AMBIENT NOISE MEASUREMENTS IN THE STRAIT OF ISTANBUL

Ufuk Ulug Department of Electronics and Communications Eng., Istanbul Technical University, Istanbul, Turkey
Tayfun Akgul Department of Electronics and Communications Eng., Istanbul Technical University, Istanbul, Turkey
Cengiz Gezer Department of Electronics and Communications Eng., Istanbul Technical University, Istanbul, Turkey

INTRODUCTION

Shallow water acoustics is a challenging topic that creates interest among the researchers. Acoustic conditions in the shallow water may drastically change with tiny temporal and spatial variations, hence modeling or analyzing shallow water environment mostly becomes a complicated task. Recently, with a support from TUBITAK-ÇAYDAG (The Scientific and Technological Research Council of Turkey – Environment, Atmosphere, Earth and Marine Sciences Research Group), we have designed and constructed a data acquisition system for the purpose of measuring and modeling the underwater ambient noise of the Strait of Istanbul which is commonly known as the Bosporus. As well known, this is not only a strait that forms the boundary between the European and Asian parts of Turkey but it connects the Black Sea to the Sea of Marmara. The Strait of Istanbul is approximately 30 km long, 800 m wide with an average of 80 m deep and has high traffic density due to the merchant ships passing by between Black Sea and Sea of Marmara, and ferries carrying people and goods across sides, plus sailing yachts and fishing boats.

The main objective of our study is to measure the underwater ambient noise level in the Bosporus and reveal its nature for various environmental effects. Since the system is nearby the commercial shipping route, the main noise source will clearly be ships, ferries, yachts and fishing boats. It is relevant to mention here that the Strait has complicated currents, i.e., one flowing from the surface towards south direction, the other towards north direction on the bottom with varying speeds of 0.5 knot to 4 knots. Since the surface flow is directly affected by wind, database will also include daily weather conditions and traffic density reports.

Our custom design system namely, Bosporus Ambient Noise Acquisition System (BANAS), consists of an equally spaced 8-element vertical hydrophone array with an inter-array distance 4 m, and a buoy carrying electronic modules: an Analog-to-Digital Converter (ADC) module connected to an embedded PC with the data storage and transmission units. In other words, acoustic underwater signals acquired by each hydrophone are digitized and stored in high capacity hard disks which are slaves to the embedded PC. The data acquisition software in the embedded PC, developed by using LabVIEW, has the capability of controlling the acquisition parameters and performing the database management which is needed for further offline processing of the collected data. Software is also able to transfer data to a remote location (shore office) over an underwater fiber line.

Below, we give details on the hardware design and components, plus the software of the underwater acoustic data acquisition system. In Section 3, we present preliminary results of the field tests.

SYSTEM DESCRIPTION

In Figure 1, a sketch of BANAS shows both subsea and surface components of the system. Preamplified underwater ambient noise signal, which is collected by equally-spaced broadband hydrophones, is transmitted to the surface electronics over insulated coaxial cables. Also, water temperature is measured by the digital temperature sensors which are positioned next to a hydrophone and transmitted to the housing in the buoy. Below, main components of the system such as buoy, hydrophones, data acquisition and transmission devices and the data analysis software are introduced.

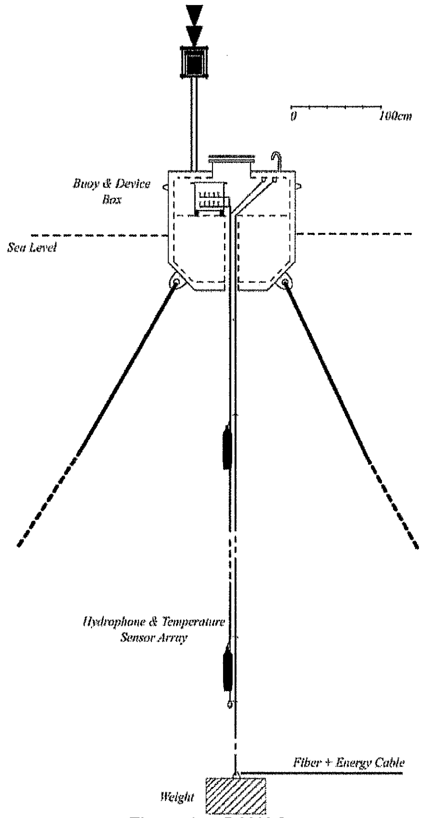

Figure 1. BANAS

HOUSING AND BUOY DATA

Electronic devices which are responsible for the acquisition of underwater ambient noise are located in a water-proof housing in the surface buoy. The device box with dimensions of 30cm x 40cm x 40cm (HxWxL) is made of polyethylene coated fibreglass which has a rigid structure against strikes and water leakages. Specially designed water resistant underwater connectors are used at the entry points of the cables to the box.

The surface buoy, which carries the hydrophone array and houses the electronics, is a cylindrical float with 1.4 m diameter and 1.3 m height. The interior of the buoy has two separate cells: The lower isolated cell is empty to assure that the buoy floats against the load of the system and the upper cell contains the device box housing for electronic equipments.

As described in Part 3.1, the site has strong water currents from opposite directions at the bottom and at the surface. The buoy is designed to be fixed to the seabed from multi-points with Dyneema ropes to keep the hydrophone array more stable. This process is not as hard as fixing such a system in the oceans since the maximum depth of the site is not more than 70 meters.

HYDROPHONE ARRAY

BANAS has a vertically located hydrophone array, which consists of equally-spaced eight hydrophones attached on a polyurethane rope. Hydrophones are ITC6050C model and have nearly flat broadband frequency response from 30 Hz to 20 kHz [1]. Each one has a sensitivity level of -158dBm in the band of operation which can be considered as omni-directional in the x-y plane. Since the system is designed to operate in shallow water environments, the spacing between hydrophones is set to 4 meters making the length of the array 30 meters long.

DATA ACQUISITION AND TRANMISSION

Electronic components of the system are located in a water-proof box in the buoy. The block diagram of each component is shown in Figure 2. The output of each hydrophone is directly connected to an input channel of the ADC since the hydrophones have internal preamplifiers. Data acquisition system is manufactured by National Instruments and contains a chassis and the measurement modules. Measurement modules can be selected for the best solution and plugged into the slots of the chassis, which provides flexibility to the system. The chassis in the system has eight slots for module insertion and a USB port for data transfer. For broadband data acquisition, NI9239 ADCs, which have four differential input ports with up to simultaneous 50 ksample/s/ch sampling rate and 24 bits resolution, are used.

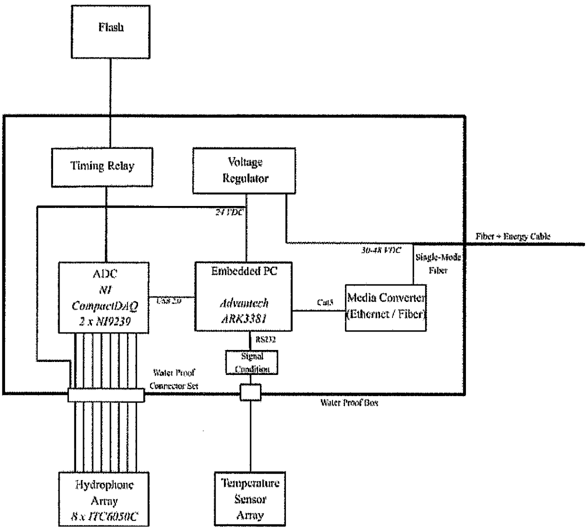

Figure 2. Configuration of the System

The data acquisition system is connected to an embedded PC through a USB port in order to transfer real-time digital data to its high-capacity hard discs. During data recording, most of the parameters about acquisition such as sampling rate, duration and active hydrophones, or file sizes and names, paths where the files are going to be saved can be changed easily by using the user interface developed using a commercial software package (LabVIEW). Furthermore, real time record session logs about the environmental and meteorological conditions can be attached to data files remotely from the shore office.

BANAS is designed for continuous data acquisition in eight channels with a sampling rate of 5 kHz per channel and the data is transmitted to the shore office for further signal processing and archiving. Since radiated noise for ships are highly dominant in a few hundred hertz, a 5 kHz sampling rate is sufficient for the analysis of ship noise. However, if a higher bandwidth is required, it is possible in BANAS to remotely connect to the embedded PC from shore office and change the value of the sampling rate up to 50 kHz per channel. With 8 channels this forms 400 kHz sampling rate in total.

DATA ANALYSIS SOFTWARE

In order to analyze the collected underwater ambient noise data, a graphical user interface (GUI) has been developed in MATLAB. Before investigating the signal characteristics deep in details, many statistical and spectral properties of the examined signal can be monitored easily through a quick analysis with the GUI. Time-frequency, wavelet, and distribution fitting analyses of the signal or the statistical properties such as variance, kurtosis, and skewness can be computed. Software also gives opportunity to easily extract any desired part of the collected signal for the analyses.
Distribution fitting implemented in the software is done with the Kolmogorov Smirnov (K-S) Test [3]. Cumulative Distribution Functions (CDF) are fitted to the data using Maximum Likelihood Estimation (MLE) method [4] and ordered with respect to K-S distances.

FIELD TESTS AND PRELIMINARY RESULTS

The main objective of this work is to analyse and reveal the spatial and temporal variability of underwater ambient noise in the Strait of Istanbul. In order to fulfil this objective, long term ambient noise data should be collected and archived in a database with some other environmental data, such as water temperature, wind velocity, rain and ship traffic densities. Below, geographical and meteorological properties of the measurement environment are summarized and some analysis results are discussed.

GENERAL CONDITIONS OF THE FIELD

The Strait of Istanbul is at the north-west of Turkey shown in Figure 3. As described in the Introduction, the major noise sources are commercial shipping passing through Black Sea to Marmara Sea or vice versa and local fishing and sightseeing boats. Because of the two-way current flow structure of the Strait, water temperature changes rapidly with depth and also it fluctuates seasonally. In one year, water temperature values vary between 4 to 24 near the surface, 8 to 16 in the middle, and 10 to 15 at the bottom [5]. Wind usually blows from north-east or south-west with average speed 5-6 knots which can reach up to 40-60 knots in some days. About 800 mm rain falls to Istanbul in a year; about 35% is in winter, 15% percent in summer and 25% both in spring and fall [6].

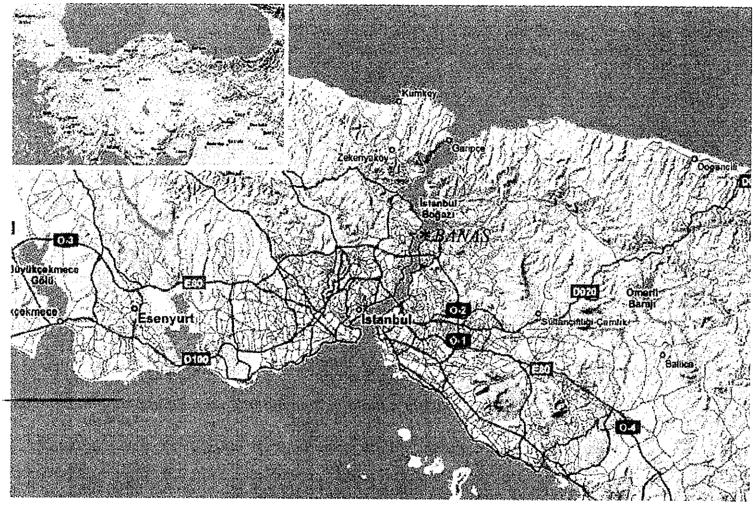

Figure 3: The Strait of Istanbul

PRELIMINARY RESULTS FOR THE AMBIENT NOISE CHARACTERISTIC

Collected underwater ambient noise data is analysed with our custom-made signal analysis software both statistically and spectrally. As described above, the objective of this study is to construct a model for the ambient noise of the Strait of Istanbul where near-field passage of merchant ships is the major noise source. With BANAS, 24 hours non-stop data can be acquired in a fixed location and underwater noise characterization with respect to the ship traffic, weather conditions and seasonal changes can be accomplished at any desired point. In January 2008, a three-hours-long preliminary data is collected with BANAS to test the system.

During the test, hydrophone array is fixed to a small float without any weight located to the seabed which causes low frequency noise because of the free movement of the array especially at the bottom. This low frequency noise is later digitally filtered with a high pass filter which has 10 Hz cutoff frequency. In the statistical analysis only the acoustic pressure data of the hydrophone at the bottom of the array is presented. Many different window sizes and overlap ratios are used to observe the statistical behavior of this three-hours-long data in different scales and time intervals. As expected, best distribution fit estimation using the signal analyzing software described in Part 2.4 is observed as normal distribution in most cases. Also particular time intervals, where it is known that there is a near-field passage of a ship, are compared with the typical silent part of the recording to reveal the relationship between the ship radiated noise and the silent noise. From these particular time intervals one minute long continuous ambient noise data is extracted and it is windowed with ten seconds long %50 overlapped windows. For each ten seconds long data set, the optimal parameters for the Normal distribution were estimated by using the Maximum-Likelihood-Method [4]. Thereby, theoretical normal distributions are constructed from the optimal parameters. Finally the Kolmogorov – Smirnov (K-S) distance [3] between these theoretical distributions and the empirical distributions are calculated. Lower K-S distance means better theoretical distribution fit to the empirical distribution. Box plot representations of K-S distances calculated at different circumstances are shown in Figure 4. In the first column the silent interval has the minimum lower quartile and the median value among the other intervals. Length of the whiskers specified as the length of interquartile range. In this length of whiskers configuration, maximum K-S distance observed in the silent interval became an outlier and it is represented as a plus sign in Figure 4. This maximum value may be considered as statistically unreliable.

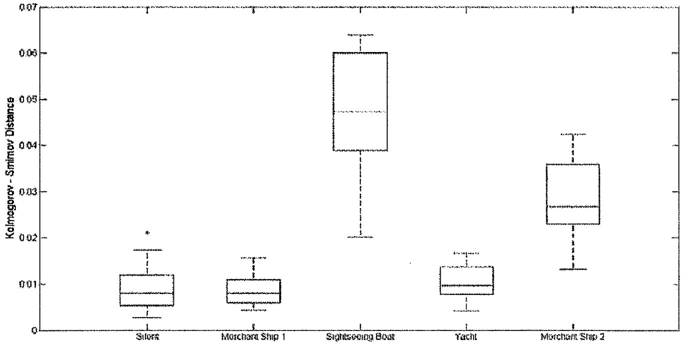

Figure 4. Box Plot of K-S Distances in Different Circumstances

Basic statistical analysis of the intervals shows that near-field ship noise deviates from the normal distribution. Among these, the highest deviation was observed for the sightseeing boats as presented in Figure 4. In order to see the deviation from normal distribution, this time one minute long entire sightseeing boat interval is examined without windowing it. K-S distances for the other distributions mentioned in Part 2.4 were calculated. The K-S distance values of the four best ranked fits to the interval can be found in Table 1. Gamma distribution has the minimum K-S distance which is the best fit to the one minute long data. PDF of this interval and the fitted distributions to it can be seen in Figure 5. In Figure 5, sign of the acoustic pressure stands for the directivity of the vibration (compression and expansion). At the other ship dominated intervals such as "Merchant Ship 2" gamma distribution is also witnessed as a best fit to the acoustic pressure in different length windows. Consequently, in the statistical analysis it is observed that near-field shipping causes acoustic pressure data collected with our system deviates from the normal distribution to the gamma according to the K-S test.

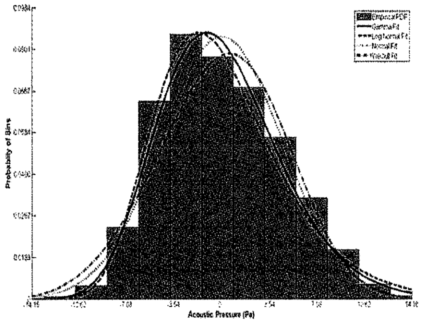

Figure 5. Distribution fitting to a Sightseeing Boat Recording

Rank	PDF	K-S Distance
1	Gamma	0.0203
2	Lognormal	0.0251
3	Normal	0.0437
4	Weibull	0.0464

Table 1. K-S Distances for the Sightseeing Boat Recording

For the spectral analysis, many spectral estimation methods are used with different sizes. In Figure 6, estimated sound pressure spectrum level using Welch method with FFT size of 128 of one minute long underwater ambient noise is shown. For the comparison with other studies in the literature, the most silent part of the data, where there is not any ship in sight and wind speed is below 1 knot, is chosen and the spectrum is shown below. Data 1-7, given in the legend, are the order of the hydrophones from surface to bottom. This figure gives information about the depth dependency of the ambient noise over the spectrum: At higher frequencies, spectrum levels of the deeper hydrophones are lower. Clearly, more data is needed for the analysis of the depth dependence of the ambient noise. Compared to the results for the ocean ambient noise in the literature [7, 8], spectrum level is 20 to 30 dB higher at the frequency band of 100 Hz to 500 Hz.

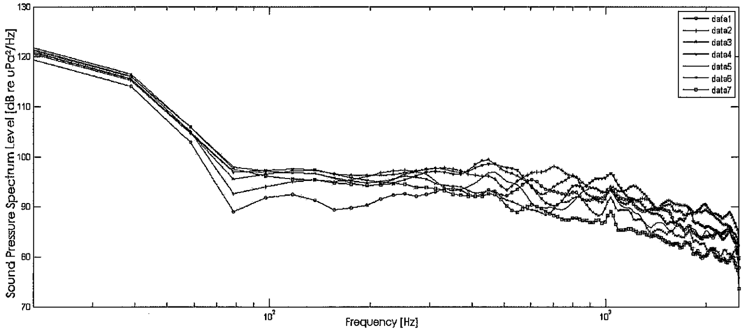

Figure 6. Spectra of the Underwater Noise Data Acquired by Hydrophones from 1 to 7 (from surface) During Minimum Shipping Activity

In Figure 7, spectra of underwater ambient noise during a passage of a ship versus no ship in sight are given. For spectral estimation, Welch method is used with FFT size of 4096. Ship noise is at least 20 dB higher in the frequency ranges greater than 60 Hz. Because of the canal effect of the Strait, it is thought that distant shipping noise still exists in the lower frequencies. The effects of the environmental conditions and the structure of the Strait on underwater ambient noise is still studied.

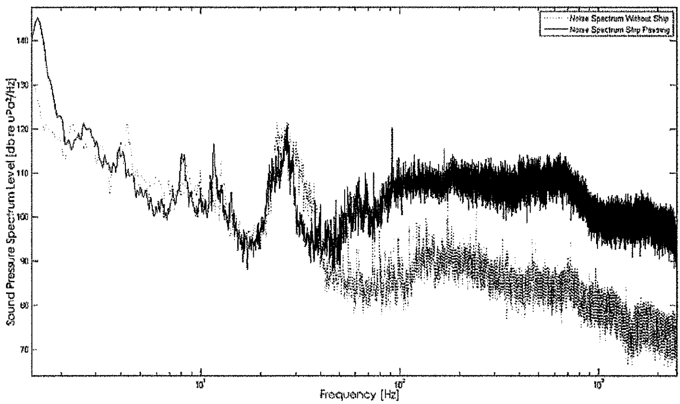

Figure 7. Underwater Ambient Noise During a Passage of a Ship versus No Ship in Sight

CONCLUSION

Bosporus ambient noise acquisition system, BANAS, is introduced. Primarily tests show that the ambient noise spectrum level is 20 to 30 dB higher at lower frequency band between 100 Hz and 500 Hz compared to the oceans. Basic statistical analysis reveal that underwater noise in Bosporus is Gaussian distributed when local wind and distant shipping dominated, which is consistent with some other studies for the oceans [7]. In the presence of near-field shipping (i.e. sightseeing and fishing boats), distribution deviates from Gaussian to Gamma. Further experiments are being conducted for the underwater noise characteristic of Bosporus.

ACKNOWLEDGMENT

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