Assessment of a shallow water area in the Tagus estuary using Unmanned Underwater Vehicle (or AUV's), vector-sensors, Unmanned Surface Vehicles, and Hexacopters – REX'17

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Abstract — **This paper describes the work done during REX'17, an exercise conducted by the Portuguese Navy in cooperation with Portuguese universities to test, demonstrate, and develop research projects, and to approach the academic and military communities. This year the exercise took place in the Tagus river estuary, and its main aim was to assess shallow water areas, regarding bottom, and acoustic characteristics. The experiments involved testing of vector sensors development at the University of Algarve, an UUV developed by INESC-TEC, a marsupial robotic team of a USV and a hexacopter capable of landing on water developed by the New University of Lisbon (Nova), and a hydrophone network used by the Portuguese Naval Academy.**

Keywords: Unmanned Vehicles, Vector Sensors, Cooperation, Experiments

I. Introduction

The Portuguese Navy conducts an annual exercise in which civilian universities are invited to showcase systems that they are developing, test those systems with the aid of navy personnel and resources, and interact with the navy's operational community [1]. These exercises, named REX (from the original purpose of Robotics Exercise) allow the Academic community to understand better the Navy's needs, thus centering their research on areas of direct interest to the country, but also enables them to test and obtain data that would otherwise be difficult and expensive, and learn from the practical perspective of seamen. It also allows the testing of civilian uses of unmanned systems in difficult environments such as shallow water areas, areas with strong currents, among many others [2]. It is also a good opportunity to test interoperability of systems developed by different teams of researchers and swarms [3] of heterogeneous vehicles, that is a major goal for the Navy [4].

For the Navy, these exercises allows a better knowledge of the state of the art in various technological areas that are important for its mission, which includes, besides the military missions of all navies, public interest missions that are given to it by national law, such as Search and Rescue [5]in the maritime domain, pollution control, and state authority at sea [6].

This paper describes the tests that were conducted in 2017, in the Tagus estuary near Lisbon's Naval Base, that had as its main aim the assessment of that shallow water area and acoustic interferences. This year four research institutions were present: CINAV (from the Navy itself), INESC-TEC (from the University and Polytechnic Institute of Oporto), CINTAL (from the University of the Algarve) and UNINOVA (from the New University of Lisbon). The paper finishes drawing some conclusions about the experience gained in each of the tests and globally with this interaction between researchers and navy personnel.

II. Dual Accelerometer Vector Sensor

One of the main technologies tested was a Dual Accelerometer Vector Sensor. The Dual Accelerometer Vector Sensor (DAVS) was developed in the framework of the WiMUST H2020 European project [7]. Figure 1 presents a photo of the DAVS system mounted on a MARES AUV before the deployment during the REX'17. The DAVS system has two main parts: the acoustic sensing part (black nose) and the container, housing all the electronics and acquisition system (white tube). The DAVS sensing part is composed of a hydrophone (pressure sensor) and two particle velocity sensors (tri-axial accelerometers) aligned in a vertical plane. This dual configuration has already proven to be a suitable solution for azimuth estimation when it's mounted on an AUV [8] or for bottom characterization [9].

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Figure 1 – A photo of the DAVS beneath the MARES before deployment

CINTAL and INESC-TEC teams participated in REX'17 Sea trial, where the main goal was to evaluate the possibilities of the DAVS system mounted on the MARES AUV, Figure 1, for:

- Platform self-localization;
- Bottom characterization;
- Port security.

During the experiment, the DAVS was positioned beneath the MARES AUV such that the two accelerometers (#49 bottom and #50 top) and the hydrophone were aligned with the vertical z-axis, as shown in Figure 2, in order to estimate the signal direction of arrival (DOA), in particular the azimuth estimates. The signals were emitted by a Lubell 916C sound source, deployed at 3m height from the bottom in a water depth range, due to tide, of approximately 4.5m to 6.5m. The emitted signals were a sequence of LFMs signals in 1-3 kHz frequency band, with a time duration of 100 ms followed by 200 ms of silence.

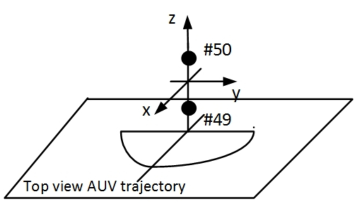

Figure 2 – Drawing of the experiment *X-Y* plane (Top view of AUV trajectory) parallel to the DAVS *x-y* plane, where the accelerometers are aligned in the vertical z axis, the #50th being the shallowest one.

The experimental data presented in this work is a preliminary result for self-localization, when the MARES navigates on the area near the source. Figure 3 presents the top view of the MARES's trajectory (blue line), the position of the source (red asterisk), the position of the pier used to reference the MARES's position (green cross) and the DAVS's orientation, where the *x*-component is pointing to the sailing direction and the *z*-component is pointing to the surface.

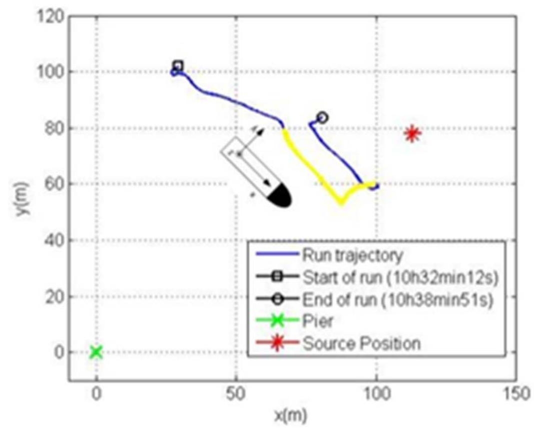

Figure 3 – Top view of the MARES trajectory relative to the pier position at the origin of coordinate system, marked by green cross and the source position marked by red asterisk, during July 12.

The results of the azimuth estimation performed with the DAVS are shown in Figure 4 as processed for the track given by the yellow line of Figure 3. These results were obtained using the Intensity based estimator described in [10]. The blue and red dots are the results of the estimation, considering the combination of the pressure with the particle velocity components using both accelerometer outputs, #49 and #50, respectively. As can be seen, the results are comparable for both accelerometers and follow the trajectory. It can be observed that the curve presented in the track (yellow line in Figure 3): after 80s on Figure 4, the azimuth reaches around 50º, then approaches 0º (in front of the source when the MARES executed the sharp curve) and then rotates to 90º. From these results it can be concluded that the experimental results are consistent for both accelerometers. They are in agreement with the MARES trajectory and the generated thruster's noise does not disturb or influence the stability of the estimation results.

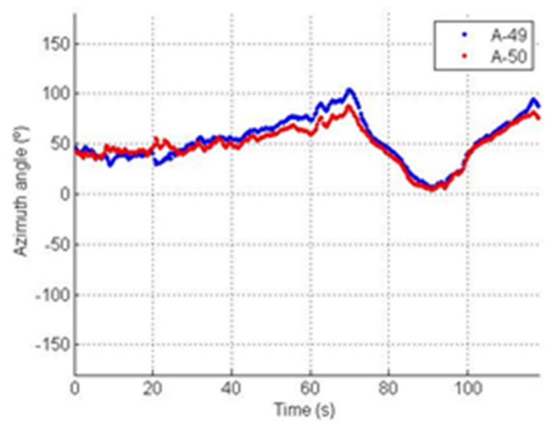

Figure 4 – The estimation of the azimuth angle between the source and the MARES for both accelerometers, blue dots for #49 and red dots for #50.

III. MARSUPIAL ROBOTIC TEAM

Another important asset used for the shallow water assessment was a cooperative marsupial robotic team composed of an unmanned aerial vehicle and an unmanned water surface vehicle, Vigil R6-WT (Figure 5) and Pelagi (Figure 6).

Figure 5 - UAV Vigil-R6-WT performing a survey

Figure 6 - Pelagi navigating during the experiments

Multi-robot marsupial teams are not a novelty as can be seen in [11], [12]. Neither the use of UAVs for maritime surveillance is a recent tendency. As a matter of fact, UNINOVA research team developed watertight units that can land on water [13],[14] and introduced them in a marsupial configuration to increase both the perception ability and autonomy of the ensemble for the surveillance of shipwreck survivors at sea [15]. While highly sophisticated fixed-wing UAVs with long flight autonomy are capable of maritime surveillance, their unit and operation costs are high. However, multiple low cost but highly rugged units can have a good global performance but low operation costs. The choice of multi-rotors might seem odd as they have notoriously low flight time, but the ability to float on the water for long periods of time and only lift for quick aerial survey missions mitigates the problem.

In this REX edition, UNINOVA research team proposed an extended version (*i.e.*, better robotic behaviors and improved perception algorithms) of the concept used in the 2017 DRONES4GOOD award in Dubai [16]. The idea is to have a team of Unmanned Aerial Vehicles, cooperatively aiding a rescue autonomous surface vessel (ASV) to permanently monitor and track the most problematic migrant routes. Due to logistical limitations the Tagus river was chosen to be the migrant route in the REX exercise.

The UAVs act as a mobile sensor network, scouting different regions in a coordinated and autonomous way, extending and optimizing the total coverage of the team from high vantage points. Whenever one of them detects and confirms the presence of a troubled vessel, the GPS coordinates are sent to the ASV, which then rushes to the location to supply basic survival kits, floaters, even inflatable life rafts to the people aboard. Meanwhile, the UAV keeps hovering and tracking the survivors until the ASV arrives. All this information is passed on to an operation control center, to have a larger, manned vessel assigned to transport victims back to land.

The high vantage point capture attained by UAVs will be then analyzed for salient objects on the water surface while the they remain hovering [10].

The proposed system was envisioned to act as a permanent early warning system for detection of shipwrecks and aid the humanitarian migrant crisis. However, a highly movable sensor network composed of rugged multi-rotor UAVs could have diverse applications in other areas. While, in the current market, UAVs are becoming prominent in applications spanning from precision agriculture to bridge inspections, they are still very frail in nature. This prevents their successful application in harsh or remote environments.

IV. HYDROPHONE NETWORK

Finally, a more traditional network of hydrophones was also used to characterize the acoustic environment, and assess the acoustic signature of a given boat. The network of hydrophones was positioned at known coordinates and collected acoustic data of all participants throughout the exercise. Two boats were used as targets, a RIB (rubber inflatable boat) and a Rodman 200 cabined motorboat (known as “Mindelo Class”). Parallel linear tracks where performed at various distances, perpendicular to the hydrophone array with each line being repeated at a higher RPM (see Figure 7 below). Instantaneous positions acquired with GPS for later comparison with triangulated positions estimated from acoustic data observations, would also enable to calculate vessel´s instantaneous speed, that along with the signal´s observed spectra (Figure 8), are useful information on acoustic signature tasks.

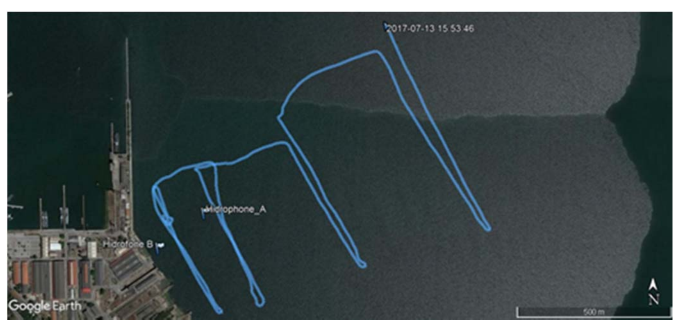

Figure 7 – Example of linear tracks followed performed by the Mindelo motorboat (satellite picture background from Google Earth).

All other acoustic data (FM chirps for the unmanned vehicles operations and communication signals, river ferry traffic, and others) was also recorded.

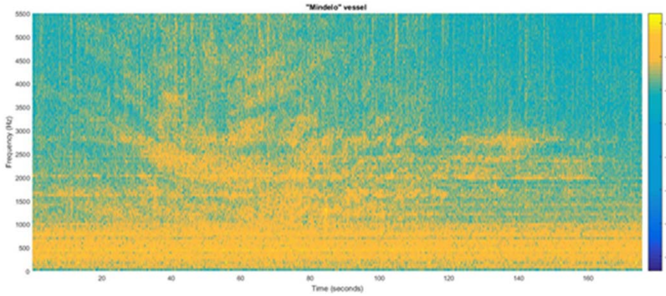

Figure 8 – Spectrogram from a set of acoustic data on hydrophone_A, recorded during a track of the "Mindelo" motorboat.

V. Conclusions

Once again, the REX exercise was important both for the participating researchers and for the Navy. This year's edition was the smallest since 2013, which had advantages and disadvantages. On the plus side, the electromagnetic spectrum management posed no problems, since there were few wireless and radio links, and coordination was trivial. In previous years this posed a major problem, and led to a significant reduction of available bandwidth and a lot of interference and broken links. Just to prevent possible problems, we monitored the use of Wi-Fi frequency bands, and allocated different and well separated bands to different groups. However, the small number of participants did not allow us to test the effects of congested spectra or the interoperability of different platforms.

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