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Development of wavelet decomposition Denoising algorithm for a linear FM chirp signal to apply any underwater communication systems

Venkataraman Padmaja,

Phd Research Scholar, Satyabhama University
ktananya@gmail.com,

Dr.V Rajendran,

HOD, ECE Dept. Vels University Chennai
drvrajen@gmail.com

Abstract
Underwater applications like Mine exploration, Pipeline / Cable laying, Hydrography, etc. warrant for different studies like Geo-technical, Geo-physical and other investigations in both Shallow and Deep water in the sea. Mostly, the mentioned studies are carried out using underwater marine acoustic instrumentations. The acoustic signals, in particular, shallow water suffers severe disturbances due to Ambient Noise in the sea. The Ambient noise in underwater is very unique, location specific and nearly deterministic also. Hence this paper aims at developing de-noising algorithm to improve the Signal to Noise Ratio (SNR) using the Uniform Filter Bank and Wavelet Packet Decomposition . The simulation was carried out using the MATLAB . The Ambient noise used for the validation is sea truth data collected in Bay of Bengal using the broad band Hydrophones. The results obtained was very encouraging as that in the range of input SNR -15dB to 0dB, the improved output SNR is order of 9dB. This shows the efficiency of algorithm simulated.

Keywords: Underwater acoustic signal processing, underwater ambient noise, wavelet decomposition, underwater de-noising techniques.

Introduction

Past two decades have seen advances in the research and development and deployment of underwater acoustic digital communication system. The area of primary interest is the military and deep sea research applications.[1]

In addition, un-tethered systems are also of increasing interest in a wide variety of applications, such as commercial fishing and oil exploration, where remotely controlled vehicles and equipment are used to probe, sense, and actuate apparatus from a surface vehicle or station. With increasing interest in environmental sensing, as well as continued exploration of the potential for research, commercial, and scientific applications in the oceans, the readily available of high-rate digital acoustic communications systems has become a catalyst for an explosion of applications. These applications range from command and control links to submarines and autonomous underwater vehicles and search-and-rescue contexts, to remote operation and control of sensing equipment in deep sea mining, off-shore oil exploration, and environmental monitoring[2]

Underwater acoustic signals are affected by shallow water condition and ambient noise during the transmission [3]. The shallow water ambient noises are both natural and human-made, with different sources exhibiting different directional and spectral characteristics. Therefore, before recovering original signal from received acoustic signals, it is necessary to remove the present ambient noise so as to keep the important signal features as much as possible using matched filter concept[4]

Wavelet packet decomposition[5] and the selection of the so–called "best basis"[6] in the sense of some criteria. It has been shown that an orthogonal wavelet basis is particularly adapted to discriminate signal and noise [7] the latter is represented by small coefficients on the wavelet domain. In that case, the "HardThresholding"[8] of the lowest coefficients leads to a noise reduction.

Gabor filter technique is projection of the signal into separate spectral channels and all filters have the same shape. In such space, the noise power is spread over all spectral channels and can be rejected by canceling all the coefficients below the noise threshold. As will be shown, the estimation of the noise threshold can be performed by means of high order statistics [9][10][11]

This paper aims at developing de-noising algorithm to improve the Signal to Noise Ratio (SNR) using the most match able Gabor Wavelet. The simulation was carried out using the MATLAB . The Ambient noise used for the validation is sea truth data collected in Bay of Bengal using the broad band Hydrophones

Classification of Underwater Noise

Acoustic noise can be considered as any sound other than the desired sounds. The ocean and many other bodies of water are very noisy with sounds being generated by the variety of different sources. The acoustic noise in the ocean is often referred to as ambient or background noise and is normally measured in terms of intensity in dB detected by an omni-directional hydrophone. Noise intensity may be measured in different frequency bands. Ambient noise in shallow water tends to be highly variable, both in time and location. It is generally classified as given Fig1. in the broad categories like wind , rain, ship, thermal based noises, etc.

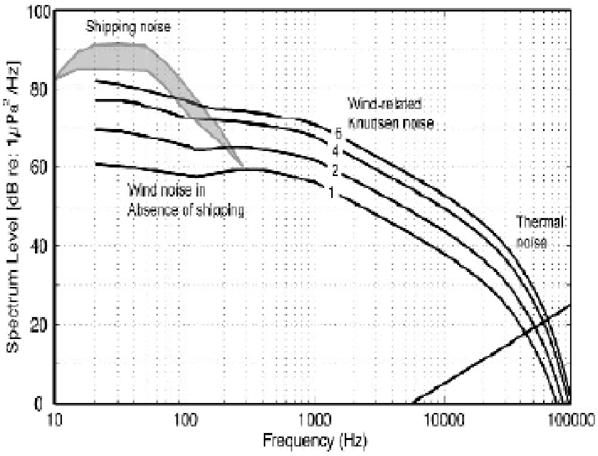

Fig.1. Classification of noise signal

Data Collection

For this particular work, Chennai has been selected in Bay of Bengal, as the data collection location. Generally, the data collection is done taking a reasonably equipped boat to a minimum of 30m depth shallow water and making a measurement.

Measurement system and its overview

The overall measurement arrangement which includes a boat in shallow water is given in Figure In this arrangement the measurement system in particular consists of two hydrophones and its mounting arrangements, Data Acquisition System (DAS) and power supply. The calibrated omni directional hydrophone sensor with receiving sensitivity of -170dB with re 1V/µPa, over a frequency range 0.1 Hz to 25 kHz was used to measure the acoustic pressure of ambient noise. Both the hydrophones are mounted as shown in figure 3.5 in "L" shaped PVC tube filled with enough concrete so that it has got its self weight to sink in the underwater without floating or drifting due to shallow water environment. The other specifications of the measurement systems are provided in Table.1

Table 1: Hydrophone Specifications

Parameter	Specifications
Frequency of operation	Upto 25kHz
Directivity	Omni directional
Sensitivity	-170dB
Type of material	Piezo electric (PZT)
Operating depth	600 m
Survival depth	700 m
Operating Temperature range	-2 to + 55 C
Operating Voltage	12 to 24 VDC

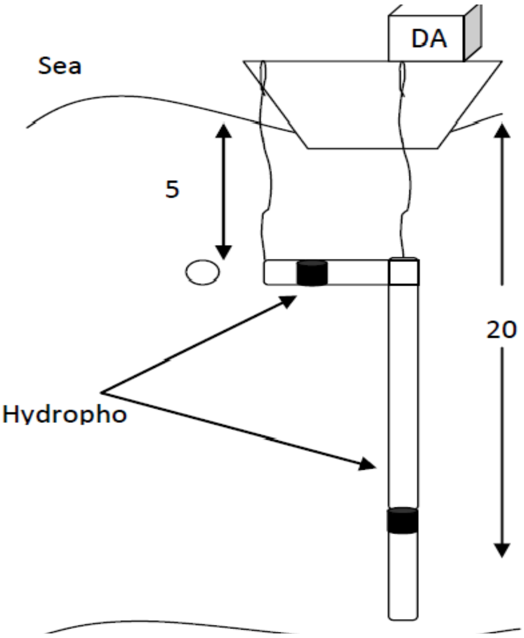

Fig 2.Measuring arrangement in the sea

Signal denoising techniques

Underwater de-noising techniques are classically based on the projection of the ambient noisy signal on a new space, in which the signal and the noise do not overlap. The ambient noise in view of new space projection is eliminated by preserving the signal into subspace only. Applying into inverse projection technique, a denoised form of the original signal is recovered.
In view of applying projection techniques, is the class of unitary transforms since they have the more useful properties for underwater signal processing. Among all, unitary transforms assure that the existence of an inverse transform technique and preserve the acoustic signal energy on the transformed space. Fig 3. Wenz [12] model of the power spectral density of the underwater ambient noise.
The underwater denoising techniques considered here are based on this framework: the acoustic signal is projected on a new space with a unitary transform technique, properly filtered in this new space and, with the inverse unitary transform technique, estimated back to the original signal space.

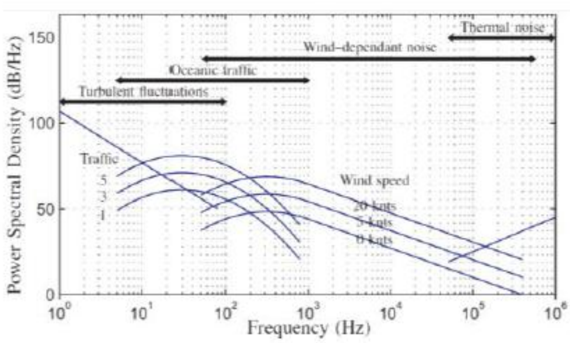

Fig.3 Wenz model of the power spectral density of the underwater ambient noise.

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Wavelet Packet Decomposition

Wavelet has generated a tremendous interest in both applied and theoretical areas [13][14]. The wavelet transform theory provides an alternative tool for short time analysis of quasi stationary signal such as Speech as opposed to traditional transforms like FFT. Wavelet analysis is a powerful and popular tool for the analysis of non-stationary signals. The wavelet transform is a joint function of a time series of interest d(t) and an analyzing function or wavelet. This transform isolates signal variability both in time t, and also in "scale" s, by rescaling and shifting the analyzing wavelet.

Wavelet packet decomposition (WPD) is extended from the wavelet decomposition (WD). It includes multiple bases and different basis will result in different classification performance and cover the shortage of fixed time–frequency decomposition in DWT.

The algorithm of the wavelet packet decomposition and reconstruction is

$$u^{j}_{2m}(n) = \sum_k h(k-2n)u^{j-1}_{m}(k) \quad (1)$$

$$u^{j}_{2m+1}(n) = \sum_k g(k-2n)u^{j-1}_{m}(k) \quad (2)$$

$$u^{j-1}_{m}(n) = \sum_k H(k-2n)u^{j}_{2m}(k) + \sum_k G(k-2n)u^{j}_{2m+1}(k) \quad (3)$$

Determination of threshold function

On wavelet packet de-noising, threshold function is embodied that it adopts different strategy to deal with coefficients accordingly which is more or less than the threshold. Soft and hard threshold function has been widely applied.

$$\hat{w}_{j,k} = \begin{cases} Wj,k, & |Wj,k| \geq \lambda \\ 0 & |Wj,k| < \lambda \end{cases} \quad (4)$$

$$\hat{w}_{j,k} = \begin{cases} sgn(Wj,k)(|Wj,k| - \lambda), & |Wj,k| \geq \lambda \\ 0 & |Wj,k| < \lambda \end{cases} \quad (5)$$

Where

sgn =sign function

λ =threshold ,

W = represents wavelet coefficients of signal decomposition,

$\hat{w}$ =Estimated value of wavelet coefficients by thresholding.

A Gabor filter expressed by

$$h_{b_i}(t) = \frac{1}{\sigma_i\sqrt{2\pi}} \exp\left(\frac{-t^2}{2\sigma_i^2}\right) \exp\,(j2\pi b \quad (6)$$

σ_i^2 Variance of Gaussian envelope signal

b_i Frequency of the complex harmonic signal and the sample wavelet

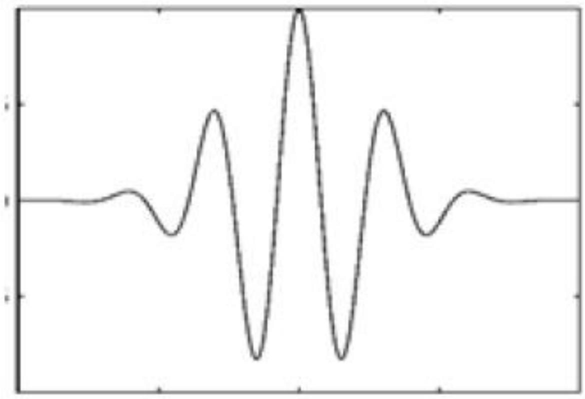

Fig.4.Gabor Wavelet

Symlet wavelet

In symN, N is the order. Some authors use 2N instead of N. The symlets are nearly symmetrical, orthogonal and biorthogonal wavelets proposed by Daubechies as modifications to the db family. The properties of the two wavelet families are similar. Here few wavelet are shown in figure 5

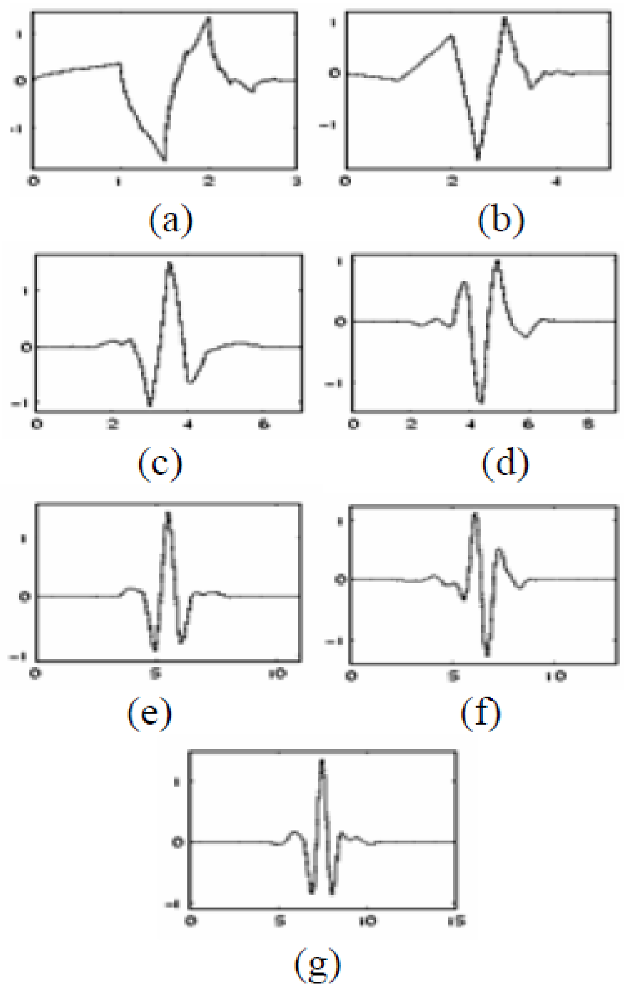

Fig 5. Symlet wavelet

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Let assume a frequency bandwidth of interest area $[b_{min} ; b_{ma}$ which will cover the different filter frequency range. Gabor filter with frequency equal to the centre of the sub-band. The representation of any bandwidth signal d(t)

$$\in L^2(\mathbb{R}) d_{bi}(t) = h_{b_i}(t) * d(t), b_i \in [b_{min} ; b_{max}], i = 1, \dots\dots \quad (7)$$

The transformation is unitary if

$$\mathcal{F}[h_{b_1}(t) + \cdots + h_{b_N}(t)](b) = 1, b, b_i \in [b_{min} ; b_{ma} \quad (8)$$

Where

$\mathcal{F}[d(t)](b)$ Fourier transform of the signal d(t)

F[x(t)](v) denotes the fourier transform of the signal x(t)

This condition implies that the number of filters and of the Gaussian envelope signal have to be carefully chosen to verify (8). If this condition is satisfied, the inverse unitary operator has a simple as it is the sum of all spectral channels. The Gabor filter provides the Time-Frequency representation of the given signal.

For a noisy coherence signal, the each spectral channel has various statistical properties. In overview, coherent components are characterized, in the Time-Frequency plane, by high and concentrated coefficients while noise is characterized by low and spread coefficients. Therefore, noise reduction has done by using thresholding lowest coefficients leads.

The estimation of the noise threshold can be addressed with higher–order–statistics [5]. The root–mean–square (RMS) expressed by

$$E_\sigma(t) = \sqrt{\frac{1}{N}\sum_i d_{b_i}^2} \quad (9)$$

This expressed equation gives the mean energy value at a specific time and over each spectral channel. At a time when only the ambient noise is present, the quantity of energy value over the spectral channels is the energy value of the ambient noise. By contrast, at a time when noise and signal are both present, the quantity of energy value over the spectral channels is the energy value of the signal and the energy value of the ambient noise. The result shows that, the RMS value is low when noise only present and high if signal and noise are both present. In the later section, Fig.10 shows the Gabor filter response for various sigma values.

Simulation and Experiment

A gated linear FM wave as signal(acoustic)e(t) is assumed to be transmitted through a mid frequency water channel and the simulated signal is given in fig. 6

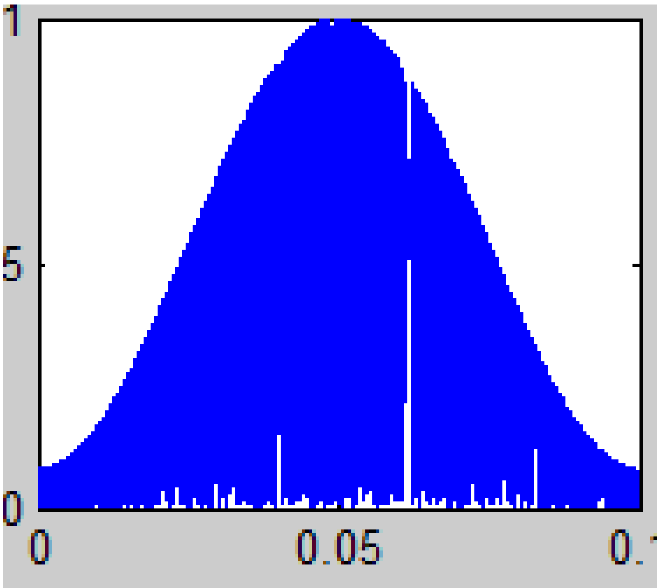

Fig.6 Gated Linear FM signal

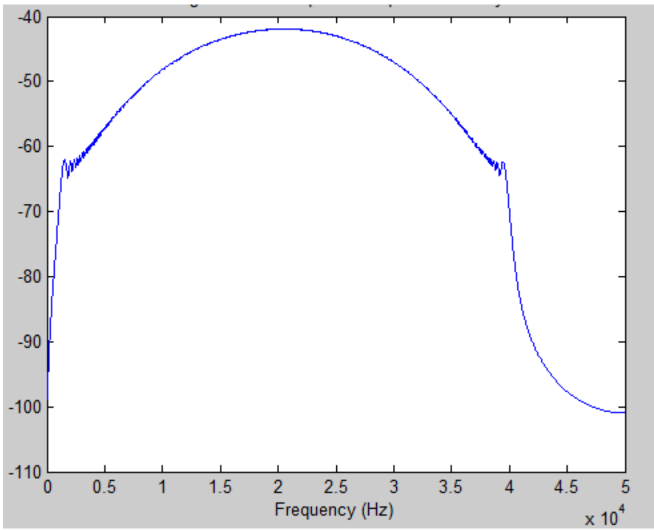

Fig:7 Power spectrum of gated signal

For analyzing the signal is added with the underwater ambient noise which collected in Chennai, at Bay of Bengal given in Fig.8. The reference signal is simulated at 20kHz. The noise data is the real time data collected and is assumed to be stationary, gaussian, with a Wenz–shaped power spectral density (Fig.3). The results have been obtained with 50 different noise realizations and have to be taken in an average

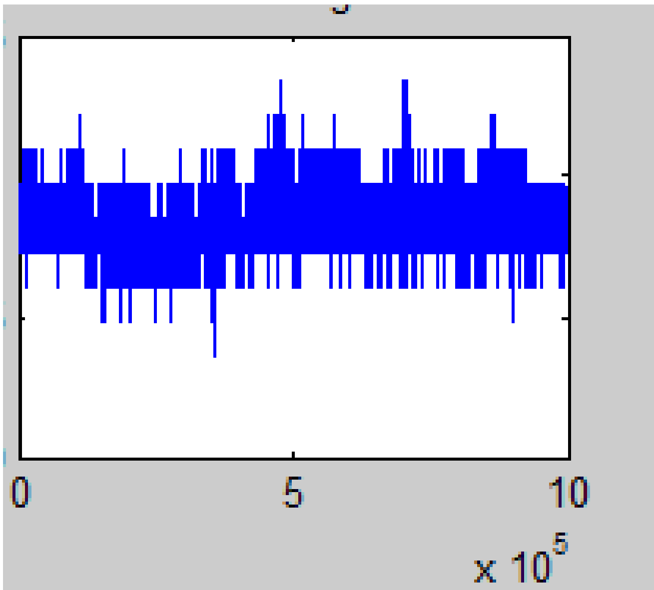

Fig.8 Noise signal

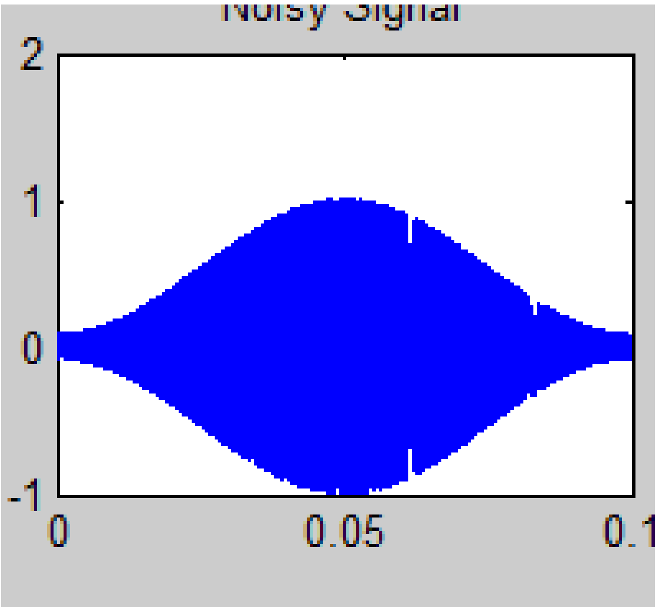

Fig.9 Noisy Signal

The proposed de-noising methods reduce the noise while preserving the useful part of the signal. Each method has different type of performance with regards to the recovery of the signal boundary. Fig. 9 shows the Schematic representation of the simulation procedure.

Fig.11 shows, as one example, the Gabor filter response for various sigma values. Fig. 9 shows the gated sine wave with noise spectrogram representation . These results come from the non–linearity of the Hard Threshold procedure, which suppress a few wavelet coefficients that are involved in less noise reduction performance. By selecting the number of retained principal components using Kaiser's rule, the noise removal is done and its shows that better performance higher sigma value although there is considerable reduction in the signal level. It is visually more satisfactory by seeing the time series original signal. It gives the best results and better performance filter

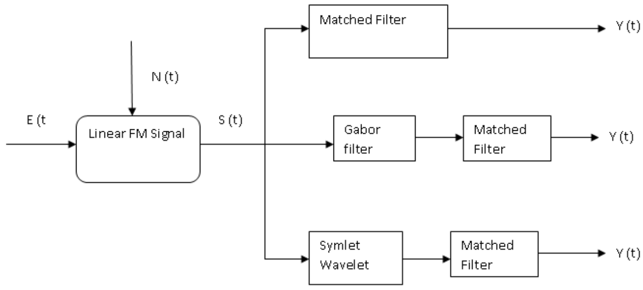

Fig.10 Schematic representation of the simulation procedure

Fig.12 shows input signal–to–noise ratio (input SNR) versus the output signal–to–noise ratio (output SNR) and used expressions are

$$SNRIn = 10 * Log_{10} \frac{\text{Input power}}{\text{Noise power}} (dB) \quad (10)$$

$$SNROut = 10 * Log_{10} \frac{\text{Output power}}{\text{Noise power}} (dB) \quad (11)$$

Where "Input power" and "Output Power" are respectively the signal power before and after denoising, and "Noise power" are respectively on the same frequency band of the signal. From the Fig 12 , it is revealed that all three methods lead to an improvement of the SNR in which confirm a significant reduction of the noise. However, this suggests that only Gabor filter gives the improved output SNR is order of 9dB in the range of input SNR -15dB to 0dB. This shows the efficiency of algorithm simulated.

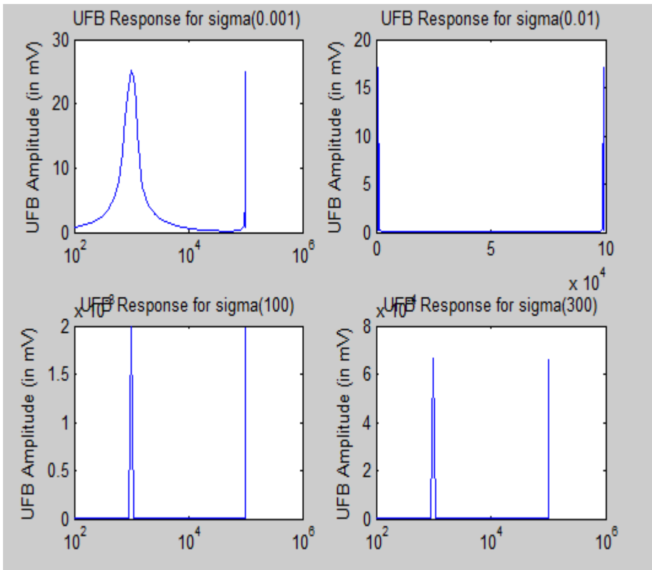

Fig.11.Gabor filter response for different sigma values

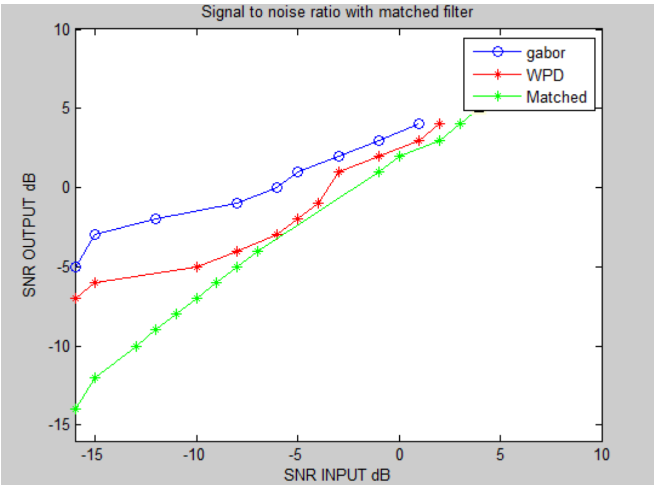

Fig.12 Comparative analysis of the de-noising procedures to improve SNR.

Conclusion

In this paper, it is explained that underwater acoustic instruments plays prominent role in exploration and exploitation of both living and non-living ocean resources of many varieties of underwater applications. It is observed that the acoustic signals, in particular, shallow water suffers severe disturbances due to Ambient Noise in the sea. The Ambient noise in underwater is very unique, location specific and nearly deterministic also. It is important that the development of de-noising algorithm with an appropriate technique. In addition, validating the mentioned algorithm with sea-truth ambient noise collected at particular location is also equally important. So, thenoise in underwater is collected in Chennai at Bay of Bengal and it is found that the collected noise is a composite of various sources with miscellaneous spectral characteristics. To overcome this primal limitation, the most proven de-noising techniques, wavelet decomposition with two different wavelet (Gabor and Symlet) have been studied. This technique is based on the transformation of the signal on a unitary space. This assurance the existences of an inverse transform.

On this new space, a FIR filtering method has been applied to remove the noise. Finally, performances of the two de-noising technique procedures with two different wavelets (Gabor and Symlet) have been investigated with realistic simulated data. Results show that these methods lead to a noise reduction. However, the proposed Gabor filter–based denoising method gives better results. It leads to a better noise reduction and significant improvement. The results obtained was very encouraging as that in the range of input SNR -15dB to 0dB, the improved output SNR is order of 9dB. This shows the efficiency of algorithm simulated. Future works concern a firmware implementation of a new class of Time Frequency filters adapted to underwater environment signals whose frequency content varies strongly in time.

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