A PASSIVE ACOUSTIC LOCALIZATION SYSTEM FOR BROADBAND SOURCES

E. Skarsoulis[a], P. Papadakis[a], M. Kalogerakis[b,a], G. Piperakis[a] and E. Orfanakis[a]

[a] Institute of Applied and Computational Mathematics (IACM), Foundation of Research and Technology - Hellas (FORTH).
[b] Department of Electrical Engineering, School of Applied Technology, Technological Educational Institute of Crete- Greece

Panagiotis Papadakis, Institute of Applied and Computational Mathematics (IACM), Foundation of Research and Technology - Hellas (FORTH) , N. Plastira 100 70013 Iraklion Crete, GREECE, Fax: 2810 391728, e-mail: panos@iacm.forth.gr

Abstract: *In the framework of the Sea-Ears project, a system is designed and built for passive acoustic localization of broadband sources laying in the water column (e.g. vocalizing cetaceans) or on the seabed (e.g. underwater locator beacons). The localization method exploits time of arrival differences between direct and surface–reflected arrivals at one or two hydrophones and accounts for refraction caused by a depth-dependent sound-speed profile. Bayesian inversion allows for the estimation of localization errors taking into account arrival time measurement errors as well as uncertainties of hydrophone locations and the sound-speed profile itself. A number of controlled localization experiments were conducted in the bay of Heraklion using an acoustic pinger as a source. In this work the system components are described, one of the experiments performed is discussed and some results on source localization are presented.*

Keywords: *Passive acoustic localization, travel times, refraction,*

1. INTRODUCTION

Effective and accurate localization of underwater sources plays a central role in security monitoring of diver operations, post-accident recovery of black boxes (voice and data recorders) at sea, marine-mammal/cetacean research and associated conservation activities, etc. The Sea Ears project addresses passive localization of broadband underwater acoustic sources, using minimal hydrophone sets, taking into account refraction effects and exploiting multipath propagation

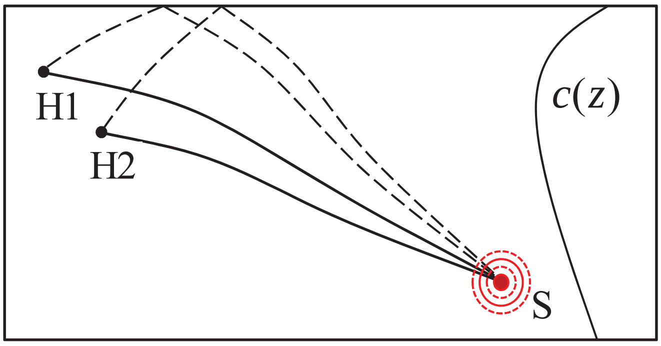


Figure.1: Localization using two Hydrophones.

The localization is based on measured travel-time differences between direct and surface-reflected arrivals at one or two hydrophones and takes into account refraction characteristics of the ocean sound channel and their effects on propagation geometry and travel times [1], [2] (Fig. 1). A Bayesian estimation framework is used to account for measurement errors and environmental uncertainties [3]. This system consists of a number of hardware components (hydrophones, depth sensors, GPS etc.) connected to a standard PC/laptop running a custom-made software suite that performs data acquisition and processing (estimation / detection / localization) and presents localization results on a geographic map in real-time aboard the ship (on-line mode). The software also features an off-line operation mode where the acquired data can be further studied and analyzed.

In this work, the above system is described in terms of both its hardware and software components. Furthermore the results of some localization experiments conducted in the Bay of Heraklion are presented and discussed.

2. HARDWARE COMPONENTS

The system's hardware comprises of three modules: the sensing module, the acquisition module and the GPS positioning module.

The sensing part of the system consists either of two towed hydrophone arrays custom made by Ecologic (each of which has three hydrophones, two depth sensors and 200-m cable) or alternatively of a single cabled hydrophone (Reson TC4032 with 200-m cable). In the first case two hydrophones (one from each array) with their corresponding depth sensors are used. A photograph of one of the arrays and also a photograph of the single hydrophone is shown in Figure 2.

For the acquisition of the acoustic signals and the depth sensors readings, a USB data acquisition system from National Instruments is used. It allows for 16-bit simultaneous sampling of multiple channels with sampling frequency up to 100 kHz. Two channels are used for the acoustic data and two more for the depth sensors.

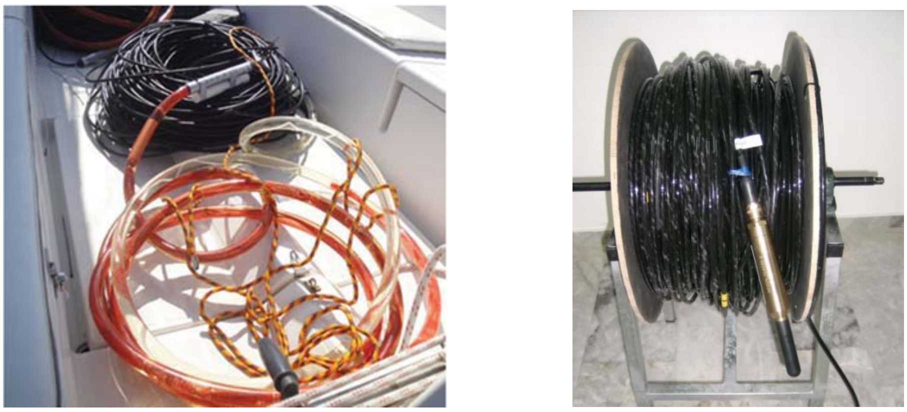


Figure 2: Left: Ecologic hydrophone array Right: Reson TC4032 hydrophone

The position (longitude, latitude) of the vessel as well as of the controlled source is monitored using Garmin GPS Units. The vessel position is directly streamed through a USB port to the PC running the detection/localization software

3. SOFTWARE SYSTEM

An interactive software system was developed for the data acquisition, preprocessing, analysis and presentation of localization results. This system, named "*Moby Dick*" is running on a standard PC/laptop interconnected with the data acquisition system and an external GPS device. It integrates data acquisition, detection and localization codes, along with a GPS module and several database components providing a user-friendly dynamic environment to be used both during field observations as well as for post-processing data analysis. Its user interface features an interactive dynamic map on which the localization results are plotted. A block diagram of the software is presented in Fig.3.

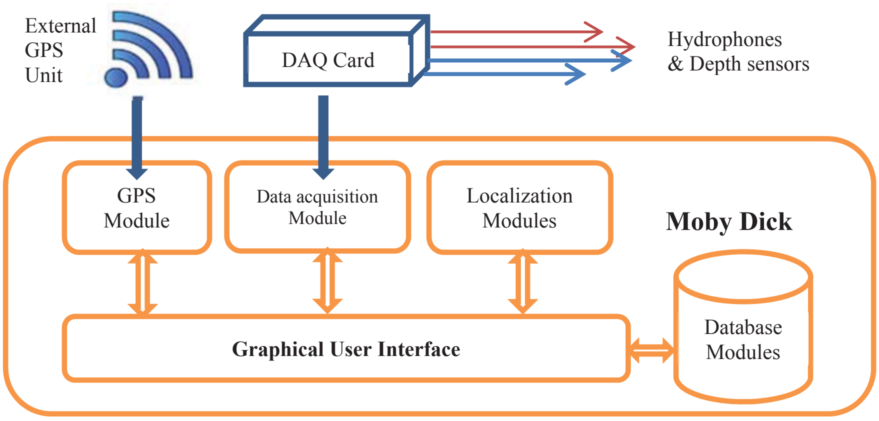


Figure 3: Block Diagram of the Moby Dick software

Moby Dick supports two Modes of operation: (a) on-line operation for real-time data acquisition pre-processing and analysis – this is the mode to be used while conducting localization in the field, and (b) off-line operation for post-processing and detailed analysis of collected data after the completion of an experiment/measurement at sea. In Figure 4 a screenshot of the Moby Dick interface is shown.

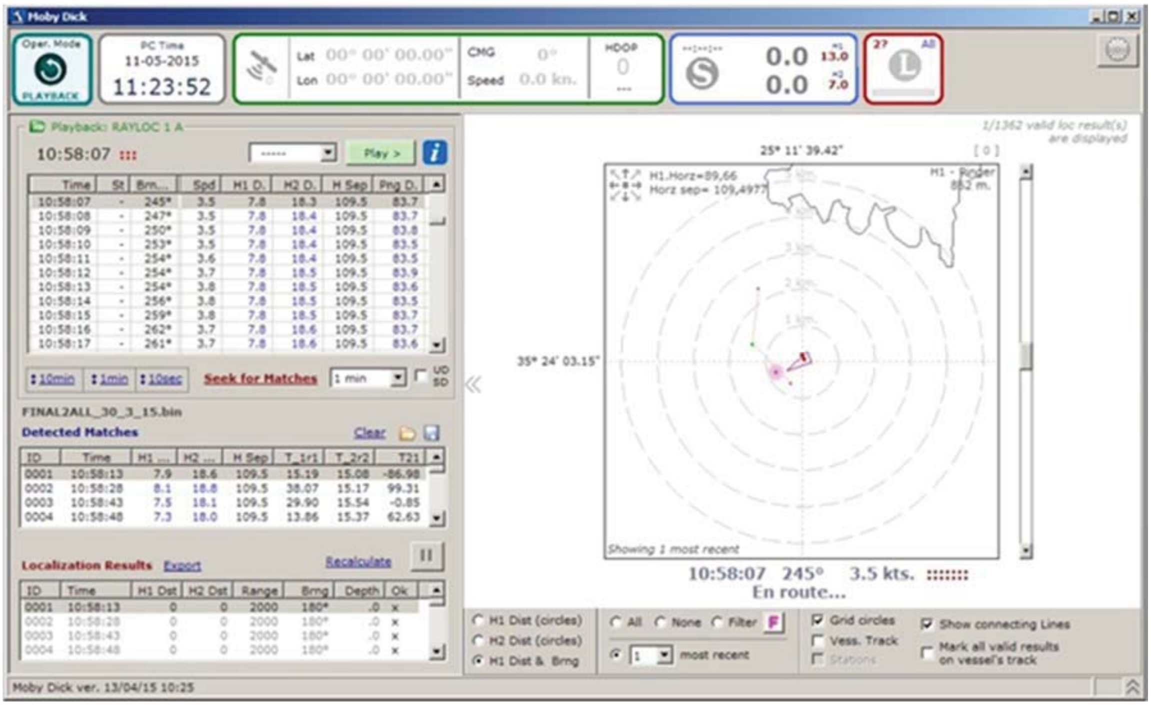


Figure 4: A screenshot of the Moby Dick

Two fundamental modules of Moby Dick that may also function as standalone applications are the data acquisition module collecting and preprocessing data from the underwater sensors and the estimation / localization module producing localization results.

The data acquisition module was developed in C++ using the Framework wxWidgets. One part of the module is controlling the communication with the data acquisition system and the collection and recording of data in binary files on the disk. The second part displays and analyzes the recorded data by applying an energy filter on them in order to detect points of interest for further processing. Further data processing results in the detection of matches which are saved separately. A match is a combination of two close waveform arrivals of a pulsed signal (considered to be direct and surface-reflected) recorded at both hydrophones (or at one hydrophone in the case of single-hydrophone configuration). The user can control the parameters of data collection and inspect the process in real-time through a data acquisition interface. A screenshot of the data acquisition module is shown in Figure 5, where the acoustic waveforms are shown in blue while in red is the result of the application of an energy filter to the signal. The large numbers on the left are the corresponding hydrophone depth readings (in meters).

The localization module features a number of codes for Bayesian localization from measured time of arrival differences between direct and surface–reflected arrivals at one or two hydrophones. Refraction caused by a depth-dependent sound-speed profile is taken into account by applying a ray-tracing approach. Travel times are linearized with respect to source range, hydrophone and source depths as well as with respect to perturbations of the sound-speed profile. The solution of the non-linear inversion problem is obtained through an iterative approach, solving a linear inverse problem in each step. The Bayesian approach allows for the estimation of localization errors caused by various sources of uncertainty, such as travel-time measurement errors, hydrophone location errors, and depth-dependent sound-speed uncertainty. In the case of a source lying in the water column synchronous recordings at a pair of two hydrophones are used to estimate the source range, depth and azimuth (subject to left-right ambiguity with respect to the vertical plane through the hydrophones). In the case of a source lying on the seabed of known depth and depth uncertainty, its location (range and azimuth) is estimated by combining recordings at a single hydrophone at various locations.

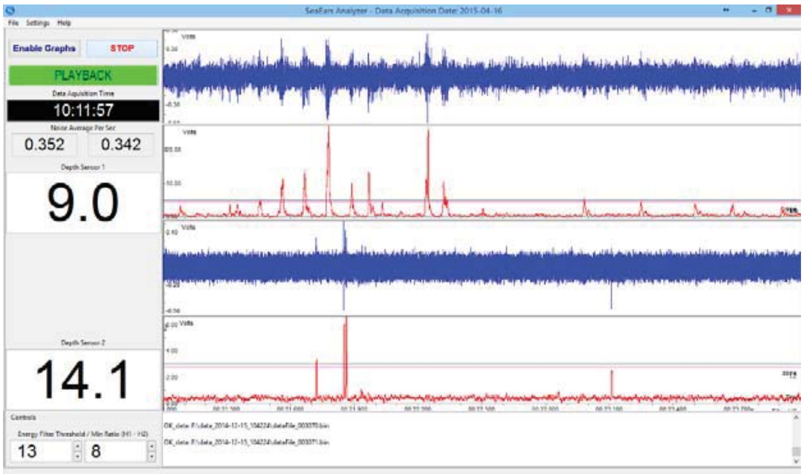


Figure. 5: A screenshot of the data acquisition module. The signal recorded is in blue and the result of an energy filter applied to the signal is shown below in red.

4. PRELIMINARY TESTS AND RESULTS

A number of controlled localization experiments were conducted in the Bay of Heraklion, between the city of Heraklion and the island of Dia, Figure 6, in an area with water depths between 140 and 200 m. A two-hydrophone configurations was used.

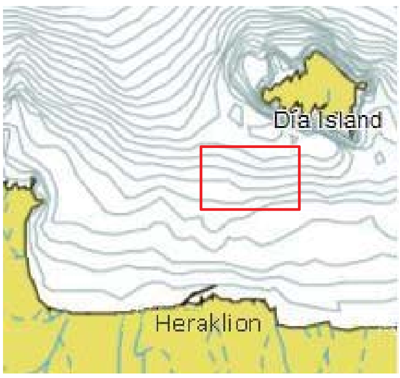


Figure. 6: The Bay of Heraklion and the experiment area (red)

A broadband pinger (acoustic pinger 1201 by Online Electronics) emitting every 5 s box-shaped pulses of 5 ms duration was used as a source. During the experiments the pinger was deployed in the water column at certain depths as well as on the seafloor. A custom-made surface float attached to the pinger facilitated its deployment and retrieval (Fig. 7). The pinger depth versus time was recorded using an autonomous TDR unit whereas the float location (longitude, latitude) was monitored through wireless GPS.

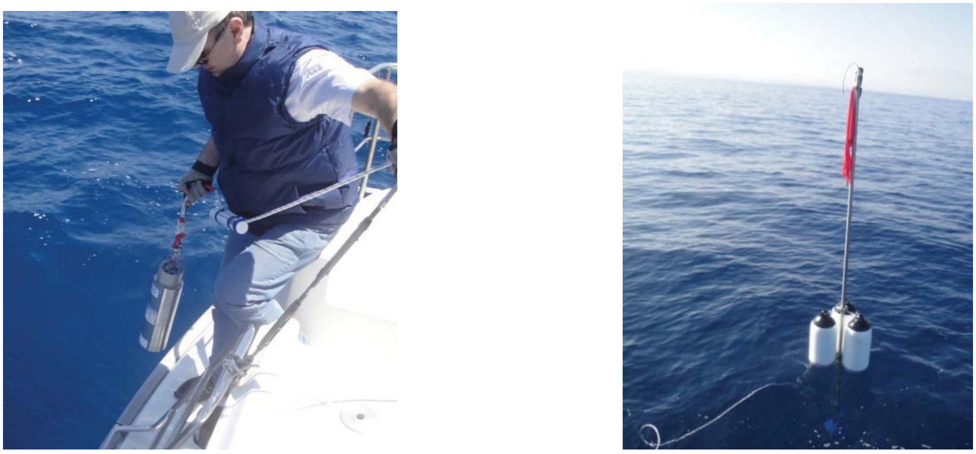


Figure.7: Left: Putting the pinger in the water. Right: The surface float

The localization experiments were conducted from SB Maryline. First the pinger and the float was put in the water, then the vessel moved away and the hydrophones were put in the water and towed by the vessel. When the vessel was moving, the distance between the vessel and the first hydrophone (H1) was about 90 meters and the distance between the two hydrophones H1, H2 was 100 meters as seen in Figure 8.

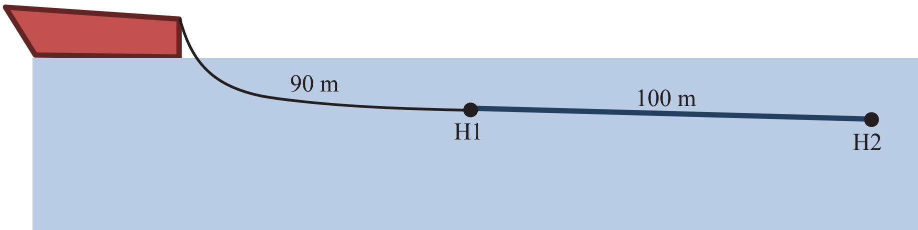
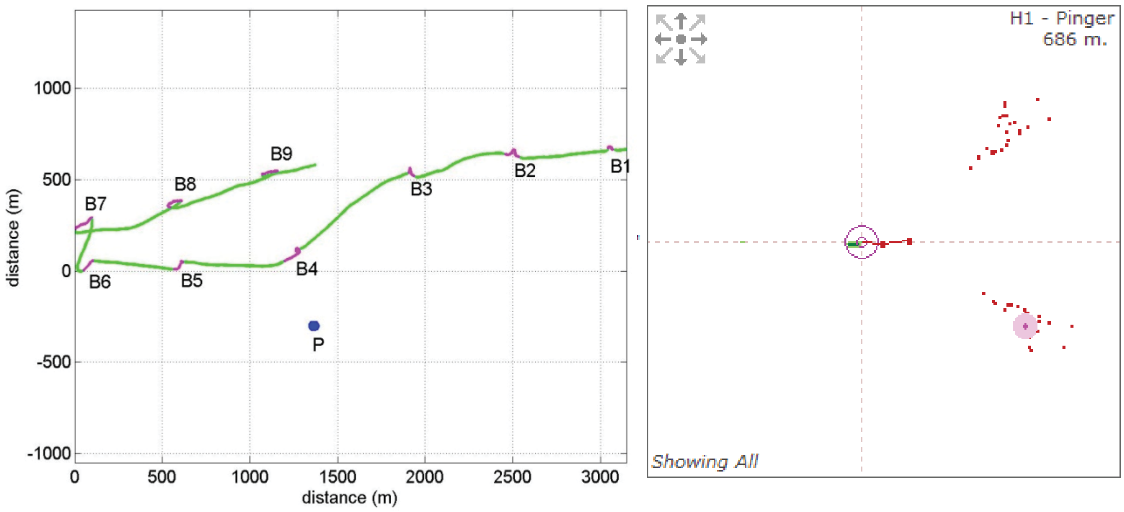


Figure 8: A sketch (not in scale) of the position of the hydrophones behind the vessel

Acoustic data from the hydrophones H1 and H2 and depth readings from the nearby depth sensors were used for the estimation of source range and depth. The depth readings were then combined with the vessel location data in order to map the location of the hydrophones in the horizontal and then using the source range estimates to obtain estimates for the source bearing (subject to left-right ambiguity).

In the following some localization results from one of the experiments, conducted on 15 December 2014 are presented. In that case the pinger was deployed on the seabed at ~140 m depth and the vessel followed the path shown in Figure 9a as a green line - the location of the pinger (P) is denoted by a blue dot in this figure. The vessel stopped at predefined positions (stations) and data were collected. These stations labelled B1 through B9 are shown as magenta segments in Figure 9a. Figure 9b shows localization results from the analysis of data collected during station B5 using the Moby-Dick software.



(a) *(b)*

Figure 9: (a) The vessel route (green) and stations (magenta) and the pinger (P) position (blue dot). (b) Estimated pinger position (red dots) while at station B5 – true position is marked by pink disk. The position of the vessel is at the centre followed by the two hydrophones.

The actual position of the pinger is shown by a pink disk in this figure. The position of the vessel is at the centre followed by the two hydrophones. The actual distance between the vessel and the pinger is 686 meters. The red dots are the estimated positions of the pinger obtained using the source localization software. A typical left-right ambiguity is observed. The standard deviation of the location estimation is about 50 m.

5. CONCLUSIONS

In this work a passive acoustic system for the localization of broadband sources is presented and its hardware and software components are described. The system has been tested in shallow water so far and one of these tests is briefly presented in this work together with some representative localization results. These results indicate that the system is working as expected and the estimation of a source position in shallow water is possible. Future work involves localization experiments in deep water.

6. ACKNOWLEDGEMENTS

This research is co-funded by the European Union (European Social Fund – ESF) and the Greek State through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF 2007 - 2013) - Research Funding Program: ARISTEIA II, Sea Ears project 3495.

REFERENCES

[1] **E.K. Skarsoulis, M.A. Kalogerakis**, Ray-theoretic localization of an impulsive source in a stratified ocean using two hydrophones *J. Acoust. Soc. Am.*, vol 118, pp. 2934, 2005

[2] **E.K. Skarsoulis, M.A. Kalogerakis**, Two-hydrophone localization of a click source in the presence of refraction, *Applied Acoustics* vol. 67, pp. 1202, 2006.

[3] **S.E. Dosso, G. Ebbeson,** Array element localization accuracy and survey design, *Can. Acoust.*, vol. 34, pp. 1-11, 2006.