Research on de-noising operation to the vibration signals based on discrete wavelet transform with hard threshold

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Abstract. Dynamical properties of mechanical systems can be obtained with the vibration signals from the systems. However, for the influence of noises, it is difficult to accurately acquire the features. Therefore, de-noising operation is significant for vibration signal in the practical engineering. In order to resolve this problem, discrete wavelet transform (DWT) with hard threshold is used to remove noises from vibration signal. We provide the principle of DWT at first. And then, a sample signal is constructed with white noise is processed by the technique. As the result shown, the random noise can be effectively eliminated. This reflects that the de-noising method based on DWT the hard threshold is effective.

Keywords: vibration de-noising; wavelet transform; random noise; hard threshold.

1. Introduction
Vibration signals are important data for the analysis to the dynamic features of the mechanical systems. But, the signal will be polluted by random noises in the collection process, which can result in reducing the analysis precision and accuracy. At present, de-noising processing is a key point of signal processing, and the scholars, at home and abroad, were working in this, such as singular value decomposition [1], Fourier transform [2] and Winer filtering and other de-noising methods [3]. The properties of signals were not taken into consideration in these methods; therefore, the universality is not good. The wavelet transforms (WT) are widely applied in many engineering fields for solving various real-life problems [4]-[6]. The Fourier transform of a signal contains the frequency content of the signal over the analysis window and, as such, lacks any time domain localization information. Noise has strong local characteristics, and WT can meet this. In this paper, the theory of the algorithm is illustrated and the de-noising effect was demonstrated.

2. The principle of DWT
WT provides a more flexible way of time-frequency representation of a signal by allowing the use of variable sized windows. In WT, long time windows are used to get a finer low frequency resolution and short time windows are used to get high frequency information. Thus, WT gives precise frequency information at low frequencies and precise time information at high frequencies. This makes the WT suitable for the analysis of irregular data patterns, such as impulses occurring at various time instances.
The continuous wavelet transform (CWT) of a signal, \( x(t) \), is the integral of the signal multiplied by scaled and shifted versions of a wavelet function \( \psi \) and is defined by,

\[
\text{CWT}(a,b) = \int_{-\infty}^{\infty} x(t) \frac{1}{\sqrt{|a|}} \psi\left(\frac{t-b}{a}\right)dt
\]

(1)

Where \( a \) and \( b \) are so called the scaling (reciprocal of frequency) and time localization or shifting parameters, respectively. Calculating wavelet coefficients at every possible scale is computationally a very expensive task. Instead, if the scales and shifts are selected based on powers of two, so-called dyadic scales and positions, then the wavelet analysis will be much more efficient. Such analysis is obtained from the DWT which is defined as,

\[
\text{DWT}(j,k) = \frac{1}{\sqrt{2^j}} \int_{-\infty}^{\infty} x(t)\psi\left(\frac{t-2^j k}{2^j}\right)dt
\]

(2)

Where \( a \) and \( b \) are replaced by \( 2^j \) and \( k \cdot 2^j \), respectively.

3. The simulate signal
In order to verify the effectiveness of the method, the simulate signal is made, and the formula is as followed

\[
x = \sin(5 \cdot 2\pi t) + \sin(10 \cdot 2\pi t) + 5\sin(20 \cdot 2\pi t)
\]

(3)

The white noise that is 30% of the standard deviation of the processed signal is added to the signal. There sampling time is 1s, and the sample period is 0.001s. The time series figure of the signal is shown in fig.1.

![Figure 1. The time series figure of x signal with white noises](image)

4. DWT decomposition
The DWT is used to the sample signal, and the decomposition layer is 4. The approximation coefficients and the detail coefficients in different layers are shown in figs. 2 and 3, respectively. As shown in fig. 2, the white noise is removed more and more with the increase in the number of decomposition layers. And the energy of the white noise also decreased.
5. The contrast between the processed signal and the original signal
We set the detail coefficients to zero. And then, the de-noising signal is reconstructed by the inverse transform, and is shown in fig. 4. Comparing fig. 1 and fig. 4, it can be known that the signal become smooth, after de-noising operation.
6. Summary
In order to eliminate noise from the vibration signal, the DWT is introduced in this paper. At first, the principle of the algorithm is illustrated, and the specific decomposition process is elaborated. The method is applied to a simulate signal, which contain harmonic components and white noise. It can be concluded that the result shows that the noise can be effectively eliminated by using this method.

References
[1] Edfors O, Sandell M, Jan-Jaap V D B, et al. OFDM channel estimation by singular value decomposition. IEEE Trans on Commun, 1998, 46(1): 931--939.
[2] Weinstein S B, Ebert P M. Data Transmission by Frequency Division Multiplexing Using the Discrete Fourier Transform. IEEE Trans.commun.techn, 1971, 19(5): 628-634.
[3] Liu T, Zhang W, Yan S. A novel image enhancement algorithm based on stationary wavelet transform for infrared thermography to the de-bonding defect in solid rocket motors. Mechanical Systems & Signal Processing, 2015, s 62–63: 366-380.
[4] Farge M. Wavelet transform and their application to turbulence. Annu.rev.fluid Mech, 1992, 56(4): 68-68.
[5] Liu T, Li J, Cai X, et al. A time-frequency analysis algorithm for ultrasonic waves generating from a debonding defect by using empirical wavelet transform. Applied Acoustics, 2018, 131: 16-27.
[6] Boles W W, Boashash B. A human identification technique using images of the iris and wavelet transform. Signal Processing IEEE Transactions on, 1998, 46(4): 1185-1188.