D.5.2.7. Results report of the demonstration 2 of the Pilot action I. and scientific paper with demonstration 2, Pilot I.

InnovaMare project

Blue technology - Developing innovative technologies for sustainability of Adriatic Sea

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

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INTRODUCTION

The Adriatic Sea is one of the crucial industrial and touristic sites of the north east Mediterranean Sea and mitigate the anthropogenic impact on this area is crucial to protect the health of the ecosystems and of the people that leave by it. One of the main aims of InnovaMare Project is the monitoring of the health of the Adriatic Sea via an innovative robotic system and, specifically, the goal of WP5 is to put into practice the collaboration among the partners on robotics solutions to be used for the sustainability of the Adriatic Sea.

To achieve this goal, two different scenarios were identified in different environmental conditions, specifically Scenario 2 was designed for the Biograd na Moru area. Biograd na Moru has a touristic marina and a refueling station for boats and it is widely popular. All types of vessels operate in the area from ferries to yachts, but also touristic and fishing boats. Thus, there may be sea litter accumulated in the sea bottom. Due to the weather conditions, fake litter was deployed (and recovered at the end) for the purposes of demonstration. As well, the large manned vessel was not used as forecast due to the inclement weather. In the interest of conciseness, the full description of the scenario is provided in Deliverable 5.2.5 and the description of the platforms to be used is provided in Deliverable 5.2.2. Finally, the results of this demonstration are presented in the following scientific paper.

Cooperative marine litter detection and environmental monitoring using heterogeneous robotic agents

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***Abstract*—In the interest of both enabling long-term autonomous monitoring of at-risk marine environments and raising awareness and capabilities among citizens, a heterogeneous system of marine robots was developed, integrated, and deployed on a mission in the Adriatic Sea. This paper details a use-case scenario for a team of marine robotic agents for the purpose of cooperative marine litter detection and mapping, while also including interested citizens in the loop and allowing them to serve as operators. Two Autonomous Surface Vehicles (ASVs), a Remotely Operated Vehicle (ROV), and a Smart Buoy were deployed in a real marine environment to demonstrate the cooperative abilities of this system.**

***Index Terms*—environmental protection, marine monitoring, Autonomous Surface Vehicles, buoys, citizen science**

I. INTRODUCTION

The Interreg Italy-Croatia InnovaMare project [1] seeks to enhance the cross-border collaboration between science and private sectors and to encourage and enable technology transfer in the field of underwater robotics and sensors, creating an innovation system in Blue Economy. An overview of the project is given in [2]. Use-cases defined and collaborations developed during this project are of high relevance, as the two countries are heavily impacted by and reliant on the Adriatic Sea where there is a noted urgent need for better environmental monitoring and protection [3].

Two use-case scenarios of great interest for the stakeholders and defined together with the other technical partners of the project have been devised and implemented by LABUST, FER, University of Zagreb and CNR's ISMAR and INM institutes. A set of complementary platforms with a different set of capabilities and functionalities is featured: the Shallow Water Autonomous Multipurpose Platform (SWAMP) Autonomous Surface Vehicle (ASV) from CNR-INM, the Korkyra ASV, the Blueye Pro Remotely Operated Vehicle (ROV) and the Smart Buoy from LABUST, FER. Fig. 1 shows the different robotic agents involved. Descriptions of the design and development of the Smart Buoy and ASV Korkyra are available in [4], [5] respectively, while the original SWAMP ASV is described in [6].

Automating inspection and monitoring of harbours, marinas, and aquaculture ecosystems, including marine litter detection, is a highly relevant problem in the area of marine robotics. This scenario aimed to showcase a heterogeneous multi-robot system tackling this issue. All agents from the above-mentioned heterogeneous robotic system form an ad-hoc communication network spanning both underwater acoustic channels and surface WiFi comms. Blueye ROV collects visual data with an objective to find sea litter and other pollution factors, while acoustic sensor units monitor and report on water quality. ASV Korkyra is controlled to follow the ROV. Once sea litter is detected, its estimated georeferenced location is sent to the ASV SWAMP using the Smart Buoy as a relay, after which SWAMP moves to the given location. The buoy monitors the vehicles during the entire length of the mission, displaying their telemetry and status data on a graphical dashboard.

All this is realised with a view towards incorporating a citizen science approach. Citizen science has in recent years seen considerable growth thanks to web-based and mobile platforms and technological advancements. In addition to serving as a tool for raising awareness, education, scientific literacy and improving scientific communication [7], it allows for expansive data collection creating large, longitudinal data sets suitable for biodiversity monitoring and biological research [8] [9], forming an early response to newly established populations thanks to surveillance and monitoring of invasive species [10],

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Fig. 1: Korkyra catamaran with tether management system and tethered Blueye ROV deployed in LABUST pool (above), SWAMP catamaran ready for deployment alongside Korkyra and Smart Buoy in Biograd na Moru, Croatia (below).

and in general forming a quantitative understanding of habitat and climate shifts as they happen [11]. Work is ongoing on the integration of citizen science approaches into the United Nations (UN) Sustainable Development Goals (SDGs), with analyses attempting to pinpoint the greatest benefits inputs from citizen science can provide to the SDG framework [12] and roadmaps outlining ways to integrate citizen science into the formal SDG reporting mechanisms [13].

The paper is organized as follows: Section II describes in detail the technologies used in the scenario. Section III describes the application scenario. Section IV shows preliminary results obtained at sea and Section V concludes the paper highlighting future work.

II. HETEROGENEOUS ROBOTIC AGENT TYPES

A. *ASV SWAMP*

The SWAMP (Shallow Water Autonomous Multipurpose Platform) is a catamaran-shaped Autonomous Surface Vehicle (ASV) which takes to the extremes the concept of a highly modular and completely wireless platform. Since the first operational requirement that led its design was that of navigation capability in extreme shallow waters ($\sim$ 0.2 m), the hulls were conceived to completely contain the propulsion devices in order to avoid the presence of protruding and moving parts (e.g. propellers) outside of the shape of the hulls themselves. For this reason, the hulls are composed of a 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 mechanically a completely modular vehicle that can be dismounted and transported to be reassembled in various different configurations.

The length of the hull (and thus of the vehicle) is 1.230 m while the width can be set, adjusting the inter-hull distance, between 0.700 and 1.250 m. The propulsion is provided by four swiveling pump-jet thrusters (two installed on each hull); each propulsion unit, called *Minion*, is equipped with its own battery and a Raspberry Pi based computing unit providing direct control of the thruster. The propulsion cylinder is installed inside the hull, with the nozzle at the same level of the bottom line of the hull. This allows the pump-jet to produce the required propulsion without any efficiency loss (due for instance to the interaction with the hull) in any direction. The thruster is composed of a main pump producing the required propulsion power and an azimuth motor which directs the water jet in the desired direction. The combination of these four thrusters allows the platform to be fully actuated.

The ASV is also equipped with an additional computing cylinder, mounting a Raspberry Pi and a Microstrain 3DM-GX3-35 AHRS with integrated GNSS, devoted to navigation, guidance and control execution and monitoring, while an additional cylinder is equipped with a long-range WiFi antenna acting as access point for the local wireless connection of all the onboard components, as well as the connection of the remote operator from the ground station. Since every cylinder is equipped with its own battery and WiFi connection capability, the platform is completely wireless and any additional component (such as sensors or modules) can be easily integrated by giving it access to the local WiFi. The platform weight for the base configuration is about 20 kg with a maximum payload of 50 kg. Its operating speed is about 0.5 to $1.0\frac{m}{s}$ (cruise and sampling), with a maximum speed of $1.6\frac{m}{s}$.

For the particular application related to this work, the SWAMP ASV is equipped with a single-beam echo-sounder; the peculiar installation aspect is that the sensing head of the instrument is mounted inside the hull. The foam of the hull, being in direct contact with the sensing head, transmits the sound wave, allowing for the altitude measurement without any efficiency loss or disturbance addition (a number of preliminary laboratory tests were carried out in order to asses the validity of the measurement in the described configuration).

From a control standpoint, the overall control architecture is composed of a set of interchangeable modules devoted to different operational tasks:

- Navigation: a data fusion and filtering module is specifically designed for providing a consistent measure of the global position, direction of motion, attitude, and velocity of the platform.

- Control: the control layer is composed of a thrust-mapping module responsible for the optimal force allocation among the four thrusters, suitably selecting the proper azimuth orientation in such a way to comply with the current operational requirement, such as maximizing the transfer speed or providing hovering capability. A higher control layer is composed of different control loops which give the vehicle capabilities such as auto-heading and auto-speed.
- Guidance: motion regulation over the operational space is achieved by a guidance system equipped with a way-point tracking mode as well as a line-following controller allowing tracking of a geo-referenced transect in the operational area.

The control architecture is completed by a safety module, continuously running throughout the entire mission execution, in charge of monitoring the status of the WiFi connection between the remote operator station and the vehicle itself. If the connection is lost for a predetermined amount of time (that is set according to the specific mission requirements), the guidance system is automatically set to way-point tracking of a specific "home" fix, preset at the beginning of the operations.

B. ASV Korkyra with tethered ROV

The ASV Korkyra is an autonomous surface vehicle designed as an aluminium catamaran with a length of 2 meters, a width of 1 meter, and hollow hulls with a diameter of 240 mm, achieving stability and good hydrodynamic properties in sea states up to state two. Its upper deck consists of a carbon hull that houses the electronics and computers that enable its autonomy, while the lower deck contains IP67-rated watertight aluminum boxes for batteries, motor electronics, the NORBIT iWBMSc multibeam sonar system INS, and an expansion box that provides easy connectivity for each payload. With a weight of 100 kg, the ASV Korkyra is equipped with four electric T200 thrusters in an X configuration, which enable it to navigate complex marine environments at lower speeds of 1-2 knots in all directions. In addition, if higher speeds are required, the 720 W Minn Kota RT 55 EM booster electric motor enables top speeds of 3-4 knots. The ASV can draw a total energy of 252 Ah or 3.73 kWh from its batteries, giving it an autonomy of 10-11 hours on average.

The vehicle uses the Applanix SurfMaster GNSS with inertial navigation system IMU, combined with base station corrections over the Long-Term Evolution (LTE) network, to localize itself globally with an accuracy of up to 10 cm. It also employs ROS as a framework for mid- and high-level control, data processing, and mission control, and communicates with the operator via Wi-Fi with a peak transmission speed of 100 Mbps over a range of 400-500 meters. Operator work and mission planning for ASV Korkyra will be facilitated by open-source, graphical user interface-based software called Neptus.

The ASV Korkyra is equipped with various payloads, such as a multibeam sonar, a remotely operated vehicle (ROV), a tether management system (TMS) for the ROV, a landing platform for the UAV, a pan-tilt-zoom (PTZ) Hikvision IP camera (mounted on top of the roll bar), and a LiDAR on the upper and front lower parts of the ASV.

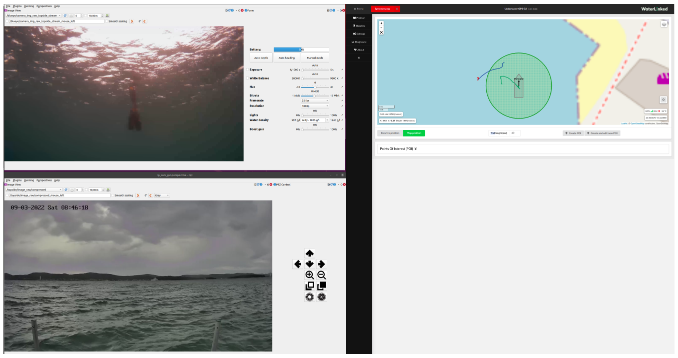


Fig. 2: Example of the operator interface used for Korkyra ASV and Blueye ROV.

The tethered ROV used in the heterogeneous system is the Blueye Pro ROV, manufactured by the Norwegian company Blueye Robotics. Its dimensions are $485 \times 257 \times 354$ mm ($L \times W \times H$). It weighs 9 kg in the air, is designed for a depth of up to 300 m (with a 400 m tether) and has an autonomy of 2 hours provided by its 96 Wh battery. It can be easily trimmed for different underwater environments, be it saltwater, brackish water or freshwater. The ROV has a total of four 350 W thrusters, with two rear thrusters in the horizontal plane, one in the vertical plane, and a side thruster allowing the vehicle to be highly maneuverable along with automatic heading and depth control modes. It can reach a top speed of up to 3 knots and operate in water currents of 2 knots maximum.

The main sensor used by the ROV is a HD camera with a $[-30°, 30°]$ tilt angle mechanism that operates at 25 - 30 fps. The ROV also features powerful 3300 lum lights with 90 CRI LEDs to ensure all images taken are well-lit. Other on-board sensors include an IMU with 3-axis gyro and 3-axis accelerometer, depth sensor, magnetometer (compass), temperature (indoor and outdoor), and an internal pressure sensor. Additional payloads can be attached to the top and/or bottom. The ROV comes with a surface unit that allows it to be connected and controlled via WiFi as well as via Ethernet in challenging wireless environments. Thus, communication between the operator and the ROV is done using ASV Korkyra's NUC main computer as a communication relay. The Blueye Software Development Kit (SDK), based on Python3, was integrated into ROS2 to allow the operator to monitor the situation underwater while viewing the video stream in the ROS2 graphical user interface (GUI). The code for the Blueye SDK-ROS2 interface and GUI is publicly available at [14]. An example of the Korkyra ASV and Blueye ROV user interfaces is shown in Fig. 2.

C. Smart Buoy

The Multifunctional Smart Buoy is a surface agent in the environmental monitoring system itself performing measurements, while primarily serving as a communication hub, data aggregator, and relay. It implements a modifiable sleep/wake cycle, allowing it to function and gather data intermittently for a long time (while also harvesting solar power using its photovoltaic solar panels), or to dedicate a continuous time-window to participate in an ongoing mission for several hours. The buoy also features a modem for acoustic communication, giving it the ability to seamlessly integrate underwater agents such as acoustic underwater sensor nodes, ROVs or AUVs into the communication structure, as well as a Teltonika TRM250 industrial grade USB LTE Cat-M1/NB-IoT/EGPRS Modem with a rugged housing for communication when WiFi access to shore is not an option. The buoy itself is 50 cm high with a diameter of 45 cm at its widest and quite light with a total weight of about 3kg. This is achieved by manufacturing it using a special molding procedure to shape polyurethane foam into a full body with solar panel mounting points (patent pending) comprising a plexiglass cylinder housing for all electronics, with a top cap equipped with penetrators for a camera or other sensors. The main computer of the Smart Buoy is a Raspberry Pi Zero, providing a balance between processing ability and low power consumption.

III. ENVIRONMENTAL MONITORING SCENARIOS

The first of the two scenarios was the environmental monitoring of a transitional environment in Venice using SWAMP and the Smart Buoy and is reported in [15]. In this scenario, SWAMP was equipped with a ROX spectrometer sensor, and was, together with the Smart Buoy, integrated into a single environmental monitoring and surveying system.

In the second scenario, all four systems are used in a cooperative joint trial. SWAMP is equipped with a Multibeam echosounder system (MBES) for creating a high resolution bathymetryc 3D model and/or mosaic of the seabed. While SWAMP is engaged in a patrol and mapping mission, Korkyra is used as a relay for a volunteer operator to remotely control the Blueye ROV with the goal of finding underwater debris. The precise location and depth of the tethered ROV is known thanks to the underwater GPS/acoustic localisation system on the vehicles. Vehicle status, location, and sensor data are all transmitted to the Smart Buoy, which collects all available data and sends it to an online IoT dashboard for user-friendly display. Once the operator has located a target with the ROV (e.g. garbage), the target location is transmitted to the buoy, and then to SWAMP. SWAMP pauses its current mission and moves to the target location in order to better map, or, in a future use-case, collect the debris.

The information flow during the second scenario is shown in Fig. 3. In both scenarios the vehicles communicate via WiFi, with the buoy serving as a relay hosting an UDP listener. Once packets of telemetry and/or sensor data are received from SWAMP and/or Korkyra, data collected by the buoy and aggregated from all other agents is sent to an online IoT dashboard which has all agents of the robotic monitoring system defined as devices, providing real-time access to the status of the catamarans and ROV. In these trials, the data sent from SWAMP is its latitude/longitude GPS position, its heading, its on-board temperature, the voltage state of its batteries, and the range reading from its MBES. The buoy itself provides its own GPS position, both on-board and in-water temperatures, and a still image taken by its top camera.

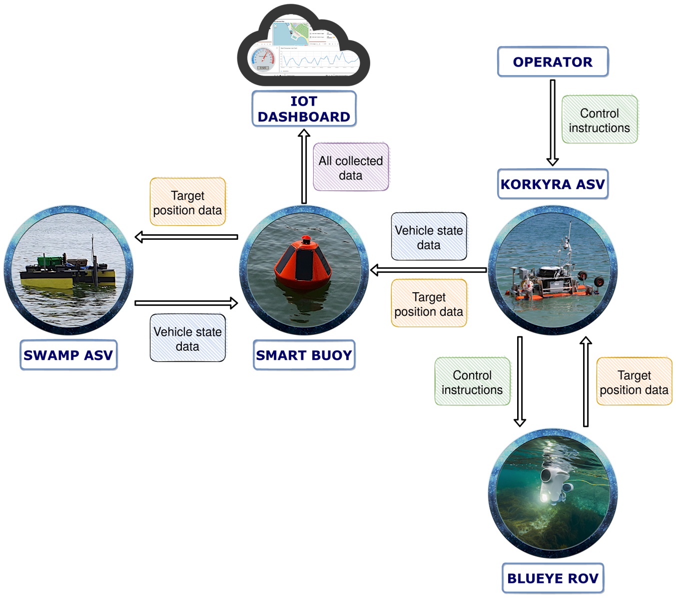
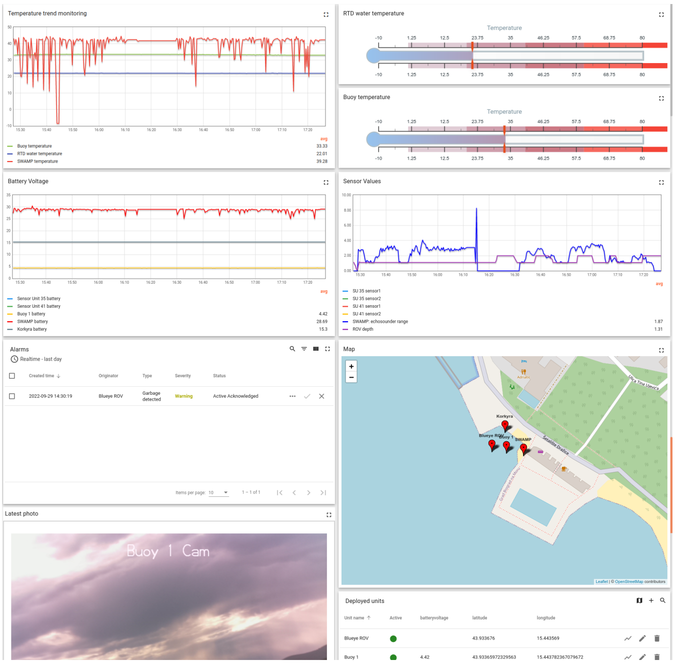


Fig. 3: Agents and communication/data flow in the second cooperative scenario.



☐	Created time	Originator	Type	Severity	Status
☐	2022-09-29 14:30:19	Blueye ROV	Garbage detected	Warning	Active Acknowledged

Unit name	Active	batteryvoltage	latitude	longitude
Blueye ROV	●		43.933676	15.443569
Buoy 1	●	4.42	43.93365972329563	15.443782367079672

Fig. 4: Example of an IoT monitoring dashboard showing the vehicles in Biograd na Moru, Croatia during second cooperative scenario.

Fig. 5: Demo participants observing operator screens and sensor unit.

Fig. 6: Smart Buoy prepared for deployment along with "marine litter" to be used in demo (left). Citizen participating in demo by piloting ROV (right).

IV. RESULTS

The second scenario was tested in Biograd na Moru during the 14th Breaking the Surface (BtS) International interdisciplinary field workshop on maritime robotics and applications [16] from September 26^{th} to October 2^{nd} 2022, with the initial results transmitted by the Smart Buoy shown in Fig. 4. It was also open to the public as a citizen science event the context of the Montenegrin Centre for Underwater Sensor Networks (MONUSEN) EU funded project [17]. MONUSEN aims to increase research and innovation capabilities of the University of Montenegro Faculty of Electrical Engineering (UoM-FEE) through a set of strategic measures: staff exchanges and expert visits for providing knowledge transfer, on-site trainings for providing hands-on experience, joint research actions, research and innovation management trainings and research-industry workshops. Moreover, among MONUSEN outreach activities are joint citizen science activities to take place during BtS summer schools. As these activities explicitly have the goal of raising awareness among the citizens for the United Nations Sustainable Development Goals and explaining how technology (underwater sensor networks and marine robots) can be used to address the SDGs, several specific SDGs were targeted. These are SDGs 7 (Clean energy), 13 (Climate action) and 14 (Life below water). To accomplish this, citizens were invited to participate in the trial described in this paper. After a brief demonstration and lecture, citizens with no experience with piloting ROVs were taught how to control it and observe its camera in a quest for marine litter (Fig. 5, Fig. 6) and were introduced to a variety of user interfaces for topside operators with control, monitoring, data display, and logging features. The easy interface of the Blueye app allowed for citizens to easily reach a basic level of proficiency in moving the ROV, and the overall communication structure performed consistently and reliably, with the SWAMP ASV interrupting its patrol and successfully replanning its mission when summoned. On the other hand, bad weather during the trials diminished the number of citizens in an area that is typically densely populated with tourists. Moreover, for safety reasons due to the worsening sea state, the area of the experiment was reduced and the task was thus simplified. Nonetheless, the feedback from the participants was very positive and encouraging.

V. CONCLUSION

A heterogeneous robotic system was formed by successfully integrating a variety of vehicles and robotic agents from several research institutions. The demonstration scenario performed at sea at Biograd na Moru, Croatia showed both a capacity for good performance as an environmental monitoring system as well as a tool for bringing interested citizens into the fold. Future editions of joint citizen science activities will take collected feedback and the experience of organising and holding this demonstration into account, offering several parallel tracks for participation with varying levels of complexity, with a view towards increasing both attendance and capacity.

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CONCLUSIONS

This report describes in detail the demonstration related to the Scenario 2 of the Pilot action I. This demonstration took place in Biograd na Moru, during the Breaking the Surface 2022 workshop. This scenario included 2 Autonomous Surface Vessels, one Remotely Operated Vehicle and one buoy acting as relay for communications. In order to prepare for this scenario a series of regular meetings have taken place among partners, looking at the different possibilities of collaboration.