Ship signature identification using Vector Sensor Array field experiment conducted at Chennai Harbor

Shweta Lokhande[1], Malarkodi. A[2], Latha. G[3] and S Srinivasan[4]
[1, 2, 3]National Institute of Ocean Technology, Ministry of Earth Sciences, Chennai-600100, India
[4]Madras Institute of Technology, Chennai-600036, India

Abstract

Shipping activities contribute significantly to ambient noise in the ocean. The noise is produced from machinery, engine and propellers. Underwater vector sensor array is used to record the sound pressure and particle velocity in three orthogonal directions. An autonomous noise measurement system (vector sensor array) is deployed in Chennai harbor for a period of one month during 19 October 2021 to 17 November 2021 at 7 m depth where the water colomn depth is 15 m. Vector sensor array has two numbers of elements, separated by a distance of 125 mm. Acoustic data collected by this system is analysed which shows that vector sensor array has measured the shipping noise during the deployement period. The sound pressure level from hydrophone and its average for the acquired signal duration is calculated. Beam forming algorithm (Multiple Signal Classification) is used for Direction of Arrival (DoA) estimation of passing ship. The autonomous noise measurement system using vector sensor element has proven to be very effective at identifying and monitoring very low frequency components of the acoustic signature.

Keywords- Vector sensor array, shipping noise, bearing angle, Noise measurement system, Ship signature

1. Introduction

One of the most critical aspects of marine security is keeping track of vessel traffic in coastal areas. One way to perform source localization and monitor the vessel traffic is the underwater acoustic Vector sensor array(VSA). Vector sensor array can be used for coastal surveillance applications. It is capable of measuring the particle velocity in three orthogonal directions along with the pressure. Studies of background noise revealed anthropogenic sources with local ship traffic density. The noise level depends on the density of local ship traffic [1]. The noise level has increased in recent years, which may impact the marine environment, especially the marine mammals'. Ship noise can travel long distances and marine species that may rely on sound for their orientation, communication, and feeding can be harmed by this sound pollution [2]. To improve our understanding of the contribution of shipping noise to the marine environment, broadband acoustic measurements of the radiated noise from individual modern ships under typical operating conditions are required [3]. In many applications, ship signature identification is performed using a hydrophone array. The hydrophone array requires a precise system to perform measurements. It is crucial to have a mechanism for establishing and maintaining

Corresponding authors: (shweta.niot@gov.in)

the sensor's position. The absence of a precise system would result in issues with uncertainty and unacceptably high processing mistakes [4]. Source localization using a hydrophone array and vector sensor array is analyzed by Paulo Santos et all [5]. Results revealed that when compared to hydrophone arrays, the VSA enhances resolution by reducing ambiguities in direction of arrival estimation and providing information in both the vertical and azimuthal direction. Direction of arrival estimation of moving source (ship) using vector sensor array data is presented using intensity based method [6]. Azigrams, in combination with spectrograms can help to identify source types based on the time and frequency information. Localization of underwater ship noise source using the discrete Fourier transform and the short-time Fourier transform and the intensity method is analyzed by I. Gloza [7]. The narrow band component of the ship hydro-acoustic noise spectrum has been identified in the time and frequency domain.

In this work acoustic vector sensor array data is used for underwater ship signature identification and sound source localization. An autonomous noise measurement system consisting of a vector sensor array is used to record the sound pressure and particle velocity in three orthogonal directions. Spectral analysis is carried out on the dataset and ship passage information is correlated with marine traffic data collected during experiment.

2. Methodology

The signal acquired by the Vector sensor array has the following form [8] [9]

$$\mathbf{y(t)} = \sum_{s=1}^{M} \mathbf{W(\theta_s\, ,\emptyset_s)\; S_s(t) + n(t)} \quad (1)$$

where W is the steering vector towards the direction$(\theta_s, \emptyset_s)$, $s_s(t)$ is the signal emitted by the s^{th} source and

$n(t) = [n_1(t).. \;\dots\; n_L(t)]^T$

is the noise vector. The weighing vector for the i^{th} element of L element VSA is given by [9]

$\boldsymbol{W(\theta,\emptyset)}$=[1 $cos\theta cos\emptyset$ $cos\theta sin\emptyset$ $sin\theta$] $exp(jk.r)$ (2)

where i =1 . . .. .L is the number of elements in array. $\boldsymbol{\theta}$ and $\emptyset$ denote the azimuth and elevation angles of the unit vector for $\theta \in [0, 2\pi)$ and $- \pi/2 \leq | \emptyset | \leq \pi/2$. The velocity gradient can be given as-

$$\boldsymbol{grad(v) = \frac{\partial v}{\partial x}} \quad \mathbf{(3)}$$

where v is the velocity and x is the distance. Velocity gradient for x y and z components calculated as-

$$V_x = (X_2 - X_1)/d$$

$$V_y = (Y_2 - Y_1)/d$$

$$V_z = (Z_2 - Z_1)/d$$

where X_1, Y_1, Z_1 and X_2, Y_2, Z_2 are particle velocities in x, y and z direction from element one and element two respectively. 'd' is the distance between the elements.

The power density spectrum for the MUSIC algorithm is [10]

$$P_{MUSIC}(\theta, \emptyset) = \frac{1}{W(\theta,\emptyset)^{\dagger}\; E_n\; W(\theta,\emptyset)} \quad (4)$$

where E_n is the noise subspace matrix which derived from the singular value decomposition of covariance matrix of sensor output data presented in equation 1 and (w$(\theta, \emptyset)$) is weighing vector calculated in equation (2).The symbol† shows complex conjugate opearator.In order to calculate sound pressure level Welch method is used to calculate the Power Spectral Density(PSD). The PSD values are derived from scaled transducer output. The output voltage has been converted from voltage to pressure form.

The range at a given one minute interval is calculated as [3]

$$R_a = \sqrt{(d_{cpa})^2 + (d_i)^2} \qquad (5)$$

where d_{cpa} is the distance of the ship from vector sensor array at closest point of arrival (CPA) and d_i is the distance the ship travelled in the 1 minute interval. Sound pressure level (SPL) is calculated from the Welch's power spectrum estimation method with 4096 FFT points and 5 kHz sampling frequency. Source level at octave frequencies are calculated from the sound pressure level and range calculated in equation (4). [3]

$$SL = SPL + 20 * \log (R_a\ [m]) \qquad (6)$$

where SPL presents sound pressure level and R_a is range in meter.

3. Data processing

Vector sensor array data is collected from Chennai harbor during October-November 2021.Vector Sensor array system was deployed for one month period during 19 Oct - 17 Nov 2021 in Open Ocean at a depth of 7 m where the water column depth is 15 m. Vector sensor array with two number of elements is used and distance between elements is 125 mm with sampling frequency of 5 kHz. Before being used for analysis, the acoustic data acquired by this system is preprocessed by detrending, filtering and hydrophone data is converted to pressure from voltage. Spectrogram analysis is carried out which shows the vector sensor array has measured the shipping noise during the deployment period.

4. Results and discussion

Figure 1 shows sound signal acquired by one element of VSA which has 4 outputs ie acoustic pressure from hydrophone and particle acceleration in three orthogonal directions X,Y and Z from triaxial accelerometer.

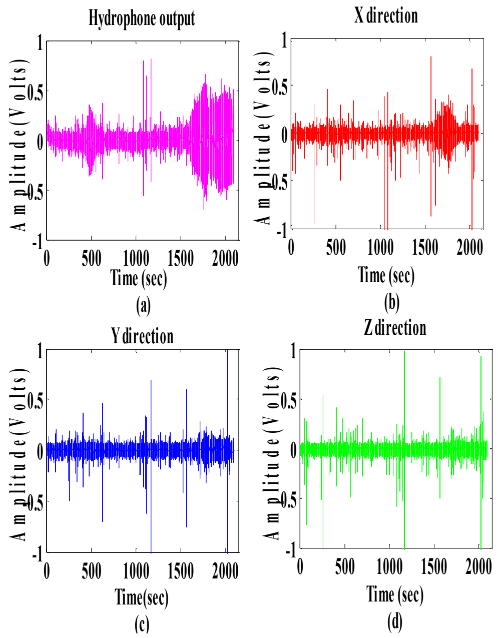

Figure 1: VSA output a) hydrophone output b) received signal from X direction c) Y direction d) Z direction

Figure 2 (a) presents the spectrogram of sound signal recorded by the hydrophone. Tonal lines can be detected at very low frequencies (below 100 Hz) due to the cavitation of the propeller blades and their harmonics. Direct signal interactions with reflected surface and bottom propagation channels result in constructive and destructive interference that results in U-shaped interference patterns at higher frequencies more than 100 Hz. This is called the Lloyd's Mirror Effect [11]. It is influenced by the depth of the source and receiver, the distance between the source and receiver, the characteristics of the water column, and bottom reflections [12], [13]. Figure 2 (b) shows the sound pressure level from one hydrophone and its average for the acquired signal duration. The highest sound pressure level is 123.4 dB re 1 μ Pa/Hz for a low frequency of 135 Hz.

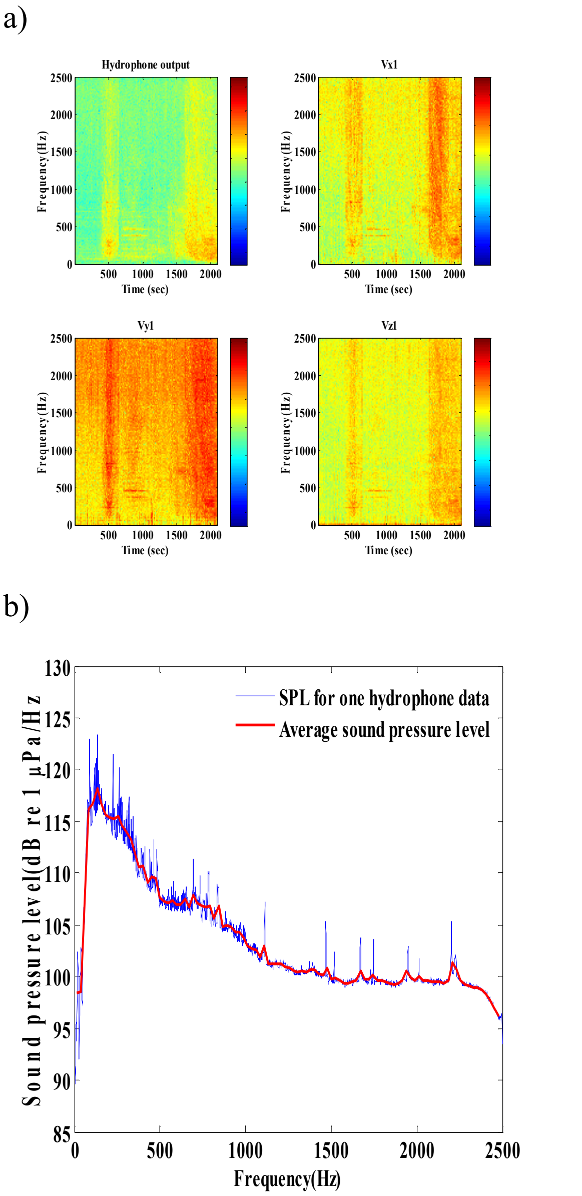

Figure 2: a) Spectrogram of noise recorded by one element of VSA b) Sound pressure level and average SPL for one hydrophone data

4.1 Ship passage information and bearing angle calculation

Marine traffic data was collected to correlate the presence of the ship during vector sensor array measurement. Vessel position, type of vessel, distance of ship with respect to the vector sensor position, time of collection, and other parameters of the ship like MMSI, speed, draught, and dead Weight are collected. The spectrogram in figure 2(a) shows the striation pattern during 400 to 600 seconds, which indicates the presence of a passing ship. A tug's (source of opportunity) presents was observed at 500 seconds during vector sensor data measurement. The spectrogram illustrates that the closest point of arrival (CPA) occurs at 500 seconds. Figure 3 shows the source level of source of opportunity at octave frequencies of 31 Hz, 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1 kHz and 2 kHz. The highest source level of tug is 131.8 dB re 1 µ Pa at a frequency of 125 Hz

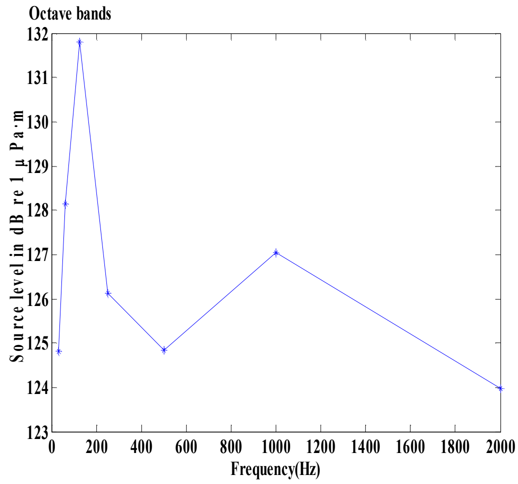

Figure 3.Source level for tug at octave bands

Beam forming algorithm (Multiple Signal Classification) is used for direction of arrival estimation of passing ship (tug). Acoustic data is pre-processed before being used for source localization algorithm. The hydrophone output voltage is applied with receiving sensitivity to obtain the pressure signal and velocity gradient is used for calculation of spectrum. . Estimated azimuth angle after being corrected from compass data is 250 degree and elevation angle 5 degree with one ambiguity present at 110 degree as shown in figure 4. The actual angle is 247 degree calculated from GPS.

5. Conclusions

The data collected by Chennai harbor used to identify the ship signature and to find the direction of arrival and localization of the moving sources. Data collected by acoustic vector sensor array is processed in time and frequency domain and acoustic parameters of ship like sound pressure level and source level are calculated. In its ability to recognize and keep track of very low frequency components of the acoustic signature, the autonomous noise measurement system using vector sensor element has shown to be very effective

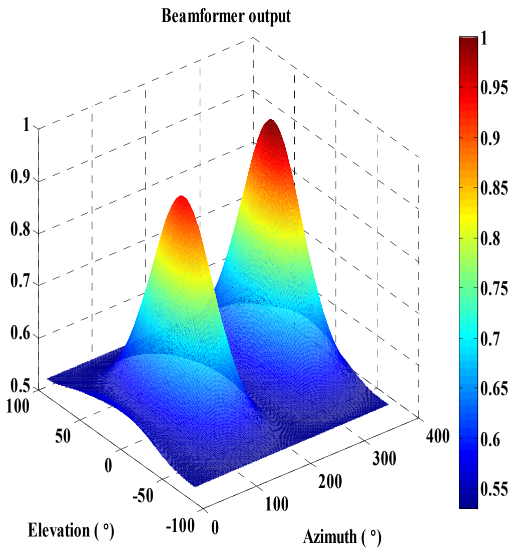

Figure 4: Beam former output

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