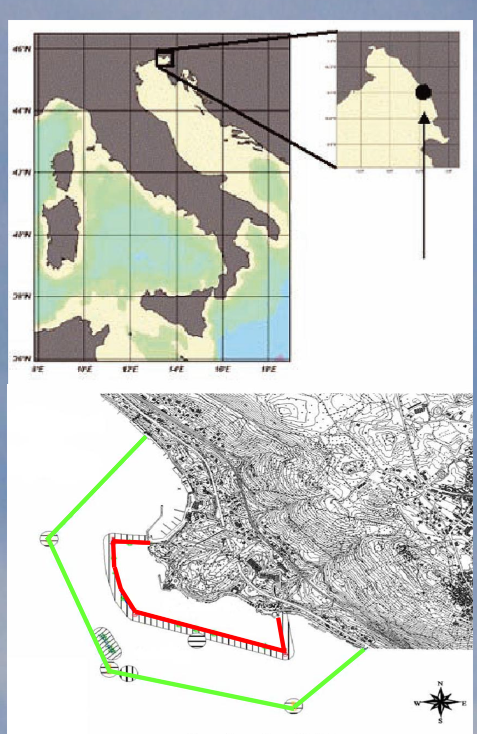
First description of the sound pressure and particle velocity components of the ambient noise and boat noise recorded at the WWF- Miramare Natural Marine Reserve (Trieste, Italy)

Marta Angelo Farina[1 *], Adriano Farina[5], Enrico Armelloni[1], Linda Sebastianutto[2], Carlo Franzosini[3], Marta Picciulin[3,4]

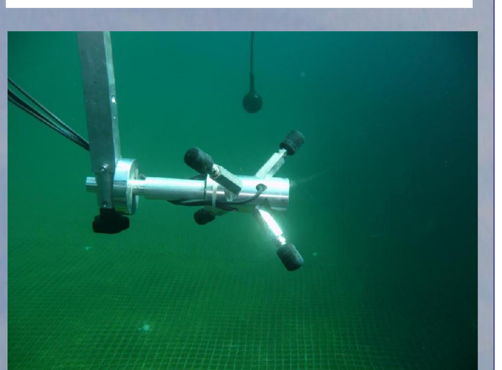
1 University of Parma, Ind. Eng. Dept., Parco Area delle Scienze 181/A, 43100 Parma, Italy;
2 SISSA-International School of Advanced Studies, Cognitive Neuroscience Sector, Via Lionello Stock 2/2 34135 Trieste, Italy;
3 WWF-Natural Marine Reserve of Miramare, viale Miramare 349, 34014 Trieste, Italy;
4 University of Trieste, CSEE - Department of Life Sciences, via Giorgieri 7, 34127 Trieste, Italy; marta.picciulin@gmail.com
5 University of York, Department of Electronics, Heslington, York, UK, YO10 5DD.

Summary of the present work

A **novel hydrophonic probe ("Soundfish")** placed inside the WWF-Natural Marine Reserve of Miramare (Trieste, Italy) allowed for characterization of the underwater acoustic background noise, and the noise produced by a small outboard-engine boat moving at 6 knots not just in terms of sound pressure, but also of the three Cartesian components of the particle velocity.



WWF-Natural Marine Reserve of Miramare

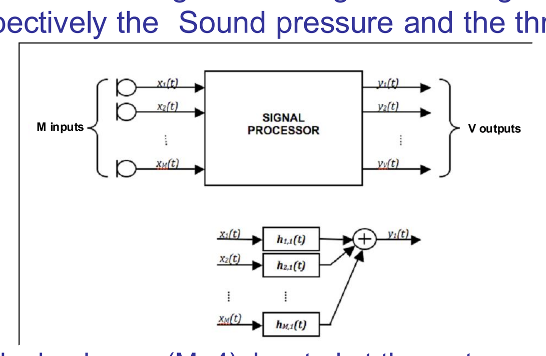


Currently the probe was assembled with a radius of 100 mm, resulting in an optimal frequency range comprised between 100 Hz and 2 kHz, where most of the noise generated by boats is known to exist.

Description of the recording probe

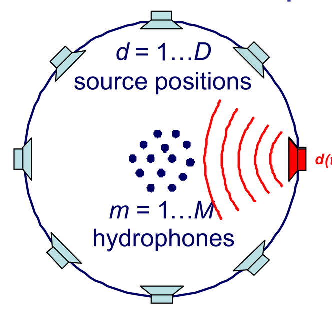
The system is based on a modified ZOOM H2 digital sound recorder, re-named Brahma, capable of recording the signals coming from a probe consisting of 4 hydrophones, placed at the vertexes of a tetrahedron: this is the underwater equivalent of a Soundfield™ microphone. The recorder operates at 48 kHz, 24 bits and records standard uncompressed WAV files over a 16Gb SD card, which can be easily processed later on a PC.

A software tool, named *Brahmavolver*, was developed for converting the raw signals coming form the 4 hydrophones to output signals, representing respectively the Sound pressure and the three Cartesian components of particle velocity. **Ultimately this analysis reconstructs the trajectory of the sound source, and, with some approximation, also evaluates the distance of the sound source from the probe.** The processing is based on the use of a matrix of 4x4 FIR filters, currently 2048 points long,as shown in the figure on the right.



The inputs are the sound pressure signals sampled by the M hydrophones (M=4), located at the vertexes of a tetrahedron, properly aligned with the Cartesian reference system of the probe (which is usually manually aligned with the geographical reference system). The inputs are the sound pressure signals sampled by the M hydrophones (M=4), located at the vertexes of a tetrahedron, properly aligned with the Cartesian reference system of the probe (which is usually manually aligned with the geographical reference system).

The filter coefficients are computed numerically, inverting a matrix of measured impulse responses, obtained with the sound source placed at a large number *D* of positions all around the probe.



$$C = \begin{bmatrix} c_{1,1} & c_{1,2} & \cdots & c_{1,d} & \cdots & c_{1,D} \\ c_{2,1} & c_{2,2} & \cdots & c_{2,d} & \cdots & c_{2,D} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ c_{m,1} & c_{m,2} & \cdots & c_{m,d} & \cdots & c_{m,D} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ c_{M,1} & c_{M,2} & \cdots & c_{M,d} & \cdots & c_{M,D} \end{bmatrix}$$

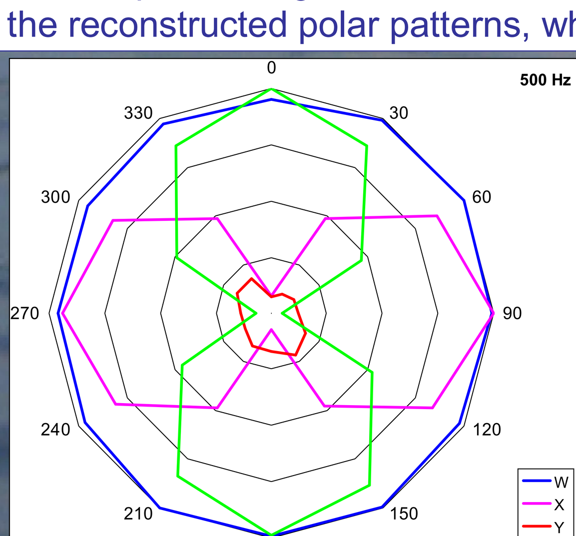
Preliminary tests in pool

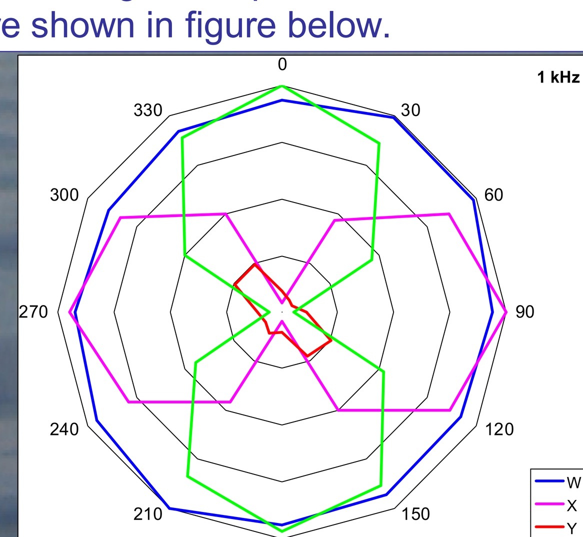
The suitable number of impulse response measurements were performed on the Soundfish probe inside the test pool kindly made available by WASS in Livorno, Italy.

A turntable, controlled by our Aurora software used for generating of the test signals, controlling of the turntable and for the deconvolution of the impulse responses) , was employed for automatically rotating the probe in steps of 30 degrees both along azimuth and elevation, yielding a set of 6x12 impulse responses.

After the measurements were finished, the set of 4x4 processing filters was computed, and loaded into the multichannel Brahmavolver processor, making it possible to derive the pressure and particle velocity signals.

The first test was done processing a set of measurements during a complete rotation of the probe, for checking the accuracy of the reconstructed polar patterns, which are shown in figure below.

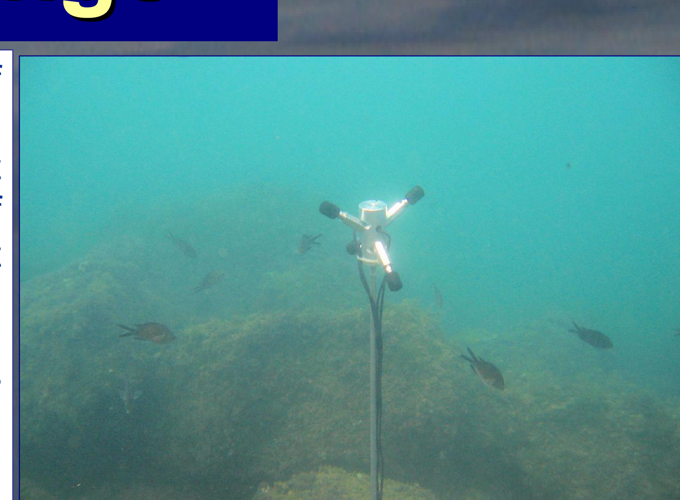


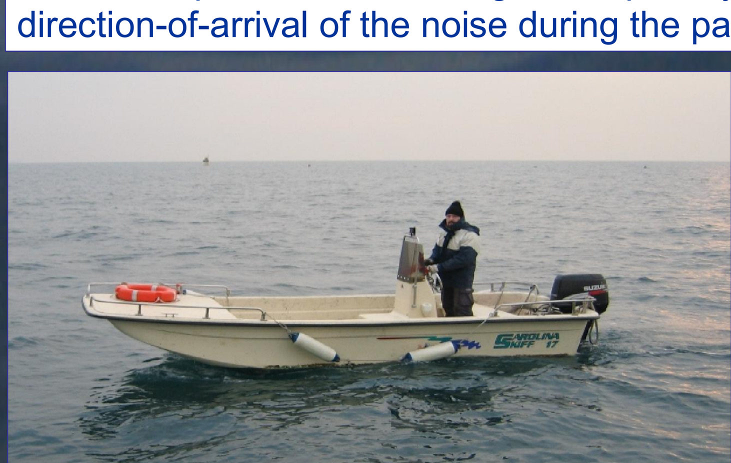


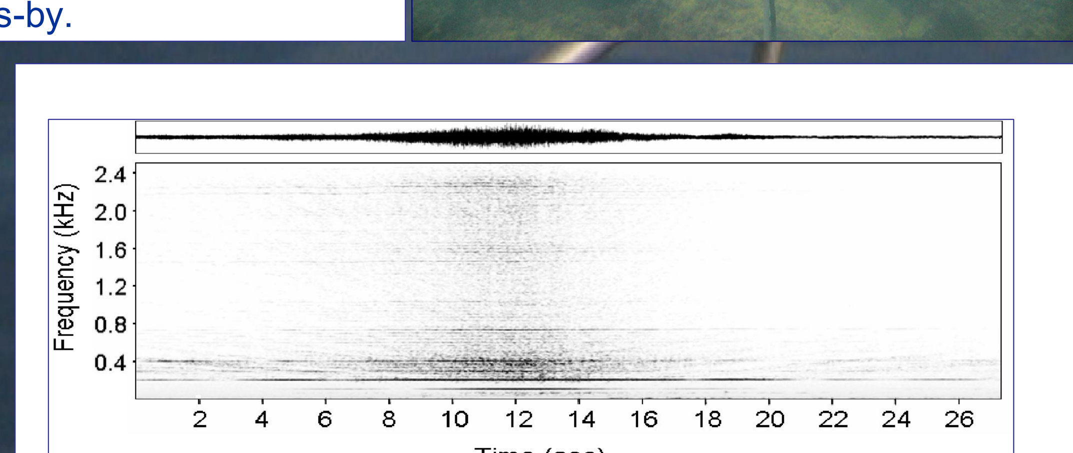
Field recordings

The probe and the Brahma recorder, located inside a waterproof container, were placed on the sea bottom, at a depth of 8m, in the protected area of the Miramare Reserve (recording point: Lat 45°42'10.61"N, Long 13°42'41.96"E). A 30 minutes long recording of the Sea Ambient Noise (SAN) was performed, without significant boat activity around.

Then a fiberglass speedboat, (w-shaped hull, 4,70 m lenght, 815 cm^3 / 4 strokes outboard engine) was operated, in a series of passages above the probe, for checking the capability of detecting the variable direction-of-arrival of the noise during the pass-by.

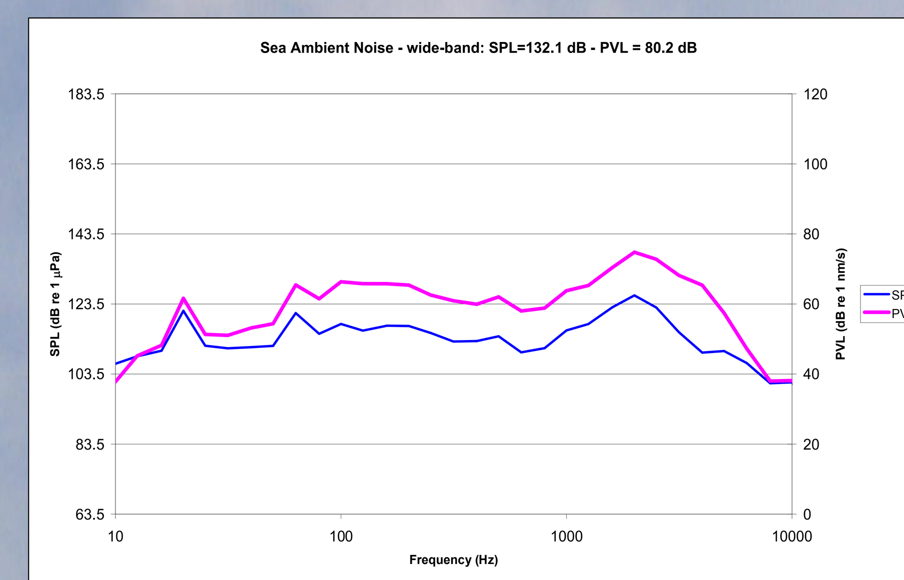


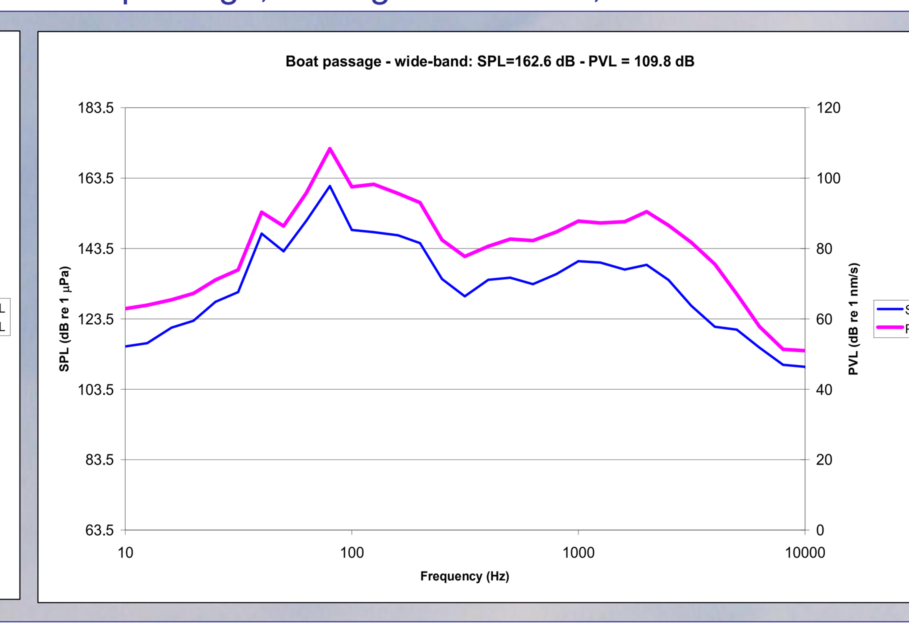




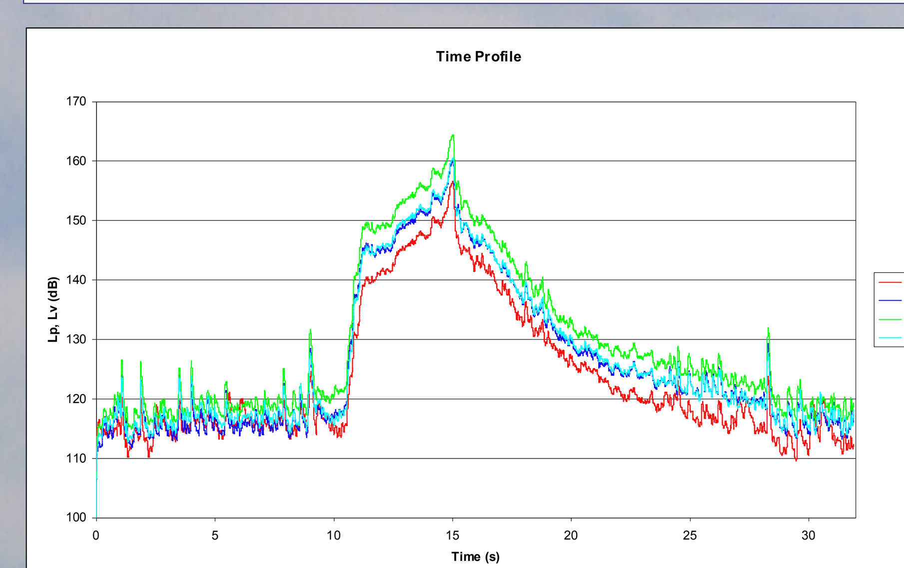
Data Analysis

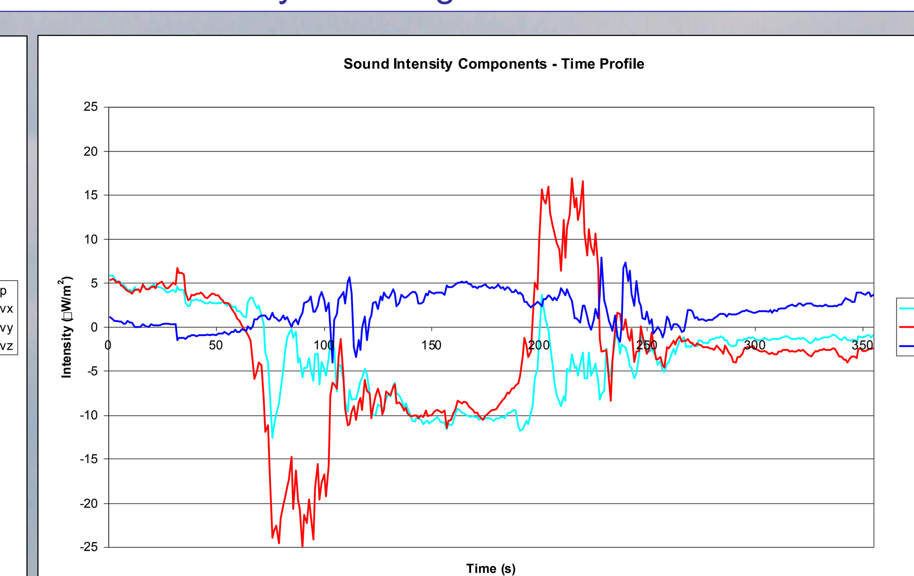
The figure on the left presents the spectral analysis of the SAN recording, showing the 1/3 octave band spectra in terms of SPL and PVL.
The figure on the right present the spectra; analysis of a boat passage, averaged over 10 s,





The figures below show the analysis of one of these passages, occurred at a speed of approximately 6 knots. It shows the time history of SPL and PVL, and the magnitudes of the three Cartesian components of Sound Intensity computed in the central two-octaves band 309 to 1414 Hz. The analysis of these Cartesian components allows for estimating the azimuth and elevation of the boat at every instant, making it possible to reconstruct approximately its trajectory, by projecting the sound intensity vector against the sea surface





Overplotting the coordinates of the estimated position o the sound source on the map of the site, a rough estimate o the boat trajectory is found:

Conclusions

The new *Soundfish* probe can be employed for an **analysis of the cause-effect relationship**, as at every instant the position of the source, relative to the receiver, is known, alongside with the **quantities relevant for assessing the impact of human-produced noise over marine species**, either sensitive to sound pressure or to particle motion.

The reliability of the new measurement system must now be assessed by employing it in a number of surveys, under different sea conditions, at different depths, and with various kinds of noise sources.
It could also be advisable to repeat the calibration in the pool, employing narrower angular steps, for ensuring computation of even better digital filters. .

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