D.5.2.1 Preliminary conceptual design of multifunctional robotic and sensor solutions

InnovaMare project

Blue technology - Developing innovative technologies for sustainability of Adriatic Sea

WP5 – Cooperation in innovation on robotic and sensors solution (TT) – pilot actions

Project References

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Contents

INTRODUCTION

The development of multifunctional robotic and sensor solutions is envisioned as part of Activity A2, WP5 Cooperation in innovation on robotic and sensors solution (TT) – pilot actions. In this Activity the design and realization of robotic platforms and sensors is planned. Leveraging on extensive partners' Research and Development (R&D) experience and previous collaborations, a cross-border development process is forecast. The type of solutions envisioned include autonomous marine robots and Internet of Underwater Things (IoUT). These solutions will be developed according to the Living Lab (LL) methodology defined in Activity A1, WP5 and should be flexible enough to provide integrated monitoring solutions that can be easily applied to several pilot applications. These applications will be defined together with end-users making use of the LL methodology and in a quadruple helix model. The aim is to developed platforms that can be easily transferred to and adopted by public-private sector for wide range of products or services, through the LL.

The developed multifunctional robotic and sensor solutions will be developed in line with LL of the Good Environmental Status (GES) addressing a number of European Marine Strategy Framework Directive (MSFD) descriptors [1]. However, at the preliminary conceptual design stage, the platforms are designed taking into account a wide range of use case scenarios and applications (not only addressing MSFD descriptors). These are a starting point and will be refined through the Living Lab. An infographic illustrating all of the possible use cases and tasks has been produced in WP2 by partner PP3 ARTI Puglia and will be used to disseminate the possible use of the platforms among target end-users to get feedback and input regarding the most relevant ones in the Adriatic ecosystem.

This deliverable reports on the initial conceptual design and prototyping of a series of solutions provided by partners PP9 FER, PP4 CNR and PP12 GEOMAR. In the context of WP5, Activity 2, the work developed until now included a series of technical workshops as well among InnovaMare partners involved in WP5 and one conceptual design workshop given by three external leading speakers from robotic companies [2,3,4]. Moreover, the engagement of external stakeholders took place and a demo from the company Statim d.o.o. will take place in the upcoming Breaking the Surface event. This company will keep being involved in InnovaMare activities and will help us shape the applications according to LL.

The remainder of this report is organized as follows. The Multifunctional robotic and sensor solutions are presented in the next section by detailing their hardware and software prototyping status. Then, use cases of potential application together with their connection to the MSFD descriptors are presented in the section Use Case Scenarios. Finally, the section Conclusions draws some conclusions and highlights future work.

MULTIFUNCTIONAL ROBOTIC AND SENSOR SOLUTIONS

Given the user-centred LL methodology, instead of focusing in one fixed platform, the partners have been developing a series of different platforms and sensors that offer a higher degree of flexibility. These can be used and tailored for specific applications according to end-user needs and feedback. The mapping between the possible use of each platform and specific use cases is presented in the next section. In the following, a preliminary description of the hardware and software modules of each platform is presented.

SWAMP ASV

Within Innovamare CNR is going to implement a solution to access and monitor extremely shallow water by means of portable, modular, reconfigurable and highly maneuverable robotic vehicles. The identified vehicle is SWAMP, an innovative highly modular catamaran ASV whose first prototype was recently developed by CNR-INM. SWAMP AUV is characterized by small size, low draft, new materials, azimuth propulsion system for full redundant controllability and agile maneuvering in shallow waters and modular WiFi-based hardware&software architecture.

Prototype SWAMP ASV has been designed and built in CNR-INM laboratories in Genova. Two prototype ASVs will be built during in InnovaMARE project and released to CNR-ISMAR in Venice. The construction is accomplished by acquiring all the micro-components and semi-finished products and building and integrating them in all SWAMP ASV macro-components: Hull & Structure, Propulsion, Power system, Communication, Perception and Sensor management modules.

In the InnovaMare Project two new upgraded versions of SWAMP ASV ASVs will be released to CNR-ISMAR in Venice. The new SWAMP ASVs will be built and enhanced with a new series of kits, tools and sensors to perform a number of strategic actions in the environmental monitoring of shallow waters:

- an air-cushion-system-kit will be designed and developed. The vehicle will become a SES ASV, I.e. a side-wall air-cushion-vehicle with reduction of drag and increase in speed. This will also increase the payload with a reduction of draft. This kit will be built and designed within InnovaMare project.

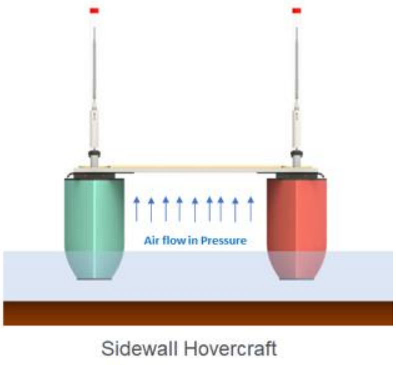

Fig. 1 SWAMP ASV.

- an intelligent winch kit with a communication cable for the management of underwater sensors and tools. This kit will be built and designed within InnovaMare project.
- A GPS-RTK kit for highly accurate positioning in the range of centimeters that will be built and integrated within InnovaMare project.

This platform will be equipped with a set of sensors that will allow monitoring activities in lagoon and coastal environment.

The final result of this pilot action is the creation of an innovative prototype platform for sea environmental monitoring. This will be validated through the analysis of results and draw up of guidelines for the improvement of underwater conditions.

Hardware modules

SWAMP (Shallow Water Autonomous Multipurpose Platform) is a robotic solution targeted to answer the practical needs of monitoring the extremely shallow waters that are peculiar of Wetlands for a better acquisition of the environmental parameters. In this environment, robotic tools are intended to help human beings to improve the precision and the quality of the surveys and to perform tasks in those areas where the access is dangerous or difficult.

SWAMP is the first of a new class of modular, portable, lightweight, re-configurable ASVs for extremely shallow water and remote areas applications and was built in a collaboration between CNR-INM and DITEN-Unige. SWAMP is a double-ended catamaran that combines the ability of working in a few centimeters of water together with satisfactory control abilities. This is achieved thanks to the use of a four modular azimuth thruster based on Pump-Jet that are designed for extremely shallow waters. Moreover, to work in these areas, SWAMP is characterized by small draft soft-foam, unsinkable hull structure where all the elements are contained within the hulls in a protected impact resistant zone. The requirement of making different kinds of surveys demands for high modularity and a flexible hardware/software architecture. SWAMP architecture is based on an onboard WiFi network that allows for easily integrating sensors and samplers. Fig.1 shows the SWAMP prototype during a survey.

The vehicle is a sum of innovative concepts. It is a full-electric Catamaran 1.23 m long with a design breadth of 1.1 m; by adopting a sliding structure the breadth is variable between 0.7 m and 1.25 m. The hull height is 0.4 m and the vehicle with the structure and the antennas is 1.1 m high. SWAMP lightweight is 38 kg with a draft of 0.1 m, the standard maximum payload is 20 kg with a consequent maximum design draft of 0.14 m but the reserve of buoyancy of SWAMP allows to embark up to 60 kg with a draft of 0.22 m. The small dimensions of the vehicle comply with the idea of a reduced logistics.

The hull shape is inspired by the double-ended Wigley series but with a flat bottom as shown in fig.2

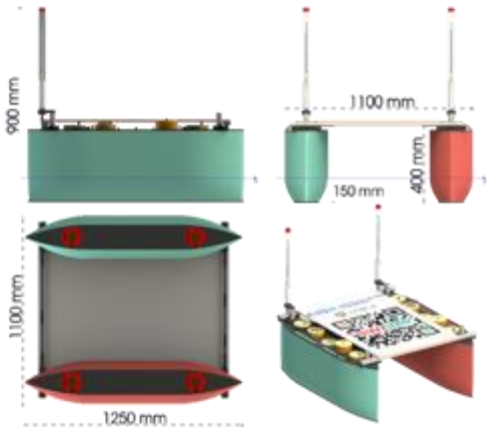

Fig. 2 Main dimensions of SWAMP

The double-ended hull form and propulsion system is characterised by equally efficient sailing ahead and astern with the possibility of manoeuvring in narrow spaces, Longitudinal centre of buoyancy LCB is centered mid-hull. The hull configuration shape is chosen both for hosting four Pump-Jet type 360 azimuth thrusters expressly designed and studied for this vehicle and to create an innovative structure that also avoids the presence of sharp edges on the hull bottom. Indeed, one of the main peculiar aspects of SWAMP is the use of light, soft and impact-survival flexible structure made with a sandwich of soft closed-cell HDPE foam, HDPE plates and pultruded bars. With this design SWAMP is a completely modular vehicle that can be dismounted and transported to be remounted in various possible configurations. This flexible design allows to host various types of tools, thrusters, control systems, samplers and sensors. Also, for this reason for the propulsion the choice has fallen on the design of a modular propulsion unit based on Pump-Jet that can be easily installed on the vehicle. Such a solution allows also to remove, if necessary, some of the thrusters and/or substitute them with sensors, tools or even other thrust units. Using for azimuth thrusters gives SWAMP the controllability that is required for high quality surveys.

One of the main peculiarities of SWAMP consists in the fact that each hull is conceived to be a single vehicle with its propulsion, navigation, guidance and control (NGC) and power system from the battery. Each monohull results to be an ASV and, thanks to the azimuth thrusters, is highly controllable. Moreover, the intelligent core of each vehicle controls the monohull but is able to take over the control of the entire vehicle in the event of failure of the other core. This possibility is guaranteed by the existence of a Wi-Fi-based communication architecture.

Each Pumpjet Thruster produces 12.25 N at 1200 RPM and a Power consumption of 90 W. Maximum speed of SWAMP in infinite depth waters is 1.6 m/s, while the speed in extremely shallow waters down to 200 mm is reduced to 1 m/s due to the peculiar hydrodynamic effects occurring in shallow water.

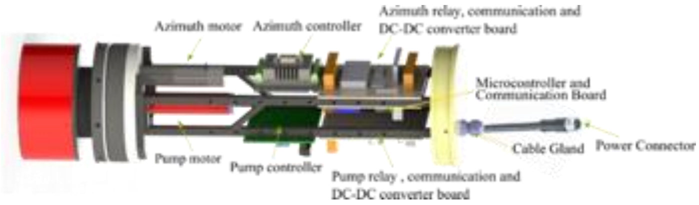

Fig. 3 Pump-Jet thrusters flush with the hull

Software modules

The software architecture of SWAMP is based on Commercial off-the shelf components. One of the main hardware innovations introduced in SWAMP is the elimination of most of the possible wiring reducing the number of wires to just the power connections made with IP69k connectors and wiring.

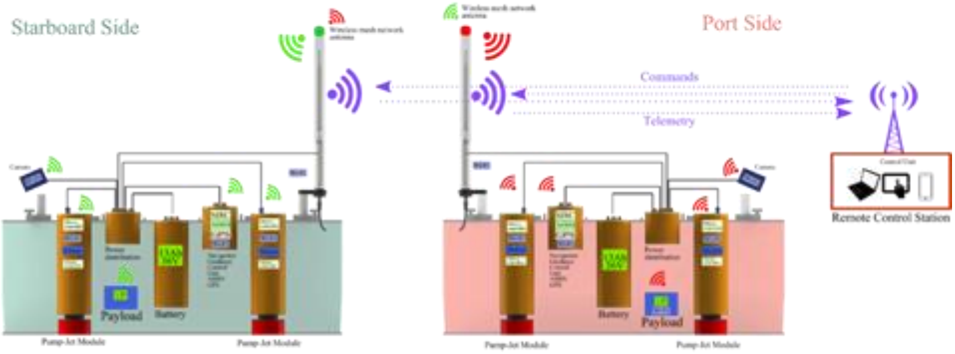

Fig. 4 Hardware and communication configuration of SWAMP

The basic NGC package of each hull is composed by an Inertial Measurement Unit (IMU) and a GPS. The communication is created by one communication module each hull that provides a communication framework for both its same hull and for the other hull’s modules when its work is required. The communication module is a Pilot station Wi-Fi radio (with Omnidirectional antennas for pilot station and Vehicle Wi-Fi radio that can work both in AP (Access Point) mode and in SA (Station Adapter) mode depending on which mode is working the computational mode of the single hull (either master or slave). This allows to have the internal communication of the vehicle and the communication with the land station.

The computational module is based on a Raspberry Pi 3.0 model B SBC running the Raspbian OS (Operating System). On the computational module runs the control system software of each single hull. When the vehicle is in the complete configuration (i.e. the two hulls are physically connected together) one of the two computational modules becomes the master and the other one becomes the slave. Inside the computational module canister also is present the basic navigation sensor.

The basic idea is to have a vehicle made up of N modules (control modules, actuators, sensors, etc.) which communicate via a Wi-Fi connection using the 192.168.29.0 network.

The command packets sent to the AM modules are ASCII strings derived from the C programming language. The commands are sent via a datagram-type network connection.

All the commands developed for the architecture of SWAMP can be used in an ease way by a computer connected to the network. The commands can be sent from a C-program, from Matlab, Simulink or other programming tools in an ease way.

Preliminary testing

During the week form May 29 to June 6, 2021, prototype SWAMP ASV was exposed at Venice Salone Nautico in the headquarters of CNR-ISMAR in Venice Arsenale. Just before and after this event preliminary tests have been carried out in the water area in front of CNR-ISMAR headquarters in order to:

- demonstrate SWAMP ASV technology to a number of CNR-ISMAR marine scientists;
- evaluate the logistics requirements to perform R&DI experimental activity in the waters directly accessible form CNR-ISMAR Venice headquarters;
- perform SWAMP ASV identification, navigation, guidance and control tests.

Moreover, on June 17, 2021 synergetic activities of the EC EMFF BlueRoSES, Interreg Italy -Croatia InnovaMARE and MIUR TRIM have been carried out. In the framework of BlueRoSES the team demonstrated the basic features of the SWAMP ASV, discussing with researchers at CNR-ISMAR future research innovation and exploitation opportunities, including the ones given by InnovaMARE project. In addition to the tests, a remote online fieldwork lecture was given to the students of TRIM Italian project post-degree master.

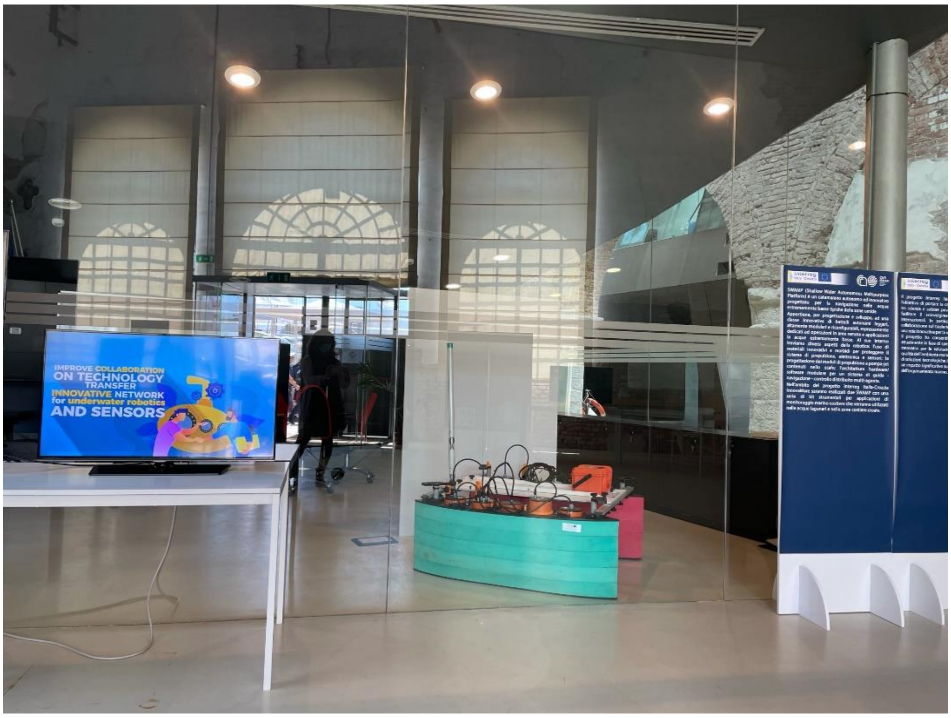

Fig. 5 SWAMP ASV @ Venice Salone Nautico exhibition.

Fig. 6 SWAMP ASV @ Venice Salone Nautico

Fig.7 SWAMP ASV demonstration in Venice Arsenale

Korkyra ASV

In INNOVAMARE project, FER will be implementing a fast autonomous vehicle that can provide a fast area coverage as well as map congested areas (together with a small Remotely Operated Vehicle). The first Autonomous Surface Vehicle (ASV) prototype is named Korkyra and has been built and integrated at FER, Laboratory for Underwater Systems and Technologies (LABUST). The hull and structure was manufactured by an external company but all integration has been performed at FER. This ASV can be seen as complimentary to the SWAMP ASV as it has a different size, top speed and sensor suite. The description of this ASV follows.

Hardware modules

The ASV Korkyra has been designed as a catamaran to enable better stability and hydrodynamic properties at sea states up to state two. It is made of aluminium, 200 cm long, 100 cm wide with hollow hulls of 24cm in diameter (see Fig. 8). It is designed to be modular and flexible regarding payload in accordance to Living Lab methodology. Its top deck contains a carbon hull which contains all the electronics and computers that enable vehicle's autonomy. The bottom deck of the catamaran holds waterproof IP67-graded aluminium boxes containing additional batteries and motor electronics. The row bar above the top deck enables integration of signalling maritime lights, surveillance camera(s), LIDAR or other sensors etc. The design of the carbon hull and the electronics therein are based on the aPad vehicle previously developed at LABUST, FER [5]. The catamaran is 80 cm high from the bottom of the hull to the top of the carbon hull and 140cm high to the top of the row bar. Currently it weights 100 kg in air.

Fig. 8 Initial prototype of Korkyra ASV.

The autonomous catamaran can be mounted with various payloads, e.g. a multibeam sonar, a remotely operated vehicle (ROV), tether management system (TMS) for the ROV, landing platform for an aerial drone, on the top and front bottom part of the ASV Korkyra. It can take another 50 kg (in air) of payload to have hulls half-submerged for best hydrodynamic properties. If needed, it can be mounted with at most 100 kg (in air) of payload when its hulls would be completely submerged giving the catamaran slightly inferior hydrodynamic properties. Four electrical T200 thrusters in X-configuration enable it to navigate complex marine environments omnidirectionally at lower speeds (1-2 knots), while its booster electrical motor Minn Kota RT 55 EM enables top surge speeds of 3-4 knots. Twelve BlueRobotics 14.8V, 18Ah batteries enable it 4 to 5 h of autonomy depending on the sea state and sensors used. Global Navigation Satellite System (GNSS) assisted with IMU, named Applanix SurfMaster, coupled with corrections from base stations over Long Term Evolution (LTE) network, enables the ASV to globally localize itself with precision of up to 10 cm, which is very important in survey and inspection missions.

Software modules

The autonomy of the Korkyra ASV is facilitated by two Intel NUC mini PCs. One NUC of 7th generation is used for multibeam sonar data acquisition and processing on Windows, while another NUC of 10th generation is running Linux and Robot Operating System (ROS) [6] for mid- and high-level control, data processing, and mission control. Communication with the vehicle is performed over Wi-Fi.

The operator's work and mission planning for ASV Korkyra is made easy with graphical user interface-based mission planning and review software named Neptus [7]. Neptus communicates with the vehicle over Intermodule Communication (IMC) messages that are at the same time integrated into ROS by a ROS-IMC bridge.

Long-range surveillance of the catamaran via video stream from a pan-tilt-zoom (PTZ) Hikvision IP camera (mounted at the top of the row bar) ensures that the operator can react to any risky situations that might happen at sea. The IP camera is also integrated into ROS, so the operator can have visual feedback from the camera over Wi-Fi. The ROS-Qt (RQT) graphical user interface (GUI) containing the video stream and PTZ controls is shown in Fig. 9. Apart from the Real Time Streaming Protocol-based (RTSP) video stream, this GUI also enables the operator to control pan, tilt, zoom, as well as focus and aperture of the camera lens.

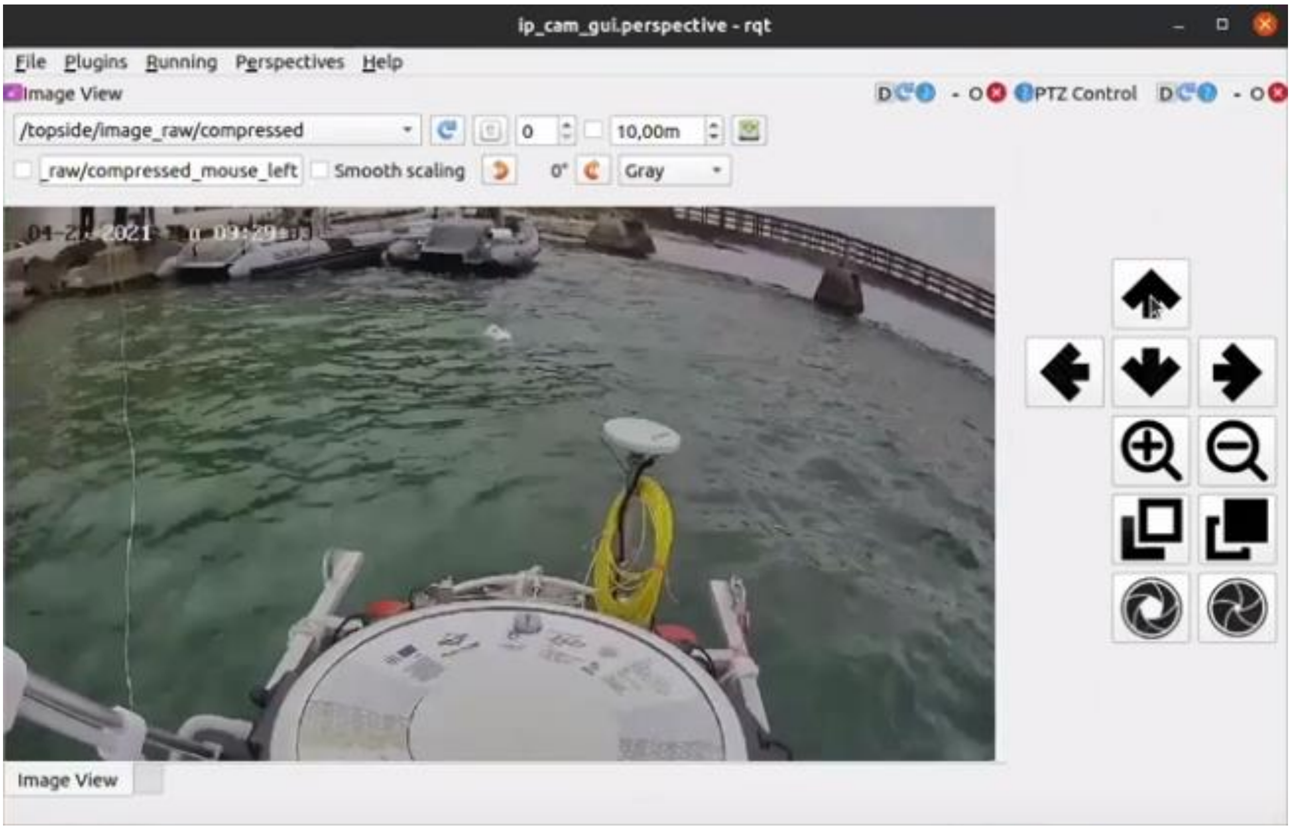

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Fig. 9 The Korkyra ASV GUI view with the camera image.

Preliminary testing

The ASV Korkyra has been initially tested in the new facilities of LABUST. The new laboratory is positioned on an area of 200 m^2, with 80m^2 allotted for the workshop and offices and 120 m^2 for the pool area. The pool itself has an area of approximately 32 m^2 (7.8 m × 4.1 m) and depth of 3 m with a dedicated crane for vehicle deployment. For monitoring underwater and surface activities, the pool is equipped with four underwater cameras and three ceiling cameras covering the complete pool. Fig. 9 shows initially testing at the LABUST pool.

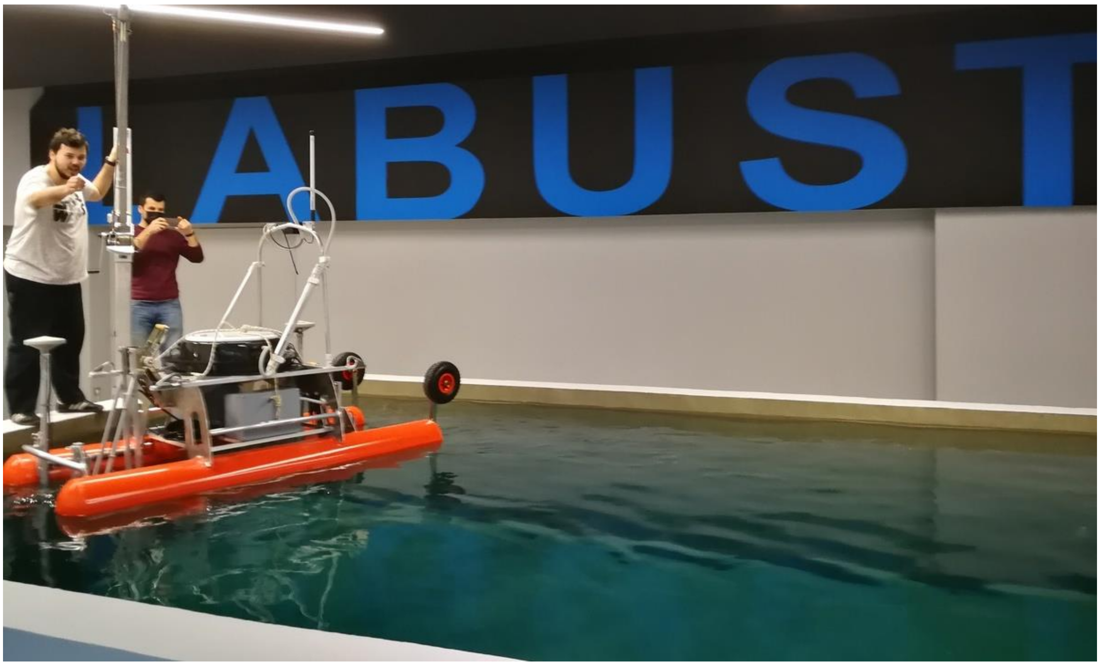
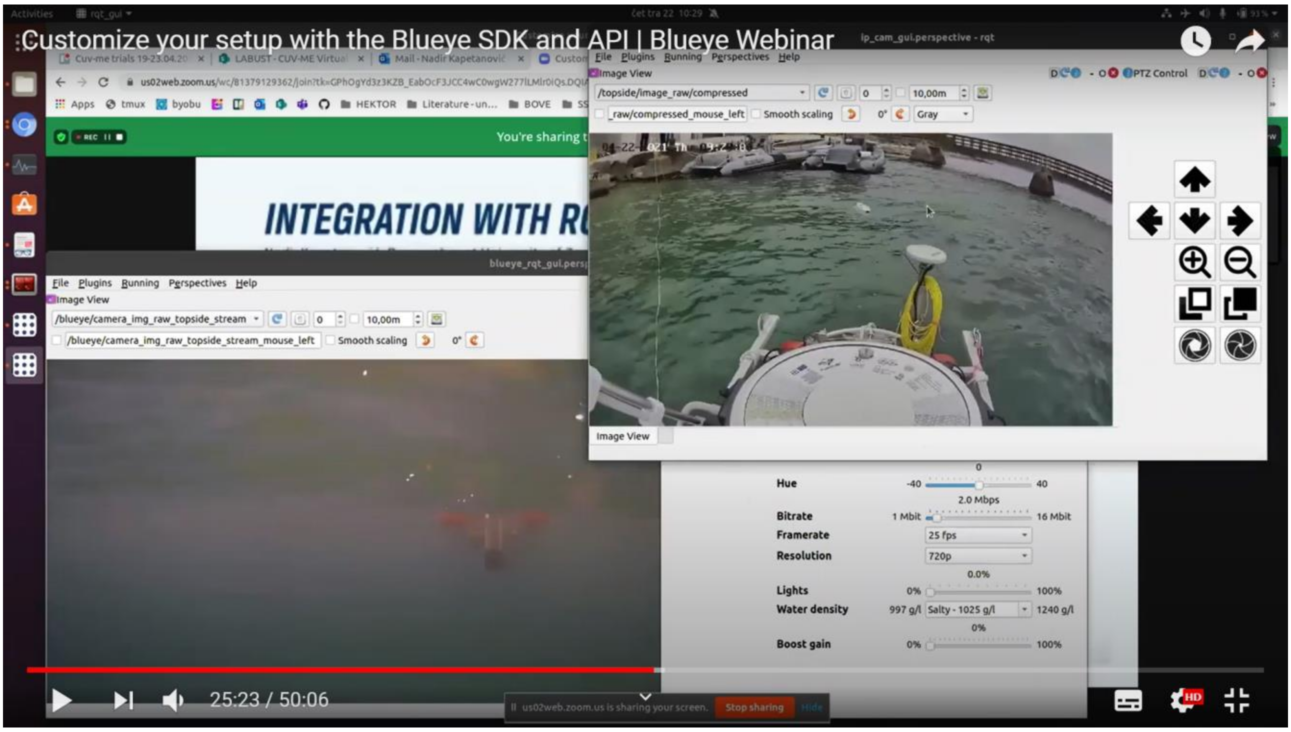


Fig. 10 The Korkyra ASV in the first tests in the pool.

Korkyra ASV has been later tested in open sea in Split, Croatia in April 2021 (see Fig. 11). The maiden voyage took place on the 21st of April, 2021, and its manual and automatic controls were tested as well as the integration of the surveillance IP camera. These trials have also validated the ROS2 package developed by FER, which interfaces the ROV Software Development Kit (SDK) with ROS2 for future autonomy tasks, i.e., data sending between the ROV and the operator's PC with the ASV acting as a data relay in between the two.

The maturity of the platform and readiness has been shown also through a public demo. On the 22nd of April, 2021 the Blueye company organized a one-hour webinar named "Customize your setup with the Blueye SDK and API". FER participated in this webinar with a live demo of the ASV Korkyra and Blueye Pro ROV deployment and manual control (see Fig. 12). The complete recording of the webinar can be found on https://youtu.be/243JWUpxBY8.

Fig. 11 The Korkyra ASV preparing for its maiden voyage.



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Framerate 25 fps
Resolution 720p
Lights 0% 0.0% 100%
Water density 997 g/l Salty - 1025 g/l 1240 g/l
Boost gain 0% 0% 100%

Fig. 12 The Korkyra ASV + Blueye ROV live demo during the Blueye Webinar (and their cameras views).

Buoys

As part of the platforms offered by FER, innovative smart marine buoys for long-term operation and persistent deployment in marine environments are being developed. The concept of smart buoy can be explored in different perspectives and in the following we will present three distinct configurations. It explores wind and solar energy harvesting methods, anchoring solutions, and a variety of communication methods, including a LoRaWAN (Long Range Wide Area Network) connection for long-range connectivity in the desired Internet of Things (IoT)/Smart City context.

The buoy can operate as a remote marine platform performing water quality measurements (very relevant for INNOVAMARE project), as well as a relay for an extended underwater sensor network. Algorithms based on the buoy's inertial measurements can be used to estimate and report on wave height and sea state, and image processing algorithms can be used to implement video monitoring and potential intrusion detection using the buoy's camera for instance for archaeological sites (as mentioned in the Use cases section). The three configurations of the smart buoy concept are described below.

The first configuration features a static buoy gathering, analysing, and storing measurements of various environmental values (for both water and air) using built-in sensors while ensuring long-term autonomy of up to several months by employing energy consumption optimisation algorithms as well as renewable energy sources. Communication-wise, the buoy represents a node in a smart city network with real-time remote access (see Fig. 13). This configuration best embodies the system's application in tourism-heavy areas, providing continuous remote access to water quality, sea state, beach, harbour, and waterway data.

Fig. 13 The first configuration with a static buoy.

The second configuration expands upon the first by adding support for an extended network of seabed-mounted sensors and devices such as cameras and sonars, providing two-way remote access to them for expanding an IoT approach into an Internet of Underwater Things (IoUT) approach (Fig. 14). This configuration is of particular relevance to marine archaeology-related applications of surveillance and protection of culturally significant underwater sites such as shipwrecks, while also being appropriate for sites of biological and ecological significance such as coral reefs.

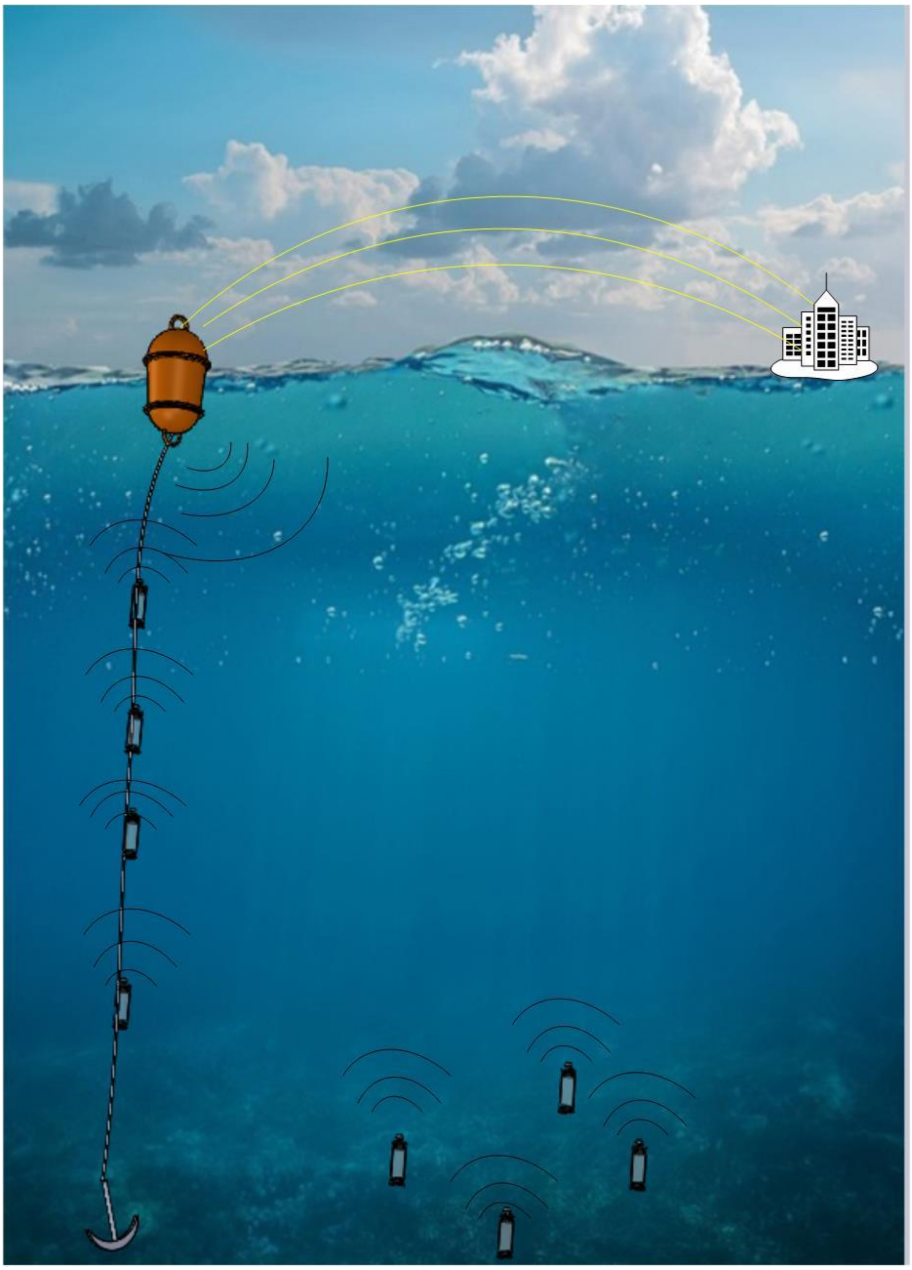


Fig. 14 Static buoy and sensor node concept realised as underwater acoustic sensor network.

The third and final configuration is a mobile, dynamic buoy, an ASV, uniting the IoT approach of the previous configurations with significantly enhanced movement and control capabilities which enable the coverage of a wider measurement area for pollution detection, while optimising energy use in order to maintain long-term operation. This configuration emphasises the system's capability to detect and map ecologically threatening phenomena such as oil spills and its ability to raise appropriate alarms over long distances. This configuration is similar to the Korkyra ASV and will not be explained in the next subsections.

Hardware modules

The various subsystems of the three buoy configurations are initially being developed and tested independently, then slowly integrated into a whole. This subsection describes the progress made on several different subsystems.

For the static buoy, the inertial measurement unit (IMU) is used to estimate wave height and direction. The buoy also contains a GPS unit in order to accurately report its location. Mounted on the top of its hull is a domed surveillance camera, making a video feed possible, as well as offering potential intrusion detection functionalities in use-cases such as deployment near archaeological or aquacultural sites. The first developed static buoy concept is shown in Fig. 15.

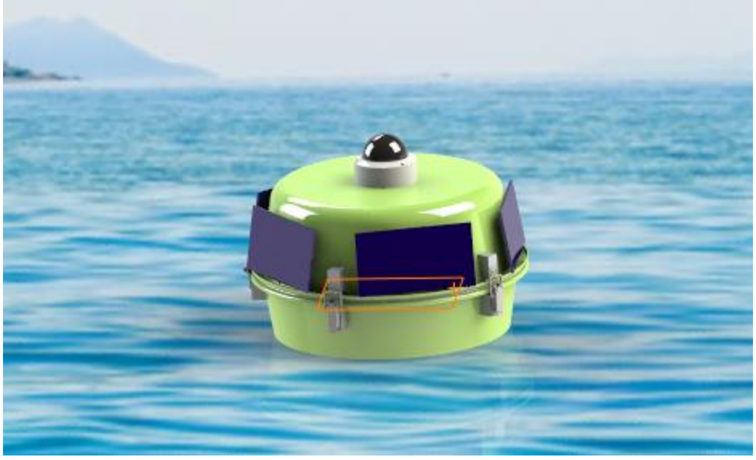


Fig. 15 First prototype conceptual design.

In addition to a camera and a standard pressure-temperature sensor, when operating as a remote marine platform performing water quality measurements, the buoy uses existing in-situ sensors such as those for detecting oil, chlorophyll, green algae, and rhodamine; sensors for measuring water turbidity and conductivity (salinity); as well as Coloured Dissolved Organic Matter (CDOM). For this purpose, Turner Designs' Cyclops-7F sensors are being integrated into the buoy system.

Chosen communication methods for the buoy system include WiFi for shortest-range communication, GSM/LTE for primary data reporting when far away from any access points, LoRa for low-bandwidth and low-frequency long-distance reporting of small data packets, and acoustic communication between the surface unit and the underwater network using well-tested miniature acoustic nanomodems, the use of which in an underwater acoustic sensor network was established in [5].

Each buoy contains Li-ion batteries and is equipped with solar panels to increase its autonomy. It also uses electronic power boards to control power usage and put its various components into a low-powered sleep mode or turn them on and off completely, ensuring long-term autonomy. Experiments with a wind generator are planned for the third, mobile buoy configuration.

As mentioned above, in the second configuration, the buoy can be paired with underwater sensor nodes. These can be attached to a static buoy's mooring line, or deployed on the seabed in the area surrounding a buoy as in-situ sensors, acting as an extension of the buoy system. In both variants the sensor nodes communicate with the buoy acoustically. The design of a sensor node with two optical sensors for water quality measurement is shown in Fig. 16. The main node housing consists of a plexiglass tube with two end caps forming a watertight enclosure. The top cap of the node contains cable penetrators for submersible sensors mounted on the outside, a vent for pressure equalisation, a power switch for activation and deactivation without the need for opening the enclosure, and an acoustic nanomodem transducer.

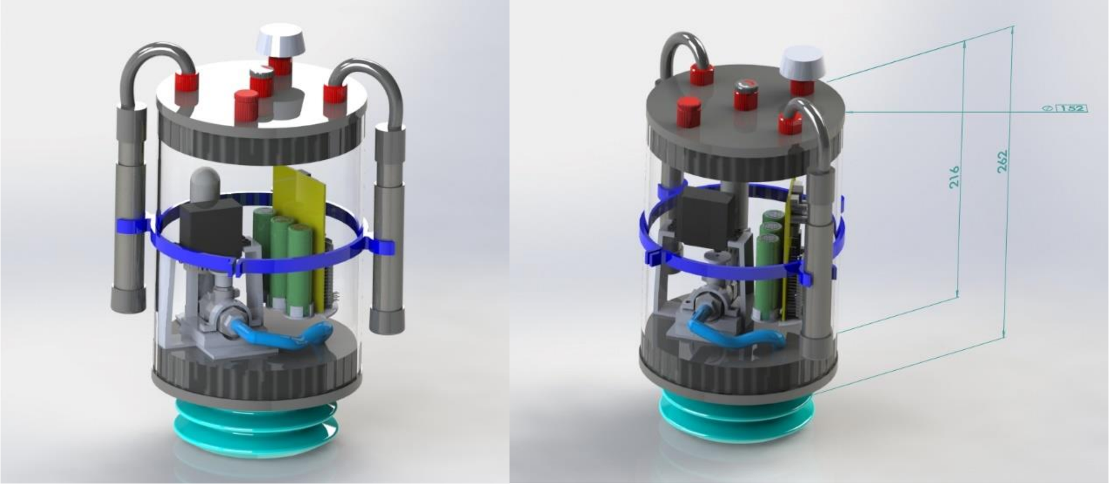
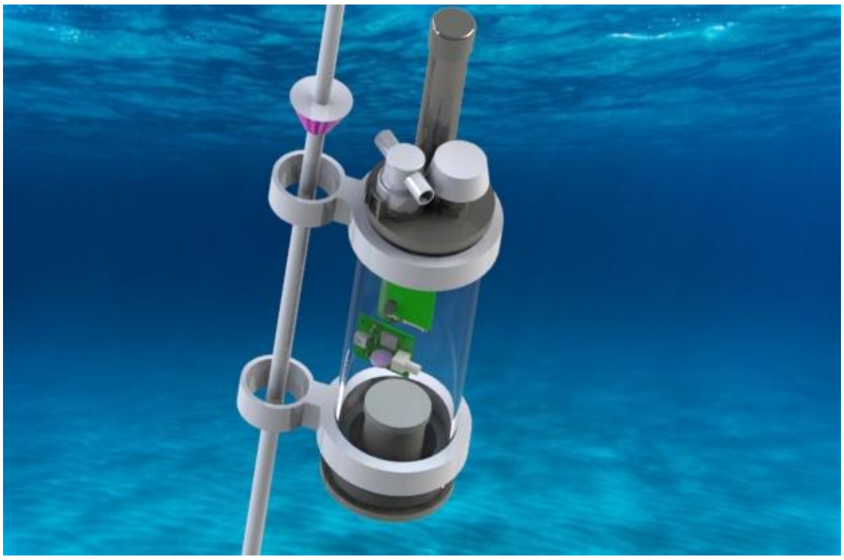


Fig. 16 Sensor node design with dual optical Cyclops-7Fsensors mounted.

The mooring line of the buoy contains variable-radius attachment points for rings present on each sensor node. Thus, each node deployed along the mooring line will attach to its designated point after sliding over smaller-sized attachment points meant for other nodes, and will be held in place vertically by two rings (Fig. 17). This enables vertical profiling and performing measurements at specific desired depths, which is frequently used in the monitoring of marine environments.



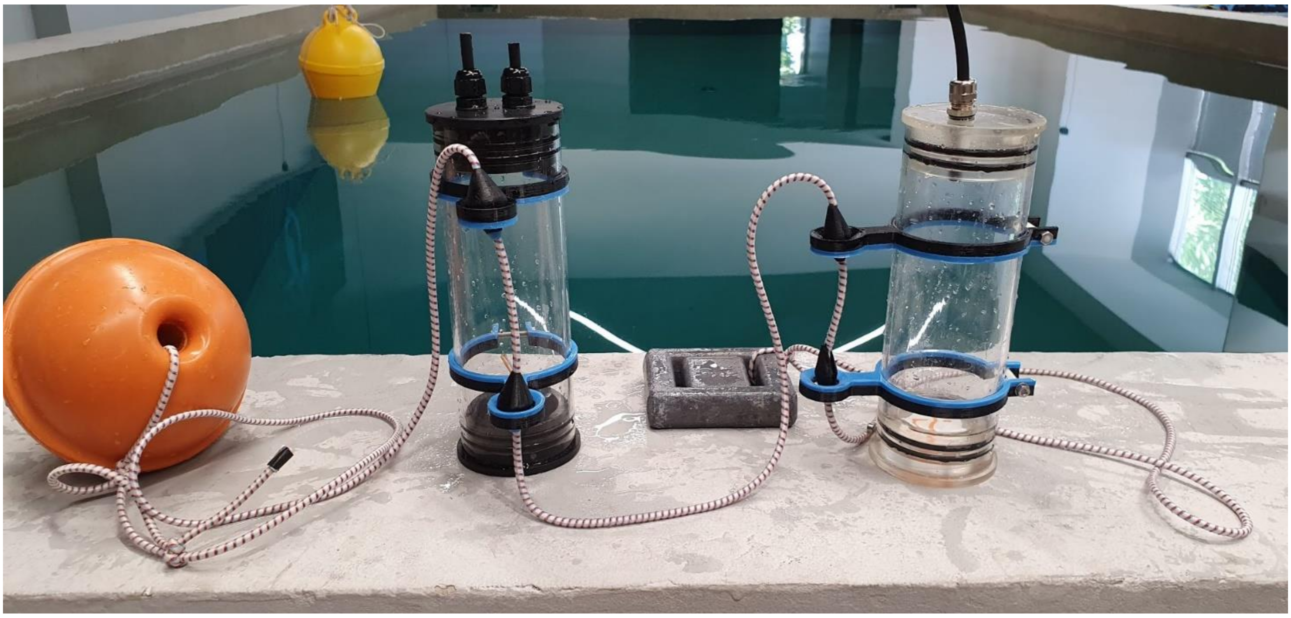


Fig. 17 Mooring line carrying sensor nodes. 3D concept and first prototype.

A surfacing system is being developed for the sensor nodes deployed on the seabed and not attached to the main buoy mooring line, to make retrieval of the sensor network simple. The bottom of each sensor node contains a CO_2 ampule attached to a servo motor-actuated mechanism controlling a valve, which when acoustically activated inflates a floater/expansion unit, allowing the node to rise to the surface and be collected. As explained in the Preliminary testing subsection, the first prototype concept in Fig. 18 has been redesigned as shown in Fig. 19.

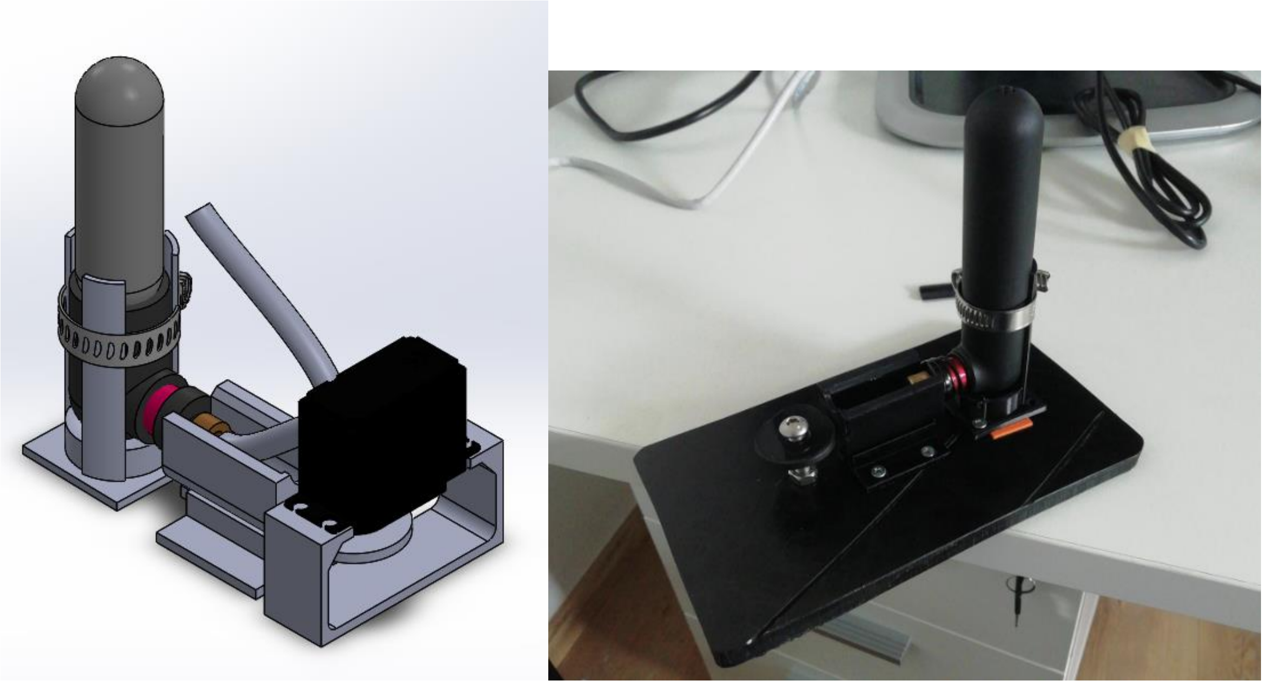


Fig. 18 First prototype for inflation mechanism (in 3D concept and the designed version).

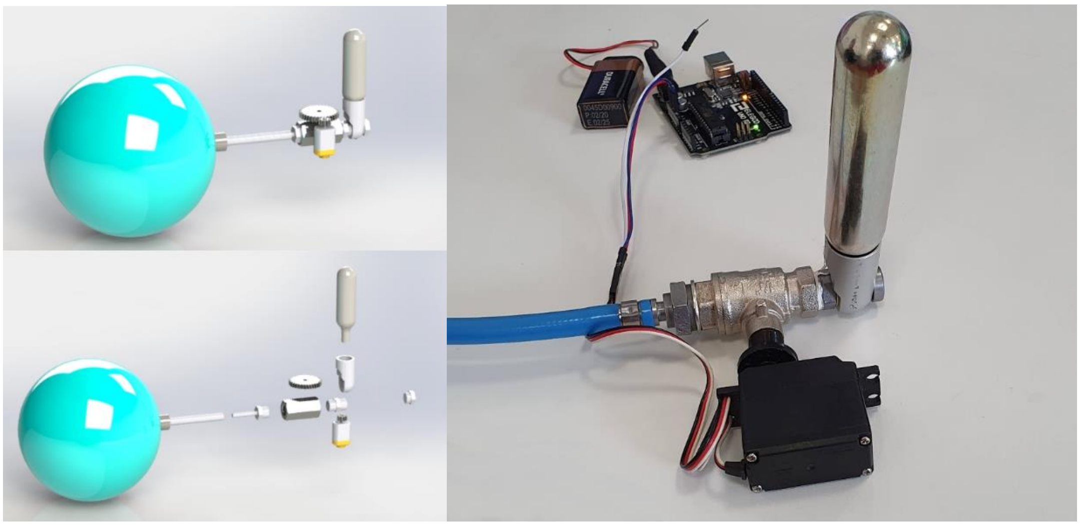


Fig. 19 Revised concept and prototype of the inflation mechanism.

Software modules

The main on-board computer used in the buoy is a Raspberry Pi running Ubuntu with Robot Operating System (ROS). Both a low-power version using a Rasberry Pi Zero and a high-capability version using a Raspberry Pi 4 are being tested. The sensor nodes use an Arduino Micro as their main board.

The currently envisioned operation cycle of the buoy system is shown in Fig. 20 and includes the buoy waking up from its own sleep mode on a preset fixed timer interval, sampling environmental data using its own sensors, then starting acoustic interrogation of all deployed sensor nodes. Each sensor node is awakened from its low-power mode by the acoustic ping, then samples data from its own sensors and sends the readings in an acoustic response to the buoy's ping using a predefined payload format. This communication is done in the node's own designated timeslot, ensuring no acoustic channel interference happens. Once the buoy replies with a reception acknowledgment, the sensor node goes back to sleep. The buoy, once it has collected all the sensor node data (or any of the sensor nodes reach a predefined time-out without response), sends its data to the IoT cloud in an appropriately formatted message, where it is displayed on a dashboard for users to see, track, and react to accordingly (for instance, if any alarms are raised).

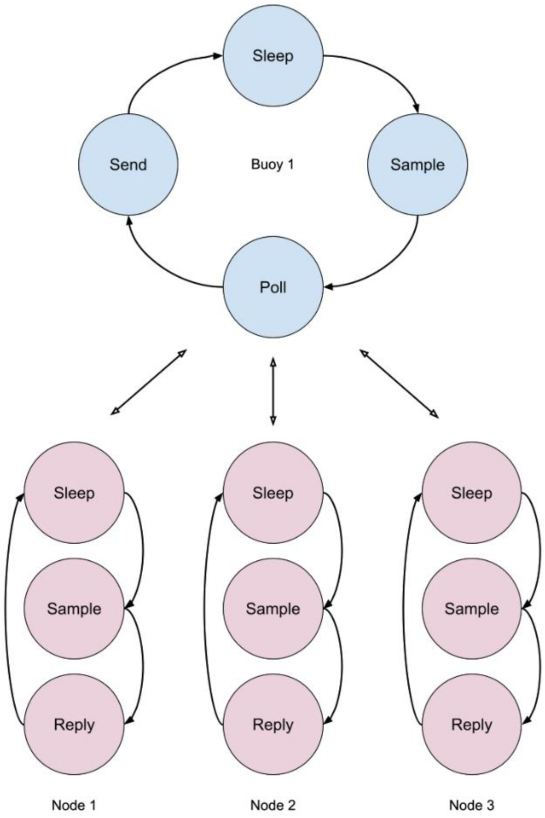


Fig.20 Buoy and sensor nodes standard operation mode.

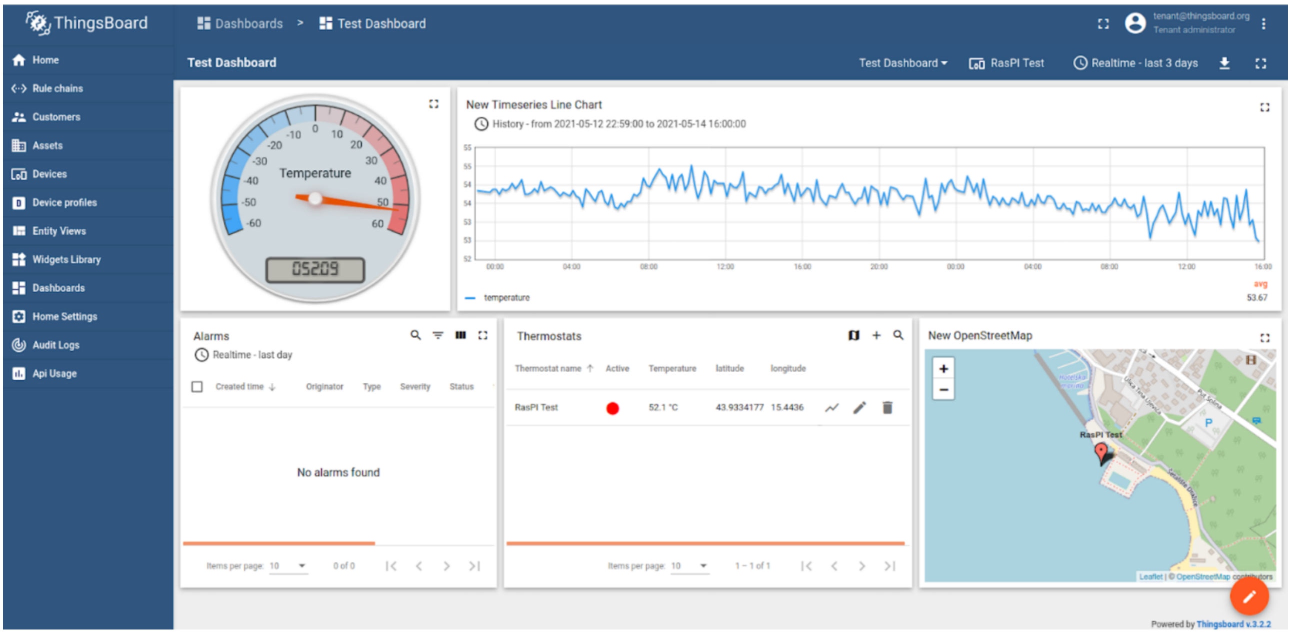
The buoy also serves as an acoustic relay to the sensor nodes, whose surfacing is triggered from the buoy. This can be a unicast intended for retrieval of a single node, or a broadcast when retrieving the entire underwater sensor network is required.

In terms of IoT, an open-source IoT platform called ThingsBoard was chosen for data collection, processing, visualization, and device management. The service was installed on a laptop to act as a server, and a dashboard was configured with appropriate widgets to display desired measurements for proof-of-concept experiments.

Preliminary testing

The first prototypes for sensor nodes and inflation mechanism can be seen in Fig. 17 and 18. The first prototyped design of the inflation mechanism (Fig. 18) was quite bulky and its eccentric component proved to be inadequate for proper pressure regulation, as a relatively large force was needed to move the piston regulating gas flow. The revised design (Fig. 19) simplifies the mechanism needed to achieve regulation, reduces the force required to turn the valve and regulate flow. By reducing the force, it also saves energy in a system that needs to be highly energy-efficient. The revised design reduces the dimensions of the entire mechanism, making it more suitable for use in a small underwater unit.

Regarding the software modules, IoT test devices were provisioned and user accounts with various levels of access were created. Data packets were sent using the Message Queuing Telemetry Transport (MQTT) protocol, as it is a lightweight communication protocol designed for small devices based on a publish/subscribe paradigm. Several proof-of-concept tests of the IoT ThingsBoard dashboard were performed. In the initial test, two laptops were involved in the communication and data collection, one acting as the server, the other as a "buoy" with a publisher, sending generated position, temperature, and humidity data to the server. The second test included a Raspberry Pi "buoy" measuring its own CPU temperature and reporting on its GPS position (a variant with a generated position, as well as a variant using a real GPS sensor and antenna were performed) and data from a simulated humidity sensor. The Pi was connected to a 4G LTE modem, hosted a publisher and transmitted data every 60 seconds for three days via 4G, sending it to a laptop hosting the IoT server and dashboard. The dashboard included an alarm widget set up to alert the user of events where the device registered and reported temperature or humidity outside of user-defined limits. A Dynamic Domain Name System (DDNS) service was set up, making the dashboard available at a human-readable address http://labustbuoy.ddnsfree.com. The results of this test in the example IoT dashboard as visible on desktop PCs are shown in Fig. 21, whereas Fig.22 shows the mobile dashboard.

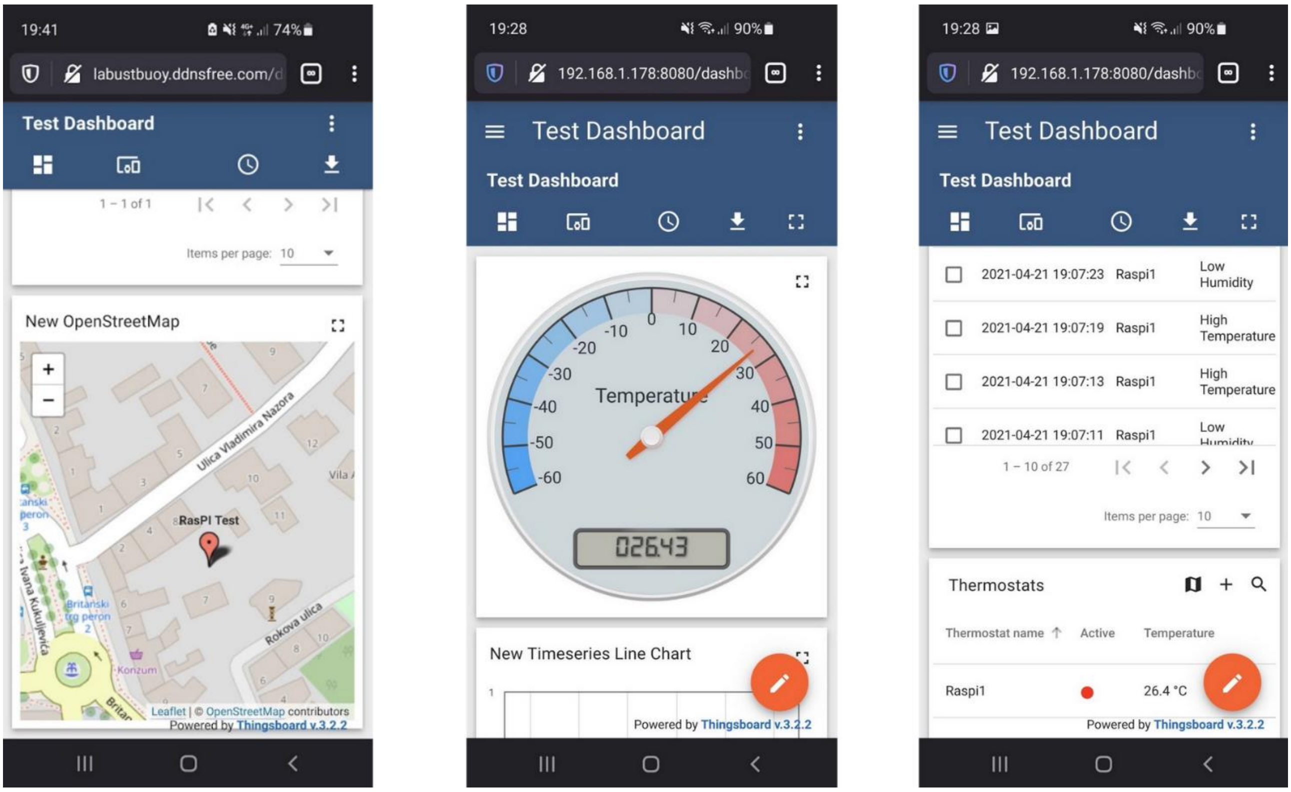


☐	Created time ↓	Originator	Type	Severity	Status

No alarms found

Thermostat name ↑	Active	Temperature	latitude	longitude
RasPI Test	●	52.1 °C	43.9334177	15.4436

Fig. 22 Desktop ThingsBoard IoT dashboard showing proof-of-concept for experimental data.



☐	2021-04-21 19:07:23	Raspi1	Low Humidity
☐	2021-04-21 19:07:19	Raspi1	High Temperature
☐	2021-04-21 19:07:13	Raspi1	High Temperature
☐	2021-04-21 19:07:11	Raspi1	Low Humidity

1 – 10 of 27

Items per page: 10

Thermostat name ↑	Active	Temperature
Raspi1	●	26.4 °C

Fig. 23 Mobile ThingsBoard IoT dashboard showing proof-of-concept for experimental data.

Blueye Pro ROV

This Remotely Operated Vehicle (ROV) is a commercial product and it has not been developed by any of the INNOVAMARE partners. However, it can be connected to and support Korkyra ASV in some use case scenarios as it shall be seen in the Use Cases section and therefore it is briefly introduced here.

Hardware modules

Blueye Pro ROV (shown in Fig. 24) was acquired from the Norwegian company Blueye Robotics company. Its dimensions are 48.5 cm x 25.7 cm x 35.4 cm (Length * Width * Height). It weighs 9 kg in air, is rated for up to 300 m depth (with a 400 m tether) and has autonomy of 2 h ensured by its 96 Wh battery. It can easily be trimmed for various underwater environments, saltwater, brackish, or fresh water. The ROV has in total four 350 W thrusters. Two rear thrusters in the horizontal plane, one in the vertical plane, and one lateral thruster enable high manoeuvrability of the vehicle together with auto-heading and auto-depth control modes. It can reach surge speed of up to 3 knots and operate in water currents of 2 knots at most.

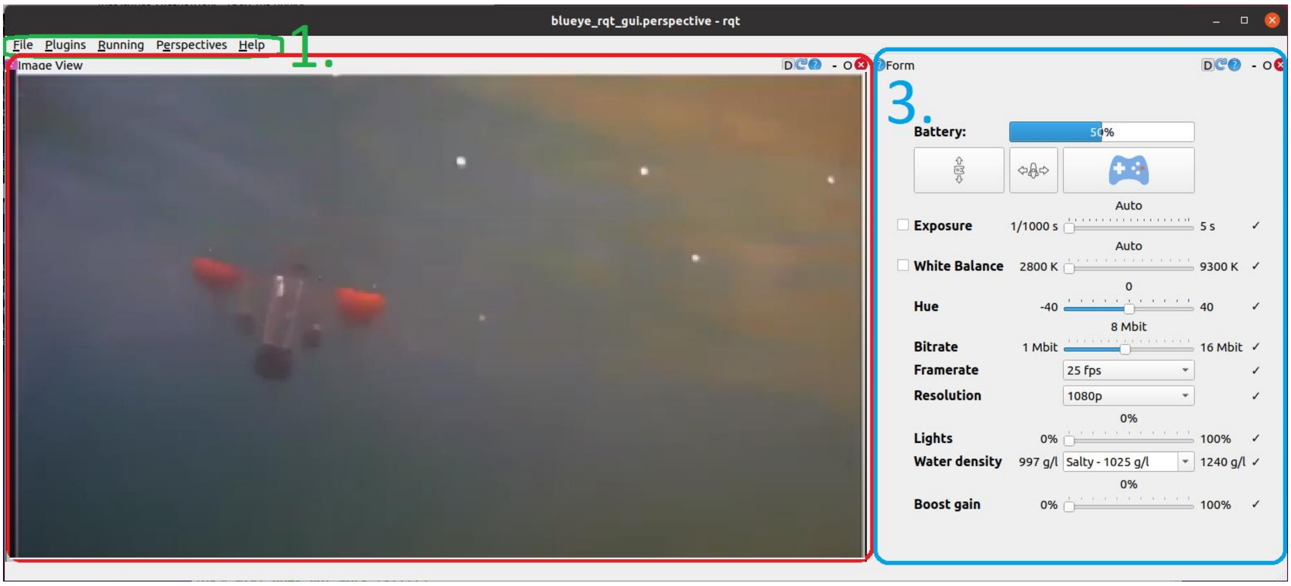
Fig. 24 Blueye Pro ROV.

Its main sensor is a full HD camera with a tilt angle mechanism in the range [-30º, 30º] and able to capture 25 to 30 frames per second. Blueye Pro ROV has powerful 3300 lum lights with 90 Color Rendering Index (CRI) LEDs ensuring well-lit imagery and excellent colour rendition. Other sensors include IMU with 3-axis gyro and 3-axis accelerometer, depth sensor, magnetometer (compass), temperature (inside and outside) and internal pressure sensor. Additional payload can be mounted at the top and/or the bottom.

The ROV comes with a surface unit that enables connection and control of the ROV via WiFi as well as via Ethernet in difficult wireless environments. For the use cases forecast in INNOVAMARE, the ROV can be integrated with the ASV Korkyra over Ethernet cable. Communication from the operator to the ROV is thus using ASV Korkyra's main NUC computer as a communication relay. A TMS is used together with a docking mechanism to connect and operate the ROV in connection with the Korkyra ASV. This TMS and docking mechanism is still under development.

Software modules

Blueye software development kit (SDK) is Python3-based and has been integrated into ROS2 for the operator to be aware of the situation underwater while observing the video stream in ROS2 graphical user interface (GUI). The ROV-ROS2 GUI shows the ROV's battery charge status, and enables/disables auto depth and auto heading diving modes. It also switches between manual mode (control via a gamepad connected to operator's computer) and autonomous mode (in which the main NUC computer aboard ASV Korkyra sends controls based on images that the ROV records). ROV's camera parameters (exposure, white balance, hue, bitrate, framerate, and resolution) as well as lights, water density and boost gain can be easily changed through this GUI, as shown in Fig. 25. All parameters are easily changed via buttons, sliders or combo boxes that prevent any of the parameters to be set outside their range. Minimum and maximum value of each parameter is shown to the left and right of each parameter control. The reference value of each parameter is shown above its slider/combo box. Since Blueye-ROS2 interface reads the parameter values that are achieved by the ROV, the GUI shows a checkmark to the right of each parameter whose reference and real value are matched, otherwise it shows an up- or down-facing arrow if the reference value is still above or below the measured value from the ROV.



Battery:		50%	
☐ Exposure	1/1000 s	Auto	5 s
☐ White Balance	2800 K	Auto	9300 K
Hue	-40	0	40
Bitrate	1 Mbit	8 Mbit	16 Mbit
Framerate		25 fps	
Resolution		1080p	
Lights	0%	0%	100%
Water density	997 g/l	Salty - 1025 g/l	1240 g/l
Boost gain	0%	0%	100%

Fig. 25 Blueye ROV Pro GUI view.

Preliminary testing

Preliminary tests to check the functionalities of this ROV took place and some issues with the cable were detected. These issues have been solved by the manufacturer and the ROV is now fully functional. It has been tested again together with the Korkyra ASV in April 2021 as shown in Fig. 11 and no issues have been detected. The ROV will be used in a real life context to inspect aquaculture farms nets images as per use case scenarios (described in the next section) and is ready to be used in future trials according to user needs.

Surface vessel

The INNOVAMARE partner GEOMAR has a Surface Vessel (SV) that can be used in support of trials. This surface vessel can be used for various tasks such as Multi-beam sonar (MBES) surveys, ROV tasks and sampling by various sensors. This vessel (of up to 10m) can serve a platform for performing various tasks, surveys as well as an office at sea, especially in locations such as ports, mariculture farms, etc. The current vessel can be seen in Fig. 26.

Fig. 26 GEOMAR's hydrographic vessel (8 m).

Hardware modules

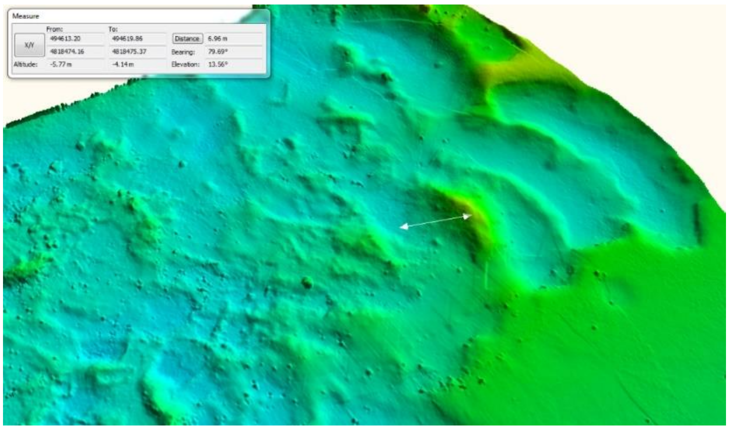
The surface vessel has the same modularity as the SWAMP ASV and the Korkyra ASV. Typical sensors mounted in this boat are:

- multibeam echosounder (MBES) Teledyne RESON SeaBat T20-P;
- sound velocity profiler Valeport mini SVP;
- Trimble-Applanix positioning system;
- geological parametric sub bottom profiler (SBP) Innomar ses 2000 Light for geological surveys.

ROVs such as the SIRIO Ageotech in can also be launched from the Surface Vessel and tracked using an Ultra-Short BaseLine (USBL) Tritech system.

Software modules

For the surface vessel, a captain pilots the boat and therefore there are no autonomous functions. However, a set of proprietary software is used to process the data collected by the sensors. An example of a bathymetric map produced by the software on-board the SV is presented in Fig. 27.



From: 494613.20, 4818474.16
To: 494619.86, 4818475.37
Distance: 6.96 m
Bearing: 79.69°
Altitude: -5.77 m, -4.14 m
Elevation: 13.56°

Fig. 27 3D model of the harbour seabed (after dredging)

USE CASE SCENARIOS

Within the Innovamare activity 5.2, FER and CNR started a proposal on the definition of applicative scenarios both in Italy (Venice) and Croatia (Šibenik) for the use of the robotic solution and sensors in order to reach the GES for the MSFD descriptors.

The foreseen use cases are related with inspection and monitoring activities of several typologies of target groups and the table 1 resumes them. The table includes the technologies to be used, namely, the ASVs from FER and CNR (Korkyra and SWAMP), the Surface Vessel from GEOMAR as support vessel and the ROV and Buoys from FER.

All the proposed use cases should be revised accordingly to the stakeholders and target groups needs during the evolution of the project activities. Note that the use cases include both the MSFD descriptors but also other blue growth economy sectors such as archaeology.

Tab.1 Potential use cases, technologies and target groups

	Technologies to be used		
Use cases	**ASVs+SV*+ROV**	**Buoys**	**Target Groups**
Inspection and monitoring of aquaculture ecosystems	• Map and detect biofouling in aquaculture cages (MSFD 5)	• Water quality inspection of sea in aquaculture farms (MSFD 5, 7)	Aquaculture companies
Inspection and monitoring for harbours and marinas including marine litter detection	• Creating high resolution bathymetryc 3D model (by Multibeam echosounder system; MBES) and/or mosaic of the seabed (MSFD 6) • Sediment erosion near structures (MSFD 7) • Automatic (offline) marine litter detection on mosaics (MSFD 10) • Creating high resolution digital ortophoto (aerial), surface litter/pollution detection on ortophoto map • Creating interactive maps/GIS for charting/tracking pollution/litter	• Water quality monitoring in marinas to detect wastewater (MSFD 5, 7) • Traffic activity detection using acoustic monitoring of the environments (MSFD 11)	Municipalities, Marinas, Environmental Protected Areas (EPAs), Marine Protected Areas (MPAs), coastal authorities
Benthic habitat mapping	• Benthic habitat mapping (MSFD 1 and 6)		EPAs, MPAs

Cultural heritage inspection and monitoring	- Submerged archeological sites monitoring - Inspection of buildings and structures conditions	- Submerged archeological sites monitoring (intrusion detection)	Municipalities, archaeological superintendencies, UNESCO

CONCLUSIONS

This report has introduced several platforms being developed/used by the INNOVAMARE partners. These include ASVs being designed and built by CNR and FER, Buoys and sensor nodes built by FER, commercial ROVs used by FER and a surface vessel from GEOMAR. These platforms are somehow complementary, and each has a different set of sensors as well as a different set of capabilities and functionalities. The platforms are at an advanced stage of prototyping and testing and will be ready for trials as per the plan in INNOVAMARE project proposal. The heterogeneity of the platforms allows for extreme flexibility and the coverage of a wide range of use cases. Possible use cases were presented and matched with the different platforms in a summarized way. These use cases address not only areas related to the MSFD descriptors but more in general other Blue Growth economy areas. It is worth notice that these use cases are representative of what the platforms can achieve but are not exhaustive and the platforms can be used in other contexts (in accordance with user needs). The work in Activity 5.2 is going according to the plan and no delays are foreseen at this moment. Good collaboration is in place and a series of regular meetings and technical workshops have taken place to ensure exchange of experiences and awareness of the possibilities brought by the technology being built. The developed platforms will be also showcased at the upcoming Breaking the Surface 2021 workshop.

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GLOSSARY

AP Access Point
ASV: Autonomous Surface Vehicle
Benthic zone: is the ecological region at the lowest level of a body of water such as an ocean, lake, or stream, including the sediment surface and some sub-surface layers.
CDOM Coloured Dissolved Organic Matter
CRI Color Rendering Index
DDNS Dynamic Domain Name System
EPA: Environmental Protection Agency
GES MSFD: Good Environmental Status descriptors of Marine Strategy Framework Directive
GIS: geographic information system
GNSS: Global Navigation Satellite System
GPS: Global Positioning System
GUI Graphical User Interface
IMU Inertial Measurement Unit
IMC Inter-Module Communication
IoT Internet of Things
IoUT Internet of Underwater Things
LABUST Laboratory for Underwater Systems
LL Living Lab
LoRaWAN Long Range Wide Area Network
LTE Long Term Evolution
MBES: MultiBeam EchoSounder
MPA: Marine Protected Area
MQTT Message Queuing Telemetry Transport
NGC Navigation, Guidance and Control
Ortophoto: is an aerial photograph or satellite imagery geometrically corrected ("orthorectified") such that the scale is uniform: the photo or image follows a given map projection.
PTZ Pan-Tilt-Zoom
ROV: Remote Operated Vehicle
RTK Real Time Kinematic
RTSP Real Time Streaming Protocol
SA Station Adapter
SBP Sub Bottom Profiler
SDK Software Development Kit
SV: Surface Vehicle
SWAMP: Shallow Water Autonomous Multipurpose Platform
TMS Tether Management System
UNESCO United Nations Educational, Scientific and Cultural Organization
USBL Ultra-Short BaseLine