Passive hydroacoustic method of detection and tracking object moving on the sea surface and floating in the depth

Wojciech SZYMCZAK, Krystian BUSZMAN

Polish Naval Academy
Smidowicza St. 69, 81-127 Gdynia, Poland
w.szymczak@amw.gdynia.pl

The main goal of the paper is to present passive, autonomous system to observe objects moving on the sea surface and floating in the depth prepared to work in very shallow water. Complete system will be described starting from hardware realization finalizing on configuration of sensors and presentation of algorithms implemented in prepared to this project software (alarm types, setting parameters responsible for alarm generation etc.). Finally example of object detection will be presented concentrating on remotely operate vehicles ROV – seabotix and combustion motorboat. At a given point of discussion, stability of algorithms eliminating the occurrence of false alarms will be presented. [1, 3].

Keywords: passive hydroacoustic, hydrophone array, direction of arrival calculation

1. Introduction

Purpose of this article is to present results of detection and tracking very small objects floating in the depth and moving on the surface of water. Algorithms used for calculation direction of arrival are based on time delays between signals reaching the individual hydroacoustic field sensors. It is interesting to consider the analysis of data obtained in very shallow waters up to 15 meters depth [5, 6, 8,] where the propagation conditions are specific and do not affect the improvement of the range and stability of the systems detecting and tracking algorithms.

2. Underwater autonomous system description

During investigation underwater autonomous system was based on industrial computer from National Instruments company model cRIO9030 with one analog to digital converter (Sound and Vibration Input Module) with sampling frequency 51,2 kS/s/channel with built-in anti-aliasing filters that automatically adjust to set sample rate. Selected hardware has the great advantage of being able to be program by user depending on the main goal of work, starting from acquisition A/D part going to the source-based detection and tracking algorithms. The prepared measurement unit has two modes of work:

a) Autonomous mode - implemented algorithms determine if a hydroacoustic field disorders are caused by the background noise characteristics occurred in a given area. If yes, calculation of bearing to the source of noise is realized and information from underwater system is sent to the operator via cable line indicating that the object was detected at the specified time and calculated bearing value. Additional to verify that the system is working properly at a certain time interval, system status information is sent (including information like: 'System status OK').

b) Research mode - in this mode, special software must be installed on the service computer that is connected to the underwater module via cable. It allows to change the parameters involved in calculating the bearing to the specific source of the hydroacoustic field disturbance like: sound velocity in water, distance between sensors, number of samples used for single analysis, sampling frequency, acoustic filter parameters etc. The software enables to observe: changes of bearings in the user's declared time buffer (for example plot with changes from 100 seconds), analysis the hydroacoustic signals by spectral presentation (important during changes band-pass filter parameters), listen to the acoustic signals from the selected sensor and record data to further post-processing work in the laboratory conditions.

The measuring system after spreading is 3.4 meters wide, 1.5 meters deep and 0.4 m high. Frame construction is made of stainless steel pipes. Automatic hinges enable quick preparation of the antenna for measurement without the need to twist any components.

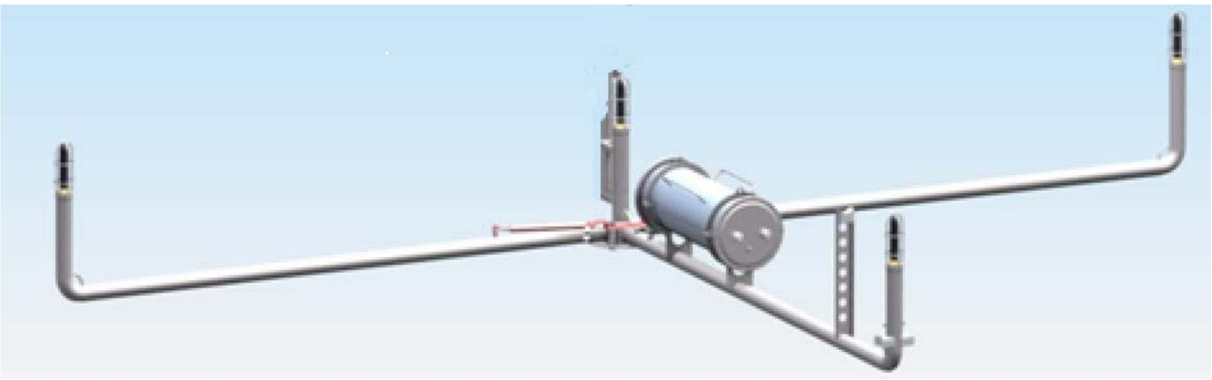

Fig. 1. Measuring system ready for immersion.

Electronic devices and peripheral units connected with power management and data transmission are installed inside the waterproof enclosure, allowing easy access during the service, without necessary of unplugging cables coming from sensors.

3. Hyperbolic bearing calculation

The algorithm for the source of noise detection and tracking is based on the delays of the signals reaching each hydroacoustic field sensor (hydrophone) calculated with use of cross-correlation function. Signals are in first step, after acquisition, filtered through the for example 15Hz-20kHz bandpass filter. It is possible to specify the duration of a signal samples taken to analysis (duration in time from 100 ms to 1000 ms). The registered and filtered signals are checked for their automatically calculated level - RMS and dynamic of its change. If during a given time required change of level is taking place algorithm passes to the next step. This protection removes not necessary continuing calculations, directly connected with power consumption of industrial computer for example when the state of the sea changes. The next step is to calculate the delay between the individual sensors Fig. 2.

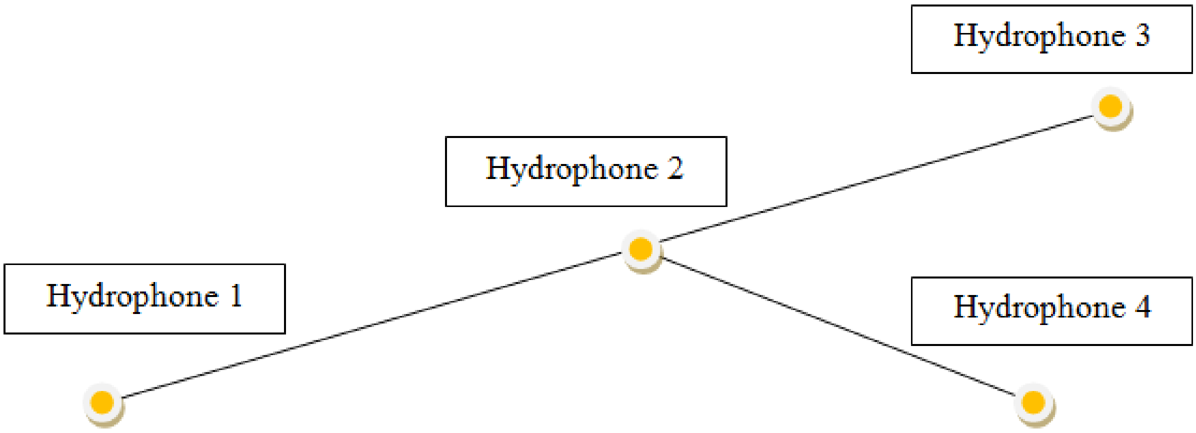

Fig. 2. Hydroacoustic sensors configuration.

Cross-correlation function does not charge high CPU and is realized in very short period of time. The basic formula number 1 is used to determine the angle to source of noise.

$$\sin NR = \frac{c(\tau_1+\tau_2)(L^2-c^2\tau_1\tau_2)}{L[2L^2-c^2({\tau_1}^2+{\tau_2}^2)]} \qquad (1)$$

where:
NR - calculated bearing
L - distance between hydrophones
τ_1 - delay between hydrophone H1 and H2
τ_2 - delay between hydrophone H2 and H3
c - sound velocity

The calculated bearing from group of 3 hydrophones (Hydrophone 1,2,3) are stored in the memory buffer. In this step algorithm have a bearing on the object but it is not specify whether it is in the front or the rear of the antenna. To define this cross-correlation between hydrophone 2 and 4 must be calculated. If the delay value is positive, the source should be oriented on the antenna side where the hydrophone 4 is presented. If the value is negative, the source should be placed on the opposite side.

The calculated bearing (coming from formula 1) is not geographically oriented. Involving to the antenna indication readings from digital compass, we obtained bearing in which the target appears that could be plot directly on the navigation map.

If a specified number of angles pointing source (for example 10) differ from each other by a maximum of 6 degrees, a decision is made to send information that object has been detected and tracked.

Due to the fact that it may occur situation that the algorithm for detecting and tracking the object stop sending bearing value because one of the 10 bearings stored in the buffer is out of range. In the service software is implemented function for peak elimination to provide a more stable operation of the system without changing the state object detected/object. Described example can appear when rapid, short duration noise reach measurement unit sensors.

4. Results from real condition tests

The tests were conducted in Poland in the yacht marina located in the Górki Zachodnie. The depth of the water was on average 5 meters. Measurement unit was lowered to the bottom from the end of the pier, which made possible to observe the open area of river Martwa Wisła at distances up to 430 meters. During the tests, two target objects were used: the remotely controlled ROV and 4 meters length, two-stroke engine rubber boat. When the antenna was lowered to the bottom from the end of the pier, readings obtained from pitch and roll sensor where checked to confirm proper arrangement and also reading from digital compass was checked to confirm that it has correct indication after its calibration.

The first example is presented for noise measurements obtained during low noise ROV Seabotix vehicle. After several tests it has been determined that it is possible to obtain stable detection and tracking information from very silent object. On the map in Fig. 3, the marina was presented and the black color on the yellow background present GPS track of ROV during one pass measurements.

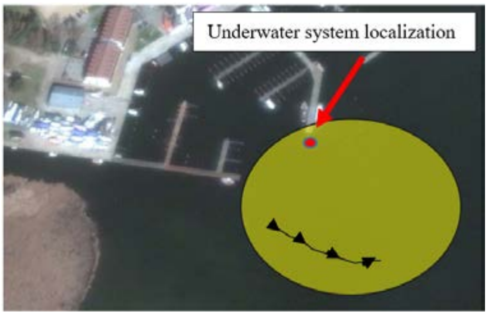

Fig. 3. Path of tracked ROV

Blue plot in Fig. 4 showing angle after integrating the antenna bearing and reading from the digital compass. In the first 286 seconds it can be clearly notice trend of bearing changes starting from 290 degrees to 12 degrees. After this time, the motors that drive the floating object were turned off. It is also possible to notice the chaotic changes of the bearing calculations (results in Fig. 4. From 287 s.) are coming from the uncorrelated background noise.

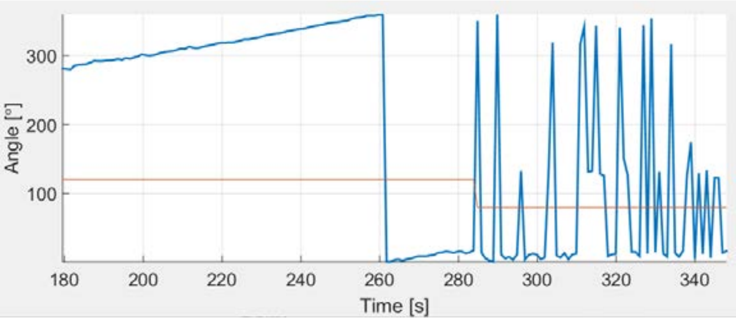

Fig. 4. Presentation of bearing calculation results changing in time.

The correlation results from the selected fragment, when the target object has the motors turned on and when the motors are switched off, placed in the matrix for 3D visualization, as shown in Fig. 5. The differences between the clear signal and the uncorrelated background noise can be clearly notice.

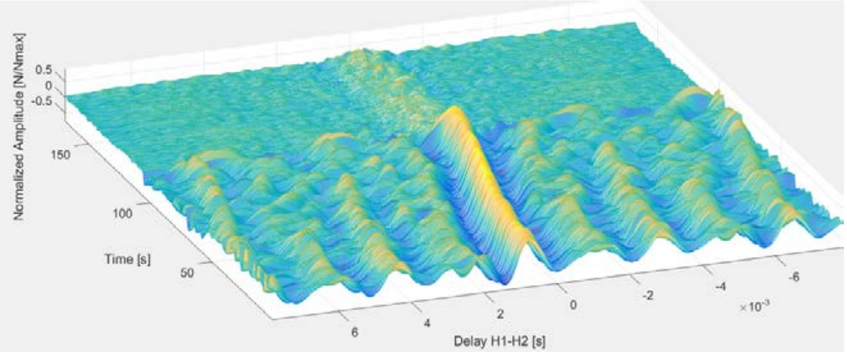

Fig. 5. 3D presentation of cross-correlation result matrix.

The second measured object was a rubber boat powered by a two-stroke engine. Figure 6 shows the path recorded on the GPS receiver which was moving during the given test. The main noise from the engine made possible detection and bearing calculation when the object was moving on the whole measurement range.

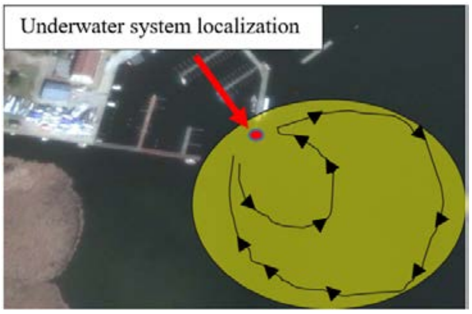

Fig. 6. Path of tracked rubber boat

In Fig. 7 can be clearly notice stable indication of the bearing during long period of time (up to 417 seconds, when the object has got turned on engine). The discrepancies in the bearing were on average 6 degrees in comparison with GPS localization and the greatest divergence were recorded when the object was on the extension of the line on which 3 hydrophones were placed.

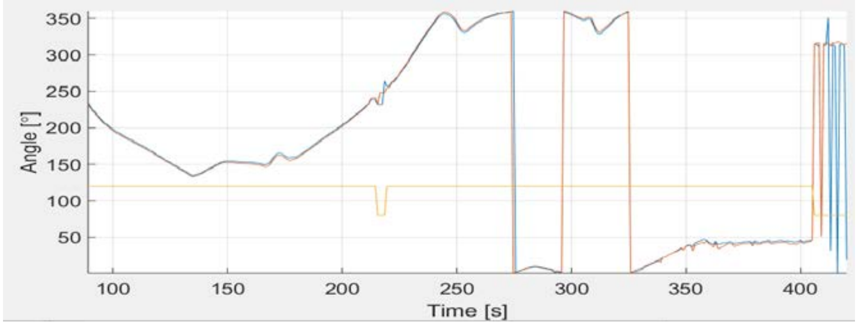

Fig. 7. Presentation of bearing calculation results changing in time.

In addition in Fig. 8 is presented the 3D illustration of the cross-correlation function results for a single pair of hydrophones. There is a noticeable trend of changes throughout the whole observation period as well as changes in the time delay from maximum to minimum values what is connected with making circles around the antenna.

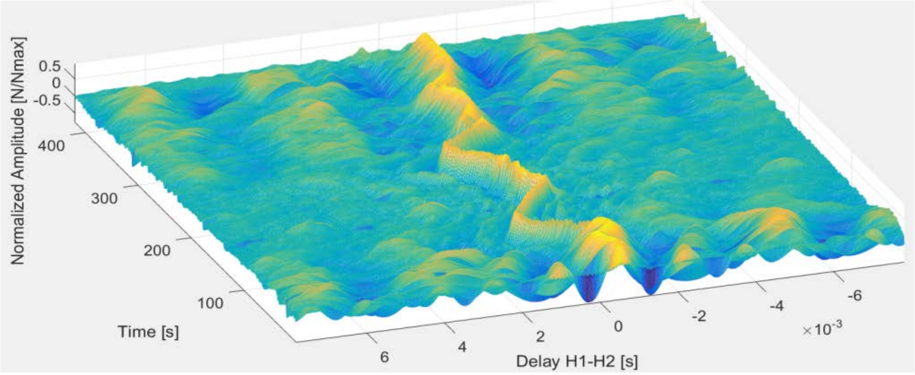

Fig. 8. 3D presentation of cross-correlation result matrix.

Conclusions

The article presents the possibility of stable detection and tracking objects moving on the water surface and floating in the depth using antenna made of three hydrophones in line and fourth one to determine bearing location. The next step will be extending hydrophone array to five hydrophones and check possibility of calculation distance to the sources of noise with specific parameters [2, 7].

The presented solution of the system allows realization of fast measurement polygon preparation due to mobility and small size system. Additional acoustic information obtained is characterized by low noise levels due to the use of measuring hydrophones connected in differential configuration.

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