Application of Wavelet De-noising in Vibration Torque Measurement

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Abstract

For vibration torque is the key to the rotation system state inspection and fault analysis, a vibration torque test is implemented for no slot rotor three-phase asynchronous when under no load condition. While the vibration torque signal is annihilated by lots of noise, a de-noising scheme based on wavelet transform is constructed. The actual signal is decomposed with wavelet Sym8, then processed by half soft threshold, and reconstructed signal finally. Simulation results indicated that the method can get rid of most of the high frequency noise, recover the factuality and improve the fitting and generalization capability of the data, and de-noising effect is far better than the traditional fast flourier transformation.

Keywords: *Grating, Angular Acceleration, FPGA, Speed-feed*

1. Introduction

Getting "correct and true" signal plays an important role to the realization of automatic control system, but because of different kinds of errors, including measurement error、calculation error、instrument precision and even the human element, the measurement data exist noise unavoidably. The noise can lead to the resolution and accuracy of measurement system decrease, and even causes the true signal obliterated, therefore, eliminate the noise in measurement data become an important technology in data processing and application. Signals are usually divided into the unstable signal and stable signal, the ideal tool to deal with the stable signal is still Fourier analysis, but the majority actual signal in application is unstable, and the suitable tool is wavelet analysis.

In recent years, some experts applied wavelet transform in de-noising and obtained a series of achievements. The spectral reflectance of soil was measured by a ASD, then its first derivative of spectra were acquired and de-noised by the threshold de-noising method based on wavelet transform [1]. The vibration signals of vibratory roller are processed by wavelet de-noising, the result keep the smoothness and similarity of excitation signal [2]. Zhou Zuo-feng[3] proposes a blind image restoration algorithm iteratively using wavelet de-noising and total variation regularization, the experimental results show that the proposed algorithm achieves better performance than the existing algorithms. Yang Zui-zhong[4] proposes a method that combines multiple wavelet transform with a new threshold function, the method can remove most random noise, extract true signal and improve the confidence level of the data. A multi-scale image enhancement algorithm combining wavelet de-noising is proposed by Xu Ying[5], and experimental results demonstrate that the proposed algorithm can remove noises efficiently. A new de-noising algorithm based on customized threshold function is proposed by Li Jia-sheng, the proposed de-noising algorithm has two thresholds, the lower threshold and the upper threshold [6]. Wavelet threshold are used to de-noise the signals by Xie Qi, the result indicates that the method of threshold has practical value in improving the precision and creditability of the instrument [7]. An integrated fault detection method based on wavelet de-noising and feature vector selection-KPCA (FVS-KPCA)was developed[8], the results show that the proposed method vail effectively improve the speed of fault detection.

A vibration torque test for no slot rotor three-phase asynchronous is implemented when no load in this paper. In order to decrease the noise in vibration torque signal, a de-noising scheme based on wavelet transform is constructed. Simulation results indicated that the method can get rid of most of the high frequency noise, recover the factuality and improve the fitting and generalization capability of the data, and de-noising effect is far better than the traditional fast flourier transformation.

2. Wavelet and Wavelet Transform

Set $\psi(t) \in L(R) \cap L^2(R)$, it means that $\psi(t)$ is absolutely integrable and square integrable, its flourier transform is $\hat{\psi}(\omega)$, if $\hat{\psi}(\omega)$ satisfied the allowable condition:

$$\int_{-\infty}^{\infty} \frac{|\hat{\psi}(\omega)|^2}{\omega} d\omega < \infty \quad (1)$$

The $\psi(t)$ is called a base wavelet or mother wavelet, when this mother wavelet is stretched and translated, we can get wavelet sequence:

$$\psi_{a,b}(t) = \frac{1}{\sqrt{a}} \psi\left(\frac{t-b}{a}\right) \quad (2)$$

The continuous wavelet transform of signal $f(t)$ is defined as:

$$W_f(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} f(t) \overline{\psi\left(\frac{t-b}{a}\right)} dt \quad (3)$$

In this formula: a is scale factor(corresponding to the frequency information); b is translation factor(corresponding to the time and space information); $\psi(t)$ is wavelet function(base wavelet or mother wavelet); $\overline{\psi(t)}$ is the complex conjugate of $\psi(t)$.

In practical applications, the continuous wavelet transform need to be discreted, the discrete is to scale factor a and translation factor b, not to time variable t, if order $a = 2^k$, $b = n2^k$, we can obtain discrete wavelet transform:

$$W_{2^k} f(n) = 2^{-k/2} \int_{-\infty}^{\infty} f(t) \overline{\psi(2^{-k} - n)} dt \quad k, n \in Z \quad (4)$$

To ensure the precision of reconstructing signal, the wavelet function should meet the framework conditions:

$$A\|f\|^2 \le \sum_{k=-\infty}^{\infty} \sum_{n=-\infty}^{\infty} \langle f, \psi_{k,n} \rangle \le B\|f\|^2 \quad (5)$$

In this formula, $0 < A \le B < \infty$, A and B are the bounds of the frame.

3. Wavelet De-noising

The signal de-noising based on wavelet is a function approximation problem, it means looking for the optimal approximation to the real signal in the space which expanded by wavelet function telescopic and translation according to a certain standard.

The principle of de-noising. The mathematical model of one-dimensional signal with noise can be expressed as:

$$f(t) = s(t) + \sigma e(t), \quad t = 0,1\cdots,n\text{-}1 \quad (6)$$

in this formula, $f(t)$ is the signal with noise; $s(t)$ is the real signal; $e(t)$ is the noise; σ is the coefficient level of noise.

Because of signal and noise on different scales of wavelet transform will presents different characteristics, so the process of eliminating noise is: Decomposition the signal with noise by wavelet transform firstly, because the noise usually be contained in high frequency details, so, we can process wavelet coefficients which corresponding noise in the form of the threshold or threshold, then reconstruct the signal and achieve the purpose of signal de-noising.

Steps of threshold de-noising. The steps of threshold de-noising are:

(1). Signal decomposition with noise: Choose a certain wavelet base function and wavelet decomposition level N, then decomposite the signal $f(t)$ by wavelet with N layers.

(2). Quantify the threshold value of high frequency coefficients: Choose a quantification criteria of threshold, then implementing quantified threshold process to high frequency coefficients of each layer.

(3). Reconstruct the signal: ICWT according to the high frequency coefficients of 1 to N layers and the low frequency coefficients of N layer, the coefficients are all quantitative threshold.

The determination of wavelet base and

decomposition of layer. The basic characteristics of wavelet base including symmetry, orthogonality, vanishing moment and compact support, we should compromise these characteristics when choosing wavelet base. It can be proved that the wavelet with approximate symmetry is optimal for de-noising [9]. According to the balance, choose the sym8 wavelet as basis function, its supports length of $2N-1$, the order of vanishing moment is N, the sym8 with approximate symmetry and has the highest vanishing moment for the given support width. For sym8 wavelet basis, the decomposition layers is 5 according to the formula (7)in reference[10].

The determination and quantification of threshold. To ensure the authenticity and the smoothness of signal, select the adaptive threshold which based on the principle of *Stein* unbiased likelihood estimate as the methods to deal with the vibration torque signal with noise. The selected principle of soft threshold value estimation which based on the *Stein* unbiased likelihood estimation (SURE) is getting its likelihood estimate for a given threshold t firstly, and then minimize the likelihood function, last receive the required threshold.

The methods of threshold function to signal are two kinds usually, hard threshold value method and soft threshold value method. Hard threshold processing can keep more local edge features of real signals, soft threshold processing can produce more smooth results because it decomposites for wavelet coefficient. In order to combine the advantages of each other, we use the improved half soft threshold function [2]:

$$\eta(\omega)=\begin{cases}\omega+T-\dfrac{T}{2k-1},(\omega<-T)\\ \dfrac{1}{(2k+1)T^{2k}},(-T<\omega<T)\\ \omega-T+\dfrac{T}{2k-1},(\omega>T)\end{cases} \tag{7}$$

4. De-noising Experiment

The actual sampling vibration torque signal is shown in figure 1, the sampling frequency is 10 K, sample data point is 1000.

Decompositing the actual signal with noise 5 layers based on sym8 wavelet, the approximation signals and detail signal of each layer are shown in figure 2 and 3 respectively.

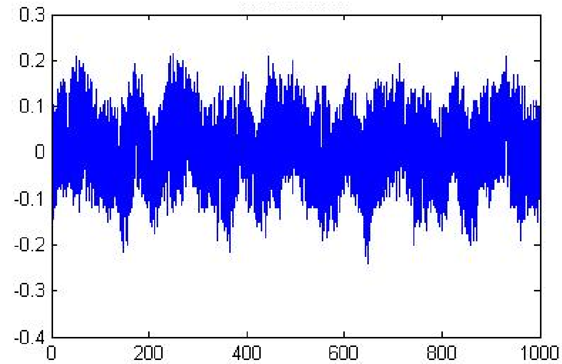

Fig.1 Actual sampling signal

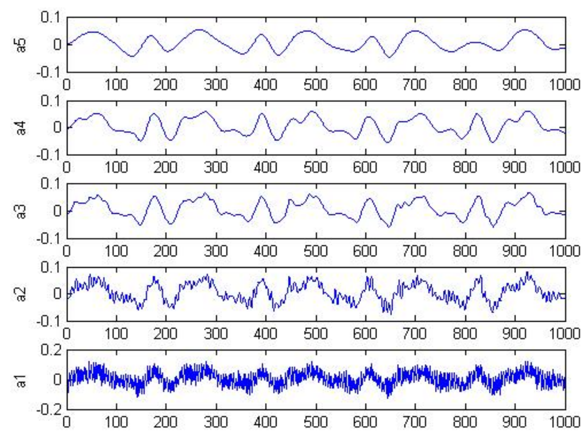

Fig.2 Approximation signals of each layer

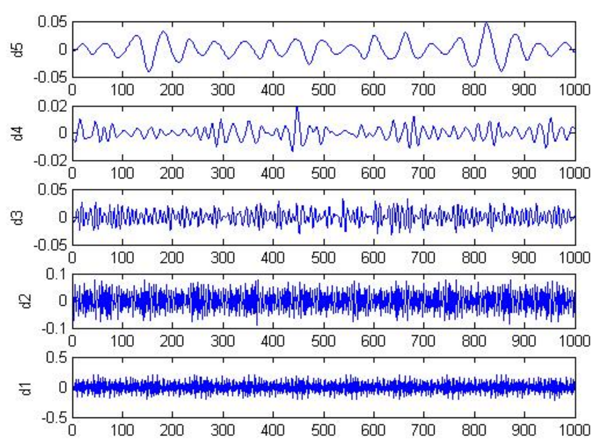

Fig.3 Detail signals of each layer

It is known that the detail signal d1 and d2 is related with noise, and the detail signal d3 (especially the d4) is associated with sine signal is presented in figure 3.

Quantify the high frequency coefficients of the each layer with half soft threshold, de-noising with soft threshold value estimation which based on the *Stein* unbiased likelihood estimation (SURE), the reconstruction signal is shown in figure 4. And we know that this de-noising method can remove the most noise in vibration torque signal. In order to validate the superiority of wavelet de-noising, dealing with the actual vibration torque signal with noise by FFT, the results is as shown in figure 5.

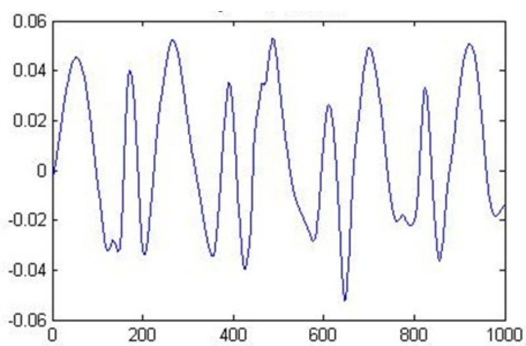

Fig.4 De-noising signals by wavelet

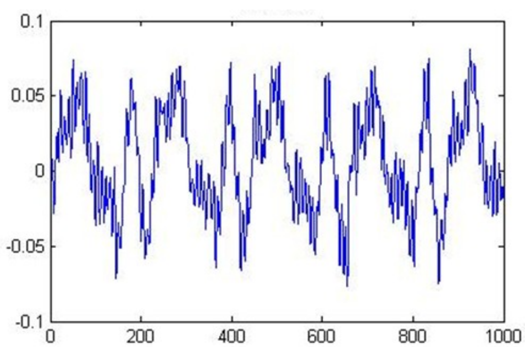

Fig.5 De-noising signals by FFT

5. Conclusion

A de-noising method based on wavelet transform is constructed in this paper, according to the de-noising experiment to the vibration torque signal,. This method can keep the smooth and the similarity of signal better while compared with traditional fast flourier transform. And the results indicated that the method can get rid of most of the high frequency noise, recover the factuality and improve the fitting and generalization capability of the real signal. This paper proposes a high precision speed feedback type angular acceleration measurement system based on FPGA and SCM, the measuring principle and method of system are introduced in details. According to the experiments results, the system could overcome the error when system speeds up. The measurement system has short responding time and high precision, we expect it will be used widely.

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