d

Project Number: 902204

Project Start: Jan. 1, 2025[1] **Project Duration (in years): 1 of 5[1]**

Please indicate if proposal includes requests for any of the following (mark all that apply).

X	X			X
Ship Time	**ROV**	**AUV**	**Wave Glider**	**Mini ROV**

Please indicate what type of project is being proposed (mark only one).

		X				
Feasibility/Scoping [<100 days effort]	**Development[2]**	**Research**	**Infrastructure[2]**	**Education**	**Time Series**	**Institute Initiative**

Project Manager[3]: Eric Martin
Principal Investigator: Giancarlo Troni
Lead Scientist:
Lead Engineer: Sebastián Rodríguez

Project Title: Scalable Marine Robotics

Please indicate which category best describes the project theme (mark only one).

			X
Ocean biogeochemistry	**Ecosystem dynamics**	**Ocean visualization**	**Exploration & discovery**

Please indicate percentage of effort on this project anticipated for 2025 toward these three highest institutional goals from the [Strategic Roadmap](#) (percentage total should equal 100%).

Goal	**Innovate and Build**	**Explore and Protect**	**Inspire and Engage[4]**
Percentage	70%	10%	20%

[1] This date and number should remain the same for the duration of the project. If your project start date for 2025 is not January 1, please indicate the start date in the first cell of the milestone chart. Format for duration example: "Year 2 of 5".
[2] Development and infrastructure projects must complete the risk matrix (see end of the proposal form).
[3] Not all projects will require all four titles to be filled in. Please indicate individuals only for those titles that are appropriate for your project.
[4] This category includes transfer of hardware, know-how, publications, presentations, etc.

1) ABSTRACT (all projects)

This **research project** seeks to enable scalable—cost-effective, energy-efficient, and portable—marine robotics using novel **perception, navigation, and control methods** to allow ocean science. The core of this effort will continue the research work done at the project "*Scalable Marine Robotics Foundation*" (902204).

For this year (2025), the main focus of the project will be to develop the technology to deploy our 6-DOF research platforms from other platforms, such as ROVs or clumps, to enable deepsea exploration, low-altitude navigation, and terrain-following. We expect to publish much of our research developed in the laboratory related to (i) navigation, such as visual and sonar simultaneous localization and mapping (SLAM), (ii) perception, such as enabling forward-looking sonar AI-based methods, or (iii) control, such as our deep reinforcement learning-based methods for surface and underwater platforms.

2) PROPOSAL (all projects)

<u>Background</u>

This project addresses the limited autonomy and high costs of ocean exploration. Underwater robotics has revolutionized ocean exploration and is currently used for various applications, such as high-resolution seafloor mapping and tracking animals in midwater. However, the scalability of these platforms needs improvement as they are still expensive to build and operate, leading to limited access to ocean exploration and discovery for scientists. Lowering barriers is crucial, particularly for problems that require high-resolution information on a large spatial or temporal scale. The main focus is to enable autonomous exploration of complex marine environments without prior knowledge of the area, such as seafloor maps, to map and monitor marine ecosystems.

In the long term, we aim to achieve three main objectives, which are (1) the implementation of multiple vehicles for high-resolution seafloor mapping in complex and unexplored terrains, (2) repeated mapping to detect small-scale changes, and (3) tracking and target sampling using multiple midwater vehicles. However, we must address several common technological challenges to accomplish these objectives, such as:

- Precision **underwater localization** based on low-cost, power-efficient, and compact sensors is critical for autonomous systems.
- Precision **in-situ sensor calibration**, such as sensor alignment or camera calibration, is critical for reliable long missions and even for creating accurate models of the environment.
- Novel, low-cost, power, and size **3D mapping sensors** are required.
- Robust **6-DOF control** is critical to navigating complex environments.
- Embedded and on-shore **AI data analytics tools** for improved ocean exploration.
- An advanced **open-source software framework** for scalable system development.
- Enable platforms with a higher level of **autonomy**, which is critical for multi-vehicle operations.

The current proposal directly supports the MBARI Strategic Roadmap 2022—2032. Its central core helps address the **technology development** challenge and supports the seafloor imaging and data analytics challenges. It also complements the challenges associated with ocean science and engagement. In addition, all are relevant to the Packard Foundation's goal of improving our understanding of the ocean.

This project is the research and development at the core of the CoMPAS Lab team. The goal is to develop technology in collaboration with other internal projects and transfer this technology into field applications for collecting and analyzing field data to enable semantic mapping in the context of the Scalable Semantic Mapping and Monitoring project (902504, Troni).

Other collaborations related to this project are as follows:

Internal projects:

- 2025 Arctic Expedition (902505, Paull).
    - MiniROV navigation and mapping for Arctic fieldwork.
- Seafloor Processes (902312, Micallef).
    - Seafloor mapping of complex terrain and high resolution to monitor changes.
- Seafloor Mapping (901101, Caress).
    - Data processing tools and calibration work.
    - Support field work and system development.
- Deep-Sea Coral-Sponge Community Observatory (901904, Barry).
    - Hyperspectral imaging development.
- Deep-Sea Bioinspiration (901809, Katija).
    - Camera systems architecture and tracking.
- Precision Control Technologies (902405, Rock).
    - Control framework development and multibeam profiling sonar interfaces.
- LRAUV Technology Development and Fleet Operations (902101, Hobson).
    - Enable hovering modalities for LRAUV based on our 6DOF controller.

External

- PUC-Chile: Continued collaboration with research organizations and related projects in Chile, such as an ONR-G project for ASV, the Robot-X marine challenge, and graduate students.
- Kungliga Tekniska Högskolan (KTH), Sweden: Collaborating with academics and researchers for improved underwater vehicle model-based control using data-driven learning techniques.
- Continued collaboration with marine scientists and robotics groups around the world.

This work is essential for our group to develop new methods enabling the deployment of scalable robotics at MBARI. We aim to create a cost-effective, portable, autonomous platform for ocean exploration. Additionally, based on this new technology, we anticipate supporting multiple research groups inside and outside MBARI. Our goal is not only to advance current ocean science but also to introduce a new way to visualize the oceans using autonomous platforms.

Nature and Scope of the Proposed Project

This work combines fundamental research and development (R&D) goals of perception, navigation, and control tasks with platform and sensor integration to address future science challenges. This core research effort will likely remain constant over time.

Does this activity relate to one or more 2025 proposals your team is submitting?

This project builds on the research conducted at the "Scalable Marine Robotics Foundation" (902204) over the last three years. It continues the development of technologies for scalable platforms, which is the core mission of the CoMPAS Lab and, therefore, our highest priority. In addition, the team is proposing the Scalable Semantic Mapping and Monitoring project (902504), which will focus on transferring technology into field applications for collecting and analyzing data to enable semantic mapping.

Our priorities for our proposed 2025 activities for both projects (LAB - 902204 and S2M2- 902504) are as follows:

1. LAB - Activity 1 - Semantic Field SLAM with FLS and MBES
2. S2M2 - Activity 1 - Antarctic Expedition
3. LAB - Activity 2 - MOLA DRL Deep Deployment
4. LAB - Activity 3 - AI-based Laser Scanner with Stereo Cameras and HSI
5. S2M2 - Activity 2 - Preparation for the Arctic Expedition
6. S2M2 - Activity 4 - Integration Scalable ROV-Based Mapping
7. LAB - Activity 5 - Remotely Operated Surface Vessel Mapping in Shallow Water
8. LAB - Activity 4 - Research Platform Improvements
9. S2M2 - Activity 3 - Forward Looking Sonars and Scalable Semantic Mapping from ROV Ventana

Anticipated Shared Resource Needs

This project will require a balanced combination of resources, from in-house development to external contracts and some COTS solutions, to achieve the research and development goals. It will also require approximately 2,800 hours of Engineering time spanning all disciplines.

For 2025, some limited fabrication efforts are planned to enable new systems. During the initial testing stage, there will be a need for limited ship/ROV/AUV support. Requirements for extensive fieldwork will be requested in separate proposals.

Anticipated Expenses

We anticipate a direct expense budget of around $150k per year for testing sensors, materials, and travel for this proposal. The ability to have internal personnel or rely on external contracts might affect the expenses. These expenses should remain relatively constant in subsequent years of this project. Developing large initiatives in collaboration with other groups would require new separate projects.

Intellectual Property (IP) Considerations

This work primarily focuses on the advancement and development of open-source libraries (such as SLAM navigation, camera calibration, and underwater sensor alignment libraries). We expect this dissemination scheme to impact multiple communities significantly.

Data

As part of this research and development project, modest data will be generated (<1 TB).

Anticipated Impact

Most technology and methods developed through this basic research effort will be shared in respected conferences and journals. Additionally, open-source code, data, and information will help the community adopt the technology to tackle related challenges. We expect to impact scientific research in continental margins, submarine volcanism, and benthic ecology. We have fostered academic connections with institutions such as KTH, the University of Milano-Bicocca, and PUC-Chile. Still, we expect to expand to other institutions, such as NGOs, MBAs, the MBMS, and NOAA. Internally, we have been working with various MBARI researchers to help identify areas of interest to aid in grounding the focus of our work.

Anticipated Outreach Needs

We aim to initiate outreach support with multiple communities, particularly those in STEM fields. We are keen to explore close collaboration opportunities with the MBA, specifically regarding aquaculture management and the utilization of robotics in underwater exploration. Additionally, we intend to create illustrations and videos to broader explain the concept of scalable robotics.

Continuing Projects Only: Status Report

As previously mentioned, this project continues the work on the research and development of technologies for scalable platforms from the Scalable Robotics Foundations (902204) project.

Current status of the project and results to date

Scalable Navigation:

- *SLAM:* We have been continuously working on the development of our Simultaneous Localization and Mapping (SLAM) framework for navigation with low-cost sensors that leverage visual information for accurate localization. We have used this framework in test tank validations with our research platform, MOLA, and field deployments using different platforms, such as the Low Altitude Survey Sled (LASS), the MiniROV, the ROV SuBastian, where we have been able to validate this framework and keep improving it continuously.
  Furthermore, we have been working on extending this framework to allow for the use of sonar sensor data for a more robust operation when the terrain is not informative enough for the operation with stereo cameras.

- *FLS:* Methods have been developed for ego-motion estimation for underwater vehicles with imaging sonar data using recurrent convolutional neural networks (RCNN). These methods enable the sensor to operate as an imaging sonar and as a DVL to estimate the vehicle's velocity.

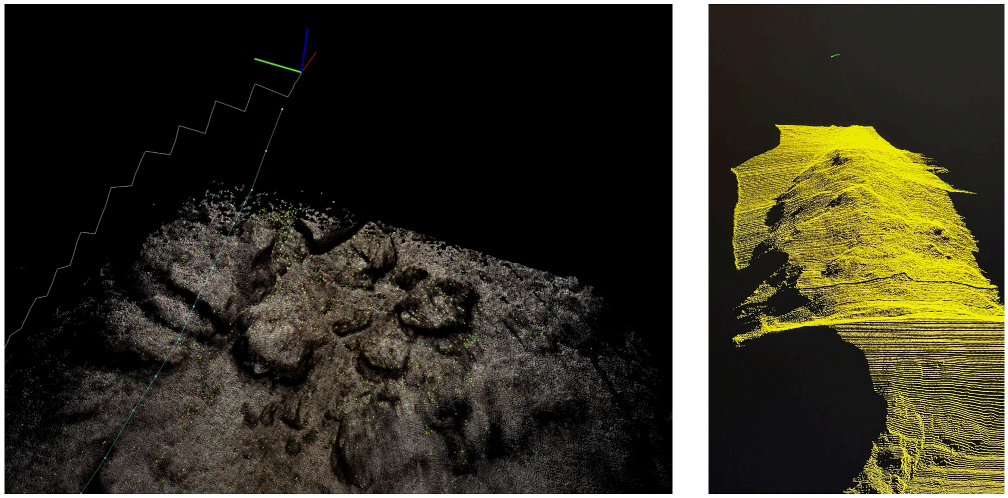


Figure: Real-time point cloud generated using the SLAM framework, incorporating stereo cameras and navigation data (left) and multibeam sonar data visualization (right).

Scalable Control:

- *6-DOF AUV:* The 6-DOF agile controller has been continuously developed, enabling MOLA to survey complex areas. We have tested it in the test tank with our platform, collecting data from the bottom and walls of the tank.
  Furthermore, a Deep Reinforcement Learning (DRL) control for docking has been under development, and preliminary results show that it performs better than the current controller.
- *USV DRL-based control:* In collaboration with Atlant Correa (Master's Student from PUC, Chile), a DRL-based control was developed in a simulation environment to control USVs in an environment perturbed with waves, showing better results than the state-of-the-art methods.

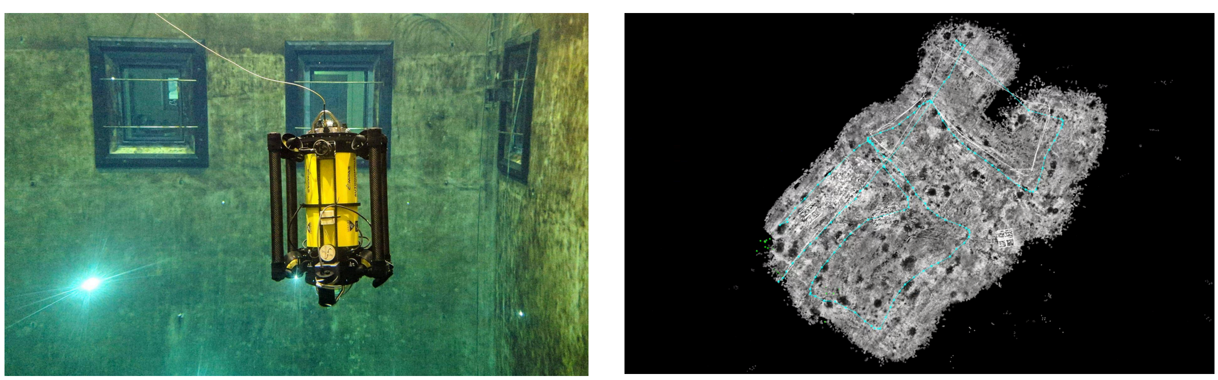
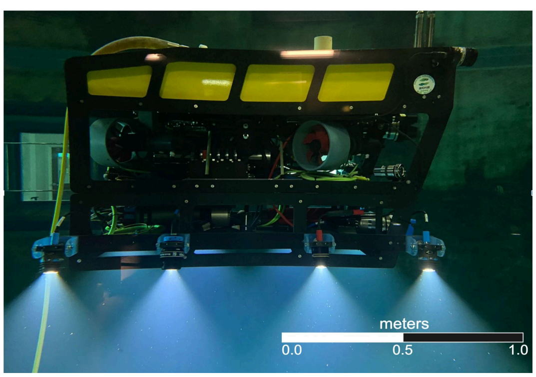


Figure: MOLA operating with the 6-DOF controller in the test tank (left). Test tank bottom section point cloud generated with the SLAM framework with data collected with MOLA (right).

Scalable Perception:

- *Mapping Sled:* A multimodal mapping sled has been designed and manufactured to be deployed with the MiniROV. This mapping sled features vision stereo cameras and navigation sensors (INS, DVL, pressure sensor) to collect feature-based visual information and integrate it with a navigation solution. This sled can be used in a benthic survey capacity to create maps and implement SLAM, structured light bathymetry, photogrammetry, and hyperspectral data collection. This capacity illustrates steps toward more scalable sensor payloads. A compact version of this sled was also manufactured and deployed with the ROV SuBastian aboard the R/V Falkor(too) from SOI during a 40-day scientific expedition to Easter Island, Chile.
- *FLS*: In collaboration with Yiping Xie (Ph.D. Student from KTH, Sweden), a self-supervised framework based on volume rendering was developed to produce seafloor bathymetry using imaging sonar data and the odometry of an underwater vehicle.
- *USV Perception:* We have designed, manufactured, and deployed on the R/V Paragon a portable frame for enhanced perception in surface vehicles. This frame collects simultaneous color and monochrome imagery, LiDAR point clouds, and inertial data. These data will enable the development of sea surface event detection and algorithms for larger-scale autonomous surface vehicles.
- *Deep-Open-HSI:* We have deployed a hyperspectral imaging package with a hyperspectral camera, a spectrometer, and a pair of stereo cameras for novel seafloor mapping across a hundred contiguous hyperspectral bands. Although the system requires further development for comprehensive data collection, we identified the scientific interest in products with this package.



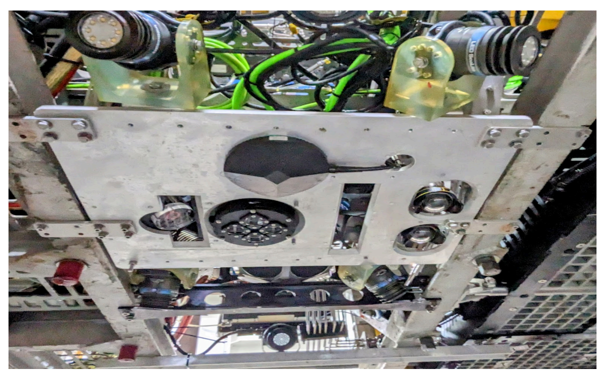


Figure: MiniROV with the CoMPAS Mapping Sled mounted during test tank validation before deployment (left). The compact version of the mapping sled mounted on SOI's ROV SuBastian (right) in February-March 2024.

Research Platform: We are actively developing our 6 DOF research platform (MOLA) for underwater navigation in complex terrain, like canyons or smokers**.** This work is focused on our deployment in the Maldives at the end of Fall 2024, where we plan to produce high-definition 3D reconstruction for coral-rich areas, which requires complex terrain mapping capabilities. This platform's developments have focused on the system's AUV capabilities.

What percentage of labor and budget have been used through the 1st half of the year?
Labor: 58% and expenses 55%.

Will you complete the current year's scheduled work?
Yes.

Significant changes from the previous project proposal
None

Over the past two years, what peer-reviewed publications, education, and/or outreach activities have resulted directly from this project? Please be brief.

Peer-Reviewed Publications (2024):

- B. Muñoz and G. Troni, "**Learning the Ego-Motion of an Underwater Imaging Sonar: A Comparative Experimental Evaluation of Novel CNN and RCNN Approaches**", in IEEE Robotics and Automation Letters, vol. 9, no. 3, pp. 2072-2079, March 2024.
- S. Rodríguez-Martínez and G. Troni. "**MAGYC: A Factor Graph Based Method using Angular Rate Measurements for Full Three-Axis Magnetometer and Gyroscope Bias Estimation**", in International Conference on Intelligent Robots and Systems 2024, Abu Dhabi.
- A. Correa, S. Rodríguez-Martínez and G. Troni. "**Deep Reinforcement Learning Trajectory Control of Nonholonomic Autonomous Surface Vehicles in Challenging Wave Conditions: Theory and Preliminary Evaluation**", in IEEE AUV OES Symposium 2024, Boston, USA.
- G. Boré, V. Sufán, S. Rodríguez-Martínez and G. Troni. "**Toward 6-DOF Autonomous Underwater Vehicle Position Control based on Deep Reinforcement Learning: Preliminary Results**", in IEEE AUV OES Symposium 2024, Boston, USA.

Posters and workshops (2024)

- G. Troni, S. Rodríguez-Martínez, B. Muñoz, E. J. Martin, K. Barnard, M. Risi and P. Roberts. "**MOLA AUV: Toward Scalable Ocean Science with Precision Control and Localization of Agile Autonomous Underwater Vehicles and Deep Learning Enhanced Perception**", in Oceans Science Meeting 2024, New Orleans, USA.
- S. Rodríguez-Martínez, G. Troni, K. Barnard, E. J. Martin, T. Laurinen, J. Peralta, A. Sherman, F. Flores and P. Roberts. "**Scalable Low-Cost Visual Inertial SLAM for Widespread Underwater Mapping and Navigation with Inspection-Class ROVs**", in Oceans Science Meeting 2024, New Orleans, USA.
- P. Roberts, G. Troni, F. Eterovich, S. Rodríguez-Martínez, E. J. Martin and S. Y. Litvin. "**Open HSI Cam: Scalable Subsea Hyperspectral Imaging Using Open Source Hardware and Software**", in Oceans Science Meeting 2024, New Orleans, USA.
- E. J. Martin, G. Troni, G. Stern, M. Anderson, J. Figurski, and S. Rodríguez-Martínez. "**Sea Surface Event Detection and Localization with Ships of Opportunity using Multimodal Perception and Navigation Sensors**", in Oceans Science Meeting 2024, New Orleans, USA.
- D. W. Caress, G. Troni, S. Rodríguez-Martínez, K. Barnard, E. J. Martin, K. L. Headley, J. B. Paduan, M. Risi and C. Kecy. "**Addressing the Challenges of 1-cm Resolution Seafloor Mapping: A SLAM-based Navigation and Alignment Method**", in Oceans Science Meeting 2024, New Orleans, USA.

<u>Outreach activities (2024):</u>

- Schmidt Ocean Institute's YouTube video, "Seeing the Deep | Unexplored Seamounts of the Salas and Gómez Ridge," features the compact mapping system and HSI imaging package, both explained by Giancarlo Troni.
- CNN's Tech for Good visited on June 26 to collect footage in the test tank with MOLA and the MiniROV and interviewed Giancarlo Troni for our novel efforts with AUVs for ocean exploration.
- Giancarlo Troni presented findings and underwater robotics developments during the SOI expedition aboard the R/V Falkor(too) at PUC Chile on March 20, 2024.

All Projects: Specific Plans for 2025

Research Activities

For this year, the main focus is on the following research areas:

<u>**Activity 1**: Scalable Navigation and Mapping - Semantic Field SLAM with FLS and MBES</u>

We focus on developing our multi-sensor SLAM framework to integrate still images, forward-looking sonar (FLS), multibeam echosounder (MBES), and navigation data for a more robust solution. Since both FLS and MBES do not require good visual conditions, this will enable the system to operate in environments with low visibility. Even in good visibility conditions, these sensors will provide additional information due to their structure and field of view.

Furthermore, we will work on extending the system's capabilities to include semantic benthic mapping, which allows for a better representation of the environment by adding identifying labels to spatial maps. Semantic maps contain high-level features that enhance our understanding of the environment and enable novel representations for autonomous robotics platforms in scientific research.

This research will benefit other efforts in the short term, such as the Seafloor Mapping group (Caress) and the Seafloor Processes group (Micallef), and it will enable forward-looking mapping during the 2025 Arctic Expedition (R/V Araon, KOPRI, Fall 2025).

We plan to continue deploying and developing novel navigation and mapping algorithms based on multibeam imaging sonars and forward-looking sonars (FLS) using deep learning AI techniques. Additionally, we will continue collecting data with multiple platforms, such as ROV Ventana, MiniROV, and MOLA.

<u>**Activity 2**: Scalable Control - MOLA DRL Deep Deployment</u>

As part of the extension of our 6-DOF control algorithms, we plan to develop a flyaway control mode to enable us to operate in rough environments in the field. Cameras and acoustic sensors will allow the vehicle to be deployed from a cage from another ROV or static mounting structure. This mode can enable the use of the research platform in other applications, such as fieldwork deployments in the Arctic and other expeditions.

We will implement our novel deep reinforcement learning (DRL) techniques to maneuver our 6 DOF platform, improving his performance and energy efficiency. In addition, we have to adapt the code to be integrated into other platforms, such as ROV Ventana and the Mini ROV. The LRAUV team is working this year to adapt the LRAUV so we can implement this controller into the hovering platform for mid-water tracking and methane bubble plum inspection.

Activity 3: Scalable Perception - AI-based Laser Scanner with Stereo Cameras and HSI

- *Stereo cameras:* We will continue to support the evaluation of compact standalone cameras that can integrate into our mapping system, as some vendors present many new offerings. Our efforts using the power over ethernet (POE) cameras from DSPL on loan have shown promising results, but the optics may be better in newer models. Regardless, the loan will end this year, and we request resources to buy dedicated cameras from DSPL or evaluate newer, less expensive models. In parallel, we have leveraged outside labor to build a self-contained single-housing stereo camera that will be tested in 2024. In 2025, we will compare data from these early models and make a build/buy decision about augmenting the single housing design with dome ports for improved optics or purchasing an off-the-shelf set of cameras.
- *Laser Scanner:* We will continue developing an AI-based laser sheet scanner for seafloor mapping in collaboration with Javiera Fuentes, our visiting lab member.
- *HSI:* We will continue developing our HSI imaging package, focusing on improvements in the hardware for benthic mapping, such as optics and lighting, which were the systems' weak points in previous developments. With this development, we expect a base package for more comprehensive data collection and a better scope of the effort for new sensor development in the future.

Engineering/technology development

Activity 4: Research Platform Improvements

We plan to improve the 6 DOF research platform, Mola AUV, to perform regular fieldwork in Monterey Bay and other research locations. We plan to continue acquiring spare components and sensors for a more robust platform operation for fieldwork, especially at higher depths. We intend to design and fabricate custom electronics to replace some lighting and thruster controls that will improve the efficiency and control of the platform. Our existing sonar has suffered some damage because the vendor removed the anode, and purchasing a replacement unit would be prudent before failure occurs.

In addition, we plan to develop and manufacture a station for deployment and charging in the test tank, which will later be used in field operations. This station will use fiducial markers to navigate short-range targets, ensuring precise docking accurately.

Activity 5: Remotely Operated Surface Vessel Mapping in Shallow Water

We intend to further develop our remotely operated surface vessel (ROSV) to facilitate the mapping of shallow water areas that cannot be covered by large ships. This platform will be a useful tool for surveying and inspecting specific areas. We also plan to collaborate with Micaelf (902312) to map the Monterey Canyon head. The surface vehicle will be able to create a low-resolution map, which will then be enhanced by a high-resolution map of the area using MOLA in the areas of interest. This approach will improve our efficiency by helping us identify areas with interesting features and focus our efforts accordingly. We are planning to trial this platform in Monterey Bay, deploying it from the Paragon and taking advantage of the current development of an AI-based controller, which will enable the vehicle to navigate more precisely under challenging conditions.

Field programs (detail ship requirements/deployments/diver requirements)

We plan a field program during the third year to transfer our work to science field deployment efforts. Still, we expect to continue using the test tank for development and conduct tests on the R/V Paragon.

Cruise Plan

- R/V Paragon MOLA Deep Deployment - All year
  - 5 sea days with the Paragon for engineering testing and data collection.
- R/V Paragon ROSV Deployment - All year
  - 5 sea days with the Paragon for engineering testing and data collection.

In addition, we intend to participate in the fieldwork proposed for project 902504 (Scalable Semantic Mapping and Monitoring), focusing on implementing our advancements from this project in scientific applications.

Specific deliverables

2025 Project Activities	Deliverables
1. Scalable Navigation and Mapping - Semantic Field SLAM with FLS and MBES	● Development of a SLAM framework that integrates still images, forward-looking sonar, multibeam echosounder, and navigation data. ● A peer-reviewed publication presenting the developed SLAM framework, experimental results, and performance evaluations. ● Creation and release of an open dataset for the research community, including sensor data used in developing and testing the SLAM framework.
2. Scalable Control - MOLA DRL Deep Deployment	● Development and implementation of a DRL control system enabling docking and deployment in the test tank and the field. ● A peer-reviewed publication presenting the DRL controller and its capabilities, including comparisons to the previously developed agile 6DOF control and state-of-the-art methods.
3. Scalable Perception - AI-based Laser Scanner with Stereo Cameras and HSI	● Development of a portable stereo camera package designed to be mounted on different platforms. ● Construction of an in-house Hyperspectral Imaging (HSI) camera based on the current open-source version. ● Improvements in optics and lighting specifically tailored for benthic mapping. ● Implementation of laser scanner 3D reconstruction capabilities.
4. Research Platform Improvements	● Design and manufacture a docking station for deployment in both the test tank and the field.
5. Remotely Operated Surface Vessel Mapping in Shallow Water	● Enable a small remotely operated surface vehicle for mapping in shallow areas. ● Map of shallow areas in the Monterey Bay.

Activities and required personnel (see personnel classification list for staff classifications)

See the above table for milestones with specific deliverables called out for each one.

2025 Project Start Date: MM/DD/2025	**Activity 1**	**Activity 2**	**Activity 3**	**Activity 4**	**Activity 5**	**Total Resources[5] (in hours)** for each resource category for all milestones listed here
Milestone Date	**12/2025**	**09/2025**	**09/2025**	**08/2025**	**03/2025**	
Milestone Description	**Scalable Navigation and Mapping**	**Scalable Control**	**Scalable Perception**	**Research Platform Improvements**	**ROSV Mapping in Shallow Waters**	
Electrical Engineer	**EM - 40**	**GS - 100** **JV - 200**	**PR - 260**	**EM - 160** **GS - 200**	**JV - 120**	**EM - 200** **GS - 300** **JV - 320** **PR - 260**
Software Eng-Embedded	**AH - 500** **KH - 220**	**MA - 400**		**AH - 80**		**AH - 580** **KH - 220** **MA - 400**
Software Eng-Info Eng	**KB - 300**		**KB - 60**			**KB - 360**
Mechanical Engineer		**FC - 150**				**FC - 150**
Mechanical Eng-Division						
Mechanical Eng-Mfg						
Associate Engineer						
Electrical Tech		**TBD - 20**		**TBD - 100**		**TBD - 120**
Software Tech						
Mechanical Tech		**TBD - 80**		**YH - 80** **TBD - 40**		**YH - 80** **TBD - 120**
Machinist			**TBD - 40**	**TBD - 40**		**TBD - 80**
Divers						
Video Lab						
DMO		**JF - 40**			**JF - 40**	**JF - 80**

[5] This number should be the same number you entered on the web budget resource requests for this particular resource.

Budget justification

Item	Expense
BlueBoat ROSV - BlueBoat Development	$2,500
Control 6DOF + DRL - Contract Labor - Bastian Munoz	$52,000
Graduate Fellows - Support	$2,000
HSI - Lighting Improvement	$10,000
HSI - Optics Improvement	$10,000
MOLA Deep Deployment - Top Hat Components - Batteries	$5,000
MOLA Deep Deployment - Top Hat Components - Slip Ring	$5,000
MOLA Deep Deployment - Top Hat Components - Tether	$5,000
MOLA Deep Deployment - Top Hat Components - Winch	$5,000
MOLA Improvements - Blueprint Subsea Oculus M750d	$30,000
MOLA Improvements - Embedded control	$10,000
MOLA Improvements - Sensors integration	$1,000
Publications - Conference Travel and Attendance	$8,000
Stereo Cameras - Contractor Labor - Dome adaptor design	$10,000
Stereo Cameras - Dome adaptor build	$5,000
Stereo Cameras - Self Contained Cameras	$10,000
TT Infrastructure - Docking Charging MFG	$5,000
Grand Total	**$175,500**

Project team

- Giancarlo Troni: PI
- Eric Martin: EE, PM
- Sebastián Rodríguez: Research Engineer, Lead Engineer
- Paul Roberts: EE, HSI development
- George Stern: EE, Research Platform Improvements and Docking.
- Johan Voigtlander: EE, MOLA Deep Deployment, and RSOV mapping.
- Michael Anderson: SEE, 6DOF control, and DRL.
- Kent Headley: SEE, FLS drivers, and support.
- Akshay Hinduja: SEE, SLAM, and docking.
- Yamir Hernandez: MT, Docking Station Design and Manufacturing.
- Francois Casenave: ME, Top Hat Deployment.
- Kevin Barnard: SEI, SLAM.
- Jared Figurski: DMO, MOLA, and ROSV testing deployment.

This proposal is closely coupled with the efforts of David Caress, Aaron Micallef, Charlie Paull, Kakani Katija, and Steve Rock.

External consultants/contractors

We plan to continue collaborating with Bastian Muñoz to support the development of new methods for the controller's basic infrastructure, simulation environment, and forward-looking sonar. Additionally, we will work with Todd Gregory to continue the design and improve a self-contained single-housing stereo camera.

Project lab and office space requirements

We expect a postdoc and two graduate students to visit the lab next year. We will also need to keep using office space to allocate visiting students.

Risk matrix (development and infrastructure projects only)

	Technical Risk	Organizational Risk	Tech Transfer Risk	Labor Estimate Risk
High				
Medium	X			
Low		X	X	X

Compliance and Planning Considerations

All responses must be recorded in the Google form linked below. A form must be submitted for every project.

Link to Google Compliance and Planning Considerations form ***-OR-***
https://forms.gle/mRYKKEztAPYaiTz7A