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Ship detection using Neyman-Pearson criterion in marine environment

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ABSTRACT

This paper presents Neyman Pearson (N-P) criterion based detector for ship detection in marine environment. Statistical modeling of ambient noise data with and without ship noise, collected in the shallow waters of the Bay of Bengal, are utilized to build the detector. The noise data with and without ship noise are collected using the hydrophones at the depths of 5 m/15 m and 3 m/5 m, respectively, from the ocean surface. The ambient noise without and with ship noise is shown to have generalized extreme value and generalized Gaussian distribution, respectively. The presence of a ship leads to changes in the statistics of the ambient noise. This statistical characterization is used for designing a N-P criterion based log likelihood ratio test for the detection of presence of a ship. The proposed method detects the presence of a ship with an accuracy of 98.33%.

1. Introduction

Ambient noise refers to sustained unwanted background sound at a particular location in the ocean (Robert, 1984). This noise excludes (1) occasional sounds: for example, the noise of a close-by passage of a ship, rainfall, etc. and (2) all forms of self-noise: for example, the noise of current flow around the measurement hydrophone and its supporting structure, electrical noise, etc. (Robert, 1984, CATO, 2008). Ambient noise is made up of contributions from both natural and anthropogenic sources. These sources include distant shipping traffic, wind related noise, seismic noise, and biological noise (CATO, 2008; Hamson, 1997; Van der Graaf et al., 2012). Noise generation mechanism in an ocean involves impact noise, bubble noise, turbulence, seismic, cavitation, and machinery noise (Robert, 1984). The overall ambient noise at a particular location is the sum total of noise due to the individual sources.

The detection of vessels in the oceans is an important activity for improving port security and the security of coastal and offshore operations. Presence of a ship alters the characteristics of ambient noise. Ship noise usually depends on the machinery such as engines, shaft line, air conditioning systems, cargo handling and mooring machinery, vortex shedding mechanism, intake and exhaust, propeller radiated pressures and bearing forces, etc. (Robert, 1984; Ross, 2013, 1981; Lourens, 1990; Rajagopal et al., 1990). Currently, ship detection is of major interest to defense organizations throughout the world. Many works have been carried out in the area of ship detection (Yang et al., 2002; Yang and Li, 2003; Viitanen, 2004; Chung et al., 2011; Lourens, 1988, 1990; Li et al., 1995; Sakthivel Murugan et al., 2011; Firat and Akgul, 2013; Zhao et al., 2011; Zak, 2008; Shi et al., 2008; Soares-Filho et al., ; Xin-Xin et al., 2008; Averbuch et al., 2011; Das et al., 2013).

These works primarily use feature-based classifiers for ship detection. Different methods have been used in the past to derive features that help with the detection and classification of ships. Chaotic modeling (Yang and Li, 2003), fractal (Yang and Li, 2003; Viitanen, 2004), Fourier (Lourens, 1988, 1990; Li et al., 1995; Sakthivel Murugan et al., 2011; Firat and Akgul, 2013; Zhao et al., 2011; Xin-Xin et al., 2008; Zak, 2008; Shi et al., 2008; Soares-Filho et al.,), wavelet transform (Xin-Xin et al., 2008; Averbuch et al., 2011), cepstrum (Das et al., 2013), and empirical mode decomposition (EMD) (Bao et al., 2010; Shuguang and Xiangyang, 2014) based features are some of the examples that have been used in the literature.

It is known that ship noise is modulated at a rate dictated by machinery parameters (Robert, 1984; Ross, 2013, 1981; Lourens and Wynand Coetzer, 1987; Rajagopal et al., 1990). This is used for ship noise estimation in an envelope modulation method known as DEMON (Detection of Envelope Modulation on Noise) (Chung et al., 2011). Measurements of this envelope provide useful information for vessel detection and identification (Chung et al., 2011). For the problem of ship detection, DEMON provides a more reliable method as compared to spectral methods. However, this method requires additional operations (Chung et al., 2011) such as bandpass filtering to suppress ambient noise followed by Hilbert transform for the extraction of the envelope. The Fourier transform of this envelope provides the DEMON spectrum, which is studied in the form of spectrogram to detect and classify a ship.

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In all the prior work mentioned above, frequency domain features such as number, duration, position of the line spectrum, the average level of line spectrum over the average power spectrum, spectral centroid, roll-off, etc. are used. These features are extracted after a number of pre-processing steps required to reduce distortions due to noise from other sources.

Wavelet transform has been used in Xin-Xin et al. (2008), Averbuch et al. (2011) for the detection and characterization of a marine vessel. Ship identification is carried out by analyzing the energy distribution of wavelet packet coefficients of the received acoustic signal, each of which is related to a certain frequency band. Energy in these frequency bands is used as a feature set for the classifier (Xin-Xin et al., 2008; Averbuch et al., 2011). In Averbuch et al. (2011), the overall classifier combines the output from two classifiers: linear discriminant analysis (LDA) and classification and regression trees (CART) for better results.

In the cepstrum-based feature classification (Das et al., 2013), computation of cepstrum involves application of the logarithm function on the signal spectrum that decouples the channel spectral distortion and the source signal spectrum. This is followed by homomorphic deconvolution and cepstral averaging. This helps in enhancing the features for marine vessel classification. EMD based methods have also been used for ship classification (Bao et al., 2010; Shuguang and Xiangyang, 2014). In Bao et al. (2010), ensemble EMD is used to compute the intrinsic mode functions that are then utilized for the analysis of ship-radiated acoustical noise. In Shuguang and Xiangyang (2014), Wavelet analysis and Hilbert-Huang transform (Hilbert transform of Intrinsic Mode Functions obtained using EMD) are used for marine vessel classification and detection. The received acoustic signal is first denoised using Bark-Wavelet transform. The Hilbert-Huang transform is then employed to extract instantaneous frequencies. Features are derived from the instantaneous frequencies. The feature set is used in a support vector machine (SVM) classifier to identify marine vessels.

Although a number of methods have been proposed for ship detection (Leonardo, 2004; Jarabo-Amores et al., 2009, 2013), to the best of our knowledge, no work has been carried out so far to detect underwater ships using the statistical characterization of noise and with Neyman-Pearson (N-P) criterion. In this paper, we propose statistical signal modeling based approach to design a detector for ship detection in underwater environment. The statistical modeling is utilized in N-P criterion to derive the likelihood function to be used for detection. This is to note that N-P criterion is a standard method of statistical detection theory used in various applications of signal processing and wireless communications. While many of the existing methods require pre-processing steps to deal with the ambient noise (Chung et al., 2011; Zak, 2008; Soares-Filho et al., 2000; Das et al., 2013; Shuguang and Xiangyang, 2014), the proposed method utilizes the changes in the statistics of noise to an advantage in ship detection. We carry out statistical modeling of noise with probability density function (pdf) estimation. The estimated pdf parameters and the log likelihood ratio of N-P criterion are used for ship detection in the proposed method.

Note: This paper proposes a methodology to build a ship detection system based on statistical modeling of noise (or data) measured at a particular location and hence, is specific to the noise types occurring at that location. This is to note that, in the proposed modeling, any noise other than ship noise would be included within the statistical modeling of ambient noise. In other words, the proposed noise modeling is based on statistics of the captured signal and hence, includes all types of noise specific to that location.

The paper is organized into seven sections. Section 2 describes the dataset used. Section 3 presents the statistical modeling of ambient noise with and without ship noise. In Section 4, the log likelihood ratio test (LLRT) of N-P criterion is discussed. The statistical characterization of Section 3 is used to develop N-P criterion based LLRT. The performance of LLRT for ship detection is evaluated in Section 5. Assumptions and the related limitations of the proposed work are presented in Section 6. In the end, conclusions are presented in Section 7.

2. Data description

These data were collected in Chennai, India from the Bay of Bengal (Source of Data: NIOT, Chennai, India). Ambient noise measurements without the ship noise were made using Reson hydrophones at depths of 5 m and 15 m from the surface, where the ocean depth was 58 m. Data were acquired at a sampling rate of 500 kHz. Twenty four sets of data were collected by periodic measurements. Twelve dataset were collected at a depth of 5 m and twelve are collected at a depth of 15 m, where the temperature was around 29 °C and the wind speed was varying in the range of 3 m/s to 4 m/s, i.e., wind speed was approximately 7 − 10 knots on the Beaufort Wind Scale. Data were collected at a latitude of $N13°21.893'$ and a longitude of $E080°27.438'$ in the Bay of Bengal, Chennai, India.

Ambient noise with ship noise measurements were made using a Reson hydrophone at depths of 3 m and 5 m from the ocean surface. Thirteen data sets were collected corresponding to four different ships with ocean depth varying from 16 m to 22 m. These four ships were BUNGA TERASEK, DUBAI ENERGY, STEFANIA and ALTAIR. The measuring boat sizes were approximately $46 \times 16 \times 10\ \text{feet}^3$ having 106HP engine capacity. The data were acquired at a sampling rate of 10 kHz. Each set of data was collected by measurement for 60 s. Measurements were carried out at temperature conditions of around 28 °C and wind speed varies in the range of 3 m/s to 4 m/s.

In both the cases, the hydrophones were suspended from the measurement platform using the rope and mounting arrangement that links to the rope as shown in Fig. 1. The hydrophones had a receiving sensitivity of −170 dB over a frequency range 0.1 Hz to 120 kHz. The data were acquired at a rate of 10 kHz (for ship noise) and 500 kHz (for ambient noise), filtered and digitized with a portable data acquisition system with 12-bit resolution. The noise value was the voltage measured at hydrophone output. The unit is volts with a reference value of '0'. During the period of data collection all machinery on the boat/ship were switched off and the recording system was powered by battery. Wind speed was simultaneously measured during data acquisition.

This is to note that this work proposes a novel methodology for the detection of the presence of a ship and not the classification of different ships. Thus, these dataset with four different ships are valuable in the

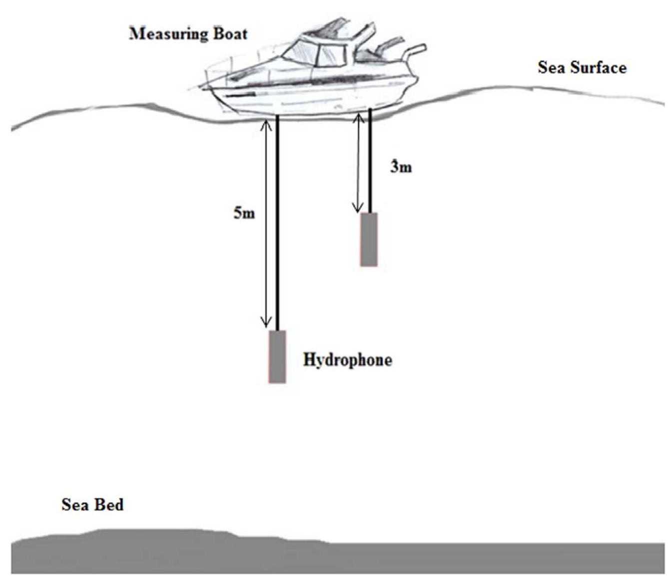

Fig. 1. Data measurement set-up.