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Dual Accelerometer Vector Sensor (DAVS) - REX'17 Sea Trial Data Report

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Abstract	The objective of this report is to present the data collected with the Dual Accelerometer Vector Sensor during the REX'17 Experiment. The data was acquired from July 11th to 13th, 2017, in the area of Naval Base of Lisbon (BNL), Alfeite, Lisbon. During this trial, the DAVS was mounted on the autonomous underwater vehicle, MARES AUV, from INESC-TEC, Porto and acquired data along pre-determined geometries. The goal of the experiment was to evaluate the possibilities of combining a compact directive device (DAVS) composed by an hydrophone (pressure sensor) and two particle velocity sensors (accelerometers), installed in an AUV (MARES) for: platform self-localization, bottom characterization and port security for intruders detection. This report describes the experimental results obtained to characterize the objectives of the experiment.
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Abstract

A Dual Accelerometer Vector Sensor (DAVS) is a compact device, consisting of two tri-axial accelerometers and one hydrophone aligned in a vertical plane. It was developed during the framework of the E.U. WiMUST project to improve bottom image by enhancing bottom returns and decreasing direct paths interference. The objective of this report is to present the data collected with the DAVS during the REX'17 Experiment and the respective processing thereof in order to comply with the planned objectives. The goal of the experiment was to evaluate the possibilities of combining this compact directive device (DAVS) for: platform self-localization, bottom characterization and port security for intruder detection. The DAVS recorded passive and active signals, which were emitted by a Lubell source in the 1 to 3 kHz band. The data was acquired from July 11th to 13th, 2017, in the area of Naval Base of Lisbon (BNL), Alfeite, Lisbon. During this trial, the DAVS was mounted on the autonomous underwater vehicle, MARES AUV, from INESC-TEC, Porto, at the first two days, acquiring data in different geometries and different depths, and for the last day it was moored in a water depth of 2.5 m (approximately). The results for azimuth estimation are stable for all AUV missions and compares the presumed true azimuth given by the DAVS compass. Moreover, the DAVS is able to detect noise (passive) signals produced by boats near the area where DAVS is moored. The combination of particle velocity with the particle velocity gradient, possible with the dual configuration of the DAVS system, is useful for bottom characterization where the bottom reflected paths are improved in contrast with the direct paths attenuation.

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Chapter 1

Introduction

The Dual Accelerometer Vector Sensor (DAVS) was developed in the framework of the WiMUST European project in order to complement the streamers' data for bottom characterization, [1]. The DAVS is a compact sensor, composed by a hydrophone (pressure sensor) and two particle velocity sensors (tri-axial accelerometers) aligned in a vertical plane and allows for easy mounting and operation on autonomous underwater vehicles (AUV's). The use of a dual accelerometer configuration with a single hydrophone was based on previous studies [2, 3], which showed that a combination of the particle velocity with pressure or with the particle velocity gradient has the ability to cancel or significantly attenuate the direct and the surface-reflected paths, improving bottom-reflected paths useful for seismic imaging. Moreover, this configuration is already proven to be a good solution for azimuth estimation when it's mounted on AUV [4] or for bottom characterization [5].

The objective of this report is to describe the data acquired with the DAVS system mounted on the MARES AUV, from INESC-TEC, Porto, during the REX'17 Sea trial. The REX'17 experiment was organized by the Portuguese Navy and was carried out in the area of Lisbon Naval Base (BNL), Alfeite, Portugal, between the 11th and the 13th of July 2017. CINTAL and INESC-TEC teams participated in this experiment, with the goal of evaluating the DAVS system mounted on the MARES AUV for:

- **platform self-localization** - the MARES, with the DAVS attached, navigates on the area near the source for self-localization;
- **bottom characterization** - the MARES navigates at constant depth near the surface and near the bottom to cover all the area around the source for seabed exploration;
- **port security** - the anchored DAVS collects passive signals for detection and follow intruders.

The report is organized as follows: Chapter 2 describes the setup of REX'17 experiment and the equipment used; Chapter 3 presents the experimental data analysis for several missions of the AUV trajectory, in terms of received and processed signals for the three proposed objectives and finally Chapter 4 draws conclusions of this experiment.

Chapter 2

REX'17 Experiment Setup

This chapter describes the REX'17 Sea trial setup where the location, the equipment used during the trial, the emitted signals and the CTD measurements will be presented. The REX'17 experiment was organized by the Portuguese Navy in collaboration with the Naval School, where the Naval Base of Alfeite facilities was made available for research operations. The CINTAL and INESC-TEC teams participated in REX'17 Sea trial to evaluate the DAVS behavior when mounted on an AUV, the MARES from INESC-TEC, Porto, for seabed exploration, bottom characterization and for intruders detection.

(a) (b)

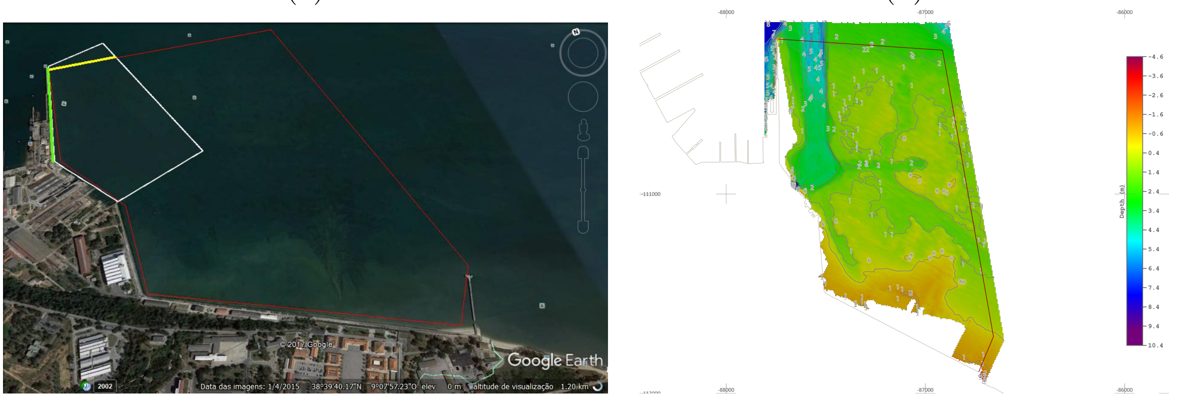

Figure 2.1: Satellite view of the test location area, in the channel area of the Naval Base of Alfeite, Lisbon, (white line) (a) and the bathymetry map of the satellite view (b). In figure (a), the length of the yellow line (channel width) is 270 m and the length of the green line (channel length) is 615 m.

2.1 Location

The operations were conducted in the channel area of the Naval Base of Lisbon (BNL), Alfeite, Lisbon, between 11th and 13th of July, 2017. Figure 2.1 (a) shows a satellite view of the area. The white line delimits the experimental area, while the yellow and the green lines represent the width and the length of the channel, approximately 270 m and 615 m, respectively. Figure 2.1 (b) shows the bathymetry of the experiment area (inside the red line), where the access channel (white line) has a variable water depth between 3.5 m and 10 m. The estimated tide height for the period of the tests varied from 0.75 m (low tide) to 3.60 m (high tide).

The experiment was divided in three events, being the Event 1 dedicated to platform self-localization, the Event 2 to bottom characterization and finally the Event 3 reserved to port security. In the two first events the DAVS was mounted beneath the AUV-MARES and a sound source was moored in a fixed position. The third event was dedicated to port security when the DAVS was moored in a fixed position, acquiring noise produced by boats and by MARES in the area. Figure 2.2 shows a satellite view of the test area where the location of the source and the DAVS on the three events were included. The point located on the pier was used as a reference (origin of the Cartesian coordinate system) to the several positions and trajectories of the MARES during the experiment. At the source location, is was estimated that the bathymetry varied approximately from 4.5 m to 6.5 m and the area for operations is mostly flat.

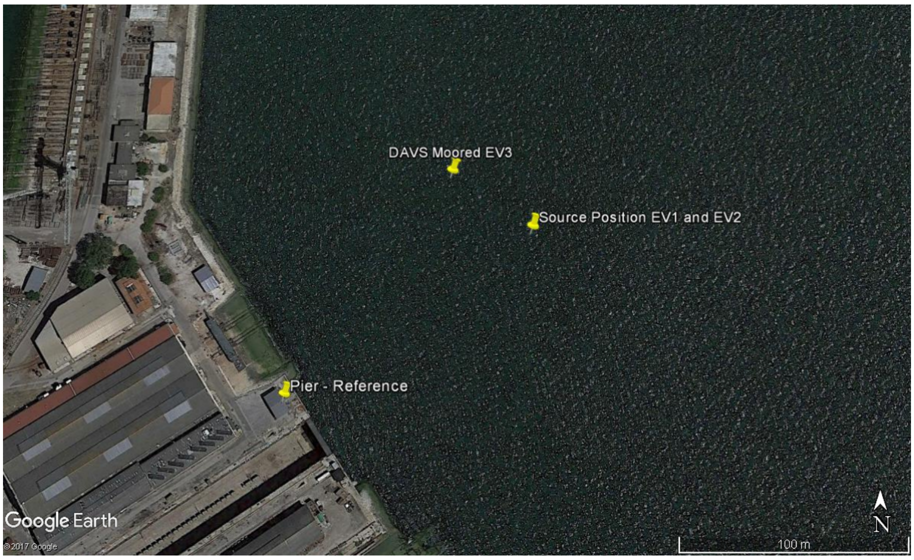

Figure 2.2: Satellite view of the test area where the location of the acoustic source during the events 1 and 2 and the DAVS location on the event 3, as well as the reference point located in the pier are included.

2.2 Equipment

The equipment used during the REX'7 experiment was:

- Dual Accelerometer Vector Sensor (DAVS) from CINTAL;
- MARES autonomous underwater vehicle from INESC-TEC;
- Long Baseline (LBL) positioning system from INESC-TEC;
- Lubell 916C acoustic source, including Minirator Pro for signal generation, PASU, for amplification and powering from CINTAL;
- RBR CTD from CINTAL;

- Patrol boat and two RHIB from CINAV.

Figure 2.3 shows some equipment used during the REX'17 experiment. It can be seen the Lubell 916C acoustic source used for signals transmission and the PASU in the yellow box for amplification and power supply in (a), the RHIB boat from CINAV used to help the operations in (b) and the AUV MARES with the DAVS mounted (c) and (d).

2.3 CTD measurements

The sound speed profiles taken in the area were obtained with the RBR concerto CTD. The RBR concerto CTD is a multiparameter probe made by RBR with built-in conductivity, temperature and depth sensors rated to a maximal depth of 200m. This version supports

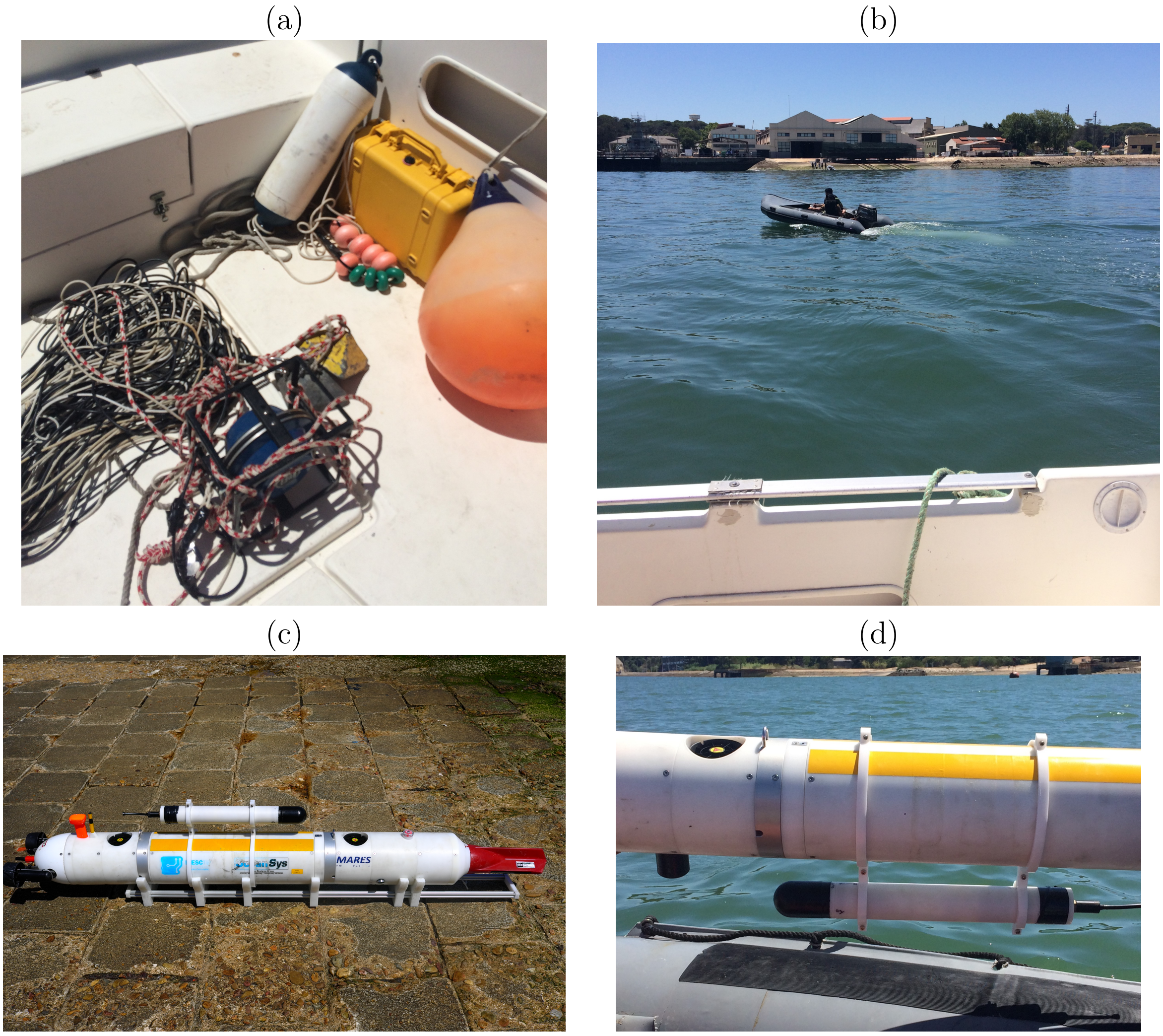

Figure 2.3: Some equipment used during the REX'17 sea trial. The Lubell 916C acoustic source and the PASU yellow box on the boat before deployment (a), the RHIB from CINAV to help the operations (b), the AUV MARES with the DAVS attached to it on the pier (c) and in position before deployment (d).

(a) (b)

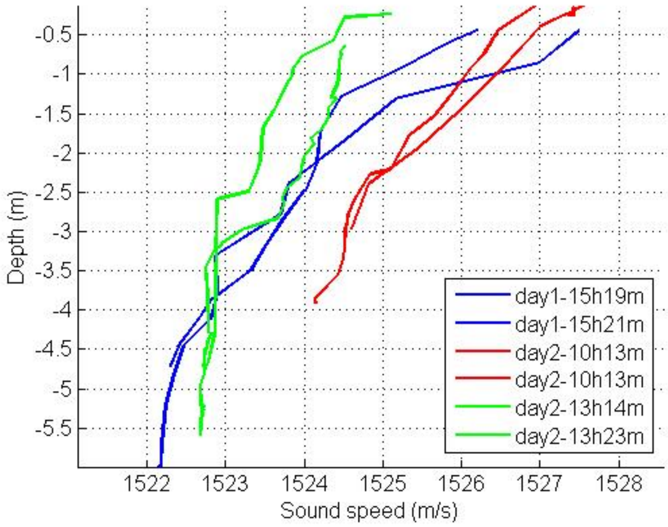

Figure 2.4: The RBR concerto CTD equipment (a) and the sound speed profiles taken in Alfeite area during the three days of the Rex'17 experiment (b).

moored and profiling configurations and is expanded with a dissolved oxygen sensor (Rinko Optode).

Several sound speed profiles taken in the area are shown in Figure 2.4 (b). As it can be seen, the velocities varied from 1527 m/s at the surface to 1522 m/s at 6 m depth, being around 1523 m/s at source depth (3.5 m). From morning (red lines) to afternoon (blue and green lines), the profiles show a negative shift of approximately 1.5 m/s.

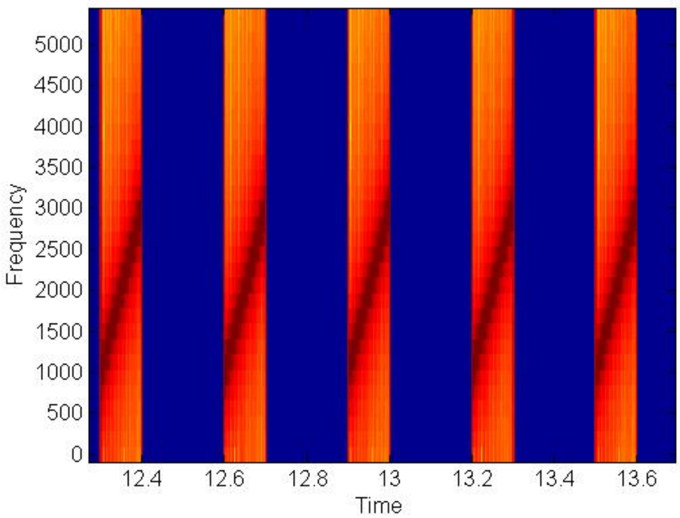

Figure 2.5: Spectrogram of the emitted signal. Each LFM has a time duration of 100 ms in the 1-3 kHz frequency band, followed by 200 ms of silence in a repeated sequence.

2.4 Emitted signals

The signals were emitted by the Lubell 916C source from CINTAL, deployed at 3 m from the bottom in a variable water depth (due to tide) of approximately 4.5 m to 6.5 m (source location in Figure 2.2). During the Event 1 and 2, the emitted signals were a sequence of Linear Frequency Modulated (LFM) in 1-3 kHz frequency band, with a time duration of 100 ms followed by 200 ms of silence. Figure 2.5 shows the spectrogram of the emitted signal where a sequence of 5 LFM can be observed.

Chapter 3

Experimental data analysis

This chapter presents the analysis and the discussion of the DAVS acquired data throughout three events. Event 1 was dedicated to DOA estimation; Event 2 encompassed bottom characterization and Event 3 was reserved for ambient noise estimation. The three events are related with the CINTAL objectives integrated in the REX'17 experiment: platform self-localization, bottom characterization and port security.

During Events 1 and 2, the DAVS was positioned beneath the MARES AUV such that the two accelerometers and the hydrophone were aligned with the vertical z-axis, being the #50 the shallowest accelerometer. The DAVS x-y plane is parallel to the experiment X-Y horizontal plane as shown in Figure 3.1 (a). The positive z-axis points upwards and the positive x-axis points to the sailing direction. In Event 3, the DAVS was moored whit the x-axis pointing to the surface and the horizontal plane is defined by the DAVS y-z plane seen in Figure 3.1 (b). The signals were sampled at 10547 Hz for Event 1 and 2, and at 52734 Hz for Event 3.

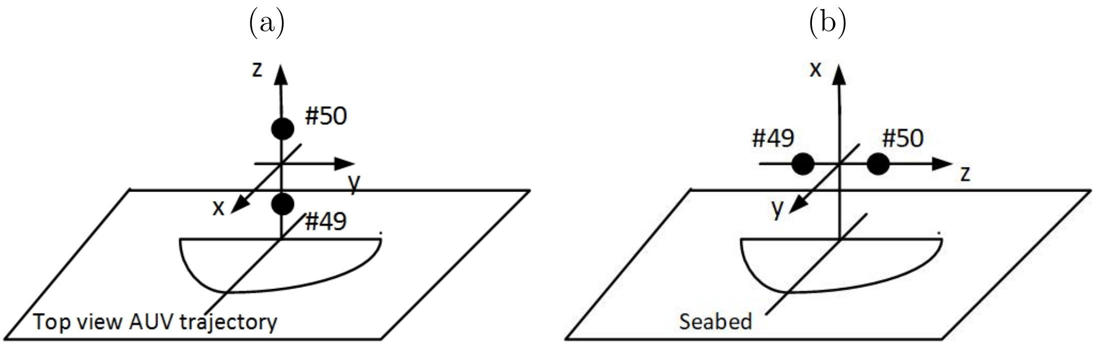

Figure 3.1: Drawing of the DAVS orientation for: Events 1 and 2 when DAVS was AUV mounted with X-Y plane (Top view of AUV trajectory) parallel to the DAVS x-y plane and the accelerometers were aligned with the vertical z-axis, being the #50th the shallowest one (a) and for Event 3 when DAVS was moored with x-axis pointing upward and the accelerometers were in the horizontal plane parallel to the DAVS y-z plane (b).

3.1 Event 1 - Platform self-localization

This event was dedicated to acquiring data for platform self-localization. Event 1 was divided in three missions, where MARES AUV executes several paths, navigating near the surface at constant depth to cover an area near the source, in order to estimate the azimuth angle for self-localization. Figure 3.2 presents in the left panels three missions performed by the MARES AUV in the morning of 12th of July (second day of REX'17 experiment) (a), (c) and (e), and on the right the respective depths (b), (d) and (f). The trajectories are divided by colors to relate with the acoustic data files and to simplify the data analysis. The red asterisk indicates the source location and the green asterisk shows the position of the pier used as reference to the MARES's position, corresponding to the origin of the Cartesian coordinate system. For each mission, the MARES's trajectory starts at position marked by ($\square$) and ends at position marked by ($\circ$). During the missions, the depth of the MARES was approximately constant at 1.2 m for the first two missions and 1.7 m for the third mission, as shown in Figure 3.2 (b), (d) and (f).

3.1.1 Mission 1

Figure 3.2 (a) and (b) refer to the trajectory and depth of the MARES between 10h32m12s and 10h38m51s of day 2. The red, yellow and green paths correspond to DAVS' files DATA0015.WAV to DATA0017.WAV, respectively.

Figure 3.3 (a) presents the spectrogram of the signal received on the pressure sensor of DAVS, for DATA0016.WAV (yellow path of plot 3.2 (a)). The thruster's noise can be clearly seen for frequencies bellow 1 kHz, out of the signal frequency band and the noise level increases at approximately 80 s, due to sharp curve in the yellow trajectory. Figure 3.3 (b) presents the particle velocity signal, in time, received on the accelerometers, considering top for # 49the and bottom for #50th element. The blue lines relate to x components and the red lines to y components for the total time duration of DATA0016.WAV (yellow path). In this plot, it can be observed between 80 s and 100 s that the amplitude of v_y signal component is reduced in relation to the amplitude of v_x component, due to the sharp turn on the yellow path. In this case, the MARES is approaching the source in a zero azimuth direction and then the azimuth value rises, increasing, as expected, the amplitude of v_y signal component.

The results of the azimuth estimation for Mission 1 are presented in Figure 3.4. The blue and red dots are the result of the DOA estimation considering the combination of the pressure with the particle velocity components using #49 and #50 outputs, respectively. These results are very close to the green dots, which were obtained from the Heading DAVS' compass data. The sequence of paths along the trajectory can be observed with an increase of 100° at the begin of red path up to 0° and remains constant until the end of red path. In the yellow path, the results start with an increase of 100° and at 200 s (after 80 s of File DATA0016.WAV) the azimuth goes to 0°, corresponding to the sharp curve and then the angle increases up to 100°. After that, the azimuth angle decreases almost 180°, corresponding to the rotation at the start of green path and remains negative, as it can be seen by the green trajectory of Figure 3.2 (a). The offset verified between the azimuth results from the acoustic data (blue and red dots) and the Heading DAVS' compass data (green dots) could be due to the fact that MARES AUVcomes to the surface whenever there is a curve in the trajectory, which in this case appears at 200 s (yellow path) and at the begin of green track, as shown in Figure 3.2 (b), producing the variability of these data.

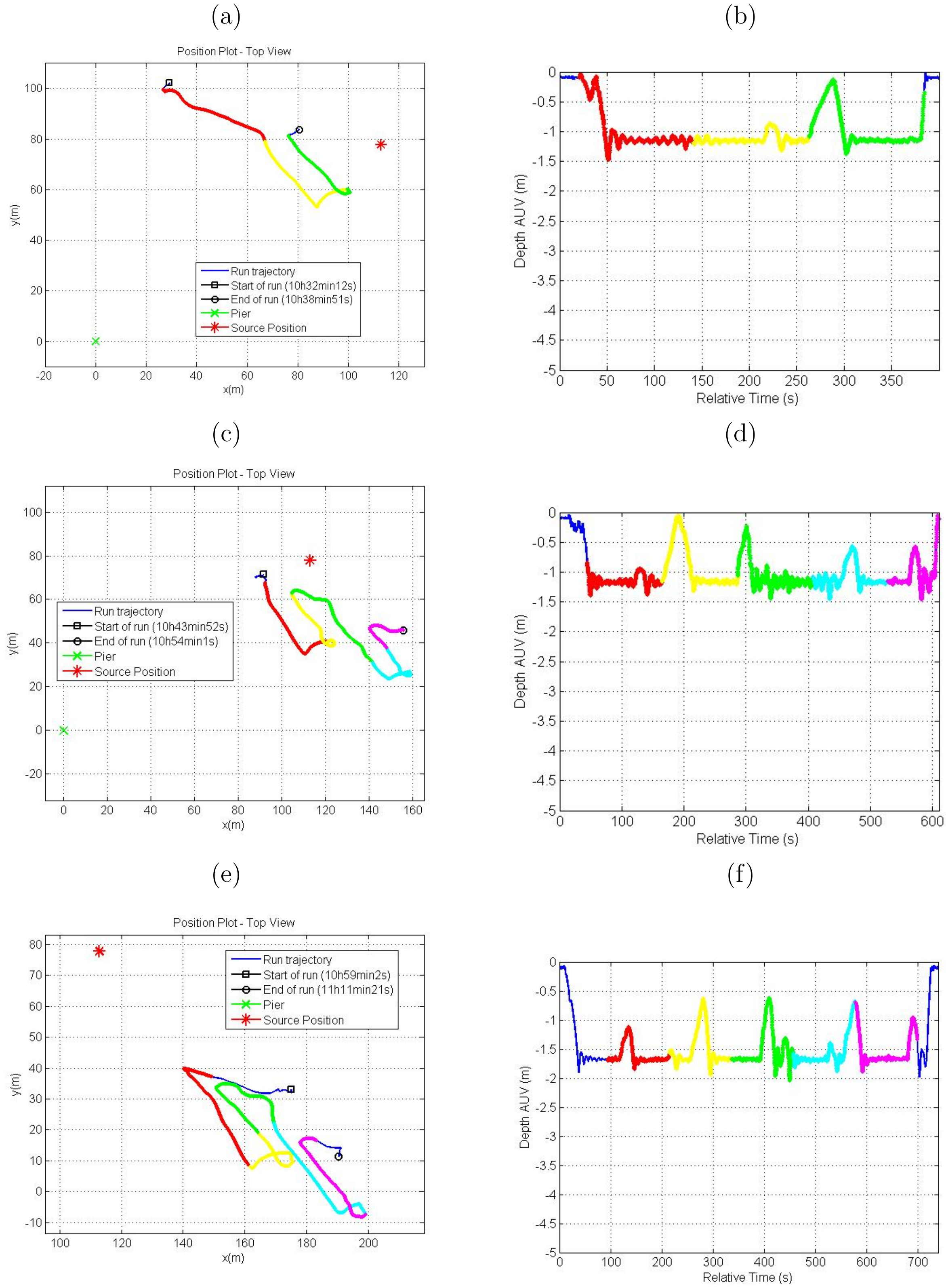

Figure 3.2: Top view of MARES trajectory relatively to the pier position at the origin of the coordinate system, marked by green asterisk and the source position marked by red asterisk for: mission 1 (a), mission 2 (c) and mission 3 (e). The corresponding depth position of the MARES for: mission 1 (b), mission 2 (d) and mission 3 (f)

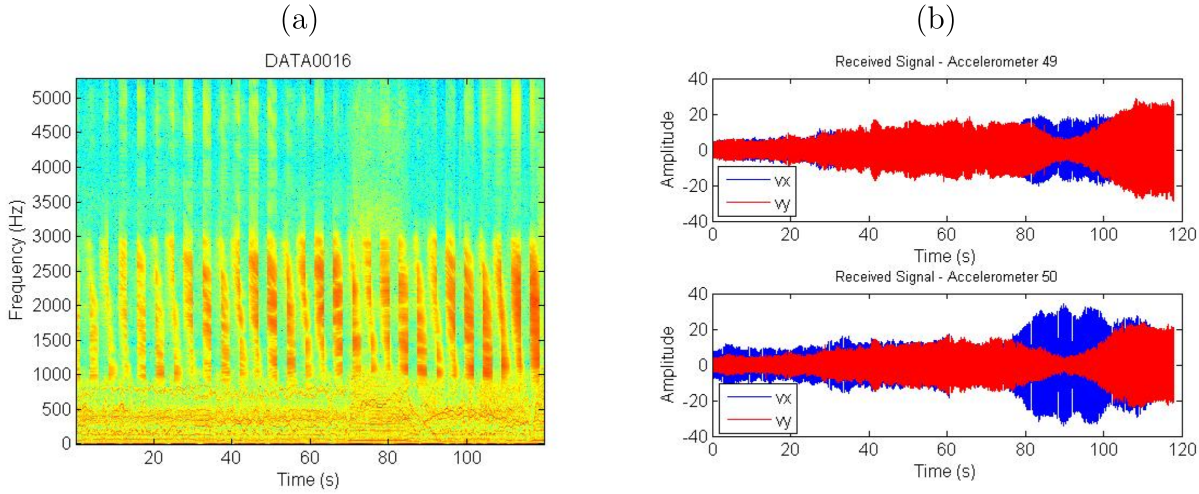

Figure 3.3: Spectrogram of the received signal on the pressure sensor of DAVS (a) and the particle velocity time signal received on the accelerometers (b), considering top for # 49 and bottom for #50 element, blue lines for x components and red lines for y components, for the total time duration of DATA0016.WAV.

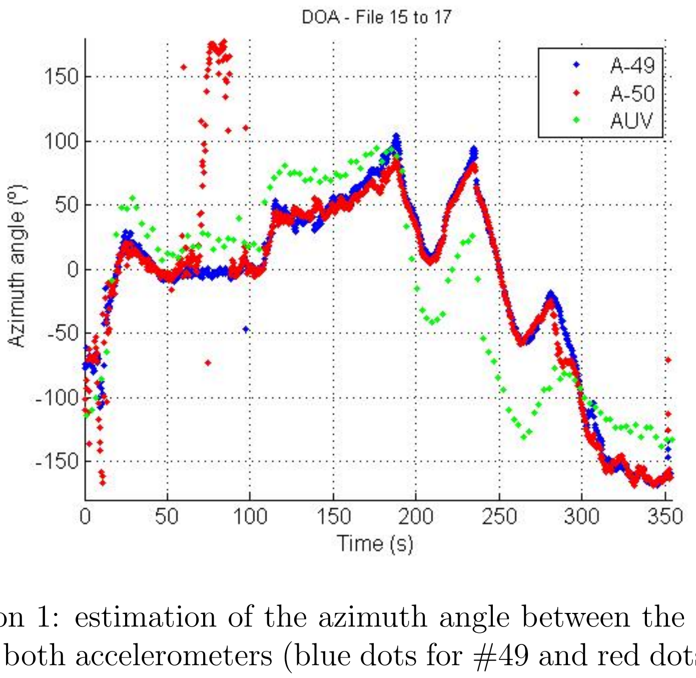

Figure 3.4: Mission 1: estimation of the azimuth angle between the source and the MARES obtained for both accelerometers (blue dots for #49 and red dots for #50) combined with the heading angle from the DAVS' compass data (green dots) for the total duration of files DATA0015.WAV to DATA0017.WAV.

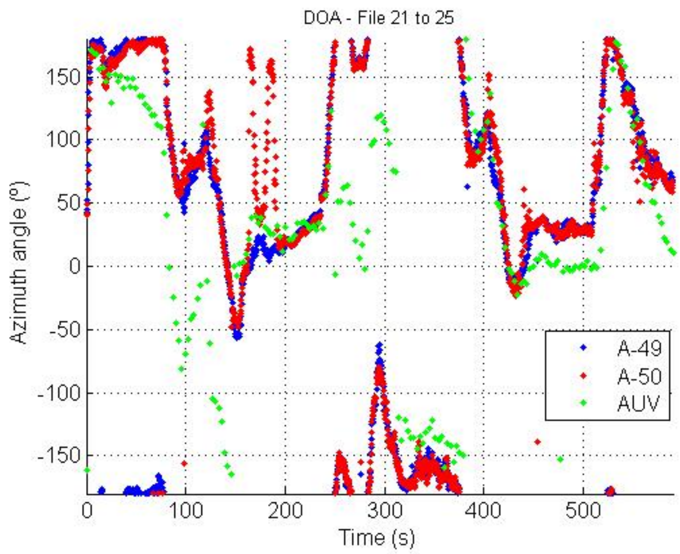

Figure 3.5: Mission 2: estimation of the azimuth angle between the source and the MARES obtained for both accelerometers (blue dots for #49 and red dots for #50) combined with the heading angle from the DAVS' compass data (green dots) for the total duration of files DATA0021.WAV to DATA0025.WAV.

3.1.2 Mission 2

Figure 3.2 (c) and (d) refer to the trajectory and depth of the MARES between 10h43m52s and 10h54m01s of day 2, respectively. The red, yellow, green, cyan and magenta paths correspond to DAVS' files DATA0021.WAV to DATA0025.WAV, respectively. As it can be seen, this mission is a more complex trajectory than the previous one, with several turns on the trajectory. Comparing the depth (plot (d)) and respective trajectories (plot (c)), whenever the MARES makes a tight curve it comes to the surface.

The result of azimuth estimation for mission 2 is presented in Figure 3.5. As observed, the azimuth estimation from both accelerometers (blue dots for #49 and red dots for #50) are inline and compare favourably with the green dots (from Heading DAVS' compass data) with exception when the MARES is coming to the surface. The results are also in line with the trajectory observed in Figure 3.2 (c)

3.1.3 Mission 3

Figure 3.2 (e) and (f) refer to the trajectory and depth of the MARES between 10h59m02s and 11h11m21s of day 2. The red, yellow, green, cyan and magenta path correspond to DAVS' files DATA0029.WAV to DATA0033.WAV, respectively.

The result of azimuth estimation for mission 3 are presented in Figure 3.6 and the plot shows again a high variability on the results due to the complex trajectory and several surfacing maneuvers of the AUV. Comparing the depth (plot (d)) and these trajectories (plot (c)), whenever the MARES makes a tight curve it comes to the surface, causing differences between the azimuth estimation results, blue dots for #49 and red dots for #50, and the green dots from Heading DAVS' data. The various turns on the trajectory, Figure 3.2 (e) are perfectly estimated by the DAVS, as it can be seen from the results in Figure 3.6. For example, the sharp turn of almost 270° in the yellow path of Figure 3.2

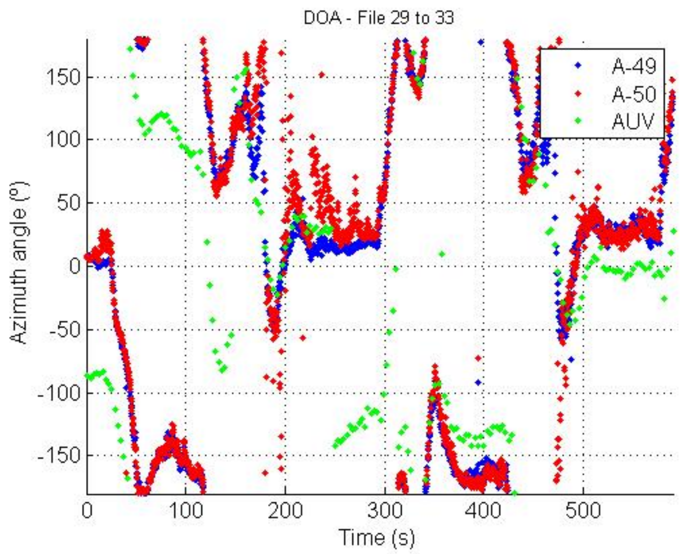

Figure 3.6: Mission 3: estimation of the azimuth angle between the source and the MARES obtained for both accelerometers (blue dots for #49 and red dots for #50) combined with the heading angle from the DAVS' data (green dots) for the total duration of files DATA0029.WAV to DATA0033.WAV.

(e) is estimated between the 120 s and 220 s of Figure 3.6, finishing with an azimuth of almost 0°, between 220 s and 300 s, when the MARES is approaching the source (the end of yellow path and the begin of green path).

3.2 Event 2 - Bottom characterization

The purpose of the dual accelerometer configuration in the DAVS system is for multi-path discrimination. Combining the particle velocity with the pressure or with the particle velocity gradient, the bottom-reflected paths are improved in contrast with the attenuation of the direct path. The theory and the equations which combines the vertical particle velocity with the pressure or with the particle velocity gradient were presented in [2] and preliminary results of the usage of DAVS for bottom characterization were presented in [4] and [5].

The Event 2 of the REX'17 experiment was dedicated to bottom characterization, where part of the MARES trajectories presented in Figure 3.2 were used for this objective. The arrival patterns (pressure equivalent in dB re to 1 μPa) for two missions of MARES: the first 60 s of yellow path of mission 1 are presented in Figure 3.7 and the last 80 s of yellow path of mission 2 are shown in Figure 3.8, considering the pressure only (a), the combination of pressure with the vertical particle velocity (b), the combination of particle velocity with the particle velocity gradient (c) and slice for one instant of time of both missions considering those combinations, blue, green and red respectively (d). The advantage of using the combination of particle velocity and particle velocity gradient over the pressure only can be seen in both figures as follows: 1) in the pressure only plot (a), the dominant path is the direct path and the others paths (mainly the bottom-reflected paths which are more interesting for bottom characterization) are less clearly observed, 2) the combination of pressure with the particle velocity plot (b) attenuates the direct path and 3) in the combination of particle velocity and particle velocity gradient plot (c), the bottom-reflected paths are much more clearly observed in contrast with direct path attenuation. The direct path attenuation is visible in plot (d), where a slice for one instant of time for both missions is considered. The combination of particle velocity and particle velocity gradient (red line) attenuates the direct path in around 80%, improving the bottom-reflected paths.

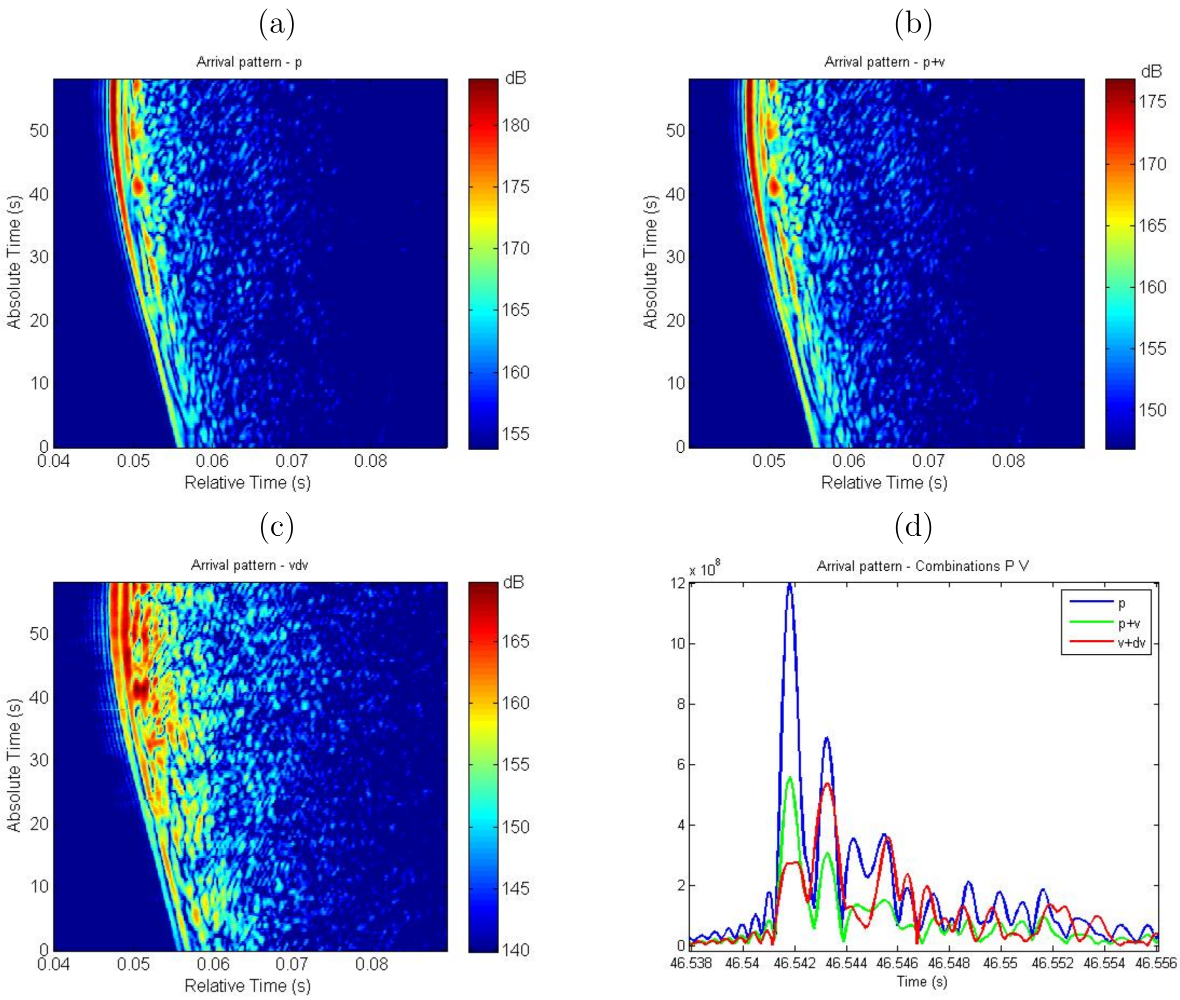

Figure 3.7: Event 2 bottom characterization, mission 1: Arrival patterns in the time interval of the first 60 s of yellow path (File DATA0016.WAV) of Figure 3.2 (a), where the azimuth and the depth are approximately constant considering the pressure only (a), the combination of pressure with the vertical particle velocity (b) and the combination of the vertical particle velocity with the particle velocity gradient (c). Slice for one instant of time: considering the pressure only (blue line), the combination of pressure with the vertical particle velocity (green line) and the combination of the particle velocity with the particle velocity gradient (red line) (d).

3.3 Event 3 - Port security

The objective of the third event, on 13th of July, was to estimate the DOA of noise of sources of opportunity applied to the detection and tracking of intruders. For this purpose the DAVS was moored at position N38° 39.936 and W9° 8.377 and ≈2.5 m depth,

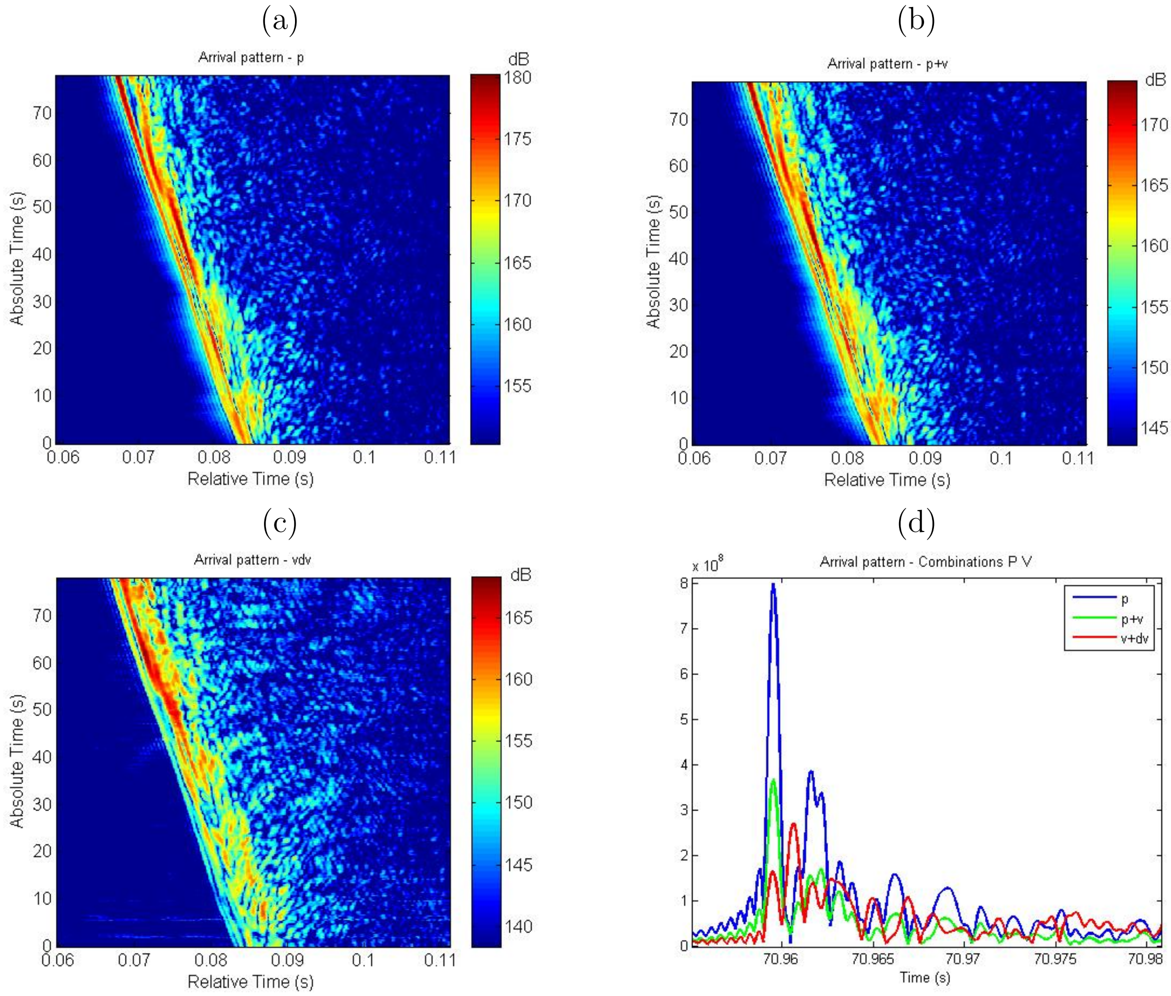

Figure 3.8: Event 2 bottom characterization, mission 2: Arrival patterns in the time interval of the last 80 s of yellow path (File DATA0022.WAV) of Figure 3.2 (c), where the azimuth and the depth are approximately constant, and the MARES is approaching the source, considering the pressure only (a), the combination of pressure with the vertical particle velocity (b) and the combination of the vertical particle velocity with the particle velocity gradient (c). Slice for one instant of time: considering the pressure only (blue line), the combination of pressure with the vertical particle velocity (green line) and the combination of the particle velocity with the particle velocity gradient (red line) (d).

Figure 2.2, and acquired ambient noise due to various nearby boats and also the MARES AUV. In Event 3, the DAVS accelerometers and the hydrophone were aligned in the horizontal plane, being this plane defined by y-z accelerometers' components and the x-axis component is pointing upward, as shown in Figure 3.1 (b).

Figure 3.9 shows a satellite view of the test area with two runs of a boat passing near the DAVS moored location and finishing the run over it, corresponding to files DATA_TP1_0215_194093520.wav and DATA_TP1_0215_194093720.wav, respectively (a) and (b).

Figure 3.10 shows the spectrogram of the received signal on the pressure sensor of DAVS from noise produced by the boat passing over the DAVS location (a) and the particle velocity time signal received on the accelerometers (b), considering top for #49

(a) (b)

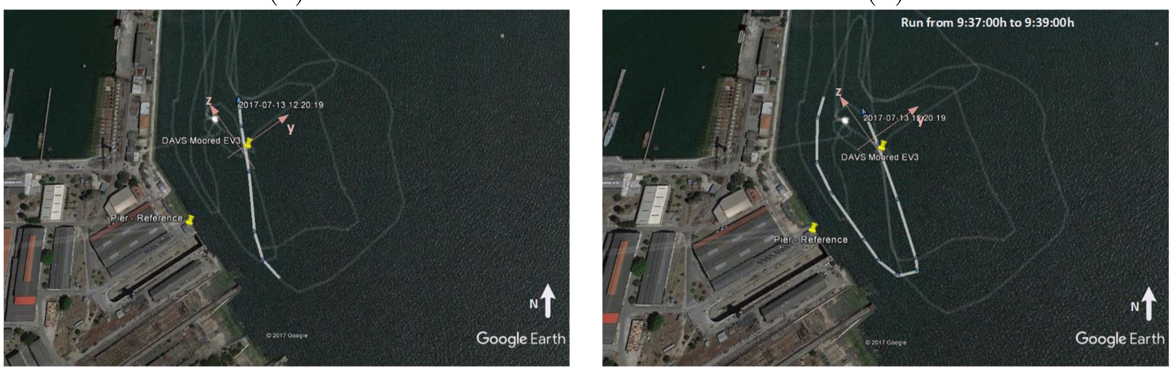

Figure 3.9: Satellite view of the test area with the position of the DAVS moored with two boat's runs near the DAVS (a) and (b).

and bottom for #50 element, blue lines for x components, red lines for y components and green lines for z components, for part of time of File DATA_TP1_0215_194093520.wav, when the signal is detected. It can be seen that when the boat is over the location of the DAVS, the x components (blue line) have the highest amplitude due to this axis is point to the surface.

(a) (b)

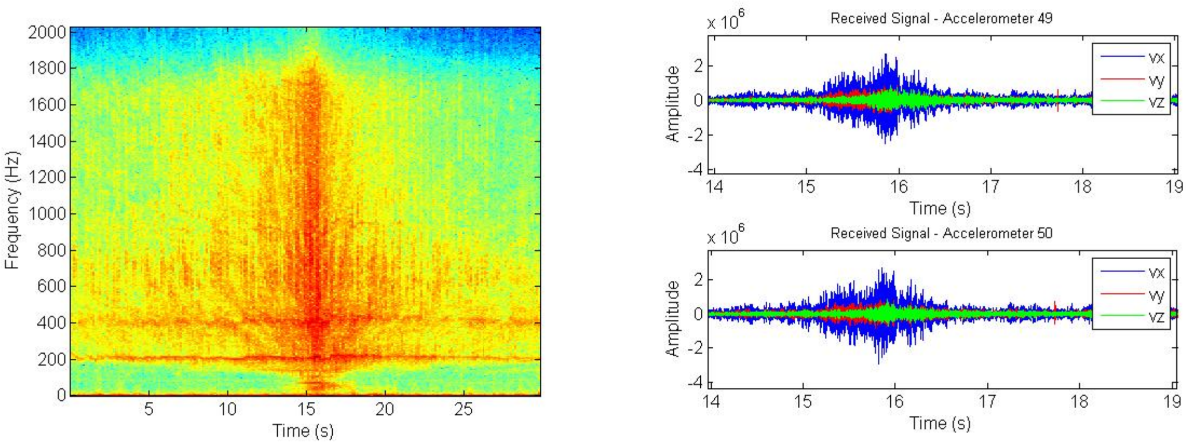

Figure 3.10: Event 3: spectrogram of the received signal on the pressure sensor of DAVS (a) and the particle velocity time signal received on the accelerometers (b), considering top for #49 and bottom for #50 element, blue lines for x components, red lines for y components and green lines for z components, for part of time duration of File DATA_TP1_0215_194093520.wav, when the signal is detected.

Figure 3.11 shows the respective estimation of the azimuth angle for the runs presented in Figure 3.9, respectively. The results are almost inline with the inserted y and z components orientation on Figure 3.9 taking into account that the heading of the DAVS compass marked 330° (z component was assumed the origin). The results in the second run have more variability than the first one but, it can be seen comparing the 30 s of plot (a) with the results between 80 s and 120 s of plot (b), that when the boat is passing over the DAVS location, the same transition from negative to positive angles, passing through zero, are the same for both plots.

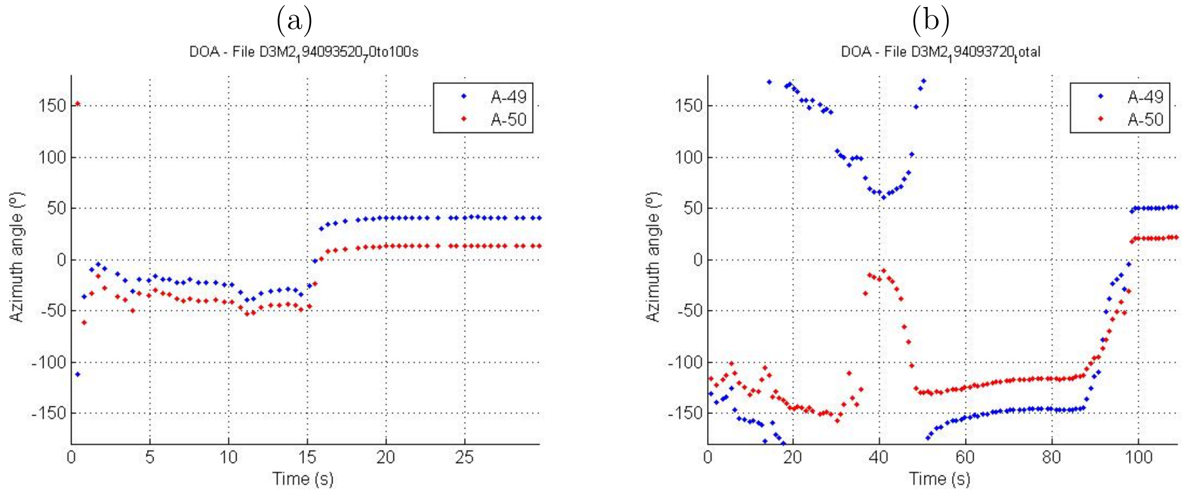

Figure 3.11: The estimation of the azimuth angle for the noise produced by the boat passing near the DAVS for the runs of Figure 3.9 on day 13th of July, (a) and (b) respectively. These estimation were obtained for both accelerometers (blue dots for #49 and red dots for #50) for 30 s of File DATA_TP1_0215_194093520.wav (a) and for total duration of File DATA_TP1_0215_194093720.wav (b).

Figure 3.12 (a) shows the spectrogram of the received signal on the pressure sensor of DAVS, filtered in the band 1 kHz to 1.6 kHz, from the noise produced by a Catamaran passing south of the DAVS position when the signal is detected and (b) presents the correspondent azimuth estimation, for part of time duration of File DATA_TP1_0215_194105520.wav. The results are coherent with the DAVS orientation and the trajectory of the Catamaran.

After 10h57min18s of day 3, the MARES AUV starts a run in the area where the DAVS was moored. The data files when the noise signal produced by MARES AUV is detected start at DATA_TP1_0215_194105920.wav and end at DATA_TP1_0215_194113020.wav. The spectrogram of the received signal on the pressure sensor of DAVS from the noise produced by MARES for file DATA_TP1_0215_194105920.wav is presented in Figure 3.13. This signal has a very low SNR and it required to filter twice with a band pass filter first in the band of 180 Hz to 600 Hz, Figure 3.13 (a), and then for three frequencies band 275 Hz to 295 Hz; 375 Hz to 395 Hz and 565 Hz to 585 Hz, as shown in Figure 3.13 (b). Then the data was processed in order to determine the azimuth for this signal.

Figure 3.14 (a) shows the trajectory of the MARES for day 3 (13th July) in the morning which starts at 10h57min18s and ends at 11h30min27s. The red asterisk indicates the DAVS moored position (with the horizontal axes y and z-components on the inserted) and the green asterisk shows the position of the pier used to reference the MARES's position, corresponding to the origin of the Cartesian coordinate system. The MARES's trajectory starts at position marked by (□) and ends at position marked by (○). During this mission, the depth of the MARES was approximately constant at 2 m except when the MARES AUV makes turns, when it surfaces, as shown in Figure 3.14 (b). The azimuth estimates obtained for the red path (included on plot (a) and (b)) are shown in Figure 3.14 (c) and the results are in line with this trajectory. More work is necessary for this event and for this trajectory.

(a) (b)

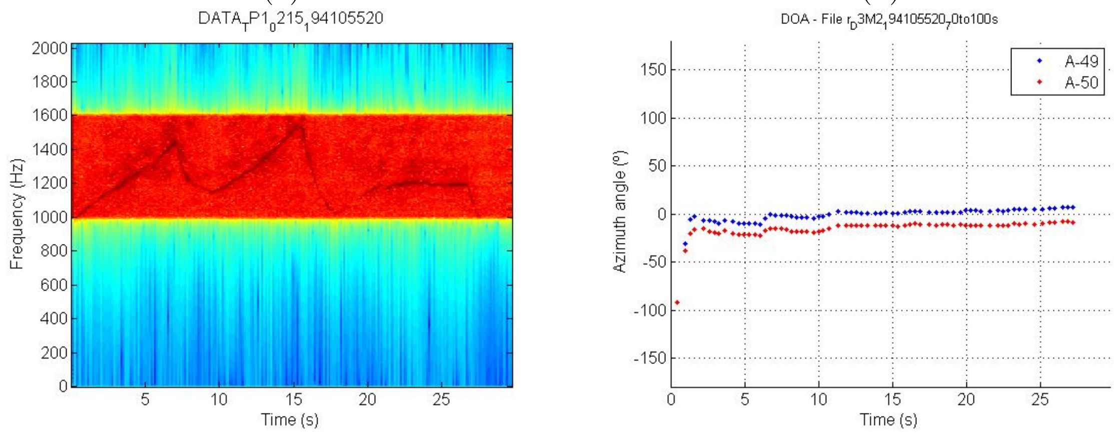

Figure 3.12: Event 3 Catamaran detection: spectrogram of the received signal on the pressure sensor of DAVS from the noise produced by a Catamaran passing south of the DAVS position (a) and the respective estimation of the azimuth angle when the signal is detected (b) for part of time duration of File DATA_TP1_0215_194105520.wav.

(a) (b)

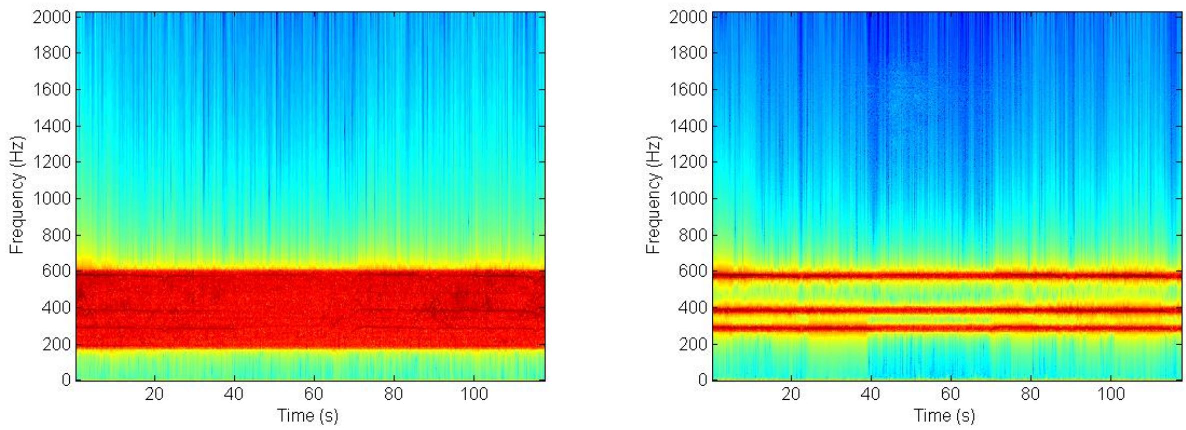

Figure 3.13: Event 3 MARES AUV detection: spectrogram of the received signal on the pressure sensor of DAVS from the noise produced by MARES for File DATA_TP1_0215_194105920.wav filtered in the band of 180 Hz to 600 Hz (a) and with another filter for three frequencies of interest (b).

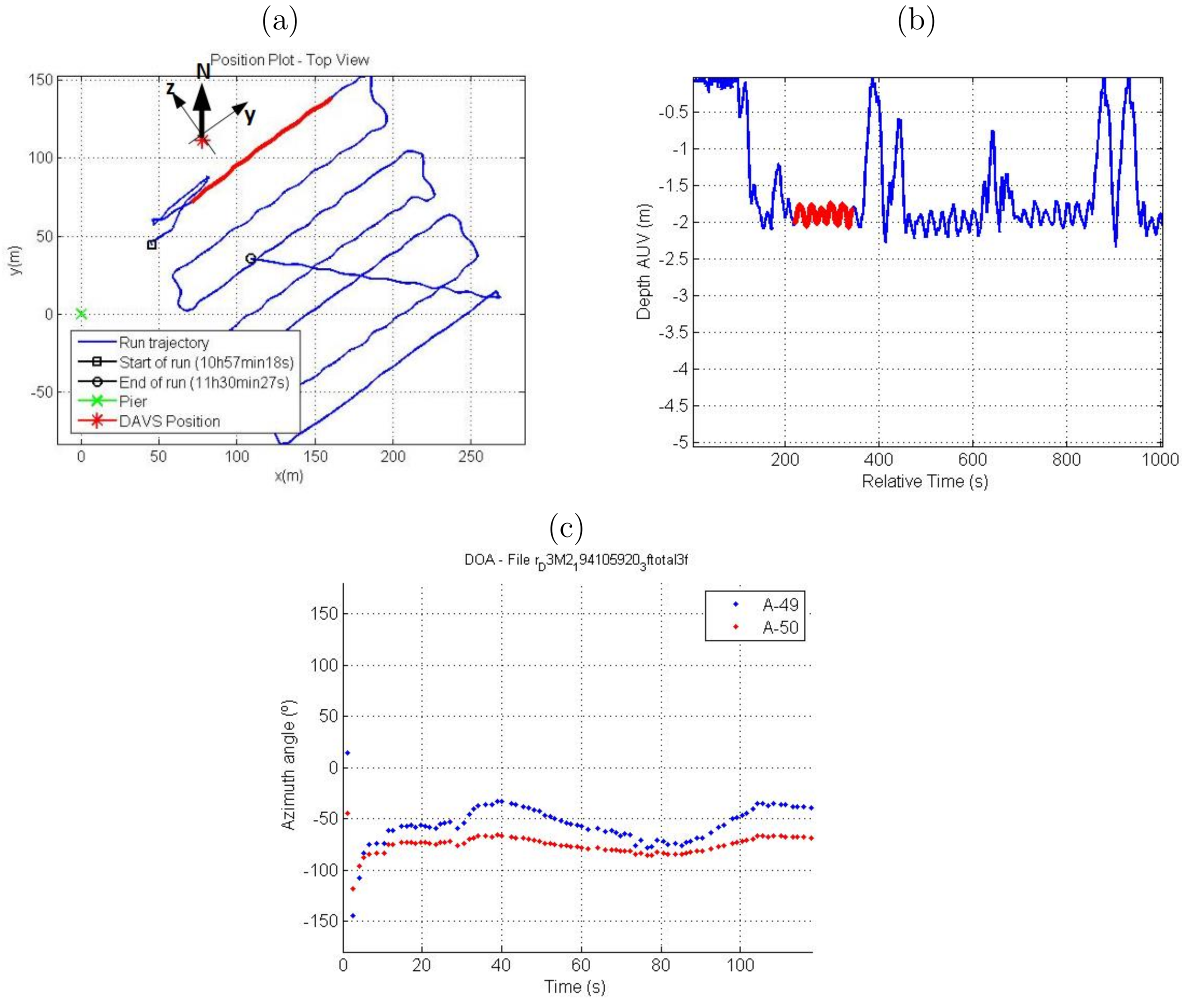

Figure 3.14: Event 3 MARES AUV detection:Top view of MARES trajectory relatively to the pier position at the origin of coordinate system, marked by green asterisk and the DAVS moored position marked by red asterisk for day 3 (a), the corresponding depth position of the MARES (b) and the azimuth estimation for the path marked by red line on the trajectory (c). These data correspond to the File DATA_TP1_0215_194105920.wav.

Chapter 4

Conclusion

This report describes the REX 2017 experiment and the data acquired by the Dual Accelerometer Vector Sensor (DAVS) mounted in the MARES AUV from INESC-TEC, Porto. This experiment had three objectives: Event 1 - platform self-localization, Event 2 - bottom characterization and Event 3 - port security. These objectives were attained. In the first two events the DAVS was mounted beneath the MARES acquiring signals emitted by an acoustic source and in the third event the DAVS was moored at 2.5 m depth acquiring noise produced by boats and by MARES AUV navigating in the surrounding area.

The evaluation of the DAVS directivity in motion was achieved when the DAVS was mounted on the MARES, while signals in the 1-3kHz band were emitted by the Lubell source deployed at 3.0m depth from bottom. The experimental results on the estimation of azimuthal directions for different types of AUV missions were analyzed and these estimates are very stable and equal for both accelerometers and compare favorably with the heading data extracted from the DAVS compass. In this experiment the results for DOA are stable concluding that the container doesn't shadow the acoustic sensing part.

The concept of the dual accelerometer configuration was validated for bottom characterization, showing the advantages of using the combination of particle velocity with particle velocity gradient when compared with the pressure only. This combination is useful for the direct and surface-reflected path attenuation in contrast with the improvements verified on bottom-reflected paths from the received waveforms. The effectiveness of the DAVS system and the use of particle velocity information for bottom characterization are the subject of ongoing research work.

For the third objective of this experiment, the DAVS was moored, acquiring noise signals produced by boats and by MARES in order to estimate the DOA for detection and following "the intruders". It was shown three types of signals in different frequency bands and the azimuth estimation results are coherent with the known trajectories. In this case, the azimuth estimation is difficult to achieve, since the SNR is low and the characteristics of the signals are unknown. More work is necessary on this topic.

Bibliography

[1] A. Mantouka, P. Felisberto, P. Santos, F. Zabel, M. Saleiro, S. M. Jesus, and L. Sebastião. Development and testing of a dual accelerometer vector sensor for auv acoustic surveys. *Sensors*, 17(1328):1–12, 2017.

[2] P. Felisberto, P. Santos, D. Maslov, and S. M. Jesus. Combining pressure and particle velocity sensors for seismic processing. In *Proc. MTS/IEEE/OES Oceans'16*, Monterey, USA, September 2016.

[3] P. Santos P. Felisberto and S. M. Jesus. Acoustic pressure and particle velocity for spatial filtering of bottom arrivals. *submitted to IEEE Journal of Oceanic Engineering*, 2017.

[4] P. Santos, P. Felisberto, F. Zabel, S. M. Jesus, and L. Sebastião. Dual accelerometer vector sensor mounted on an auv - experimental results. In *Proceedings of Meetings on Acoustics (POMA)*, volume 30, page 0055011. Acoustical Society of America, 2017.

[5] P. Santos, P. Felisberto, F. Zabel, S. M. Jesus, and L. Sebastião. Testing of the dual accelerometer vector sensor mounted on an autonomous underwater vehicle. In *Proceedings of 4th International Underwater Acoustics Conference and Exhibition.* UACE'17, September 3–8 2017.

Appendix

Document all the files of DAVS and the AUV data.