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Advancing the EU Marine Robotics Research Infrastructure Network: the EU Marine Robots project

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Abstract :

This paper provides an overview of the H2020 Marine robotics research infrastructure network (EU Marine Robots) project. The overview is organized around the three main activities of infrastructure projects: i) Networking activities (NA); ii) Transnational access (TNA) in which access to marine robotic infrastructures from the partners is granted in competitive calls; iii) Joint research activities (JRA) aimed at making robotic infrastructures more operable and transitioning new systems and technologies to field operations. The strategic significance of the project and future developments are discussed as conclusions.

Keywords : H2020, marine robotics, research infrastructure

I. INTRODUCTION

The Marine robotics research infrastructure network (EUMarine Robots) addresses the H2020 call topic INFRAIA-02-2017: Integrating Activities for Starting Communities by mobilizing a comprehensive consortium of most of the key marine robotics research infrastructures to achieve the following main objectives: open up key national and regional marine robotics research infrastructures (RIs) to all European researchers ensuring their optimal use and joint development to establish a world-class marine robotics integrated infrastructure.

The infrastructure network covers a wide spectrum of systems. Individual robot systems, autonomous or remote operated, lean fast deployment systems for shallow water as well as heavier, ship-deployed vehicles for deep-sea intervention, are completed by specific technological solutions at subsystem level such as wireless communication, optical and acoustical mapping, assisted remote manipulation etc. Multi-platform operation is a particular dimension of the RI network with dedicated fleets associating marine, submarine and aerial vehicles. The strong representativeness of consortium and assets stem from the expertise gained by all actors built on significant feedback from operational use of assets : all 15 EUMR partners are major players in end user fields such as ocean science, industrial intervention, defense, cultural heritage and training.

EU Marine Robots (EUMR) is organized around an evolving network model. It builds on existing networks of the EU marine robotics community and is synergistic with the worldwide marine robotics communities. EUMR is also aligned with the strategy for development of the European innovation ecosystem for robotics and autonomous systems, seeks to underpin the development of the next-generation observing systems, and complements large European Marine RIs. EUMR´s vision is to foster and contribute to the development of methods, tools, and robot vehicles required for a sustained presence in the ocean. Access to marine robotic infrastructures will enable the scientific community to understand and monitor how key issues such as climate change, ocean acidification, unsustainable fishing, pollution, waste, loss of habitats and biodiversity, shipping, security, and mining are affecting global ocean sustainability and stewardship. Joint research activities towards

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integrated marine robotics RIs will contribute stepping-stones for other developments worldwide.

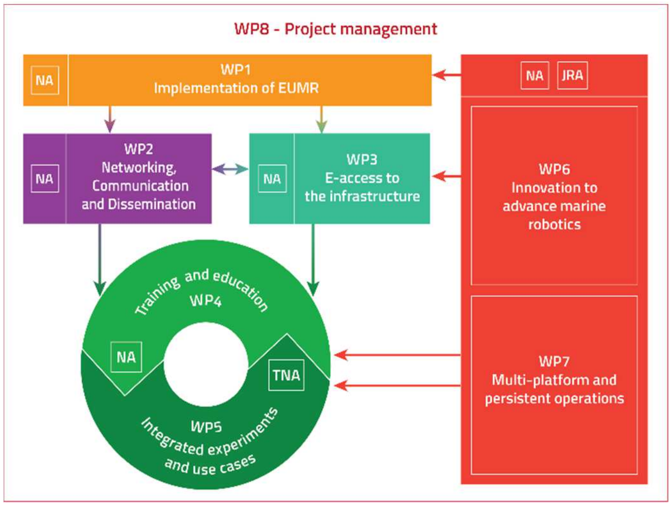

Figure 1: Work plan - work-packages and interactions.

This paper is an overview of the main activities of the project (check https://www.eumarinerobots.eu/ for details). The work program is organized into 8 work-packages (WPs) encompassing NA, TNA and JRA as depicted in Figure 1.

TNA aims to provide access to marine robotics infrastructures from the 15 EUMR partners (Table 1). They include a large number of heterogeneous autonomous underwater, surface and air vehicles, ships, and testbeds. There are two modalities of access: to marine robotics RIs operated by the partners and to collaborative sea experiments/use cases taking place in the Atlantic and Arctic oceans and in the Mediterranean sea. Access is granted through competitive calls.

JRA addresses the development of advanced marine robotic systems and technologies with a view to substantially improve existing infrastructures and thus afford scientific and commercial end-users cutting edge tools for ocean exploration/exploitation. This is being actively pursued along all technical tasks: i) Advanced vision, acoustic, and manipulation systems for automated inspection and intervention operations; ii) Cooperative navigation and control of networked vehicles for increased autonomy at sea; iii) Hybrid acoustic-optical underwater communication networks for next-generation cooperative systems; iv) Advanced Systems for Under-Ice operations; v) Enhanced underwater LARS system; and, vi) Cooperative human-marine robot systems. JRA is also about taking these developments to sea and demonstrate operability and improvement of Technology Readiness level.

Partner	Country
University of Porto (UPORTO)	PO
University of Bremen (UNIBRE)	DE
Associação do Instituto Superior Técnico para a Investigação e Desenvolvimento (IST-ID)	PO
University of Genoa (ISME)	IT
Faculty of Electrical Engineering and Computing, University of Zagreb (UNIZ-FER)	HR
University of Girona (UdG)	ES
University of Limerick (UL)	IR
Oceanic Platform of the Canary Islands (PLOCAN)	ES
Centre for Maritime Research and Experimentation (CMRE)	BE
Heriot-Watt University (HWU)	UK
Norwegian University of Science and Technology (NTNU)	NO
Marine Institute (MI)	IR
Distretto Ligure delle Tecnologie Marine (DLTM)	IT
Natural Environment Research Council (NERC)	UK
Institut Français de Recherche pour l'exploitation de la Mer (IFREMER)	FR

Table 1: EUMR partners.

EUMR network activities (NA) are based on the concept of an evolving network model to become a world-class marine robotics network. Networking activities included co-organization and participation in the Breaking the Surface interdisciplinary field workshop of marine robotics and applications (Croatia), the PLOCAN glider school (Spain), the EMRA annual conference, as well as the participation by UPORTO in the Exploring Fronts with Multiple Robots science cruise funded by the Schmidt Ocean Institute. Networking activities also include educational activities targeting the community at large. To meet these goals, an e-access infrastructure was also developed to provide remote access to robotic infrastructures, to electronic versions of training courses and tutorials, as well as to data sets from robotic experiments. This e-access infrastructure proved key to support TNA during the COVID pandemic situation. Similarly, due to the COVID-19 situation networking was also expanded to the virtual world through the "Coffee with EUMR" webinar series.

This paper is organized as follows. Section II provides an overview of the most significant networking activities. Section III describes transnational access by listing all facilities, and projects in calls 1-3 and presenting the main results of four selects projects. Section V, describes the joint research activities, developed in WP6 and WP7. Section VI discusses the strategic significance of the project and future developments.

II. Networking activities

NA activities encompass Work packages (WP) 1-4, as well as WP 6-7 (Figure 1). WP1 is about the strategic implementation of EUMR with views towards the development of a world class marine robotics research infrastructure (discussed in more detail in section V). WP2 is about networking, communication, and dissemination activities to ensure that: i) the project will be highly visible to stakeholders in European Science and Technology and highly valuable to leading public and private entities, at both European and international level; ii) significant outreach will be targeted toward the wider public, including schools, students, and teachers for long-term marine robotics research sustainability; and, iii) the project triggers joint activities in the area of marine robotics research. WP3 is about the development of the e-access infrastructure and WP4 addresses training and education in support of the project goals. A description of the networking activities follows.

The EUMR website (https://www.eumarinerobots.eu/) and the presence on social networks provide windows to the world, even more so in the current pandemic situation. The partners have been strongly involved in the organization of international conferences (2021 IEEE/MTS Oceans San Diego Porto), meetings (EMRA), special sessions in key oceans and robotic related conferences, professional events, and industry demonstration days. Partners have delivered invited talks and plenary sessions at international conferences and wrote over 100 journal and conference publications.

The Breaking the Surface international interdisciplinary field workshop of marine robotics and applications, organized by UNIZ-FER, and the glider school, organized by PLOCAN were the two key training events of EUMR. UPORTO and CMRE have also been organizing, in cooperation with the Portuguese Navy and the MUS initiative, of the large-scale annual REP-MUS exercise taking place in Portugal.

EUMR partners have been reaching to international organizations devoted to policy development and legislation at dedicated events and sessions. EUMR is also working to further develop links with international coordination groups such as the European Robotics Forum ERF or the advanced community INFRAIA project Eurofleets+. Annual project workshops address RI coordination and development and provide a strategic vision of critical aspects through SWOT analysis covering: i) standardization of data, software, communication, and electrical interfaces; ii) data management of vehicle and payload data, long-term policies for access and storage; iii) open software policies; iv) best practice in marine robot operation for TNA, quality of service, risk management; and, v) assessment of sites for testing and coherent guidelines for rules and procedures, local site constraints (access rules, logistics etc.).

III. Transnational access activities (WPs 5-7)

A. Open calls

EUMR has two modalities of access: to infrastructures and to experiments at sea. The infrastructure's catalog and the catalog for experiments at sea are presented in Annex 1 – TNA Catalogs.

Access was granted through competitive calls. There were 3 open calls for TNA access. The first call closed October 1, 2018, with 26 eligible applications (70% from Europe, 22 from Asia and 7% from North America), and 22 projects were approved. The second call closed August 15, 2019, with 31 applications and 28 projects approved. The third call closed June 30th, 2020, with 11 applications and 11 projects approved. The lists of the approved projects are presented in Annex 2 – TNA projects. Figure 2 presents the results of TNA submissions (by continent and area) for the 3 calls.

Figure 2: Calls 1-3 - TNA submissions by continent and by area

Several NA and TNA initiatives targeted articulation with other projects and initiatives. Figure 3 presents a geographic distribution of institutions with approved TNA projects.

Figure 3: TNA access. Blue - facilities of the partners; Green, red, and yellow: Institutions with successful applications to TNA access.

B. TNA projects

Space limitations preclude a presentation of all approved projects. A selection of representative projects is detailed next.

1) High-resolution 3D terrain models of cold-water coral HABitats in Blanes Canyon

The project was about the detailed mapping and characterization with unprecedented detail (i.e., sub-metric resolution) of the vertical seafloor habitats hosting cold-water corals in Blanes Canyon (NW Mediterranean) using the mapping tools offered by IFREMER's hybrid remotely operated vehicle (H- ROV) Ariane. This task was part of the research activities conducted onboard the R/V Sarmiento de Gamboa, linked to the Spanish project ABRIC (Assessment of Bottom - trawling Resuspension Impacts in deep benthic

Communities), led by the Principal Investigator who submitted the TNA proposal.

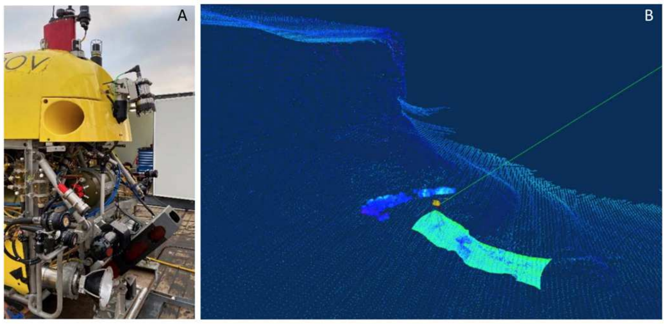

Figure 4: A) Photography of the frontal part of the H‑ROV with the MEBS mounted in a 45 º angle. B) Point cloud representation of one of the surveyed areas with the 3D position of the H‑ROV (yellow vehicle) while acquiring a photo‑mosaic and a much higher resolution bathymetry.

2) DAMOSS

DAMOSS was focused on the detection and mapping of submarine C02 Seeps performed with two AUVs, FeelHippo and MARTA, part of the ISME SEALAB AUV infrastructure. Two different sea campaigns were carried out at the Vulcano Island to “map” carbon dioxide bubbles in the sea (responsible for negative effects on underwater fauna and flora). The project was proposed and performed by Jacobs University, Germany.

Figure 5: Operations at the Vulcano Island.

3) ISUVI

ISUVI addressed the issues of interoperability software integration and testing for multiple autonomous underwater vehicles. The project was submitted and performed by the Polytechnic University of Cartagena (UPC). The main goal of the proposal was successfully attained with an Iver2 from UPC and a LAUV from the Porto-Local infrastructure. The 2 AUVs were controlled in a uniform fashion with the same software.

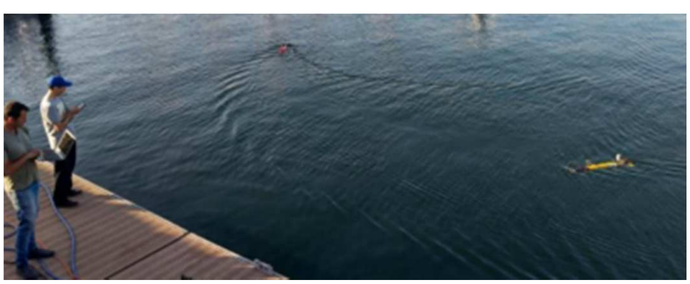

Figure 6: ISUVI operations.

4) Survey and Mapping of Falconera Cave with Sparus II

This project addressed the problem of mapping an underwater cave with high archaeological interest. Expert cave divers were taught how to operate the Sparus II AUV and different mapping strategies were discussed in different meetings and tests on the UdG water tank facilities. The cave divers successfully guided the AUV in several dives in the Falconera cave gathering extensive data by the moving multibeam echosounder sensor at different maximum ranges. This data was processed in-situ with dead-reckoning to select the most suitable multibeam range to use in the last dive. A more precise map was obtained in post-processing.

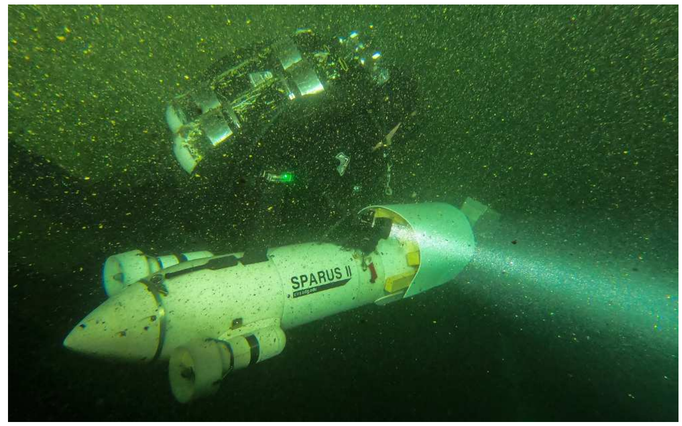

Figure 7: Sparus II AUV mapping the Falconera cave.

IV. Joint research activities

From the point of view of systems design, implementation, and field tests, the backbone of EUMR is organized in two main complementary activities: Innovation to Advance Marine Robots (WP6) and Multi-Platform and Persistent Operations (WP7), detailed below. The first has a special focus on innovation as a catalyzer for the development and operation of new vehicles, methods, and tools for ocean exploration and exploitation. The second aims to take new developments and outputs of WP6 to sea and demonstrate operability and improvement of Technology Readiness Levels (TRL).

A. Innovation to advance marine robotics (WP6)

JRA places strong emphasis on leveraging the extensive expertise of the partners on both theoretical and practical issues in the areas of marine robotics to make substantial progress towards the design, implementation, and testing of a new breed of robotic systems for scientific and commercial applications. During this WP several initiatives took place with the final goal of substantially improving existing infrastructures, thus contributing to affording scientific and commercial end-users' new cutting-edge tools for ocean exploration and exploitation. Representative initiatives are highlighted below.

T6.1 Advanced vision, acoustic, and manipulation systems for automated inspection and intervention operations [Leader: ULIM]. This task built upon the expertise of the partners in automated acoustic/vision-based navigation and marine robotic manipulator control to address the challenges of auto/semi auto-intervention in challenging marine conditions. Two key lines of action were pursued: i) development of advanced inspection and intervention robotics for Marine Renewable Energy (MRE) with design features suited to the challenging conditions of wave motion and currents disturbing ROV/AUV robots and ii) development of advanced vision, acoustic, and manipulation systems for a new breed of Intervention AUVs, effectively allowing them to maneuver freely and interact with the environment.

T6.2 Cooperative navigation and control of networked vehicles for increased autonomy at sea [Leader: IST-ID]. This task witnessed intensive work aimed at the design of cooperative motion planning, navigation, and control systems for networked marine robots, connected via multimodal communication networks. This was followed by experimental tests with selected systems. The activity addressed a broad spectrum of topics that include: i) cooperative vehicle motion planning with due account for possibly complex vehicle dynamics and inter-vehicle and vehicle-obstacle collision avoidance, ii) cooperative motion control systems with a view to reducing the amount of information exchanged among a number of marine vehicles over the underlying communication channel, iii) cooperative range-based techniques for marine vehicle navigation and target localization, iv) distributed estimation systems with quantized and rate-limited communications as a means to substantially reduce the amount of information exchanged among vehicles, v) methods for underwater geophysical navigation using nonlinear filtering techniques, and vi) cooperative missions with multiple marine vehicles working at very close range, using hybrid acoustic-optical communications and relying on the latter for fast inter-vehicle data transmission. An interesting case study involved front mapping and tracking of frontal zones and on the application of dynamic programming techniques to multi-vehicle coordination problems.

T6.3 Hybrid acoustic-optical underwater communication networks for next-generation cooperative systems [Leader: CMRE]. The key thrust of this task was the development and testing of a hybrid acoustic/optical underwater communication network for multirobot cooperative operations. Two major applications were targeted: i) Data retrieval from benthic stations or underwater infrastructures and ii) Multiple vehicle cooperation. *CMRE* led this effort in cooperation with IST-ID towards the design, implementation, testing, and validation of a hybrid network for next generation cooperative systems. The work done witnessed the integration of the BlueRay optical modem developed by IST-ID with the *CMRE* Cognitive Communications Architecture (CCA). After the initial step of integration, *CMRE* implemented and tested in simulation an adaptive solution to switch between acoustic and optical transmissions based on the distance between the nodes and link reliability. Data volume and priority were also considered as key metrics. The work progressed to the level where the overall system was implemented on board two MEDUSA vehicles that performed a cooperative path following mission in Lisbon, August 2021, while exchanging data over the optical channel.

T6.4 Advanced Systems for Under-Ice operations [Leader: NTNU]. In the context of this task, the work done addressed the sequence of steps required to the design, development, and operational testing of new navigation systems for autonomous under the ice operations, with the following key objectives in sight: 1) Navigation system design for automatic rendezvous maneuvers on a recovery site; 2) Simulations of missions and rendezvous algorithms; 3) Inshore testing of rendezvous procedures, and 4) Full-scale experiments in Svalbard, in the Barents sea. For under ice operations, margins are low, as there are few alternatives for safe completion of a mission in a contingency situation. In fact, all missions must end with the vehicle homing in on the recovery site. Faulting homing would likely lead to loss of vehicle. The homing procedure must hence be robust and contain diagnosis, threshold, and fall backs, making the vehicle returning for as many failure modes as possible to reduce risk. For this purpose, the research work was focused on developing a new method for intelligent risk-based under-ice altitude control. Experimental results showed that the AUV successfully adapted its behavior to the varying levels of risk throughout its mission by adjusting its decisions.

T6.5 Enhanced underwater LARS system [Leader: UNI BRE]. This task aimed at the design of a LARS (Launch and Recovery System) for the MARUM HROV and the IFREMER HROV Ariane with the versatility to be adaptable to other marine robots. The key governing factor for the development is the latch-unlatch mechanism. A major development criterion was safe and seaworthy operations from modern research vessels. Part of these considerations were the increasing number of moon-pools as well as increasing handling capabilities of state-of-the-art research vessels (e.g., RV Polarstern II, Chikyu, etc.) helping in the mitigation of heavy seas to ensure safe operation.

T6.6 Cooperative human-marine robot systems [Task leader: UNIZG-FER]. The specific objectives of this task were to: i) develop a system for robust exteroceptive recognition of a diver´s position and orientation, ii) develop collaborative motion strategies between a human diver and an autonomous underwater vehicle (AUV) through exteroceptive recognition of diver´s position and orientation, and iii) evaluate and demonstrate human-robot interaction solutions in a real environment. Among the results obtained, the following are worth stressing: 1) Algorithms for movement around the diver were designed and tailored for the AUV and tested in simulation, 2) Two versions of a dive glove for gesture recognition were designed. Two groups of gestures were selected for comparison: one utilizing only existing diving gestures with extra capabilities accessible via a matrix type selection; the other group introduces completely new gestures for extra capabilities, 3) Field experiments were carried out at BTS19/BTS20. AUV integration tests were completed and required improvements identified. The glove prototype was tested underwater to validate basic gesture recognition. Furthermore, the AUV and glove were integrated, and the interaction chain (glove-AUVV) was tested. This included gesture recognition, acoustic data transmission and reaction from the AUV.

B. *Multi-platform and persistent operations (WP7)*

In WP7, the EUMR consortium has been testing all the infrastructure capability enhancement components developed in EUMR in a comprehensive, distributed approach to provide proof-of-concept at various levels. Tests take a staged approach across the entire work package or across several work packages. This provides proof of functioning of the Marine Robotics RI and takes new developments of WP6 to sea and demonstrates operability and improvement of TRL.

Most of the sea trial programs were preceded by harbor integration trials in the unique facilities of the EUMR consortium. Representative examples of these trials are discussed next. ULIM MRE-ROV, ROV Latis and I-ROV are based at Limerick Dock where in-dock system trials, system integration testing, shakedown and mobilization for offshore missions is undertaken. Two trials involving ULIM's MRE ROV Étain were supported by the Marine Institute. The first in Galway Bay off the Commissioner for Irish Lights ILV Granuaile and the second in Cork Harbor off the RV Celtic Explorer. ULIM activity within this task focused primarily on advanced imaging and interventions systems for ROVs offshore, particularly in the energy sector (Oil & Gas; Offshore Wind;) and in high energy sites. ULIM's MRE ROV Étain was deployed from the RV Celtic Explorer in close collaboration with Marine Institute from 4th – 14th January 2019. These trials had several scientific objectives, all of which were successful, including Dynamic Automatic Docking; Automated Navigation and Imaging on Kinsale Gas Field; Imaging System Testing (a) Laser Line Scan (b) Sonar (c) Photogrammetry; Marine Habitat and Hydrographic; Mapping on Shipwreck sites. PLOCAN and NERC also performed harbor tests of an Autonaut unmanned surface vehicle with the collaboration of Autonaut Ltd. and Seiche Ltd.

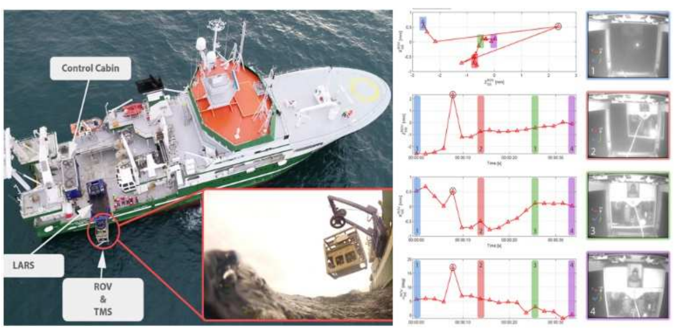

Figure 8: Dynamic docking system trials from the MRE-ROV and RV Celtic Explorer, South Coast Ireland.

UPORTO led the *Exploring Fronts with Multiple Robots* Schmidt Ocean Institute cruise onboard the R/V Falkor to successfully demonstrate a novel approach for finding, tracking, and sampling dynamic features of the ocean. The area of the study was the Northern Pacific Subtropical Front, located approximately 800 nautical miles west of San Diego.

The center piece of UNIBRE seagoing operations was the dedicated EUMR cruise carried out on R/V ALKOR. Operations encompassed the bulk the TNA work using ROV SQUID to recover observatories and do seafloor work in conjunction with tests of developments from WP6, including tests of ROV photo- and video-mosaicking, as well as additional operations with a small BlueRobotics ROV. This was the 3rd UNIBRE cruise. Besides TNA access, several experiments relative to task T6.3 (Hybrid acoustic-optical underwater communication networks for next-generation cooperative systems) were also conducted: robustness of medium range optical communications to changes in turbidity and testing of cooperative operational multi-vehicle concept using an optical controlled fly-out type daughter vehicle.

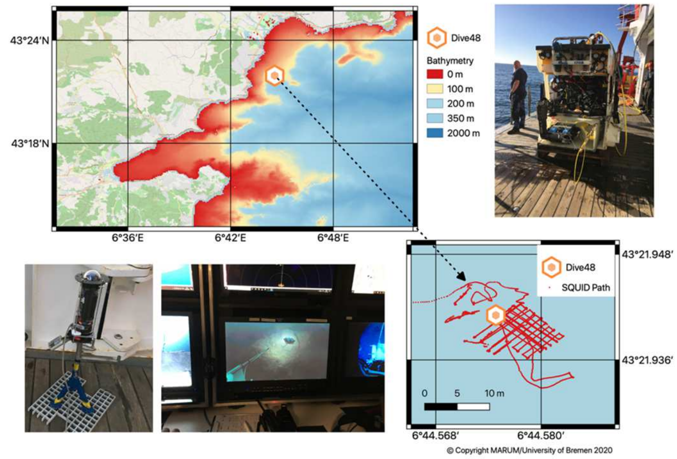

Figure 9: Image panel in the upper left and lower right show location and trajectory of the ROV MARUM SQUID dives for an optical survey of the experimental site. The image on the lower left shows the stationary bottom node on deck. The bottom middle image shows a photo of the ROV control console as the mini ROV was controlled via the optical communication link from the larger ROV as shown on deck in the picture on the upper right.

V. Strategic Significance and Future Work

The EUMR consortium developed the fundamentals for a comprehensive, constructive, and feasible strategic framework for long-lasting transnational access. As shown in the diagram from Figure 10, this framework is based on three core elements:

Infrastructure. Marine robotics RIs are the foundations for long-lasting transnational access. This element is focused on comprehensive cost analysis, infrastructure life cycle management, strategies in sustainability and cost-effective maintenance. This provides strategic guidelines in constructing, maintaining, and operating marine robotics RIs for a long-lasting TNA, but also directly feed into and facilitate the overall development of the strategy for the European innovation ecosystem for robotics and autonomous systems. Based on the experience stemming from three successive calls for TNA applications, the consortium establishes a proven concept of RI attribution and is today able to recommend evolved models of calls, focusing on facilitated access management through synchronized as well as continuous calls allowing to take account for scientific, logistic, and connected infrastructure constraints.

Skill sets. Cutting edge yet application oriented technological infrastructure needs a seamless integration with a variety of embedded skill sets to keep its long-lasting performance and sustainability. Compared to long established, often national level research infrastructure platforms, EUMR assets are highly representative of current robotics research at various levels of technological maturity (TRL). The technological engineering and scientific skills of the consortium are hence a key enabling factor for fruitful third-party projects. As such, the TNA paradigm of EUMR benefits from an approach that associates specialized R&D teams with user applications ensuring an optimal conduct and outcome of TNA projects. The approach answers the specific needs of each application, as TNA usually requires more complicated planning and sophisticated implementation, considering different system setting-up, local regulations, national standards, environment unfamiliarity, operating cultures and so on between the infrastructure providers and users.

Ecosystem. With the integration of skill sets into research infrastructures, the TNAs are augmented from a pure structured ecosystem of infrastructure assets towards a service-oriented paradigm, extending research infrastructure with core skills to support the offer of TNAs. The service-oriented ecosystem will build a strategic framework for EU marine robotics research infrastructure around stakeholders, data access, technology innovation, services and business, and knowledge sharing.

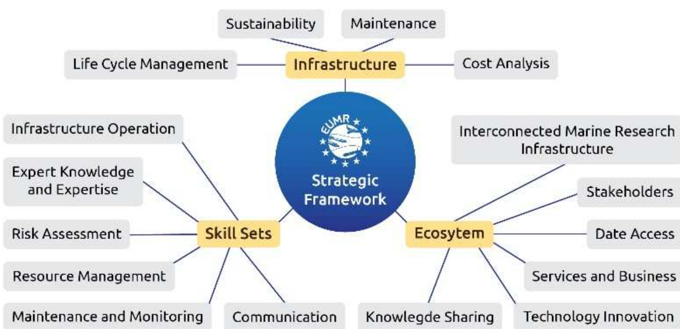

Figure 11: EUMR strategic framework.

The goal of this strategic framework is to enhance clarity, reduce risks, and realize the opportunities of sustainable research infrastructure and skill sets for long-lasting TNA in marine robotics, ensuring that the innovation mechanisms are re-enforced from the transnational infrastructure access funds at the EU. It will also help promote convergence among key stakeholders on the objectives for sustainable and long-lasting TNAs, provide a common language for dialogue around TNAs, and ensure a more consistent approach toward key challenges and opportunities across long-lasting TNAs.

There are many stakeholders in the EU, covering robotics, stationary or mobile observation networks, data center networks etc. Specifically, a few marine infrastructure research programs have been funded and are being carried out in the EU Horizon 2020 for TNAs. Building an interconnected ecosystem for these marine research infrastructures will require active engagement and close collaboration among these EU initiatives, increasing awareness of overlapping areas and building synergies to fill infrastructure gaps. Therefore, this task has also been extended to open towards collaboration with other European Research Infrastructures, including Eurofleets+, Groom II, and SeaDataNet. Drawing on experience and knowledge from participation in projects such as Eurofleets+ a desktop review of strategic analysis deliverables has been undertaken to better understand the potential opportunities available. During the EUMR project duration a joint workshop on synergies, shared experience, best practice, and opportunities of convergence was held in April 2021 to examine the results of a SWOT analysis, discuss networking opportunities, challenges which EU Marine Robots may face and finally the sustainability of the RI.

In summary, EUMR will greatly contribute to a sustained presence in the ocean by opening-up key national and regional marine robotics research infrastructures (RIs) to all European researchers and will also establish a model of world-class marine robotics integrated infrastructure. By doing this, EUMR has the potential to uniquely impact other initiatives, as well as the landscape of marine research infrastructures with a view to address global ocean observation and sustainable exploitation challenges. Future joint initiatives will enable truly coordinated ocean observation and sustainable exploitation at the Atlantic scale, from pole to pole. The time is ripe for EUMR to have a lasting impact, well beyond the duration of the project.

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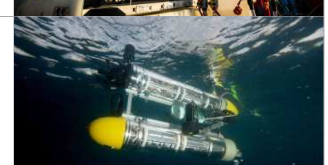
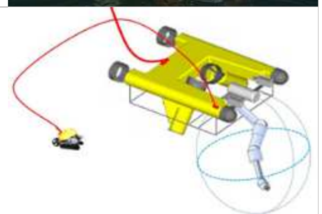
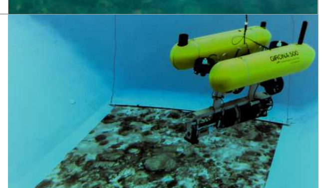
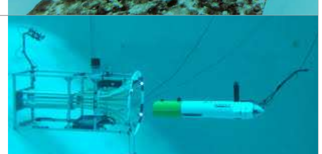
REFERENCES

Please check https://www.eumarinerobots.eu/publications for the list of the publications of the project.

ANNEX 1 – TNA CATALOGS

The TNA catalogs are presented next.

Infrastructure	Provider	Infrastructure elements
Multiple AUVs, ASVs and Manta Gateways	UPORTO	
Multiple AUVs, ASVs and Manta Gateways	UPORTO	
ROV Simulator	UBRE	
ASVs, AUVs and supporting instrumentation and infrastructures	IST-ID	
SBL, LBL, transponders, multiparametric probes	ISME	UNICAL Testbed

Catamaran, quadrotor	ISME	
ROV, 6DOF arm + hand, miniROV videoray	ISME	
Catamaran, Velodyne PUCK Lidar, Basler scout sca1000 Camera, movable mast to install underwater equipment(s)	ISME	
4 possible AUVs (Marta, Typhoon, Folaga)	ISME	
Marta AUV, bearing-only acoustic sensor network or deployable acoustic sensor network	ISME	
Multiple USVs	UNIZG-FER	
G500 AUV in CIRS Water Tank	UdG	
SPARUS II AUV in CIRS Water Tank	UdG	
G500 AUV in the Sea with Sextant Boat	UdG	
SPARUS II AUV in the Sea with Sextant Boat	UdG	

ROV	UL	
ROV	UL	
Glider / AUV	PLOCAN	
ASV	PLOCAN	
Littoral Ocean Observatory Network (LOON) testbed	CMRE	
AUV, ROV and ASV	HWU	
ROV	NTNU	
AUV	NTNU	
AUV	NTNU	

RV Celtic explorer - vessel	MI	
EDP facilities	DLTM	HPC-IT
UUV, USV and Ship	NERC	
ROV/AUV harbour tests	IFREMER	
ROV/AUV sea trials	IFREMER	

Table 2: Catalog of infrastructures.

ID	Use Case	Provider
UC-01	Cultural Heritage	UdG/ISME
UC-02-01	Security: Modulation and coding schemes	CMRE/UP
UC-02-02	Security: Detection/classification solutions	CMRE/UP
UC-02-03	Security: Navigation and control of Unmanned Underwater Vehicles	CMRE/UP
UC-02-04	Security: Underwater acoustic networking	CMRE/UP
UC-03	Arctic under-ice and ice-margin	NOC/NTNU
UC-04	Ecosystem mapping	IST-ID/UdG

Table 3: Catalog for experiments (use cases).

ANNEX 2 – TNA PROJECTS

Table 4, Table 5 and Table 6 list the TNA projects approved in calls 1, 2 and 3 respectively.

Acronym	Installation	Institution	Description
FALCONERA	UdG-SEA_S2	SUBMARIS (Academia)	Survey and Mapping of Falconera Cave with Sparus II AUV
ADVS4AUV	UdG-WT_S2	U. Haifa (Academia)	Autonomous Adaptive Visual Survey
OA4AUV	UdG-WT_S2	U. Haifa (Academia)	3D Obstacle Avoidance for AUV
MOCAV-G500	UdG-WT_G500	TUT (Academia)	Model-based control architecture for an AUV
MultiCoop-Arch	UdG-EU_G500	INESC-TEC (Academia)	Multirobot cooperative survey (Archeology Use Case)
MultiCoop-WT	UdG-WT_G500	INESC-TEC (Academia)	Multirobot cooperative survey (Water Tank)
AEFMIST	UdG-SEA_S2	JU Bremen (Academia)	Autonomous exploration and fault management integration sea trials
ISUVI	UPORTO-Local	UPCT (Academia)	Integrated Software for Underwater Vehicle Interoperability
LARAU	UPORTO-Atlantic	Maritime Robotics (Industry)	Launch and Recovery of AUVs from USVs
NPPALC	UPORTO-Local	Texas A & M University (Academia | Industry)	Novel Path Planning Algorithms for AUVs with Localization Constraints
AUVCover	UPORTO-Atlantic	IIIT-Delhi (Academia)	Multi-AUV Area Coverage under Currents
MUPOS	UNIZG-aPad	UNEW (Academia)	Multi-user surface LBL network
CC-MICRO	UNIZG-aPad	HUST (Academia)	Cloud-based coordinated mission control of fleet of ASVs
CRYO-SUBMARINE	ISME-SEALAB_AUV	CERN (Research)	Investigation and experimental activities aimed at developing an AUV for Liquid-Argon Time Projection Chambers
DAMOSS	ISME-SEALAB_AUV	JU Bremen (Academia)	Detection And Mapping Of Submarine C02 Seeps
RANGE TRACK	ISTID-Local	UNED (Academia)	Range-based multiple underwater target localization and tracking using cooperative ASVs
CTAN	ISTID-Local	NIO-Goa (Gov.)	Cooperative Terrain-Aided Navigation of Multiple AUVs
SUMMER	ISTID-Local	U. Exeter (Academia)	SoUrce and Boundary Exploration of Marine PhenoMena using coopErative Robotic-Based Systems
AHMF	NTNU-SF30K | NTNU-SMALL_AUV	U. Southampton (Academia)	Autonomous habitat mapping in fjords
Deep Spectrum	HROV / IFREMER-HARBOR	Ecotone AS (Industry)	Underwater Hyperspectral imaging – Scientific payload integration and evaluation on hybrid ROV
IRNOS	HWU-T_ROBO	CIFICEN (Academia)	Integrated Robotic Network for Observation of the Seas
EnviroLough	HWU-T_ROBO	MarEI – UCC (Academia)	Developing a Real-time Sensor network to monitor Environmental Health of Lough Currane System

Table 4: Projects approved in Call 1.

Acronym	Installation	Institution	Description
VTMCAUM	HWU-T_ROBO	Louisiana State University (Academia)	Validation of transferable modern control architectures for underwater manipulation
FEATURE	UPORTO-Local	University College London (Academia)	Fault detection, isolation, and recovery for AUVs
DINGOS	CNR-Swamp	Technische	Distributed Navigation, Guidance

		Hochschule Mittelhessen (Academia)	and Control of Modular Autonomous Surface Vehicles
UV-HC	UdG-WT_S2 and UdG-WT_G500	University of Toulon (Academia)	UV-Hydro-Cable: Hydrodynamics parameters identification and cable management for underwater vehicles.
EvoNetNavi	CNR-INM	Evologics GmbH (Industry)	Evologics Network-based USBL-Positioning Approach for Polar Applications
STAI	UPORTO-Local	Cartagena Oceanographic Research Institute (Research Institute)	Salinity Tracking Algorithm Integration for underwater vehicle
TEME	DLTM-HPCIT	University of Strathclyde (Academia)	Tidal Energy for Marine Exploration
C3-MUN	ISTID-Local	University of Essex (Academia)	Cooperative and COLREGs-Compliant Multi-USV Navigation
MOGLI	ISTID-Local	Oslo Metropolitan University (Academia)	MOdel Identification and maneuverability assessment of of a miniature underwater GLIder using ASV-supported range-based target localization and tracking techniques
VAHM	UdG-SEA S2	University of Southampton (Academia)	Visual autonomous habitat mapping
EXEMPLUM	NTNU-SF30k	Biodentify (NL) and iDROP (NO) (Industry)	Autonomous DNA-Sampling in Deep Water
BLUE-INTEROP	NATO-T LOON	WSense Ltd (Industry)	Enabling BLUE Economy devices INTEROPerability through the JANUS standard

Table 5: Projects approved in Call 2.

Acronym	Installation	Institution	Description
RoboWind	HWU-T_ROBO	Zhejiang University (Academia)	Integrated Structural Inspection of Offshore Wind Turbines Based on Unmanned Robotic Systems
3DHAB	IFREMER-SEA	ICM-CSIC (Academia)	High-resolution 3D terrain models of cold-water coral HABitats in Blanes Canyon
DAMOSS 2	ISME-SEALAB	Jacobs University Bremen (Academia)	Detection And Mapping Of Submarine C02 Seeps 2
LAUA	ISME-SEALAB_AUV	Jacobs University Bremen (Academia)	Localisation Approaches for Underwater Autonomy
ANEMONE	ISME-UNICAL	Golestan University (Academia)	Analysis, Development and Demonstration of Sliding-Mode Nonlinear Observers for Underwater Acoustic Localization
VHMSH	UC-05	Newcastle University (Academia)	Visualizing HMS Hampshire
Fault-Robot	MARUM-TEC	UTM-CSIC (Academia)	ROV observatory recovery and monitoring survey at Europe-Africa plate boundary fault system
AM-CMS-20b	MI-CELTIC	Ulster University (Academia)	Advanced Mapping of Complex Marine Structures - 2020(b)
SAUWAN	NATO-T LOON	ISEN Brest - Yncrea Ouest (Academia)	Self-configurable and Adaptive UnderWater Acoustic Networks
CSI-ACQUA	NATO-T LOON	Norwegian Research Center AS (NORCE) (Academia)	Channel State Information Acquisition for Adaptive Underwater Acoustic communication schemes
RASDAC	NATO-T LOON	Rutgers University (Academia)	Reliable Adaptive OFDM-based Underwater Acoustic Communications using Software-defined Acoustic Modems
EvoLoon	NATO-T LOON	Evologics GmbH (Industry)	Long Term Underwater Networking in Extreme Conditions
TESEO	NATO-T LOON	WSense Ltd (Industry)	Testing JANUS Enabled protocol Stacks enabling multi-vendor undErwater netwOrks (TESEO)
OAS-3D	NTNU-ARCTIC	Université Laval (Academia)	Observing Arctic Substrates: Unveiling ice, water column and benthic physical and biological properties using laser remote sensing from autonomous underwater vehicles
SPEED	NTNU-SMALL_AUV & NTNU-SF30k	Tallinn University of Technology (Academia)	Speed and turbulence measurements for AUVs
IDUG	PLOCAN-SLOCUM	University College London (Academia)	Identification of the Dynamics of Underwater Gliders
ECOGLIDER	UC-03 (NOC)	Cyprus Subsea Consulting and Services (Industry)	Ecosystem profiling with ocean gliders
IMP-UI	UC-03 (NOC)	Nelson Mandela University (Academia)	Improving Measurements of Phytoplankton Under-Ice
GINCAN	UC-06 (PLOCAN-SeaGlider)	Instituto Hidrográfico Portugal (Government)	A Gliders look at the Impacts of a long and Narrow submarine CANyon on the slope circulation.
FRIPP-CI	UC-06 (PLOCAN-SLOCUM; PLOCAN-WG)	CNR-ISAC (Public R&D Institution)	Frontal and mesoscale dynamics Impacting Primary Production - Canary Island case study
MOCAV-G500 2.0	UdG-SEA_G500	Tampere University (Academia)	Model-based control architecture for an Autonomous Underwater Vehicle in an offshore environment.
UV SPH	UdG-WT_S2	University of Toulon (Academia)	Identification and variability study of Hydrodynamics Parameters for Underwater Vehicles using Smooth Particle Hydrodynamics techniques
RACE	UL-IROV	Williams College Massachusetts (Academia)	Robotics Assessment of Cliff Erosion (Inishmore, Aran Islands, Ireland)
FASP	UL-IROV	DAERA UK (Government)	Freshwater Archaeology Survey Project (FASP)
STILE	UL-IROV	Ulster University (Academia)	Survey Technology transfer to Ireland's Lake Ecosystem
AM-CMS-20a	UL-MRE_ROV	Ulster University (Academia)	Advanced Mapping of Complex Marine Structures - 2020(a)
DivGlo	UNIZG-BUDDY	University of Auckland (Academia)	Diver-robot interaction based on a diver glove with integrated wearable sensors

Table 6: Projects approved in Call 3.