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Enhancement of Signal Denoising and Fault Detection in Rolling Bearing using Stationary Wavelet Transform

M.Tech. Scholar Virendra Singh Rajput, Assistant Professor Seema Shukla
Department of Electronics & Communication Engineering,
Millennium Institute of Technology & Science,
Bhopal, M.P., India
vsr1397@gmail.com, seematiwari.a@gmail.com

Abstract

Vibration signal plays very important role in fault diagnosis of machine because it carries dynamic information of the machine. Signal processing is essentially needed to process and analyse signal but it is difficult to process and analyze the noisy signal. In many cases the noise signal is even stronger than the actual vibration signal, so it is important to have some mechanism in which noise elimination can be effectively done without affecting the actual vibration signal. In order to enhance the desired features related to some special type of machine fault, a technique based on the Stationary wavelet transform (SWT) is proposed in this paper. It is demonstrated that SWT enjoys better shift invariance and reduced pectoral aliasing than Discrete Wavelet Transform (DWT) and empirical mode Decomposition (EMD) and Ensemble empirical mode Decomposition (EEMD) by means of numerical simulations. This paper presents two robust techniques for denoising of vibration signals corrupted by Additive White Gaussian Noise.

Keywords: SWT, DWT, DTCWT, Thresholding, Minimaxi.

I. INTRODUCTION

Vibration analysis has been used in rotating machines fault diagnosis for decades . It is claimed that vibration monitoring is the most reliable method of assessing the overall health of rotor system. Each fault in a rotating machine produce vibrations with distinctive characteristics that can be measured and compared with reference ones in order to perform the fault detection and diagnosis. Traditional techniques like Fast Fourier Transform (FFT) used for analysis of the vibration signal is not appropriate to analyze signals that have a transitory characteristic. Moreover, the analysis is greatly dependent on the machine load and correct identification of very closed fault frequency components requires a very high resolution data . Wavelet a very powerful signal-processing tool can be used to analyze transients Signal and thus eliminating load dependency. Variable window size allows the possibility to extract both low frequency as well as high frequency information as per requirement. During recent years many different ideas have been proposed for fault detection and denoising in which vibration signals are corrupted due to additive white gaussian noise. A brief literature about such methods is furnished here.

Arun et Al [1] proposed an ensemble empirical mode decomposition (EEMD) based denoising method and discrete wavelet transform and Fourier transform for fault diagnosis of rolling bearing. The denosing result were compared on the basis of RMSE of both Raw-EEMD vibration or TSA-EEMD vibration signal. Wang et al. [2] suggested the Dual Tree Complex Wavelet Transform (DTCWT), a shift invariant wavelet transform for multiple fault detection. Mortazavi et al. [3] compared the noise performance of various denoising techniques like DWT , WPT, SWT, DT-CWT for partial discharge signals. Naveed et al. [4] proposed a signal denoising framework algorithm which employs goodness of fit (GOF) test on complex wavelet coefficients obtained via dual tree complex wavelet transform (DT-CWT). The GOF test is used to identify the noisy DT-CWT coefficients whereby statistics based on empirical distribution function (EDF), namely Anderson Darling (AD) statistics, is employed to quantify the distance between the EDFs of local wavelet coefficients and reference white Gaussian noise (WGN) distribution.

Abdelkader et al. [5] proposed method is based on a Complete Ensemble Empirical Mode Decomposition with an Adaptive Noise (CEEMDAN) associated with an optimized thresholding operation. Wang et al. [6] presented the diagnosis of gear fault by power spectrum of vibration signal in time-frequency domain and signal were denoised by EEMD method. Liu et al. [7] used DT-CWT technique for signal denoisng and its extraction for weak gear fault diagnosis. Chaari et al. [8] employed the Short Time Fourier Transform and then Smoothed Wigner–Ville distribution for gear fault diagnosis. Chen et al. [9] proposed a novel method for identification of gear crack from the low-frequency modulated vibration signal. Hilbert transform were used to present the envelope of the modulated vibration signal to show the modulating frequency.

Dybala et al. [10] diagnosed the rolling bearing fault at early stage and employed Empirical Signal Decomposition Methods as a tool. Garde et al. [11] presented two robust techniques for denoising of vibration signals corrupted by additive white Gaussian noise. The method uses the Stationary Wavelet Transform (SWT) and the Dual Tree Complex Wavelet Transform (DTCWT). Yadav et al. [12] proposed a method based on intra-scale and inter-scale dependency of coefficients of stationary wavelet transform for vibration signal denoising. The parent and children coefficients of the non-noisy signals show larger correlation while these are less correlated in case of noisy signals

II. PROPOSED WORK

In our propsed work we used the stationary wavelet transform (SWT) for signal decomposition and reconstruction. Due to its shift invariance property SWT is more efficient than convantinal DWT. This gives results in separate approximation and detailed coefficients at each level of wavelet decomposition. The signal coefficients have correlation with their neighbours while the wavelet coefficients corresponding to noise are uncorrelated [11]. Using this concept, in this proposed work, denoising is done by first averaging the noisy wavelet coefficients inside a window at each level of decomposition and then thresolding is done by using the minimaxi scheme.

The threshold value is evaluate using minima technique for averaged detailed coefficients and is level adaptive which means at each level different threshold is selected. These averaged complete coefficients are compared with the threshold estimated and wavelet coefficients are replaced by the thresholded value. This procedure will be repeated for every subband. As shown in Fig. 1, for a window of size 3, the coefficient Wi will be threshold if (Wi-1+Wi+Wi+1)/3 is greater than the selected threshold.

W_{i-1}	W_i	W_{i+1}	- - -	W_n

Figure 1: Noisy wavelet coefficients in a sub band.

III. VIBRATION SIGNAL DENOISING OF REAL TIME FAULTY SIGNAL

A standard set of data is collected from the test setup prepared by bearing data centre of Case Wastern Reserve University[13], it is consisting of a 2 hp motor (left) running at the speed of 1797 rpm. The motor shaft is supported by test bearings. An accelerometer is attached to the housing with magnetic bases of the machine to collect the vibration signal from it. The test bench setup for vibration signal capturing and bearing geometry is depicted in Fig. 2 and Fig. 3 respectivel.

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Figure 2: A test bench set-up [13]

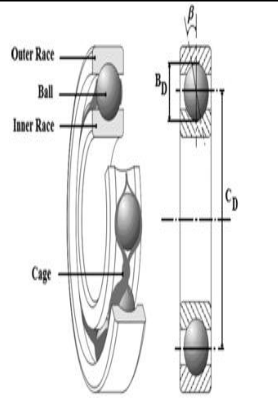

Figure 3: Geometry of a rolling bearing.

Table -1: A bearing geometrical dimensions

Inside diameter	Outside diameter	Thickness	Ball diameter	Pitch diameter
0.9843	2.0472	0.5906	0.3126	1.537

Vibration signals are collected from the accelerometer by using a 16 channel DAT recorder For this noisy signal the noise free signal is often not known hence SNR cannot be calculated. Thus for the comparison of results, statistical parameter known as *kurtosis* is calculated and is given by the equation

$$Kurtosis(x) = E(x-\mu)^4/\sigma^4 \quad (1)$$

here, μ and σ are the mean and the standard deviation of signal x. Kurtosis is the standard fourth population about the mean. It tells the data sets have heavy tails or outliners and light tells or lack of outliner. The higher the kurtosis of a signal the lesser the effected from noise

Table -2: Parameter s of real time faulty signal denoised data of faulty gear box.

S.No	Signal	SNR	Kurtosis	RMSE	Entropy
1	Original signal	-	2.7799	-	3.9395
2	Noisy Signal	-12.0317	5.3994	-	4.6376
3	Denoised Signal	-5.3952	31.5141	4.2694*(10^-4)	4.1998

Hence SNR is Improved by 7.36db and kurtosis is improved. Further the entropy of reconstructed signal is reduces signifies better noise reduction and RMSE is drastically improved. 5000 samples of the practical noisy vibration data from CWRU and the denoised signal using the proposed averaging method with universal thresolding technique and hard thresholding of the detailed wavelet coefficients are plotted in Fig. 4

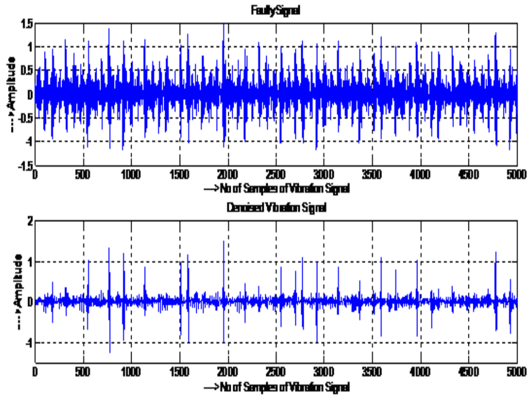

Figure 4: (a) Noisy real time noisy signal (b) Denoised Real time signal.

Table -3: Result Comparison of denoising.

S.NO	DENOING METHOD	THRESOLDING TECHNIQUE USED	Root mean Square Error (RMSE)
1	RAW- EEMD	Donoho (using FFT)	0.1260
		Panellized (using DWT)	0.3775
2	TSA –EEMD	Donoho (using FFT)	0.1178
		Panellized (using DWT)	0.2428
3	*Averaging window-SWT*	*Minimaxi (using SWT)*	*4.294*10^-4*

The Result may be shown Bar chart form for comparison as depicted in fig. 5 which shows that our proposed scheme is very far ago than other existing method.

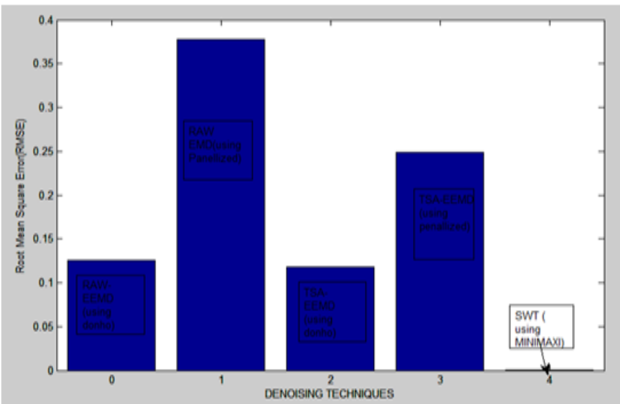

Figure 5: Bar chart of result comparison of denoising.

This shown that very negligible RMSE is observed in our approach of signal denoising as compared to other available techniques for vibration signal.

IV. FAULT ANALYSIS

Fault detection and analysis is a major concern during condition monitoring of a machine . The gear box generates complex and wide vibration spectrum which starts from the frequency that is much lower than the shaft rotational speed and is extended to multiples of gear-mesh frequencies. The product of number of gear teeth and shaft frequency determines the gear-mesh frequency. The real time data of faulty inner race of bearing number 6205 has used for fault analysis at a speed of 1797 rpm. For bearing number 6205, $N = 9, B = 0.312, P = 1.535$. This yields a characteristic fault f requency of inner race (BPFI) f_C equals to 162.1343 Hz.

The vibration signal data of faulty gear box is subjected to heavy noise. Thus it is first denoised using the proposed SWT averaging thresholding technique. From the denoised vibration signal in Fig.6 it is evident that it is not easy to detect the fault. The spectrum of the denoised signal is also shown in Fig 6 which gives an indication of faulty data present in form of impulses other than the characteristic frequency impulses.

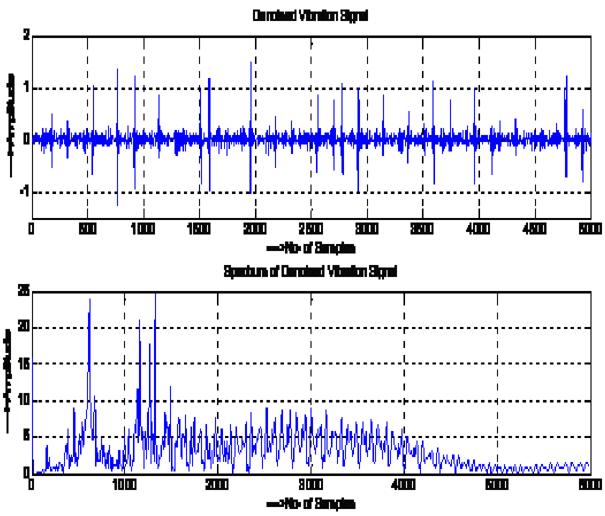

Figure 6: Vibration signal and its spectrum.

To find out the fault, the Approximation coefficient (A5) and its spectrum is plotted in Fig.7 This shows some considerable amplitudes at few frequencies corresponding to fault other than the characteristic frequency.

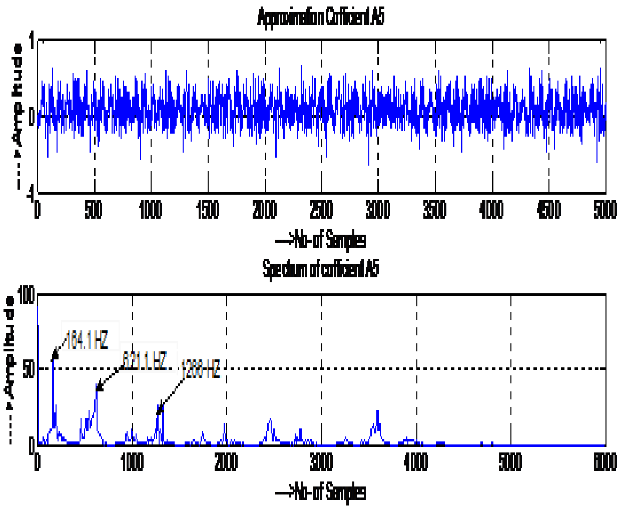

Figure 7: Approximation coefficient (A5) and its spectrum.

Spike at the frequency (164.1Hz) which is the characteristic frequency of inner race can be observed along with the spikes at 621 Hz and 1266 Hz which indicates the fault present in the gear box.

V. CONCLUSION

In the proposed work the correlation property of wavelet coefficients is used in which the wavelet coefficients belonging to noisy signal are not correlated with each other while those corresponding to the signal are correlated. SWT is used as it is shift invariant and hence does not introduce aliasing. It is concluded that the SWT provided the best result when combined with the proposed averaging windowing technique. After denoising, the detection of fault in the machine was done easily.

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