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An automated passive acoustic monitoring system for real time sperm whale (*Physeter macrocephalus*) threat prevention in the Mediterranean Sea

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ABSTRACT

The sperm whale (*Physeter macrocephalus*) is one of the largest and most widely distributed marine mammals. The Mediterranean population, classified as Endangered in the IUCN Red List, is affected by a number of anthropogenic threats, including noise increase. The individuals of this species tend to spend long periods "rafting" and socializing at the surface inbetween deep dives and this make them highly vulnerable to ship strikes. In the Pelagos Sanctuary, 8% of photo-identified sperm whales has evidence of wounds from propellers. In the framework of the Life+ Nature WHALESAFE, an interference avoidance system capable of detecting and tracking sperm whales in the range of about 7 km was developed in order to identify the threats and potentially prevent collisions and other risks; this tool issues warning messages in real time to ships. In this work, the technical details of the WHALESAFE detector and of the two reconstruction algorithms developed for the sperm whale tracking will be described. The analysis of a cetacean signal has been used to test the performances of WHALESAFE, revealing that the average error on the position is 50 m at a distance of 1 km. The accuracy in the reconstruction of the cetacean position fits the requirements for an efficient animal tracking and species preservation.

1. Introduction

The goal of the WHALESAFE project [1] is the development of an interference avoidance system aimed at detecting and tracking sperm whales (*Physeter macrocephalus*). The monitoring of the cetaceans is required to prevent collisions and other risks by issuing warning messages in real time to ships in the area of the Pelagos Sanctuary.

The Pelagos Sanctuary for Mediterranean Marine Mammals is a special marine protected area located between Liguria, Tuscany, France and Sardinia in the north-western Mediterranean Sea. It covers an area of around 90 000 km^2 [2]. The Pelagos site is the most important breeding and feeding site for cetacean populations living in the Mediterranean Sea. The unique seabed features in the area, such as canyons, attract a large number of sperm whales that often emerge near the coast [3–6]. The marine traffic (e.g. passenger, cargo and fishing boats) in the Ligurian sea is rather intense and it increases particularly during the summer, when the presence of sperm whales is higher. Collisions and injured animals are consequently frequent and have a very high negative impact on the species (8% of photo-identified sperm whales has evidence of wounds from propellers [7]), whose Mediterranean subpopulation counts at just 2500 mature individuals [8].

The WHALESAFE system is innovative because it has the capability to prevent ship impacts with the whales by monitoring and tracking the animals underwater, by acoustic means using hydrophones, microphone designed to be used underwater for recording or listening to underwater sound. This aspect is vital, considering that sperm whales spend three quarters of their life underwater. This approach has been borrowed from our experience in the LIFE09NAT/IT7000190 ARION project [9] where an interference

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avoidance system capable to detected and track the dolphins has been implemented. The detector consisted of two elastic beacons both instrumented with four analogical hydrophones arranged in a mechanical frame describing a tetrahedron shape, whose vertices are the locations of the hydrophones.

A similar approach for the study of whales has been used by the Woods Hole Oceanographic Institution in Cape Cod Bay (Massachusetts, USA). Two vertical line arrays with 8 hydrophones and a single "L-shaped" array with a vertical and an horizontal line (including 8 hydrophones each) have been anchored to the sea bottom. The real-time acoustic tracking system was deployed on two one-day cruise detecting vocalizations from six whales, fin whales, humpback whales and North Atlantic right whales. The project demonstrated that this is a potential method to monitor whales in a large area from a single site [10]. In the Baltic Sea, the BIAS project was directed exclusively towards monitoring of continuous low frequency sound (ambient noise). BIAS project investigated 36 measurement locations where stand-alone lines with a single hydrophone have been installed at the sea bed discovering that high-frequency ship noises cause significant behavioral reactions of porpoises. This solution is not feasible for the WHALESAFE project since the sea floor in the Ligurian Sea is much deeper compared to the Baltic Sea and another major difference was that WHALESAFE utilization required realtime monitoring whilst BIAS data can not be accessed until the detection unit is retrieved and opened [11].

The only efficient strategy to retrieve data from a detection unit located at the sea bottom could be the data transmission with an optical fiber cable which would allow connection to the shore. This approach is very expensive and goes beyond the funding available for the WHALESAFE project, but it has been used by the NEMO collaboration [12] in Sicily and the ANTARES collaboration [13] in French Riviera.

ANTARES is a neutrino telescope located 40 km offshore of Toulon (France) at depth of 2800 m, the project involves over 100 scientists from 8 countries. The telescope counts 12 detection lines with optical sensors designed for the detection of the feeble optical radiation induced by the passage of neutrinos in the surroundings of the detector. The instrumented lines house also a series of hydrophones which are normally used for the calibration of the instantaneous shape of the detector, but they can also detect the sounds emitted by sperm whale. The ANTARES collaboration revealed the year-round presence of sperm whales in the Ligurian Sea, probably associated with the availability of cephalopods in the region [14].

In the next section the approach selected for the WHALESAFE project will be described, providing details about the detection principle and the instruments installed in our apparatus.

2. The WHALESAFE detection principle

The WHALESAFE detector originally consisted of two detection units (at a relative distance of 1 km). Each detection unit counts 2 buoys, the "primary" and "secondary" buoy. The primary buoy is anchored to the seabed with a 1500 kg ballast and a dyneema rope connects the primary buoy to the ballast. The two buoys are connected on the sea surface thanks to a rope with several floats while two cables are in the depths: one is a mechanical connection (16 mm diameter Kevlar rope), the other carries the instrumentation signals. Two couple of hydrophones are located below each secondary buoy at a depth of 65 m on a tetrahedral mechanical frame, the buoy houses also the junction box, where all the electronic devices for signal processing are housed. The secondary buoy is not anchored to the seabed, but it has a 30 kg ballast that maintains the line vertical. Fig. 1 shows all the components of the system described above.

The WHALESAFE project goal is the detection and the tracking of sperm whales to prevent collisions with boats and ships by issuing warning messages in real time to the vessels in the area. The tracking is performed recording the vocalisations of sperm whales, known as "clicks", and reconstructing the animal position exploiting the measured source direction as shown in Fig. 2.

This configuration has the advantage of a complete decoupling of the hydrophone array with respect to primary buoy movements, however it could be subject to damage to the kevlar rope that connects the two buoys.

The reconstruction of the sperm whale position could be performed also using one single detection unit exploiting the sound wave reflection on the sea surface as shown in Fig. 3.

These methods allow a real time reconstruction of the cetacean paths.

During immersions sperm whales periodically emit echolocation clicks until they are starved of oxygen and they start to go back to the surface for breathing. Sperm whales swim almost vertically [15] while they are ascending to breathe, so the coordinate of the latest reconstructed cetacean position by the WHALESAFE system could be used as predicted emersion point. The expected distance between the coordinate of the last click and the emersion point is around 100 m [15]. Thanks to this typical behaviour of the

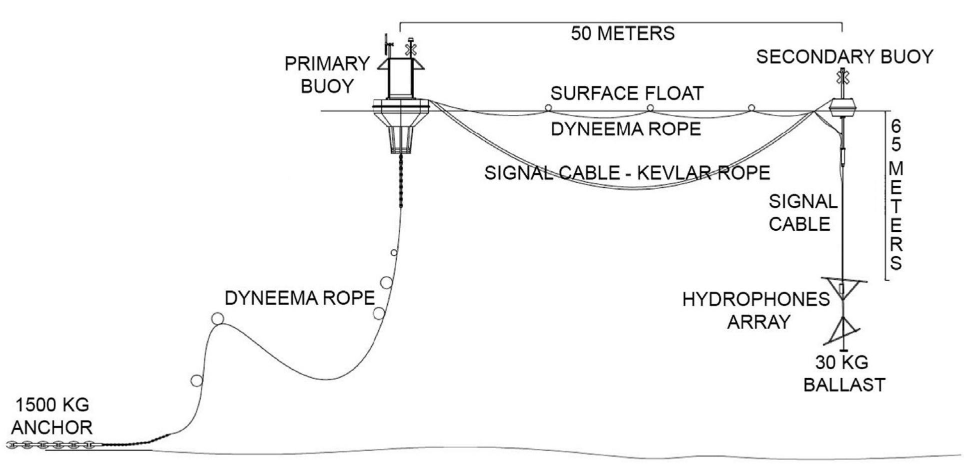

Fig. 1. Components of a WHALESAFE detection unit.

sperm whales, the WHALESAFE system could predict with good accuracy the emersion point of a cetacean with an advance of 10–15 min, the typical duration of a sperm whale ascent [15].

This anticipation is crucial to put in place the preservation action planned to avoid collision between vessels and sperm whales breathing at the sea surface. The WHALESAFE system is planned to be connected with the control rooms of the Coast Guard authorities which patrol the waters around the Savona-Vado harbour.

A protocol of conduct has been defined in case of sperm whale presence in the area that has been developed thanks to a synergy of all partners involved in the project. Also, several stakeholders have been surveyed in the process of the protocol of conduct definition, like cruise companies, fishing associations, maritime work companies, recreational boating associations, boating schools and whale watching companies. Most of them signed the protocol of conduct with the commitment to comply with the agreed rules. The protocol of conduct defines four levels of alarm:

- GREEN: absence of Sperm whales in the area, free navigation;
- YELLOW: one or more sperm whales detected underwater;
- ORANGE (duration: 15 min): one or more sperm whales breathing at the surface, no ship on collision course;
- RED: one or more sperm whales breathing at the surface, ship/s on collision route.

When the Savona Coast Guard will receive a communication from the WHALESAFE detection system about the expected emersion location of a sperm whale, the Coast Guards personnel will promptly inform the ships in the area. This information will be transmitted by radio (VHF channels), only in case of presence of naval activity in the interested area according to the monitoring system (VTS) of Maritime Traffic. Therefore, three level of communication are foreseen corresponding to different alarm levels. A first "warning" message informs the ship's commander of the presence of a sperm whale in close proximity and invites him to adopt the protocol of conduct, a second "advice" message communicates

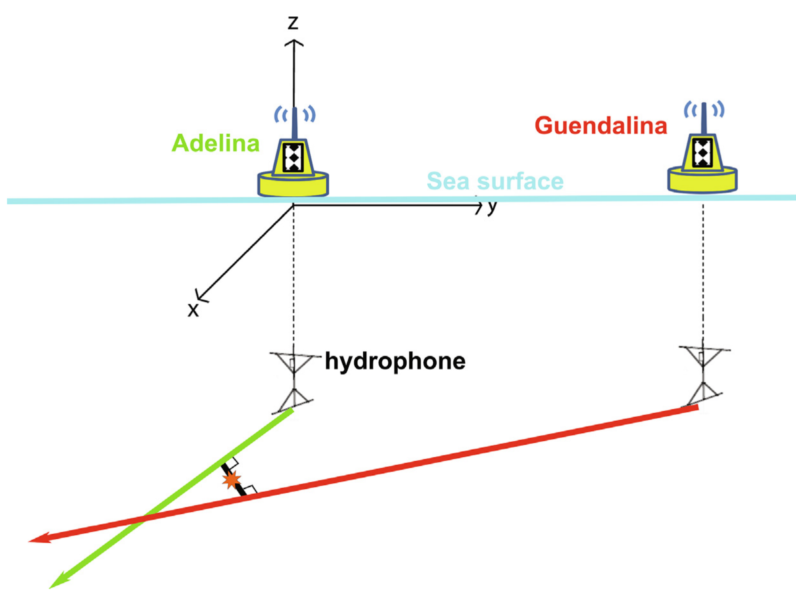

Fig. 2. Detection principle using two detection units.

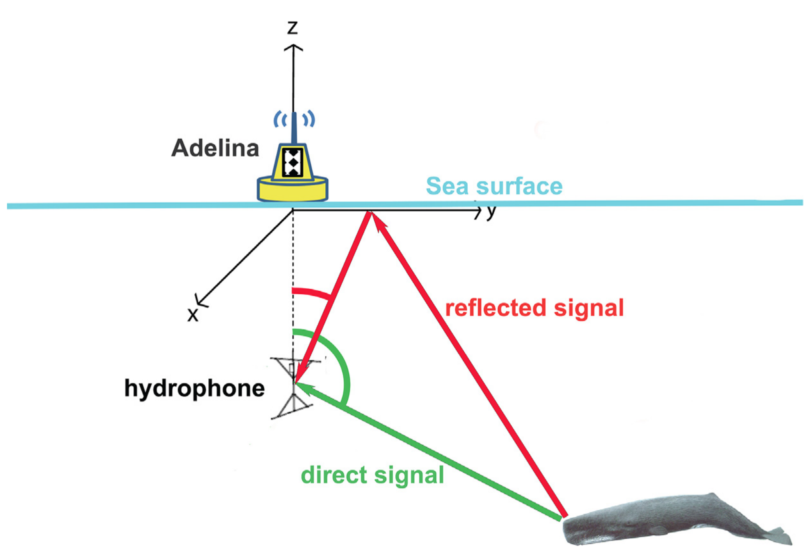

Fig. 3. Detection principle using only a single detection unit.

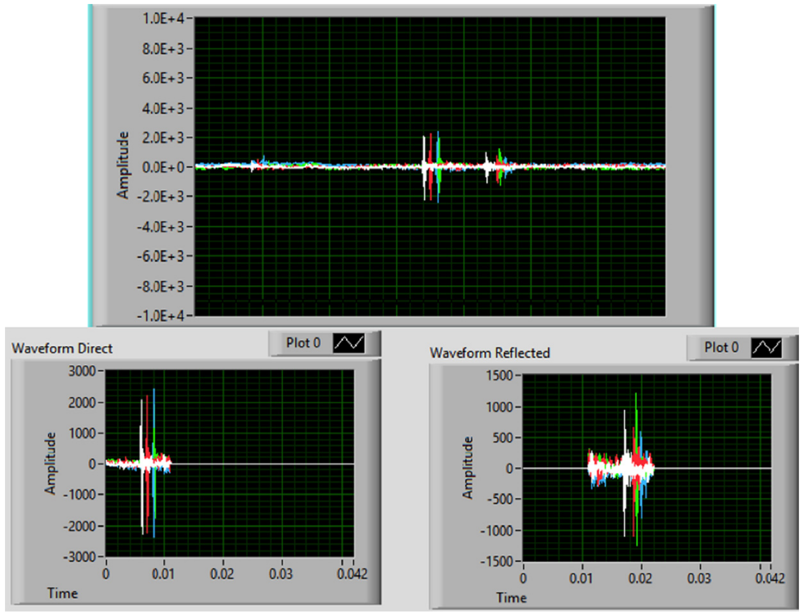

Fig. 4. Sample of the acoustic track used in the analysis: the whole audio track (top), the track selected as "direct signal" (bottom left) and the track selected as "reflected signal" (bottom right).

the emersion coordinates in order to allow the ships to follow a safe route; a third "emergency" message warns the ship's commander of the risk of collisions in case of mis-respect of the protocol of conduct. The alert system has been not implemented yet since the WHALESAFE system is still under test.

Details about the detector power system and the data acquisition are described in Appendix A. In the next sections the online and offline algorithms for data processing are presented.

3. The online WHALESAFE reconstruction algorithms

3.1. Software running on the primary buoy

The reconstruction algorithm running on the computing modules of the primary buoys is devoted to the most important ingredients of the data readout: hydrophone data acquisition, periodical reading of slow control (compass, tiltmeter, hygrometer) and identification of cetacean clicks. All the code has been developed using LabView2014. The software includes monitoring of the data acquisition, setting of acquisition threshold values for the identification of a cetacean click, monitoring of vessels in the area and data transmission to shore.

The typical requirements for the identification of a cetacean click are based on the recipes of W. Zimmer [16], i.e. mainly the concurrent presence in the four sound tracks of a transient (a signal with a signal-to-noise ratio SNR that exceeds a threshold TH) plus the concentration of the sound power in the frequency interval 2–10 kHz.

The software running on the primary buoy also computes the relative position of the detector. The absolute orientation angle of the sound direction with respect to the vertical direction is computed from the output of the compass-tiltmeter module performing a series of rotation according to the convention of Tait-Bryan. The order of rotation is therefore: heading, pitch and roll.

3.2. Software running on shore

As described in the previous paragraph, the data are transferred on shore thanks to the WiFi link. The PC in the control room houses all the software packages for the reconstruction of the sperm whale route.

In the single unit configuration, the reconstruction of the position of the cetacean can be performed thanks to the reflection of the sound waves on the surface of the sea. When the cetacean is below the hydrophones level, two different sound signals are expected: the direct signal and the reflected signal (Fig. 3). The two signals can be used to reconstruct the cetacean position assuming a perfect reflection on the sea surface.

When a sperm whale click is recognised, the buoy transfers to the shore station an audio track with length of 70 ms. The direct click is at 34 ms after the beginning of the track; this is a safe choice in order to verify that there are no previous associated signal (meaning that the selected click is actually a reflected signal).

A dedicated program reduces the track length to 42 ms with the start of the click at 6 ms and it duplicates the resulting track. On the resulting tracks an 18th order Butterwoth high-pass filter with threshold at 1 kHz is applied. The Butterworth filter is a type of signal processing filter designed to have a frequency response as flat as possible in the band-pass (in our case above 1 kHz) and it suppresses all the signals at lower frequency. Such high order filter is required to achieve the necessary angular accuracy; lower order filter have been tested, but in this case the difference between the reconstructed azimuth angles of direct and reflected signals, which theoretically are identical, started to be consistent. The first version of the track is 11 ms long and contains only the direct signal, the second version contains the corresponding reflected signal and it is also 11 ms long. An example of the duplication of the track is provided in Fig. 4.

The polar angle of the acoustic sample direction with respect to the absolute reference frame is computed for both direct and reflected signal. The compatibility of the time delay Δt of the two signals with the expected value, according to the supposed difference of path Δx of the sound waves, is required to associate a reflected signal with its direct signal.

The reflected signal can be imagined as a "direct" signal detected by a "ghost" detector above the sea level symmetrical with respect to WHALESAFE hydrophone structure. If the source is far enough away from the detector, the direct and reflected signal can be assumed parallel. In this hypothesis Δx is the cathetus of a right-angled triangle, where the distance of the hydrophone

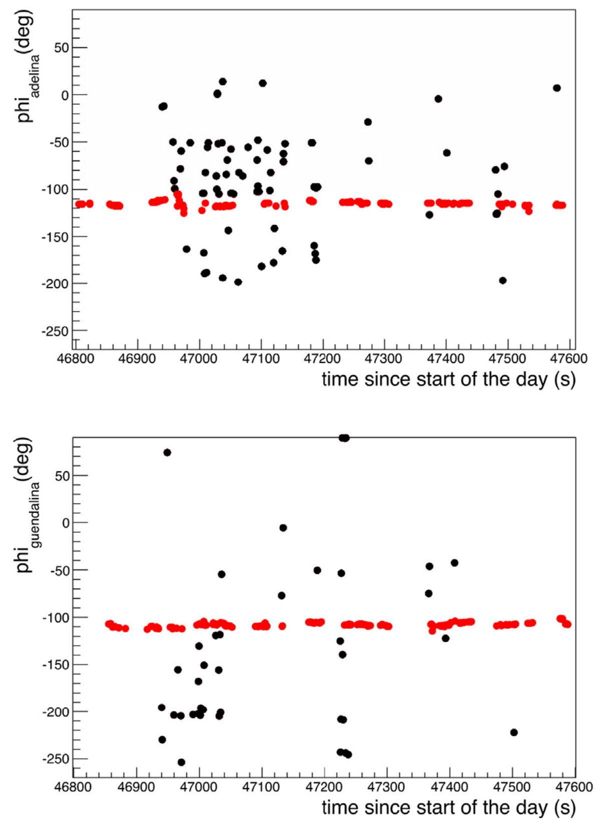

Fig. 5. Azimuth direction ϕ of the detected signals for Adelina unit (top) and Guendalina unit (bottom) as a function of the time (s). In particular event recognised as cetacean signal are marked with red dots.

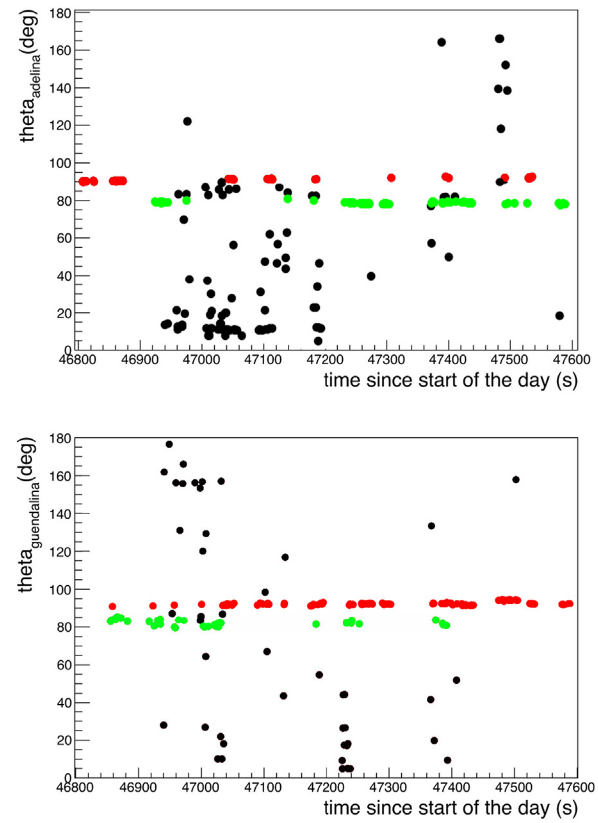

Fig. 6. Zenith direction θ of the detected signals for Adelina unit (top) and Guendalina unit (bottom) as a function of the time (s). In particular event recognised as direct and reflected cetacean signal are marked with red and green dots.

structure from the "ghost" detector Δs is the hypotenuse. The difference of path Δx is finally computed as $\Delta s \cdot cos(\theta)$, where θ is the zenith angle of the signal direction. If $\Delta x < 0$ the source of the signal is below the hydrophones level, while $\Delta x > 0$ indicates a source close to the sea surface.

Finally the position of the sperm whale is computed as the point of closest approach of the two straight line defined by the absolute polar angle computed above. The position obtained is included in a "sperm whale route" if it satisfies the following condition:

$$P_n - P_{n-1} < 0.1 \cdot D + t_P \cdot v_{sw} \tag{1}$$

where P_n is n-th candidate point of a sperm whale route and P_{n-1} is the last included point, D is the distance of the P_n point with respect to the hydrophones location, t_P is the time interval between P_n and P_{n-1} points and v_{sw} is the average speed of a sperm whale (~ 5 m/s). If the new point satisfies the condition, its position is corrected using a Kalman filter.

When no new points are added for a minute, the sperm whale is assumed to coming up to surface and the estimation of the emersion time and location is computed. This information could be provided to Coast Guard for the prevention of collision between the cetacean and vessels in the area.

In the next section the algorithm applied offline for a more accurate reconstruction of the sperm whale location are described. More precise location information are incredibly valuable for biological studies of the sperm whale behaviour.

4. The offline WHALESAFE reconstruction algorithms.

In the next sections the two developed algorithms for the reconstruction of the cetacean position will be described. The first uses

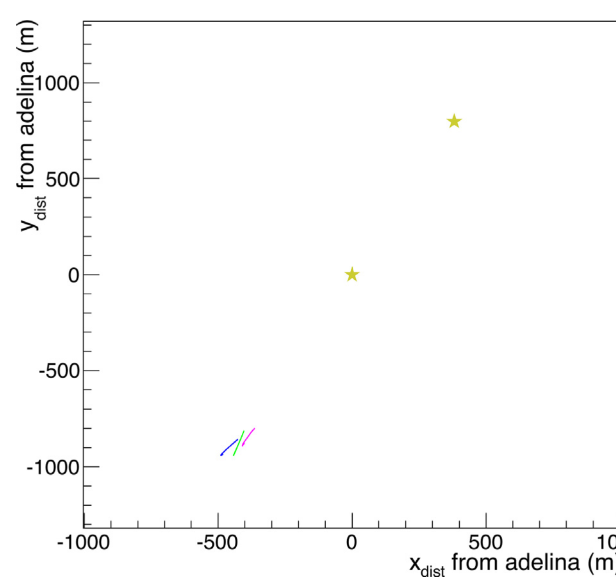

Fig. 7. Reconstructed track of the cetacean according to the "two units algorithm" (green) and according to the "single unit algorithm" using only Adelina unit (blue) or Guendalina unit (magenta), x_{dist} and y_{dist} are the distance of the reconstructed track from the Adelina buoy in the direction West-Est and North–South respectively. The two stars represent the position of the Adelina and Guendalina buoys. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the signal detected by the two detection units to derive the sperm whale location, the latter exploit the reflection of sound waves to reconstruct the cetacean position using only one detection unit.

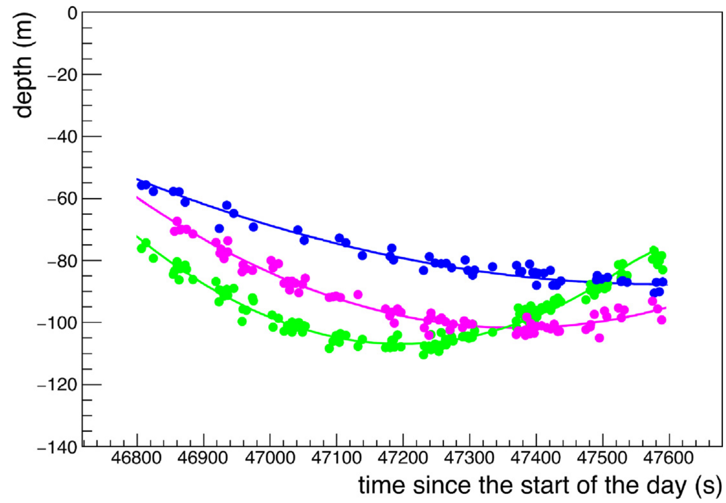

Fig. 8. Reconstructed depth of the cetacean according to the "two units algorithm" (green) and according to the "single unit algorithm" using only Adelina unit (blue) or Guendalina unit (magenta) (Dots: reconstructed depths; line: fitted value). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

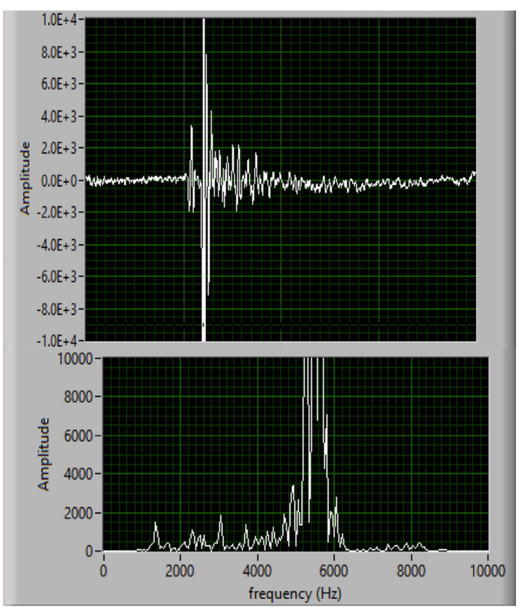

Fig. 9. Amplitude of a sperm whale click vs time (track length 20 ms) (top), frequency spectrum of a sperm whale click (bottom).

4.1. Reconstruction algorithm with two detection units

The reconstruction algorithm reads the data output of the click identification software in the following format: $< time >< date >< theta >< phi >< longitude >< latitude >$, where $< time >$ is the time of the signal in the format HH:MM:SS. $< date >$ is the date of the events in the format DD/MM/YY, $< theta >$ (θ) and $< phi >$ (ϕ) are respectively the zenith and azimuth angle of the direction of the signal, $< longitude >$ and $< latitude$ are the geographical coordinates of the units.

The cetacean signal is generally expected to come from below the hydrophones, so only events with $\theta > 90^\circ$ are considered. In case of interesting signals near the horizon of the hydrophones, the lower threshold on the zenith angle could be adapted. First signals that are clearly uncorrelated are discarded by the selection algorithm, which looks for space–time correlation of subsequent signals, and a fitting algorithm is used to determinate the temporal behaviour of the parameters of the selected events (zenith and azimuth of the signal, longitude and latitude of the units). A quadratic polynomial is adequate to reproduce the time dependence. The fitted behaviour of the zenith angle θ and the azimuthal angle ϕ is used to derive the time behaviour of the signal direction cosines.

The information on the position of the two detection units and the direction cosine of the signals from each unit allow to find the most likely location of the cetacean. The segment of minimum distance between the two straight lines that represent the directions of the signals detected by the two units is computed and the medium point of the segment is taken as the cetacean position (Fig. 2).

The computation of the position of the cetacean described above is repeated as a function of the time in order to derive the track of the cetacean in the sea around the detector.

4.2. Reconstruction algorithm using only one buoy system

The reconstruction algorithm applied in the case of the single unit configuration exploits the sound wave reflection on the sea surface as described in Section 2 for the online algorithm (Fig. 3).

The data readout is identical to that used in the previous algorithm, but this time all the signal are divided in two different categories (direct and reflected signals) and are treated separately.

The same data filtering and fitting of the previous algorithm are performed and the time behaviour of the direct and reflected zenith angle (θ_d and θ_r) and the azimuthal angle ϕ is used to derive the position of the cetacean as a function of the time. For example the cetacean depth $d(t)$ as a function of the time can be computed as

$$d(t) = \sqrt{\left(\frac{2\bar{z}}{cot(\theta_d(t)) + cot(\theta_r(t))}\right)^2 + \left(\frac{2\bar{z}cot(\theta_d(t))}{cot(\theta_d(t)) + cot(\theta_r(t))}\right)^2} \quad (2)$$

where $\bar{z}$ is the depth of the hydrophones (65 m), the subscript d and r indicate direct and reflected signal respectively. This formula has been derived from the geometrical configuration of Fig. 3. Since the depth of the hydrophones and the arrival angles of direct and reflected signal are known parameters, the distance of the source can be computed analytically (it corresponds to the length of the green vector in Fig. 3).

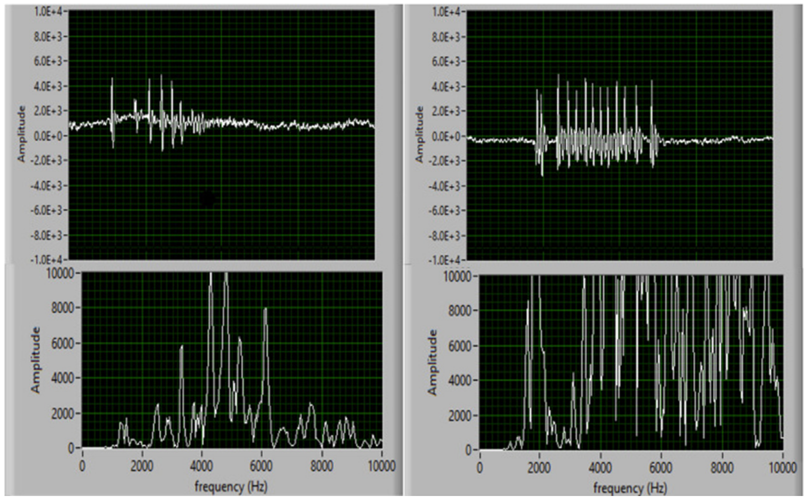

Fig. 10. Two examples of background sounds: amplitude vs time (track length 20 ms) (top), frequency spectrum (bottom).

This computation of the position of the cetacean is repeated as a function of the time in order to derive the track of the cetacean in the sea around the detector.

4.3. Performances of the two reconstruction algorithms

The two reconstruction algorithms have been tested on one of the first cetacean signal detected by the WHALESAFE system on the 28th June 2016 between 1 P.M and 2 P.M., at that time the detector was in testing phase and both detection units were in operation.

The azimuth direction ϕ and the zenith direction θ of the signals detected by the two units (named Adelina and Guendalina) are shown in Figs. 5 and 6 respectively. The signals which satisfy the space–time correlation and are selected by the tracking algorithms are highlighted in red and green.

Direct and reflected signal can be easily distinguished since $\theta_d(t)$ is typically larger than 90°, while $\theta_r(t)$ is always below 90°. In particular cases, like the one presented in this paper where the animal is close to the hydrophones level, an *ad hoc* threshold must be set in order to separate the two populations of selected clicks (the coloured points in Fig. 6). In this case the threshold has been set at $\theta = 85^\circ$.

The reconstruction of the cetacean track has been performed independently with the two different algorithms and the results are compared. The reconstructed tracks according to the "two units algorithm" and the "single unit algorithm" are shown in Fig. 7. The position of the cetacean is expressed as a function of the distance from the Adelina unit.

The results of the two algorithms are quite compatible, the difference on the average reconstructed geographical position of the cetacean is roughly 100 m.

The difference on the reconstructed geographical position could be due to a systematic error in the estimation of the absolute azimuthal orientation of the units. If we assume a systematic error of about 1 degree in the relative absolute orientation of the two units, we obtain an even better agreement on the location of the cetacean. This systematic orientation issues could be investigated using a calibration sound wave source with known position, for example the sound of a boat engine which follows a predetermined path using GPS positioning.

Similarly, the reconstructed depth according to the "two units algorithm" and the "single unit algorithm" are shown in Fig. 8.

The predicted depth of the cetacean is quite similar during most of the period considered in this analysis, the difference of the estimated depth between the algorithms is below 40 m.

An example of a sperm whale click is provided in Fig. 9 where the amplitude of the sound wave vs time and the frequency spectrum is provided.

The signal has the typical shape of a sperm whale click and the frequency spectrum between 5–6 kHz matches the expected range according to previous studies [17]. In Fig. 6 a population of reconstructed events with zenith angle close to 0 is present for the Adelina unit. In other words the unit reconstructed several sounds coming from above the hydrophone, in proximity of the Adelina primary buoy. It can be noted that the events does not present a clear pattern neither in the zenith angle plot (Fig. 6) nor in the azimuth angle plot (Fig. 5). These reconstructed sounds could be due to a boat or several boats which stationed in proximity of the Adelina buoy; the pattern and the frequency spectrum of two of these background events are shown in Fig. 10.

5. Conclusion

The WHALESAFE project goal is the protection of large cetaceans within the Pelagos sanctuary. An interference avoidance system capable of detecting the sounds emitted by sperm whale has been deployed near the Savona harbour, in the Ligurian sea. The detection system and the different online and offline algorithm for the reconstruction of the cetacean routes, has been described. The results of the analysis of a genuine signal of a cetacean have been presented. These show that the data obtained are quite promising and the detector can achieve the foreseen scientific results to be applied for the prevention of collision and sperm whales conservation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. The detector power supply and data acquisition system

The power supply of the system is provided by two 250 W solar panels and two 75 W solar panels located on the primary buoy, all the panels have 24 V outputs and they charge two batteries. The four panels are connected to a W30 Western CO charge regulator that checks the current of the panels using the pulse-width modulation (PWM) technique. It also discharges the batteries isolating the loads in case of electric shock in the battery, its maximum threshold current is 30 A. The global power supply system is summarized in Fig. A.11.

The detection system is an improved version of the ARION units [9]. The four hydrophones are located at the vertex of a tetrahedral frame as shown in Fig. A.12.

We opted for omnidirectional hydrophone GP0280-M produced by COLMAR, the same used in ARION. These are optimal for our purposes, with high sensitivity, low noise and wide bandwidth (2.7–90 kHz, sensitivity -169 dB re 1 V/μPa on single output @ 5 kHz, equivalent input acoustic noise 31 dB re μPa/$\sqrt{Hz}$ @ 5 kHz). The distance between each pair of hydrophones is 4 meters and the vertical spacing is also 4 meters.

The signals of the four hydrophones are transferred to the junction box (Fig. A.12) where all the electronic devices for signal processing are housed. Signals are amplified with a custom made 4-channel amplifier and are digitized using a 4-channel Analog-to-Digital Converter (ADC) NI9223 capable of up to 1000 ksample/s.

The output of a compass-tiltmeter, a power control board and a Cablematic digital thermo–hygrometer is provided to a NI9870 RS232 interface modules that provides 4 serial ports RS232. The compass-tiltmeter is a high resolution PNI Corp. TCM5XB compass with nominal precision of 0.1 degree. This device is able to compensate the magnetic deviation due to presence of iron near the acoustic station. The ADC and the interface module are both located in a NI9149 eRIO chassis that allows to add I/O modules to any standard Ethernet network.

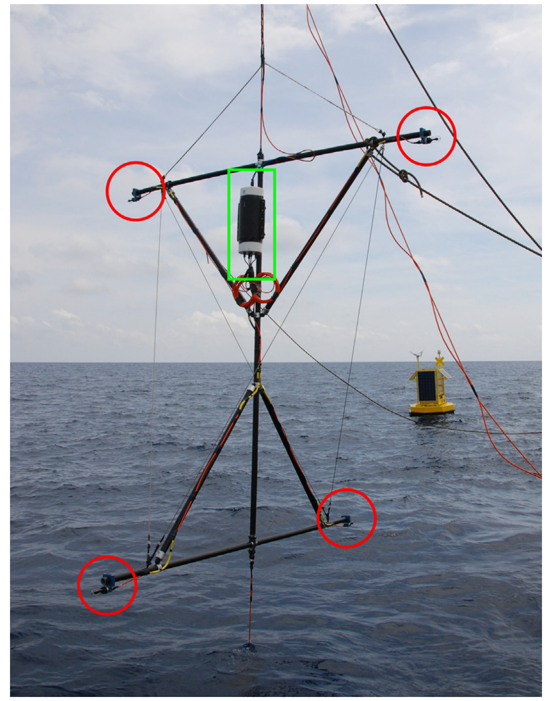

Fig. A.12. Picture of the WHALESAFE hydrophone array. The positions of the four hydrophones is highlighted with red circles, while the position of the junction box is indicated with a green box. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

All the digitized information are broadcasted via Ethernet by the eRIO module to the NI9081 compactRIO module located in watertight box on the primary buoy. This module features a processor where a software performs real time pattern matching

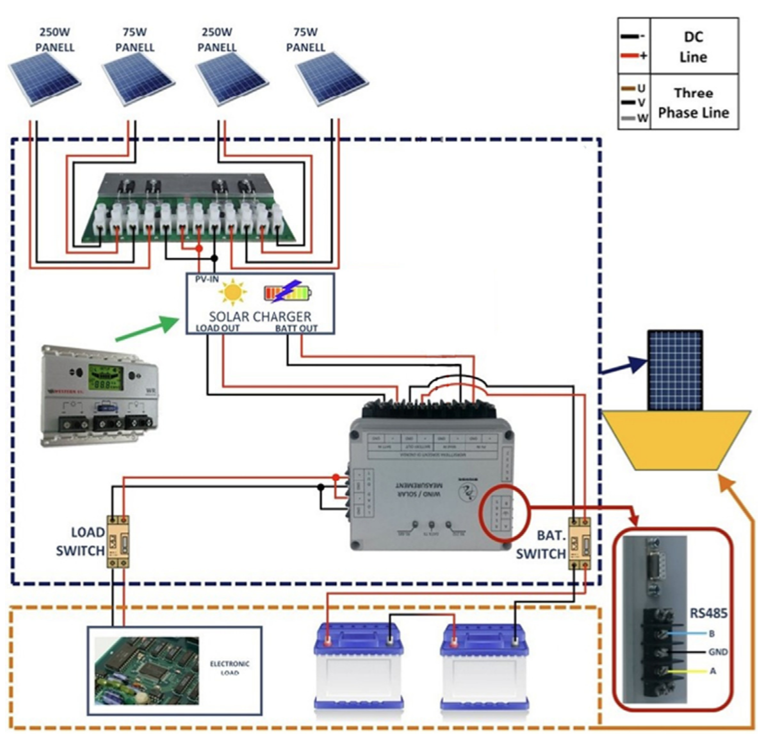

Fig. A.11. Scheme of the WHALESAFE power supply system.

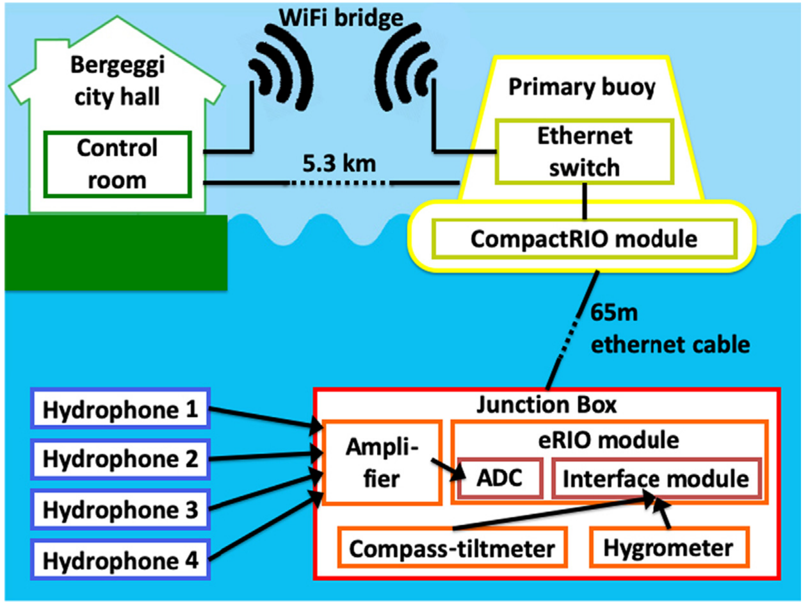

Fig. A.13. Scheme of the WHALESAFE data acquisition and transmission system.

and decides if the sound signal is sperm whale click or it is not. The details of the click recognition software will be described in the next section.

The compact RIO module is connected to the WiFi antenna, which allows the data transmission to shore, thanks to an Harting Ha-VIS eCon 2080B-A ethernet switch. The receiver WiFi antenna is located in the Bergeggi City Hall (200 meters above the sea level) at a distance of 5.3 km from the WHALESAFE detector location. The WiFi link is extremely stable reaching signal strength of −57 dBm with transmission and reception rate up to 100 Mbps.

A scheme of the data acquisition and transmission system is provided in Fig. A.13.

The position of the primary buoys is continuously monitored thanks to GPS module that is connected to the Ethernet switch allowing communication with the WiFi antenna. The primary buoy houses also an automatic identification system (AIS) equipment, which is the standard automatic tracking tool used by vessel traffic services. The system sends automatic warning messages when a vessel approaches the WHALESAFE detector at distance below 300 m.

The primary buoy houses also a PGS/GSM SEA9721 module which allows the remote configuration of the detector, the delivery of control SMS on the status of the instrumentation and it can be used as backup channel for data transmission.

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