D.5.2.6. Results report of the demonstration 1 of the Pilot action I. and scientific paper with demonstration 1, 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

Project References

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Contents

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 1 was designed for the Venice Lagoon. The Venice Lagoon is a perfect test bed due to its environmental characteristics and has been used to demonstrate some of the INNOVAMARE technologies. In this scenario the interaction between technical solutions was also tested. In the interest of conciseness, the full description of the scenario is provided in Deliverable 5.2.4 and the description of the sensors to be used is provided in Deliverable 5.2.3. Finally, the results of this demonstration are presented in the following scientific paper.

Heterogeneous marine robotic system for environmental monitoring missions

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***Abstract*—Environmental monitoring and protection of our oceans has become an absolute priority recognized as well by the United Nations and its UN Ocean Decade. Marine robotic systems can play a fundamental role in this field due to their lower cost and autonomous behavior when compared to research vessels. This article details the first use-case scenario defined within the INNOVAMARE project where an Autonomous Surface Vessel (ASV) and a Smart Buoy cooperate in a real and fragile environment as the Venice Lagoon. Preliminary results show the effectiveness of the equipment and methods and serve as validation for the more complex second use-case scenario.**

***Index Terms*—environmental protection, ocean monitoring, Autonomous Surface Vehicles, buoys**

I. INTRODUCTION

Pollution, over-fishing, and other environmental issues deeply affect oceans and seas around the globe. This is particularly concerning in the Adriatic Sea where the need for better environmental monitoring and protection is urgent [1]. The United Nations Ocean Decade highlights the need for better science and technology to understand and monitor comprehensively our threatened environments. This need can be addressed with environmentally-friendly technologies with low impact and low cost such as small Autonomous Surface Vehicles (ASVs) and buoys instead of using larger research vessels. On the other hand, in the Adriatic area, there are several Research and Development (R&D) institutions, companies, and universities working in the Blue Economy domain [2]. To leverage previous synergies and create an innovation ecosystem in Blue Economy answering to the environmental monitoring and protection needs, 14 partners from Italy and Croatia led by the Croatian Chamber of Economy created a consortium and started the Interreg Italy-Croatia InnovaMare project [3]. The goal of the INNOVAMARE project is to enhance the cross-border collaboration between science and private sectors and encourage and enable technology transfer in the underwater robotics and sensors field. For an overview of the InnovaMare project, the interested reader can consult [4].

While different monitoring platforms have been used in the past, both static and mobile, a specific multi-robot system dedicated to environmental monitoring in relevant scenarios of interest for end-users such as national parks and environmental protection agencies is lacking. Moreover, given the open science paradigm and the increase in citizen science initiatives, it is important to create easily accessible representations of collected data. This is tackled by the Internet of Things (IoT) dashboard presenting the data produced and received by the a smart buoy as it shall be presented.

This paper reports on the initial scenario developed within the INNOVAMARE project, the technologies used and preliminary results obtained. The remaining of the paper is organized as follows: Section II describes the application scenario and the technologies used. Section III shows preliminary results obtained in this scenario and Section IV concludes the paper highlighting future work.

II. SCENARIO AND TECHNOLOGIES

Within the framework of the INNOVAMARE project, two of the partners have been collaborating in use-case scenarios of interest for the stakeholders and defined together with the other technical partners of the project. In particular, LABUST, FER, University of Zagreb and CNR (both ISMAR and INM institutes) have devised two potential scenarios which will test the developed technologies. In the first scenario, the technologies to be used are the Shallow Water Autonomous Multipurpose Platform (SWAMP) Autonomous Surface Vehicle (ASV) from CNR-INM and the Smart Buoy from LABUST, FER. Figure 1 shows the different autonomous systems. Descriptions of the design and development of the Smart Buoy is available in [5], and the original SWAMP ASV (now updated and adapted) is described in [6]. The main aim of this application is the

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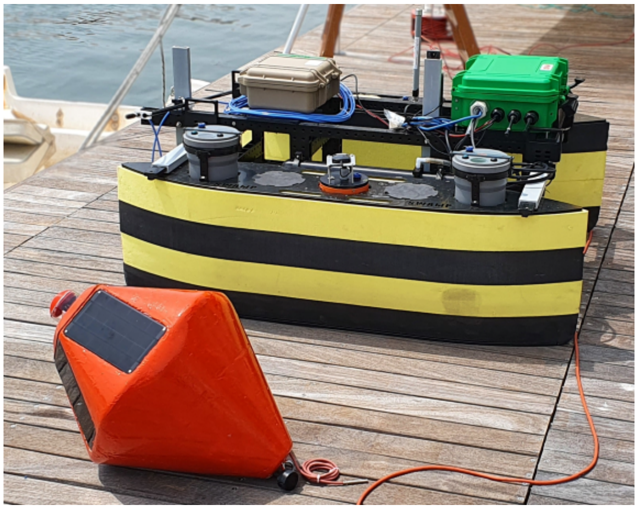


Fig. 1: Smart Buoy and SWAMP catamaran ready for deployment in the Venice Arsenale (below).

monitoring of the health of the Adriatic Sea via an innovative robotic system and, specifically, the goal of INNOVAMARE 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, the first of the two scenarios is the environmental monitoring of a transitional environment in the lagoon of Venice (Figure 3) and uses SWAMP and the Smart Buoy, as shown in Figure 2. Moreover, SWAMP is equipped with a RoX spectrometer sensor (JB Hyperspectral) for the acquisition of autonomous and continuous hyperspectral measurements. In this scenario, the goal was to test each individual system as well as the integration of SWAMP and the Smart Buoy into a single environmental monitoring and surveying system. In particular, the communication and functioning tests were carried out in two test areas marked in Figure 3).

A. *SWAMP and ROX spectrometer*

SWAMP - Shallow Water Autonomous Multipurpose Platform - is a portable, modular Unmanned Surface Vehicle (USV), designed and built by CNR-INM Genoa research group. It is a catamaran, equipped with four azimuth Pump-Jet trusters, all contained within the hulls, and designed specifically for SWAMP. The hulls are made of a soft-foam lightweight material, and each hull hosts a propelling and control unit - MINION. The design of SWAMP ensures high modularity and floatability, rendering the vehicle adaptable to the mission and user requirements. The physical modularity is reproduced also in the software architecture. Moreover, the hulls are fully independent, as each of them includes its own control, guidance, power, propulsion, navigation, and communication systems. SWAMP has an onboard Wi-Fi communication network that enables communication among every single modular element, other than between the two hulls. This design renders SWAMP a completely modular vehicle that can be dismounted and transported, and then remounted in various possible configurations. SWAMP ASV allows for extremely shallow water navigation, disclosing unprecedented data in a hostile navigation environment.

Fig. 2: SWAMP and Smart Buoy deployed in the Venice Arsenale (top) and Venice Lagoon near Sant'Angelo della Polvere (bottom) during first cooperative scenario.

The RoX is a field spectrometer designed to acquire continuous hyperspectral measurements in the visible and near infrared (VNIR) spectral region. The instrument employs two Ocean Optics spectroradiometers that simultaneously collect the upwelling radiance from the water body and the downwelling irradiance of the atmosphere in the wavelength interval between 400 and 950 nm, with a spectral resolution of 1.5 nm. The integration time of the sensor depends on illumination conditions. The RoX consists of a small waterproof rugged case (dimensions: 30 × 25 × 13 cm) with a low weight (about 3 kg). These characteristics, paired with the low power consumption, make the RoX a perfect field spectrometer for InnovaMare applications. Generally, the spectrometer is used in fixed stations and mounted in vertical direction on a tripod [7] or on a floating buoy [8] for monitoring the temporal dynamics of optical properties with high frequently observations. In the present application, RoX was mounted on the ASV SWAMP in order to test its performance while collecting optical properties for benthic habitat mapping.

The two spectroradiometers of RoX are mounted on the SWAMP in a way that ensures the first one points upward to collect the downwelling irradiance (Ed) reaching the target and the second one points downward to measure the upwelling

Fig. 3: Testing area for the operations in the Venice Lagoon.

radiance (Lu) rising from the water body. The Ed optic is placed on a fiber levelling gimbal to ensure the measurements are always perpendicular to the water surface regardless of the SWAMP oscillations. To avoid the solar glint from the water surface, the sensor collecting Lu is placed below the water surface (about 15 cm) and pointed downward. Finally, the two sensors are installed far enough from the vehicle in order to avoid any shadow. In view of satellite remote sensing applications, the above-surface water-leaving radiance (Lw) is calculated from the Lu measured by the RoX below the water surface. Lu is multiplied by the correction factor equal to 0.543, found in [9], to take into account the water-air interface. The calculated Lw is divided by the Ed, to obtain the remote sensing reflectance Rrs. Since Lw is measured in Wm^{-2} nm^{-1} sr^{-1} and Ed in Wm^{-2} nm^{-1}, the Rrs is reported in sr^{-1}. Rrs data are filtered considering several quality flags that are automatically evaluated on the ROX spectral measurements. These quality flags allow detecting spectral measurements collected in suboptimal illumination conditions which can occur when working during cloudy weather, deleting them from the time series.

The trials of the SWAMP-ROX configuration were performed first at CNR-ISMAR Arsenale premises (Figure 3, Area 1), to test all the basic functioning and the SWAMP navigation software, and then in the lagoon central basin, near Sant'Angelo della Polvere island (Figure 3, Area 2), to collect hyperspectral data over optically shallow waters along a transect, where different bottom substrate coverage is present (e.g. seagrasses, macroalgae, sand).

B. SWAMP and Smart Buoy interaction

The Multifunctional Smart Buoy is a surface agent in the environmental monitoring system performing measurements, while at the same time 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 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, Remote Operated Vehicles (ROVs) or Autonomous Underwater Vehicles (AUVs) into the communication structure.

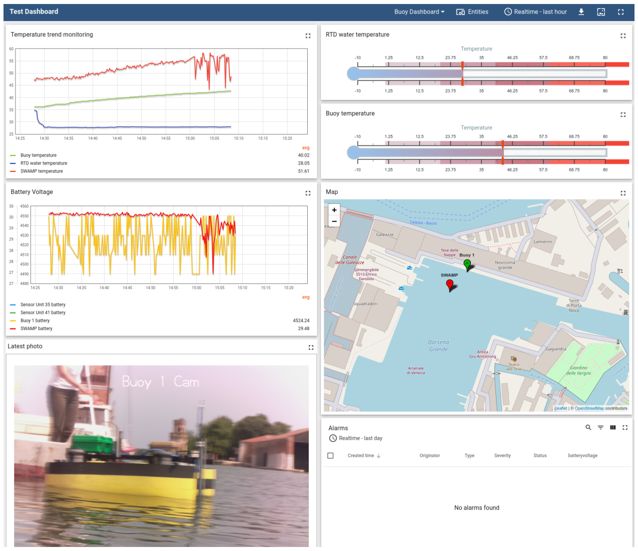


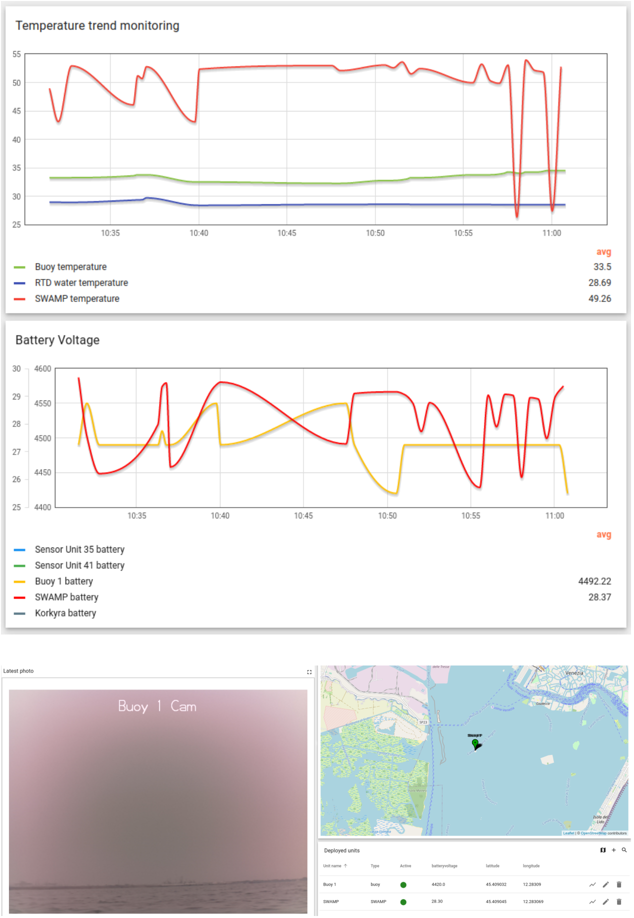
Fig. 4: Example of an IoT monitoring dashboard showing the vehicles in the Venice Arsenale during integration and initial tests for the first cooperative scenario.

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, data collected by both the buoy and SWAMP is packaged into Message Queuing Telemetry Transport (MQTT) messages sent to an online Internet of Things (IoT) dashboard with a user-friendly display which has SWAMP included as a device, providing real-time access to the status of the catamaran as it goes about an algae mapping mission. For the first trials, the data sent from SWAMP is its latitude/longitude GPS position, its heading, its on-board temperature, and the voltage state of its batteries. The buoy itself provides its own GPS position, and both on-board and in-water temperatures to compare, as well as a still image taken by the camera in its top cap. The monitoring dashboard is hosted on a server at LABUST and is accessible to one or more operators via the internet.

III. RESULTS

Preliminary results of the first scenario from the trials in June 2022 are presented here. Results of the IoT dashboard displaying different info from the Smart Buoy and the SWAMP vehicle can be seen in Figure 4 and Figure 5 proving the correct integration of SWAMP and the Smart Buoy.

Moreover, during these trials, several spectrometer measurements were taken with the RoX mounted on the ASV SWAMP. Figure 6 shows several example of Rrs spectra collected over optically shallow waters, near Sant'Angelo della



Deployed units

Unit name ↑	Type	Active	batteryvoltage	latitude	longitude
Buoy 1	buoy	●	4420.0	45.409032	12.28309
SWAMP	SWAMP	●	28.30	45.409045	12.283069

Fig. 5: IoT monitoring dashboard showing SWAMP status during RoX acquisition as aggregated and reported by the Smart Buoy in the Venice lagoon during first cooperative scenario trials on June 22.

Polvere island (central basin of Venice lagoon), with respect to various benthic habitats and water column depth. The Rrs spectra are relatively low and gradually rose with the increase in wavelength in the range of 400–500 nm. Two peaks are clearly visible near 580 nm, caused by the weak absorption of chlorophyll-a (Chl-a) and the scattering effect of cells, and at 700 nm, due to the increasing of the backscattering of suspended matter. The valley at 680 nm is the absorption peak of Chl-a and it represents an important spectral feature of algae-containing waters, useful to estimate the concentration of Chl-a in the water column. In optically shallow waters, where light reflected off the seafloor contributes significantly to the signal, the Rrs spectra can give information about the optical properties of the water column, bottom coverage, and water depth. Based on visual observation of the area, spectra 1 and 2 corresponded to bare substrates, while 3 and 4 represented an area colonized by submerged aquatic vegetation. Aquatic plants absorb most of the light under the water, resulting in a decrease in Rrs. The results confirm the capability of the RoX to perform well in terms of autonomous data acquisition during navigation, keeping a quite adequate perpendicular orientation to the water surface, regardless the vehicle oscillations. Further tests are needed to define the best trade-off between RoX acquisition interval and ASV SWAMP speed in order to ensure a spatially representative sample of in situ Rrs measurements, useful for satellite-derived products validation. In Figure 6, the comparison of in situ and satellite Rrs data is also shown. In term of shape and magnitude, the two datasets are consistent, although fieldwork activities and satellite overpass were not synchronous (22th June and 19th June 2022, respectively), due to overcast weather during fieldwork. To support the Rrs interpretation and validate satellite-derived products, water quality parameters (e.g. Chl-a and suspended sediment concentrations, water turbidity, water temperature and salinity) should be simultaneously collected during RoX acquisition.

IV. CONCLUSION

Given the need for environmental monitoring, a heteregenous marine robotic system developed within the framework of the INNOVAMARE project has been presented here. The INNOVAMARE first pilot was a great test bed to apply the robotic solutions in a transitional environment, testing both the quality of the RoX data acquired by ASV and the interaction possibilities between the different platforms solutions. The results achieved during trials shown that the optical data are consistent and allows to identify different substrates (bare or submerged aquatic vegetation. The results confirm also the capability of SWAMP-RoX system to perform well in terms of autonomous data acquisition during navigation regardless the vehicle oscillation. Moreover, the possibility to communicate with a smart buoy was demonstrated. The joint use of ASV equipped with RoX and the smart buoy that collect information on water quality in a particular location will open new possibilities on habitat mapping monitoring activities.

This scenario has validated not only the individual systems but also the communication between SWAMP and the Smart Buoy. It has served as a building block for the second scenario where two additional systems, another ASV and an ROV are used together with SWAMP and the Smart Buoy in a marine litter monitoring mission. This scenario has been already tested in late September 2022 and will be presented in different paper. As future work, we envision the use of smart buoys for long-term deployment and anomaly detections as well as the use of SWAMP in harsh environments such as the Artic.

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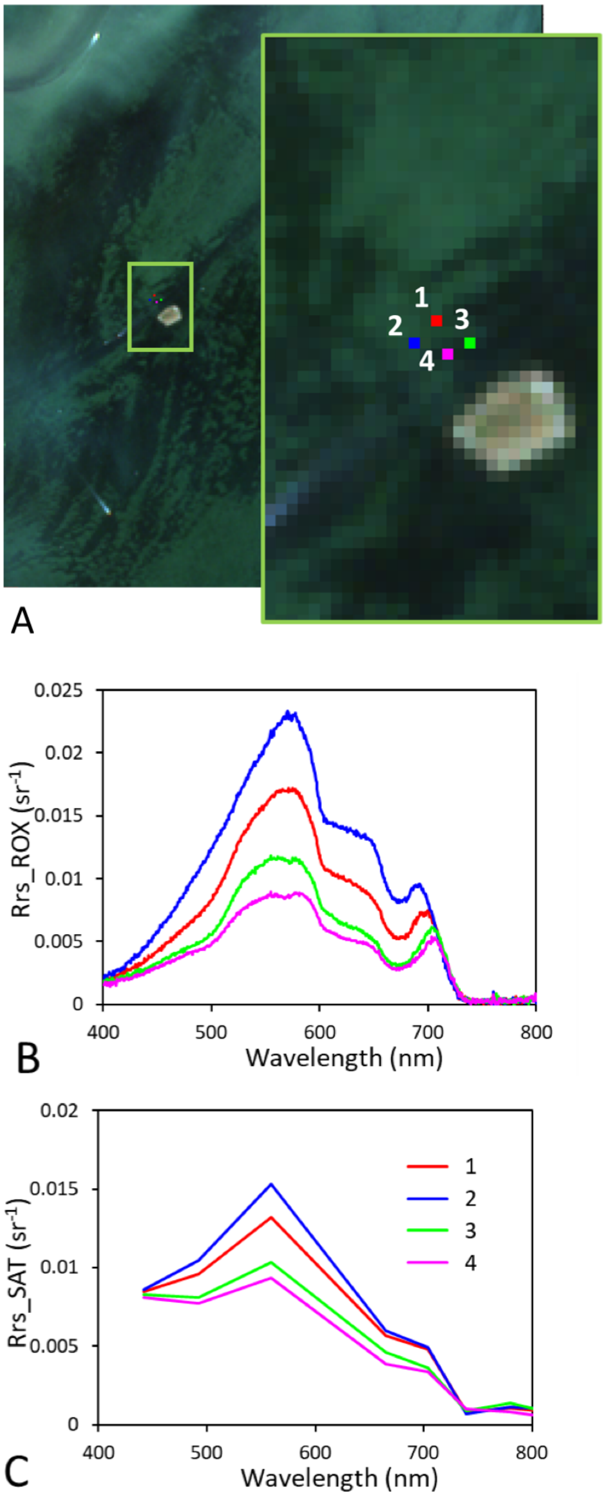

Fig. 6: A) Sentinel-2 satellite image, acquired on 19th June 2022, with the location of the targets measured by RoX; B) In situ Rrs spectra collected by RoX on 22nd June 2022 at the Sant'Angelo della Polvere island; C) Sentinel-2 derived Rrs spectra matching the targets measured by RoX.

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CONCLUSIONS

This report describes in detail the demonstration related to the Scenario 1 of the Pilot action I. This demonstration took place in the Venice Lagoon, a real and challenging environment to test the different capabilities and functionalities of platforms and sensors. In order to prepare for this scenario a series of regular meetings have taken place among partners, looking at the different possibilities of collaboration. A showcase of the platforms and sensors in a more elaborated scenario has taken place at the Breaking the Surface 2022 workshop and is reported in Deliverable D.5.2.7.