SEADETECT: Multi-sensor Cetacean Collision Prevention in the Pelagos Area of the Mediterranean Sea

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Abstract

The Pelagos Sanctuary for Mediterranean Marine Mammals is a designated marine protected area in the north-western Mediterranean, encompassing waters between the Côte d'Azur (France), the Ligurian and Tuscan coasts (Italy), and Monaco, extending southward to the northern coastline of Sardinia. This area hosts a diversity of cetacean species. Due to high levels of maritime traffic, the Mediterranean Sea is a global hotspot for whale-vessel collisions. The frequency of both lethal and sub-lethal collisions in the region is considerable, with a general consensus that both direct mortality and long-term population-level effects significantly hinder the recovery and persistence of whale populations.
We present SEADETECT, a LIFE programme project aimed at the development of innovative technological solutions to help prevent lethal incidents between cetaceans and ships. Two complementary technical approaches with a combination of different sensors are developed to bring automatic whale awareness onboard vessels in order to avoid collisions.

1. Introduction

Whale-vessel collisions have become one of the primary causes of human-induced mortality for large cetaceans worldwide as a consequence of the increasing global volume of maritime traffic (Nisi et al., 2024; Shoeman et al., 2020). The Mediterranean Sea is one of several global high-risk areas of fatal incidents primarily involving fin and sperm whales (Minton et al., 2021). Collisions are not only a lethal threat to marine wildlife; vessel strikes also represent economic losses for ship owners and are recognized as a concern for human safety.

Enhanced maritime situational awareness is crucial to mitigate collisions with marine mammals and unidentified floating objects (UFOs). Additionally, ensuring safe navigation is essential in areas with high levels of traffic. However, the continuous monitoring of a vessel's surroundings by crew members requires substantial human resources while remaining prone to human error due to the inherent nature of maintaining prolonged human vigilance.

As a result, automation of this task is an active area of research, ultimately aiming to develop the Autonomous Surface Vehicle (ASV), similar in objective to its counterpart in the automobile industry. While an increasing number of autonomous navigation-assistance systems are integrated into the ship bridges, the challenge of collision prevention with cetaceans has not received equivalent attention.

Situational awareness tools for vessels exists but they are largely destined for the tracking of other vessels in the surroundings and up to the horizon of the vessel. Ships or UFOs are by their very nature visible on the water surface. They advance in a continuous fashion. For example, container ships move comparably slow but steady. Abrupt manoeuvres are infeasible. Smaller ships and race boats are faster, but also these do not move erratically but rather trace continuous curves. Continuity is key for tracking other surface vessels in a camera-based situation awareness system.

The detection of cetaceans at the surface is inherently challenging (Oliveira-Rodrigues et al., 2022) due to their diving and feeding behaviours, as well as their responses to anthropogenic disturbances. Both fin and sperm whales can spend considerable time submerged, with only brief and intermittent surfacing events e.g., (Panigada et al., 1999). To breathe, they break the surface and exhale a distinct jet of vapour which bursts upwards and can be seen at distance as illustrated in Figure 1a. Occasionally they are close to the surface and can be seen partially, like for example when sticking their fins out of the water. The perfect adaption to their habitat with the bluish-gray skin colour camouflaging them effectively and making them difficult to spot.

The cryptic behaviour of cetaceans and their difficult to predict surfacing, combined with the limited manoeuvrability of large vessels, are primary factors contributing to the high incidence of ship strikes. In addition, elevated levels of underwater noise produced by ships may exacerbate the situation by impairing cetacean communication and navigation. While not all collisions result in immediate mortality (Figure 1b), the cumulative impact of both lethal and sub-lethal incidents has been shown to have significant detrimental effects on cetacean populations e.g., (Cooke et al., 2020).

(a)

(b)

Figure 1. Sperm whale (a) creating a vapour jet while exhaling, (b) with evidence of a sub-lethal collision with a vessel showing clear scars caused by a ship's propeller on the trailing edge of the fluke.
Photos © Anne-Laure Minardi.

In 1999, the Pelagos Sanctuary for Mediterranean Marine Mammals was established by a multilateral agreement between France, Italy and the Principality of Monaco with the aim to promote common actions to protect marine mammals (Notarbartolo di Sciara 2007). This Marine Protected Area (MPA) encompasses waters between the Côte d'Azur (France), the Ligurian and Tuscan coasts (Italy), and Monaco, extending southward to the northern coast of Sardinia (Figure 2) and supports high densities of cetaceans. However, the region is subject to significant anthropogenic pressures, including seasonal activities related to tourism, commercial fishing, and both passenger and commercial maritime traffic. Historically, collisions between whales and vessels in this region have been notably high (e.g.,Nisi et al., 2024). Efforts at the international and regional levels led eventually to the establishment of the North-Western Mediterranean Particularly Sensitive Sea Area (PSSA) by the International Maritime Organization (IMO, 2023) and the Cetacean Migration Corridor SPAMI, designated by Spain. The region has been recognised as the North-Western Mediterranean Important Marine Mammal Area (Tetley et al., 2022) by the IUCN Marine Mammal Protected Areas Task Force.

Figure 2. The extent of the Pelagos Sanctuary in the Mediterranean Sea.

In a nutshell, the options to reduce vessel strikes are:
Speed reduction. For commercial shipping it would be possible to reduce the traveling speed without any significant economic impact (Jacob et al., 2016). However, enforcement of a lower speed for passenger ferries running between the continent and Corsica and Sardinia, would render this mode of public transport unsustainable.

Exclusion areas. While the establishment of exclusion areas that forbid maritime traffic to create protected habitats is generally welcome and positive, the populations cover most of the Pelagos Sanctuary and their movements and real-time distribution are not predictable.

Cetacean monitoring and broadcasting. Ferries are the fastest (Figure 3) and the vessels that navigate most, therefore it is the economic activity concentrating the largest ship strike risk in the Pelagos Sanctuary (Jacob et al., 2016). Monitoring solutions for these maritime routes are required to broadcast information on animal presence so that vessels can take corresponding preventive evasive actions.

Onboard Cetacean detection. The capability of the vessel to detect cetaceans needs to be improved with sufficient notice to act and to avoid encounters.

The project LIFE SEADETECT strives to demonstrate the feasibility of the latter two options in a complementary approach to reduce the risk of whale-vessel collisions.

The remainder of this paper is structured as follows: Section 2 presents the project. The Passive Acoustic Monitoring and related field tests are described in section 3. The Onboard Cetacean Detection System with its sensors and field campaigns are presented in section 4. Concluding remarks are found in section 5.

2. Project overview and objectives

LIFE SEADETECT is a 4-year project bringing together eleven partners from industry and research of Belgium, France, and Italy with the aim to reduce the risk of collisions with marine mammals and UFOs combining state-of-the-art technologies.

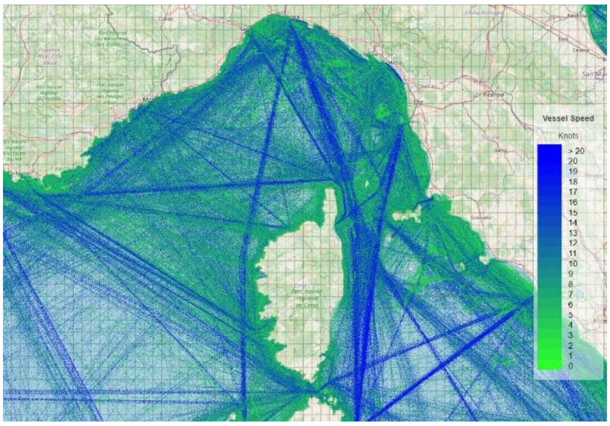


Figure 3. Shipping in the Pelagos Sanctuary where the colours represent speed. Ferries connecting main land with islands are the busiest and the fastest routes.
Map background © OpenStreetMap 2025.

The European Climate, Infrastructure and Environment Executive Agency (CINEA) provided funding in the scope of the LIFE programme through the EU Project LIFE-21-NAT-FR-LIFESEADETECT with grant agreement n° 101070722. The actions regarding the understanding of biological, behavioural, and ecological factors associated with whale collisions, particularly the investigation of fin whale avoidance responses to approaching traffic through biologging and satellite telemetry, are presented in (Paoletti et al., 2023). The remainder of the paper puts the focus on the technical solutions.

The project LIFE SEADETECT proposes two complementary approaches to detect cetaceans: The passive acoustic monitoring (PAM) system consists of a network of buoys at the sea ground which can detect animals based on their characteristic sounds (Erbe and King, 2008). The detections are broadcasted in real-time to the vessels at sea. Section 3 gives a detailed overview of this stationary system and the ongoing field campaign. In complement, the ship is equipped with the Onboard Cetacean Detection System (OCDS) which detects animals using a combination of sensors: cameras, 3D-LiDAR and radar. Alerts are displayed in a dedicated control centre (C2) on the bridge of the vessel so that corresponding actions can be taken by the crew. This system and the test campaigns are described in section 4.

3. Passive Acoustic Monitoring

Ferries connecting the continent to the islands habitually keep following the exact same routes back and forth. The trajectories do not diverge significantly, as can be seen in Figure 3. The idea is to create a shared, permanent infrastructure that allows users of this route to be warned of the presence of animals in real-time. This would enable vessels to take preventive actions, i.e. course corrections or speed reductions. A Passive Acoustic Monitoring (PAM) system (Sousa-Lima, et al., 2013) is the technical solution proposed by LIFE SEADETECT to detect the presence of cetaceans on the concerned routes.

The PAM system consists of a network of dedicated deep-sea acoustic modules, which will be deployed along the routes to be protected. Each module is equipped with a hydrophone listening continuously to the underwater soundscape. Real-time detection of fin and sperm whale vocalization on the recorded sound signals is done independently onboard each module by a embedded neural network. Detection times are relayed to the control centre on the shore, where the position of the animal can be determined by triangulation by combining them (Jang et al., 2022). Figure 4 shows the general setup of the PAM system.

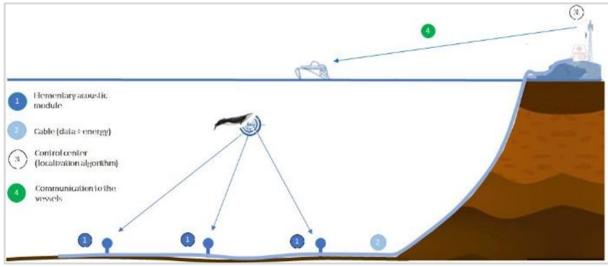


Figure 4. Concept of the PAM system.

In the autumn of 2024, the LIFE SEADETECT project reached an important milestone: the first full-scale deep-sea deployment of its passive acoustic monitoring system off the coast of Toulon, France. Four acoustic modules were deployed on the seafloor in 2500m depth. *Figure 5* gives an impression of the deployment. The devices were recording continuously for about 35 days. In addition, the WWF vessel Blue Panda was present in the first 10 days of this first measuring campaign to help collect ground truth, i.e. to record visual sightings of cetaceans.

Figure 5: Deployment of an acoustic module in the Pelagos sanctuary in October 2025.

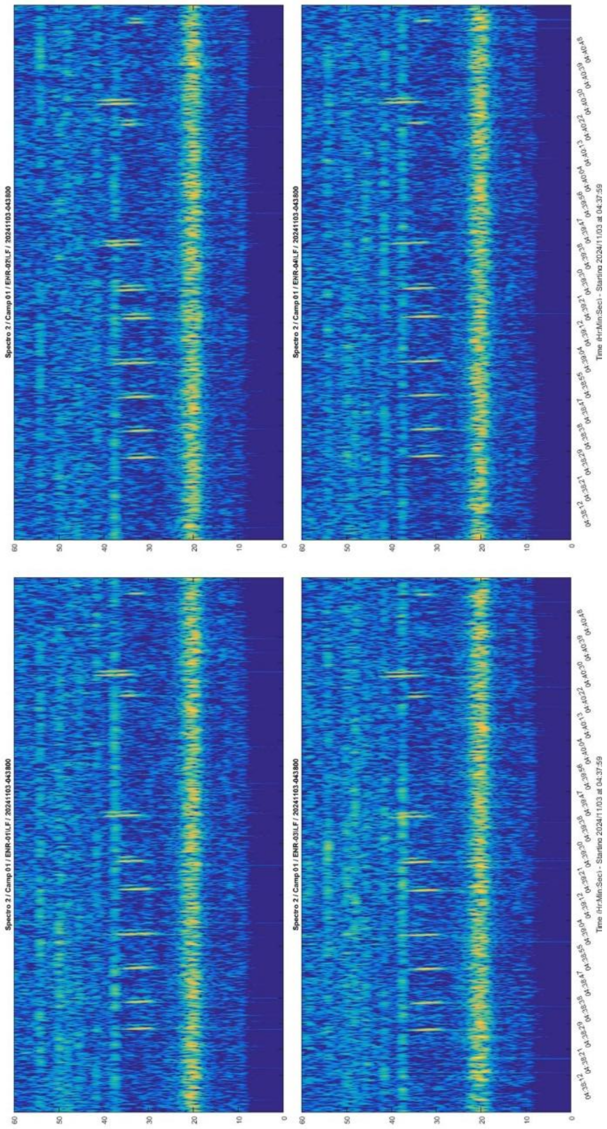


Figure 6. Sound data recorded during the preliminary tests.

Each acoustic unit took about 35 minutes to reach the ocean floor. The team spent a day deploying all four modules and another day verifying their precise location. Despite the depth, the positioning uncertainty was estimated to 10m x 10m x 5m, which was well within acceptable bounds for the detection algorithm.

To test the system, mimicked whale-like acoustic transmissions from various locations up to 10km away from the acoustic modules was performed. This tested both detection capability and the potential for triangulating whale positions in real-world conditions. The preliminary analysis of the collected data, a sample of which is presented in Figure 6, shows a continuous background at 20Hz formed by the accumulation of fin whale signals coming from far. Signals from closer animals emerge from the background, as can be identified in the data. Around 40Hz, distinct signals clearly emerge from the background synchronously in the data of the four hydrophones.

For automatic data processing, a deep learning algorithm has been trained which will be embedded in the acoustic modules laying on the ground floor. The neural network has been trained with 610 hours of past recording data which were annotated to create a database containing 4,726 10-second fin whale calls and several thousand audios with no fin whales. The audios are resampled to 220Hz to facilitate signal visibility, then transformed into spectrograms between 10 and 30Hz. These spectrograms were then analysed by convolutional neural networks. Two types of networks were tested: one two-dimensional, the other one-dimensional. The one-dimensional neural networks performed better (less overlearning), since the fin whale signal spans only a few frequencies. The length of the audios studied were also reduced (from 10 to 3 seconds), which improves accuracy (from 81% to 87%). Results were compared with existing deterministic methods. The outcome indicates that the AI model detects more Fin whale signals than deterministic methods, but the AI model tends to have increased false presences. False alarms on the detectors may not be an issue since it is assumed that the triangulation would fail. This assumption will be studied next.

4. Onboard Cetacean Detection System

At present, ships have little information on the location of cetaceans. To date, the real-time plotting of cetaceans, REPCET, (REPCET, 2025) is the state-of-the-art platform to broadcast known positions of animals among ships. However, it is a crowd-sourced platform and depends on volunteer work to share information on cetacean sightings, as well as volunteer participation from ship owners to make use of this information. As a result, the available information on cetacean presence is incomplete and adoption is not widespread. The PAM is a possible solution to provide systematic coverage for whale presence detection in the long term, but as of this moment, ships are in urgent need of a navigation-assistance solution that does not rely on third-party information sharing to prevent collisions with cetaceans.

With this perspective, the OCDS is developed by the project LIFE SEADETECT: The OCDS is a situational awareness tool intended to alert the crew of the presence of a whale in the proximity of the vessel. It benefits from the complementary characteristics of three different types of sensors: cameras, 3D-LiDAR and radar. The detections issued from the three sensor subsystems are received by a common processing module, which combines the data and evaluates the data. Eventually, alerts on animal presence are displayed in the control centre (C2) on a dedicated monitor on the ship's bridge in order to make the crew aware of the cetacean detection.

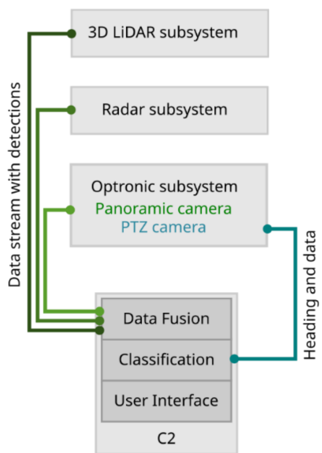


Figure 7. Overall system architecture of the OCDS.

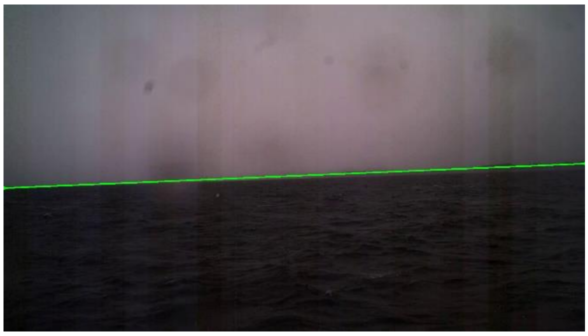
Figure 7 depicts the overall system architecture. The sensors are located on the upper deck of the boat and are installed on a specially fabricated mast shown in Figure 8. This dedicated installation assures an unobstructed view on the water surface in the heading of the ship. In the following subsections, the three different sensor subsystems and the field campaigns are presented briefly.

Figure 8. The sensors are located on a dedicated mast fabricated for the project and installed at the front of the ship: The radar dome on the top, the 3D LiDAR below and underneath it the cameras. A GPS antenna is installed on the right side of the mast.

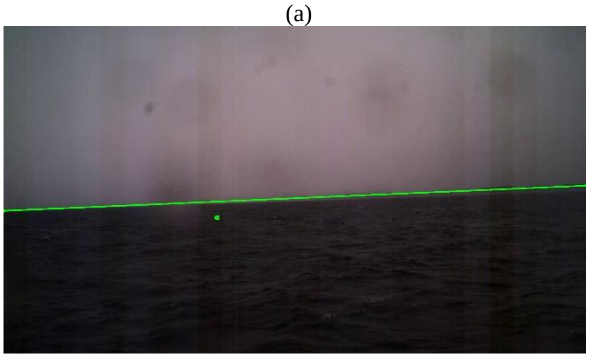
4.1 Optronic subsystem

The optronic subsystem of the OCDS consists of a 180 degrees panorama camera for continuous observation of the water surface and a PTZ[1] camera to zoom in on the animal, once it has been detected. As the ferries run over night, the panorama camera consists of two types of sensors: Each 60-degree sub-view has a sensor in the visible band, as well as in Long Wave Infra-Red (LWIR). The visible band sensor has a size of 4096px x 4096px and records at 15 fps, while the LWIR sensor has a size of 640px x 480px with 12µm of pitch, recording at 60 fps. The result are two independent video streams, which are processed in real-time by an FPGA that is part of a dedicated embedded vision processing unit (Nexvision, 2025) solution. The image data is then forwarded to a Nvidia AGX Orin processing unit running a dedicated AI-detection algorithm.

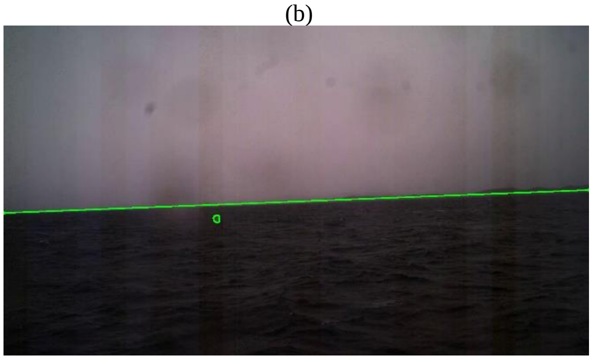
The detection method is based on a deep learning approach and decomposed in three steps: Using a residual network architecture with 18 layers (ResNet-18), the position of the horizon is inferred in an image. The image is subdivided in columns. For each column, a histogram is predicted by subdividing the column in cells and determining an offset for each cell. The algorithm outputs a segment fitted on the horizon per column. Figure 9a-d illustrates the identified horizon line. Knowledge of the horizon is then used to estimate the distance and the heading of detections.



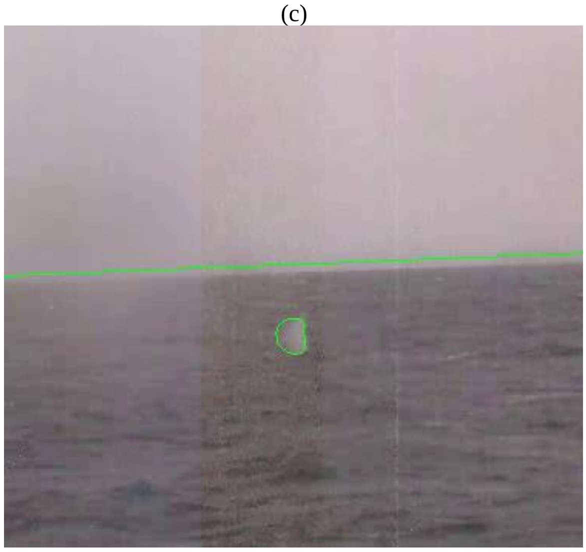
(a)



(b)



(c)



(d)

Figure 9. Detections of the cetacean's vapour jet in the image sequences: In all images the horizon line is visible. (b) and (c) shows the detection of the vapour jet. (d) is a colour processed version of the detection shown in (c) to make the vapour jet visible.

[1] PTZ: Pan-Tilt-Zoom

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The detection of cetaceans is based on the segmentation of the vapour jet ejected when the whale is at the surface to breathe as shown in Figure 1a. The semantic segmentation in *vapour jet* and *no jet* is done using a U-Net standard architecture. Once a vapour jet is identified in an image, a bounding box is estimated. An algorithm of type Region Proposal Network with a ResNet-18 backbone is used for this task. The choice for ResNet-18 has been made because it is the lightest of the family of residual network algorithms.

The optronic subsystem was installed during several months on the whale cruise ship of (Découverte du Vivante 2025) in spring 2024 to collect field data. Thanks to the ship's crew, ground truth could be obtained: On a whale sighting, a human observer would press a button and thus triggering the tagging of the video sequence with an animal present. During the field campaign, data collection with the LWIR camera was, however, not possible due to due difficulties in the provision of the technical components for the camera.

While image processing is done before the data is fed to the detection method, the design objective is twofold: On the one hand, image processing is only useful if it systematically yields superior results. On the other hand, the constraints imposed by real-time processing need to be respected. Therefore, several experiments were carried out with the obtained data to study the impact of different image processing methods like for example white balance, auto exposition, or a colour correction matrix.

The acquired field data of the visible camera was divided in a training set and a validation set. Figure 9b and c show examples of the detected vapour jet in images of the validation set, i.e. images that were not used for training the model. Figure 9d shows an image processed section of Figure 9d in order to make the vapour jet visible. However, for detection only raw image sequences obtained from the visible camera are used and the results are promising for the detection of cetaceans based on the vapour jet.

A test system version of the optronic subsystem was installed in late spring 2024 onboard the ship of (Découverte du Vivant 2025) to obtain field data during a whale watching cruise. This data was used to train the models and preliminary performance evaluation.

Figure 10. The Livox Avia 3D LiDAR scanner.

4.2 3D-LiDAR subsystem

A defining aspect of the LiDAR system setup is the deployment of a low-cost COTS sensor. The (Livox Avia 2025) has been selected due to its comparably large field of view and the ease of integration as the (Livox SDK 2025) provides interfacing with ROS2 (Macenski et al., 2022). The point cloud stream is sent continuously to the 3D LiDAR processing module, a ROS2-based data processing software. When a detection is made, the information is sent to the data fusion module of the C2.

The Livox Avia scanner is continuously measuring points, which are streamed in packages. Each package has the same amount of points, i.e. in single return mode there are 100 000 points, which does not cover the entire field of view. The device measures in a non-repeating pattern due to laser deflection mechanism using rotating prisms. As a result, the point data of a certain time period has to be accumulated in order to have a point sampling of the surfaces in the entire field of view, i.e. a point cloud frame of the stream. A frame rate of 100ms has been chosen for the point cloud stream. That way, the data is updated rapidly enough to enable tracking of the whale emerging from the water to breath. It also has to be noted that the ship is moving making a high frame-rate mandatory. Consequently, the data processing needs to be low latency as well.

The laser wavelength of the Livox Avia (905nm) is absorbed by the water. The obtained scan data therefore has to be a sampling of a surface emerging from or floating on the water, like whale skin, an UFO, or possibly a boat. In addition, reflections of the laser on the water surface are possible, which may lead to noise effects depending on the state of the water surface. While the whale is only at the surface for a few second, the frame rate of the point cloud stream allows a tracking of a group of points measured on this surface, i.e. the whale skin, over several frames. In contrast, random noise points are unlikely to be stable over several frames and likely sparse.

An occupancy-grid inspired method has been developed to identify relevant groups of points in the point cloud stream. A voxel space is created over the estimated volume of the scanner's field of view. Each voxel is initialized in an *unoccupied* state. It is also possible to exclude regions, i.e. voxel cells, entirely from the processing by assigning to them the label *occupied*. The points of the incoming point cloud are mapped to the voxel space. Points mapped to *occupied* labelled voxels are ignored. Points that are mapped to non-background voxels provoke state changes: A voxel can transition from the label *unoccupied* to *appearing*, and *tracked*. It keeps being in *tracked* state while points map to this voxel. If there is no point mapping to a voxel that was so far in an *appearing* or tracked state, the voxel is labelled *disappearing*. After *disappearing*, the voxel reset to unoccupied state if no point has mapped to it in the subsequent frame.

After each frame, clusters are identified in the stateful occupancy-grid using a union-find data structure (Tarjan 1975). Clusters can only be consisting of *tracked* voxel cells, which implicitly means points in this region were measured over at least two subsequent frames. In this way, noise points are unlikely to create clusters. At the same time, the voxel cell size has to be chosen so that the offset of surfaces between incoming point clouds are not dissociating potential clusters w.r.t. the movement of the ship. The cluster voxels are mapped back to the point data to calculate the bounding box, which is eventually sent to the C2 with the isolated group of points sampled on the surface. Further filtering can be applied to exclude groups of point if the number of points is outside a permitted interval.

Preliminary testing of the LiDAR subsystem was carried out in August 2024 onboard a ship of (Découverte du Vivant 2025) during a whale watching cruise. Analysis of the collected data

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showed a good correspondence between observations and detections.

4.3 Radar subsystem

The radar subsystem of the OCDS, shown in Figure 8 consists of a Band X pulse compression coherent radar. The radar is equipped with a 12KW chirpable magnetron, and a gyrostabilized antenna, enabling an optimal illumination of the radar scenery. In addition, it is equipped with a 600 x 250mm carbon fiber slotted waveguide antenna (SWA) with an azimuthal beamwidth of 3.8°. While being relatively small, this antenna has a 30dBi boresight gain while having sidelobes inferior to -25dB.

Thanks to its coherent front end, real time doppler processing can be applied, which drastically improves the quality of the radar echo and allows to filter unwanted echoes. With the chirpable magnetron, the pulse waveform up to 20MHz of bandwidth can be obtained. Using advanced pulse compression techniques, this bandwidth can be converted to pulses of 7.5m of resolution in distance enabling the detection of small or elusive targets.

As whale appearances on the surface are sporadic and of very short duration, a sufficiently high refresh rate of the data is necessary. Hence, the rotation speed of the radar has been configured to 43rpm, resulting in a frame every 1.4 seconds to maximise the probability of detection.

Although the radar is able to detect at 360°, mute sectors have been enabled to prevent illumination of sensitive components such as the ship's magnetometer. The effective field of view of the radar is therefore 180° in the heading direction of the ship. Similarly, the instrumented range of the radar has been configured to a limit of 4 NM to optimise detection of cetaceans, even if it is able to detect ships and structures at more than 100km. In doing so, the system avoids acquisition cells packing and allows to have a sampling distance of 1.5 m. Using such a fine resolution and doppler processing, detection of relevant echoes in sea clutter is improved.

The radar video is sent to the radar processing unit (RPU), where post processing is applied. Several CFAR (Constant False Alarm Rate) filters such as Sea and Rain clutter filters are applied to the radar video in order to filter out unwanted echoes. Afterwards, a segmentation algorithm is applied to the filtered video to isolate multiple echoes in term of their size and other characteristics. The results of this algorithm are the detections containing information w.r.t. echoe amplitude, azimuthal and distance position. These detections and the video are sent to the data fusion module of the C2 using the ASTERIX communication protocols.

Preliminary tests of the radar were carried out in October 2024 onboard the whale watching cruise ship of (Découverte du Vivant 2025). During this cruise several cetaceans, such as dolphin and fin whales has been spotted by the radar and a human observer. Following this cruise, the collected data was used by to further improve the post processing algorithm.

4.4 Sensor data processing

The detections of all sensor subsystems are sent to the data fusion module that is part of the C2. All sensor data is timestamped with time information from a common time server, but as the subsystems are not synchronised, new detection data may arrive at any moment. The purpose of the data fusion module is to handle this incoming asynchronous stream of data and to evaluate it to track potential objects of interest. The probability of more than one sensor generating the same spurious detection is low considering the complementary nature of the sensors. The combination of detections of the different sensor types therefore makes the result more robust. The confidence in detections that contribute to the tracking of an object of interest is higher.

While the data fusion module creates situational awareness data with the generation of tracked object trajectories, the object of interest is not classified and as a result still of unknown nature. In a following classification stage, the information about the tracked object of interest is sent to the optronic subsystem and the PTZ camera is oriented to zoom in on this object. The obtained image is processed and classified with a model previously trained on cetacean images. The classification result is sent back to the C2.

If the classification result confirms the presence of a cetacean, it is displayed as an alert on the C2, the graphical user interface installed on the ship's bridge so that the crew can take evasive action. Figure 11 illustrates the user interface.

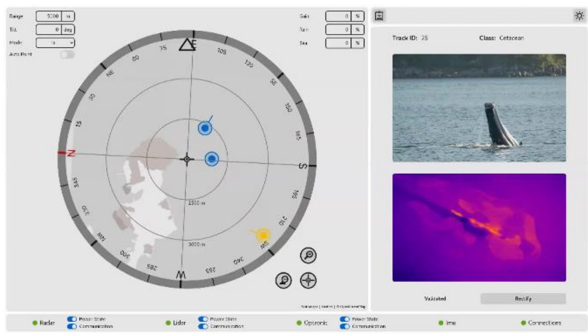

Figure 11. The C2 interface on the bridge displaying cetacean detection alerts.

4.5 Field campaigns

Two field campaigns, as well as a demonstration campaign are planned in the scope of the project. The first prototype of the OCDS was installed in early 2025 on a passenger ferry of (La Méridionale 2025) running nightly between Marseille and Ajaccio. The following weeks were dedicated to ensure a correct and continuous functioning of the OCDS prototype onboard. Evaluation of the detection performance is planned for the end of 2025. In the meantime, a second system will be installed on another passenger ferry of (La Méridionale 2025) in late summer 2025 for a field campaign until early 2026.

The first OCDS prototype will eventually be transferred to the research vessel (Belgica 2025) of the Royal Belgian Institute of Natural Sciences, which can be considered a floating laboratory in the North Sea. The objective of this campaign is to demonstrate that it is possible to transfer the system to another kind of vessel and to confirm the detection capabilities in a different setting, with the local cetacean species and in other environmental conditions.

5. Conclusion

Preventing vessel-whale collisions is an urgent issue because it has a direct impact on the population of already threatened cetacean species worldwide. It demands adequate technical solutions to enable ships to be aware of the presence of cetaceans in order to take evasive action. LIFE SEADETECT develops two solutions, which are complementary, in response to this need: A stationary Passive Acoustic Monitoring system to detect the presence of animals underwater along the major traffic routes, which would eventually enable the vessels to adapt their trajectory once the detections are broadcasted; and an onboard cetacean detection system based on a combination of sensors (optronic, 3D LiDAR, radar) aimed at bringing cetacean presence awareness onto a ship's bridge. This ambition is in line with international strategic plans, e.g. (International Whaling Comission 2022), and environmental guidelines, e.g. (International Whaling Commission 2014). Moreover, the field campaigns in the Pelagos Sanctuary, ensures that the project's results will be relevant towards current regional and national requirements e.g. (Fortuna 2021).

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References

Belgica, 2025. https://odnature.naturalsciences.be/belgica, accessed : 2025-03-06.

Cooke, J.G., 2020. Eubalaena glacialis (errata version published in 2020). The IUCN Red List of Threatened Species 2020: e.T41712A178589687. doi.org/10.2305/IUCN.UK.2020-2.RLTS.T41712A178589687.en, accessed: 2025-03-31.

Erbe, C., King, A. R., 2008. Automatic detection of marine mammals using information entropy. *JASA*, 124(5), 2833–2840.

Fortuna, C., 2021. Management Plan for the Pelagos Sanctuary 2022-2027. https://pelagos-sanctuary.org/documents/#93-95-wpfd-2-management-plan, accessed: 2025-03-06.

International Whaling Commission, 2022. Strategic Plan to Mitigate the Impacts of Ship Strikes on Cetacean Populations 2022-2032. https://archive.iwc.int/pages/view.php?ref=19858, accessed: 2025-03-06.

IMO, 2023. Designation of the North-Western Mediterranean Sea as a Particularly Sensitive Mediterranean Sea Area. Resolut. MEPC38080 26, 1–24.

Jacob, T., Ody, D. Gallou, R., L. David, N. Di-Méglio, and Folegot, T., 2016. Characteristics of maritime traffic in the Pelagos sanctuary and analysis of collision risk with large cetaceans, WWF France report.

Jang, J., Meyer, F., Snyder, E. R., Wiggins, S. M., Baumann-Pickering, S., & Hildebrand, J. A., 2022: Bayesian Detection and Tracking of Odontocetes in 3-D from Their Echolocation Clicks. arXiv:2210.12318.

Découverte du Vivant, 2025.
https://www.decouverteduvivant.fr/, accessed : 2025-03-06.

La Méridionale, 2025. https://www.lameridionale.fr/fr, accessed: 2025-03-06.

Livox, 2025. https://www.livoxtech.com/avia, accessed: 2025-03-06.

Livox, 2025. Livox SDK. https://github.com/Livox-SDK/Livox-SDK, accessed: 2025-03-06.

Macenski, S., Foote, T., Gerkey. B., Lalancette, C., Woodall, W., 2022, Robot Operating System 2: Design, architecture, and uses in the wild, *Science Robotics*, 7(66).

Minton, G., Folegot, T., Cosandey-Godin, A., Jacob, T., Lancaster, M., Ushio, M., 2021. Shipping and cetaceans: A review of impacts and mitigation options for policymakers. WWF Report 72.

Nexvision, 2025. eVPU. https://nexvision.fr/products/evpu-video-processing-unit/, accessed: 2025-03-06.

Nisi, A.C., Welch, H., Brodie, S., Leiphardt, C., Rhodes, R., Hazen, E.L., Redfern, J.V., Branch, T.A., Barret, A.S., Calambokidis, J., Clavelle, T., Dares, L., de Vos., A., Gero, S., Jackson, J.A., Kenney, R.D., Kroodsma, D., Leaper, R., McCauley, D.J., Moore, S.E., Ovsyanikova, E., Panigada, S., Robinson, C.V., White, T., Wilson, J., Abrahms, B., 2024. Ship collision risk threatens whales across the world's oceans. *Marine Conservation*, 386(6724), 870-875.

Notarbartolo-di-Sciara, G., Agardy, T., Hyrenbach, D., Scovazzi, T., Van Klaveren, P., 2007. The Pelagos Sanctuary for Mediterranean marine mammals, Acquatic Conservation: Marine and Freshwater Ecosystems, 18(4).

Oliveira-Rodrigues, O., Correia, A.M., Valente, R., Gil, Á., Gandra, M., Liberal, M., Rosso, M., Pierce, G., Sousa-Pinto, I., 2022. Assesing data bias in visual surveys from a cetacean monitoring programme. *Scientific Data*, 9, 682.

Panigada, S., Zanardelli, M., Canese, S., Jahoda, M., 1999. How deep can baleen whales dive? *Mar Ecol Prog Ser*, 187, 309-311.

Paoletti, S, Rumes. B, Pierantonio, N., Panigada, S., Jan, R., Folegot, T., Schilling, A., Riviere, N., Carrier, V., Dumoulin, A., van Hamme, D., Marquis-Laisné, G., Bruliard, F.-A., Petitpierre, F., Demoor, D., 2023. SEADETECT: developing an automated detection system to reduce whale-vessel collision risk, *Research Ideas and Outcomes*, 9:e113968.

Schoeman, R.P., Patterson-Abrolat, C., Plön, S., 2020. A Global Review of Vessel Collisions With Marine Animals. *Frontiers in Marine Science*, 7, 292.

Sousa-Lima, R. S., Norris, T. F., Oswald, J. N., & Fernandes, D. P., 2013. A Review and Inventory of Fixed Autonomous Recorders for Passive Acoustic Monitoring of Marine Mammals. *Aquatic Mammals*, 39(1), 23–53.

Tarjan, R. E., 1975. Efficiency of a good but not linear set union algorithm. *Journal of the ACM*, 22(2), 215–225.

Tetley, M. J., Braulik, G. T., Lanfredi, C., Minton, G., Panigada, S., Politi, E., Zanardelli, M., Notarbartolo di Sciara, G., Hoyt, E.. 2022 The important marine mammal area network: a toolfor systematic spatial planning in response to the marine mammal habitat conservation crisis. *Front. Mar. Sci.* 9, 841789.