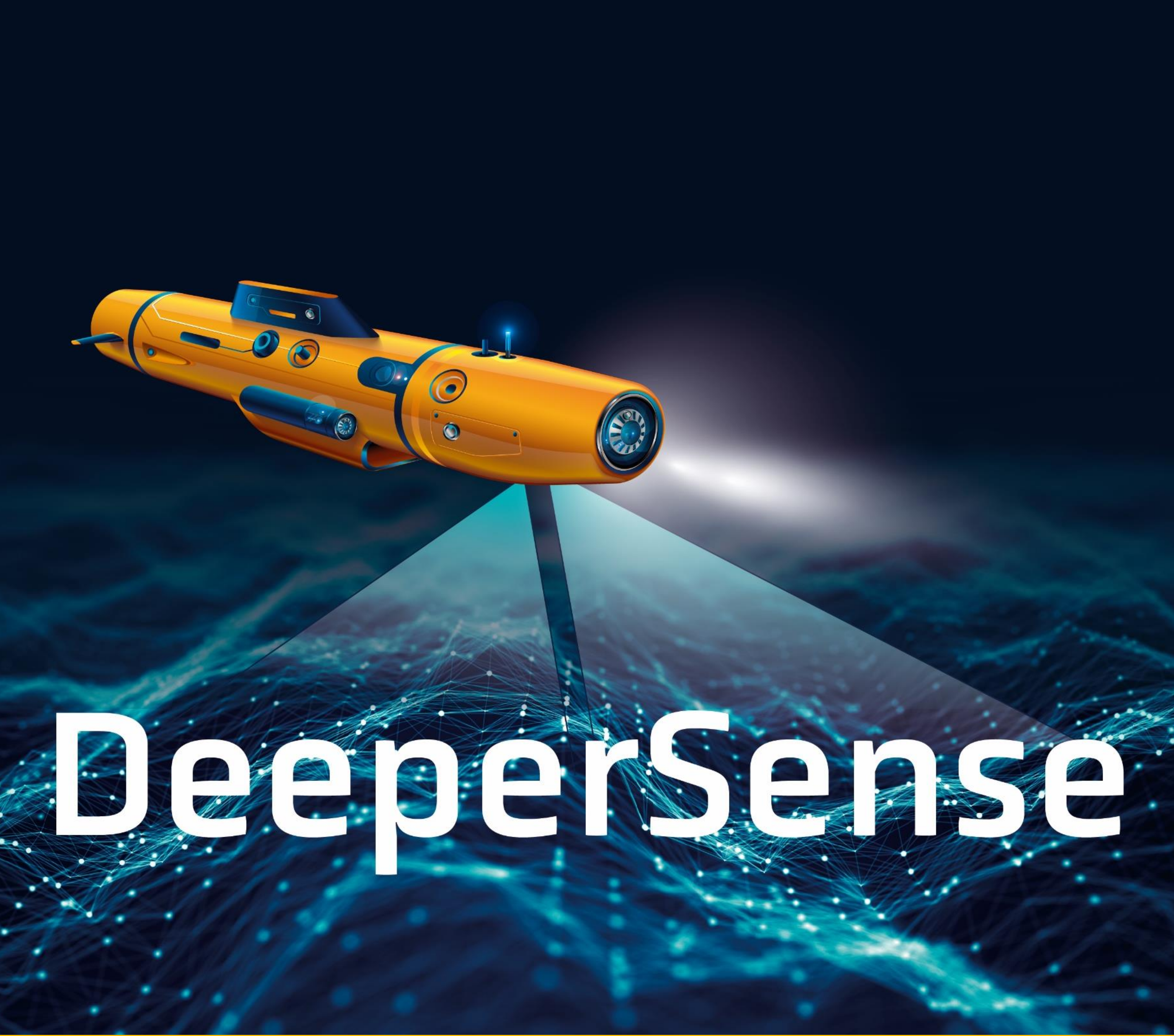

Use-Case Requirements

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1. EXECUTIVE SUMMARY

The main objective of DeeperSense is to enable a significant improvement in non-visual sensing for underwater operations. Therefore Artificial Intelligence (deep learning) will be applied to enable a knowledge transfer between sensors that use different physical sensing concepts and modalities.
To achieve this in a user-driven way the following 3 different Use-Cases will be addressed;

- Hybrid AUV for diver safety monitoring
- Surveying and monitoring complex benthic environments
- Efficient exploration and mapping of the sea bottom

This deliverable documents the use-case specific end-user requirements, which lay the foundation for the further development of the DeeperSense project. Thus, enabling the consortium to develop solutions which address end-user needs.

In the first part of the document (chapter2) the reader is introduced into the approach followed here.
The following part is the main section (chapter 3), here all three use cases are described in a more detailed way, then the specific task that has to be addressed is described, followed by the individual requirements.
Some of the listed requirements go well beyond the scope of DeeperSense, however for the later exploitation of the results end-users believed that these resemble also a valuable contribution.
It is important to mention that these additional requirements will not be used to rate the overall success of DeeperSense during the final demonstration.
The last part (chapter 4) is a brief summary.

2. INTRODUCTION

The main objective of DeeperSense is to enable a significant improvement in non-visual sensing by applying methods from Artificial Intelligence (deep learning) to enable a knowledge transfer between sensors that use different physical sensing concepts and modalities. By leveraging and combining the power of visual and non-visual sensors, this data-driven inter-sensoric learning concept will help to significantly improve the environment perception capabilities of autonomous robots. This will enable new functionality and initiate a step-change in the performance ability and reliability of professional service robots and other autonomous robots under real-world conditions, in particular in harsh environments. As it represents the prototype of an extremely harsh and difficult (from a sensing point of view) environment, the DeeperSense concept will be demonstrated in the marine / underwater application domain, with a focus on visual and acoustic sensors.
The DeeperSense concept will be demonstrated in three use cases. These use cases were selected based both on their importance for pushing the state-of-the-art in robotics and for their societal relevance.
To enable the technological development of the DeeperSense platform and the three use case specific algorithms, this document provides the requirements as defined by the users representing their use-cases.
Therefore, chapter three is separated in the three use cases. For each use case;

- a detailed introduction for the use case,
- a detailed description of the specific task for the algorithm and platform combination,
- as well as the end-user driven requirements

are provided in the following.

Although, DeeperSense is not about the design of platforms, but on the creation of efficient algorithms to increase the usability of various sensors, a holistic approach is necessary to ensure a future exploitation of the results. Therefore, this deliverable will also address these use case specific requirements that may not be foreseen or accounted for in the context of this project.
To allow a more structured description of the specific requirements the following four categories will be used to group them for each use case;

- User Experience (handling of front end)
- Regulatory aspects (all requirements on legal aspects/safety/ethics, etc)
- Operational requirements (description of the needed output, interoperability, data security, data repository/recording, compatibility/operating system requirements, interfaces)
- Plattform parameters (requirements needed to ensure a potential deployment of the solution, like run/operation time, weight class, size, propulsion, etc…)

To enable the consortium to focus on the most critical aspects end-users will also prioritize their requirements:

- A – is mission crucial
- B – should be realized
- C – would be beneficial

These requirements have been compiled to three use case specific list, like the following example.

Figure 1: Exemplary table summarizing the functional requirements

Category	Requirement	Description	Priority
User-Experience	General handling	Needs to be deployable without extensive training of the operators. The User Interface should be self explanatory..	**A**
Regulatory aspects	Safety Rules	Any threats by the system for the diver must be avoided	**A**
Operational requirements	Broadcast to the diver	Transfer the images/videos to the diver, either via heads-up display or small tablet-like solutions.	**C**
Plattform parameters	Operational / run time(*)	The system should be operable for 2 hours. If operated untethered on-site change of power packs should be possible,. If the system's power supply is cable bound, both 12V und 240 V should be possible.	**B**
...	...	...	...

The requirements listed in this document are the result from meetings with the owners of the three individual use cases. The information was either collected during interactive workshops with the users or in consultations between the partnering institutions.

The consortium is well aware that some of the user needs which result in the requirements cannot be addressed by DeeperSense. However, these additional requirements are valuable for future exploitation activities. Therefore, they will be listed in chapter 3, but be marked with an asterix in brackets (*) and cannot be used to evaluate the project's success at the final demonstration (WP6).

3. USE-CASE BASED REQUIREMENTS

1. USE CASE 1 „HYBRID AUV FOR DIVER SAFETY MONITORING“

1. Introduction to the use case

In many underwater applications related to inspection & maintenance, professional divers still play an important role. While even the regular professional/industry diving is inherently dangerous and needs to be well planned and monitored, safety aspects are even more important for professional diving related to civil protection and emergency response. Here, compared to standard industry diving, only a very limited time for planning may be available while the divers have to perform complex tasks such as welding, cleaning, and debris removal.

The divers have to perform these activities in a complex and mainly industrial and artificial environment, such as ports, piers, industrial basins, and channels, which makes it difficult to navigate and self-localize. In addition, even if visibility is good at the beginning of the dive, almost all of the activities mentioned above cause the turbidity of the water to increase, which leads regularly to white-out situations, where the team on-land monitoring the divers is not able to visually detect them anymore. Figure 1 shows some tasks that cause turbidity in the surrounding of the diver: the use of a pneumatic drill (A), drilling into a piece of wood (B), or pumping operations (C).

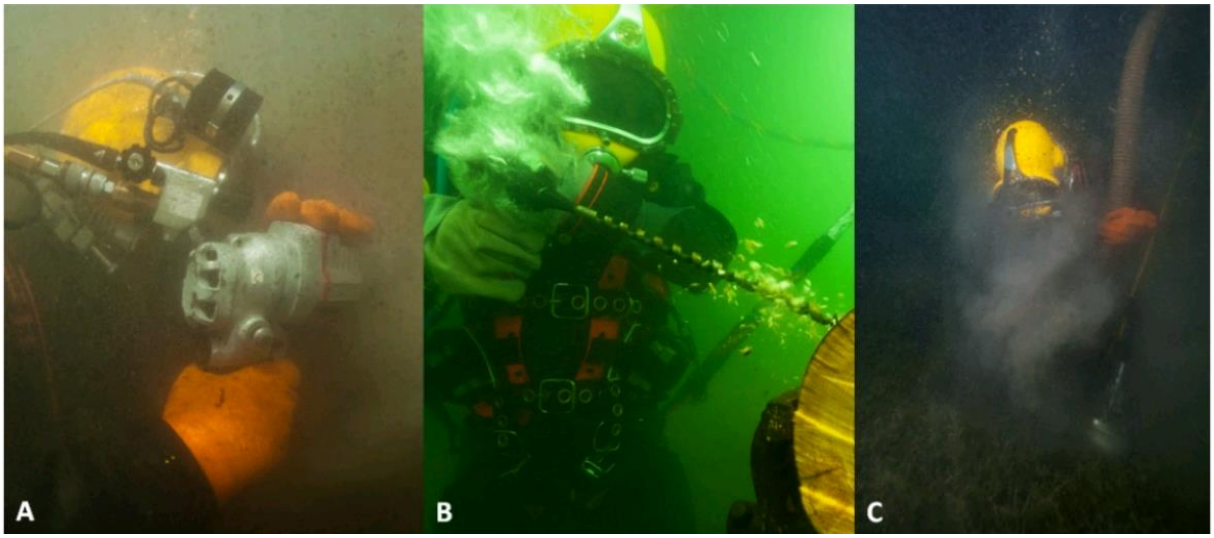

Figure 1: Typical diver operations causing white-out (Photos: Maier/THW)

In such white-out situations, as in standard working situations, it is essential for the safety of the diver to receive guidance and instructions from an operator in the mission control center who has an overview of the situation and knows where the diver is, what he/she is doing, and where he/she should move to next.

State-of-practice diving equipment includes a first-person viewpoint camera directly on the helmet. In addition, ROVs are used sometimes to observe and instruct the diver from a third person perspective (Figure 1-3). Under perfect visibility conditions this may suffice, but to monitor heavy underwater work (creating significant turbidity), both the suit camera and the ROV camera are of limited use.

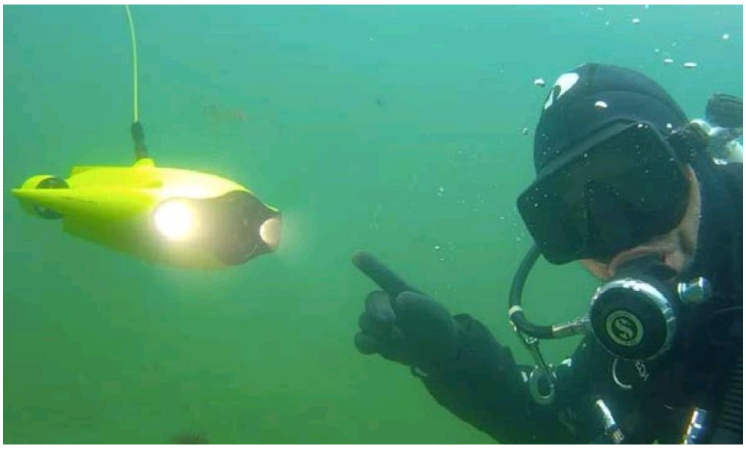

Figure 2: ROV watching diver

The use-case will be driven by end-user THW and demonstrated with real divers in a training facility under continuously decreasing visibility conditions interpret situations and to make decisions (e.g. trajectory re-planning) based on these interpretations.

2. Task of the AUV/sensors

In DeeperSense, a hybrid AUV (DFKI's DAGON) will be equipped with a sonar sensor that has learned from a HD camera how to reliably interpret low-resolution sonar signals of a diver and transform them into a visual view. This visual image of the diver will then be used by the human operator in the control center to evaluate the actions, state and position of the diver as well as by the "follow-me" control algorithm of the hybrid AUV to keep a constant distance to the diver (Figure 3-3). As this application relies only on the acoustic SONAR data, it will not be affected by low visibility, darkness or other optical disturbances.

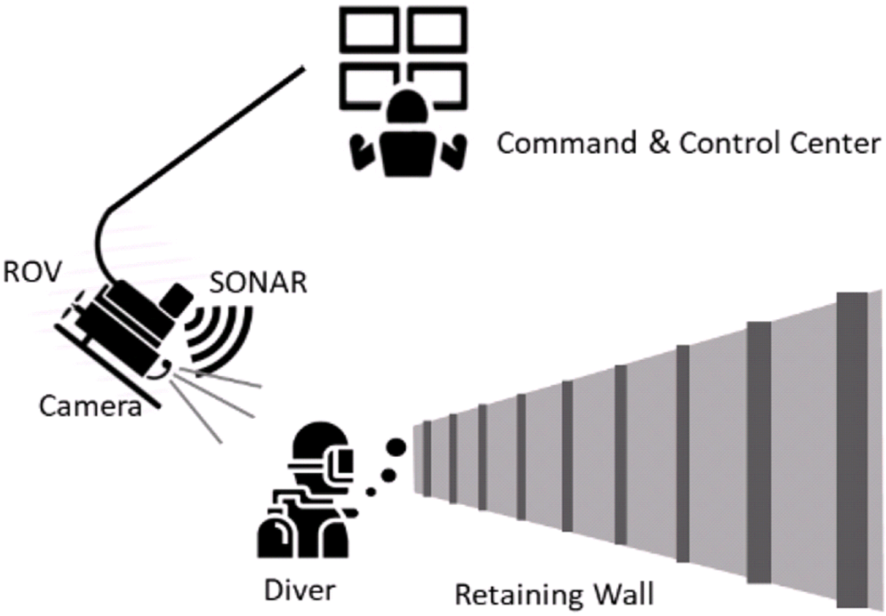

Figure 3: Schematic view illustrating the use-case 1

3. Functional requirements

In two online workshops end-user's from the field of civil protection discussed with the partners DFKI (Academia) and Kraken (Industry). During these two 4 hour long workshops the field of operative underwater surveying and working was discussed. Practitioners could lay out their typical activities and formulate their needs. As mentioned earlier, these needs also result in requirements which cannot be addressed by DeeperSense.

Table 2: Functional requirements for Use Case 1

Category	Requirement	Description	Priority
User-Experience	General handling	Needs to be deployable without extensive training of the operators. The User Interface should be self-explanatory..	**A**
	Control (*)	The controlling unit should be comparable to today's gaming consoles, to ease the handling.	**B**
		The operator's control unit should be combined with a screen.	**C**
	Visibilty (*)	A selectable night mode is needed to ensure the use at low light situations without blinding the operator.	**A**
		The screen needs to be readable a direct insolation as well.	**A**
	Sounds	The system should alert the operator acoustically in the case of any problem (front and back end)	**B**
	Directional information	The image needs to be annotated with directional information to enable the operator to navigate the diver even in white-out situations. Therefore, the following information needs to be available: viewing direction (horizontal & azimuthal) depth distance to the diver	**A**
		The system should recognize the positioning of the diver, e.g. • is the diver facing the AUV? • is the diver flipped over/upside down? • is it possible to see the hands of the diver?	**B**
	Signaling to the diver (*)	The operator should be able to navigate or point the diver. Possible options are:	**C**

		• acoustically • signaling/Warning light • via AR • or via a laser pointer / light	
Regulatory aspects	Safety Rules	Any threats by the system for the diver must be avoided.	**A**
	Risk assessment	Specific risk assessment for the AUV Risk assessment for each individual diving mission	**A** **A**
Operational requirements	Interoperability	Interface to transfer the live data to other systems.	**B**
	Data security	The system needs to be protected against data theft and manipulation	**B**
	Data recording	Besides the image data also parameters like depth, temperature, horizontal/azimuthal orientation	**A**
	Interfaces(*)	Image/data broadcasting to other vehicles or command posts using Wifi for example	**B**
	Resolution	The image resolution needs to be >= 3x3 cm to enable the operator to observe the diver's activities. In the best case the resolution is up to 0.5 x 0.5 cm, to make ropes visible.	**A** **B**
	Object identification	The system will provide images that enable the operator to identify; • the body parts of the diver • the tools used • single objects the diver is working on • the surrounding of the diver The diver will be recognizable even if he is partly covered by algae or other vegetation, or behind an object	 **A** **B** **B** **C** **A**
	Streaming quality	The video broadcast needs to be live and more than 15 frames per second Better would be a quality of >30 FPS to enable the operator for a detailed monitoring	**A** **B**
	Safe Distance	The AUV needs to keep a safe distance of 2.5 m to the diver.	**A**
	Broadcast to the diver	Transfer the images/videos to the diver, either via heads-up display or small tablet-like solutions.	**C**
	Emergency	In case of an emergency a buoyancy device	**C**

	support (*)	should be provided to or accessible for the diver	
	Training(*)	A precise and easy to access user introduction is needed Online instructional courses are needed	A B
	Monitoring	The system provides a vital monitoring as decision support to the operator. As such the system recognizes from the exhale bubbles breathing frequency and intensity or the speed of movement to identify artefacts which point toward any problem the diver might have.	B
	Follow Me mode	The system enables the AUV to follow the diver autonomously at a safe distance from >2.5 m	A
Plattform parameters	Operational / run time(*)	The system should be operable for 2 hours. If operated untethered on-site change of power packs should be possible,. If the system's power supply is cable bound, both 12V und 240 V should be possible.	B
	Weight Class(*)	The systems needs to allow a safe handling for one or two people, therefore the weight should be at best >= 25 kg and < 30 kg, but should not exceed >50 kg	 B A
	Propulsion(*)	If using a propeller, it needs to be secured so that the lifeline or body parts can not be injured. At best the system has a jet propulsion.	A C
	Propeller protection	If a propeller is used a proper protection by casing or cage is needed, to protect the diver	A
	Speed(*)	The AUV should have two speed settings (slow/fast) where the slow setting allows a safe deployment in the vicinity of the diver At the slow setting the maximum speed should be around 2.5 m/s.	A
	Color scheme(*)	AUV should be painted in an easy to identfy color scheme (e.g. orange, yellow, red) Additionally positioning lights should mark the position of the AUV	A
	Field Maintenance (*)	Small maintenance tasks should be performable by the user in the field.	B
	Impact reduction (*)	To reduce the danger fort he divers the AUV should not have any sharp edges, and if feasible some collision buffers.	A B
	Connections (*)	Connections and plugs should be kept to an minimum to avoid any problems caused due to the field deployments such as sand in the connector or damaged plugs.	B
	Hoovering mode	The AUV should be able to stay stable in a	A

	(*)	position even up to a current of 1.5m/s	
	Allowed temperature (*)	The system should be deployable all seasons and therefore allow operations from -10 to 45°C.	**A**
	Handling (*)	Handles are needed for two users to transport the AUV	**B**
	Emergency accent(*)	In the case of a technical emergency, e.g. system failure, the plattform should accent to the surface to avoid material loss.	**A**

2. USE CASE 2 „SURVEYING AND MONITORING COMPLEX BENTHIC ENVIRONMENTS, E.G., CORAL REEFS“

1. Introduction to the use case

This use case deals with advanced sensing for autonomous navigation of an Autonomous Underwater Vehicle (AUV) in complex structures underwater. Exploring such structures (such as a coral reefs) with an AUV requires advanced environment perception and navigation capabilities, in particular related to Obstacle Avoidance (OA). OA for AUVs has gained importance as the use of AUVs is increasing rapidly in a wide range of scientific, commercial and military applications, such as archaeological surveys, ecological studies and monitoring, wreck exploration, subsea equipment inspection and underwater mines detection.
Visual sensors (cameras) and acoustic sensors (sonar) can both be used to detect obstacles underwater. However, acoustic sensors, which are most commonly used for OA in underwater applications, are not effective at close range (< 5m) due to interference noise and multi-path phenomena. In addition, acoustic sensors can provide only 2D information on the surroundings, rather than a full 3D structure, with limited resolution and details. Acoustic OA is therefore almost useless in complex underwater environments that require delicate manoeuvring, such as artificial structures, wrecks, canyons or reefs, and standard OA schemes are very basic, usually only instructing the AUV to ascend until the obstacle disappears from the sensor.

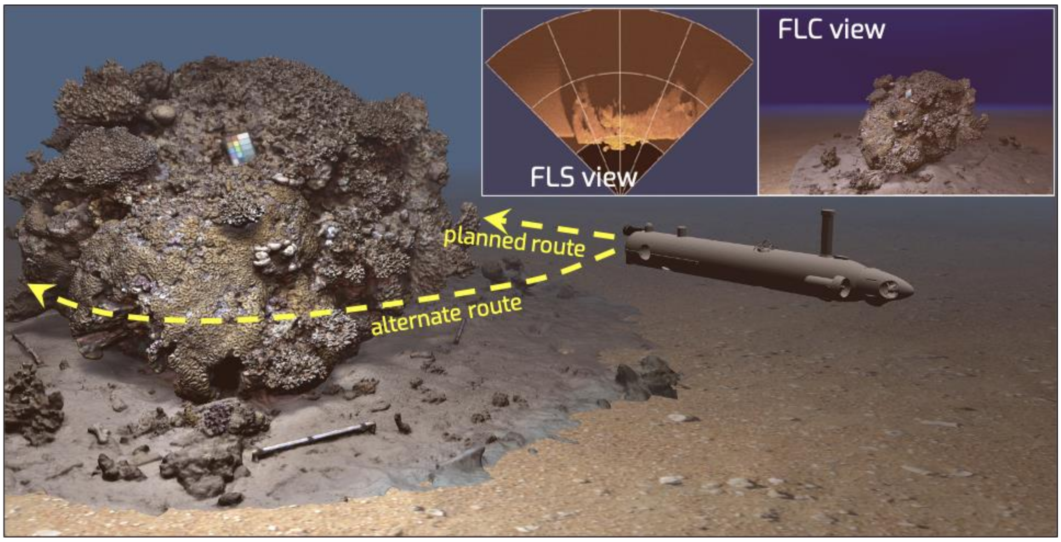

Figure 4: Schematic view illustrating the use-case 2

Optical OA, on the other hand, is still in its infancy for underwater applications, with only few recent academic attempts in clear water and simple scenes, but no commercial products. This is mainly due to poor visibility and contrast in underwater optical images that result in a very limited imaging range. Nevertheless, optical OA would be a better solution for close-range OA and navigation (Fig. 4).

In this use case we aim to develop a novel **acoustic-visual OA system** to facilitate delicate robotic underwater missions such as surveys of complex underwater environments. This OA system will be able to overcome the current limits of OA in complex environments by combining information from a Forward Looking Sonar (FLS) into a Forward Looking Camera (FLC), thus enhancing the sensing capabilities of the visual camera in low visibility conditions.

Figure 5: Shift from flying above (left) to within (right) coral reef

The system will be integrated with an AUV and used to explore a coral reef in the Red Sea. The new OA system will enable the AUV to fly right through the coral reef instead of having to stay well above the reef, which is the standard procedure currently (Fig. 5).

Specifically, we are going to focus our use case and work ground is Eilat's Coral Beach Nature Reserve, the northernmost shallow water coral reef in the world, that covers 1.2 KM of shoreline in the red sea. Israel Nature and Parks Authority are focusing their research on the coral`s live coverage, sea grass coverage and marine life biodiversity. Our purpose is to bring our technologies to that effort (Figs. 6,7).

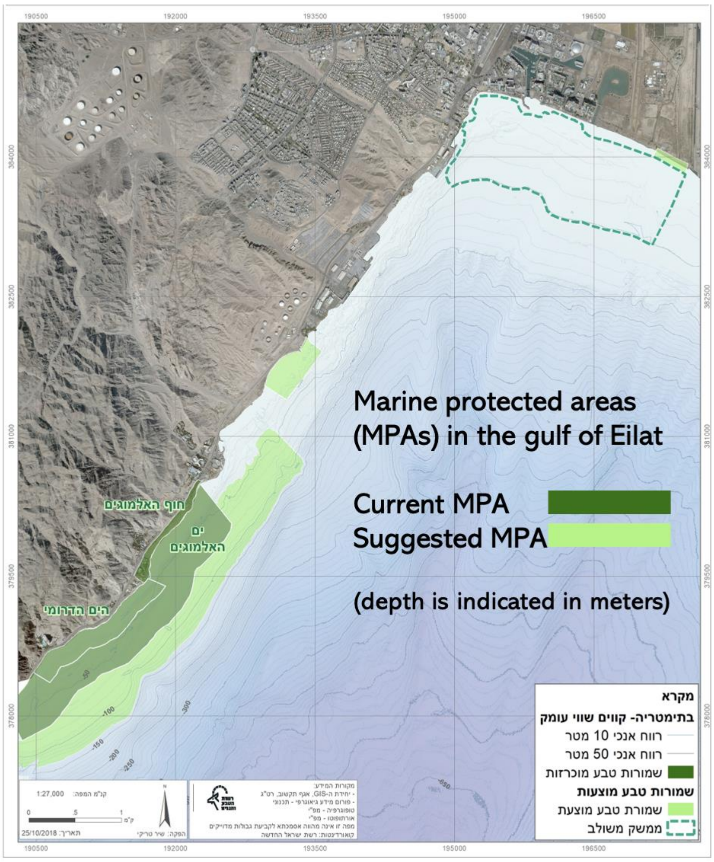

Figure 6: Marine protected areas in the gulf of Eilat. Eventually, we hope that our technology will assist in monitoring these areas, and especially the deeper ones.

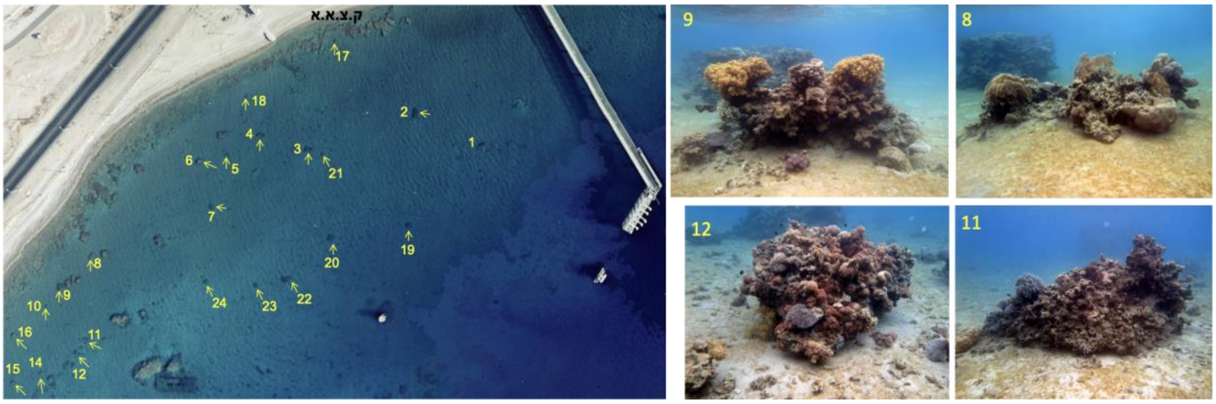

Figure 7: Example pictures from a complex reef in the gulf of Eilat.

2. Task of the AUV/sensors

In the complete task, the AUV should autonomously map a given area, i.e., navigate and acquire images of the corals. In this project, the focus is on the task of autonomous navigation, i.e., the ability to maneuver in a complex environment without hitting any obstacles. In each time, the AUV will be given a starting point and an endpoint, and will need to move between these two while avoiding obstacles without changing altitude. The AUV should be able to maintain a constant distance from the bottom (depending on the needs defined above) and in addition avoid encountering with the reef. In areas where the reefs are the most structurally complex (at a depth of ~10 m), the AUV should be able not to encounter with reef-knolls protruding from sandy bottom areas to a height of ~5 m above the bottom.

The AUV has a payload that contains adjacent camera and a sonar, looking forward on an underwater vehicle (Fig. 8).

Figure 8: Sensors mounted on the AUV.

The camera is imaging the objects that are in front of the AUV. However, the image is lacking both range and visibility. Our goal is to assign absolute range to the objects identified in the image using the range measured by the sonar. This will be done by matching objects between the sonar and the visual images (Fig. 9).

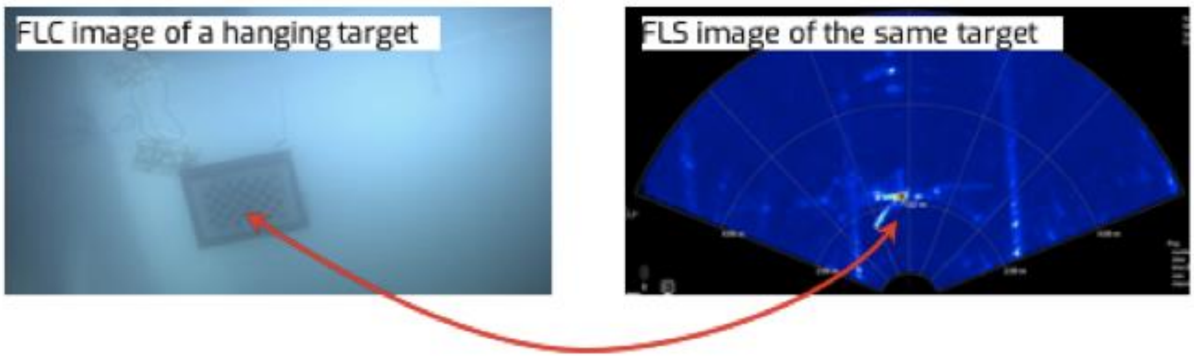

Figure 9: Desired object matching between the FLS and FLC image.

A future outlook: the goal of this obstacle avoidance is to create the capability of mapping complex areas such as coral reefs, i.e., creating mosaics and 3D models. Although this project is not aiming at the creation of photomosaics themselves, the imaging requirements for the coral reefs are recapped here, as they guide the requirements for the obstacle avoidance.

This use-case aims at an improved ability to monitor the seabed (the substrate and life on it) so that an algorithm distinguishes sandy bottoms, seagrass meadows and coral reefs. In terms of coral reefs, the ability to distinguishing between rock and live coral, or other invertebrates (e.g., sponges and accadians) is og high interest. Within the coral reefs, a differentiation between the different corals at the genus level (not the species) is a goal. In addition, the identification of bleached corals is a goal. These require image resolution of ~1mm, that imposes a slow speed to avoid motion blur and close proximity to the objects of ~2m.

3. Functional requirements

Table 3: Functional requirements for Use Case 2

Category	Requirement	Description	Priority
User-Experience	Display	Display of the generated obstacle map	
	Mosaic (*)	Resolution of 1mm, areas in the order of tenths of m^2	**B**
Regulatory aspects	Coral reef safety	Experiments should be conducted such that no coral is harmed	**A**
	Operation and dive safety	Conduct experiments according to dive safety rules	**A**
Operational requirements	Operation pattern	maneuver between two defined points	**A**
	Imaging range	5m	**B**
	Spatial Resolution of obstacle detection	50cm	**B**
	Range Resolution	20cm	**B**
	Runtime	0.5Hz	**B**
	Sensor synchronization	100ms	**B**
	Acquisition rate	0.5Hz	**B**
Platform parameters	Min altitude	Constant altitude of 2m	**B**
	speed	0.2m/s	**B**
	Proximity to objects	2m	**B**
	operation time	4 hours	**C**
	Platform type	hovering	**B**
	Max Depth	30m	**C**

3. USE CASE 3 „EFFICIENT EXPLORATION AND MAPPING OF THE SEA BOTTOM“

1. Introduction to the use case

This use case deals with seafloor mapping and interpretation for geophysics using multiple sensors. The importance of this capability comes from the fact that high-resolution maps of the seafloor, with the topographical features, bottom type, habitats of benthonic life forms, and other features identified and classified correctly are the basis for the scientific exploration, environmental monitoring, and economic exploration of the oceans.

The surveys for creating such maps are typically conducted from sea-going vessels, using side-scan sonars and multibeam echosounders. Both the depth-measurements and the acoustic return (backscatter) of the sonars are used for the interpretation, which is done manually and off-line, by a group of experts in marine geology or biology. To assist the interpretation, video samples are acquired to enable a visual check of the properties of the bottom and thus have ground-truth for the interpretation. Due to the limited range and limited operational conditions of the optical cameras underwater, such video samples are acquired over small areas only, and therefore lack representativeness over the much larger areas typically covered by the acoustic sensors.

Figure 10: Conceptual representation of seafloor classification with an AUV in use-case 3).

Figure 10 presents a conceptual representation of seafloor classification with an AUV intended for UC3. The goal is to endow acoustic data acquired by an AUV (left and center) to produce accurate maps of bottom types (right) from acoustic sensing alone, but with mean average precision comparable to that achieved by fusing acoustics and optics.

The DeeperSense approach for implementing this capability will be based on advanced machine learning techniques to enable multisensor fusion of different sources, mainly from side scan sonars, but also from multibeam echosounders. Optical imagery will be used as another layer for training, classification and benchmarking with the overall objective of allowing, by the end of the project, to perform accurate sea-floor characterization with an AUV and without the need for optical imagery.

The intended solution will be validated and demonstrated on one or more survey missions that Tecnoambiente (TA) conducts each year. Developed methods will also be demonstrated with data acquired by the AUVs available within the consortium.

2. Task of the AUV/sensors

As stated before, the demonstrator for UC3 will be organized to illustrate the capability to perform seafloor classification using acoustic sensing alone, while achieving an accuracy level comparable to that of combined optical and acoustics. The UC3 field validation will have two components:

1. The first component will serve to illustrate the advantages of this capability in an autonomous-systems context and will focus on the use of an AUV to perform an adaptive mission of seafloor classification. The AUV will use one acoustic sensor modality only. Due to integration and sensor interference constraints, the sensor will be either a multibeam, a forward-looking sonar or a side scan sonar. The AUV will adapt its predefined survey pattern according to the on-line classification results being computed onboard. The goal of this adaptive behavior is to illustrate that onboard classification can assist bottom surveys by guiding the spatial sampling to areas that are more informative, such as detecting the boundaries of two or more different bottom types and adapting flying altitude to allow collecting additional close range data.
2. The second component will be centered on a survey organized by TA, using TA's surveying equipment and sensors. The goal of this component is to acquire and process data to demonstrate the performance of the developed algorithms over a larger area than the one that can be covered by the AUV. This component will also validate the DeeperSense approach on a typical survey mission, as they are currently conducted by surveying companies.

The Girona500 AUV will be used in tandem with TA's demonstration cruise, and the vehicle will be deployed from the same ship, or using UDG's support vessel. A suitable testing site is the coastal area near the port of Sant Feliu de Guíxols. The port facilities have been used in several European project experiments of the UDG and is conveniently close to the UDG campus in Girona. TA has surveyed the area near the port in the last few years including the acquisition of side-scan sonar, seabed imaging and multibeam bathymetry. Accessibility to the port surroundings is easy, so direct surveillance of the operations can be done from the shore or the boat.

3. Functional requirements

Table 4: Functional requirements for Use Case 3

Category	Requirement	Description	Priority
User-Experience	User interface	Graphical User Interface adapted to operation at sea, for component 2 of field validation. Should be intuitive and self-explanatory	**C**
	Real-time classification output	Indication of type of seafloor being reported by the classifier, for component 2 of field validation.	**A**
	Simple mission planner interface	Simplified interface to define parameters of adaptive mission for the AUV, for component 1 of demonstrator	**B**
Regulatory aspects	Safety Rules	No specific safety rules are of concern, apart from established safety procedures of AUV deployment and recovery (component 1)	

Operational requirements	Side scan image resolution	10-20cm / pixel. Required for gathering of training data and components 1 and 2 of demonstrator.	**A**
	Optical camera ground resolution	<2 cm / pixel (pixel footprint). Required for gathering of training data.	**A**
	Multibeam height map resolution	< 20 cm vertical resolution. Required for gathering of training data.	**C**
	Time interval between acoustic and optical data collection	Less than 1 month, to avoid large differences in seafloor appearance	**B**
Platform parameters	Altitude of sidescan (SS)	4-10m above seafloor. Required for gathering of training data and components 1 and 2 of demonstrator.	**A**
	Sidescan frequency	900KHz, to ensure adequate ground resolution. Required for gathering of training data and components 1 and 2 of demonstrator.	**A**
	Sidescan trajectory information	Roll, pitch, yaw angles, lat, long, depth, and altitude over time. Required for gathering of training data and components 1 and 2 of demonstrator.	**A**
	Optical camera altitude	2 to 4 meters above the seafloor. Required for gathering of training data.	**A**
	Camera trajectory information	Roll, pitch, yaw angles, lat, long, depth, and altitude over time. Required for gathering of training data.	**A**
	Multibeam frequency	450KHz. Required for gathering of training data.	**C**
	Integration of the sidescan sonar	Integration of the sidescan sonar in the frame of the AUV (required for component 1)	**B**

4. SUMMARY

The three use-cases have been described in detail and in all three use cases specific end-users needs could be identified.
Some of the identified requirements go well beyond the goals of DeeperSense and address the specific use-cases, such as platform/AUV parameters or the later-processing of the data. These requirements are valuable for the later exploitation of DeeperSense solutions.

Some of the requirements, named in all use-cases, such as a functional user-interface and most important that the solution must not harm the environment or humans. Then in more details the requirements such as resolutions have been described, as well as imaging frequencies, or the kind of information obtained and being documented.

Overall, this deliverable provides the base for the technological development, the generation of training data as well as the test and validation concept (D2.2 – D2.5).

In general, it became obvious that there is a strong need for these types solutions. For underwater work (use case 1) performed by divers a reliable surveillance technology would improve their safety significantly. And especially, seafloor surveys using autonomous robotic platforms (AUVs; see use-case 2 and 3) where the sensing and mission planning are intertwined, in order to be able to adapt the survey pattern to the terrain encountered on-the-fly. Allowing for AUVs to perform missions of large area acoustic mapping with integrated benthic classification will lead to significant cost savings in terms of survey operations. It will also contribute to a better characterization of the benthos, and therefore support a more informed decision making in terms of planning for intervention or for monitoring human impact.

DeeperSense Consortium