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PASSIVE ACOUSTIC UNDERWATER NOISE MEASUREMENTS IN CONSTANTA PORT AREA

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Abstract: *Generally, underwater noise measurements are made to monitor the impact of commercial and military activities in oceans and seas and to provide information for vessel identification. In this paper, the authors analyse the noise produced by ship traffic at the entrance of Constanta harbour. Comparisons between background noise and ship noise are made, and an analysis of the propagation of noise produced by each measured ship is made regarding the distance between ship and hydrophones (CPA – closest point of approach). Also, we discussed about the characteristics of ship's noise spectral components and the dependence of sound propagation in port aquatorium on these characteristics. The recorded signals are thoroughly analysed by means of FFT and Wavelet for low and mid frequency bands. A few conclusions and remarks are made in the end about spatial distribution and level of underwater sound in entrance of Constanta harbour which is obtained from measurements by superimposing one or more noise sources in the area of interest.*
Keywords: *ship noise, ship characteristics, underwater source spectra*

INTRODUCTION

Underwater noise represents an area of interest for marine specialists since early decades of 20th century. During 1970's, there was an increase of research regarding the impact of underwater noise over the marine wildlife. Since then, numerous researches have been done including underwater noise from various sources: ship traffic, military activities, economical exploitation of marine resources, offshore constructions, tourism. These activities involve shipping, sonar utilization both by military and civilians, explosions, drilling, dredging, piping etc. The result is a wide range of frequencies which affect almost every marine life form.

Measurements have been made all around the globe regarding underwater noise produced by human activities. Harbours are also a part of these regions where is an intense human activity which generates high levels of underwater noise.

During these measurements, the hydrophones are deployed in the water and are connected through an acquisition system to a laptop which can record and analyse the signals. K.W.Chung et al studied the underwater noise using a method to estimate the modulation of noise radiated from a ship according to parameters like: number of propeller blades, rotational speed, shaft rotation frequency which is known as DEMON method (Detection of Envelope Modulation on Noise) [1].

Other method involves the placement of hydrophones tied to a buoy and connected to a recording system [9]. This is a passive monitoring system of the underwater noise and is used to determine the underwater noise over a long period of time. Ship's acoustic signature can be determined in an acoustic underwater range. A number of hydrophones are tied to seabed and connected to computers onboard a research ship; the monitored ship passes over the hydrophones at various speeds including ship's speed service. This kind of measurement is more accurate, but requires special conditions [4].

UNDERWATER NOISE MEASUREMENT AT CONSTANTA HARBOUR ENTRY/EXIT

In Romania, underwater noise measurements have been done over the years by Marine Research Centre, and also by other institutions like Naval Academy „Mircea cel Batran", during research projects. Naval Academy made several measurements of underwater noise in the Romanian Black Sea coast during the research project RoNoMar [4]. These measurements included the area of Constanta harbour and their purpose was to determine the underwater noise made by shipping and its impact on marine wildlife.

In this paper, the authors have selected the measurements made at the entry/exit of port Constanta.

Figure 1 – Entry/exit at north Constanta port

These measurements have been made using equipment from Bruel & Kjaer: a hydrophone type 8104, portable data acquisition system (Machine Diagnostics Toolbox 9727), laptop with Pulse software (capable of measuring, recording and analyzing signals). The hydrophone was deployed at about 7m from the shore and at a depth of about 10m. The measurements were made during 12 hours, different days and in different periods of the year. During measurements, a large number of ships passed the measuring point. From these measurements were selected the ones about commercial ships (table 1). The weather conditions were favourable for measurements: calm sea (very small waves), temperature of 15-18 ^{0}C.

N^O	Vessel's name	Vessel's type	Dimensions Length x Breadth x Draught	Displacement	Speed Max / Avg	Passing speed
1.	ELTEM (IMO:7009988)	Bulk Carrier	124 m x 17 m x 7,2m	7611 t	9.2 / 8.9 kn	4 kn
2.	OANA (IMO: 9405736)	Chemical/Oil Tanker	100 m x 18 m x 3.6 m	6474 t	12.5 / 10.5 kn	5 kn
3.	ATASOYLAR (IMO: 9040936)	Cargo	98,75 x 12m x 6,3m	5033 t	11.2 / 9.1 kn	5 kn
4.	AGIOS EFRAIM (IMO: 9156278)	Bulk Carrier	224 x 32 x 7.1m	73018 t	13.4 / 10.3 kn	3 kn

Table 1 – Ships characteristics

The measurement method used was CPA (Closest Point of Approach) [5]. The position of the hydrophone was known, but the distance travelled by the ships was estimated; in order to reduce the errors, the measurements started and ended when the ships passes the same references. The length of the measurements was set to 120sec.

Date and time	**Source of noise**	**Approximated distance**	**SPL [dB re 1μPa]**	**Comments**
07:26	Ship: ELTEM	100 meters to entrance	151	Ship 1 passing measurement point Ship 3 approaching
07:33	Ship: OANA	100 meters to entrance	141	Ship 2 passing measurement point Ship 3 approaching
07:42	Ship: ATASOYLAR	100 meters to entrance	138	Ship 3 passing measurement point
08:41	Ship: AGIOS	800meters	135	Mooring

Date and time	Source of noise	Approximated distance	SPL [dB re 1μPa]	Comments
	EFRAIM			maneuver
08:46	Ship: AGIOS EFRAIM	400meters	146	Mooring maneuver
08:58	Ship: AGIOS EFRAIM	200meters	138	Mooring maneuver

Table 2 – Position of the ships

MEASUREMENTS ANALYSIS

Underwater noise produced by ships is caused by different sources: machinery (main engine, generators, auxiliaries), propulsion system (gears, propeller), propeller cavitations, turbulence around ship's hull etc. [6]. These sources can be identified during spectral analysis of underwater noise, but one must know the technical specifications of each installation onboard the ship.

When engineers and researchers analyse underwater noise produced by shipping, a number of parameters must be taken into account: hydro-meteorological conditions, water depth, seabed topography, seabed structure, physical properties of sea water (salinity, temperature).

The conditions of the measurements made at entry/exit of port Constanta were: shallow waters (maximum depth ≈ 15m), relative constant temperature and salinity, muddy and sandy seabed.

For the analysis, a specialized software was used, Pulse LabShop from Bruel&Kjaer. The frequency range was set from 1Hz to 10kHz, in 1/1 octave bands; so, the underwater noise level in these frequency bands were determined and also the global noise level over the entire frequency range. In figure 2 are presented these noise levels.

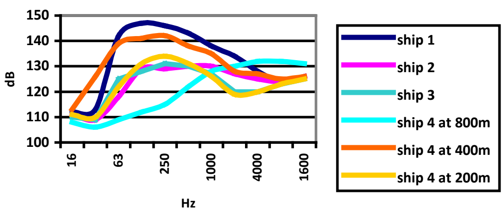

Figure 2 – Underwater noise levels of ships

Another useful analysis is analysis in time-frequency domain of the signals, thus resulting a spectrogram representing the variation of underwater noise level vs. time and frequency. The authors used an analysis software based on MATLAB routine, Virtual Sound Level Meter [7]. In the figures 3-8, are presented the spectrogram for each ship (Table 2).

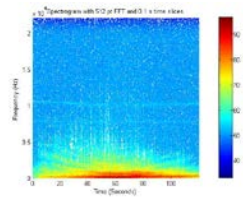
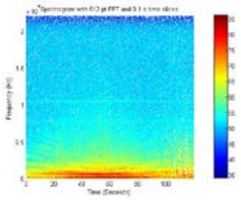

Figure 3 – Ship 1 **Figure 4 – Ship 2**

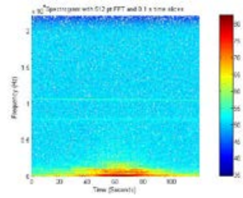
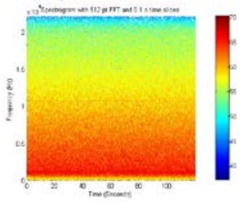

Figure 5 – Ship 3 **Figure 6 – Ship 4 at 800m**

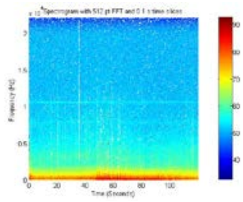
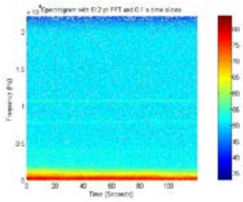

Figure 7 – Ship 4 at 400m **Figure 8 – Ship 4 at 200m**

Given that the ambient noise transients occur from several sources and STFT is not sufficient to detect all frequencies of these sources.

There are also some frequency bands of interest to be analyzed in detail. Wavelet analysis based on Discrete Wavelet Transform (DWT) is needed for recorded signals. DWT decomposition is performed by approximating signal coefficients (low frequency bands) and signal details (high frequency band) using a wavelet function which has a scale and a window, moving during the processing of all analyzed signals [2].

The wavelet analysis can be used for many functions taking into account the properties of wavelet function and wavelet similarity between the signal and wavelet function, and could get different results from the same signal processing meshed in samples.

In the signal processing based on DTW applied to signals recorded in Constanta (the background noise and emissions from ships) it was used the wavelet function Coiflet, up to 12 levels of decomposition. At each level of DTW, it was used filter bank analysis to decompose the signal based on detail coefficients d_i and approximation coefficients a_i. The signals recorded for the same vessels (Table 2) were analyzed on a 25.6 kHz frequency band.

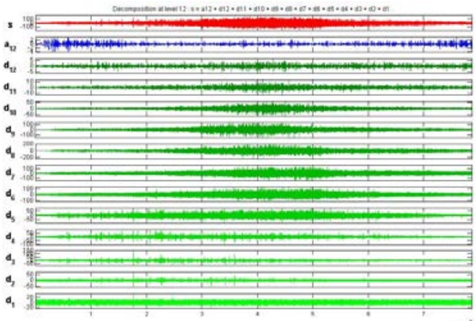

Figure 9 - DWT of Ambient noise with Ship 1

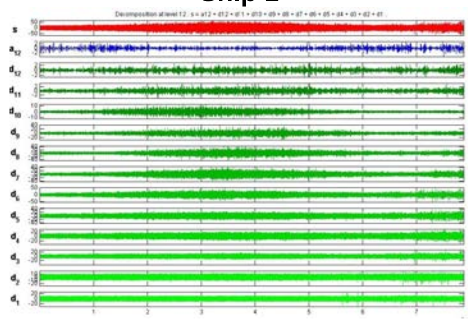

Figure 10 - DWT of Ambient noise with Ship 2

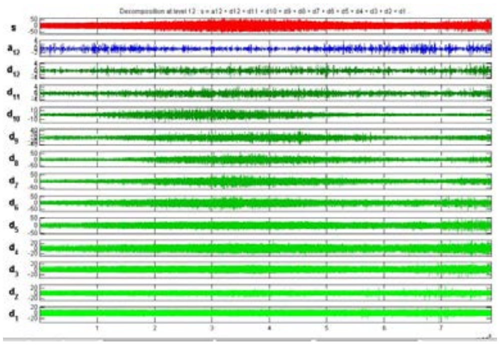

Figure 11 - DWT of Ambient noise with Ship 3

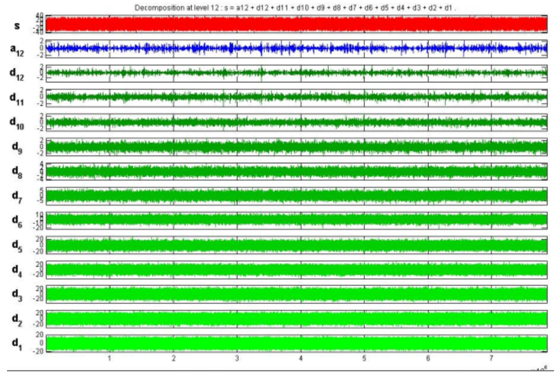

Figure 12 - DWT of Ambient noise with Ship 4 at 800m

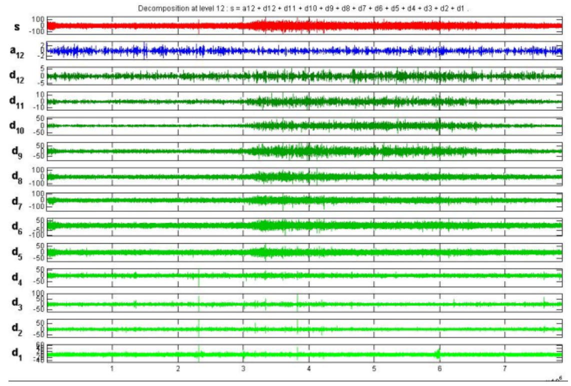

Figure 13 - DWT of Ambient noise with Ship 4 at 400m

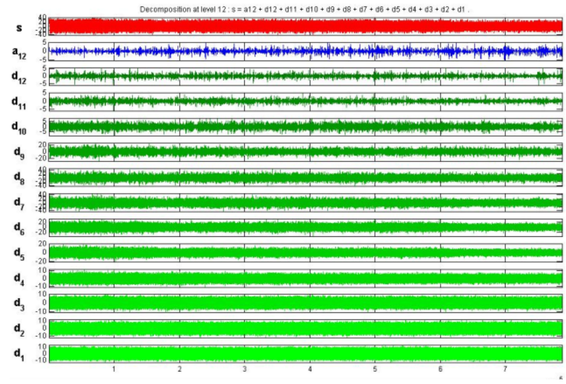

Figure 14 - DWT of Ambient noise with Ship 4 at 20m

RESULTS AND CONCLUSIONS

From the analysis of underwater noise produced by shipping at entry/exit of port Constanta, a number of important conclusions can be made. The spectrograms of ships 1, 2 and 3 show a variation in time of noise level when a ship is passing the hydrophone; for the ship no.4, the spectrograms are different as the ship is manoeuvring. In figures 7 and 8 the underwater noise level radiated from the ship is relative constant, because the ship is moving at very small, but constant speed. Ship 4 presents a identifiable spectra in figures 7 and 8, while in figure 6 there is low level of noise with no peaks. This can be explained because of the ship's position (800m distance from the hydrophone) (figure 15), the sounds travelling from the ship suffer different phenomena: reflexion, diffraction, absorption. Thus, ship's acoustic signature is „masked" by underwater background noise.

Figure 15 – Ship 4 at 800m

In the spectrograms, the peaks of the noise level from the ships are in the low frequency range which corresponds to main sources of noise: machinery and propulsion system. Analyzing figure 2 the noise level have a descending slope starting 250Hz octave band as expected. Also, from this figure, for ship 4 at 800m the noise level has a relative flat plot in the low frequency range, followed by an ascending curve; the effect of distance shows that the hydrophone need to be placed closer to the passing point of the ship in order to measure an accurate signature of the ship.
As predicted, the high peaks in the spectrum are in the low to mid frequency range (0-500Hz) which corresponds to noise sources onboard, their fundamental frequencies and their harmonics.
The noise level determined in this measurement point is dependent on ship's speed. During exit and entry, a ship must travel at low speed, which means the frequency of the main engine, propulsion system – propeller, shaft, are lower than the values at ship's speed service. That's why, in this zone, the underwater noise levels of the ships are lower than in open sea. But the intense traffic in this zone compensate this difference, meaning the noise level is *constant* comparison to the noise level in open sea which is *variable* (no ship is following the exact same path!).

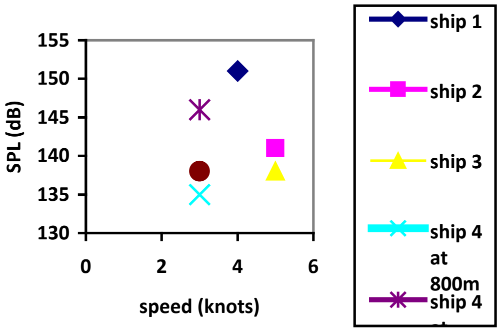

Figure 16 – Noise level vs. ship speed

In the last figure (figure 16), one can notice that the noise level of the ship manoeuvring is higher than ship 2 and 3 which travel at higher speed. It can be explained that during these procedures, the engine operate at different revolutions depending on the manoeuvre. Plus, large ships are „helped" during these manoeuvres by tugs which add to the underwater noise coming from the group.
The displacement of the ship is not relevant when measuring underwater noise in such zone. As stated above, the ships are travelling at low speeds and there are small variations in noise levels vs. ship displacement, and cannot be correlated. This concurs with other results in other harbours. [8]
Analyzing the frequency range < 10Hz, one can expect to find the contribution of the hydro-acoustic noise generated by the flow of the water around the hull [5]. But this is very hard to identify because in this range

low speed engines and propeller blade tones have their main component of frequencies. So, in the analysis of these measurements it is noticed the same phenomena.

From the wavelet analysis in the frequency range from ships, one can easily see that there is a mismatch between the noises that propagates from stern to bow, with higher values in the stern.

The variations are caused by frequencies of the sources and the type of ship. Using DWT, one can more precisely analyze the frequency ranges of different sources and their evolution in time.

Finally, comparing shipping underwater noise with underwater background noise we find differences ranging 17dB to 30dB. These results are not unusual because in similar areas in other ports, the differences are smaller or bigger. This variation is explained as a function of ship traffic (how many ships are passing in a given time interval); but it can be explained on the differences on seabed structure and depth. Here, in Constanta port, the seabed is not solid, no stones, rocks, only sand. So, part of the sound radiated from the ship is absorbed or diffracted from the seabed. Because ships are sailing in shallow waters, the underwater noise measured represents mainly the direct sound waves from the ships. In future works, these aspects regarding sound propagation in this area will be investigated.

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