult. Wavelet analysis has a good ability to distinguish time-frequency signal processing to become a powerful tool [1]. In the field of signal processing, Using wavelet transform in signal de-noising has gained more and more extensive application [2]. Rolling element bearing defects are classified as firstly on the basis of fault location and secondly on the basis of their fault type, It may be single point defect or it may be multi point defect as in [3]. Numbers of researchers are interested in finding the location of fault.

The main purpose of installing the rolling element bearing in machinery is to hold or support an element and transmit the moment of the load to the another element. When a machine rotates by drive, the Shaft bearing response to the vibrations of the drive is main cause of vibration. All drives have nature to vibrate (*Vibrations cannot be eliminate*) and itself is not a fault. However excess of vibration can be a symptom of a developing fault and an early warning of machine failure. Many methods for rolling element bearing fault diagnosis are presented in the literature on the basis of their different fault characteristics listed in [4]. When the signal is analyzed as a function of time then analysis is called time domain analysis. Time domain analysis has been performed to monitor the bearing health condition in [5]. This technique has been further subdivided as time waveform analysis and time indices as in [6]. How to set up, acquire and manipulate time waveform data is detailed in [7] proposes a method of the nonlinear wavelet threshold de-noising. So the paper combines the method of the wavelet transform and the adaptive filtering, proposing the adaptive filtering algorithm of wavelet transform. Mallet algorithm was adopted, which can decompose the input orthogonal vector in multi-scale space, and reduce spectrum dynamic range of input vector autocorrelation array of the adaptive filter in order to improve the LMS convergence speed and stability. Through analyzing the weak signals detection in the practical engineering, the results show that the method based on adaptive filtering algorithm of wavelet transform is better than the traditional adaptive filtering.

2. ADAPTIVE FILTERING ALGORITHM OF WAVELET TRANSFORM

2.1 Multi-resolution analysis of wavelet transformation

Wavelet analysis has the characteristics of multi-resolution analysis, which has a wide range of application. The basic concept of wavelet are as follows: if $\Psi(t)\epsilon L^2(R)$, and Fourier transform $\Psi(\omega)$ meets the allowable condition, so $\Psi(\varphi)$ is called a basis wavelet or mother wavelet. The wavelet transform of $f(t)$ is defined as:

$$W_\varphi f(t)(a,b) = \langle f(t), \varphi_{a,b} \rangle = |a|^{\frac{1}{2}} \int_R f(t) \left(\frac{t-b}{a} \right) dt \qquad (1)$$

Where, ***a*** is scale factor, ***b*** is translation factor.

The concept of multi-resolution analysis was proposed by Mallet, when he structured orthogonal wavelet basis [7], which illustrated the multi-resolution properties of wavelet from the concept of space, and unified the method of orthogonal wavelet basis, and put forward fast algorithm of the orthogonal wavelet transform that is Mallat tower-type algorithm [8].

Multi-resolution analysis is that signal C_o was stepwise decomposed in two orthogonal space of the $L^2(R)$, and per step input was decomposed for high-frequency details signal and low-frequency approximate signal, and the sampling frequency of output was halved. The formula of this algorithm is:

$$c_{j+1,k} = \sum_k g(m-2k) C_{j,m} \qquad (2)$$

$$\mathrm{d}_{j+1,k} = \sum_k h(m-2k) C_{j,m} \qquad (3)$$

Where, $c_{j+1,k}$ is approximate output when the signal is in the j+1 step, and $d_{j+1,k}$ is output when the signal is in the ***j+1*** step. Two-scale sequence $\{g(k)\}$ is regarded as the coefficients of the low-pass filter, and $\{h(k)\}$ is the coefficients of the high-pass filter, the whole process gets a group of multi-rate filter signal reconstruction formula of Mallat is:

$$C_{j+1,k} = \sum_k c_{j,k}.g(m-2k) + \sum_k d_{j,k} h(m-2k) \qquad (4)$$

Through continuous compute the formula (3), we can obtain the original signal C_o

2.2 LMS Adaptive Filtering Algorithm

In this paper, using transversal structure of the LMS adaptive filter, LMS adaptive transversal filter is composed of two basic components: (1) it has transversal filter of the adjustable weights, when time is n, this set of weights was shown with, $\omega_1, \omega_2, \ldots\ldots \omega_M(n)$; (2) it adopt the weight adjustment mechanism of the LMS adaptive algorithm LMS adaptive transversal filter is closed system, its weight vector with the input data and output signals are related.

In $x(n)$ is weak signal when time is n, the input vector is:

$$X(n) = \left[x(n).x(n-1)..........x(n-\overline{M+1}) \right]^T \qquad (5)$$

Filter parameter vector is:

$$W(n) = \left[w_1(n).w_2(n)..........w_M(n) \right]^T \qquad (6)$$

Filter output is:

$$Y(n) = \sum_{i=1}^{m} w_1(n) x(n-i+1) = W^T(n) X(n) = X^T(n) W(n) \qquad (7)$$

Error ***e(n)*** which is ***y(n)*** relative to the desired output ***d(n)*** of the filter was shown as:

$$e(n) = d(n) - y(n) = d(n) - W^T(n) X(n) \qquad (8)$$

Using least mean square (LMS) algorithm, finding the optimal filter weights, and to improve detection signal. Output mean square error of filter is:

$$E[e^2(n)] = E[d^2(n)] - 2P^T W + W^T R_x W \quad (9)$$

In this paper, the minimum mean square error (LMS) algorithm was adopted; the iteration formula is as follows:

$$W(n+1) = W(n) - 2\mu e(n)X(n) \quad (10)$$

Where, $W(n+1)$ is the adaptive filter weight vector at $n+1$ time, μ is physical quantity which describes speed of the iterations,

2.3 Adaptive Filtering Algorithm of wavelet transform

When a weak signal with noise has wide frequency, the traditional adaptive filtering algorithm has some shortcomings which are not easy to obtain the optimal step size and the effect of filtering is unsatisfactory, combined with the advantages of wavelet decomposition, designing an adaptive filtering algorithm of wavelet decomposition, the block diagram of algorithm is shown in figure 2.

For a weak signal collected with noise, firstly, setting the parameters of wavelet decomposition (wavelet function, decomposition layers), the signal is conducted in multi-scale wavelet decomposition, and the signal of different frequency band can be got, including low frequency signal $C_{n,k}$ and high frequency signal $d_{1k}, d_{2k}, ...d_{nk}$. Through adjusting the parameters of every filter, the decomposed signal is conducted in adaptive filtering in order to reach the optimal effect of filtering. And when all the signal in the frequency bands meet the filtering requirements, the adaptive filtering comes to the end .the signal filtered is conducted wavelet synthesis, and finally the

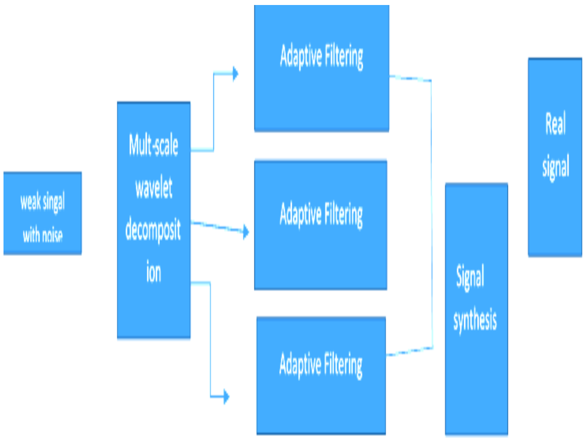

Fig. 1 Adaptive filtering algorithm diagram of wavelet decomposition

3. Adaptive filtering algorithm of wavelet transform in the application of week signal detection

In the practical engineering, echo signal is weak it's extremely easily affected by various noise. The traditional adaptive filtering algorithm fails to set parameters easily, and it is not conducive to extract weak signal, which is extremely unfavorable in engineering practice. In this case adaptive filtering algorithm of wavelet transform is applied in the engineering practice.

Although the weak signal is susceptible to noise interference, the spectrum distribution of signal and noise are obvious difference. The frequency of weak signal is low, and the main effect of noise is in the high frequency band, so using this difference in frequency distribution to separate them by wavelet transform. Through using the wavelet multi-scale decomposition, weak signal is decomposed into the detail components and the approximation components in different scales and then using the adaptive filtering algorithm to filter for signal on the each scale , at the last , the signal , which is filtered on each scale , is needed to be synthesized , then we can get the useful signal . This method will not lose useful information about weak signal, which can accurately and essiciently extract weak signal from the noisy signal.

4. Simulation and analyze

In the simulation, we use original signal which is $s=x_s+x_n=3*sin(0.5*t)+x_n$, where x_n, is interference noise. Vibration signal and current signal are separately shown in the figure 2 and figure 3. We can see weak signal was seriously interfered by white noise, which can produce serious impact on the practical engineering.

Using the traditional adaptive filtering algorithm and the adaptive filtering algorithm of wavelet transform to detect weak signal , the result to detect weak signal , the result are shown in the figure 4 and the figure 5 analyzing the result show that when using the traditional adaptive filtering algorithm for weak signal detection, the wave is rough and many noises fail to be filtered , but using adaptive filtering algorithm of wavelet transform for weak signal detection the wave is very good .

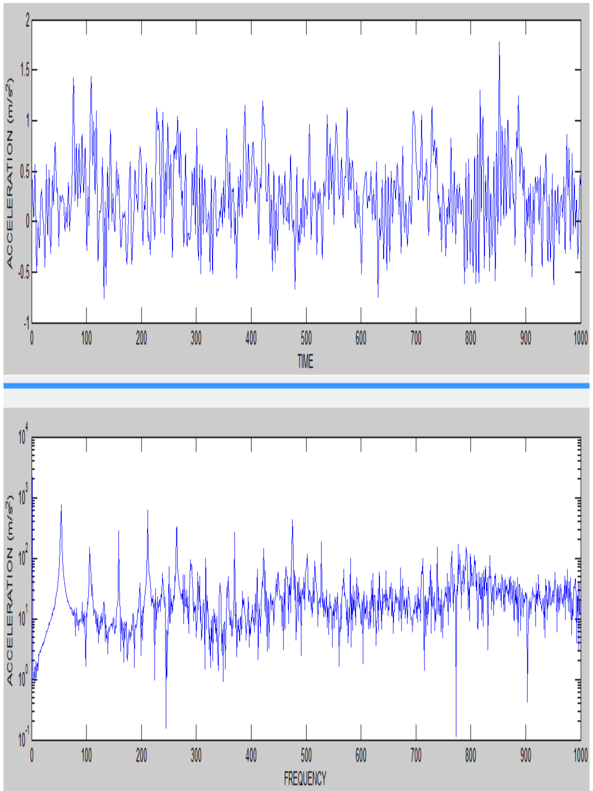

Fig.2 vibration signal with noise

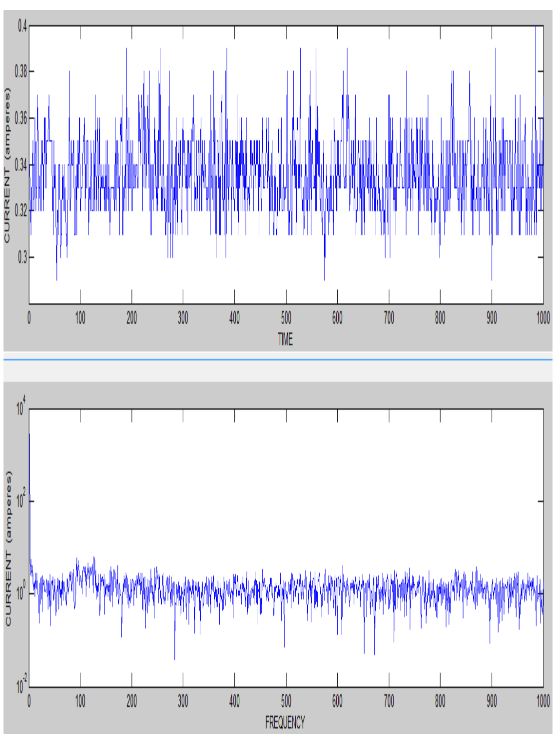

Fig.3 Current signal with noise

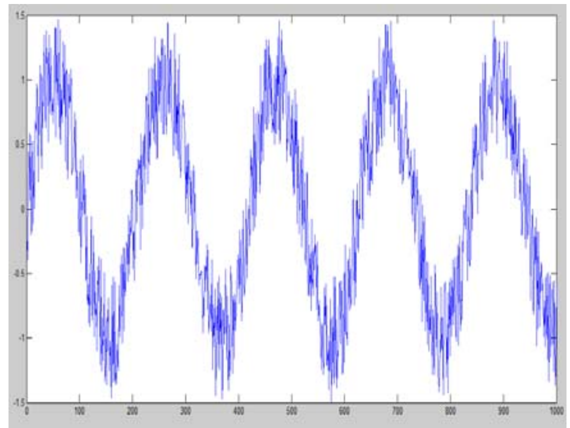

Fig.4 Traditional adaptive filter algorithm

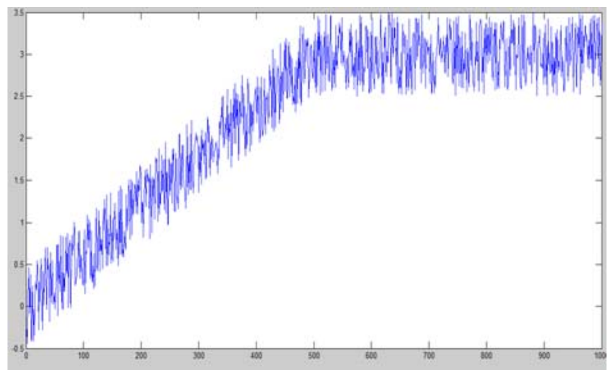

Fig 5 Adaptive filtering algorithm

5. Conclusion

The paper aims at the shortage of the traditional adaptive filtering algorithm and proposes adaptive filtering algorithm of wavelet transform, using this method to detect weak signal (vibration signal and current signal). The traditional adaptive algorithm and adaptive filtering algorithm of wavelet transform were compared and simulated by using the MATLAB software, the result show that the effect is better based on adaptive filtering algorithm in filtering noise and adaptive filtering algorithm of wavelet transform can greatly improve the weak signal to noise ratio, we can obtain , we can obtain a more good convergence speed and stability , so the performance of the traditional adaptive LMS algorithm was improved . The algorithm for weak signal detection provides a good way

6. REFERENCES

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