The EU project BlueRoSES – Blue Robotics for Sustainable Eco-friendly Services

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Abstract: Blue RoSES aims at developing innovative services that seek to adapt marinas and leisure boat design to changing customer demand. It is envisioned that new job opportunities and business models will result from the exploitation of state-of-the-art technologies in marine robotics and ICT. The unifying concept of BlueRoSES is to enable the general public to access and explore underwater sites by piloting Remotely Operated Vehicles (ROVs) from a leisure boat, ground control room or remote web app. The ROVs will also be used to monitor water quality, the seabed and yacht hulls for safer refitting and dismantling. This communication details the software and hardware architecture, as well as technologies, used to allow the safe networked remote operation of the ROVs, as well as suitable user-friendly apps for robot piloting, and an IoT middleware supporting their integration with communication networks. The paper concludes with results from a representative mission at sea.
Key words: Remotely Operated Vehicle, Marine Robotics, Marine Services.

1. INTRODUCTION

In a worldwide context where the blue economy is already significant and has huge potential for future increase, the Blue Growth strategy aims at removing obstacles to further growth through sectoral and cross-sectoral initiatives in knowledge and research, skills, removal of regulatory and policy obstacles, financing, and global level playing field. Based on the notion that maritime economic activities cannot be sufficiently captured through a sectoral approach, the Blue Growth rationale focuses on maritime functions: it promotes actions to increase knowledge needed to foster business innovation and inform policy makers, and to create a business-friendly regulatory and policy environment through a more strategic transnational cooperation supported by EU sea-basin strategies and initiatives. Blue growth is a priority in the Smart Specialization Strategy of over 50 EU regions, focusing on several business areas, namely manufacturing and tourism. One of its principal objectives is the support of coastal and maritime tourism through the design of innovative technologies, leading to increased and sustainable economic growth.

The BlueRoSES project builds on previous Projects such as FP7 CADDY (Cognitive autonomous diving buddy) (Mišković et al., 2015), FP7 MORPH (Marine Robotic System of Self-Organizing, Logically Linked Physical Nodes) (Kalwa et al., 2015) and H2020 WiMUST (Widely scalable Mobile Underwater Sonar Technology) (Simetti et al., 2020), which fomented the development of cooperative marine robotics technologies, and FP7 SaMMY (Smart Application for the Management of Yachting Marinas), H2020 MAG SaMMY (Market Acceleration programme for SaMMY Platform), H2020 Neptune MaSSY (Mobile collAborative Systems for the improvement of Services and business development in Yachting industry) supported, in the area of Smart Solutions for Marinas, the delivery of new improved services for the yachters and marina admins. Leveraging the competencies acquired in these previous projects, the consortium engages the European Commission's Goals for Research and Innovation Policy (2015) of encouraging transfer of knowledge between technology developers and stakeholders, user-centric approaches to all the IT and IoT systems and services.

BlueRoSES aims to developing innovative services that seek to adapt marinas and leisure boat design to changing customer demand. By integrating robotics and IoT, these new services result in creating job opportunities and new business models. Customers are enabled to visit underwater sites by piloting a Remotely Operated Vehicle (ROV) from a leisure boat, ground control room or web app. This facilitates access to the subsea environment by the elderly and young people alike, thus adding a "new dimension" to marinas and attracting increasing interest from diversified users. The project thus fosters the design of innovative leisure boats that integrate robotic vehicles with ever-improving ICT services. The project also addresses environmental challenges since the ROVs can be used to monitor water, seabeds and yacht hulls for safer refitting and dismantling.

2. BLUEROSES CONCEPT

BlueRoSES aims at exploiting state-of-the-art technology in marine robotics (networked control of Remotely Operated Vehicles - ROVs) and ICT (IoT middleware for sensor networks, smart apps) to develop innovative services for marinas and leisure boats in order to adapt to changing demands from users and address environmental challenges. Figure 1 depicts the seminal idea behind the BlueRoSES project, where current technology is exploited to facilitate remote access to fragile underwater sites of naturalistic or cultural interest. Anyone onboard leisure boats, in control rooms inside marinas or through Internet connection worldwide will be able to do so. To achieve this goal we design, develop and integrate an architecture for networked remote control of underwater robots, as well as suitable user-friendly apps for robot piloting from PCs, smart phones, tablets, etc., and an IoT middleware supporting their integration with communication networks onboard leisure boats and in marinas.

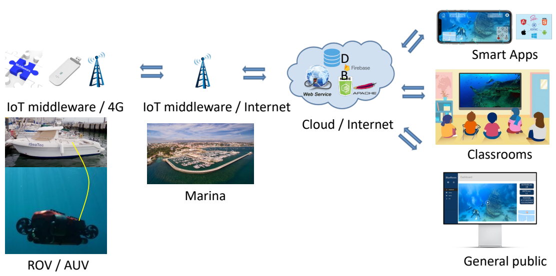

Fig. 1. BlueRoSES concept.

Given this technology, robotics and ICT researchers will endeavour to yield a whole range of results:

- enabling visitors to "stroll" through an underwater archaeologic museum or a pristine marine habitat from their house, leisure boat cabin, or hotel room inside a marina;
- fitting marinas with robotic tools for automatic monitoring of water quality and pollution, providing open, immediate access to measured geo-physical-chemical parameters as well as acquired images of the seabed status;
- hiring leisure boats equipped with robotic tools for remote visit of underwater sites and/or inspection of hull conditions

3. SYSTEM ARCHITECTURE

The general project concept, as summarized in Figure 1, includes *i)* an underwater ROV/AUV hybrid deployed from a ship or marina; *ii)* connected to shore or the global internet via a 4G/LTE cellular connection using an IoT middleware; *iii)* a secure cloud architecture enabling users to connect to the IoT middleware, receive the video-feed and telemetry, and issue commands, regardless of their physical location.

This communication focuses on the first of these elements, the deployment of ROV/AUVs and accompanying software stack, that allows for remote, high-level vehicle operation (triggering of a set of operating modes "protected" by on-board safety features) as well as visualization of data acquired on-line by the robots (vision and acoustics-based), together with telemetry data.

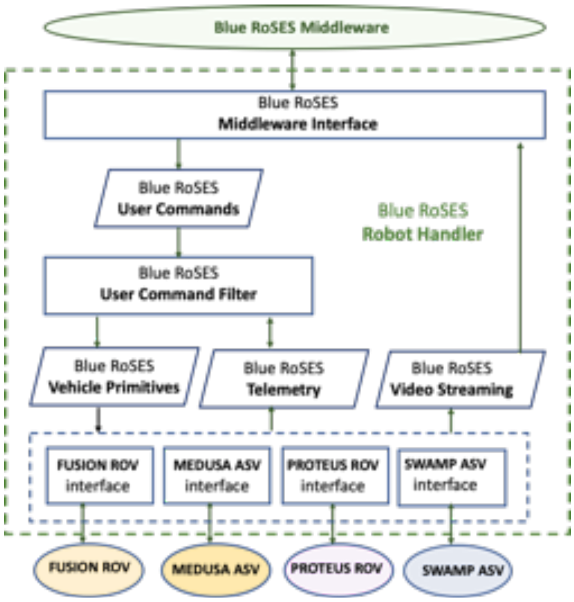

Fig. 2. Block diagram for the BlueRoSES Robot Handler and its connection to the marine Vehicles and Middleware.

The workflow for BlueRoSES operations is depicted in Fig. 2, corresponding to the left-most section of Fig. 1. It comprises a remote operator, possibly without previous ROV operation experience, issuing commands through the use of a smartphone app, with the commands passing through an unreliable communications channel (the internet), where delays and packet losses can occur, before reaching the wired communications network at the deployment boat, which serves as a launching station for the ROV and communicates with it while submerged via an umbilical cable.

For the middleware layer, a publish/subscribe messaging transport mechanism was identified as the right technical solution for sharing commands and telemetry data. In particular, the machine-to-machine (M2M)/"Internet of Things" connectivity protocol MQTT (Message Queuing Telemetry Transport) has been adopted. This protocol was designed with the particular requirements of IoT devices in mind and is extremely lightweight, ideal for connecting remote devices with a small code footprint, minimal network bandwidth, high-latency or unreliable networks.

Considering the unreliable nature of the communications channel, a "Robot Handler" software is designed to stabilize the communication from the commanding operator so that the vehicle operates always smoothly (i.e., does not follow jittery commands arising from possible delays) and a safe

operating mode is enabled, according to the quality parameters of the internet (typically 4G) connection. It's inner working and interaction between the internal modules will be presented in more detail later in this section.
The development of the Robot Handler software and its communication with the vehicles uses the open-source Robot Operating System (ROS) middleware – a collection of software frameworks (tools, libraries, and conventions) for writing robot software across a wide variety of robotic platforms. The Robot Handler itself is designed to run on a Single Board Computer (SBC) equipped with the Ubuntu 20.04 Linux OS. The consortium coded the Robot Handler in the C++ language and followed standard ROS practices and a node structure to promote interoperability and compatibility. This runtime environment combination resulted in a performant and lightweight software which, not only runs on Ubuntu 20.04 and ROS Noetic but is still compatible with legacy, but still prevalent, hardware and software combinations such as Ubuntu 18.04 and ROS Melodic and even older versions such as Ubuntu 16.04 and ROS Kinetic. The vehicles can be commanded in a variety of motion primitives, namely velocity or position control, heave velocity, altitude or depth, combined with yaw or yaw rate control.
The Robot Handler itself, see Fig. 2, can be divided logically in modules, corresponding to i) MQTT middleware interface, ii) network stabilization, iii) vehicle safety, and iv) vehicle interface, with ii) and iii) implemented in the "User Command Filter" block. This modular approach maps neatly onto the ROS's architecture of nodes and message passing. The implemented Robot Handle is thus composed of 4 ROS nodes, as depicted in Fig. 3, corresponding to the outlined Robot Handler modules.

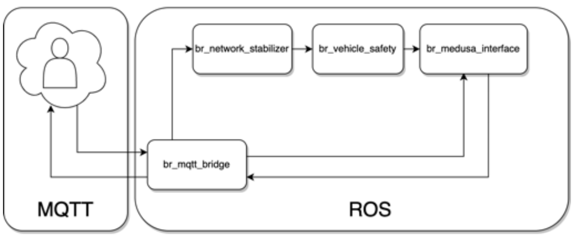

Fig. 3. Diagram of the Robot Handler ROS nodes.

The node `br_mqtt_bridge` receives MQTT messages from the middleware and converts them to ROS messages, and *vice versa* for the telemetry data. It is thus a *bridge* between the MQTT middleware and the ROS system used for vehicle control. The Network Stabilizer node implements a state machine for the operative mode of the ROV. The main goal is to detect abnormal network conditions and react by modifying the operative mode of the ROV to a less demanding one in terms of reference updates. As an example, if the network delay is longer than a few tenths of a second it becomes very hard to command the ROV via direct velocity commands as there is a mismatch between the images and telemetry being seen by the remote operator and what the vehicle is actually doing. In the limit, with an unaware operator, the delays can lead to instability and a strong overreaction in commands issued. The solution to this destabilizing positive feedback loop taken in this Project was to downgrade the working mode from *velocity control* to *position control* while the network instability endures.
The final safety feature of the Robot Handler is the enforcing of strict safety volumes where the ROV is allowed to operate and strict safety distances from the ROV to obstacles, including the sea bottom. Safety volumes are defined in a *yaml configuration file* appropriate for data serialization and sharing. The volumes can be defined as rectangular prisms by providing the coordinates of their corners or as vertical cylinders by providing a radius and the center location. Maximum depth and minimum altitude to be maintained can also be specified. Locations of known obstacles and the minimum distance the ROV should maintain from them can also be specified as rectangular prisms or cylinders.
The final Robot Handler component node is charged with converting standard BlueRoSES reference messages, ensured to be safe by the network and vehicle safe modules, to appropriate commands accepted by the actual vehicles; and to convert the telemetry data in the vehicle message format to the standard BlueRoSES telemetry message. For this project interfaces with four AUV and ASV vehicles were coded, namely IST's Medusa class of vehicles (Abreu et al., 2016) and BlueROV 2 (which was adapted to run on the same software stack as the Medusa vehicles), and CNR's Proteus (Bruzzone et al., 2000) and Swamp vehicles.

4. EXPERIMENTAL RESULTS

The *Ocean Revival Underwater Park*, situated off the coastal town of Portimão, Portugal, was chosen as the first test site for the BlueRoses project for its easy access to the site by local support boats and potential in terms of affording users remote access to fascinating underwater sites from the comfort of land locations. The site consists of four ex-Portuguese Navy vessels that were deliberately sunk in the same place and form the largest single artificial reef structure in the world with the ideal conditions for the proliferation of marine life. It is at 26-32 meters bathymetric and is located 2 miles from the coast and 3.3 miles from the bar of the village of Portimão, where a good 4G/LTE cellphone internet connection is possible.
The underwater vehicle employed was a BlueROV 2 in a Heavy Configuration, see Fig. 4, with 8 total thrusters (four vertical thrusters and four thrusters along the horizontal plane) enabling 6 degree-of-freedom control. The ROV was equipped with a Pixhawk microcontroller, a Waterlink A50 DVL and

a High Definition 1080p camera. Several dives were performed in the vincinity of the Frigate Ex-NRP Hermenegildo Capelo F481, one of the sunken vessels at *Ocean Revival Park*.

Remote partners at CNR-INM, Italy and IST, Portugal demonstrated successfully the remote-control capabilities of the overall system proposed in BlueRoses. Several dives were undertaken where the underwater robot was piloted from remote locations from the internet, namely Lisbon, Portugal and Genova, Italy. The remote pilots, controlling the vehicle by issuing velocity commands, were able to successfully explore the sunken ship, observing features such as the ship's wheel (Fig. 5), bridge, artillery gun (Fig. 6), bow (Fig. 7), among many others, as well as entering inner galleries and rooms.

Throughout the field tests, a live video-feed of the camera onboard the vehicle was made available to the general public, in addition to the video and telemetry links for the remote pilots, Fig. 6, making it possible for the public to follow the trials without interfering with the missions.

The sea trials brought the vision of the BlueRoSES project to life, proving the validity of the proposed integrated solutions for robotics and IoT for remote operation of underwater ROVs, and successfully immersing the pilots and the spectating public in the usually inaccessible underwater environment.

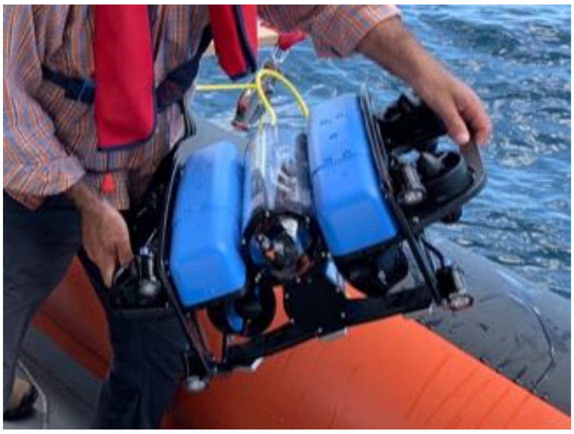

Fig. 4. BlueROV 2 underwater vehicle employed in the field tests.

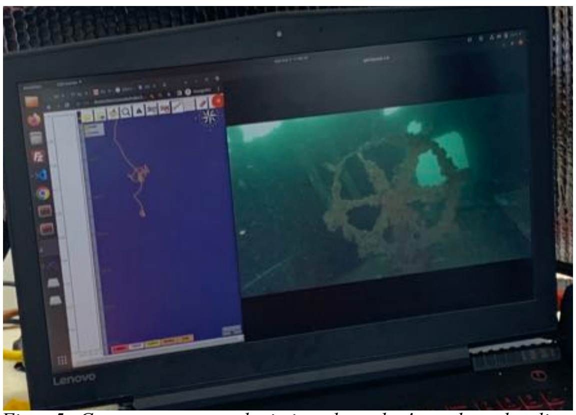

Fig. 5. Computer screen depicting the robot's path and a live video-feed showing in detail the sunken ship's wheel.

Fig. 6. Remove pilot in Genova, Italy, commanding the underwater ROV in Portimão, Portugal. The live-video shows a detail of the sunken ship's artillery gun.

Fig. 7. Detail captured in video of the sunken ship's bow.

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