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Investigation of the underwater noise associated with remotely-operated vehicles

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Abstract

There is increasing demand for various types of submersible and floating remotely-operated vehicles which have herein been studied with respect to the threats posed by these kinds of objects. Local physical field disorder analyses have demonstrated the possibility of detecting and classifying objects based on hydroacoustics. Hydroaocoustic analysis results are presented as narrowband and One-Third-Octave spectra of different types of remotely-operated vehicles. Investigations were performed using an underwater measuring system located in very shallow water in a coastal zone characterized by conditions considered as poor for sound propagation.

Introduction

Vehicles which are remotely controlled by a user are called Remotely Operated Vehicles (ROVs). There are many types of ROV which can be separated according to the environment in which they are operated (Gloza, Buszman & Józwiak, 2013):

- air – Unmanned Aerial Vehicles (UAVs);
- land – Remotely Controlled Vehicles (RCVs);
- water surface – Unmanned Surface Vehicles (USVs);
- underwater – Remotely Operated Underwater Vehicles (ROUVs).

This research is strictly concerned with the water environment; therefore, no results are presented for aerial or land-based ROVs. The ROVs studied are further subdivided according to propulsion type, for example:

- electric engine propulsion for objects moving on the sea surface;
- two- or four-stroke engines for objects moving on the sea surface;
- jet engines for objects moving on the sea surface;
- typical propeller propulsion for underwater objects;
- undulating propulsion for underwater objects.

Results are presented for investigations conducted for surface vehicles with electric and two-stroke engine propulsion and for underwater vehicles with propeller propulsion.

These studies were carried out because of threats posed by the increasing use of ROVs, particularly by unauthorized persons or in illegal situations, especially:

- collecting information in the form of sound and video recordings of people without their permission;
- collecting data of prohibited places and objects owned by uniformed services (Police, border guards, army, etc.);
- transporting dangerous or forbidden goods, especially chemical, biological, radiological and nuclear materials.

Measurements in real conditions

The investigations were carried out at the yacht marina in Górki Zachodnie near Gdańsk (Figure 2). The measurement base was located on the quay and the maximum operating depth was about 5 m. The measurement system (Figure 1) consisted of a very high voltage sensitivity hydrophone Reson TC-4032 industrial signal recorder from National Instruments (NI-9188) with an Ethernet connection and 4 inputs and a 24-bit analog to digital converter (NI-9234). All recordings were performed using the software NI Signal Express. The whole recording circuit was configured using the software NI Measurements & Automation Explorer.

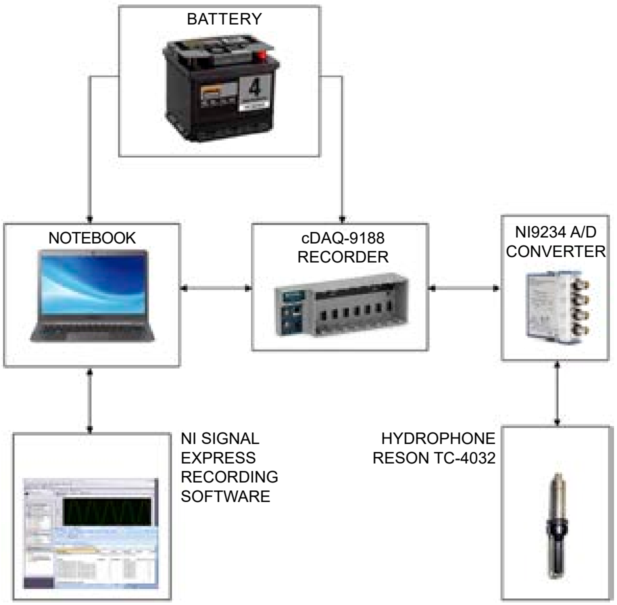

Figure 1. Underwater noise measurement system scheme

Figure 2. Gulf of Gdańsk map indicating the measurement location

Underwater sound propagation in the chosen location was very difficult because of the very shallow water and high possibility of reflection of the noise generated by the test vehicles (Kozaczka & Grelowska, 2017).

The surface vehicles tested were equipped with GPS receivers, providing information not only about location, but also the real distance between hydrophone and target correlated in time from the GPS PPS (Pulse Per Second). It also allows the comparison of signals processed from the different vehicles studied.

The obtained trajectories from the GPS receivers were recorded and are shown in Figure 3 as lines superimposed on a detailed map of the marina.

Figure 3. Chosen trajectories of moving vehicles during the investigation

Results

Sound pressure level (SPL) analysis

Signals recorded by the underwater measurement system were first processed using the SPL method to show the difference in acoustic pressure level in the whole measured band from 5 Hz up to 25 kHz. Analysis was performed according to the following formulae (Gloza, Buszman & Listewnik, 2012):

$$\mathrm{SPL} = 20 \log \frac{p_{\mathrm{RMS}}}{p_{0\,RMS}} \tag{1}$$

where

$$p_{\mathrm{RMS}} = \sqrt{\frac{1}{N} \sum_{n=1}^{N} \left| X_n \right|^2} \tag{2}$$

p_{RMS} is the Root Mean Square value of N time probes of signal X corresponding to 1 s. The processed results for the different vehicle types are shown as a common plot in Figure 4. These plots represent differences in the research objects from the SPL point of view. In the first 100 s there are no significant

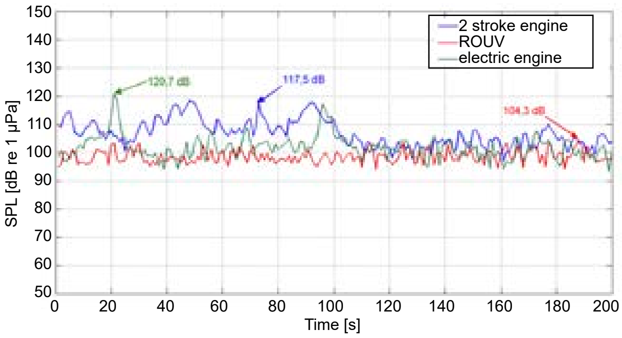

Figure 4. Sound pressure level generated by three types of vehicles with respect to time

dissimilarities between the surface moving vessels. The maximum pressure level was 120 dB re 1 μPa at the closest distance from the hydrophone (Listewnik, 2013b). The SPL of the underwater vehicle was invariable during the experiment at about 100 dB re 1 μPa and is comparable to surface vessels moving at a farther distance from the hydrophone.

Frequency domain analysis by the narrow band method

In the second step, analysis in the frequency domain, including ambient noise to show the SNR aspect, was performed for each vessel type. The frequency range was limited by the hydrophone (low limit 5 Hz) and analog-to-digital converter frequency sampling (high limit 25 kHz). Results after processing are shown in Figure 5.

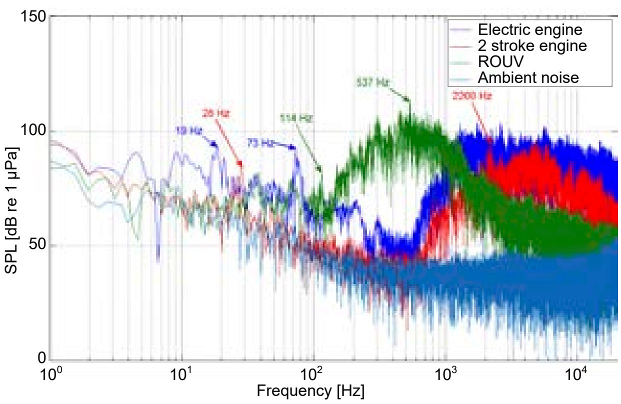

Figure 5. Narrow band spectrum for the three types of vehicles

Analogously to the sound pressure level analysis, there is a similarity between the data collected for the surface vessels, but only at frequencies great than 500 Hz. Below this frequency, the vessel with the electric engine shows a higher level than that with the two-stroke engine, except in the range 20 Hz to 30 Hz. The noise of the two-stroke engine vessel is comparable to the ambient noise up to 600 Hz. The spectrum of the ROUV noise is completely different (much higher) to the others at frequencies above 100 Hz. Above 1 kHz, a significant decrease in the noise level generated by this vehicle is observed.

One-Third-Octave analysis method of hydroacoustic signals

The last type of analysis which was performed during processing was One-Third-Octave analysis (Gloza, Józwiak & Buszman, 2014). It enables a comparison between the different sources of noise in both the frequency and time domains. Similarity in signal character is very clear for the two types of surface vehicle, especially from 1 kHz to 10 kHz. Results obtained after calculations are presented as a spectrogram shown in 2D view (Figure 6 – two-stroke engine, Figure 7 – electric engine).

There are significant differences in the spectrogram of the underwater vehicle in comparison to both surface vehicles. The highest level appears in frequencies up to 1 kHz and a decrease of over 20 dB re 1 μPa from 1 kHz to 2 kHz is observed (Figure 8), due to the connection with the type of propellers used in this vehicle.

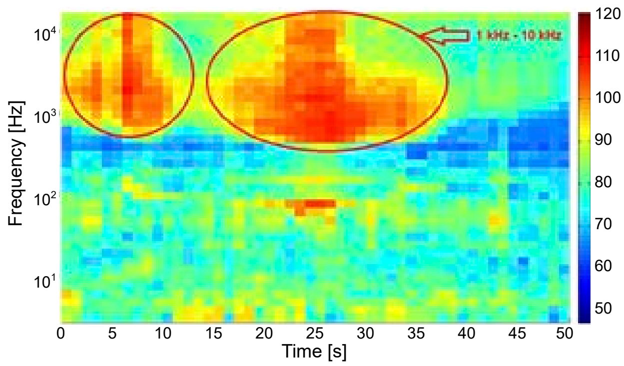

Figure 6. OTO spectrogram of water surface vehicle with two-stroke engine

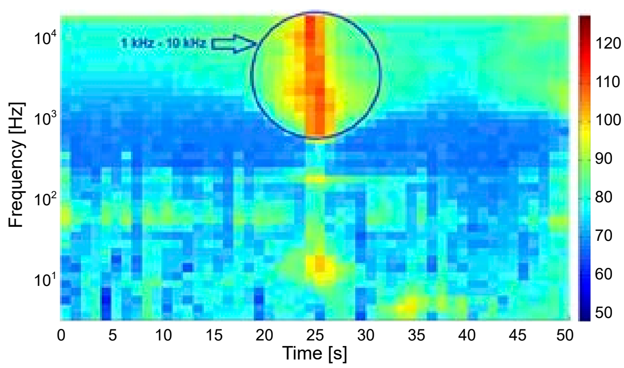

Figure 7. OTO spectrogram of water surface vehicle with electric engine

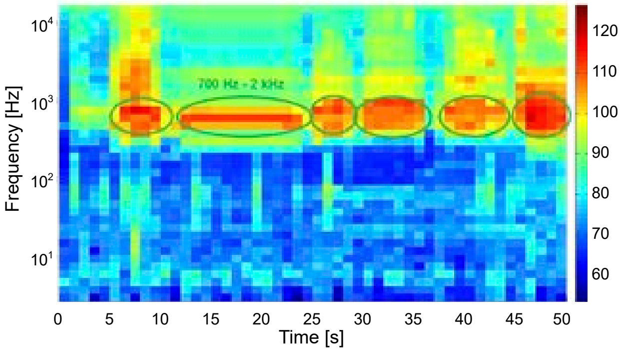

Figure 8. OTO spectrogram of underwater vehicle with electric propellers

Conclusions

Using an acoustic method for the detection of a small object moving in a specified area can be considered as justified. For all tested objects, the impact of the environment on elastic wave propagation can be observed (Kozaczka & Grelowska, 2017). The shallow water reservoir in which the tests have been carried out acts as a high pass filter (Kuperman, 1996), this is noticeable on the displayed spectra and should be taken into account during identification of the noise source.

Many years of research into the noise from merchant ships has confirmed suppositions about the large differences in the signals in comparison to remotely operated vehicles (Listewnik, 2013a). Sound pressure level and frequency characteristics are significantly different. The results presented in this paper confirm the necessity of further research into this topic. The next step should be to perform tests in real conditions at depths of greater than 10 m in areas similar to those close to wind farms.

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