Journal of Engineering and Applied Sciences 13 (Special Issue 12): 9380-9384, 2018
ISSN: 1816-949X

Study of Ship Noise from Underwater Ambient Noise Using Discrete Wavelet Transform

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Abstract: Underwater signal processing includes several application areas like military application, disaster detection, finding natural resources, etc. When signal transmits through water, it may get overlap due to some inherent mechanisms like ship noise, wind noise, marine mammals noise, noise generated during all stages of oil production and due to other industrial sources. In this study, the main focus is an analysis of ship and wind noise present in data recorded on the West coast of India. The analysis is based on spectral characteristics of ship noise from the available signal. Identification of noise from the signal is carried out by using spectrogram and edge detection. Then shipping noise is mitigated with the help of discrete wavelet transform and signal to noise ratio is calculated to validate its performance. Software tools like MATLAB, SigView are used for analysis.

Key words: Ship noise, wind noise, spectrogram, discrete wavelet transform, MATLAB, analysis

INTRODUCTION

Underwater sound can be used to monitor the marine environment. Acoustic communication is very vast and highly variable. This process gets corrupt due to background noise in ocean environment called as underwater ambient noise. Underwater ambient noise is one of the major contributors to a downgrading of the environmental status of ocean from previous few years. The ambient noises add more effect on degrading the quality of the acoustic signal. There are two types of ambient noise sources, i.e., natural sources and anthropogenic sources. Natural sources include hydrodynamic sources, seismic sources, biological sources, ice cracking, wind noise where anthropogenic sources include ocean traffic, military operations, oil and gas exploration, seismic survey, etc. Here, we concentrate on ship noise and wind noise (Yashaswini *et al*., 2015). According to the survey conducted by Wenz, the origins of noise between 1 Hz and 20 kHz in the ocean are wind noise and ship noise. If these two noises superposed, then overall spectrum will be composite of the two noise sources and varies as a function of the area because of the ship generated portion. It is a very important task to analyze, classify and remove the sources of underwater ambient noise from collected data (Perrone and King, 1975). Classification of different noise sources is the critical task.

Ship noise: Ship noise is more low-frequency sound than wind or rain. Close ships loud at all frequencies and distant ships (shipping) relative loud at lower frequencies. Noise from shipping traffic can sometimes travel up to distances of 1000 miles or more and its probable origin is in between frequency range 10 Hz-1000 kHz. Shipping density is most important term in the underwater environment because ocean traffic is proportional to shipping density. Northwest Atlantic ocean contains some busiest sea routes in the world. Main shipping lanes are traversing the Scotian Shelf in a North-south direction and several ports in Nova Scotia receive internationally. Each ship may generate unique noise because of the unique combination of their machinery and this noise is nothing but the signature of that particular ship. This signature can be helpful to identify the specific ship. Ship signature can be affected by propagation or can be masked due to other oceanic noise sources. Ship sounds are complex and variable. It is composed of different resources mentioned below.

Machinery noise: Machinery vibration transmits to water through the hull. Machinery noise is nothing but mechanical vibrations generated due to many parts inside moving vessel, i.e. rotating unbalanced shafts, repetitive discontinuities, explosions in cylinders, capitation and turbulence in the fluid flow in pumps, pipes and valves, mechanical friction in bearings (Harland and Richards, 2006). Machinery noise comprises that part of the tonal noise of the vessel cause by the ship machinery. The main sources contributing machinery noise are the engine, air conditioning, shaft line, cargo handling, control equipment, mooring machinery (Kozaczka and Grelowska, 2004). A mechanism for exhaust noise reduction techniques in Direct Injection (DI) diesel engines is presented by Raman *et al.* (2014).

Propeller noise: When propeller rotates in water region of negative pressure get creates on the surface of the water. The negative pressure causes any gas in the water to evolve into bubbles. The formation and the collapse of the bubbles are called propeller cavitations (Kozaczka and Grelowska, 2004).

Hydrodynamic noise: This type of noise originates in the irregular and fluctuating flow of fluid past the moving vessel. Hydrodynamic is the due to a flow of water through the ship hull and behind the vessel.

Wind Noise: Wind noise generates due to an action of wind force against ocean surface. Over frequency range 500-100,000 Hz ambient noise generated due to spray and bubbles, it is called as breaking wave noise. It increases with increasing wind speed. A storm passing over a receiver can temporarily increase mid-frequency sound level by 30 underwater dB or more, it depends on the strength of the storm.

Bubble noise: This type of noise generate due to bubbles or foamy region created on the surface of the water. It categorized in two types, active bubble noise and passive bubble noise. Passive bubble noise doesn't create that much of noise but active bubble noise generates noise due to wave break and rain shrinking surface. Above frequency 1 kHz, noise is the result of volumetric radial oscillations of individual bubbles (Kozaczka and Grelowska, 2004).

Impact noise: It occurs due to water strike water, i.e., breaking wave noise, water strike solid or heating a rock. Also, noise generates due to solid strike solid, i.e., sediment noise.

Turbulence: It is associated with surface disturbances or turbulent tidal flow generates low-frequency continuous noise (Kozaczka and Grelowska, 2004).

MATERIALS AND METHODS

Characteristic of ambient noise: The signal can be characterized with the help of its spectrum, spectrogram plots. The spectrum of the noisy signal shows how noise level can vary with the different range of frequency. Signal spectrogram gives instantaneous frequencies and energy present at the particular frequency. Spectrogram helps us to identify ship noise. We can detect wind noise with the help of power spectrum of noisy the signal.

Ship noise: Ship's auxiliary generator is a major source of noise at low speed of the ship. Ship generate tonal component which is responsible to radiate noise power of the ship. This type of radiations is not dependent on the speed of the ship. Some component can generate strong ship signature. At higher and moderate speed noise generates due to propulsion engine and propeller. This noise presents over the frequency range of 100 Hz. The tonal ship level is unstable due to variations of loading the propeller at various sea state. The propeller is also a major contributor to ambient noise. At the higher speed of a ship, noisy signal and its harmonics contribute low-frequency tonal level. Spectrum frequencies associated with the activity of propulsion engine and propeller varies with ships speed (Harland and Richards, 2006).

Spectrogram of the noisy signal is shown in Fig. 1, the upper part of the figure shows acoustic signal with sampling frequency 44100 Hz and recording period. X axis shows time, i.e., 0-45 sec and the Y-axis shows the amplitude of the signal. The lower part of the figure shows spectrogram of a signal where X axis shows time from 0-45 sec, the y- axis shows frequency from 10-500 Hz and Z axis shows amplitude.

The spectrogram shows one horizontal tonal line over the frequency range of 139-150 Hz and also, it shows another faint line over the range of 53-64 Hz. This line is corresponding to signal generated by ship machinery. Fig. 2 shows the spectrum of a noisy signal over the frequency range of 139-152 Hz. It shows the peak at 145 Hz also harmonics at 139 and 150 Hz. Simulation results are shown in Fig. 1 and 2 are obtained by using 'SigView' Software tool.

Ship tonal line can also be identified by using image processing technique edge detection. Here, sobel edge detector is used which helps to detect horizontal, vertical lines from the image. Sobel operator returns 3*3 filter that emphasizes horizontal edges using smoothing effect by approximating a vertical gradient. Here, 203*932 image is used where Y axis indicates a number of columns and X-axis denote the number of rows.

Wind noise: In the absence of noise from ships and marine mammals, wind speeds contribute to ambient noise levels at frequencies between 100 and 25 kHz. The absence of local shipping and biological noise in shallow water, wind noise dominates the noise of distant shipping

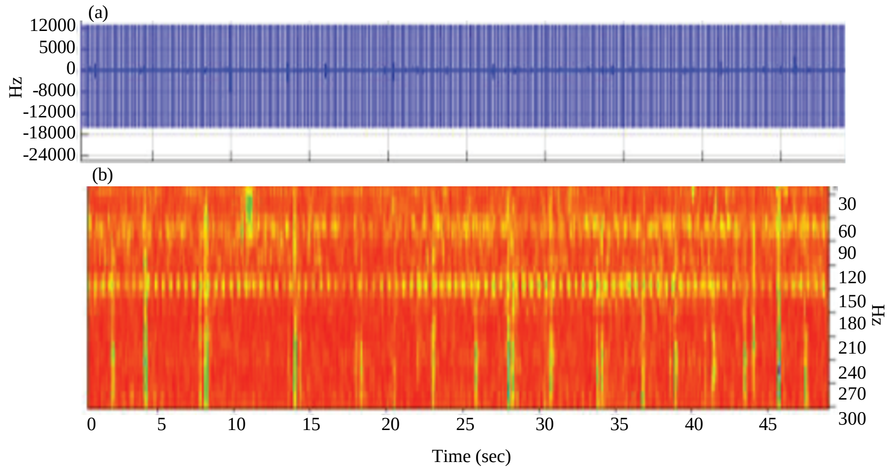

Fig. 1: Spectrogram of ship noise

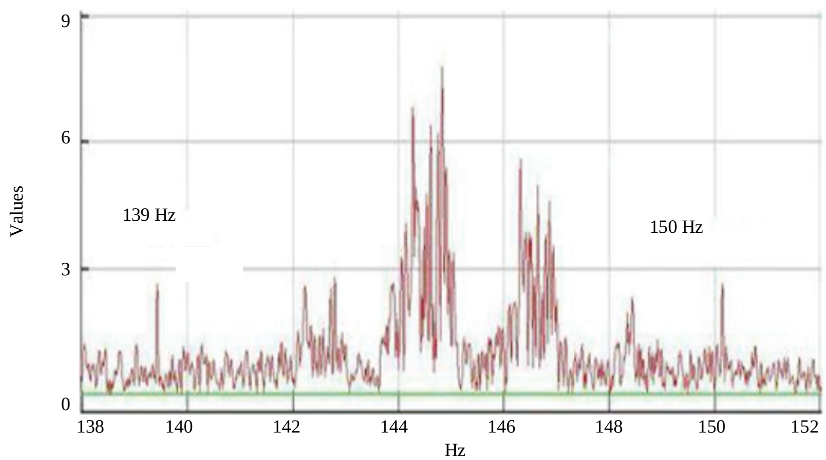

Fig. 2 Spectrum of acoustic signal

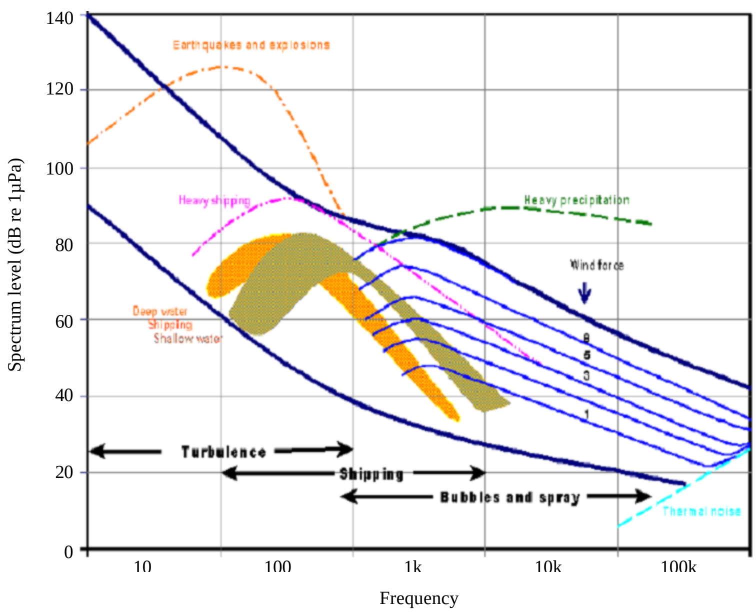

Fig. 3: Ambient noise spectrum

over the entire frequency. Ambient noise in the band of 500-20,000 Hz has been called knudsen noise because knudsen discovered this noise and it correlated very well with wind speed. In all frequency bands, at low wind speeds, the average noise level was independent of wind speed and at high wind speeds, the noise level was linearly related to the logarithm of the wind speed (Perrone and King, 1975).

Figure 3 shows the spectrum of ambient noise in which Y axis shows frequency in Hz and X axis shows spectrum level in dB. Wind noise can also produce due to breaking waves at low frequencies (30-500 Hz). Each breaker produces impact noise and random collection of each spectral event. A wind noise spectrum is shown in Fig. 3 (Elfouly *et al*., 2008) over the frequency range of 500-25 kHz and it is shown by faint blue curved lines. The intensity of noise below 500 Hz is a function of wind speed. Breaking waves responsible to generate an impact, bubble plume and bubble cloud. Wind noise curve is shown by Wenz using Wenz curve. Distribution of low-frequency wind noise and high-frequency noise is shown with the help of Wenz curve.

Mitigation of noise using discrete wavelet transform: To analyze non-stationary signals wavelet transform came to view as a rising technique. It is a tool which having advantages over traditional time-frequency representation techniques, it is effectively used in the application like image processing, signal processing, computer vision (Kadali and Rajaji, 2015). The discrete wavelet transform is used to break out signal into its lower resolution components, so, the benefit of this is we can study signal at the different resolution and we can observe frequency component of the signal in detail. Real world data is non-stationary, so, this method is useful to analyze non-stationary signals. In this method, initially signal gets decomposed in an essential number of levels and signal get down sampled after each level.

After decomposition thresholding is used to remove higher frequency component from the signal. There are two types of thresholding that are soft thresholding and hard thresholding. Soft thresholding is best to reduce noise but not suitable to preserve edges and hard thresholding is good in preserving edges but poor performance de-noising, so, here soft thresholding is used to reduce noise. An efficient approach for the removal of bipolar impulse noise using median filter is presented by Raman *et al*. (2014).

The first family of the wavelet transform is Haar wavelet. It proposed in 1909 by the mathematician Alfrd Haar. The second orthogonal wavelet constructed by Yves Meyer in 1985 called Meyer wavelet. As Haar is not smooth when compared to other wavelets, it has limitations when applied to non stationary signal and acoustic signals are non stationary. Because Haar wavelet cannot compress the energy of signal into high-energy values above the threshold, so, for signal denoising Haar wavelet is not always effective. Daubechies wavelets use overlapping windows, so, the high-frequency coefficient spectrum reflects all high-frequency changes (Kadali and Rajaji, 2015). So, to perform decomposition of signal Daubechies wavelet is used.

To reconstruct original signal the (IDWT) Inverse Discrete Wavelet Transform can be applied, so that, original signal can be achieved without loss of information. For reconstruction of original signal detail coefficients of each level and approximate coefficients of the last level are used. In IDWT interpolation is used to preserve bit rate of the signal.

RESULTS AND DISCUSSION

In this study, we have used ambient noise signal having sampling frequency 22050 Hz and ship tonal lines are present at frequency range 400-800 Hz. With the help of denoising algorithm, i.e., discrete wavelet transform, the signal is decomposed at level 6 and thresholding is applied to levels 4-6. Then the signal is reconstructed. Now in Fig. 4, decomposition of an acoustic signal is shown. The signal at each level is having lower frequency component of the previous one.

Also, we can compare the spectrum of the noisy and denoised signal and observe those frequencies where noise is present in the signal. Fig. 5 shows Welch spectrum of both noisy and denoised signals. We can see that how the spectrum changes over the frequency range of 0-2 kHz.

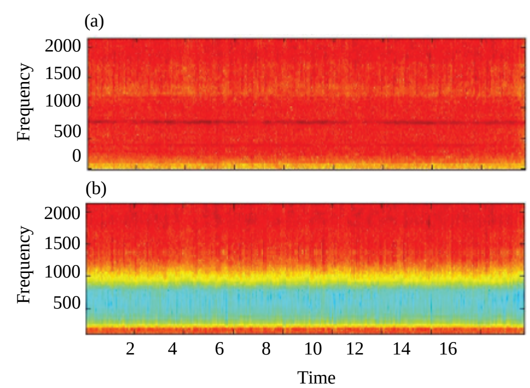

Fig. 4: Spectrogram of acoustic signal

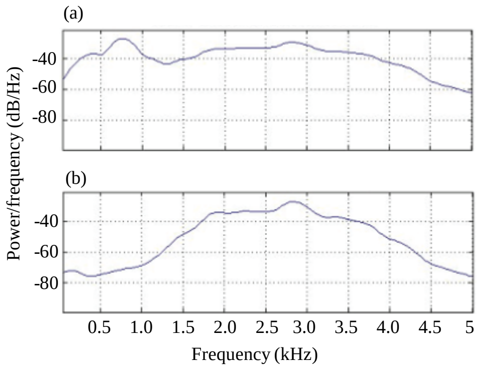

Fig. 5: Spectrum of acoustic signal

CONCLUSION

Underwater ambient noise is the major concern for underwater signal processing algorithm. Apart from all noise sources ship noise is dominant over range 0-500 Hz and wind noise is dominant over the range of 500-25 kHz. These frequency ranges may be variable according to sea state. In this study, ship noise characteristics are observed using, respective spectra of noise with the help of SigView and MATLAB and characteristics of wind noise are observed with the help of wenz curve. Also, discrete wavelet transform is applied to mitigate the ship noise signal. Use of wavelets can be explored further for improve filtering wind noise and other noise sources present in the underwater ambient noise signal.

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