LOW-FREQUENCY PASSIVE ACOUSTIC SURVEILLANCE WITH DIRECTIONAL SENSORS

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Abstract: *Underwater monitoring has an important role in many civilian and defence applications, ranging from stopping smugglers and illegal immigration to anti-submarine warfare and protection of high value assets.*
Underwater monitoring is typically performed with passive acoustics using large antenna of hydrophones that cannot be towed by small autonomous vehicles. However, recent advances in sensor technology allowed the use of acoustic vector sensors that can be installed even on small unmanned vehicles or small bottom sensor stations.
This opens the possibility to perform long-term monitoring of a sea area using networks of mobile, smart and long-endurance platforms and allowing portability, flexibility and re-configurability of the network.
The present activity extends the previous work by integrating in a Slocum glider an acoustic vector sensor able to provide directionality in the band few Hertz up to some kilohertz, despite its limited size. The glider has been equipped also with an acoustic modem to share in real time its detections during the underwater missions, without need of surfacing. The paper provides a detailed analysis of the system and of the processing chain, along with at-sea results.

Keywords: *Acoustic Vector Sensor, Buoyancy Glider, Passive Acoustic Monitoring*

1. INTRODUCTION

Underwater monitoring has an important role in many civilian and defence applications, ranging from stopping smugglers and illegal immigration to anti-submarine warfare and protection of high value assets.

Underwater monitoring is typically performed with passive acoustics using large antenna of hydrophones that cannot be towed by small autonomous vehicles. However, recent advances in sensor technology allowed the use of acoustic vector sensors that can be installed even in small unmanned vehicles or bottom nodes [1].

This opens the possibility to perform long-term monitoring of a sea area using networks of mobile, smart and long-endurance platforms and allowing portability, flexibility and re-configurability of the network.

In the latest decade, the Centre for Maritime Research and Experimentation (CMRE) has been developing a heterogeneous, robotic autonomous network for underwater surveillance applications [1] -[6]. By the term “heterogeneous” we mean that mobile nodes work in cooperation with fixed nodes. Fixed nodes can guarantee monitoring at fixed locations, but for extended periods. The mobile robots can exploit motion to improve the mission performance.

The CMRE passive sonar network consists of two bottom nodes with Acoustic Vector Sensors (AVS), two gliders equipped with AVSs, one wave glider towing an array of AVSs and two Autonomous Underwater Vehicles (AUV) towing linear arrays of hydrophones, plus a certain number of communication gateway buoys, either moored or implemented with wave gliders.

Fig. 1 shows the assets of the network equipped with acoustic vector sensors.

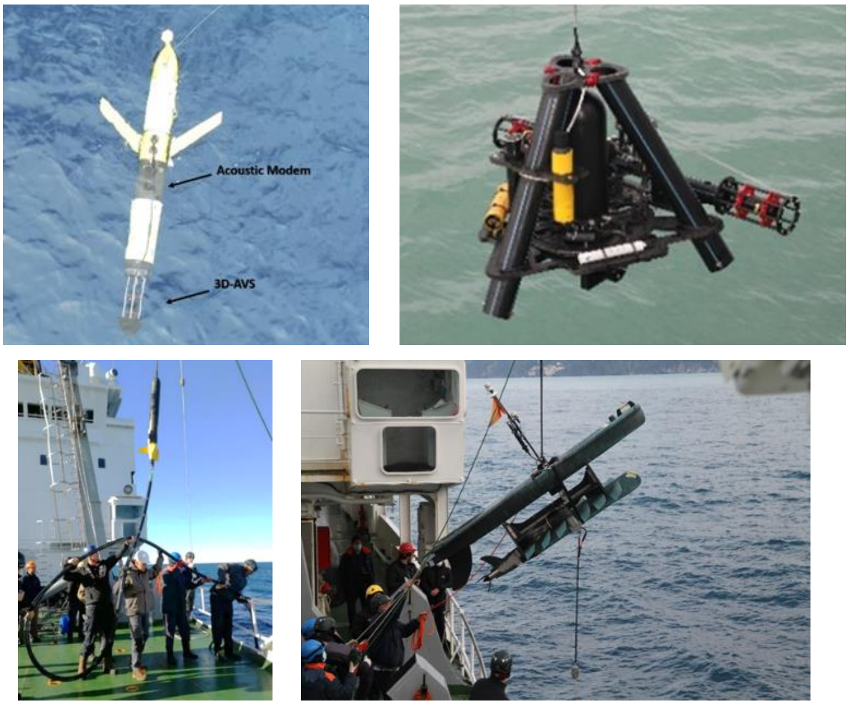

Fig. 1 – Assets of CMRE passive sonar network equipped with acoustic vector sensors, namely buoyancy gliders, bottom nodes and wave glider towing an array of AVSs.

2. BUOYANCY GLIDER EQUIPPED WITH AVS

This paper shows the results obtained with a buoyancy glider.

Two Teledyne Slocum buoyancy gliders were equipped with one three-dimensional acoustic vector sensor (AVS) and with a CMRE Acoustic Payload composed of CPU, A/D, NtpServer and a mid-frequency modem. The modem was used to send broadcast acoustic messages containing maximum 15 detection, each characterized by timestamp, frequency, azimuth and elevation. Commands, controls and health status between the buoyancy gliders and the C2 station are exchanged with separate radio links (Iridium satellite or Freewave) when the glider is on the sea surface.

Fig. 2- Buoyancy gliders equipped with AVS.

3. REAL-TIME PROCESSING OF ACOUSTIC DATA

Recent works [1] -[6] demonstrated that an underwater glider can detect and produce accurate Direction of Arrival (DOA) of low noise sources when equipped with AVSs.

Unlike scalar pressure sensors, AVSs are able to measure both the acoustic pressure and the Cartesian components of the particle velocity by using one omnidirectional pressure sensor and three (or two) orthogonally co-located directional sensors.

Compared with a conventional pressure sensors array, AVSs have the advantage of being small and light-weight. Moreover, they provide directionality with a constant beampattern across a wide frequency band, from few Hertz up to some kilohertz.

Hence, AVSs are more attractive than conventional pressure sensor array for installation on small UUVs, especially when working at low frequencies. For more details we refer the reader to [1]-[6].

Fig. 3 shows the block diagram of the AVS receiver running in R/T on board the glider.

The receiver processes the three dimensional intensity vector measured in the time-frequency domain. The intensity vector is related to the parallel components of pressure and particle velocity and corresponds to the local net transport of sound energy.

In polar representation, each time-frequency point of the intensity vector is a 3D vector pointing at the DOA of the noise source.

The modulus is normalized for target detection in the time-frequency domain. To enable target detection firstly the modulus of the intensity vector is normalized in the time-frequency domain. Then the clustering algorithm groups and labels neighboring time frequency bins that show a stationary or slowly varying frequency-azimuth curve over time. All the bins that do not belong to a cluster are rejected.

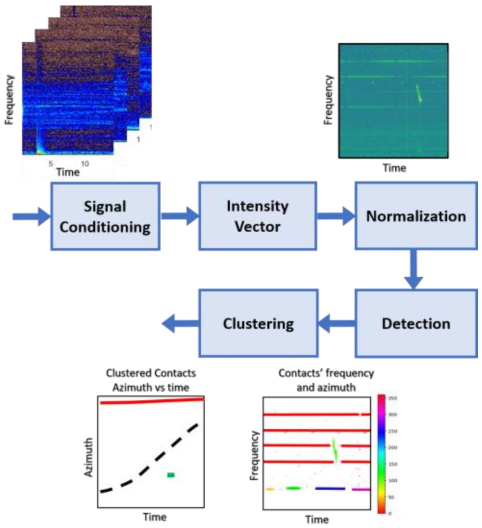

Fig. 3 – Block diagram of the AVS receiver for the detection of multiple narrow-band tones exploiting the time-frequency representation of intensity vector.

4. RESULTS AND CONCLUSIONS

Fig. 4 shows the geometry of the experiment described in this section. In this 15 minutes run, the Craken workboat turned clockwise around the glider at a short distance ranging from 100 to 500 m, at a speed of 5 to 6 knots. The consequence is an important azimuth variation rate, up to 30 deg/minute, and a very high Signal-to-Noise Ratio (SNR). During this run, several sources of low SNR radiated noise were also present in the vicinity of the glider, as shown in the zoom-out picture in Fig. 5.

Fig. 6 shows the azigram of the detected signals in the time-frequency domain. The colour indicates their azimuth in degrees, positive clockwise from North.

The signal from Cracken is the 50 Hz tone with its harmonics. The colour of these frequencies is constantly changing because the target is rotating around the glider. In the azigram there also several detection from other ships of opportunity in the area.

Fig. 6 also shows the output of the detection and clustering algorithm. A summary of the detection performance in terms of time on target (percentage of time a target has been detected during the run) is given in Table 1.

The association between the detections and the noise sources is based on the AIS data.

A total of 12 ships transmitted their positions in a 30x30 km^2 area around the glider. Their positions are reported in Fig. 5 along with their distances from the glider.

The ships detected by the processing chain are plotted in coloured lines, while the missed detections are plotted in black dashed lines. All the black trajectories belong to 15 to 20 m long fishing boats, having speeds slower than 3 knots. The detected ships are 4 fishing boats and one pleasure craft. The distance of the detected sources is up to 25 km.

There are also three detected targets that cannot be linked with AIS data. In coastal areas like this, such a situation can often occur due to the presence of small pleasure-boats for which AIS reporting is not mandatory. Instead, in high-seas, where all big ships have to report their positions, this is the typical kind of situation that could interest authorities, as it could correspond to a ship hiding its position during illegal activities.

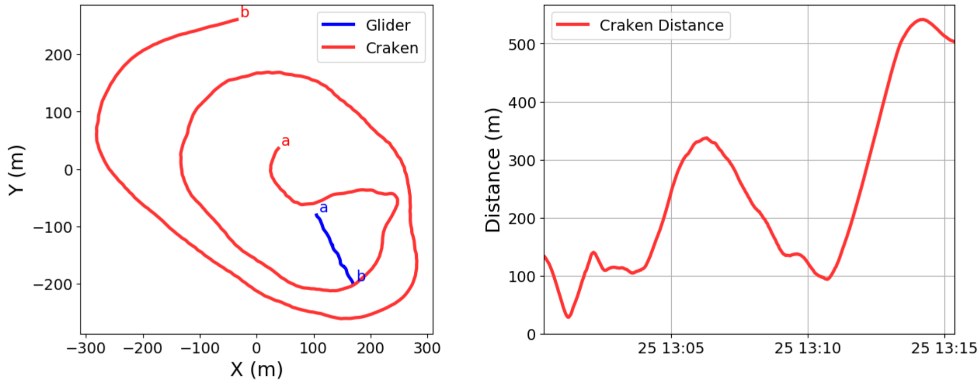

Fig. 4 - Geometry of the experiment. Workboat Cracken (red) running around buoyancy glider (blue).

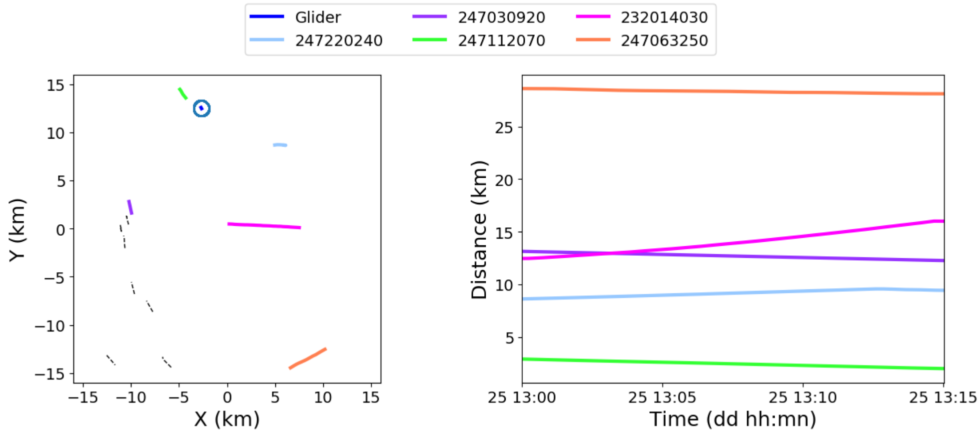

Fig. 5 - Ships positions (AIS data) during the experiment with the Craken workboat (in the blue circle). The detected ships are plotted in coloured lines; black dashed lines represent ships not detected by the algorithm. Left - Distances of the detected ships.

MMSI	**Speed (kn) [min - max]**	**Distance (km) [start - end]**	**Time on target (%)**
Craken	[5.0 – 6.1]	[0.05 0.5]	100%
247112070	[2.0 - 3.2]	[2.9 - 2.0]	70%
247030920	[2.2 – 3.2]	[12.3-13.1]	35%
247220240	[0.6 - 3.6]	[8.6 - 9.4]	20%
232014030	[14.6 - 17.3]	[12.5- 16.0]	80%
247063250	[8.50 - 10.6]	[28.5- 28.1]	50%
Unknown	/	/	10%
Unknown	/	/	20%
Unknown	/	/	30%

Table 1 - Detected sources and their corresponding ground truth

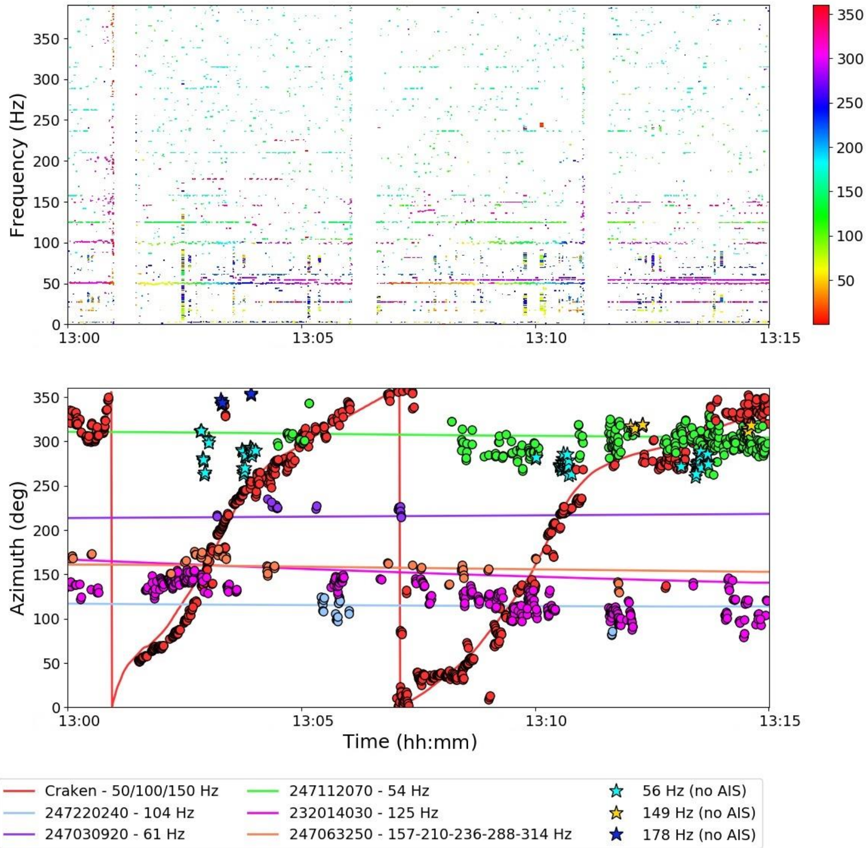

Fig. 6 - Top - Azigram of the detected signals. Bottom – contacts compared with ground truth. Colour indicates contacts labelled as belonging to the same target.

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