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ARTICLES

INFORMATION

FOREWORD

Ocean Acoustics ,a prime area of research focused on underwater sound, its propagation and behavior in the dynamic ocean, provides many insights to understand the ocean environment through active and passive acoustic techniques. Since electromagnetic and optic waves do not penetrate significantly in underwater, sound waves are the most sought after tools to probe the oceans for immense applications. Though satellite remote sensing techniques are available for measurements in the ocean, they are more suitable for ocean surface related data. The active techniques have been in use for seabed imaging and sub bottom classification using devices such as side scan sonar and multibeam sonar. These involve transmission of high frequency sound in the ocean. In the last one decade, a lot of research has been carried out on impact of anthropogenic sound on marine ecosystem and there has been a major shift towards development of passive techniques for estimation of ocean environmental parameters. Apart from the scientific purposes, the development of passive systems for strategic requirements of the country is another major requirement.

Journal of Acoustic Society of India (JASI) has been publishing quality research papers on advanced acoustic techniques and recent findings from our region. The current special issue on "Passive Acoustics" involves bringing together the researchers working in this area in Indian region . This will pave way to strengthen the investigations carried out and provide a joint platform to assess and carry out future needs in ocean acoustics research and technology development. National Institute of Ocean Technology, Chennai under Ministry of Earth Sciences Government of India has made significant progress in the last ten years, in the development of indigenous passive acoustic systems for autonomous operations in the open ocean including polar region, time series data collection on ocean ambient noise and using the same for acoustical oceanography as well as other strategic applications. Significant collaborative work in major areas such as marine bio acoustics and geo acoustics jointly with CSIR- National Institute of Oceanography, Goa have been carried out. These efforts have resulted in high impact research papers in reputed journals.

In this special issue, 5 papers were chosen through peer review process. Among them, 2 papers are related to the Arctic ambient noise measurements and analyses of ice melting (Ashokan *et al.*) and clustering techniques for segregation of ship sources (Nasiha *et al.*). Two papers are on Shallow water noise off Goa (Williams et al) and Kavaratti island (Kashyap Jois *et al.*) and one paper is on characterizing acoustic vector sensors (Sridhar *et al.*). In a nutshell, these investigations are elucidation of passive acoustics techniques for ocean environmental studies.

I express my gratitude to Director, NIOT and Director CSIR-NIO Goa for their encouragement in carrying out this work. I sincerely acknowledge Ministry of Earth Sciences for their support in funding this research work. I am thankful to Dr. Bishwajit Chakraborty, Chief Editor, Journal of Acoustic Society of India for his agreement to go ahead with this special issue, and his guidance.

— G. Latha
Guest Editor - JASI

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Unsupervised vessel type clustering in the Kongsfjorden Arctic using passive acoustic data

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ABSTRACT

Ship noise is a significant component of underwater noise in the open ocean and plays an important role in underwater acoustics. In this paper we present an approach for surface vessel classification from underwater radiated noise and ship parameters. Unsupervised machine learning method called k means algorithm is used to classify vessels that transit in Kongsfjorden, Svalbard region during 2015.To achieve ship classification, we use spectral features of noise acquired by an autonomous Ambient Noise Measurement System deployed by National Institute of Ocean Technology in the Arctic. Time series underwater sound measurements in the shipping noise indicator band at 63 Hz is used to find distinct ship features.Acoustic signal and ship parameters were grouped via k means clustering algorithm. Our findings confirm the suitability of proposed approach for classifying different vessels into four different groups such as cruise liners, sailing vessels, motor boats and cargo ships.

1. INTRODUCTION

Identification of sources from underwater ambient noise is a substantial field in areas dealing with maritime traffic management, coastline surveillance, security in the seas, fishing and marine environment protection. Shipping generated noise contribute significantly to underwater acoustic signals among other sources (Wenz, 1962; Carlton, 2007; Hilderbrand, 2009). Underwater shipping noise is generated in low frequency domain from 50 to 150 Hz from its propulsion systems and especially the propeller blade cavitation sound (Ross, 1976; Southhall *et al.*, 2017).Cavitation takes place when the rotating blades cause the local pressure variance in water to drop below a critical value (Park *et al.*, 2009). The generated pressure difference in the water column is measured by the acoustic sensors as underwater ambient noise signals along with background noise. The measured acoustic signals may vary based on ship type, speed, size, propulsion system and also sea conditions.

In recent years arctic marine transportation is notably increasing for different purposes such as arctic shipping routes for global trade, research and tourism.Detection and classification of vessels used for shipping purposes can be useful for monitoring marine traffic (Fillinger *et al.*, 2010, Chung *et al.*, 2011) and environment monitoring systems. This study is an application of the passive acoustic method for vessel classification in an Arctic fjord region namely Kongsfjorden, Svalbard. Acoustic soundscape of Kongsfjorden region were studied in detail for its several sound sources (Mahantyet al1., 2020), ice melting dynamics (Ashokan *et al.*, 2016; Mahanty *et al.*[2], 2020), anthropogenic and other sources (Buscaino *et al.*, 2014).

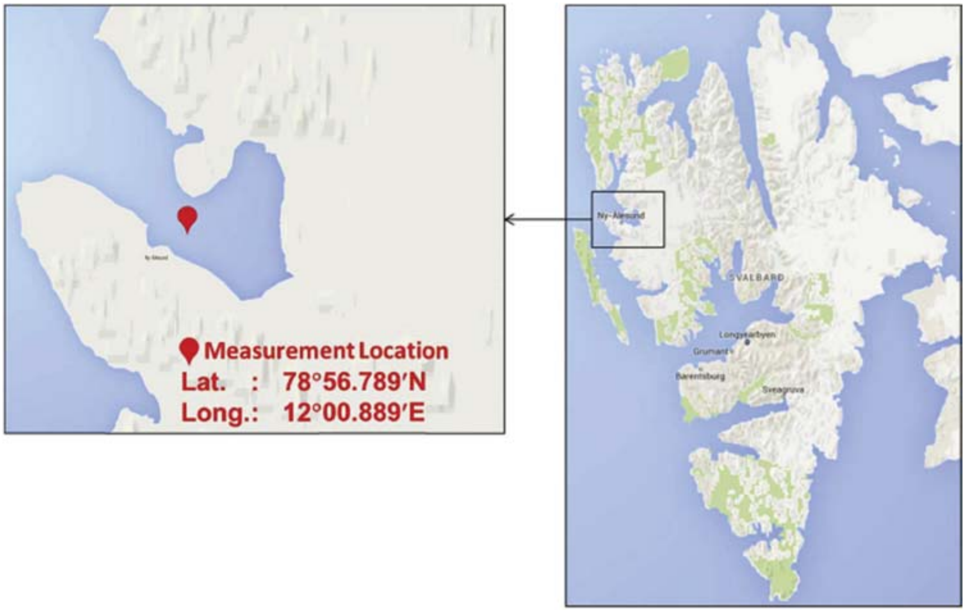

Fig. 1. Location of acoustic measurement site at Kongsfjorden, Svalbard.

Recent ambient noise propagation studies reveal the fact that low frequency acoustic band is dominated by marine traffic during summer period in this fjord region (Sanjana *et al.*, 2018). In this study the underwater acoustic signals were measured and processed from ambient noise measurement system deployed at Kongsfjorden in the vicinity of Svalbard shipping port to analyse shipping activity and vessel classification.

Unsupervised machine learning method called *k* means clustering method is used in this study to classify the vessel types into different dissimilar groups. Application of this algorithm will be helpful in maritime monitoring, management and to detect the ship transits for security purposes. *k* means clustering method uses unlabelled data to discover categories in the given data. Principal component analysis is used for dimensionality reduction and grouping of vessel data. Based on this study four different vessel classes were recorded in the Kongsfjorden waters during open water period of 2015, July-September.

2. DATA AND METHODS

2.1. Acoustic Recordings

a. *Deployment Site of acoustic recordings :*

Time series passive acoustic measurements were recorded using Autonomous Ambient Noise Measurement System (ANMS) deployedas part of Indian Arctic mooring called 'IndArc' (Venkatesan *et al.*, 2016) at Kongsfjorden, Svalbard archipelago, jointly by National Institute of Ocean Technology (NIOT) and National Centre for Polar Ocean Research (NCPOR), Ministry of Earth Sciences (Fig. 1). Kongsfjorden is a glacial fjord system, located in the west coast of Spitsbergen. It is a narrow fjord with 20 m long and varying width of 4 km to 10 km. Kongsfjorden is an open fjord system without any sill in the entrance, which lead to the stratification in summer and mixing of Arctic and Atlantic waters during winter seasons (Svendsen *et al.* 2002, Noufal *et al.*, 2017). Hence the fjord dynamics is governed by this exchange process. The fjord is frozen in winter and with open waters during July to September months of a year.

The mooring system is deployed at the location 78°57′N and 12°01′E in 198 m depth in the inner basin of Kongsfjorden and 3 km away from the Ny-Alesund shoreline. Along with the passive acoustic sensor (hydrophone), the mooring consists of various subsurface profilers such as Conductivity, Temperature and Depth profiler (CTD), Acoustic Doppler Current Profiler (ADCP), and PAR (Photosynthetically Active Radiation) sensor. Continuous passive acoustic data recorded during the period July 2015 to April 2016 are used in this study.

b. *System Overview and Acoustic Data description :*

The ambient noise measurement system (ANMS) consists of single omni directional hydrophone (Cetacean C55) and a data acquisition system, fixed at 30 m depth in the mooring line. The measurements were made with a sampling frequency of 50 kHz, for a duration of 60 seconds, once in every 3 hours. Acoustic pressure level difference in the surrounding medium is recorded as voltage and then converted into pressure (µPa) by applying preamplifier gain and receiving sensitivity of hydrophone. The preamplifier gain is 20 dB and the receiving sensitivity of hydrophone is -165.4 dB re 1 V/µPa at 63 Hz and 122 Hz.

2.2. Ship passage information

Fjord water mass vary seasonally and inter annually based on circulation and fresh water run-off from snow melting, ice calving, precipitation and glacier ablation. Apart from fresh water supply to the fjord system, since the fjord dynamics is influenced by the intrusion of Atlantic waters, the semi diurnal component of tide is a vital driven force in controlling the upper water mass in the Kongsfjorden. Characteristic seasonal temperature variation from spring to summer reflects an increase in fjord air temperature to 8°C (Svendsen *et al.*, 2002). Hence the seasonal hydrography and water mass increase in summer is dominated by fresh water supply due to surface melting process and iceberg calving events in the deeper levels. Previous observations by Cottier *et al.*, 2005 show that Atlantic water penetration at the fjord mouth is rapid and in higher rate during summer season.

Henceforth the cross-seasonal variability in the fjord turns the ice mass into open water mass during mid-summer. The open water environment supports the shipping activities during summer in fjord. Maritime activity in the Kongsfjorden region is comparatively more in recent years, for the purpose of tourism, fishing and research activities (Stocker *et al.*, 2020).

Since the ambient noise measurement system (ANMS) is located nearer to Ny-Alesund port, it was possible to make recordings of intensity and variety of marine traffic around port which includes cruise liners, cargo vessels, yachts, fishing boats and sailing vessels. The vessel particulars such as dimensions, gross tonnage along with detailed arrival, departure information based on port calls were obtained from marine traffic - Automatic Identification System (AIS) data source.

Vessel presence during July 2015 to April 2016 at Kongsfjorden, based on marine traffic Automatic Identification System is shown (Fig. 2). From analysis of the AIS data availed from maritime traffic data source, vessels at Svalbard coast were documented for classification purpose (marine traffic, 2018).

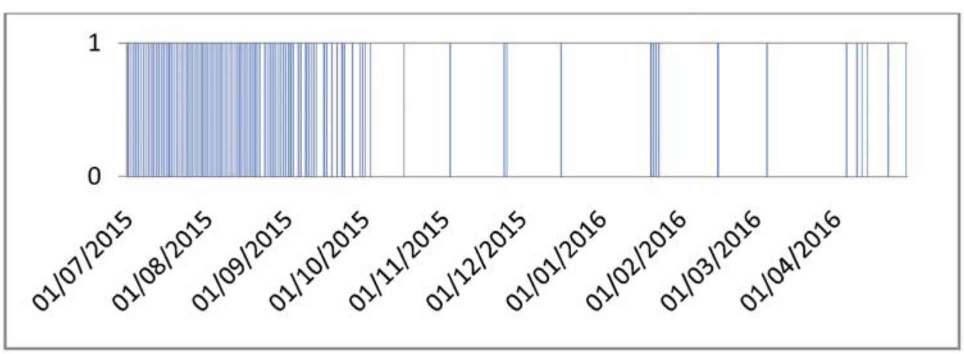

Fig. 2. Vessel presence during July 2015 to April 2016 at Kongsfjorden, based on marine traffic Automatic Identification System (AIS).

Ambient noise data is acquired every 3 hr for 60 sec. Hence total number of acoustic records during the observation period 19/07/2015 to 30/09/2015 is 587. The total number ship transits during the period is 604. There are 103 concurring marine traffic data set we could acquire when the ship is passing through the deployed sensor, based on the time stamps of ship transits.

2.3. Acoustic Data description and signal processing

Time series passive acoustic data recorded from the mooring deployment during the open-water period of 2015 is used to study the marine traffic across Kongsfjorden region. Total number of 587 acoustic data were used for this study, recorded from 19/07/2015 to 30/09/2015. Every one-minute acoustic recordings were processed using Fast Fourier transform (FFT) with FFT length of 4096.

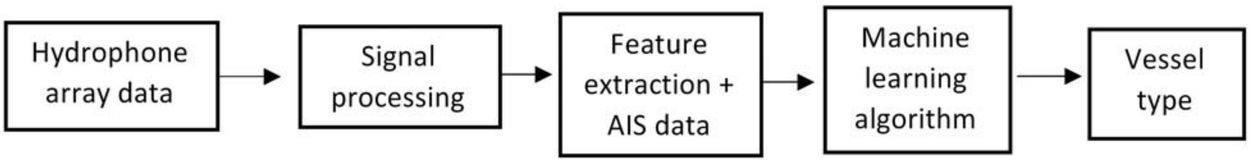

Fig. 3. Schematicrepresentation of acoustic signal processing from hydrophone array measurements.

The resulted frequency resolution achieved from the Hanning window for the acquired acoustic signal is 12.2 Hz. The analysis of Fast Fourier transform resulted mean pressure squared values in 1 Hz bin for 1 Hz to 25000 Hz. The data were converted into sound pressure levels or power spectral density (PSD) in decibel units.

Underwater ship radiated noise has the main sources of propeller cavitation and other machineries which corresponds to low frequency range (Richardson *et al.*, 1995; Hildebrand, 2009; Southall, *et al.*, 2017). Among other ship noises, propeller cavitation noise is dominant which has peak power near 50 -150 Hz (Ross, 1976; Arveson and Vendittis, 2000). In this study sound pressure levels at 63 Hz were used for the clustering analysis and classification of vessel type (Fig. 4).

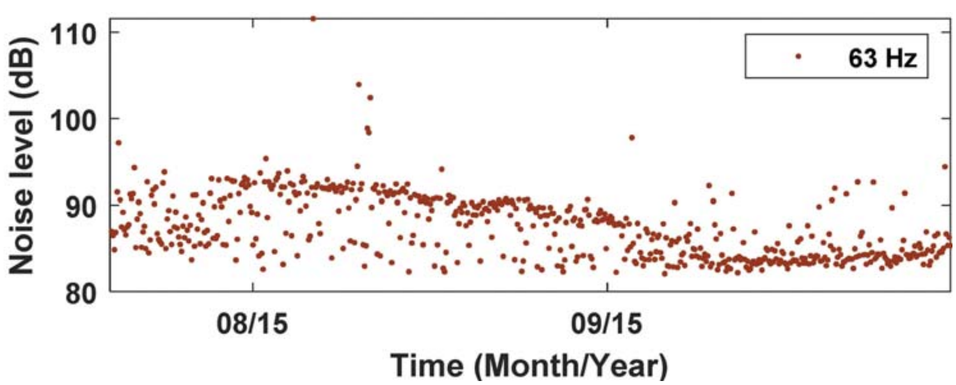

Fig. 4. Noise level at 63 Hz during July to September 2015 at Kongsfjorden during when vessel traffic is dominant.

k means clustering

k means clustering is an unsupervised machine learning technique for pattern recognition in the given dataset. This is one of the partition-based algorithms, which defines the *k* number of distinct groups in given dataset. The defined groups or clusters from *K* means clustering (*k*-MC) are alike within the group and dissimilar between the group. *k*-MC is popularly applicable in many practical applications. In this study, to classify different vessel types in polar waters *k* means clustering algorithm is used. Sound pressure level at 63 Hz and other related ship parameters were used as features with more discriminative information.

In *k*-MC, the number of clusters is user defined, prior to the classification. The number of clusters, k is decided based on the protype of vessel type data. *k*-means clustering method is briefly described in this section (Dubes and Jain, 1988; Kaufman and Rousseeuw, 1990; Mehrotra *et al.*, 1996). Let us assume an unlabelled dataset consists of m records,

$$P = \{x_1, x_2, x_3, x_4, \ldots, x_m\} \tag{1}$$

$$X_i = (x_{i1}, x_{i2}, x_{i3}. \ldots, x_{in}) \tag{2}$$

In the data record each entry is an *n* dimensional vector,

Data clusters are formed, in such a way that each object belongs to the cluster with the nearest mean. By comparing the distance between the data points to its centroid in Euclidean space, the clusters are defined. Among various methods Within-Cluster-Sum-of-Squares (WCSS) is used in this work to define the clusters. WCSS is the Euclidean distance of each data point in clusters to their corresponding centroids.

$$WCSS = \sum_{C_k}^{C_n} \left(\sum_{X_i in C_i}^{X_m} distance(X_i, C_k)^2 \right) \tag{3}$$

Where, *C* is the cluster centroids and *X* is the data point in each cluster. The best number of clusters *k* leading to the greatest separation (distance) is not known as a priori and it was computed from the data. To compute the optimum number of clusters *k*, Elbow method is used in this study.

Elbow method estimates the threshold value of cluster numbers, using elbow point graph. In this process, *k*-means clustering algorithm is run for a range of *k* values and it is plotted against respective WCSS. When cluster number increases, cluster performance decreases. Hence to select the ideal cluster performance, *k* value at the elbow point of the graph is chosen. This method produces exactly *k* different clusters of greatest possible distinction.

After defining the number of clusters, centroids *(μ)* are initialized, which is equal to the number of *k*.

$$\mu_1, \mu_2, \mu_3, \ldots \mu_k \;\varepsilon\; \mu_j \tag{4}$$

Each data point (x_i) is allocated to the appropriate cluster, by estimating the Euclidean distance of the data points to the nearby centroid (C_i) and then by calculating the distance to other centroids.

$$C_j = Cluster(X_i) = arg_j \; min \left\| X_i - \mu_j \right\|^2 \tag{5}$$

Until the number of data points allotted to corresponding cluster remains constant the procedure is repeated until convergence.

3. RESULTS AND DISCUSSION

A total of 38 ships that transited the Kongsfjorden shipping lane during July to September 2015 were analysed. Due to limited period of open water mass, only 151 total number of transits were recorded in the observation monthsfrom July to September 2015. Exact arrival and departure record based on port calls were availed from AIS marine traffic data. The acoustic measurements were made for a duration of 60 seconds, once in every 3 hours. Hence the ship transits during the timestamp of acoustic measurements were considered for the analysis. 104 concurring ship transitions were found, which resulted 38 ships in particular. The obtained ship passage information contains daily logs of ship details as follows: time stamp of vessel crossing, name of the vessel, unique identification number (MMSI), port id, port name, move type, ship type, dimensions of the ship, draught and gross onnage.

The general vessel types in Kongsfjorden area include tourist cruises, research ships, fishing, sailing and platform vessels. Power spectral density (PSD) at ship noise influencing frequency band at 63 Hz

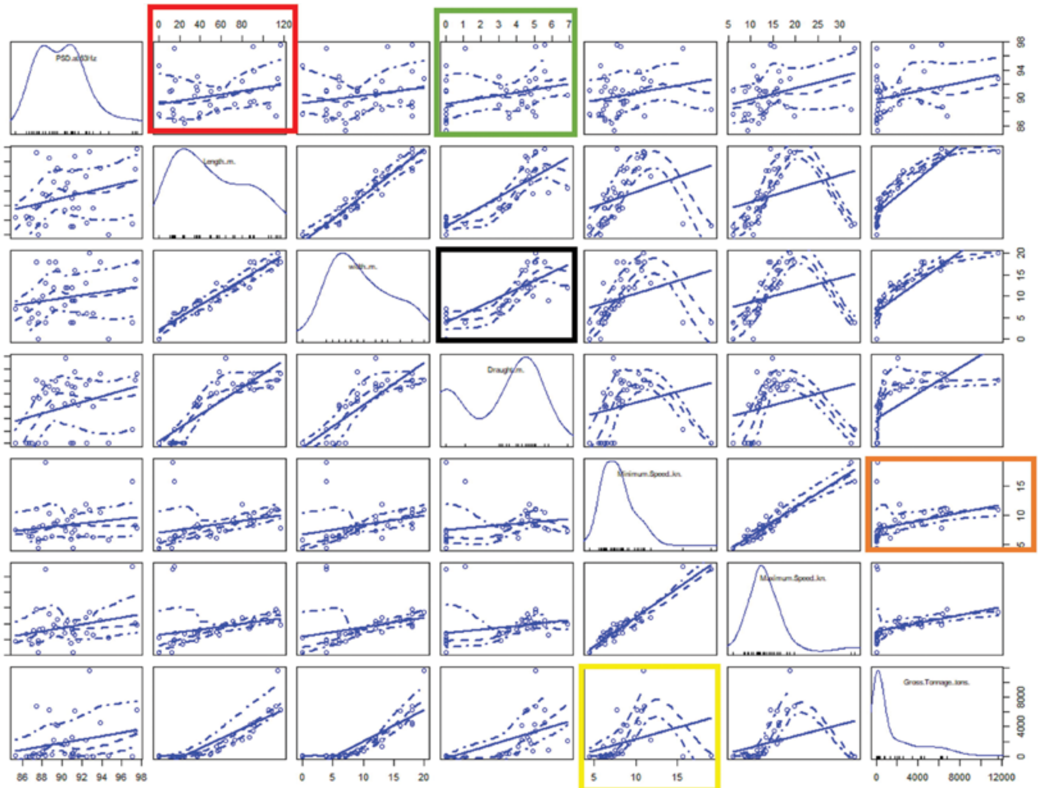

Fig. 5. Scatterplot matrix of study data including sound pressure level and vessel particulars. The diagonal tile plots explain the axes of parameters from top to bottom, such as PSD at 63 Hz; Length (m); width (m); Draught (m); Minimum speed (kn); Maximum speed (kn); Gross tonnage (tons).

was ranging from 85.28 dB to 97.58 dB. The upper range of PSD were observed with large ships like cargo vessels and cruise lines, in the similar way motor resulted lower range of acoustic signals.

Dimension of the vessels were found in the range of 11 × 4 m to 117 × 18 m. One of the important features, gross tonnage has high spread in data distribution starting from 6 tons to 11647 tons. Corresponding minimum and maximum speed of vessels were also included in the analysis for classification purpose.

This study uses passive acoustic measurements and ship parameters from variety of ships under normal operation conditions. Figure 5 shows the scatterplot matrix of study data in the Cartesian planeincluding sound pressure level and vessel particulars. A scatter plot matrix is a grid of scatter plots used to visualize bivariate relationships between combinations of variablesallowing many correlations to be explored in one chart. Each point represents the values of two variables.In the fig. 5, the diagonal tile plots explain the axes of parameters from top to bottom, such as PSD at 63 Hz; length (m); width (m); draught (m); minimum speed (kn); maximum speed (kn); gross tonnage (tons). In each tile plot one variable representsthe horizontal axis and another variable represents the vertical axis. For example, the red box in Fig. (5) is a scatter plot of x = length of the ship, ranges between 0 to 120 m and y = PSD at 63 Hz ranges between 84 dB to 98 dB. The green box is a scatterplot of x = draught (0 to 8 m) and y = PSD at 63 Hz (84 dB to 98 dB). The black box is a scatterplot of x = draught (0 to 8 m) and y = width (0 to 20 m). Orange box is a scatterplot of x = gross tonnage (6 tons to 11647 tons) and y = minimum speed of the ship (4 to 20 kn). Yellow box represents orange box with switched axis, *i.e.*, x = minimum speed of the ship (4 to 20 kn) and y = gross tonnage (6 tons to 11647 tons). The scatterplot matrix of data used in the study showed unique ship type acoustic signature is important for predicting underwater noise levels and understanding its acoustic impacts.

K-means clustering algorithm

K means algorithm, a partitioning based clustering algorithm is used in this study to classify surface vessels into different groups. Underwater ambient noisedata measured and estimated at Kongsfjorden region along with other ship parameters collected from Svalbard port had been used for this study. The general objective of this study to obtain fixed number of vessel clusters among 38 ship transited during observation period, July to September, 2015. Each cluster has to represent vessels with similar ship parameters. To fix the number of clusters *(k)*'Elbow method' was used.

The method for determining the true number of clusters in a data set is called the elbow method (Andrew, 2012). It is a visual method. Initially the number of vessel clusters K was fixed as 2 and it was increased in each step by 1. Figure 6 shows the relationship between the number of clusters and the cost function calculated from Within Cluster Sum of Squares (WCSS).

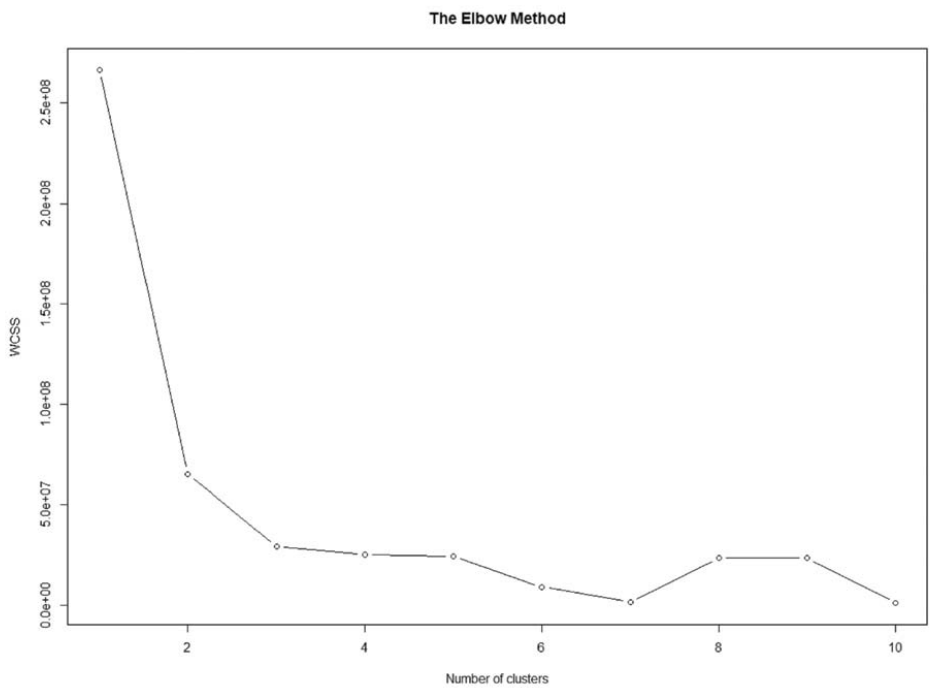

Fig. 6. Determination of number of clusters using Elbow method.

WCSS is defined as the sum of the squared distance between each member of the cluster *(x_i)* and its centroid *(ci)*.

$$WCSS = \sum_{i=1}^{m} \left(x_i - c_i\right)^2 \tag{6}$$

At some value for *K* the WCSS cost drops dramatically, and after that it reaches a plateau when *K* value is further increased. The number of clusters is chosen where the change in WCSS begins to level off. Likewise, the *K* value for vessel type classification is preferred as 4. In the fig. 6, the distortion WCSS goes down rapidly with *K* increasing from 1 to 2, and from 2 to 3. The cost function WCSS goes down very slowly from 3 to 4 and then when it reaches an elbow *K*=4, and it reached plateau. Hence number of clusters were chosen as *K*=4. Distortion goes down rapidly until *K*=4, and goes down very slowly after that hence number of clusters needed for this data set is 4.

After applying k means algorithm by considering the number of clusters as K=4, the clusterplot (Figure 7) was obtained with memberships for every presented ship. Figure 8 shows the bivariate graphical representation of vessels that grouped into similar clusters. In the graphical display called clusterplot, the objects are represented as points in a bivariate plot and the clusters as ellipses of various sizes and shapes. Since there are 38 ships with 7 characteristic parameters, the principal component analysis (PCA) technique was used for dimensional reduction purpose using the following steps. PCA is defined as an orthogonal linear transformation that transforms the data to a new coordinate system. PCA attempts to derive a set of low-dimensional set of features from a much larger set while still preserving as much variance as possible. In this study, the ship characteristic parameters along with ship noise were the features fed into principal component analysis.

$$x = \begin{pmatrix} x_1 \\ x_2 \\ . \\ . \\ . \\ x_7 \end{pmatrix} \tag{7}$$

Whereas x_1, x_2,...x_7 are acoustic power spectral density (PSD) at 63 Hz, and ship parameters such as ship length *(m)*, width *(m)*, draught *(m)*, minimum speed *(kn)*, maximum speed *(kn)* and gross tonnage (tons) respectively.

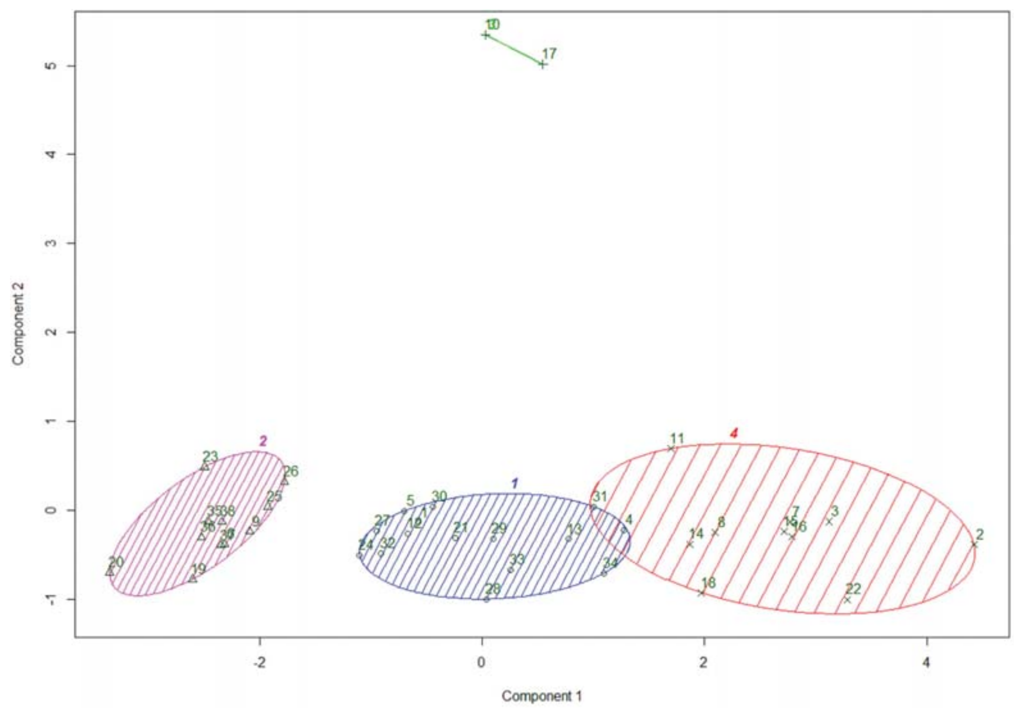

Fig. 7. Clustering of N = 38 data using k-means method. These two principal components explain 79.94% of the point variability.

STEP 1 : Initially the given dataset is standardized using mean (μ) and standard deviation (σ) of each feature.

Data standardising is to standardize the range of the continuous initial variables so that each one of them contributes equally to the analysis. Since there are large differences between the ranges of initial variables, those variables with larger ranges will dominate over those with small ranges, which will lead to biased results. So, initial data was transformed to comparable scales can prevent this problem.

STEP 2 : Covariance matrix was computed to understand the correlation between the features or variables and to identify any redundancy between them. The covariance matrix was a $x \times x$ matrix that has entries as the covariances associated with all possible pairs of initial variables.

Covariance matrix was estimated using,

$$cov_{(x,y)} = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{N-1} \tag{8}$$

Whereas x_i, y_i are feature values, $\overline{x}$, $\overline{y}$ are corresponding mean and N is total number of ships (N = 38).

STEP 3 : Eigen values *(υ)* and eigen vectors *(λ)* of the covariance matrix were computed to identify the principal components. Principal components are new variables that are constructed as linear combinations or mixtures of the initial variables. Among the principal components obtained, the first two components were selected for further analysis.

The eigenvalues were ranked in descending order ($\lambda_1 > \lambda_2$), and the eigenvector that corresponds to the first principal component (PC1) is v_1 and the one that corresponds to the second component (PC2) is v_2. These combinations are done in such a way that the new principal components are uncorrelated and most of the information within the initial variables is squeezed or compressed into the first two components.

STEP 4 : Feature vector matrix was formulated using eigen vectors corresponding to eigen values λ_1 and λ_2. This step is for the dimensionality reduction.

STEP 5 : The data was recasted along the principal component axes using,

$$\text{Final data} = \text{Feature vector}^T \times \text{Standardized original dataset}^T \tag{9}$$

Hence the first two principal components obtained from PCA were used to for cluster analysis and the ships were classified into 4 different classes. Figure 7 shows the results of cluster analysis that carried out using N = 38 samples. We could obtain 4 distinct clusters of ships with dissimilar ship parameters. Cluster 1 contains 10 vessels including passenger ships and cruise liners such as Fram, Bremen and Orttelius. Cluster 2 contains only 2 motor boats such as Spitsbergen express and Elling Carlsen. Cluster 3 contains 11 ships including mainly sailing vessels such as Chiquitita and Algol. Cluster 4 contains 15 vessels of cargo type such as Norbjorn andOrigo. Ship classes were identified from *k* means clustering algorithm as follows:

Class 1 : Cruise liners, passenger ferries, large research vessels

Class 2 : Sailing vessels

Class 3 : motor boat

Class 4 : General cargo and platform supply vessels

4. CONCLUSION

This study has demonstrated the effectiveness of utilizing unsupervised k means clustering method for ship classification. Attributes for classification were extracted from the acoustic signatures in shipping noise indicator band and the clustering algorithm was built. Our findings confirm the suitability of proposed approach for classifying different vessels into four different groups such as cruise liners, sailing vessels, motor boats and cargo ships. Future work is needed inmaintaining a catalogue for acoustic signatures and developing a library of surface vessels during different years signatures will allow for more accurateclassification of vessels.

5. ACKNOWLEDGEMENT

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Development of measurement system for characterizing underwater acoustic vector sensors

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ABSTRACT

This paper describes the development of LabVIEW based application for characterizing underwater acoustic vector sensors. This application is used for testing Acoustic Vector Sensor (AVS) elements and test results in this regard are presented. A turntable system is used for positioning the Vector Sensor Array (VSA) in underwater for determining its directionality pattern. This turntable is controlled by using IEEE-488 interface via LabVIEW. National Instruments (NI) hardware is used for signal generation and data acquisition from VSA. LabVIEW program is developed for signal processing. Each vector sensor element is tested in this setup and results show that all accelerometer based AVS elements follows di-pole pattern. All the pressure sensors are omni directional. Amplitude of each of the three accelerometers as well as pressure sensor elements are measured and corresponding correction factors due to the variation in amplitude between the elements have been characterized.

1. INTRODUCTION

Hydrophones, which are traditionally used for underwater acoustic applications, measure acoustic pressure and these are omni directional in general. Hence the hydrophones cannot produce any spatial domain data. However, by using number of hydrophones in proper combinations, direction of the acoustic source can also be detected. The accuracy of detection however, depends on the number of hydrophones being used and their positioning. By using a vector sensor, spatial response in source detection can be improved when compared to the hydrophones of same quantity[1]. Compared to pressure sensors, vector sensors provide high signal to noise ratio (SNR) owing to its spatial filtering.

Particle motion or acceleration sensor in three orthogonal directions along with an omni directional pressure sensor completes a single vector sensor element. A vector sensor, as the name implies, will give us the magnitude of pressure as well as direction of the source by measuring both the acoustic pressure and particle velocity in three directions thus improving the spatial resolution[2]. In either case where an accelerometer or pressure sensor-based system is being developed, the measurand shall be converted to particle velocity by performing time integration or time derivation accordingly.

Acoustic vector sensors have wide range of applications in sea bed mapping, geo acoustic inversion, surveillance operations and detection of the intruders by acoustical means[3]. By combining vector sensor elements to form a linear array, resolution of azimuth as well as elevation can be improved and under water source localization can be accurately estimated[4,5]. Distance between each sensor element defines the accuracy of sensor arrays in determining the Direction of Arrival (DoA). Distance shall be chosen optimally to get the desired frequency range of operation. Optimal distance is half the wavelength of the frequency of interest. In a neutrally buoyant vector sensor array, frequency range is limited only by the accelerometer and pressure sensor performances. The degree of improvement in performance of DoA estimation is proportional to the number of vector sensor elements that are being used as well as the characteristics of each sensor element[6]. Hence each vector sensor element needs to be calibrated to determine its amplitude and directionality patterns in order to estimate the DoA accurately.

The applications of vector sensor elements and their theoretical as well as experimental data is widely reported, however, when it comes to calibration of these sensors, it is not the same. Unlike hydrophones, there is no international standard available (like IEC for hydrophone calibration) for calibration of acoustic vector sensors. IEC 60565 is a standard for hydrophone calibration, wherein several absolute and comparison methods are described for calibration of hydrophones[7]. For hydrophones, accurate calibration of amplitude sensitivity is utmost important, and it is not the same in case of vector sensors. Hence in this case a reference sensor is not necessary. Relative sensitivity among the three orthogonal axes of the vector sensor plays an important role in determining the performance of the sensor[8]. Relative sensitivity is determined by comparing the characteristics of the sensor in each axes. It is imperative that the sensor elements used for constructing the VSA are of similar sensitivity. Each of the sensor element need to be checked at the beginning of the process. By comparing the sensitivity of these elements, correction factors for each axes shall be arrived. These correction factors are utilized for correcting any sensitivity variation as shown in formula 1.

$$V_{ni} = C_{ni} * V'_{ni} \tag{1}$$

n = Channel description (X, Y, Z or Hydrophone)

i = Vector sensor element number (1, 2 or 3)

V = Voltage after correction

V' = Voltage before correction

C = Correction factor

By performing the directionality test[9], orthogonal nature of the sensor can be characterized. Alternatively, from the directionality pattern, amplitude and phase behaviour of the sensor can be approximated. In this paper, a LabVIEW based application is developed for characterizing the acoustic vector sensors and 3 elements of AVS have been tested for their directionality patterns. Amplitude characterization is done and correction factors are incorporated.

2. SOFTWARE DEVELOPMENT

Laboratory Virtual Instrument Engineering Work bench (LabVIEW) is chosen due to its user-friendly Graphical User Interface (GUI) and availability of hardware drivers for vast variety of instruments. It provides a data flow oriented graphical programming environment with drag and drop tools. It consists of various virtual instrumentation tools for interfacing, acquiring data from various equipment and processing.

A LabVIEW Virtual Instrument (VI) has been developed for this application which has three tier architecture (Fig. 1). Top level architecture consists of the GUI for interacting with the user and it consists of all the controls as well as indicators. Controls are virtual tools that will take inputs from the users and send commands to the corresponding instrument via I/O tools. Data acquired from the instruments can be visualized via indicators[10]. Low level architecture consists of I/O functions of LabVIEW which are used to communicate with the hardware devices. Middle level has data processing modules that will perform predefined actions on the acquired data to present the processed data to the GUI.

VI is implemented in modular concept i.e. overall objective is divided into small chunks of VIs called SubVIs. They are especially useful when a specific code is to be used multiple times in a VI and hence

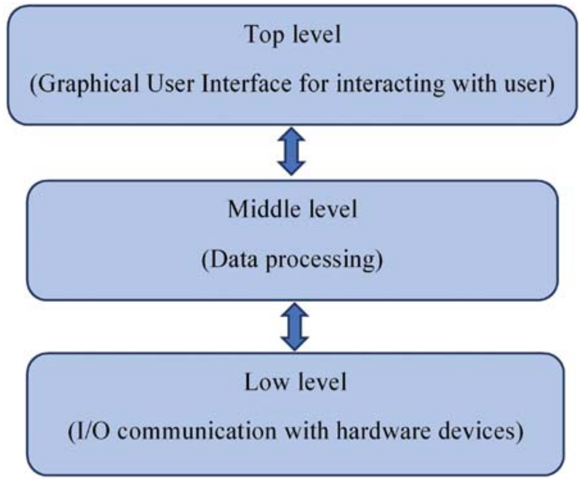


Fig. 1. 3 level architecture

avoid complex architecture. This will further make the VI much easier to read, troubleshoot during testing phase and will improve scalability.

State machine technique[10] is used for the coding. State machine is a programming tool in LabVIEW that makes the coding scalable as well as flexible. It follows Moore machine algorithm and performs specific action for each state in the VI. Adding or removing a particular state does not affect remaining states. By using state machine, this application is divided into different states and each state represents a specific event that has a separate processing sequence and is independent of the other states. When an event occurs then the processor performs an action as specified in that particular event state. Once initialized by the user input, the process sequence starts and then after each state, the execution will either lead to the next state or wait for another user event as specified in the VI. Developing application with the meaningful states is extremely useful in running the code efficiently while maintaining the ease of coding.

An enumerated constant wired to a while loop is used to implement the state machine architecture for this VI. 10 number of cases are selected for this application as shown in Fig. 2. Number of cases in the enumerated constant represent the number of states in the application. Just by adding one more case to the enumerated constant, additional state can be created, if required.

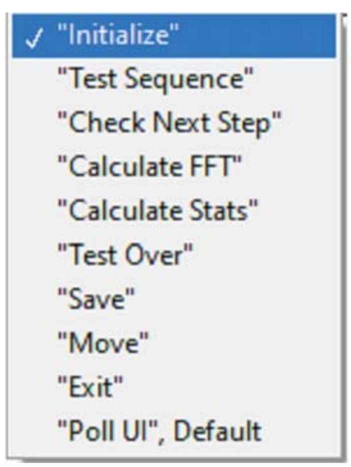


Fig. 2. Case details of enumerated constant

A "type def" control is created in LabVIEW by using the enumerated constant with the above 10 cases so that it can be used in all the state controls. The advantage of using "type def" is that changes at one place is applicable across all the "type def" controls used in the entire VI. This is especially useful in adding or removing the states during development phase and make the VI scalable with less effort. Action case for each of these states are included in a 'case' structure and the type def control is wired as case selector.

During "Initialize" state, the VI will search for the connected hardware. If the connection is successful, then default parameters are loaded into the controls otherwise an error window will popup intimating the user about the connection failure and the VI stops executing. This is indicated in the flow charts of turntable and acoustics loops in Fig. 5 & Fig. 6 respectively.

"Poll UI" is the state where the VI will wait for the user event[10]. It consists of various user events as shown in Fig. 3.

Fig. 3. User event states

When the VI is "Poll UI" state, it does not come out of that state until a user event occurs. If the requirement does not allow the VI to wait indefinitely, then a timeout function can be used to come out of the loop. In this application, since the VI requires user input to execute, timeout is not configured which means the VI will wait indefinitely for a user event. Each user event has specific event case that need to be executed.

After Initialization, VI goes to "Poll UI" state and wait for the user to set the parameter indicated in Fig. 4. It includes the turntable settings and acoustic measurement settings. Turntable settings include "Start", "Stop", and "Step angle" for turntable movement. "Acq delay" is the delay required to initiate the acoustic measurement after movement is completed. Channel selection is used to select the number of channels for data acquisition, Selected channels are indicated in green colour. Frequency of interest along with the amplitude can be set by using corresponding controls shown in Fig. 4.

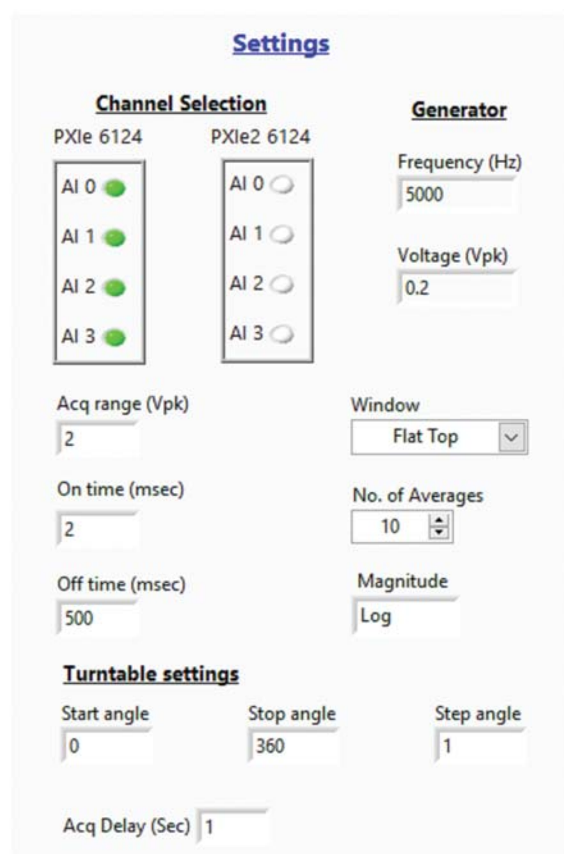


Fig. 4. Settings window

"Start" event will initialize the measurement by applying the user settings on the hardware. "Move" state is enabled immediately after executing "Start" event. Command for moving the turntable to the start position is issued in this state. After completing movement, VI waits for a time specified in "Acq delay" in Fig. 4 and then go to "Test sequence" state. Flow chart of turntable control loop is shown in Fig. 5.

Here the acoustic loop starts by generating the frequency of interest and acquiring the data from the channels selected. Flow chart of acoustic loop is shown in Fig. 6.

User can set the cursor to time select the signal portion for frequency analysis. Based on the time selected signal, frequency spectrum is being done to

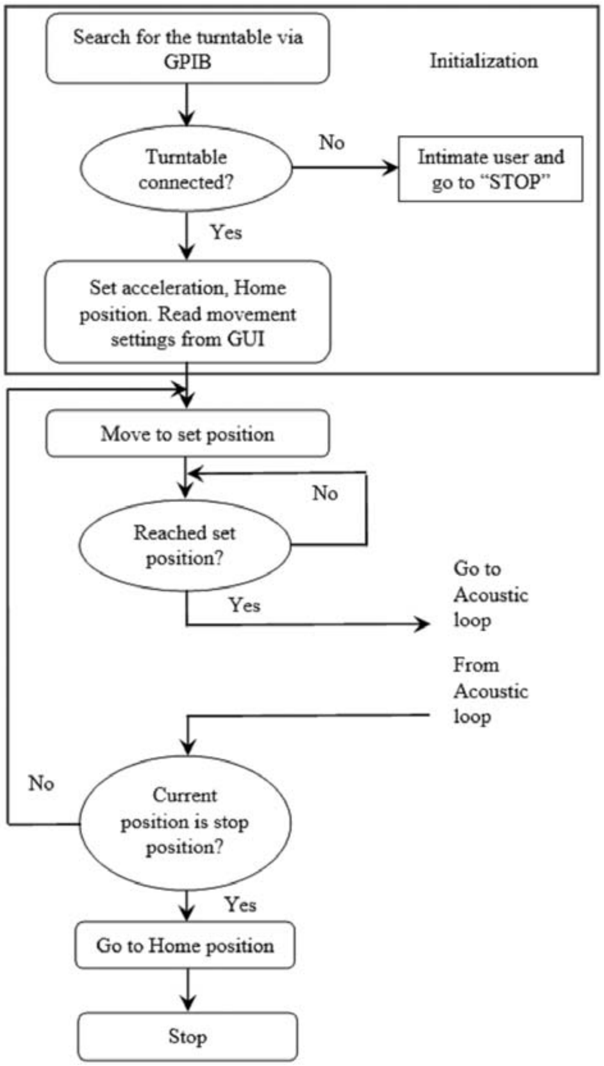


Fig. 5. Flow chart of Turntable loop

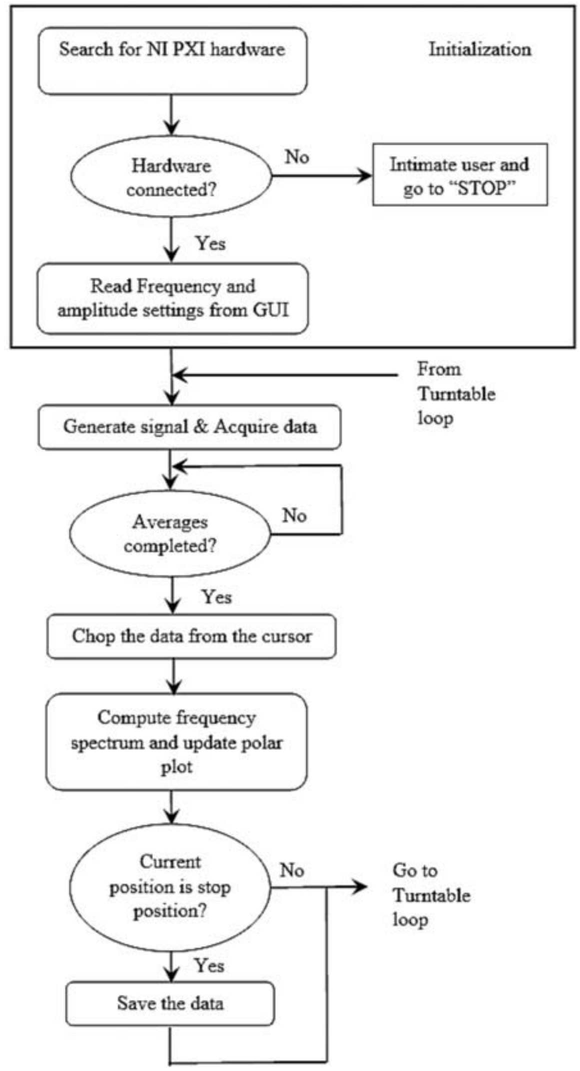


Fig. 6. Flow chart of acoustic loop

evaluate the frequency and amplitude of the measured signal. This data is stored in a variable and subsequently the amplitude vs angular position also updated on the polar plot. This is done in "Calculate FFT" and "Calculate stats" as shown in Fig. 2. Completing the measurements for the current angular position triggers the turntable loop to move to the next position. Acoustic loop then starts with generation sequence and this loop continues until the stop position is reached. If there are any disturbances during measurement and there is a need for restarting measurement then the user event named "Restart" is used.

Every time acoustic loop is completed, VI compares the current position with stop position and decides either to proceed for next movement or to stop the loop. At stop position, the measured data along with all the required parameters is exported to an excel file[10]. Polar plot is saved as an image file. Turntable is rotated back to its home position before exiting the VI.

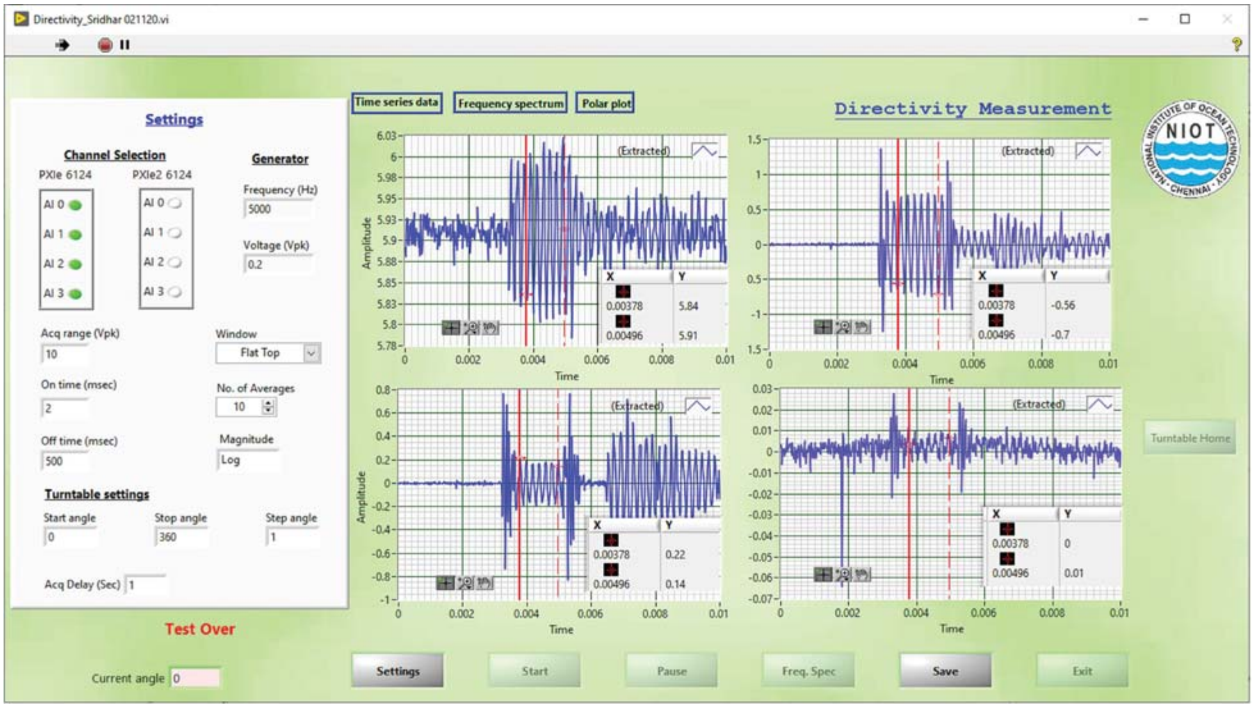


Fig. 7. Screenshot of the VI

3. EXPERIMENTAL SETUP

National Instruments PXIe based instrumentation is used for acoustic measurements. Frequencies from 1 kHz to 6 kHz are generated using a waveform generator. A single frequency burst of 2 ms is generated to avoid acoustic reflections from the boundaries of the underwater environment and to achieve free field measurements[11]. Generated frequency signal is amplified and fed to an acoustic transmitter. Neptune Sonar make omni directional acoustic projector is used for this purpose. It is mounted on a moving platform and depth is varied such that the acoustic centre of the transmitter is in line with the acoustic vector sensor of interest. Measurement schematic is shown in Figure 8.

Embedded controller acts as a PC running with LabVIEW. NI-488.2 software drivers are used for interacting with the turntable controller by utilizing IEE 488 GPIB bus standard. To overcome the cable length limitation of GPIB standard and to interface the turntable controller with PC, GPIB-Ethernet converter is used. Turntable controller offers three modes of operation namely Relative, Absolute and Continuous. Relative or Absolute modes are used when the requirement is to rotate the turntable to a

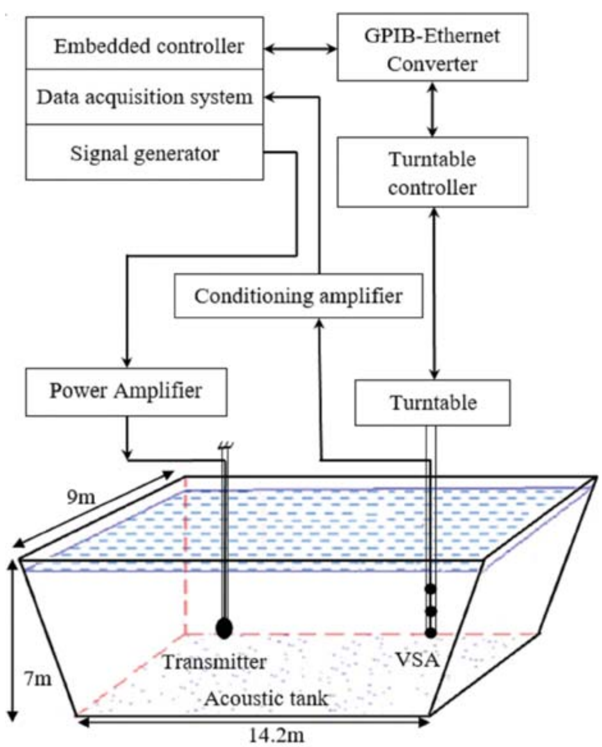
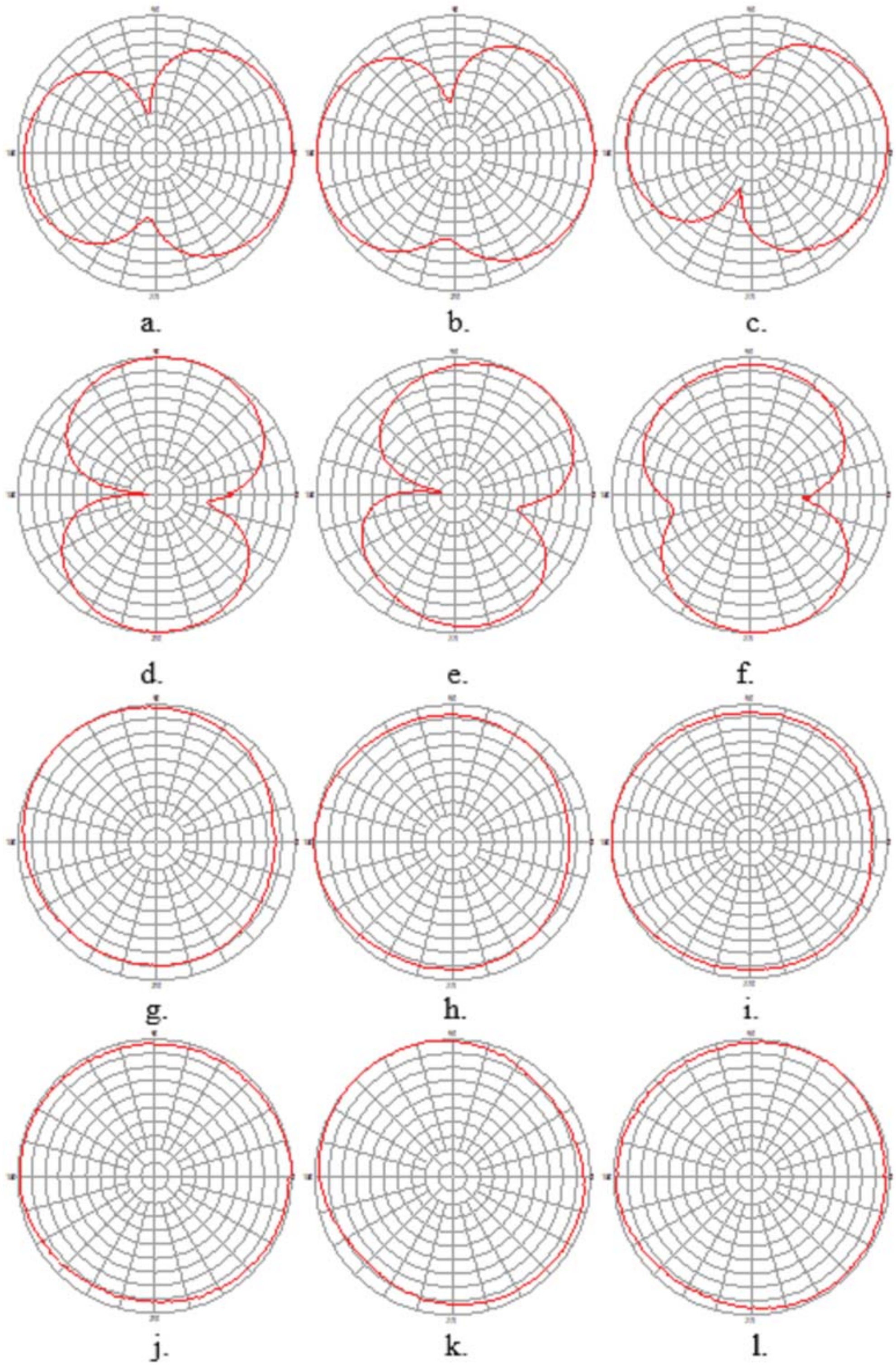


Fig. 8. Experiment schematic



a. b. c. d. e. f. g. h. i. j. k. l.

Fig. 9. Directivity pattern of the vector sensor elements (a. X axis-Element 1, b. X axis-Element 2, c. X axis-Element 3, d. Y axis- Element 1, e. Y axis-Element 2, f. Y axis-Element 3, g. Z axis-Element 1, h. Z axis- Element 2, i. Z axis-Element 3, j. Hydrophone 1, k. Hydrophone 2 , l. Hydrophone 3)

defined angular position. Continuous mode is to rotate the turntable continuously at a constant speed from 22 seconds to 720 seconds per revolution. For this application, absolute mode of operation is configured to eliminate the error accumulation over the full rotation. PC controller generates the set points of rotation defined by the user settings. Turntable controller along with the turntable will act on these set points and complete the rotation. Acceleration is chosen to be minimum to avoid structural vibration when heavy loads are operated with extension pipes.

A three-element vector sensor array is used for testing. It is mounted on a rigid platform along with turntable for the rotational movement. VSA is at 3m depth from the water surface. Signals captured by VSA are amplified in the preamplifier section before recording and analysis using a PXIe based 16-bit data acquisition system[12]. Generator and data acquisition system are time synchronized. Time selection of signal is achieved by using cursor mechanism to choose the direct path signal and to avoid the multi path[13,14] from the boundaries.

4. RESULTS AND DISCUSSION

System is developed and Acoustic tank of 16m length, 9 m wide, and 7 m deep is used for measurements. Acoustic Test Facility (ATF) of National Institute of Ocean Technology (NIOT) is used for testing purpose. VSA and acoustic transmitter are immersed in water using two separate mounting mechanisms.

All the 3 elements of the vector sensor array are characterized by using the developed VI. Depth of the acoustic transmitter is changed for each element to match the acoustic centre. Single frequency burst of 1 kHz to 6 kHz signal is transmitted and the acquired data is processed for frequency response parameters. Four channels of data acquisition are used to simultaneously acquire triaxial accelerometer data as well as hydrophone. Sampling frequency is sufficiently maintained to follow Nyquist criterion. Each element is characterized separately for directionality patterns at 5 kHz. Directional response of three sensor elements are shown in figure 9. As seen from the images, X and Y axes of three elements are dipole in behaviour. Z axes is behaving in omni directional way since the measurements are taken in X-Y plane. Hydrophone is omni directional as shown in measured data. From the directivity pattern, it is noted that AVS elements are tilted at some angle and their orientation is not proper. For computing correction factors, frequency vs amplitude characteristics are compared for all the three elements. Variation in this regard is presented in figure 10. This variation is drastically reduced after incorporating correction as shown in figure 11.

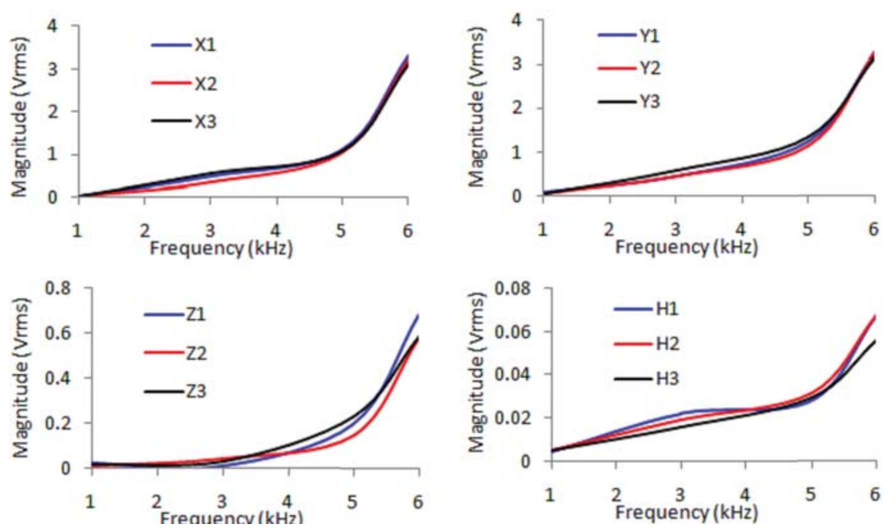


Fig. 10. Frequency vs. Magnitude before correction

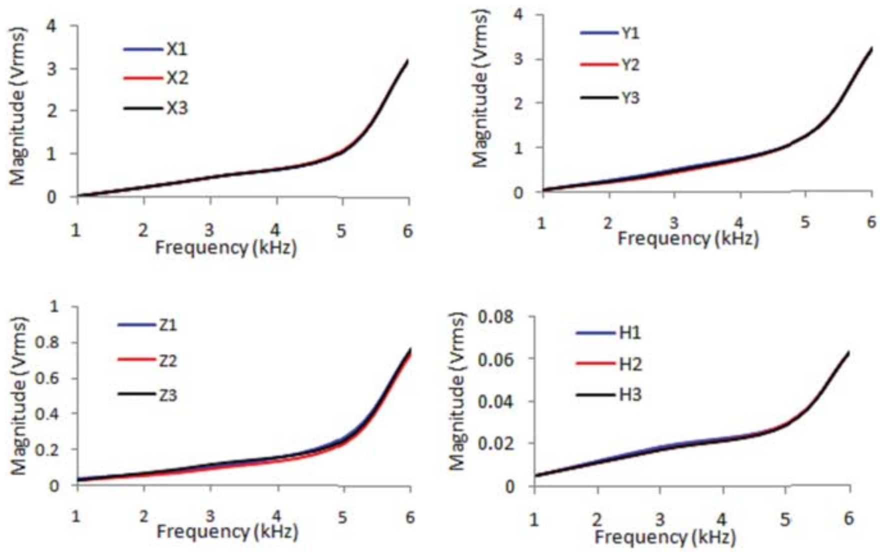


Fig. 11. Frequency vs. Magnitude after correction

5. CONCLUSION

A LabVIEW based measurement system for characterizing underwater acoustic vector sensors has been developed using NI hardware. VI executes predefined sequence of process using state machine architecture in LabVIEW environment. Development of software is explained and step by step sequence of VI execution is presented. The VI controls a turntable system using IEEE 488 GPIB interface for positioning control of the directivity measurements. Acoustic measurements are achieved by using NI PXIe based hardware. Correction factors due to variation in sensitivity is calculated and reduction in sensitivity variation after applying correction factors are presented. Directivity pattern of the three vector sensor elements for three axes of accelerometer as well as hydrophone element is measured simultaneously by using 4 channel data acquisition system. X, Y axes represent dipole behaviour and the hydrophone is omni directional which is expected for a vector sensor element. From the directivity data shown in figure 9, it is noted that the orientation of the AVS elements need to be corrected. Physical arrangement of the AVS elements will be corrected for proper orientation and the measurements will be repeated to cross check the performance of the elements for the new orientation. From the results, the developed measurement system has proven its effectiveness in characterizing AVS elements and determining the corrections to be undertaken for accurate DoA estimation. This system can be utilized for characterizing any type of underwater acoustic transducers and arrays.

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Under water sound related to ice dynamics in the Kongsfjorden, Svalbard Arctic

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ABSTRACT

An Ambient Noise Measurement System (ANMS) consisting of hydrophonesand associated data acquisition electronics with power packhad been deployed for year round time series noise measurements in the glacierized fjord, Kongsfjorden in the Svalbard Archipelago. Noise data acquired during the summer period from August to September,2016 has been analysed for sounds related to ice dynamics.Acoustic signatures of ice quakes, tremor and bubbling have been investigatedin the frequency band 20 Hz to 1000 Hz.The results indicate that icequakes, iceberg tremor, and ice bubbling contribute to the underwater acoustic field in the glacierized fjord during summer months.

1. INTRODUCTION

Noise field in glacierized fjords, have been examined in detail by Pettit *et al.* (2015), and related to ice melt through a series of laboratory measurements. A set of measurements by Deane and co-workers (Deane *et al.*, 2014; Glowacki *et al.*, 2015) in Hornsund fjord, Svalbard identified the origin of low to high frequency sources (0.02-20 kHz) during the summer and also examined glacial calving signatures from 12 glacial calving events and provided new insight into calving and its role in dynamic interactions. Buscaino *et. al.* (2014), studied the soundscape of the Kongsfjorden, and identified the biological sources, anthropogenic sources and geophysical events. Ashokan *et al.* (2016), performed measurements and analysis at Kongsfjorden and iceberg cracking has been reported.

A variety of cryogenic sound in a protected sea in the western Antarctic Peninsula has been investigated by Dziak *et al.* (2016).These sounds were associated with iceberg grounding and break up and other physical deformation related to ice/wave interactions. During the experiment, the acoustic signals produced by iceberg such as tremor and quake were recorded as it drifted from its origin in the Weddell Sea, grounded within the Bransfield Strait, and broke apart in the Scotia Sea.

Iceberg tremor, icequakes and ice bubbling related to ice melts have been recorded by the ANMS during summer season at Kongsfjordenand the results are presented in this paper.

2. MEASUREMENT METHODOLOGY

The Ambient Noise Measurement System (ANMS) is deployed at central Kongsfjorden (Fig.1), a glacierized fjord in Svalbard, Arctic which is a narrow fjord of approximately 20 km length and width varying from 4-10 km. The ANMS along with IndArc 2 mooring was deployed at 198 m depth. Ambient Noise Measurement System (ANMS) for the Arctic Region has two distinct components. First one is the Data Acquisition system with indigenously developed underwater pressure casing housing electronics for noise data acquisition and another is the Cetacean make hydrophones used as an acoustic sensor with cable. This has been incorporated in the IndARC mooring (Venkatesan *et al.*, 2016) and fixed in a PVC fixture to avoid bio-fouling and corrosion. Data acquisition system consists of NI based data acquisition card along with a processor card and flash drive memory of 1TB. The complete system worked with the help of two numbers of lithium battery packs with rating of 272Ah / 14.4 Volts.

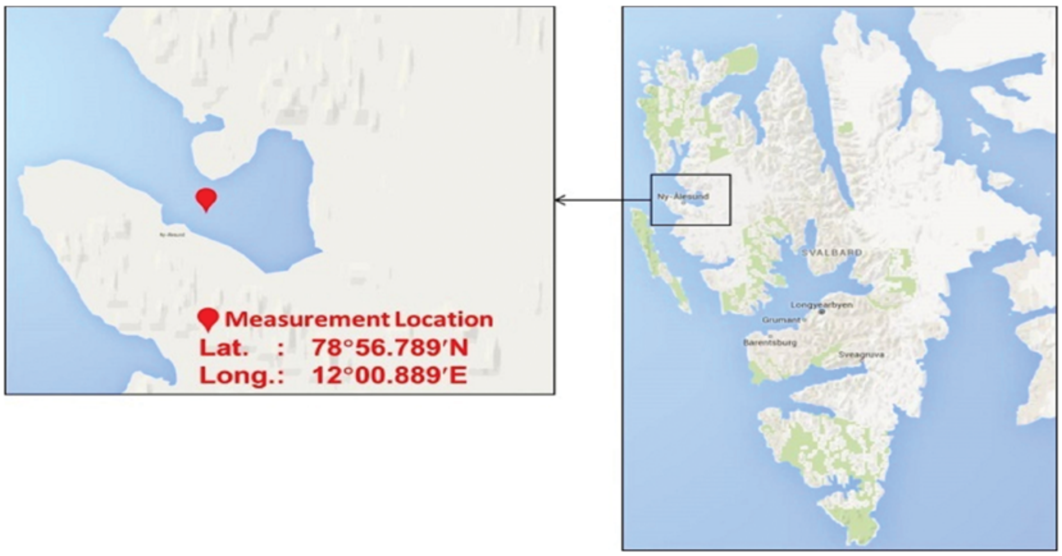

Fig. 1. Deployment location at Kongsfjorden fjord, Svalbard

The hydrophone was positioned at 34 m water depth from the sea surface where the ocean depth is 195 m. The hydrophone preamplifier gain is 20 dB and the sensitivity is -185 dB re 1V / uPa. The sensor was tested and calibrated at the Underwater Acoustic Test Facility of NIOT, which is acknowledged by National Accreditation Board for Testing and Calibration Laboratories (NABL) in India. The noise data sets are acquired periodically every 1 hour with a sampling rate of 25 kHz having sampling time 180 s with 16 bit resolution.

3. RESULTS AND DISCUSSION

During summer, overall noise is due to ice melting into the fjord, iceberg dynamics, ice wave interactions, wind, vessel noise and other transients.Noise sources such as iceberg bubbling, ice quake, iceberg tremor, shipping and instrumentation noise prevailing in Kongsfjorden fjord, Arctic sea during summer of 2016 has been analysed.

Iceberg tremor noise has been identified and analysed from the ambient noise records. The frequency of iceberg tremor noise falls in the band 100-1000 Hz and is shown in the Fig. 2. Iceberg quake noise has been studied and the frequency of this noise falls in the band100-400 Hz (Fig. 3). Maximum number of iceberg quake events has beenrecorded on September 05, 2016. Helicopter sound has been recorded during the measurement period and the frequency falls in the band 100-10000 Hz (Fig. 4).

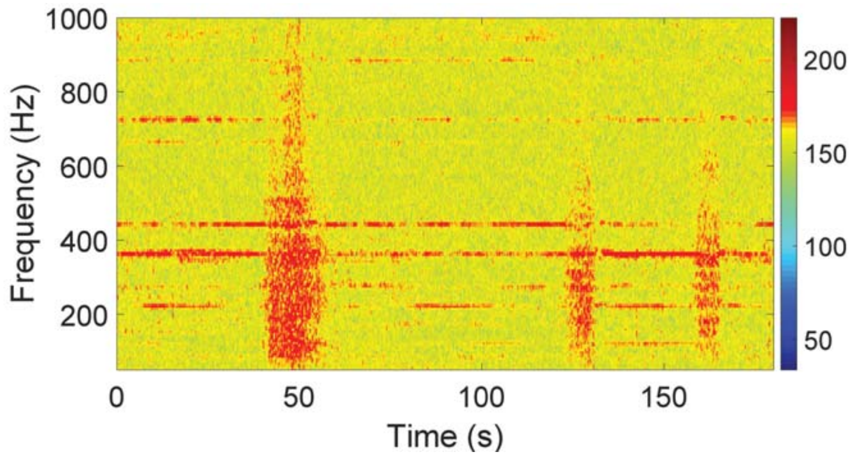

Fig. 2. Spectrogram of the Iceberg tremor noise recorded on 2016 08 0306 20 31 UTC

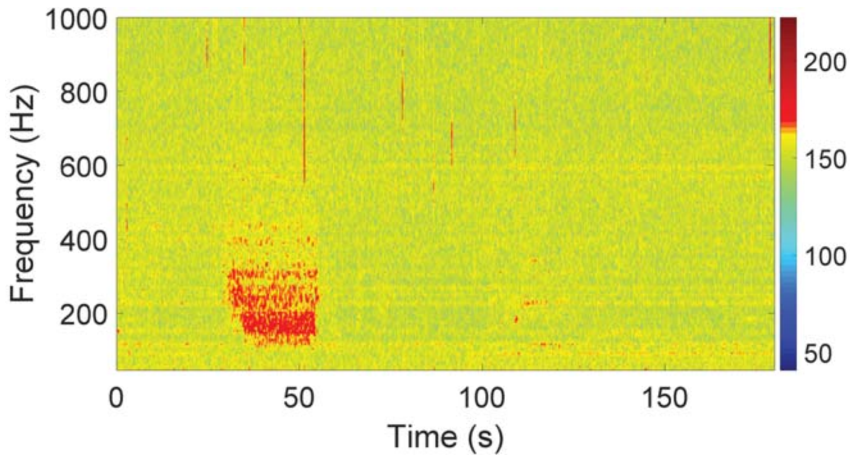

Fig. 3. Spectrogram of the Iceberg quake noise recorded on 2016 08 09_08 38 30 UTC

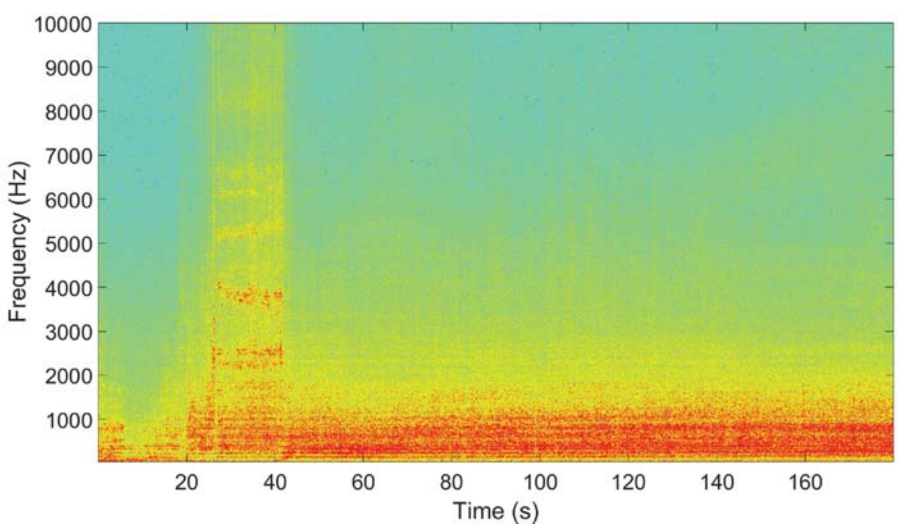

Fig. 4. Spectrogram of the Helicopter and Ship noise

Icequakes are impulsive broadband signals with durations between 10 and 80 sec and dominant energy over the ~10-500 Hz band. Ice quakes may be caused by thermal stresses, as well as physical deformation of the ice from wind, currents, and waves, which can cause fracturing and colliding of large ice blocks and bergs, producing sound (Pritchard, 1990 & Stein 2000). These external forcing factors result in shear failure of the ice crystal lattice, generating pressure waves that emanate into the water column. Studies in the Arctic have shown that there is also seasonal variation to ice fracture events, where wind speeds and the amount of ice coverage versus open water dictate longterm ambient noise levels (Roth *et al.*, 2012).

The IndArc moored system has the underwater devices such as, CTD (Conductivity, Temperature and Depth), ADCP (Acoustic Doppler Current Profiler), PAR (Photo-synthetically Active Radiation) and SUNA (Submersible Underwater Nitrate Analyser).During certain periods, the instrument noise is picked up by the ANMS. It has been observed from the noise data sets that the shipping noise falls in the band <600 Hz and iceberg bubbling noise falls in the band >400 Hz. Instruments noise falls in the frequency 400 Hz (Fig. 5).

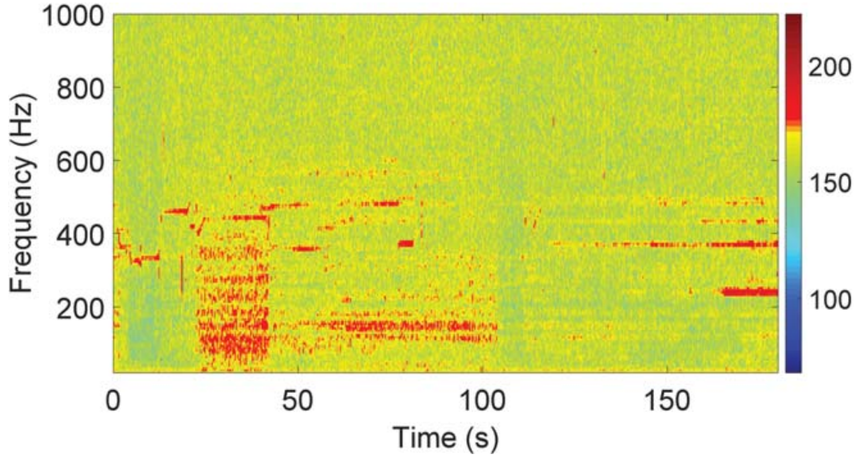

Fig. 5. Instrument noise, ice quake, ship and bubble noise overlapped, recorded on 2016 08 06_08 29 38 UTC.

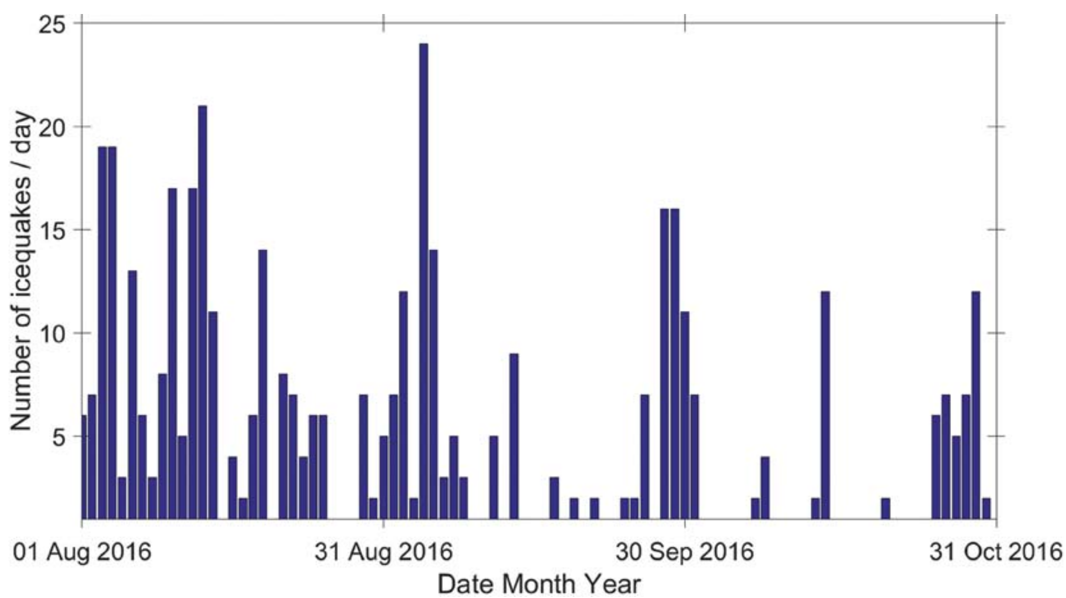

Fig. 6. Ice quakes recorded during summer of 2016 at Kongsfjorden.

Three months of data (a total 2208 noise records) were analyzed to check the ice quake signatures and the statistics are presented in Fig. 6. Majority of ice quakes occur during the month of August and with the progress of season, the intensity decreases.

4. CONCLUSION

The acoustic data collected during the summer of 2016 shows that the fjord is a region of dynamic sea ice and iceberg activity. The various cryogenic sound sources such as ice quake, tremor and bubbling noise recorded during August to October gives a clear picture of the ice dynamics in the fjord. The impulsive short duration broad band ice quake signals were recorded during the summer months of August to October 2016.The high noise levels and the frequent occurrence of quakes during summer clearly shows the role of ice in increasing the ambient noise levels in the Arctic region.

5. ACKNOWLEDGEMENT

The authors acknowledge Director, National Institute of Ocean Technology for the support and co-operation in carrying out this work. The authors are grateful to Ministry of Earth Sciences, Govt. of India for funding the project. Ocean Observation Systems group is gratefully acknowledged for the technical and field support rendered by them during the course of the experiment. We are thankful to the Scientific team of NCPOR (India) and NPI (Norway) and technical support from R V Lance for successful system deployment and data collection. The Ocean Acoustic Team is thanked for their untiring efforts in the lab and field.

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Comparative study of variations in Ambient Noise at shallow water locations off Goa

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ABSTRACT

Shallow water measurements were carried out in the study areas to understand the effects of environmental parameters on the variability of ambient noise. The location-1 is situated at around ~ 2.0 km from Cutbona jetty, off Betul and Location-2 is in the neighborhood of the Grande Island and situated around ~ 8.0 km south of Mormugao port. Both these areas reported individual contribution of biological (fish) noise, wind and transitional localized as well as commercial shipping. These areas varied in terms of water depth, tidal streams, and fish sounds. The time series measurements of ambient noise were carried out (20 March - 21 March, 2014 and 03 April - 04 April, 2014) using single standard wide band hydrophone. The data is later analyzed for noise fluctuations in the band of 0.5 kHz - 8.0 kHz within which most of the noise components are reported to be dominant[1]. The average noise levels for locations-1 and 2 are observed to be 60.9 dB and 64.6 dB respectively. An increase of ~ 5 dB in average noise level is observed at location 2 owing to commercial shipping activities. The statistics of noise measurements are stated in terms of standard deviation 'σ' of the noise levels relative to the mean. The standard deviation revealed a wide range for location 2 with higher deviation levels varying from 11.7 dB at lower frequencies to 3.7 dB at 8 kHz, while location 1 had shown variations from 9 dB to 3 dB. The analysis of noise variability in terms of Standard Deviation (σ) is observed to be higher at lower frequencies but decreases with rise in frequency. Further, the comparison with regard to noise observed at each location has revealed distinctive information that may be considered in further studies.

1. INTRODUCTION

In the past years, the shallow water regions were studied more significantly for the ambient noise variations. In general, the ambient noise is caused by the influence of biological, anthropogenic and environmental parameters. The anthropogenic activity such as shipping noise is known to have a negative impact on marine ecosystem, particularly marine mammals from the region[2&3]. Earlier research of K. Chanda, has revealed the existence of biological sources, where further classification of these sound signals were presented by employing advanced techniques[4&5]. The marine acoustic information is vital in understanding the surrounding marine environment. However, in the absence of biological and anthropogenic activities, environmental factor such as wind speed and rain dominate the complete frequency spectrum[6]. The initial investigations of ambient noise variations were studied by Knudsen[7] and Wenz[8]. The study conducted by Sanjana[9], had established the relation between ambient noise and the wind speed in the shallow water areas of Bay of Bengal. The results have also, reported dominance of low frequency spectrum by ship noise at short and moderate ranges. In a study carried out by Mahanty[10,11], in Bay of Bengal has reported similar results. Moreover, the systematic research of Ramji on ambient noise fluctuations in the shallow water of Bay of Bengal has characterized it to be wind dependent[12]. The measurement of marine ambient noise will not only help in understanding marine ecosystem but also in characterizing seabed properties such as directionality and reflection coefficient for a particular site[13].

2. MATERIALS AND METHODS

The autonomous marine Song Meter (SM2M+) recorder that provides the facility for recording and monitoring of marine biotic and abiotic activities were employed to acquire marine ambient noise data (www.wildlifeacoustics.com). The SM2M+ is a 16-bit recorder which is self-buoyant submersible having single standard wideband Omni directional hydrophone capable of measuring noise in the frequency range of 0.2 - 48 kHz with a receiving sensitivity of 164.3 dB re 1 V/µPa and is powered through 32 D-Size alkaline cells of 1.5 V each. The system provides flexible scheduling, low power operation and records pristine quality audio in wave format. The SM2M+ recorder was configured on shore with sampling frequency of 44.1 kHz to record for 120 seconds in every 15 minutes of time interval. Though the system is designed for long term deployments for depths up to 150 m, it was moored and positioned at the centre of the water column for a period of 24 hours. Considering above system configuration with 128 GB (4 slots × 32 GB) of data storage memory, the recorder can last for more than 40 days approximately.

The data was acquired at both the locations using Song Meter (SM2M+) marine recorder at pre-programmed sampling and recording time intervals. SM2M+ was deployed at 15 08.955' N, 73 55.483' E in 11 m of water depth at the mouth of Sal river and 15° 20.682' N, 73° 47.165' E in the 20 m depth south of Grande Island (Fig. 1).

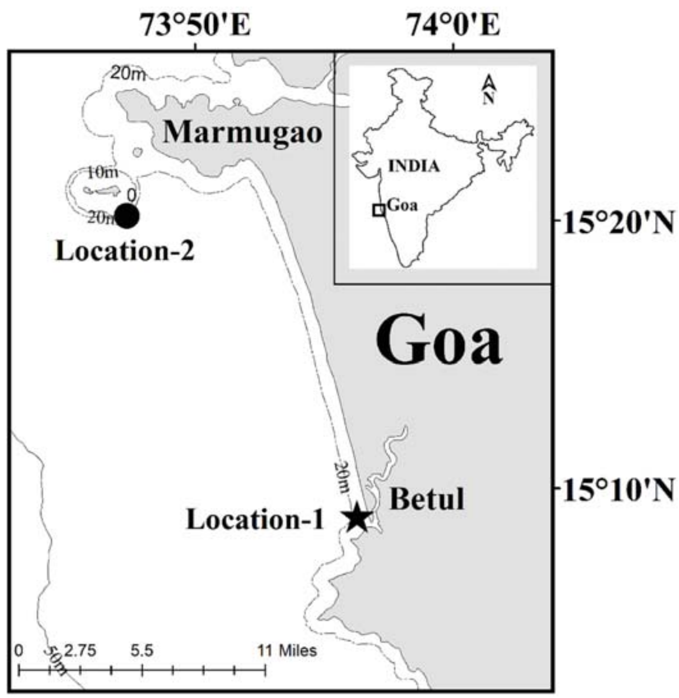

Fig. 1. Shows Song Meter (SM2M+) autonomous marine recorder deployed locations at which the ambient noise data is measured.

The environmental data such as wind speed and direction along with other parameters were measured using an Autonomous Weather Station (AWS), designed and developed at the CSIR-National Institute of Oceanography (CSIR-NIO). Considering its operational requirements, the AWS was installed on the top of the watch keeping boat. The AWS provides metrological data as 10-minutes records with samples every 10 seconds. An average of 600 samples collected in 10 minutes record is provided. The recorded wind data is vector-averaged. The Gust (*i.e.*, the largest wind speed amongst an ensemble of 60 samples that are measured during the 10-minute sampling span) is also recorded[14].

The SM2M+ recorded data was analyzed by generating underwater sound scape employing Welch's method of estimating power spectral density, where the data is divided into the overlapping sections equivalent to window length with 50% overlap. Further, a modified periodogram is computed for each segment using a Hamming window and the resultant periodograms are averaged to determine the final spectral estimate (www.mathworks.com). The average noise spectrum level was computed from the generated soundscape information for every 0.5 kHz over a frequency range from 0.5 to 8.0 kHz. Further, the standard deviation (σ) of the noise spectrum level is determined for the above frequency range. The wind speed data was also examined for its effect on the noise levels. Here, we have investigated the variation and fluctuations in the noise levels due to increase in the wind speed.

3. RESULTS AND DISCUSSION

The temporal variability of ambient noise measurements at two different shallow water areas is investigated by generating marine sound scapes using Welch's method for power spectral density

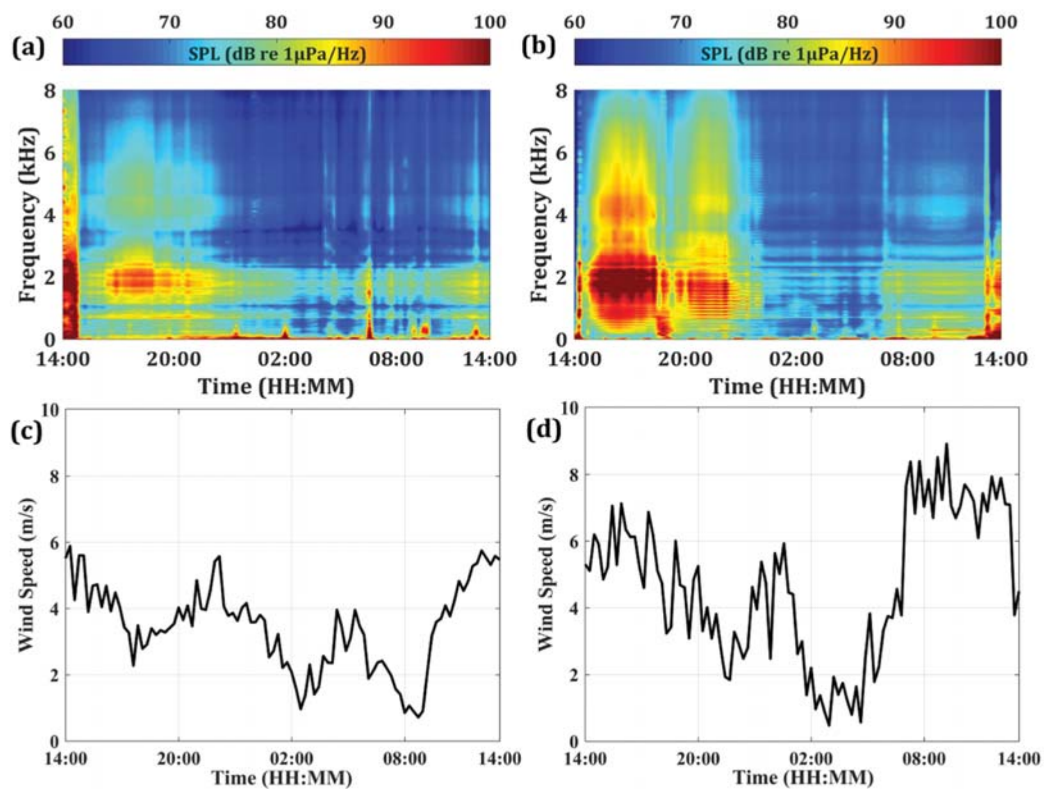

Fig. 2. Showing the soundscapes interms of power spectrum (dB re 1μPa / Hz) generated employing Welch's method for the (a) location-1, off Betul (20-21 March, 2014) (b) location-2, at Grande Island (03-04 April, 2014) while (c)and (d) are the wind speed plots in meter / second as observed during the corresponding time period, at the respective locations

estimation (Fig. 2a & 2b). The soundscapes have reported higher signal strengths during dusk period as compared to dawn period. Further analyses of the SM2M+ recorded data revealed the variations in ambient noise levels at both locations resulting from biological, environmental and anthropogenic sources. However, the useful information in relation to ambient noise variations with wind speed is found to be limited to the frequency <8.0 kHz.

The biological signatures were earlier studied in detail as fish chorus that was ascribed to Terapontidae species family because of the similarity in the 'trumpet' like sounding[15,16]. The soundscape (power spectrum) information was overlapped with respective wind speed data (Fig. 2c & 2d) and accordingly the noise level information is extracted relevant to the range of wind speed corresponding to the Beaufort scale. The noise levels reported at location-1 are the absolute power spectrum levels that vary from 56 - 96 dB at 0.5 kHz and 50 - 73 dB at 8.0 kHz. Whereas, location-2 has reported spectrum levels fluctuating from 56 - 88 dB at 0.5 kHz and 40 - 66 dB at 8.0 kHz respectively.

Table 1. Average noise levels measured at location-1 and Location-2 for different frequencies.

Frequency (kHz)	Location-1 Avg. Noise Level (dB)	Location-2 Avg. Noise Level (dB)
0.5	66.6	69.3
1.0	64.6	71.6
1.5	72.8	74.5
2.0	72.6	74.1
2.5	64.7	69.7
3.0	61.1	67.0
3.5	59.2	64.7
4.0	62.8	65.7
4.5	63.2	66.3
5.0	61.8	64.9
5.5	61.3	64.3
6.0	59.8	63.3
6.5	59.1	62.9
7.0	58.3	62.1
7.5	57.3	61.0
8.0	55.2	59.0

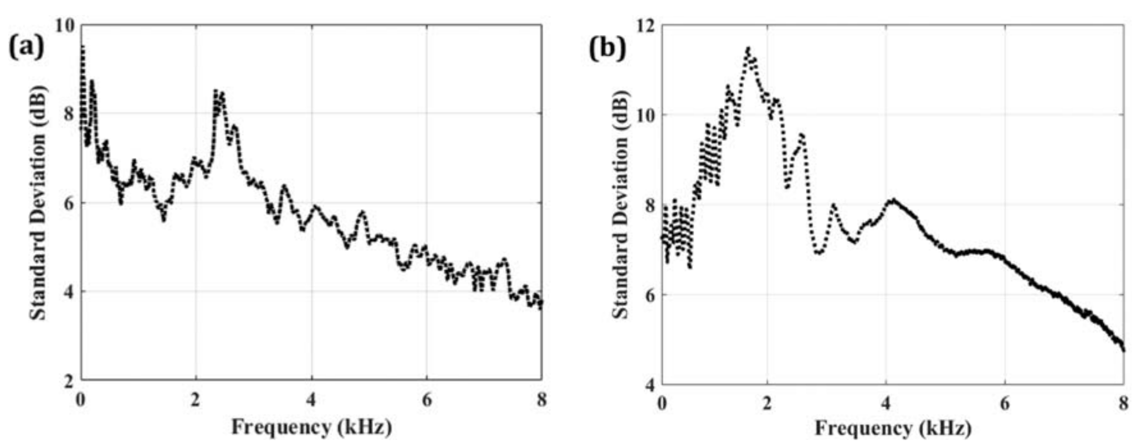

Fig. 3. Illustrates the standard deviation (dB) computed from the spectrum Noise Levels (NL) for the (a) location-1 and (b) location-2.

The average noise levels were computed from the reported spectrum levels over a frequency range of 0.5 - 8.0 kHz, which were appeared to vary from 55 - 66 dB for location-1 and 59 - 69 dB at location-2 (Table 1). The maximum boost of ~ 5 dB in the noise levels is observed at location-2 compared to location-1 owing to biological sources and surface wind. Further, the standard deviation values (in dB) of the reported noise levels were computed for both the locations relative to the mean noise level. The same were presented to be ~ 6 dB at lower frequencies with a peak at 2.33 kHz revealing the effect of bubbles burst by wind generated waves to 3.75 dB at 8.0 kHz for location-1 and location-2 shown standard deviation values varying from ~ 7.30 dB at low frequency to 4.83 dB at 8.0 kHz (Fig. 3a & 3b).

Further, location-2 has shown significant increase of σ deviation levels in the frequency band of 0.5 kHz to 2.5 kHz as compared to location-1. Both the data sets have reported higher σ deviation levels in the lower frequency range and continue to falls linearly towards the higher frequencies.

The variations seen in the lower frequency may be primarily related to the biological noise sources. However, with increase in wind speed the effects of waves, ship noises were eliminated which is revealed by the σ deviation levels decease with increase in frequency (Fig. 4a & 4b).

The pie charts were generated from the computed power spectrum of noise levels (dB) individually classified in the categories such as biological, shipping, wind generated noise, wave breaking and

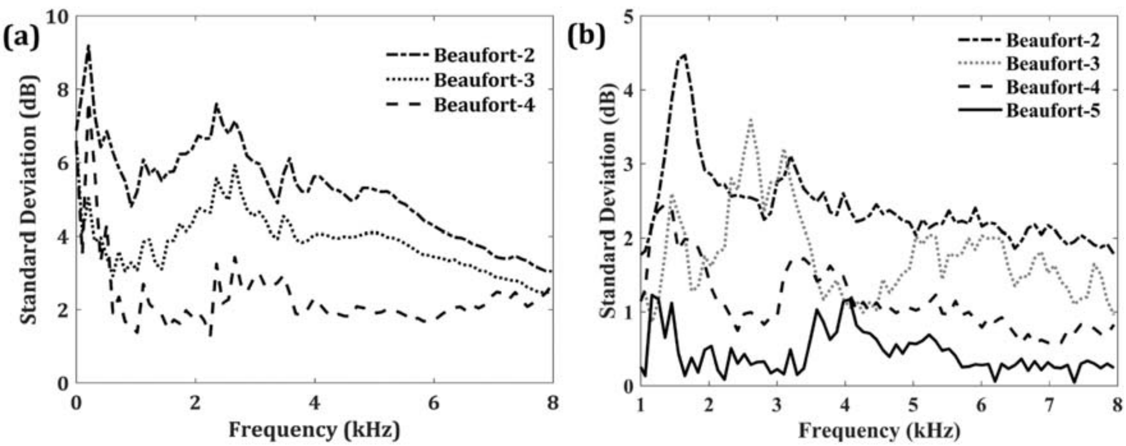

Fig. 4. Illustrates the standard deviation (dB) for wind speeds represented in Beaufort scale for the (a) location-1 and (b) location-2

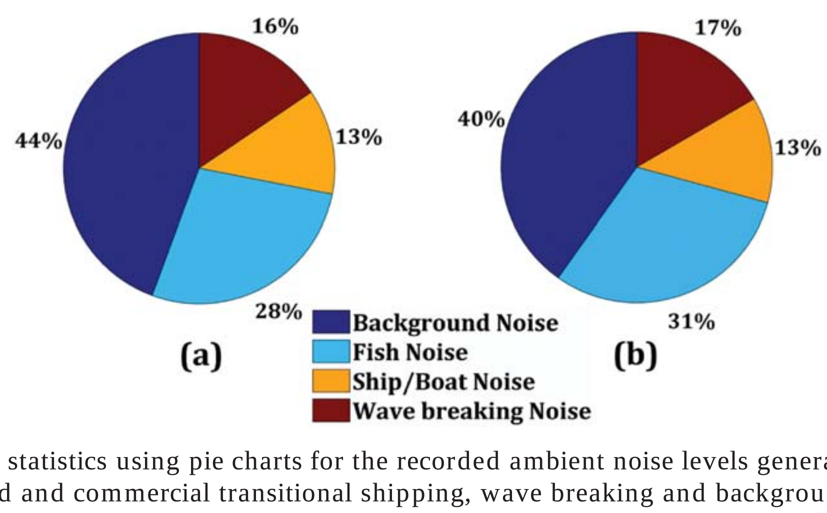

Fig. 5. Shows statistics using pie charts for the recorded ambient noise levels generated by fishes, localized and commercial transitional shipping, wave breaking and background noise activities at the (a) location-1 and (b) location-2

background noise depending on the frequency range and the corresponding range of noise levels in dB (Fig. 5a & 5b).

4. CONCLUSION

The ambient noise measurements were carried out at two locations in shallow water, off Goa to study acoustic characteristics of the areas. The noises produced at location-1 are predominantly due to localized shipping and biological activities whereas, the location-2 have reported dominant biological signatures along with moderate localized and commercial shipping noise. Additionally, the influence of wind was observed at both the locations and its impact at location-1 was observed to be less as compared to location-2. The noise levels from location-2 show dominance of wind. The recorded shipping noise has shown rapid variations with respect to time compared to wind generated noise[17]. Higher variability in average noise levels of ~ 5 dB is evident in the case of location-2 that complies with typical AN data from coastal areas with transitional shipping. The σ deviation levels show a gradually decreasing trend with increase in frequency at both the locations. Further, 'σ' levels for different wind speeds (m/s) as categorized with respect to Beaufort scale were found to be decreasing with increase in Beaufort scale and the noise levels fluctuations of ~ 0.5 to 1.0 dB is observed in the entire frequency band for wind force of 5 Beaufort. The computed σ levels at frequencies higher than 2.0 kHz along with higher wind speeds of 4 and 5 Beaufort are seen to be consistent when wind noise is dominant. Higher noise spectrum levels in the lower frequency ranging up to 4 kHz were observed to have higher correlation with wind speed that is evident from the standard deviation levels computed from ambient noise level within lower frequency spectrum.

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Biological noise from coral reef regions off-Kavaratti Island, Lakshwadeep - Employing Passive Acoustic Technique

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ABSTRACT

The passive acoustic data acquired using a single hydrophone has been examined to study the underwater sounds in coral reefs. The recorded sound data is filtered and analysed. The coral reef being home to a number of fish, are important underwater ecosystem which should be understood and protected. Fish species identification with the help of the sound they produce is implemented using passive acoustics technique in Kavaratti Island, Lakshadweep. Spectral features are used here to classify the sounds. In this research we have developed passive acoustic data segmentation techniques, and subsequent sound data classification based on the spectral features.

1. INTRODUCTION

Passive acoustics technique is a useful technique to investigate and monitor marine animals' characteristics. Underwater sound signals generated by marine animals as a means of communication travel great distances. Present study area is a coral reef located near Kavaratti Island the headquarters of the Union Territory of Lakshadweep[1]. This island is at a distance of 404 km (218 nautical miles) from Kochi. The lagoons around Kavaratti are inhabited with starfish, anemones, sea cucumbers, and countless multi-hued fishes astounding corals. Coral reefs are inhabited by a variety of fish, many of which produce sound with dedicated organs (vocalization) or generate sound while feeding and swimming. The fish that were spotted from the study area were Indo-Pacific sergeant (Abudefduf Vaigiensis), black triggerfish (Melichthys Niger) and Sapphire Damsel fish (Chrysipteraspringeri)[2]. Apart from fish there are many shrimp which make a high frequency sound, just like an impulse. Due to the diverse nature of a coral reef, the passive acoustic signals collected is very complex with a mixture of a lot of sounds produced by different aquatic animals. The shrimp sound is present throughout the data; it distorts the sound produced by other fish.

2. MATERIALS AND METHODS

A glass bottom boat was taken into sea with the instruments required. The hydrophone used to record the sound data was a Cetacean Research's C55[3] series of hydrophones which are cylindrical hydrophones designed for the detection of infrasonic, audible, and ultrasonic sounds underwater. Field notes were taken down with details about the presence of fishing boats, depth of hydrophone, time and date of recording. The sampling frequency selected was 40 kHz implying that nyquist rate is 20 kHz. Video and photos were taken to aid in identifying the different corals and fish present in the particular areas. Wind speed was also recorded. The raw data was then converted to .wav format and imported into MATLAB for the processing.

2.1 Data processing technique

The general flow to handle such type of data is noise reduction, segmentation and classification. So to understand the nature of noise present in the data we must first analyse the spectrogram of the raw data. This can be verified by observing the spectrogram, we see a red band present throughout the signal at the lower frequencies. We use a band pass filter to clean the signal because the band pass attenuates the lower frequency noise and also attenuates the high frequency harmonics. The lower and upper cut-offs for the band pass filter can be decided by taking the power spectral density of a portion of the signal without any biological activity. The PSD is plotted, there is high energy from 0-10Hz due to the surface waves. A band pass filter from 40Hz-18 kHz is designed and applied to the signal. The output (Fig. 1) can be seen to have a low frequency wave but with reduced amplitude implying that the signal to noise ratio has improved. After cleaning the signal we start segmenting it into individual sound events.

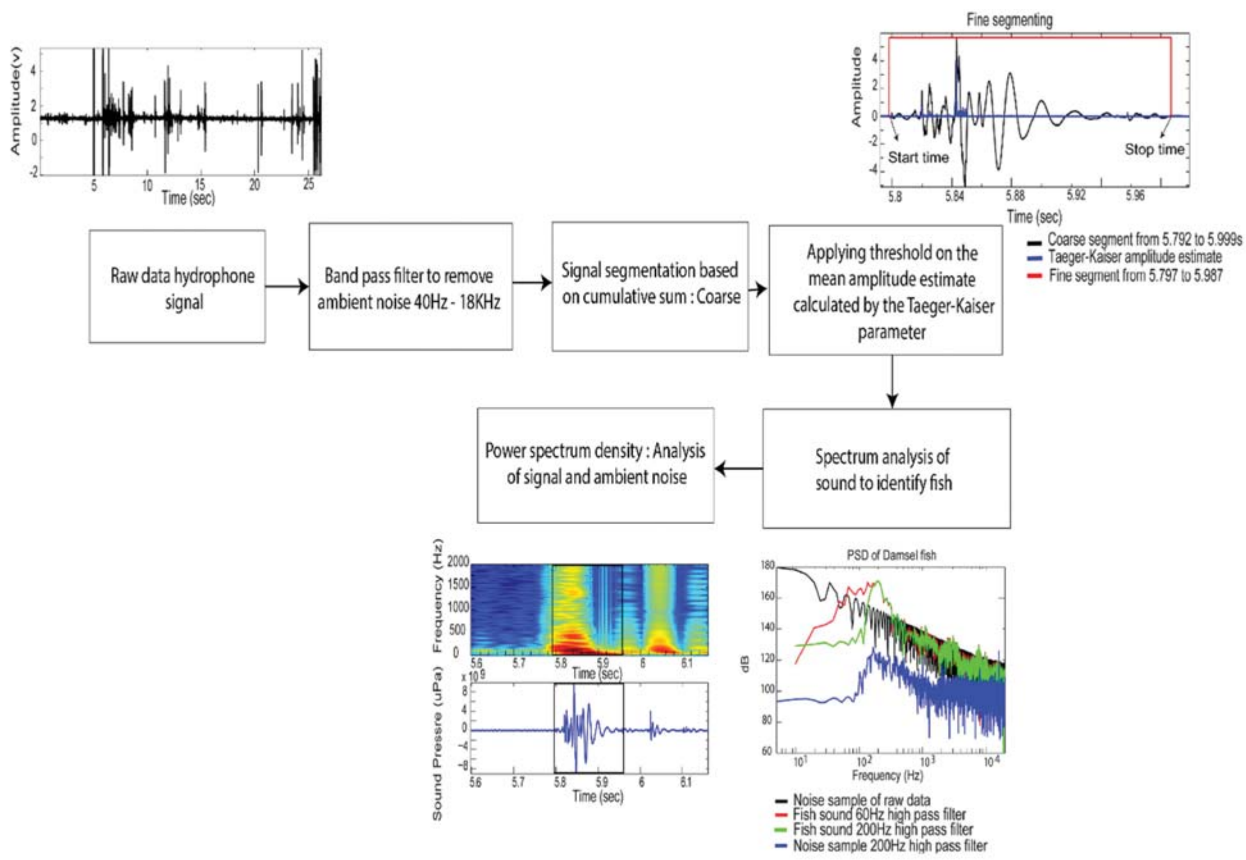

Fig. 1. Flow diagram for noise reduction, segmentationof the fish sound data. Please see the method of TK is employed to decide the threshold value.

3. RESULTS AND DISCUSSION

3.1 Segmentation

Segmenting is done in two steps; the first step is coarse segmenting with the help of the cumulative sum. A sharp rise in the slope of the cumulative sum marks the beginning of a sound event. The flat or saturated part of the curve corresponds to the end of a sound event. This can be seen in figures. The coarse segments are now passed through refined algorithm for detection to estimate the start and stop times of the segment. Present algorithm is an attempt to improve the currently developed algorithm[4]. The algorithm calculates the frequency weighted pressure amplitude known as TK. The Taeger-Kaiser parameter has been claimed to be a proper measure of sound wave energy[5,6]. Deciding the threshold is an interesting problem. If the threshold value is too low, then the algorithm would include parts which do not belong in the signal whereas if the threshold is too high we would be clipping the signal. Thus the threshold is decided by trying different values and selecting the most appropriate for the given SNR. In (Fig. 1) we can visualize the working of the algorithm; the coarse segmented segment. The blue line is the Taeger Kaiser Amplitude estimate, the first and last threshold crossing are marked by the borders of the rectangle. This gives us the start and stop time of the sound event.

3.2 Fish Identification

After segmenting the signals, we move forward to try and identify the fish species present in the coral reef by identifying the sound that they produce. The spectrogram of each segment is generated (after down sampling to 4 kHz[7]) and it is visually compared with references documenting the sound of similar fish in coral reefs (Fig. 2). Each fish species produces a variety of sounds, which all have peak frequency that distinguishes them. To find the peak frequency we plot the PSD of all the segmented signals. When we compared the peak frequency of the segments with those given in the references it was observed that the peaks were much lower than the expected values. This is due to the presence of the low frequency noise. We know that the PSD gives us an idea of which frequencies are present in a particular signal and how much they contribute to the signal. Thus the low frequency sound present in the fish sound and the noise

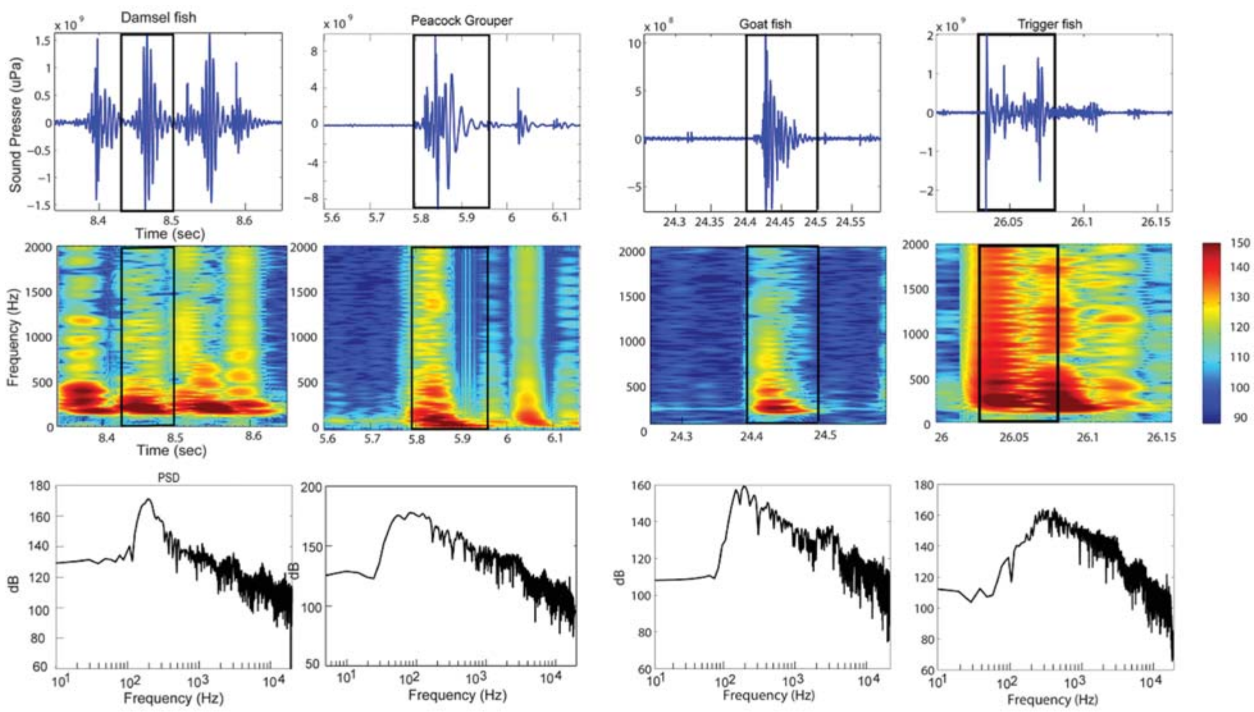

Fig. 2. Segmented data having "start" and "stop"time along with the PSD of four fish sound types.

add up giving us the false impression that the peak frequency is lower than it actually is. To prevent this from happening we must increase our lower cut off levels in the band pass filter. As can be seen in (Fig. 1) this method helps us correctly identify the peak frequency. The PSD of the raw date (background) shows a peak at around 35 Hz, which corresponds to a peak in the PSD of a portion of raw noise data (without signal part of the time series) (black line). After applying a 60 Hz high pass filter we see that there is a peak at 83 Hz which falls in the range of the peacock grouper (green line). The noise gets attenuated after applying the 60 Hz high pass filter implying that the peak produced at 83 Hz is due to the sound produced by the peacock grouper and not due to noise. Similarly, it can be observed in (Fig. 1), the first peak frequency is around 156 Hz for the raw data (red line). Whereas the data high pass filtered at 200 Hz has a peak frequency at 203 Hz which is where the peak frequency of the damsel fish falls.

3.3. Feature extraction

After applying appropriate filter, we computed five features for each data point, they are zero Crossing, spectral roll-off, spectral centroid and the peak frequency. The matlab code used to compute the zero crossing rate, spectral roll-off and spectral centroid was designed by Theodoros Giannakopoulos found in matlab file exchange[8]. The name of the program is "Some Basic Audio Features" . Zero crossing rate: it is the rate of sign changes along a signal *i.e.* a measure of the number of times the signal vale crosses the zero axe. It is small for periodic signals and high for noise. Spectral roll-off: The spectral roll - off point is the frequency so that 85% of the signal energy is contained below this frequency Spectral centroid. The spectral centroid is defined as the centre of gravity of the magnitude Spectrum of the STFT The centroid is a measure of spectral shape and higher centroid values correspond to "brighter" textures with more high frequencies. Peak frequency: It is the frequency of sound with the highest amount of energy present in the signal. Hurst exponent: The Hurst was computed using the power spectral analysis method in the BENOIT (v1.3)[9] program (Fractal Analysis System, Benoit). The range of the Hurst exponent is from 0 to 1, where H=0 for pink noise (with slope 1), white noise (with slope 0) and blue noise (with slope -1); H=0.5 for a Brownian noise (with slope 2); and where H=1 for black noise (with slope 3). Distinguishing between blue, white, and pink noise cannot be done by the Hurst exponent since all three

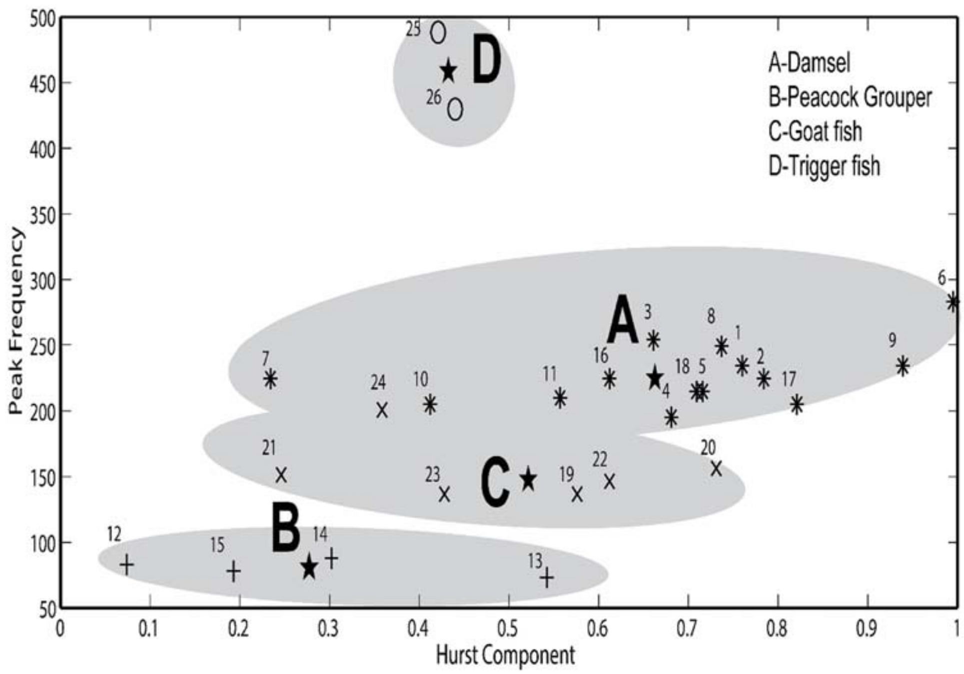

Fig. 3. Clustering pattern for four fish sound types.

have H=0. There are two simple transforms which are applied on our data to shift the slope and thereby H and D. The first transform is called "Running Sum". The effect of this transform is to shift the slope of the original time series by a factor of +2. We first analyse our original using the power spectral analysis method. Check the slope on the log-log plot. If the slope is less than 1.0, then we select running sum and transform our original data. Then we run the transformed data to measure the Hurst exponent and fractal dimensions.

3.4. Clustering

Clustering of numerical data forms the basis of many classification and system modelling algorithms. The purpose of clustering is to identify natural groupings of data from a large data set to produce a concise representation of a system's behaviour. To verify our classification manually we perform fuzzy c means (FCM) clustering on our data. Fuzzy c-means (FCM) is a data clustering technique in which a dataset is grouped into n clusters with every data point in the dataset belonging to every cluster to a certain degree. For example, certain data point that lies close to the centre of a cluster will have a high degree of belonging or membership to that cluster and another data point that lies far away from the centre of a cluster will have a low degree of belonging or membership to that cluster. A data matrix was designed with rows as segments and columns as features. This data matrix was then fed into the FCM (Fuzzy Clustering Algorithm) algorithm with 4 predefined classes. The final clustering can be seen in Fig. 3

4. CONCLUSION

Thus we have observed that the passive acoustics can be used to locate and identify fish in the sea. With this useful information we can detect fishes and the sound generated by fish to understand their behaviour. With the clustering applied here we validated our qualitative classification.

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