SEALab current research trends: Maritime Unmanned Systems for dual-use applications

Daniele S. Terracciano[1,3], Vincenzo Manzari[1], Mirko Stifani[1], Benedetto Allotta[2,5], Andrea Caiti[2,3,4], Giuseppe Casalino[2,6]

[1] *Naval Support and Experimentation Centre of Italian Navy (CSSN), La Spezia, Italy*
[2] *Interuniversity Center of Integrated Systems for the Marine Environment (ISME), Italy*
[3] *Department of Information Engineering (DII), University of Pisa, Italy*
[4] *Research Center "E. Piaggio", University of Pisa, Italy*
[5] *Department of Industrial Engineering, University of Florence, Italy*
[6] *Department of Communication, Computer and System Sciences, University of Genoa, Italy*

Abstract – **The technological potential offered by Maritime Unmanned Systems (MUS) is recognized by many countries as an effective tool for both military and civilian applications. The increasing use of MUS brought substantial and new challenges to the Test and Evaluation process that becomes significantly more complicated than traditional systems. Unmanned systems have continuously increasing complexity and capabilities and can be at different maturity levels.**
These technologies necessitate for specific Test and Evaluation tools throughout the whole program life cycle. For the above reasons, the Naval Support and Experimentation Centre (CSSN) of the Italian Navy and the Italian Interuniversity Center on Integrated Systems for the Marine Environment (ISME) founded a joint laboratory in 2015, called SEALab (Laboratory on marine heterogeneous and autonomous systems), with the main goal to jointly develop and manage applied research and experimentation activities of common interest in the field of heterogeneous and autonomous marine systems.

I. INTRODUCTION

Robotics impact in the marine environment has been discussed since a very long time; for instance, in the very early reference [1], the author identified some benefits from using Unmanned Systems: savings on personnel costs, reduced workloads for personnel, reduced exposure to dangerous tasks and improvement of decision-making in stress conditions. Although many of the promises described in [1] have been largely met by the technological evolution (e.g. [2], [3]), the development in the maritime domain is still lagging behind that of its air and land counterparts. The intrinsic hostility of the underwater environment, the lack

of GPS signal, the impossibility of radio transmission, the limitations of light penetration, all concur to pose severe challenges to the operation of autonomous marine robots. In addition, wireless acoustic communication among robots is still at development stage, with respect to all the capabilities available on land and in air [4]. From [5], it emerges that the technological potential offered by Maritime Unmanned Systems (MUS) is recognized by all Navies as an effective tool for Mine CounterMeasures (MCM), AntiSubmarine Warfare (ASW) and Intelligence, Surveillance and Reconnaissance (ISR) missions. Moreover, this potential can be exploited also for civilian applications, such as marine flora and fauna survey and protection missions. Despite their great potential, MUS use to have a marginal role in these missions due to their limitations in persistence, interoperability, modularity, costs, scalability, autonomy and information assurance. Finally, decision makers and operators perceive expectations higher than actual technology development capabilities may offer, due to customer versus supplier personal interpretation of the "job to be done" [6]. Original expectations are thus mismatched by actual activities if not supported by a dedicated strategy. They result only in a little step toward the desired path requiring anyway a consistent effort [7].

These new technologies necessitate to be assessed by specific Test & Evaluation (T&E) tools throughout their whole life cycle. Analyzing the gaps between base and emerging technologies through the S-Curve behavior [8], an area where T&E capabilities are available at different stages can be identified. Indeed, these capabilities and related skills are already present at different levels in various Italian, European and international entities, but it is extremely difficult to make the overall technological

development coherent, efficient and effectively harmonized.

For the above reasons the Naval Support and Experimentation Centre (CSSN) of the Italian Navy and the Italian Interuniversity Center on Integrated Systems for the Marine Environment (ISME) founded a joint laboratory in 2015, called SEALab (Laboratory on marine heterogeneous and autonomous systems), for study, research and experimentation applied to MUS.

The paper is organized as follows. Section II describes the philosophy and the role of the SEALab. In section III, some of SEALab activities are presented and discussed. Section IV reports the features which make the SEALab a potential Test & Evaluation Centre. Finally, conclusions are reported and discussed in section V.

II. SEALAB: THE PHILOSOPHY AND ROLE OF THE LABORATORY

The main goal of the laboratory is to jointly develop and manage applied research and experimentation activities of both civilian, commercial and military interest in the field of heterogeneous and autonomous marine systems with dual-use purposes, as well as the relative modeling and simulation framework and associated sensors and payloads. The main site is established at the headquarters of the CSSN of La Spezia, Italy (Fig. 1).

Fig. 1 - Location of the SEALab. The area designed to the experimentations is delimited by the red rectangle.

SEALab serves as a junction point between the world of T&E for experimental and logistic purposes of the CSSN and the academic research world, realizing an experimental and educational centre dedicated to identify new technologies and innovations in the maritime domain, putting the basis for a national hub with projection to international challenges. The laboratory also aims to fuse CSSN and ISME skills and resources to cover as much as possible the emerging technologies, with the final scope to improve the transition from emerging to key technologies to mature applications. Furthermore, one of the main aims is to create the necessary expertise to fill some of the technology gaps recognized and remarked by NATO. A dynamic program in the longest possible time horizon in order to reduce the gap between capacitive requirement and

technological development to pursue international competition is required. Working in synergy, CSSN and ISME agree on a 3-year program updated annually. In order to draw up the program, an overview of the main technological challenges recognized as innovative to the use of unmanned systems within the marine environment is conducted. The research activity makes use of Program Matrix (PM) approach (Table 1), which aims to share objectives on enabling technologies so that both CSSN and ISME can derive the diversified applications according to specific needs (military-only, civilian-only, dual-use).

Table 1 - The Program Matrix adopted by the SEALab. In the lines the enabling technologies or the necessary technologies to fill the identified gaps. In the columns the applications that are satisfied.

The two-dimensional PM consists of a database of technological research activities to develop, in which the enabling or necessary technology to fill the capacitive gaps identified at the international level and the relative applications are reported. In the rows of the PM the enabling technologies or the necessary technologies to fill the identified capacitive gaps at National, NATO and European level are reported. All the possible identified applications are reported on the columns. The current projects within the SEALab three-year plan are then printed in the cells. They will constitute the set of technologies to be supported and invested in.

Recently, the authors extensively worked within SEALab on MUS touching on topics that cover many marine applications. All these activities are examples of cultural exchange in line with the respective institutional tasks, which aimed to an ever more profitable collaboration between the research world and experimentation, without specifically assigned funds for the optimization of national resources.

In the last years, the CSSN has also become a reference point for SEGREDIFESA (The Secretariat General of Defence), and it has been chosen to manage tens of PNRM (The National Plan of Military Research) projects in the field of marine environment. In this sense, the CSSN provides useful indications to the participants at national level with the final goal of guaranteeing the National interests. On the other side, ISME converges part of the skills and resources absorbed in the European projects (e.g.

H2020) within the activities defined by the Program Matrix.

The CSSN involvement in the PNRM proposals, together with ISME activities, and the experimentations conducted at NATO collaboration level, gives added value to the PM, contributing to cover the gaps identified drawing up the programs.

III. SEALAB ACTIVITIES

A. WAVE Project

SEALab was involved in the WAVE (Wave-powered Autonomous Vehicle for marine Exploration) PRNM project, in 2015, which faced the development of a hybrid Autonomous Underwater Vehicle (AUV) with power recharging capabilities from environmental renewable sources [9]. In the context of this project, the realization of a hybrid glider/AUV with battery recharging capabilities from the wave motion was considered. A WAVE module consisting of two robotics wing-terminated arms was realized (Fig. 2).

At the end of the project, the AUV used for this experimentation (the eFolaga+ [10]) became part of the SEALab assets.

Fig. 2 - The WAVE prototype during the deployment phase.

This allowed the laboratory to further conduct additional experimentation.

B. Passive Acoustic Monitoring Applications

Concerning the Passive Acoustic Monitoring (PAM), one of the PM objective, an acoustic vector sensor [11] has been integrated on board the eFolaga for passive acoustic applications. Taking advantage of the vehicle modularity, an acoustic payload has been designed and developed (Fig. 3) to be fully compatible with the vehicle [12]. The development has been performed in collaboration with the GraalTech company and the NATO Science and Technology Organization (STO) Centre for Maritime Research and Experimentation (CMRE) of La Spezia, with which the CSSN has a Memorandum of Understanding (MoU). The developed acoustic payload has been extensively tested on board the vehicle in the very shallow water area in front of CSSN in La Spezia harbour and in the LCAS'18 (Littoral Continuous Active Sonar) experiment, a Multinational-Joint Research Project (MN-JRP)

organized by CMRE which took place off the coast of Elba Island, Italy, in November 2018 [13].
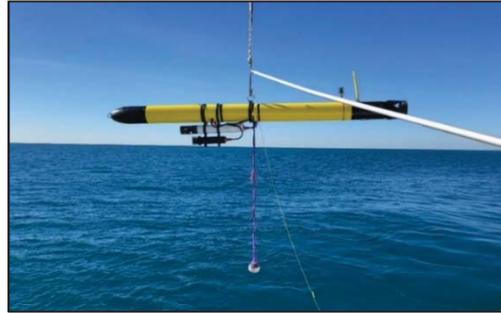
Fig. 3 - Deployment of the eFolaga AUV equipped with two different payloads: the acoustic payload with the vector sensor (suspended under the vehicle) and another payload module equipped with a Hydronaut CTD probe and an EvoLogics acoustic modem.

Different bearing estimation algorithms have been implemented in order to obtain the Direction of Arrival (DoA) of low frequency sources. Results of these measurements show that the bearing estimates are in agreement with the reference ground truth. The whole system uses completely passive technology, with no underwater emissions and no risks for marine flora and fauna. The developed system suggests new approaches to PAM. This system will enhance the SEALab ability to detect the presence of underwater targets, making possible to monitor a large area at a reduced cost with respect to traditional assets. The successful demonstration provided the basis for future system enhancements such as the ability to the autonomous classification of targets.

C. Underwater Navigation tests

The AUV tracking and self-localization problems are under deep study after an analysis of the state-of-the-art showing that no standard evaluation methods to qualify vehicle navigation skills are commonly used by the whole community. The study, design, development and test at-sea of an Underwater Test Range (UTR) is another ongoing project [14] in the SEALab context. The final goal is to certify the vehicle compliance with long-term underwater navigation. The conceived test range is an underwater network formed by Ultra Short BaseLine (USBL) acoustic modems, that can track autonomous vehicles exploiting only bearing measurements. The experimental results showed that in a challenging harbor scenario the proposed methodology leads to a tracking error below 10 meters on average. The use of autonomous surface vehicles acting as network nodes is under investigation as major future development. Such a dynamic network exceeds the limit of the current static network, with the possibility to operate in different scenarios, in particular in deeper water, and to create different geometries depending on the mission to accomplish.

D. Interoperability studies

The interoperability of heterogeneous systems with different skills is critical to accomplish complex tasks. This problem was approached in the ASW Operational Deployment of Concepts 2017 (ASW-ODC17) sea trial exercise, conducted in October 2017 off the coast of La Spezia [15]. The sea trials were organized in the context of the CMRE project MUS for ASW, involving NATO Naval Units and the SEALab. The goal of the project was the development and verification at sea of a heterogeneous autonomous ASW network based on MUS implementing a multistatic active sonar system. From the Italian point of view, the goal was to demonstrate the interoperability of a national AUV (the cited Folaga-WAVE) within the CMRE robotic network for ASW (Fig. 4).
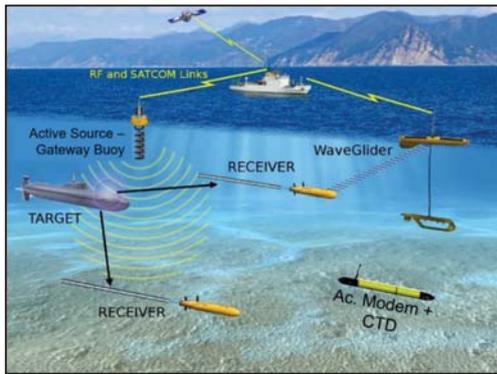
Fig. 4 - A descriptive outline of the multistatic network for ASW of the CMRE with the integration of the Folaga-WAVE.

The interoperability of the WAVE vehicle into the aforementioned CMRE heterogeneous network was demonstrated by exchanging both commands and data. The challenge lay mainly in the different robotics middleware of the Folaga WAVE vehicle and the CMRE network. Therefore, a middleware bridge software was installed on a moored buoy acting as a gateway between underwater assets. Due to the characteristics of the different AUVs participating in the experimentation in addition to the WAVE vehicle, the gateway was fitted with acoustic modems working on different frequencies. The planned interoperability tests started with a mission-planning phase, in which different parameters (e.g. waypoints, operating depth, and timeout) were sent from the CMRE Command & Control Station (C2S), where the WAVE Mission Control Station was installed as an additional module, to the vehicle through the gateway buoy. After the vehicle started its mission, it automatically (at a selectable frequency) sent to the CMRE C2S its position and Conductivity, Temperature, Depth (CTD) data during profiling operation. Another test was the asynchronous request from the CMRE C2S to the vehicle of its position and CTD data. All the tests rely on a double channel communication: acoustic between the gateway buoy and the vehicle, Radio Frequency (RF) between the Alliance C2S and the gateway buoy. The integration of WAVE Folaga within the CMRE network, aimed at enhancing the interoperability in a multi-vehicle operation, was the best demonstration of the effectiveness of the system developed in the WAVE project in an operational context.

E. SeaWHAM Project

Research on offshore wave energy extraction has been carried out, too [16]. The SeaWHAM (Seaspoon Wave HArvesting Microturbine) PNRM had the objective of developing an off-shore charging station for autonomous naval systems through the conversion of wave energy. This project led to the installation of a unique facility (Fig. 5) for testing wave energy converters in La Spezia, in the water of CSSN. It consists of an open-sea wave tank that can produce different wave sea states in a real environment. This facility can host different experimental tests in real sea conditions.

Fig. 5 – The wavemaker composed of 5 modules. Each module can be completely removed from water.

One of the main goals of the SEALab is to test the concept of Passive Acoustic Monitoring and take advantage of the wave motion and the wings from WAVE in order to move in energy-saving mode, without activating any thrusters, and recharging the vehicle's batteries by equipping it with a solar panel on its back (Fig. 6).
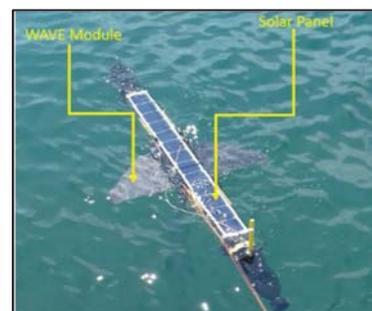

Fig. 6 – The vehicle equipped with the WAVE wings and the Solar Panel. Under the hull, therefore not visible in the photo, there is the acoustic vector sensor for PAM.

Some preliminary trials have been conducted to test the effects of the wave motion on the vehicle and refine the position of the wings on it. Tests will continue in the next future.

F. AntiSubmarineWarfare Workshops

Thanks to the SEALab, a series of workshops have been conducted in which small and medium enterprises, universities, research centers, the Italian Navy and the CMRE participated.

The initial aim was to promote the exchange of ideas and competences on the MUS subject between the participating institutions, trying to provide a common direction to define the requirements of the Italian Navy's ASW doctrine. The gaps and issues emerged from these workshops are fully reflected in the SEALab activity. The final goal was to outline the priority gaps to be filled in the underwater domain, such as sensors, autonomous decision, deployment, reconfigurability, communications, and command and control. This led to the creation of a national network, composed by all the participants in the workshop, ready to be involved at international levels in MUS projects.

IV. SEALAB AS TEST AND EVALUATION CENTRE

The increasing use of MUS brought substantial and new challenges to the T&E community. In particular, the T&E for unmanned systems is significantly more complicated than the T&E for conventional systems because of their complexity and evolving maturity.

As already mentioned, these new technologies necessitate to be assessed by specific test and evaluation tools throughout their whole life cycle. T&E can be defined as the process by which a system and its subsystems are compared against some requirements (Fig. 7). This is done through testing, that cannot occur only at the end of development, but it should be addressed continuously throughout the entire life cycle.
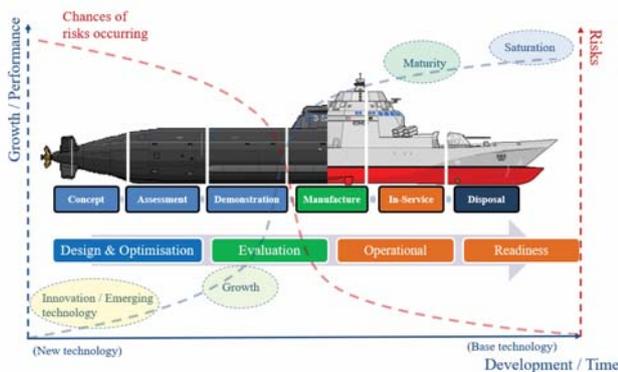

Fig. 7 - The S-Curve concept of technology life cicle. The evaluation process becomes fundamental in the development and used to reduce risk throughout the entire life cicle.

Over the years, SEALab acquired deep expertise in the field of MUS and its sensors. This allows the members of the laboratory to approach the problem of robust, well-structured and cost-effective T&E process. This means that MUS systems are not only the object of a T&E process, but they become fundamental to test and evaluate other systems, whether they are unmanned or not.

All the preparatory and research activities mentioned in Section III are illustrative of how they are necessary to carry out all those evaluations in a controlled environment that if not done would entail high risks of failure in the open sea during operational activities. They have been the starting point to providing the laboratory T&E capabilities on different interconnected topics (Fig. 8).
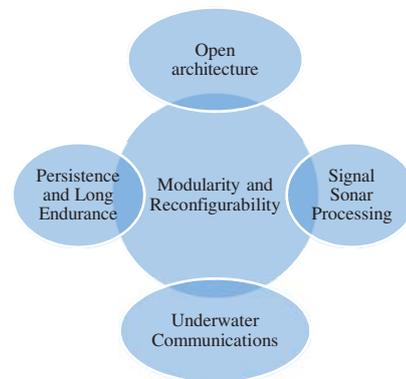

Fig. 8 - SEALab Test & Evaluation capabilities. A central role is given to the Modularity and Reconfigurability concept. All of these T&E capabilities are interconnected.

The first fundamental T&E capability is the Modularity and Reconfigurability of autonomous systems where the basic idea is the possibility to have a single macro-vehicle that can have multiple testing and evaluation capabilities. This is only possible thanks to the WAVE project which allowed the SEALab to have a platform (eFolaga) where one can install a big quantity of different module payloads, such as the WAVE module, vector sensor, acoustic modems, CTD probes, solar panels and so on. In addition, we can develop independently or together with SEALab partners a software for each module. This is possible thanks to the open-architecture (both hardware and software) of the vehicle which allows changes with extreme flexibility. Persistence and Long Endurance capabilities have been addressed thanks to the SeaWHAM project. A good expertise in the Underwater Communications has been achieved thanks to the experimentations carried out during the Underwater Navigation tests where the use of acoustic modems with particular type of communications has been fundamental. Finally, the development of the acoustic payload hosting the vector sensor gave us the possibility to test the vehicle in multistatic scenarios and increase the signal sonar processing capabilities.

V. CONCLUSION

This paper has outlined the recent developments in SEALab studies on the use of MUS for military and dual-use applications, ranging from ASW to marine mammal detection and protection. To carry out such heterogeneous missions, the SEALab Program Matrix has been designed to address a detailed methodological analysis in various fundamental research fields. Finally, SEALab's current program of work covers a number of key issues, including the implementation of an Underwater Test Range for the Verification and Validation of Autonomous Underwater Navigation; the at-sea assessment of an innovative system for the exploitation of wave and solar energies to move MUS endurance from hours to months for a persistent monitoring capability; the enhancement of autonomous behaviors in fully passive acoustic monitoring applications; the concept of reconfigurability from a single system to a system of systems.

The SEALAb overview given in this paper shows how a virtuous example of collaboration between academia and the Navy may be strategic for national technological development. This is fundamental to create a shared background reference aligning the expectations of the customer (e.g. military end-user and university researchers) to the actual technology supplier capabilities.

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