Application of wavelets for analysing ship noise from shallow water ambient noise measurements

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Time series measurements of shallow water ambient noise have been made for a week, off Tuticorin by deploying an autonomous ambient noise measurement system. Preliminary analysis of measurements showed that predominantly the noise field is due to ship crossing other than the wind noise. This paper presents the work carried out in extraction of specific ship noise sources by application of wavelet transforms as wavelet denoising algorithm has finer decomposition and reconstruction properties in the frequency domain. Frequency localization of wavelet denoising technique is used to efficiently localize the ship noise. Methodology involves study of spectrogram of the noise measurements initially and then application of wavelet decomposition (down sampling). Optimal threshold value for the wavelet coefficients is calculated and this yields 2(2n-1) levels to denoise the signal. From the wavelet coefficients, reconstruction (up sampling) of the decomposed signal is performed. Finally the spectrogram of the reconstructed signal is studied. Results show clearly the narrow band frequency components of shipping noise present. This has applications in finding different types of boats/ship noise and the technique is applied to different data sets for finding such sources.

[Key Words: Time series, Fast Fourier Transform, Power Spectral Density, Wavelet, Wavelet packet].

Introduction

Applied scientists and engineers who work with data obtained from the real world know that the signals do not exist without noise. Under ideal conditions, this noise might decrease to such negligible levels that for all practical purposes, denoising is not necessary. Underwater acoustic target recognition is an important component of marine operation and it is also difficult point out in the underwater acoustics field. Feature extraction and classifier design are primary contents of the underwater acoustic target recognition. It is well known that the marine environment is highly non-stationary, in addition the limited performance of receiver. Extraction of the signal as well as the information contained in the particular band without noise produces good results. This could be done by using wavelet packet decomposition technique. In general, wavelet transform is only suitable to identify the information in low-frequency band and unsuitable to identify the information in high-frequency band. Wavelet packet transform is suitable to clearly identify the information in both high and low frequency bands, which is ideal processing tool of non-stationary time-variable signal. In other words, it has good time resolution and poor frequency resolution at high frequencies and good frequency resolution and poor time resolution at the low frequencies.

Materials and Methods

Feature extraction using wavelet packet technique in the raw data

Three-stage wavelet packet decomposition technique for extracting the features from certain frequency bands based on wavelet transform is carried out here. Let S represents the original signal (raw data). After applying the wavelet packet decomposition level 3 of Daubechies wavelet of type 2, the raw data is decomposed, which is shown in the Figure 1. A1 represents the low-frequency component of the original signal S. D1 represents the high frequency component of original signal S. AA2 represents the low-frequency component of A1. DA2 represents the high frequency component of A1. AD2 represents the low-frequency component of D1. DD2 represents the high frequency component of D1, and so on. It can be seen that wavelet packet analysis not only decomposes the low-frequency part, but also decompose the high-frequency part. After
three-stage wavelet packet decomposition, the original signal can be expressed as \( S = AAA3 + DAA3 + ADA3 + DDA3 + AAD3 + DAD3 + ADD3 + DDD3 \).

Spectrogram and FFT studies to the raw data

Time series measurements of shallow water ambient noise have been made for a week, off east-coast by deploying an autonomous ambient noise measurement system at 30m depth. Data was collected at a depth of 15m. The noise data is sampled at a rate of 50K samples per second at the time interval of 30 sec in every 3 hour. The hydrophones with a constant receiving sensitivity of -170dB over a frequency range of 100Hz to 10 kHz were used with a data acquisition system to collect the ambient noise. Wind speed at the time of measurement was below 3m/s and hence the wind noise component was very small. Hence, the preliminary analysis of measurements showed that predominantly the noise field is due to ship crossing other than the wind noise.

Time series, spectrogram and spectrum of the raw data are shown in the Figure 2 and Figure 3. In the Figure 3, the information falls at the frequency band of 100Hz to 1000Hz which cannot be clearly seen due to the unwanted noise. Hence the threshold value (Number of sample for which the absolute value of the signal exceeds a value) and the type of threshold is applied & selected, so as to minimize the domination of noise in the information. Mathematically speaking, given a decomposition \( x \) with elements \( x_i \), then the resulting coefficient vector after applying a thresholding method with the threshold \( T \) is \( \delta_T(x) \), and this equates to

\[
\delta_T(x_i) = \begin{cases} 
0 & |x_i| \leq T \\
|x_i| & |x_i| > T 
\end{cases}
\]

**Hard Thresholding:**

\[
\delta_T(x_i) = \begin{cases} 
0 & |x_i| \leq T \\
sgn(x_i) \cdot (|x_i| - T) & |x_i| > T 
\end{cases}
\]

**Soft Thresholding:**

\[
\delta_T(x_i) = \begin{cases} 
0 & |x_i| \leq T \\
\frac{1}{|x_i|} - T^2 & |x_i| > T 
\end{cases}
\]

**Gabor Thresholding:**

\[
\delta_T(x_i) = \begin{cases} 
0 & |x_i| \leq T \\
\frac{1}{|x_i|} - T & |x_i| > T 
\end{cases}
\]

In order to find the threshold value and type of threshold, the following formula is used \( \sqrt{2 \log_2(n) \log_2(n)} \). Where, \( n \) is the number of samples in the raw data. In general, the threshold SURE (Stein’s Unbiased Risk Estimate) type is used for signal processing as well as denoising technique. This threshold type can give the better noise reduced data. Of course, the most frequently encountered threshold (entropy) function is the Shannon entropy, which can be expressed as, \( E_s(s) = - \sum s_i^2 \cdot \log(s_i^2) \) & \( E_s(s) = - \sum s_i^2 \cdot \log(s_i^2) \).

Shannon Entropy gives an estimate for the average minimum number of bits needed to encode \( s \) (raw data), which cannot give the precious result. This is the reason for going to the SURE type entropy.

Feature Extraction

Applying the obtained threshold value, the value comes as 5.874535731915793; to acquire the better result, the value of threshold is set as what is got exactly precise to the number of digits. The wavelet packet best tree decomposition structure is given in the Figure 4. Percentage of needed information presented in the raw data and the percentage of unwanted noise presented in the same raw data can be obtained from the decomposition tree, which is shown in the figure 5. From the Figure 5, it can be clearly seen only 89.59% (88.98\%+0.47\%+0.27\%) of raw data has the needed information, here probably the ship noise. Rest of the samples presented in the raw data has the percentage of 10.42% (4.12\%+5.41\%+0.62\%). Hence this 10.42% of raw data are the noise presented and dominating the original information’s. Before starting the feature extraction process it is required to find the detail and approximation co-efficient. Let us fix \( j \) is the number of levels and sum on \( k \) be the number of samples presented in the original raw data.

A detail \( D_j \) is nothing more than the function \( \sum_{k \in Z} C(j,k)\psi_{j,k}(t) \). Now let us sum on \( j \). The signal is the sum of all the details \( s = \sum_{j \in Z} D_j \). The details can be defined as, take a reference level called J. There are
two sorts of details. Those associated with indices \( j < J \) correspond to the scales \( a = 2^j < 2^J \) which are the fine details. The others, which correspond to \( j > J \) are the coarser details. These details can be grouped into \( A_j = \sum_{j > J} D_j \). It defines what is called an approximation of the signal \( S \). Then the creation of details and approximation is done. They are connected which can be equates as, \( s = A_j + \sum_{j \geq J} D_j \). Signifies that \( s \) is the sum of its approximation \( A_j \) and of its fine details. From the previous formula, it is obvious that the approximations are related to one another by \( A_{j-1} = A_j + D_j \).

From the mathematical conventions and from the Figure 5 which gives the wavelet packet decomposition tree of 3 stage wavelet packet decomposition, it is easy to find the 8 dimension characteristic vectors, as shown in the Figure 6. In the Figure 6, X axis has the number of samples (total length) in the data, whereas the Y axis has the amplitude of the data expressed in V.

Comparing the results of Figure 5 and Figure 6, it is clearly shown that the vectors \((3,0), (3,2), (3,4)\) and \((3,6)\) has the information of ship noise, whereas the vectors \((3,1), (3,3), (3,5)\) and \((3,7)\) has the unwanted noise. Hence, the decomposition here concludes. Wavelet packet reconstruction of the decomposed signal can be done by the process consists of up sampling and filtering. Up sampling is the process of lengthening a signal component by inserting zeros between samples, which is shown in the Figure 7. The extracted information in the decomposed signal is shown in the Figure 8. It is clearly identified from the Figure 8 that the needed information, the ship noise is falls at \( D_1 \) rather than \( D_2 \) or \( D_3 \) around the frequency band of 100Hz to 1000kHz lies in the samples. This could be confirmed by studying the spectrogram of the reconstructed signal, which is shown in the Figure 9. Comparing the results of raw data spectrogram and reconstructed data spectrogram, it finely explains that the ship noise exactly falls in the frequency band of 100Hz to 1000Hz, as in the Figure 3, it cannot be clearly shown due to unwanted noise presented in the raw data. For getting the better result, it is required to retune the results of reconstructed (synthesised) data.

**Results and Discussion**

Results shows clearly the narrow band frequency components of shipping noise are present. At the time of data collection, ship crossing was present at a distance of 0.5 km from the autonomous ambient noise system. Hence, the result of this research work has been cross verified.

This has applications in finding different types of boats/ship noise and the technique is applied to different data sets for finding such sources. In this paper, the method to extract features based on wavelet packet transform is also studied. Wavelet packet decomposition technique is used to extract the features of the target signals and the extracted features are used to classify the different targets.

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References


Figure Captions:

Figure 1. Structure diagram of three-stage wavelet packet decomposition technique.

Figure 2. Time series of the raw data.

Figure 3. (a) Spectrum and (b) Spectrogram for the raw data
Figure 4. Wavelet best tree decomposition structure.

Figure 5. Wavelet decomposition tree representing the percentage.

Figure 6. Eight dimension characteristic vector of three stage wavelet packet decomposition.

Figure 7. Reconstructed signal from the decomposed signal.

Figure 8. Extracted information’s in the reconstructed signal.

Figure 9. (a) Spectrum and (b) Spectrogram for the reconstructed data.