RESEARCH AND STUDIES ON THE HYDRO-ACOUSTIC SIGNATURES OF AUTONOMOUS DIVERS

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REZUMAT. În cadrul proiectului „Sistem pentru detecţie, localizare, urmărire şi identificare a factorilor de risc la adresa obiectivelor de importanţă strategică din zone de litoral" – SIROLC, dezvoltat în Programul Naţional de Cercetare Dezvoltare Inovare - PN II, membrii consorțiului de cercetători au realizat modelul funcțional al unui subsistem hidroacustic pasiv de determinare a amprentelor acustice ale unor ținte de tipul scafandrilor autonomi. În bazinul hidroacustic al Centrului de Cercetare Ştiinţifică pentru Forţele Navale autorii au efectuat înregistrări ale zgomotului generat de scafandri aparținând Statului Major al Forțelor Navale, iar în lucrarea de față sunt prezentate o parte din rezultatele obținute în domeniul înregistrării și prelucrării semnalelor hidroacustice generate de către aceștia.

Cuvinte cheie: amprentă acustică, scafandri autonomi, bazin hidroacustic, model funcţional, semnal hidroacustic.

ABSTRACT. Trough the project „System for detection, localization, tracking and identification of risk factors for strategic importance in littoral areas", developed within the National Research, Development and Innovation Program - PN II, the members of the research consortium have developed a functional model for a hydro-acoustic passive subsystem for determination of acoustic signatures of targets such as autonomous divers. In the hydro-acoustic basin of the Research Center for Navy the authors have conducted recordings of the noise generated by a few of the Navy's autonomous divers and this paper presents some of the results obtained in the domain of recording and processing hydro-acoustic signals generated by these.

Keywords: acoustic signals, autonomous divers, hydro-acoustic basin, functional model, hydro-acoustic signals.

1. INTRODUCTION

The capability of protecting the maritime transport and facilities in the shore area from the dangers associated with surface or underwater threats (small ships, divers) is considered critical for ensuring the safety of the maritime domain.

The hydro-acoustic system for determination of fingerprints of potential targets („Sistem Hidroacustic pentru Determinarea Amprentelor Potențialelor Ținte" – SHDAPT), will have to provide the detection and signaling 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.

Divers can cause immense damages to the maritime infrastructure – bridges, electrical plants, harbour and anchorage equipment, infrastructure which is expensive for any country, which is why the detection and neutralization of these sources of underwater threats is very important.

In the case of autonomous divers, the classical means of detection or interdiction of access of these in areas with limited or controlled access (active sonar, protection fences, etc.) tend to have a more and more limited applicability due to the unwanted side effects upon shipping activities and on the marine environment. Other solutions (radars, optical observation points installed on fixed or free-floating platforms) are not practical, both because of the high acquisition, installation, use and maintenance costs as well as because of the local conditions are not suitable for their use.

The acoustic waves used in active or passive mode are considered as being the most efficient information carriers for these underwater systems. In the active acoustic detection, the main unknown element when estimating the feasibility of diver detection is the strength of the signal reflected by the target (Target Strength – TS) – the diver in this case. The target strength is influenced by multiple factors, including the air supply tanks, the buoyancy control system, the type of suit used (wet or dry), orientation, frequency used, etc.

In the passive acoustic detection, the diver as target is characterized mainly by the breathing sounds. The characteristics of the breathing sounds are influenced by the type of breathing device used (open or closed circuit) and by the movement and activities of the diver.

SHDAPT is designed to supplement the security methods in littoral areas, either through integration into existing systems or by standalone use in the zone of the objective where it is installed in. The system provides the detection and signalling functions by acquiring (from one or more hydrophones) the existing hydro-acoustic noise and processing this one for establishing if specific spectral characteristics can be identified (hydro-acoustic fingerprints) for the two types of possible threat categories.

The sounds generated by the breathing of a diver have been recorded during some experiments conducted in the hydro-acoustic basin of the Research Center for Navy and the characteristics of these sounds have been investigated applying digital signal processing methods.

2. PREPARATION AND EXECUTION PROCEDURE FOR EXPERIMENTS

We have recorded the noise generated by professional divers using open circuit breathing systems and which have remained stationary in a position 1 meter away from the hydrophones of the recording system or were swimming at hydrophone depth on a distance pressure and turbulence of air flow, of about 4 meters. The type of the data acquisition system used was Bruel&Kjaer 3052A and the hydrophones were Bruel&Kjaer 8105 and 8106. Figures 1 and 2 present the arrangement of the sensors and the position of a diver during the recordings.

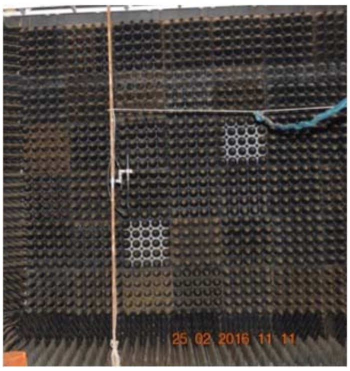

Fig. 1. Hydrophones position during recordings.

At the same time, using a Bruel&Kjaer 2250 soundmeter, we have recorded the atmospheric noise made by the pressure regulator of the open circuit diving system.

Fig. 2. Proffesional diver in stationary position.

3. RESULTS FROM EXPERIMENTS

The measurements of the level of the noise emitted into environment by an autonomous diver have indicated an average value of about 116 dB ref. 1 μPa@1m [3]. In the case of divers, the breathing process represents the main source of noise that is usable for passive detection. The breathing cycle, depending on the diver's activity, is about 10 – 30 breaths per minute.

In papers [1], [2], [3] is documented the fact that the acoustic fingerprint of a diver using an open circuit diving system is composed mainly of a sequence of wide-band pulses, equally spread, each of them corresponding to the air inhalation phase of the diver. The main source of these pulses is the pressure regulator of the diving equipment – the expansion of the pressurized air from the air tank causes pressure fluctuations and air flow turbulences and these generate structural vibrations of the regulator valve and of the air channels.

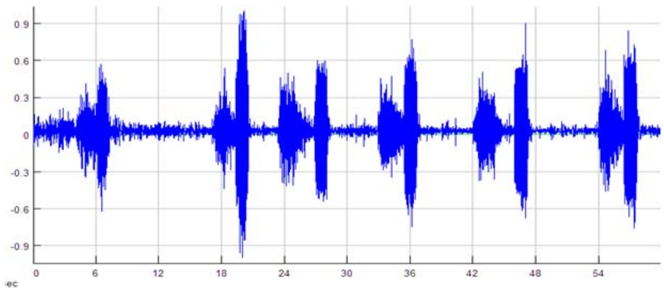

Fig. 3. Proffesional diver in stationary position.

In the case of the diver using an open circuit breathing system, the generated signal can be easily differentiated from the background noise and at the same time we can clearly distinguish the inhalation phase (lower amplitude) from the exhalation phase (higher amplitude) moments.

Following the measurements in atmosphere, for the noise generated by the pressure regulator of the breathing system, we have obtained a band distribution in one-third octaves as presented in the figure 4.

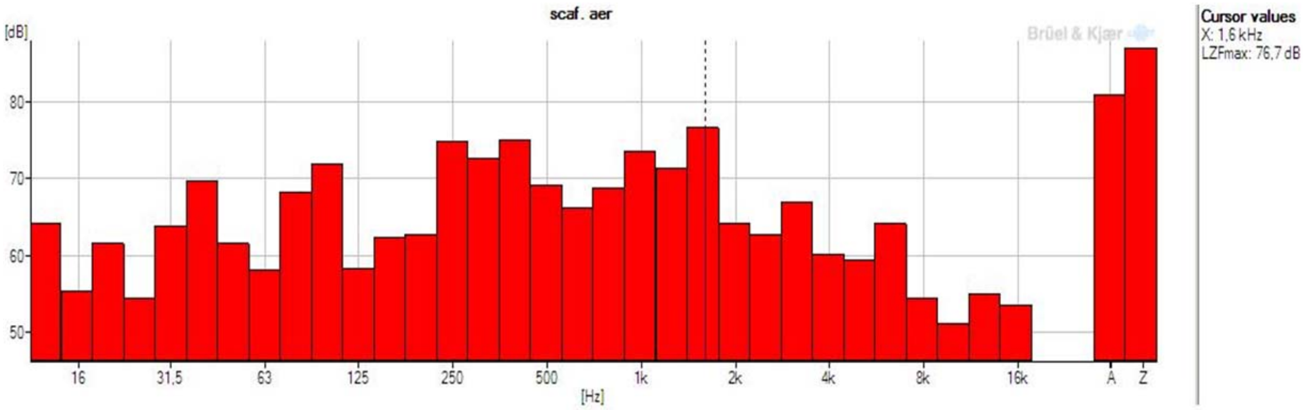

Fig. 4. Level of noise distributed in one third octaves for the pressure regulator.

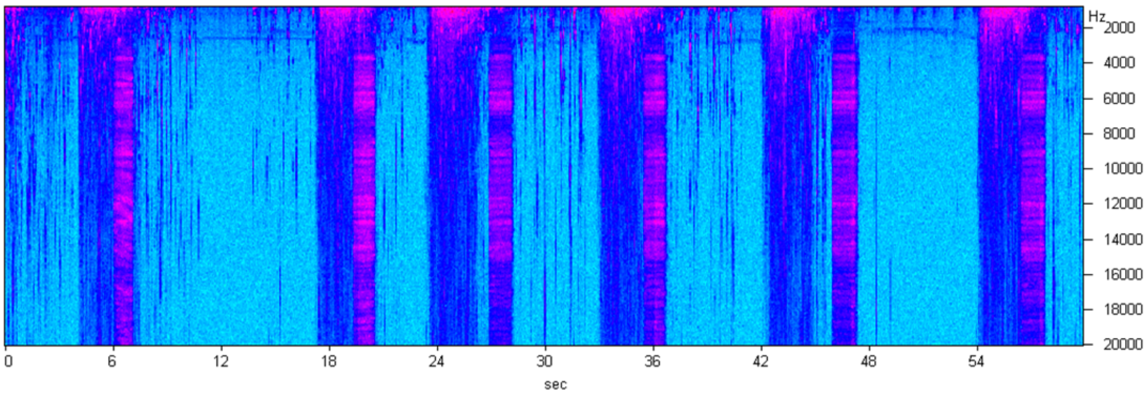

Fig. 5. Noise spectrum of stationary diver position.

In the graphical representation from figure 4 we can notice an increased energy density of the signal in the frequency band of over 250 Hz. As we can notice in figure 5, the noise spectrum of the diver's breathing is clearly distinctive from that of the background noise. Over 2 kHz this is relatively stable but under 2 kHz the variations are quite high, the signal also having components caused by the background noise.

In figure 3 we have presented the original signal and we can distinguish the inhalation and exhalation phases relatively easy. From previous analyses we know that the respiration sounds are exhalation bubbles and regular vibrations. In order to research the characteristics of these two components we have processed the recorded sounds using the following steps: First, we have filtered the raw signal through different band filters, using different frequency bands and we played back the filtered signal. The results (figure 6 and 7) show that the energy of the exhalation bubbles is mainly in the low frequency band (see figure 5 too) while the energy of the vibrations of the pressure regulator is mainly in the high frequency band. We can clearly notice that the signal periodicity is much more distinct in the high frequency band than in the low frequency band.

For the passive detection of autonomous divers, the high frequency band (~9 to 13 kHz) is the recommended one by [2] and we can also notice this in the spectrogram of the signal recorded in the anechoic basin (figure 5) because the periodicity of the signal envelope is much more distinct here than in the low frequency band and the energy attenuation in the high frequency band (the vibration of the pressure regulator) is lower than in the low frequency band (the exhalation noise).

There have been numerous mentions in speciality papers ([1], [2]) that this periodicity of the acoustic fingerprint of the diver can be noticed in the signal spectrogram from the output connection of a single hydrophone and that the analysis of the frequency cycles from the signal of the hydrophone allows for the automation of the diver detection process and an estimation of his rate of breathing. A simple method for the separation of the useful (periodic) signal out of the noise would be the use of a synchronous mediation, this process requiring the mediation of some signal sections with the length equal with the period of the target harmonic component. This mediation process would diminish all components with the exception of the periodic component. The method is useful on a theoretical level but not applicable at the current technological evolution stage due to the impossibility of knowing precisely the period of the harmonic component and/or the variation mode of this period.

The conventional analysis method for the detection and estimation of the breathing rate while initially developed for the passive detection of ships by submarines is the method that uses the DEMON algorithm (DEtection of Modulation On Noise). The DEMON algorithm variants used in the processing of signals are presented in figures 8 and 9.

For the recorded signal we have applied the DEMON algorithm with the structure from figure 8 and the obtained DEMON spectrum is presented in figure 10.

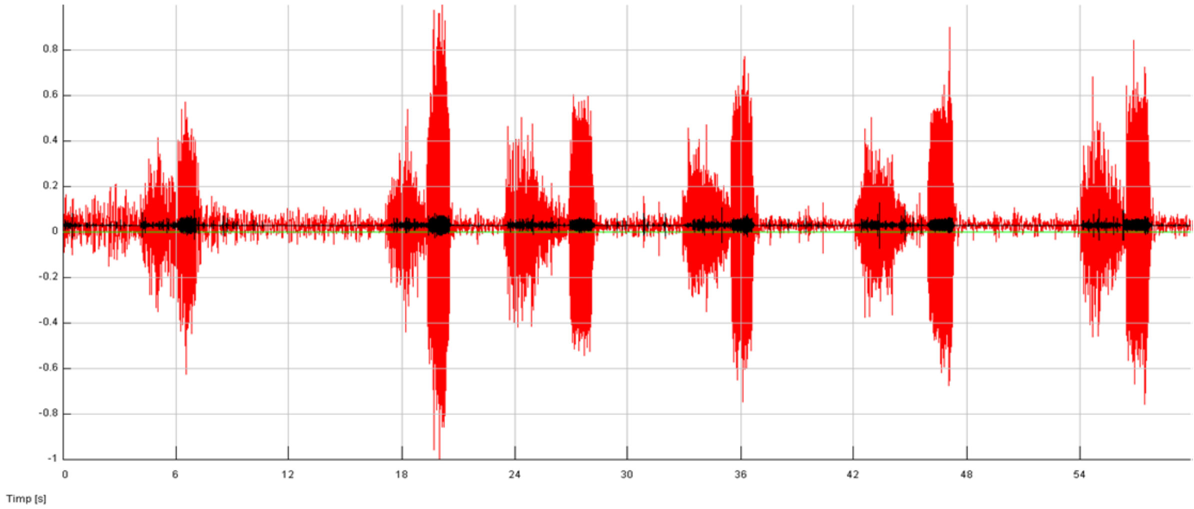

Fig. 6. Signal filtered (red) in band 4 – 8 kHz for the stationary position.

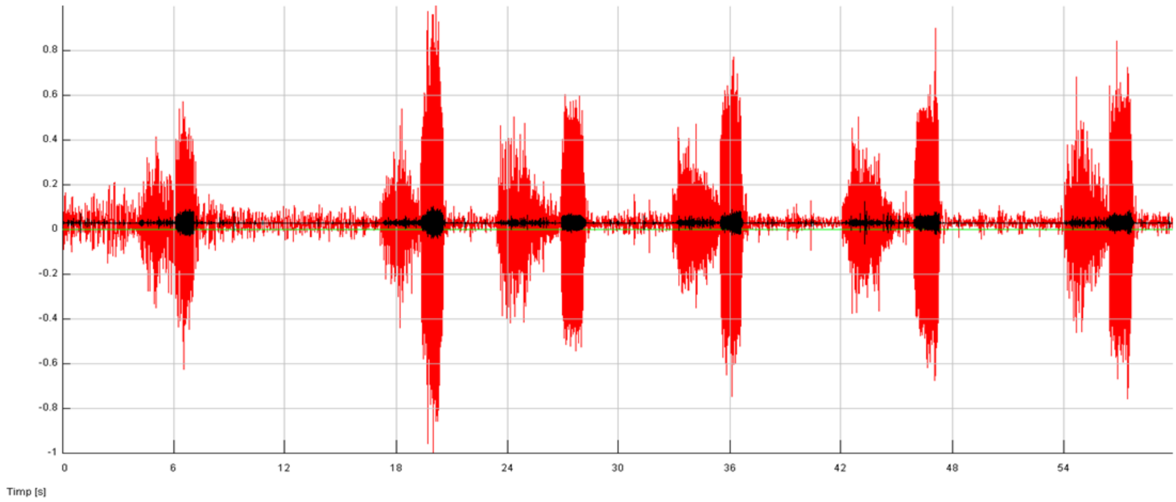

Fig. 7. Signal filtered (red) in band 9 – 15 kHz for the stationary position.

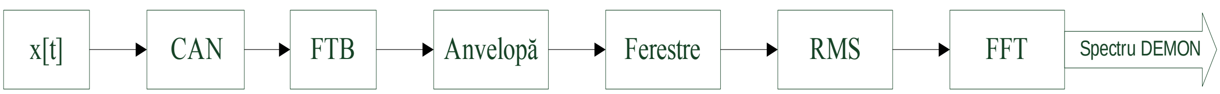

Fig. 8. The classic method [4] diagram DAEMON classic.

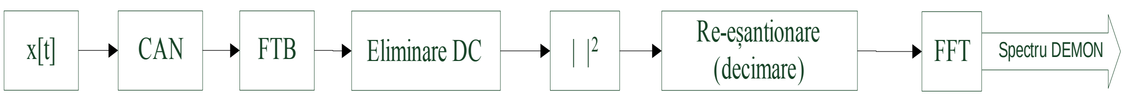

Fig. 9. Method developed in project DAEMON SHDAPT Diagram.

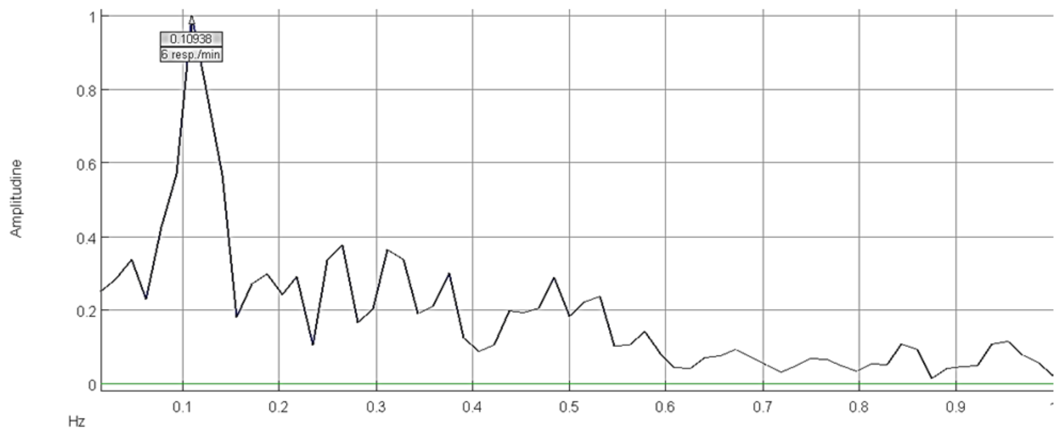

Fig. 10 Classic method DEMON spectrum

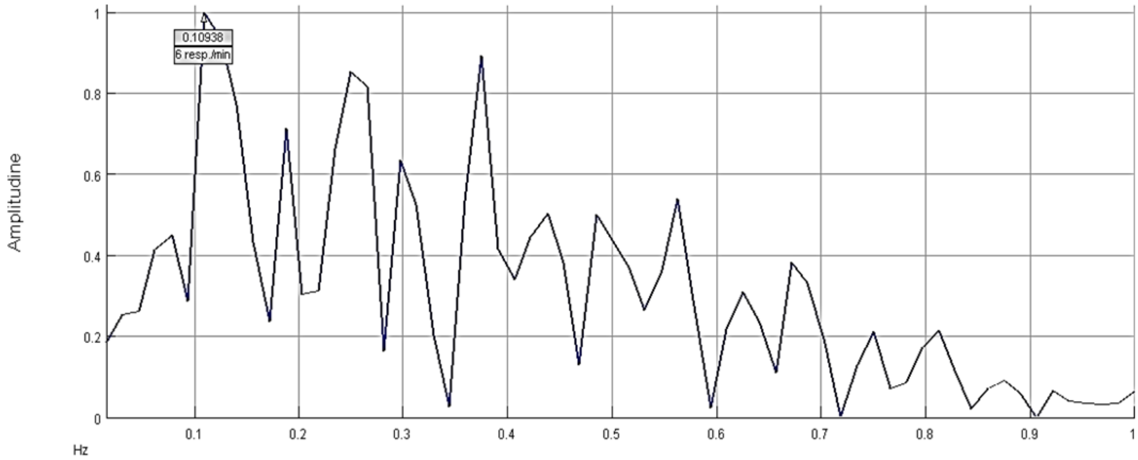

Fig. 11 DEMON SHDAPT spectrum stationary diver

4. CONCLUSIONS

Based on the available recordings and processed signals, we can affirm that the results obtained through the application of the DEMON SHDAPT are similar to those obtained through the application of similar types of algorithms presented in the speciality literature. The main difference is that the computing resources required by the DEMON SHDAPT algorithm are lower than those needed by the traditional algorithms.

For the detection of autonomous divers using open-circuit breathing system by deploying passive hydro-acoustic systems we have obtained some significant results:

● the acoustic energy of the air bubbles generated by the diver exhalation is concentrated mainly in the low frequency band, below 2 kHz;

● the acoustic energy associated with the functioning of the pressure reduction valve is concentrated mainly in the high frequency band, above 2 kHz;

● the high frequency band, 9 – 13 kHz, is recommended for passive detection of divers because the periodicity of the signal envelope of the received signal in this band is much more evident than in the low frequency band.

For the future, we intend to conduct some measurements of the noise emitted by an autonomous diver in open sea as well as deploying new methods of signal processing based on extended use of algorithms like CEPSTRUM or CMC (Cyclic Modulation Coherence) that are presently used for acoustic diagnosis of equipment with rotating movable elements.

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