DEMON-type algorithms for determination of hydro-acoustic signatures of surface ships and of divers

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Abstract. With the project “System for detection, localization, tracking and identification of risk factors for strategic importance in littoral areas”, developed in the National Programme II, the members of the research consortium intend to develop a functional model for a hydro-acoustic passive subsystem for determination of acoustic signatures of targets such as fast boats and autonomous divers. This paper presents some of the results obtained in the area of hydro-acoustic signal processing by using DEMON-type algorithms (Detection of Envelope Modulation On Noise). For evaluation of the performance of various algorithm variations we have used both audio recordings of the underwater noise generated by ships and divers in real situations and also simulated noises. We have analysed the results of processing these signals using four DEMON algorithm structures as presented in the reference literature and a fifth DEMON algorithm structure proposed by the authors of this paper. The algorithm proposed by the authors generates similar results to those obtained by applying the traditional algorithms but requires less computing resources than those and at the same time it has proven to be more resilient to random noise influence.

1. Introduction
A constant challenge for security analysts and decision makers is the prioritization of maritime security activities of a country while keeping in mind the practically countless number of possible attack scenarios. If we were to analyse the capabilities of potential attackers against some littoral targets (ships, harbours, etc.) from a point of view of availability and destructive potential, we can observe that in order to be able to define the operational characteristics of a protection system, in addition to a good knowledge of local environment parameters (propagation, natural obstacles positions, sea bottom profile, etc.) we must also consider those characteristics of a threat that refer to movement and its “signature” as registered by the type of sensor used in the detection and identification process.

The hydro-acoustic system for determination of signatures of potential targets (“Sistem Hidroacustic pentru Determinarea Amprentelor Poențiilor Ținte” - SHDAPT), which will implement the DEMON-type algorithms that are presented in this paper, will have to provide the detection and signalling of two categories of threats that can create security risks in littoral areas: small ships and divers equipped with open or closed circuit breathing systems. The classical means of detection or interdiction of access of these in limited or controlled access areas (active sonar for diver detection, protection fences, hydro-acoustic signal generators, etc.) tend to be used less and less because of their unintended side effects upon the environment and navigation. Other means (radar,
optical observation from shore, from fixed or free-floating platforms or from a geostationary satellite) are considered impractical especially because of the large costs for purchase, use and maintenance of them.

The passive detection of surface ships or of divers (including of the transport vehicles of these) is difficult when the useful signal is drowned by noise, situation that can be encountered when the marine environment is extremely noisy and/or when the potential target is situated a large distance away from the sensors system. In order to maintain the contact with the target, the detection process must be based on some signal processing in order to amplify the acoustic signature of the target and at the same time to filter the noise component out of the signal received by the sensors.

2. DEMON algorithms used in determination of the hydro-acoustic signatures

For measuring, recording and analysis of environmental underwater noise various system configurations can be used. A typical example of such a system, with a single channel, is formed by a hydrophone, an electronic module for hydrophone signal conditioning (often integrated in the hydrophone body at construction time), signal amplification modules (including digitization, filtering) and a real-time recording unit. Such an equipment can also have multiple measuring channels, for connecting multiple hydrophones as needed by that particular application.

The determinations of the maximum values of the noise spectrum density for different ship classes vary between around 140 dB ref. $\mu$Pa²/Hz @1m for small fishing vessels and around 195 dB ref. $\mu$Pa²/Hz @1m for maritime oil tankers. The main noise sources characteristic for a ship are the following:

- noise generated by the engines, machines and equipment on board;
- noise of the hydrodynamic flow across the ship hull;
- propeller noise.

At cruise speeds, the main noise source of modern surface ships is the cavitation of the propeller blades (about 80-85% of the noise strength radiated in the marine environment). The characteristic of this radiated noise is the modulation imprinted by the blade rotation frequency. The cavitation noise increases proportionally with the propeller rotation speed and decreases as the propeller operating depth increases.

At small speeds, the noise radiated by surface ships is caused mainly by the engines themselves (main propulsion engines and diesel generators).

Measurements of noise levels emitted in the environment by an autonomous diver have indicated an average value of around 116 dB ref. 1 $\mu$Pa@1m. In the case of divers, the breathing represents the main source of noise for passive detection. In fact, during the inhalation phase, wide-band periodic noise signals are emitted by the pressure regulators of the diving system. The respiration cycle, depending on the diver’s activity and operating environment, is about 10-30 breaths per minute.

If for large ships there already exist formulas that can provide an estimation of the maximum noise level radiated in the marine environment, for fast small ships or for autonomous divers we could not identify the existence of such models. The existing models no not allow for obtaining rigorous details concerning the hydro-acoustic signatures of potential targets so that identification of these with a high degree of accuracy can be done. As a consequence, conducting actual measurements is the only source with a high reliability rate for determining these acoustic signatures.

As presented in [1] and [2], the passive detection of small ships or of autonomous divers can be conducted on the basis of identifying the acoustic signatures of these in the maritime environment noise recordings and this identification can be summarized as finding periodic signals hidden by a large background noise. The periodicity is given by the rotation of the propeller, of the propeller shaft or of the engine or by the breathing cycle of the diver.

A simple method for separation of the useful periodic signal out of the noise would be to use a synchronous mediation, this process involving the mediation of signal section with a length equal to the period of the interesting harmonic component. This mediation would diminish all the components except the periodic one. This method is useful as a theory but in practice is not applicable due to the
impossibility of knowing precisely the period of the harmonic component and/or the variation mode of this period.

Another method considered classical, initially developed for passive detection of ships by submarines is the method that uses the DEMON algorithm (DEtection of Modulation On Noise). In our tests we analysed the following variants of the DEMON algorithm:

- the classical variant, conforming to [1]:

  ![Figure 1](image1.png)

  **Figure 1.** block scheme – classical DEMON.

- the second classical variant, conforming to [3]:

  ![Figure 2](image2.png)

  **Figure 2.** block scheme – classical DEMON variant.

- Multi-band variation [3] – divides the acoustic signal into multiple frequency bands and for each such filtered signal applies the algorithm according to the scheme in figure 2 and at the end it mediates the resulting signal across all bands:

  ![Figure 3](image3.png)

  **Figure 3.** block scheme – DEMON with multi-band extension

Analysing the proposals for improving the performance in the case of applying the DEMON algorithm we have developed a simplified application scheme, starting from the idea that the signal from the hydrophone has two components: one of non-correlated wide-band noise and one that is statistically correlated that contains the information resulted from the cavitation phenomenon of the propeller. Starting from this observation we have proposed for the hydro acoustic system for determining the signatures of potential targets the use of a DEMON algorithm conforming to the scheme in the next figure.

![Figure 4](image4.png)

**Figure 4.** block scheme – DEMON SHDAPT.

Obviously, based on the scheme in figure 4 we can build a configuration with filter banks similar to the structure in figure 3. Comparative tests conducted with the available recordings did not highlight significant performance increases that would require an increase in computation complexity. The
Algorithm proposed in figure 4 has also been tested with recordings of noise generated by divers, with positive results when it comes to determining the breathing period.

2.1. Determination of ships acoustic signatures

Complete simulation of the characteristics of the acoustic field generated by a moving ship is difficult due to the impossibility of describing exactly the interaction between the ship hull and the waves and also because the results can differ widely when input parameters change (propeller rotation rate, fatigue over time of various dampers, etc.)

The acoustic signature of a surface ship has three major sources, one of which predominates depending on the ship speed: at slow speeds the engine and mechanisms noise predominates while at speeds greater than 10 kn the noise of the hydrodynamic flow across the hull becomes the major component up until the ship reaches the speed where the propeller cavitation starts to appear, moment when the cavitation becomes the most important source.

For evaluating the performance of different variants of the algorithm we have used recordings of underwater noise generated by ships in real conditions (ferryboat, small diesel-propelled boat) [4] or simulated noise (ship with a propeller with 3, 4 or 5 blades, 197 rpm, 10 kn) obtained from [5].

In the following figures, 5 and 6, we present the results of applying the DEMON-type algorithms for the noise generated by a ferryboat-type ship [4].

![Figure 5. DEMON classic – real noise, Alaska state ferry_Oct_02_2000@101413.](image1)

![Figure 6. DEMON SHDAPT – real noise, Alaska state ferry_Oct_02_2000@101413.](image2)
Applying the DEMON algorithm as presented in the scheme in figure 4 has similar results to the ones obtained from the standard algorithm but allows for an easier determination of the acoustic signature of the analysed ship.

Figures 7 to 10 present the results of applying different DEMON-type algorithm variants to the signal generated by a small diesel-powered boat.

**Figure 7.** DEMON classic – real noise, small_diesel_Nov_01_2000@085906-2.

**Figure 8.** variant of DEMON classic – real noise, small_diesel_Nov_01_2000@085906-22.

Applying the variant DEMON algorithm as presented in the scheme in figure 2 has similar results to the standard algorithm with the difference that the signal on relevant frequencies is more evident because of the squaring.

**Figure 9.** DEMON with multi-band extension – 5 filers, real noise, small_diesel_Nov_01_2000@085906-2.
Application of the DEMON algorithm with multiple filters and summing has as effect an even more pronounced highlighting of the ship characteristics.

![Graph](image)

**Figure 10.** DEMON HDAPT – real noise, small_diesel_Nov_01_2000@085906-2.

The results of applying the DEMON SHDAPT algorithm are similar to the previously presented results.

### 2.2. Determining the acoustic signatures of autonomous divers

Across the world, there have been experiments in which the breathing sounds of a diver have been recorded and the characteristics of these sounds have been studied applying methods of power spectrum, wave signature in time-frequency domains and so on. The measurements of the noise level emitted in the environment by an autonomous diver have indicated an average value of around 116 dB ref. 1 µPa@1m. For divers, the breathing represents the main source of noise relevant for passive detection. Actually, during the inhalation phase, wide-band periodic noise signals are emitted by the pressure regulators of the diving system (these allow the reduction of the pressure from about 200 bar compressed air present in the bottles to the pressure needed by the human respiratory system). The respiration cycle, depending on the diver’s activity and operating environment, is about 10-30 breaths per minute.

By researching available sources we could not identify recordings of the noise generated by an autonomous diver and in this situation we have conducted direct measurements in the hydro acoustic basin existing on premises in the Research Center for Navy, Constanta, ROMANIA. We have recorded the noise generated by a professional diver using an open circuit breathing system and which has remained stationary in a position 1 meter away from the hydrophones of the recording system or was swimming at hydrophone depth on a distance of about 4 meters. The type of the data acquisition system used was Bruel&Kjaer 3052A.
In papers [2], [6], [7] we have documented the fact that the acoustic signature of a diver consists mainly of a series of wide-band pulses, equally spaced, each of them corresponding to the air inhalation phase of the diver. The main source of these pulses is the pressure regulator that is part of the diving equipment – the pressurized air from the compressed air bottle, when expanding within the pressure regulator produces pressure variations and air flow turbulences and generates structural vibrations of the regulator valve and in the air channels.

For passive detection of autonomous divers, the high frequency band (approx. 9 – 13 kHz) is recommended [6] because the periodicity of the signal envelope is much clearer here than in the low frequency band and the energy attenuation in the high frequency band (the regulator vibration) is much more reduced than the attenuation of the low frequency band (exhalation).
Figure 14. Spectre rendering of the signal recorded during one minute with the diver at rest.

Figure 15. Spectre rendering of the signal recorded with the diver in motion.

For the signals recorded, using SHDAPT specific algorithms, we have obtained the graphical diagrams in figure 16 and figure 17.

Figure 16. DEMON SHDAPT – stationary diver.
3. Conclusions
Based on the data, we can affirm that the results obtained by applying the DEMON SHDAPT algorithm are similar to those obtained by applying similar types of algorithms presented in the speciality literature. Differences that were found are the greater immunity to noise of the SHDAPT algorithm and, at the same time, its simplicity, as it approximates the second variant of the classical DEMON algorithm.

In the case of autonomous divers, based on conducted tests, we have found that in contrast to the noise ship recordings, for divers we need recordings in a wide frequency range, sometimes going up to 100 kHz.

For validating the performances of the DEMON SHDAPT algorithm we will conduct further noise recordings for ship and autonomous divers in open sea and then we will re-visit the procedures of comparing the results obtained by processing the signals according to the structures presented in figures 1 to 4 from the present paper.

4. Acknowledgement
This paper has been financially supported within the project entitled “System for detection, localization, tracking and identification of risk factors addressing important strategic objectives in littoral areas”, contract number 302 cod PN-II-PT-PCCA-2013-4-0377. This project is financed by PNII.

5. References
[1] Chung K W, Sutin A, Sedunov A and Bruno M 2011, DEMON Acoustic Ship Signature Measurements in an Urban Harbor, Advances in Acoustics and Vibration, vol. 2011, Article ID 952798, doi:10.1155/2011/952798
[2] Donskoy D M, Sedunov N A, Sedunov A N and Tsionskiy M A 2008, Variability of SCUBA diver's acoustic emission, Proc. SPIE 6945, Optics and Photonics in Global Homeland Security IV, 694515, doi: 10.1117/12.783500
[3] Cheong M J, Hwang S B, Lee S W and Jin Seok Kim 2013, Multiband Enhancement for DEMON Processing Algorithms, The Journal of the Acoustical Society of Korea, Vol. 32, No. 2, doi:10.7776/ASK.2013.32.2.138
[4] Underwater Sounds Recorded in Glacier Bay, http://www.nps.gov/glba/learn/nature/soundclips.htm
[5] Propeller Noise Simulation Web Page, http://160.75.46.2/staff/takinaci/NoiseSimulation/PropNoiseSimulation.html
[6] Labat V and Dare D 2014, Analyse de signaux acoustiques marins: identification de fréquences caractéristiques via la méthode DEMON, *Congres Francais d’Acoustique (12; 2014; Poitiers)*, Poitiers, France. pp.345-350, HAL Id: hal-01087837

[7] Sun Z, Zhang J, Qiao G, Nie D, Liao J and Liu S 2013, Experimental study on target characters of divers, *Proceedings of 2013 OCEANS – San Diego*, San Diego, CA.