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A Literature Survey on Ambient Noise Analysis For underwater Acoustic Signals

Sauda Sadaf, Yashaswini P.[1], Soumya Halagur [2], Fazil Khan [3], Dr. Shanta Rangaswamy [4]

[1234]Department of Computer Science and Engineering

R.V. College of Engineering, Bangalore-560060

Abstract- **Transmitting data with water as the medium is called underwater communication. Electromagnetic signals are better attenuated in water than sound. Hence it is the most reliable and versatile means of communication underwater. The acoustic signals will be affected by ocean driven noise during transmission. Ambient noise is the background noise which has to be subtracted from the acoustic signal for smooth transmission. Hence the recognition and reduction of ambient noise is the essential part of underwater signal transmission. Studies and research are being carried out extensively in this area. There are many works reported and the research is still in progress. This literature survey presents the work done on the research front of ambient noise affecting acoustic signals.**

Key Words: - Underwater communication, Ambient noise, SNR, MSE, Noise Reduction, Signal.

I. INTRODUCTION

Transmitting data considering underwater as the medium is called underwater communication. Acoustic wave is the best suitable optimum medium for signal transmission in ocean, because the electromagnetic waves scatter due to the high frequency [1]. Acoustic signal transmission is the most versatile and also widely used technique for transmission in underwater environments due to the low attenuation of sound in water; especially in thermally stable and deep water settings. Underwater acoustics signals are affected by ambient noise during transmission. Hence, identification and also recognition for acoustic signals is the essential part of underwater technologies. Transmitting signal under ocean considering water as a channel is a challenge because of the effect of spreading, reverberation, attenuation and absorption adding to contribution due to ambient noises. Ambient noises in ocean can be classified into two types: 1. Man made (Shipping, motor on boat, aircraft over the ocean.) 2. Natural noise (Rain, seismic, wind and marine animals.). Ambient noises have more effect towards reducing the acoustic signal quality.

Sound received by an Omni-directional sensor which is not from the sensor itself or the manner in which it is mounted is called ambient noise [2]. It is the background noise in the sea from either natural or man-made sources, and may be divided into 4 categories: hydrodynamic, seismic, ocean traffic and biological [11][12].

- *Hydrodynamic Noise*: It is caused by the movement of water itself because of tides, winds, currents and storms. Level of hydrodynamic noise present in sea is directly related to the condition of the surface of sea. When the surface is agitated by wind or storm, the noise level increases which reduces the capability of detection. Very high hydrodynamic noise levels which are caused by storms in the general area of the ship may result in complete loss of all reception of signal.

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- *Seismic Noise*: It is caused by movements of land under or near the sea (for example, during an earthquake). They are rare and also of short duration.
- *Ocean Traffic*: Effect of ocean traffic on ambient noise level is identified by the area's sound propagation characteristics, the no of ships, and the distance of shipping from the area. Noise which is caused by shipping is similar to self-noise with the frequencies which depend on the range to the ships causing the noise. Noise from nearby shipping may be heard over a large wide spectrum of frequencies, but as and when the distance increases, the range of frequencies decreases, allowing only the lower frequencies below approx. 200 Hz reaching the receiver since the high frequencies above 80 KHz are attenuated. But in deep water, the low frequencies can be heard for thousands of kilometers.
- *Biological noise*: It is the result of a number of sources like marine animals, distance shipping, rain, wind, bubbles. Ambient noise is made up of 3 constituent types – wideband continuous noise, impulsive noise and tonal noise. Impulsive noises are transient in nature and are of wide bandwidth and short duration. They are best characterized by quoting peak amplitude and the repetition rate. Continuous wideband noises are normally characterized as a spectrum level; which is the level in a 1 Hz bandwidth. This level is given as the intensity in decibels (dB) relative to the reference level of 1 micro Pascal (µPa). Tonal noise is narrowband signal and is usually characterized as the amplitude in dB ref. 1µPa and frequency. Ambient noise ranges from below 1 Hz, to well over 100 kHz covering the whole acoustic spectrum. But above 100kHz the ambient noise levels drop below thermal noise levels [9][10].

The intensity of the ambient noise, as measured with an Omni - directional hydrophone, relative to the intensity of a plane wave with 1 µPa RMS pressure is called ambient noise level. Ambient noise levels are reduced to 1 Hz frequency bands; therefore, they are 'ambient noise spectrum levels'. Below 10 Hz turbulence (irregular arbitrary flows of water) plays an important role. Distant shipping is the main dominant source of ambient noise in the 50 to 500 Hz decade.

Above 500 Hz (up to about 18 kHz) the ambient noise level depends on the 'sea state' or wind speed ('wind noise'). The 'sea state' is a measure for the sea surface roughness. The breaking of the whitecaps is an obvious noise generating process. The Knudsen spectra, noise levels as a function of frequency with the wind speed or sea state as parameter, are based on a large amount of noise measurements in deep water. Above 100 kHz, the ambient noise level is identified by the thermal noise of molecules in the sea. The spectral level of this noise contribution increases with frequency [11].

II. CHARACTERIZATION

This section provides a review about the characterization of ambient noise. Ambient noise is made of three constituent types – wideband continuous noise, impulsive noise and tonal noise. Impulsive noises are transient in nature and are of wide bandwidth and also short duration. They are best characterized by quoting peak amplitude and the repetition rate. Continuous wideband noise is characterized as the spectrum level; which is the level in a 1Hz bandwidth.

Ambient noise is characterized into sea surface noise, biological noise and traffic noise [2]. Here the ambient noises are usually measured using either buoyed drifting system or moored system. During analysis of noise it is very important to separate the noise into wind driven and non-wind driven because most of the sea area is surrounded by wind and wind noise contributes more to ambient noise.

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Classification is based on characteristics of ambient noise into frequency domain and time domain, the sea state is further classified by a model consisting of three stages, namely class determination, allocation and identification [3]. Better results in sea-state classification can be obtained in the frequency domain by applying the third octave spectrum as a parameterized signal of ambient noise.

To calculate shipping noise, the numbers of ships moving in the defined area are counted [4]. The noises which are generated by specific sources for ambient noise have their characteristic frequency, time signatures and also characteristic occurrences, durations. Eliminating the extreme weather events will have larger impact on gross percentile statistics, particularly at higher frequencies. Hence it allows the estimate of ambient noise in an area, if all of local shipping and the extreme weather periods are eliminated.

Chaotic characteristics of noise signals which are radiated from ships using the power spectrum analysis, singular spectrum analysis, Lyapunov exponents and correlation dimensions are studied [6]. It is difficult to detect and recognize the weak underwater acoustic signals because of the ocean ambient noise. The performance of underwater acoustic system depends on the characteristics of ambient field and signals. Random process theory has been employed as power tool in modeling complex signals like underwater acoustics and radar.

Since it uses only statistical characteristics of signals on specific random assumptions, the loss of information about the characteristics of pattern signals and the ambient signals is unavoidable. This may be another important reason, added to the complexity of ocean circumstance, for which the performance of underwater acoustics system is hard to improve.

III. SIGNAL DECOMPOSITION

A noise reducing system is developed and the effects of wavelet de-noising process for underwater acoustic signals are evaluated [7]. Two noisy signals are taken to examine the varied designs for doing de-noise of signals: artificial signals and actual underwater acoustic signal. During research a sophisticated procedure was developed to de-noise the signal automatically, the procedure is of three parts:

- Signal decomposition by applying wavelet transformation of the underwater acoustic signals.
- Thresholding to obtain wavelet coefficients.
- Inverse wavelet transformation for reconstructing modified signals.

The problem of de-noising makes use of genetic algorithms to find the optimal threshold value for the shrinking of wavelet coefficients. Criteria of mean-square error and signal to noise ratio are used to evaluate the result of the de-noising.

There are 2 major steps for signal de-noising:

- Signal preprocessing which including amplifying, filtering and which makes use of Analog and/or Digital (AD) technique to save signals as digital file.
- De-noising for underwater acoustic signals.

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Genetic algorithms are used to get threshold value and best suitable thresholding function for de-noising. Fitness function can be developed according to the characteristics of the input signals. Because of this property it can obtain optimal threshold value.

Hybrid denoising method is presented as the combination of Empirical Mode Decomposition (EMD) and Higher Order Statistics (HOS) [4]. EMD is an adaptive data-driven method, which is used for effective decomposition of the noisy signal into its functional components. Then the Kurtosis and Bispectrum operated as the Gaussianity estimators, ensuring detection, are supplemented by Bootstrap techniques and also the removal of signal's Gaussian components. Experimental inferences show the applicability of this method in signals denoising. Specifically, EMD-HOS outperform same denoising methods based on Wavelets for most of the test signals [16].

The reports on trend in low-frequency (10–400 Hz) ambient noise levels and the present measurements are made using a calibrated multi-element volume array at deep ocean sites in the Northeast Pacific from 1678 to 1686 [8]. In their measurements, spectral noise levels and also the horizontal and vertical noise directionality are provided. The data presented provides to the trend derived from 1660s data which is extended to around 1680, but has since then continued at a lower rate.

The ultrasonic signal is commonly used for depth estimation [5]. This signal is affected by underwater noises which result in inaccurate depth measurements. Noise reduction methods for underwater acoustic signal are developed. Signal processing is done with the data collected using TC2122, a dual frequency transducer along with the Navisound 413 echo sounder. There are two signal processing methods which are used: 1. denoising algorithm based on Stationary Wavelet Transform (SWT) and 2. Savitzky - Golay filters. Results are evaluated on the criteria of peak signal to noise ratio and the 3D Surfer plots of the dam reservoir whose depth estimation has to be done. Hence analysis of Ultrasonic signal is done using two methods: Harr Wavelet Transform and Savitzky - Golay filter. Among all wavelet transforms, Harr wavelet is the best suitable wavelet for noise reduction in ultrasonic signals because of the PSNR value being high among all the wavelets used. A good comparison of wavelet based denoising of acoustic data is provided [14].

In Savitzky - Golay Filter, analysis is done for different orders of polynomial and frame sizes which show that with larger order of the polynomial and lesser frame size PSNR is high. The output from surfer plots shows that, the harr wavelet with the decomposition level up to level 5, Savitzky - Golay filter with the order 4 and the frame size of 31 can be effectively used for smoothening the data obtained which lead to the estimation of depth with minimum error using empirical formula. Basic functions may be used for decomposing the frequency bands [6]. These basic functions used are called mother wavelets. The mother wavelets from each wavelet family differ from each other by scaling and also the shifting parameters. Thresholding in wavelet domain is used to smoothen some of the coefficients of wavelet transform sub-signals of the measured signal.

IV. Noise Reduction and Thresholding

Thresholding methods are used at the last step for maximum suppression of the signal noise, where the thresholds are set by estimating the correlation of the corrupting colored noise in the form of Hurst exponent.

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The development of modified adaptive algorithm for the detection of underwater acoustic signals is prone to the effect of ambient noise in the near and far seas [15]. The algorithm is developed to improve the SNR and get minimum mean square error with effective usage of the learning and convergence parameter. Characteristic frequency band of the real time noise data are studied on the basis of Power Spectral Density (PSD) and analyzed accordingly. A reference signal is generated and added with the noise signal. The noisy signal is applied to various algorithms and SNR values are calculated. LMS algorithm is linear adaptive filtering algorithm, and consists of two processes: Filtering process and the Adaptive process. In Modified LMS Algorithm, the equation of new LMS is modified [18].

Ambient noises are the residual background noise in the absence of individual identifiable sources that can be considered as natural noise environment for hydrophone sensors [17]. The sources include geological disturbances, non-linear wave interaction, turbulent wind stress on the sea surface, shipping, distant storms, seismic prospecting, marine animals, breaking waves, spray, rain, hail impacts and turbulence.

A thresholding function is presented which is based on wavelet thresholding denoising method which is put forward by D. L. Donoho and I. M.Johnstone [19]. The numerical result shows that new method gives better SNR gains than the hard- and soft-thresholding methods. Also, the new thresholding function is more elastic than soft- and hard thresholding techniques. It is suitable for many signals including the signals with a low SNR. The principle of wavelet denoising is to recognize and nullify the wavelet coefficients of signals which are likely to be mostly noisy. The wavelet transform is periodically time-invariant. By using different shifts of noisy signal, one can compute different estimates of unknown signal, and then linearly average the estimates. The estimates at different shifts have statistically different errors, which will be reduced by averaging.

An underwater noise reduction technology is developed that enables to minimize characteristic underwater noise [20]. The method detects underwater noise by comparison of the signal level ratios among low, middle and high bands. Reduction of noise is applied to this detected underwater noise. All the process is performed by signal processing, and a special sensor is not used in this method. Hence, the recording unit size will not rise. And also, this method reduces only the characteristic underwater noise, which results in natural underwater sound quality.

The acoustic ambience of ocean is extremely turbid with a myriad of heterogeneous competing sources, of both the manmade and of natural origin [21]. The clamor of sources like shipping, sonar, coastal machines, marine life, shore waves, and other hydrodynamic activities which is cumulative can lift the noise floor to much higher ranges due to which the vital signals are masked and buried well below the recognizable level. Degree of observability of a signal above the background noise or the ambient noise floor affects the accuracy and reliability of acoustic systems and devices. Commercial shipping and seismic surveys are dominant in the lower side of the spectrum, marine biological vocalizations, naval, commercial, fishery, and recreational sonar are dominant in the middle and higher side of the frequency spectrum.

Short - time Fourier transforms (STFT), which have variety of windows with varying length, are developed [22]. Wavelet Transform is an alternative to the Fourier transform and STFT with better time-frequency localization. The use of wavelet transform in signal detection against wind driven ambient noise are explored. To smooth out or to remove the coefficients of wavelet transform sub-signals of the measured signal, thresholding is applied in wavelet domain. Non – stationary environment reduces the noise content of the signal effectively. This threshold value is obtained from the functions namely 'rigrsure', 'heursure', 'sqtwolog', 'minimaxi' and universal [13].

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A new wavelet denoising technology is been proposed with the modification in the threshold estimation methods and the thresholding methods. The signal added with the wind driven ambient noises are denoised with this method. SNR of the denoised signal improves with this. Estimated RMSE values show that, the error is reduced in the denoised signal when comparing to the noisy signal. Analysis considers the wavelet families: Debauchies, Biorthogonal, Coiflet and Symlet. Results show that sym4 is best suited to increase SNR [22].

Hard threshold method and soft threshold method of wavelet threshold based signal denoising have some shortcomings, a new threshold function is presented to overcome this [26]. This combines both hard threshold function and soft threshold function, which have good mathematical properties and also physical significance. Denoising can be done by selecting suitable parameters with this function.

Results and comparative studies show that the proposed method is superior to both of the hard threshold and soft threshold methods, and it also has obvious effect on signal denoising. The selection of threshold can improve the performance of the algorithm. Unbiased estimation of the signal and better denoising effect can be obtained by a further extension to research on how to select optimal threshold on each scale and find the relation between noisy signal and the parameters of m and μ of new threshold function.

This section discussed the various literature related to several noise reduction techniques and Thresholding methods, rules used in noise reduction.

V. RECONSTRUCTION AND PARAMETRIC ESTIMATION

This section discusses the reconstruction process which is nothing but the reverse process of decomposition. Also the parameters used for measuring the output signal quality are discussed.

Underwater wireless sensor networks give oceanographic monitoring and reliable reporting of data [23]. In this, acoustic communication is applied to underwater applications like oceanographic data collection, offshore exploration, and pollution monitoring and disaster prevention. Signal-to-Noise Ratio (SNR) is a very important need to assess for ensuring smooth and reliable transmission of the valuable data.

The assumption is that the noise is additive and Gaussian [24]. The ambient noise spectrum above a few kHz in warm shallow waters is dominated by snapping shrimp noise. Snapping shrimp noise is impulsive and highly non-Gaussian. Time-varying multi-path propagation and non-Gaussian noise are the two major factors that limit acoustic communication performance in shallow water.

A novel recognition approach which consists of the algorithms of Bark-wavelet analysis, Hilbert-Huang transform and support vector machine is proposed based on the theory of auditory perception [25]. The results of the proposed method was validated by comparing it against the traditional method and evaluated by the recognition experiments for SNRs of 0dB, 5dB, 10dB, 13dB & 20dB. The results obtained are that the average recognition rate of the method is above 88% and can be increased by 0.75% to 6.18% under various SNR conditions compared to the baseline system .It was an attempt of applying auditory perception theory into underwater noise target classification. The experimental results have validated the performance of the method. In future work, the efforts will be made on feature selection and robustness enhancement.

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System design based exclusively on non – coherent and low signaling rates is the combined effects of multipath propagation and temporal channel variability which cause IS1 and strong phase fluctuations of the signal [26]. Established bandwidth-efficient phase-coherent communications result in the advancement of current research in a no of directions which focus on the development of more sophisticated processing algorithms which enable efficient and reliable transmission of data in varying system configurations and also channel conditions.

This section discussed the reconstruction process. Also the parameters used for measuring the output signal quality were discussed. SNR, RMSE, MSE, PSNR were considered while evaluating.

VI. CONCLUSION AND FUTURE WORK

Transmitting data with water as the medium is called underwater communication. Electromagnetic signals are attenuated in water. But sound is less attenuated. Hence it is the most reliable and versatile means of communication underwater. The acoustic signals will be affected by ocean driven noise during transmission. Ambient noise is the background noise which has to be subtracted from the acoustic signal for smooth transmission. Hence the recognition and reduction of ambient noise is the essential part of underwater signal transmission. Studies and research are being carried out extensively in this area. There are many works reported and the research is still in progress. This literature survey presents an overview of the work done on the research of ambient noise affecting acoustic signals.

The existing algorithms consider wind noise for denoising and analysis. Noises are produced from large international cargo vessels, supertankers and cruise ships are constantly in motion, from their propellers, generators, engines & bearings [15]. Ship noises dominate the frequency ranges of 20-230Hz, which is the range used by many species of whale. Hence this poses a problem for whales to communicate and also dangerously, to distinguish ship noise against natural signals and sounds [19].

This results in accidental collisions. It is the main cause for right whales around the world being dead. Ship noise, particularly wherever it becomes constant, can be a cause of whales abandoning their habitats. In coastal areas and around busy ports, this problem is too large.Fusion of existing methods is an emerging technology. In the fusion technique, the best part of each method can be used and collaborated together producing a new technique which will be more efficient than the individual methodologies.

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