Project Number: 902204

Project Start: Jan. 1, 2022[1] **Project Duration (in years):** 2 of 3[1]

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

X	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:

Project Title: Scalable Marine Robotics Foundations

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 2023 toward these three highest institutional goals (percentage total should equal 100%).

Goal	**Developing/adapting innovative technologies**	**Utilizing developments to explore and understand ocean systems**	**Technology/knowledge transfer[4]**
Percentage	60%	20%	20%

[1] This date and number should remain the same for the duration of the project. If your project start date for 2023 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)

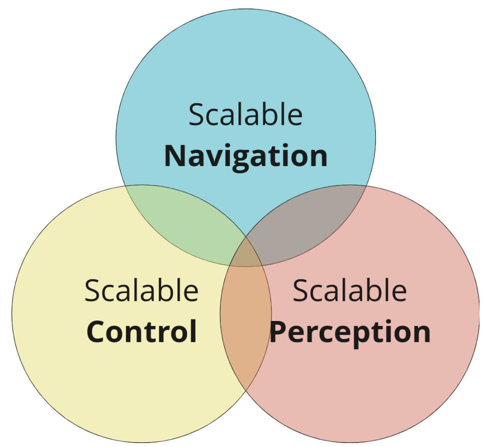
Briefly provide a high-level summary of the project (ideally no more than 1/2 page).

The main goal of the Control, Modelling, Perception for Autonomous Systems (CoMPAS) Laboratory is to develop and transfer technology for making **ocean exploration more accessible and widespread** and to help answer several questions that remain open about our planet.

This proposal seeks to build scalable marine robotics foundations — from creating the essential tools to enabling the main research lines for future developments. The primary focus is to **allow exploration without previous knowledge of the environment** (such as seafloor maps) in **complex terrain** with **multiple platforms**. Addressing the fundamental technology challenges will allow persistent presence, ocean visualization, adaptive targeted sampling, environmental change detection, and repeated ocean monitoring from benthic to midwater.

The major driving forces for this proposal over the next three years in **marine robotics** include:

- ***Scalable Navigation***: The goal is to allow precision navigation for scalable underwater platforms (low cost, power, and size). The simultaneous localization and mapping (SLAM) approach allows precise navigation in known and unknown environments based on visual and acoustic information.
- ***Scalable Control***: The goal is to enable advanced control methods in complex environments with 6 DOF scalable platforms.
- ***Scalable Perception***: Enabling scalable perception sensors for scalable platforms. Current mapping sensors, such as sonars, are large, expensive, and power-hungry. We will develop smaller and more intelligent sensors for exploring the ocean based on visual sensors.



Those are crucial elements for the **autonomy** of marine robotics platforms to enable **multi-vehicle** operations in **complex environments**.

2) PROPOSAL (all projects)

Background

Provide context for the project, being sure to address these questions:

What fundamental problem does this project address, and why is it important?

Ocean exploration has been widely developed thanks to underwater robotics, whose platforms are currently being used on several applications, such as accurately mapping the seafloor in high-resolution and continuously tracking animals in midwater. However, these platforms are not scalable, many are still too expensive to build and operate, and access to scientists, and therefore ocean exploration and discovery, is limited. Lowering barriers is needed, especially for problems requiring high-resolution information on large spatial or temporal scales.

MBARI is a pioneer in the high-resolution mapping of the seafloor, but currently, it is limited to operating in areas where maps of the seafloor already exist. We are also limited to fewer complex terrains and, depending on the resolution, limited spatial and temporal scales for mapping in a predefined plan, mainly with a single-vehicle mission approach.

To implement (1) multiple vehicles, high-resolution seafloor mapping in unexplored complex terrain, (2) repeated mapping to detect minor changes, or (3) tracking and target sampling with multiple midwater vehicles, among other problems, several common technological challenges need to be addressed, such as:

- Precision **underwater localization** based on low cost, power, and size 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.
- On-board and on-shore **AI data analytics tools** for advanced ocean exploration.
- Advance **open-source software framework** for scalable system development.
- Platforms with a higher level of **autonomy** are critical for multi-vehicle operations.

What makes this work relevant to MBARI and the Packard Foundation?

The current proposal directly focuses on supporting the MBARI Strategic Roadmap 2022—2032. The central core of this proposal helps to address the first three challenges, especially those related to technology development, seafloor imaging, and data analytics (on board and onshore). Also, complement the challenges associated with ocean science and engagement.

Our research and development efforts align with MBARI goals related to Ocean Exploration, Ocean Imaging, Enabling targeted sampling, and Advancing a persistent presence. In addition, all are relevant to the Packard Foundation to improve our understanding of the ocean.

Is this effort linked to other internal or externally funded projects or collaborative efforts?

Internal projects:

- Seafloor Mapping (901101).
  - Data processing tools and calibration work.
  - Support field work and system development.
- Precision Control Technologies for ROVs and AUVs (600034).
  - Control framework development.
- Deep-Sea Bioinspiration (901809).
  - Camera systems architecture.
- LRAUV Technology Development and Fleet Operations (902101).
  - Enable hovering modalities.
- Multi-LRAUV Simulation Environment (902102).
  - Simulation environments.
- Niobicon-Based AUV Docking Development (902106).
  - AUV docking.
- Deep-Sea Coral-Sponge Community Observatory (901904).
  - Hyperspectral imaging development.

External

- Continue collaboration with research organizations and related projects in Chile, such as the Robot-X marine challenge and graduate students.
- Foster collaboration with marine scientists and robotics groups around the world.

Where does this work fit into the ~5–10 year plan for your group, at MBARI, and in the field?

This work is the foundation for developing the concept of scalable robotics at MBARI and starting working and supporting multiple research groups inside and outside MBARI. This project is the foundation to enable a new class of vehicles between ROV and AUV to explore complex terrain with various vehicles. With primary navigation, control and perception, we expect to expand with a group of vehicles to explore the ocean autonomously in the future.

Nature and Scope of the Proposed Project

Please provide a sense of the scale and scope of the proposed work. Is this a large de novo R&D effort, modest platform/sensor integration, targeted science investigation with minimal or no engineering needs, extension of current program, small-scale scoping exercise expected to lead to a larger effort, or other? If the project is intended to be multiple years, how will the anticipated level of effort likely change over time?

This work combines fundamental R&D goals of perception and estimation tasks with platform and sensor integration to create a stepping stone to address larger science challenges in the future.

Approaches to the problems

I. Foundations for Scalable Navigation

Enable Simultaneous Localization And Mapping (SLAM) approach for known and unknown environments based on visual and acoustic information.

SLAM is a common approach to terrain and aerial vehicles where the maps are constructed in real-time as the vehicle moves in the environment. It is a natural extension to terrain relative navigation methods where the maps are known in advance. This technique can also be used for unknown environments to detect changes or to update the map as the vehicle moves.

We plan to create software modules for the graph-based SLAM algorithm based on a modular design. In this architecture, the problem is divided into two parts: (1) front-end to register the sensor information and convert it to position constraints, and (2) back-end an optimization problem (graph-based) to minimize the global position of the vehicle location consistent with the restrictions from the sensors. We aim to apply this framework with different sensor modalities, such as cameras, sonars, and multibeam/lidar bathymetry data. In addition, we are interested in including self-calibration methods and machine learning techniques to make the process more reliable and accurate and improve perception and navigation performance.

An agile, incremental approach is being adopted in which we develop these algorithms against the ROV Low Altitude Survey System (901101), carrying data sources fit for ground-truthing in the marine environment, most notably the Kearfott INS. Once confidence is gained in the fidelity of these approaches, we can begin to apply them to more resource-constrained platforms that would benefit from advances, such as the MiniROV, LRAUV, and others.

II. Foundations for Scalable Control

Enable advanced control in complex environments

Currently, most underwater platforms can move at most 4 degrees of freedom (forward, lateral, vertical, and heading), limiting the range of movement these vehicles can perform. For example, for high-resolution seafloor mapping, it is required to articulate the sensor platform to operate in rugged terrain. The additional mechanical requirement makes the system more complex, bulkier, and more expensive. Another example is that following an animal in the midwater is challenging when we cannot look in all directions making the system less reliable. We must include the ability to perform movements in all degrees of freedom (6 DOF). To achieve 6 DOF control, the platform must possess a reduced metacentric height and include a few extra thrusters (sometimes already available). This way, the platform can be more maneuverable, less mechanically complicated, and thus potentially lighter, cheaper, and more reliable for those complex environments. This platform is an ideal candidate for a scalable approach for exploring complex terrain with multiple platforms.

For a 6 DOF platform, control methods to stabilize the platform are required, which employ different approaches, such as model-based control or reinforcement learning approaches. Based on a reliable control, we can start enabling several behaviors such as station keeping, path following, tracking, and docking.

III. Foundations for Scalable Perception

Enable multi-vehicle solutions with homogeneous/heterogeneous sensors and platforms

We are currently able to explore the oceans with great success using underwater vehicles. However, many are still too expensive to build and operate, especially for problems requiring high-resolution information on large spatial or temporal scales. Approaches based on multiple vehicles are able to increase the coverage, reduce the time, and even the global energy or cost requirements for exploration. However, we propose to tackle some bottlenecks to enable the development and the quick deployment of multiple platforms requiring less human intervention and promoting a persistent presence in the ocean.

In the future, we aim to utilize an Autonomous Surface Vehicle (ASV) to deploy and support multiple vehicles. To that end, we are working on the technology required to make it a reality, such as localization, control, route planning, and moving object detection. These algorithms can be implemented in the same framework used for underwater vehicle navigation.

<u>Does this activity relate to one or more 2023 proposals your team is submitting?</u>
If so, provide a list of relevant projects by project/DQ # and provide a brief description of how they are related. Since resources are limited and cuts during Phase 1 are likely, please indicate where this project fits in the hierarchy of your priorities. Does this proposal take precedent over other ongoing or planned activities?

This project is our team's main and only proposal this year, but we anticipate branching some of the efforts into separate internal and external projects.

<u>Anticipated Shared Resource Needs</u>
What staffing is required to advance the work in 2023 (e.g., is this a multi-faceted engineering development or a targeted science investigation that does not require significant use of shared personnel)? Is in-house or contract manufacturing needed? What level of ship/ROV/AUV (DMO) support is likely? If this is intended to be a multi-year effort, please provide a rough indication of anticipated shared resource needs over the duration of the project (e.g., will stay flat, will significantly increase in Year X, will significantly decrease by Year Y).

This project will require a balanced combination of resources, from in-house development to contracts, and finally some COTS solutions to achieve the research and development goals. This project will require approximately 3000 hours of Engineering time, spanning all disciplines. Limited fabrication is planned in the initial year, but it might be needed later. In this first stage, a limited amount of ship/ROV/AUV support will be required, but in the coming year will be the main focus for many of the development of each one of the platforms.

Anticipated Expenses

What rough order of magnitude direct expense budget is anticipated annually over the course of the project? Is procurement of specialized capital equipment or outside contractors required? Will there be annual travel?

We anticipate a direct expense budget of this proposal ~$150-200k for testing sensors, materials, and travel per year. 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 to fully establish the laboratory. It would require new separate projects to develop large initiatives in collaboration with other groups.

Intellectual Property (IP) Considerations

Do you anticipate a need for a cooperative research and development agreement or licensing arrangement with an external entity? Will the work potentially result in a patentable product or service? Will novel IP and/or custom-made equipment be created, and how might it be disseminated (e.g., license agreement and/or collaborations)?

For additional guidance please review MBARI's intellectual property internal web page: [https://mww.mbari.org/itd/ip/.](https://mww.mbari.org/itd/ip/)

This work primarily focuses on open source libraries (such as SLAM navigation, camera calibration, and underwater sensor alignment libraries). We expect this dissemination scheme to have a more significant impact in multiple communities.

Data

What data will be generated? How will they be managed/stored? Are any special data visualization needs anticipated?

We anticipate generating image data from all the engineering dives 3-6 TB. Also, the surface navigation data (primarily images, lidar, and radar) with the Paragon AUV perception system is another 5-8 TB per year.

Anticipated Impact

Who are the consumers of the instruments, methods, technology, and data that will be generated within and beyond MBARI? Will the project create tangible connections with other organizations (e.g., academic, NGO, MBA, MBNMS, state or federal agency)?

We anticipate forging internal and external collaboration that will enable us to improve navigation, control, and perception solutions for different consumers. The scalable robotics capabilities can impact scientific research in continental margins, submarine volcanism, and benthic ecology, among others. We expect to collaborate very closely with the Seafloor Mapping Lab and the BioInspiration Lab on seafloor and midwater navigation. This effort can be extended with our scientific collaborators in Chile and the EU.

Anticipated Outreach Needs

Thinking about the audiences/consumers you highlighted in the question above, do you anticipate needing to create outreach assets to help increase your impact? If so, please specify whether you anticipate needing to work with ITD and also specify what type of asset (story, graphic, animation, video, etc.) you might need.

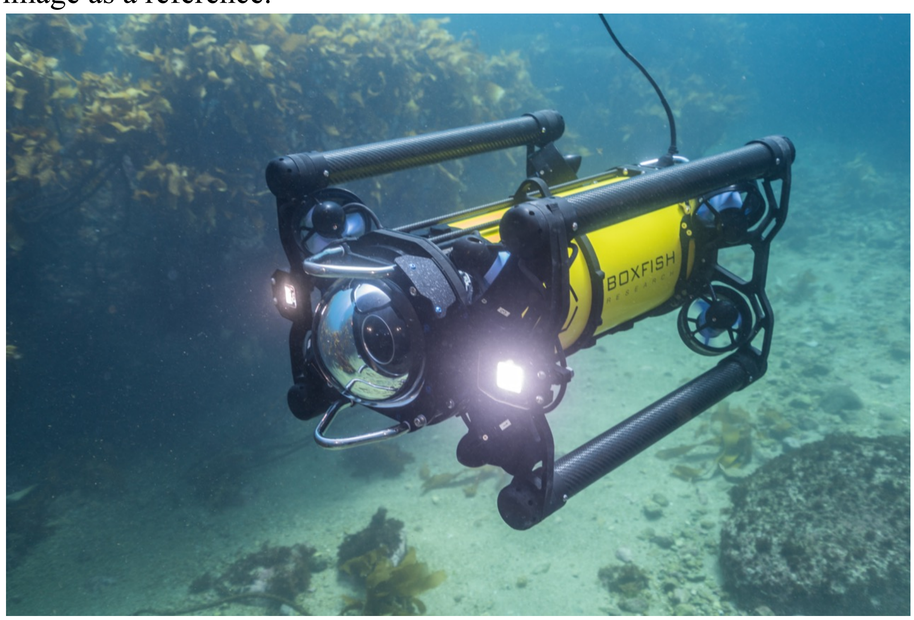
We are interested in starting outreach support with multiple communities, especially STEM communities. We want to explore the option of collaborating closely with the MBA, especially with aquaculture management and highly the use of robotics in underwater exploration. We expect to work on creating some illustrations to explain the scalable robotics concept.

Continuing Projects Only: Status Report

Briefly provide an update of the current project relative to what was proposed for 2022 by responding to the prompts below. If the project includes multiple subproject projects, please list each of these under a subheading as you deem appropriate.

Current status of project and results to date

During the first few months of the project, the focus has been to build the physical and software infrastructure to support our research. A big effort so far has been in assembling the team and laboratory space.

2022 Project Milestones	**Milestone Description**
1. Research test tank AUV/ROV development	The platform is expected to arrive late summer due to several delays due to supply change complications. Some of the work related to camera drivers has started. The second half of this year will focus on integrating this new platform in the laboratory, shown in the following image as a reference.  As proposed last year, we have been working on a stereo vision system and structural lights to provide the basic set of sensors to mimic different scenarios for research and development. These works have been successful, and the plan is next year to continue working on improving the design and packaging for fieldwork.
2. Simulator for navigation and control development	Based on an operational simulation available at the CoMPAS lab, we have been continually working to enable the initial operational

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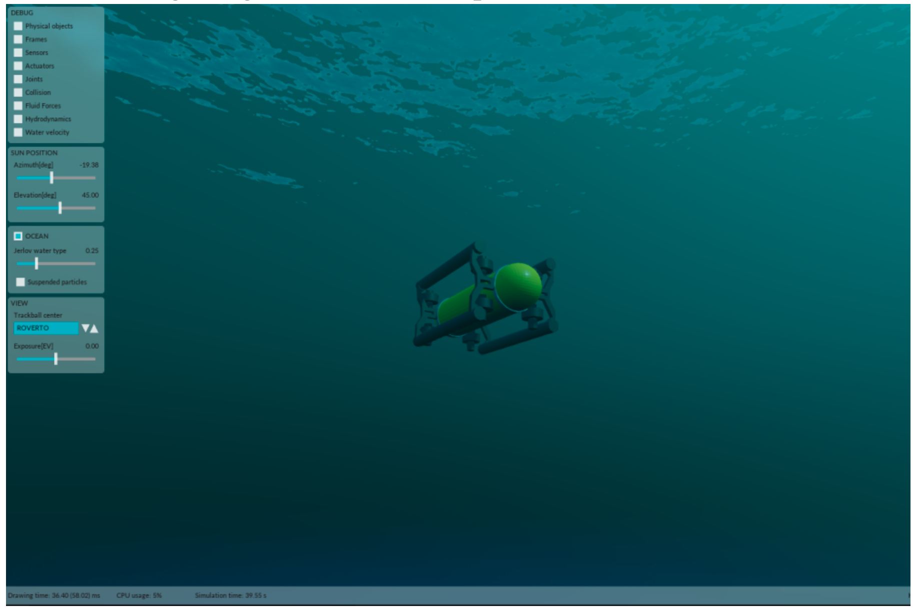
functionalities to generate visual datasets for the task 4 development. The following image shows an example of the interface.



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<td>3. Control 6 DOF platform research and development</td>
<td>The core of this work will start after the arrival of the 6 DOF platform (second half of 2022). This year's focus is on implementing an essential controller, and as part of the work in 2023, extend and make it more robust, with new challenges such as docking.</td>
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<td>4. SLAM framework and visual-inertial navigation research and development</td>
<td>So far, the lab's main effort has been developing the SLAM framework for visual navigation. The team uses field data from the ROV Low Altitude Survey System (LASS) (project 901101) to validate the designed software levering open-source libraries. This effort is in collaboration with GIM Robotics as a contractor. So far, we are about to finish the first Work Package (WP) of four planned. The work is already showing indirect benefits as an accurate validation of the internal data and protocols and precise calibration and validation of all the data products, which are critical for long-term success. Lab interns have been essential in the success of this task. The following image shows an example of visual navigation only from data from the 2021 Axial Seamount hydrothermal vent fields expedition.</td>
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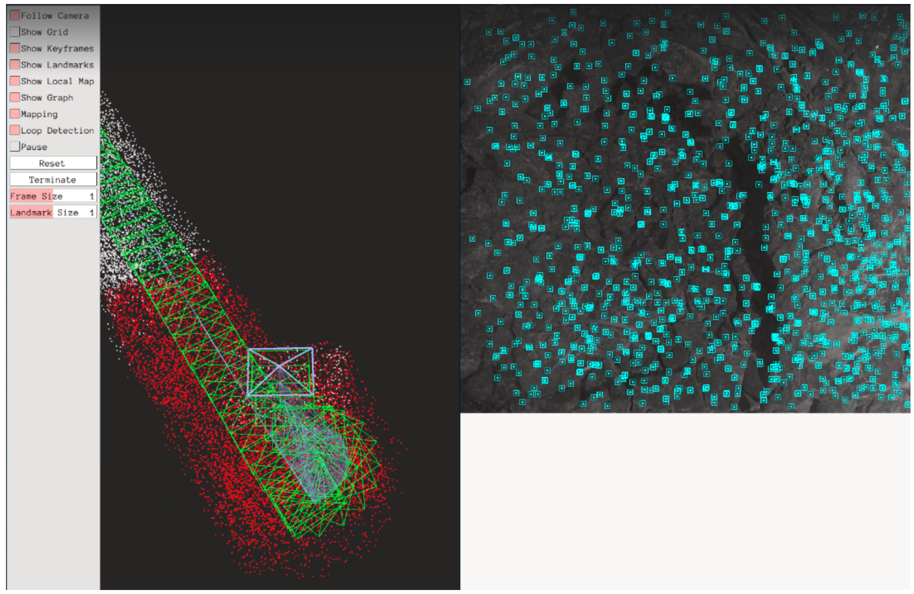
	
5. Proof of concept ASV Autonomy	This work started with the main system design, including stakeholders' options. We are currently in the acquisition stage of primary sensors and equipment to have it built by the end of the year. The data acquisition will be performed as part of next year's work.
6. Develop the required interfaces for current vehicles at MBARI	Due to limited time for individuals related to those platforms (MiniROV, LRAUV, and Dorado AUV), this effort will probably not advance much this year. As soon as replacement personnel involved with those platforms are available, this effort will be reassessed.
7. Attending conferences and visiting potential collaborators	Due to a late start at MBARI and currently limited restrictions due to COVID, this task hasn't been accomplished. Still, the plan is to be able to participate in at least a conference in the second half and visit some collaborators overseas.

What percentage of labor and budget have been used through the 1st half of year?
Labor (25%)

- Giancarlo Troni: 720/1856 hrs (39%)
- Eric Martin: 95/320 hrs (30%)
- Mike Risi: 139/600 hrs (23 %)
- Kevin Barnard: 15/222 (7%)
- Paul Roberts: 5/60 hrs (8 %)
- Mechanical Tech TBD 2/60 (3%)
- Kent Headley: 2/240 hrs (1 %)
- Andrew Hamilton: 2/200 hrs (1 %)
- Francois Cazenave: 0/120 hrs (0 %)
- Electrical Tech TBD 0/60 (0%)
- Brett Hobson 0/20 (0%)
- Erik Trauschke 0/120 (0%)
- **Ben Erwin: 0/30 hrs (0%)**
- **Ben Raanan: 2/100 hrs (2 %)**

We are planning to use personnel time available. Unfortunately, some individuals are not going to be available at MBARI.

Budget
30%.

Will you complete the current year's scheduled work?

Yes, we are planning to use all the budget this year.

Significant changes from previous project proposal

The core of the proposal remains the same. Due to logistics issues related to the global supply chain crisis and covid, it has been challenging to assemble the infrastructure and the team. We anticipate accomplishing this by the year-end acquisition and main tasks. Some tasks such as integration with the MiniROV and LRAUV might be postponed for next year until the personnel is available.

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

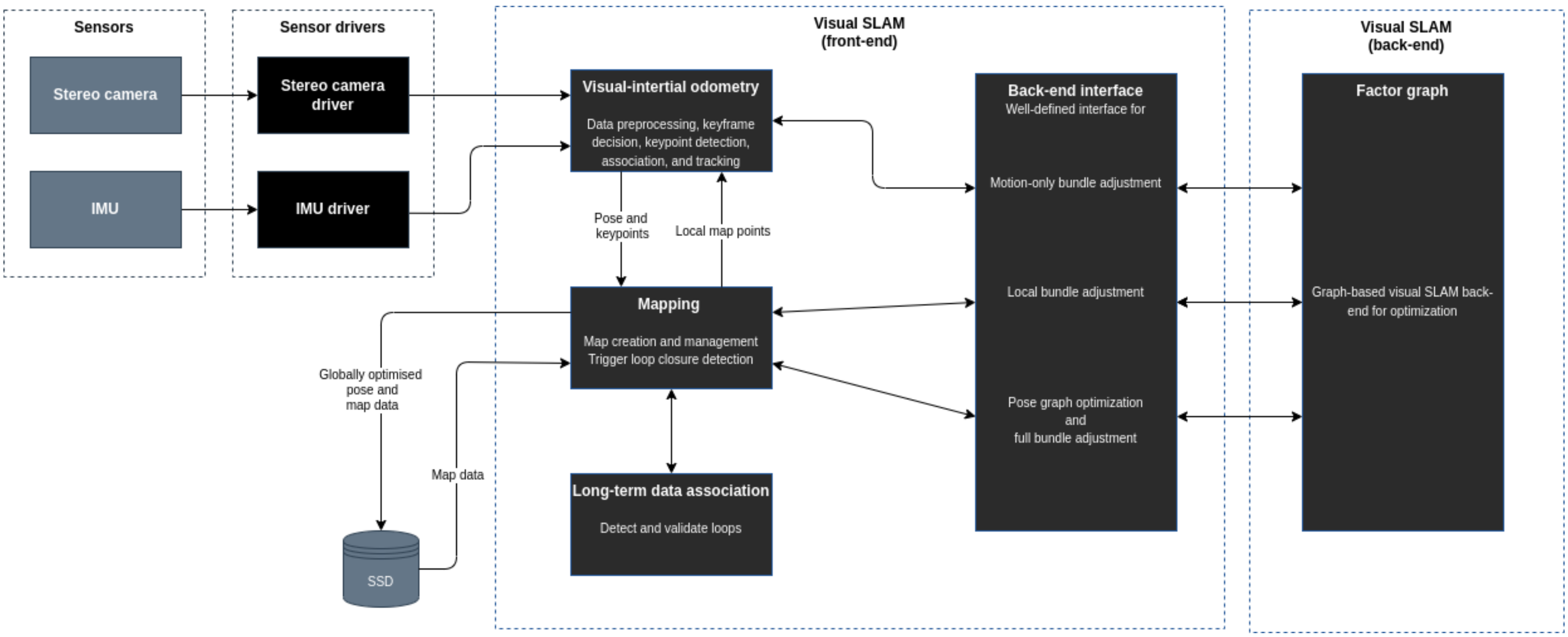
N/A

All Projects: Specific Plans for 2023

Research Activities

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

- **Task 1**: Scalable Navigation
  - **Task 1.1**: *Field SLAM* - Validate the visual SLAM framework on the field.
    The core effort this year has been achieving the visual SLAM navigation framework for ocean exploration without previous maps, as shown in the following diagram (from our work with GIM Robotics):



    The focus is to start exercising this in the field. We plan to deploy this in two architectures: The LASS system on ROV Ventana and the MiniROV. A key component to deploying it on these platforms is task 3.1. In addition, we will continue working based on the research platform (Mola AUV) for shallow water deployments. Several software tasks are required, such as transfer/integration of the GIM framework, usage documentation, field deployment/trial data collection, post-deployment data analysis, and documentation.

  - **Task 1.2**: Extend our SLAM framework to sonar sensors.
    A natural extension of the developed SLAM framework is integrating other sensor modalities. We are interested in point cloud sensors (such as multibeam sonar and Lidars) and acoustics imaging sensors (Forward-Looking Sonars). Based on sensor fusion, the navigation solution is more robust in different operation conditions. The final part of this work will be extending it for multi-vehicle operation in 2024.

- **Task 2**: Scalable Control
  - **Task 2.1**: *6-DOF Docking* - Enable docking on the AUV/ROV research platform.
    Working with the AUV/ROV research platform, we would like to demonstrate autonomous docking in the test tank as a first step towards deploying in the field. Cameras and acoustic sensors will enable the vehicle to dock in a charging station based on the Wisub integrated connector. Following that, an extension will be to start docking on a Niobicon-based cable, allowing to charge/transfer data and recover the vehicle with the same structure. We are interested in exploring novel model-based control and reinforcement learning techniques for docking underwater platforms.

  - **Task 2.2**: Control for a hovering LRAUV.
    As part of an effort with the LRAUV team to eventually develop a hovering LRAUV. This kind of platform will enable navigating closer to the seafloor. The scope for this year is to have a LRAUV vehicle with a set of at least 4 hydromea (or similar) thrusters to enable hovering in the test-tank (this development effort is allocated in the 902101 project). This combined with precision navigation can enable mapping of the seafloor.

- **Task 3**: Scalable Perception
  - **Task 3.1**: *Stereo-SLAM-Box* - Package stereo-INS-depth-SBC system.
    Validate the proposed visual-inertial navigation methods in the field. We have a prototype stereo camera system with inertial and depth sensors connected to a computer module that we are planning to use as a base for testing our Visual SLAM framework. This system needs to be packaged and prepared to be tested in the field. Part of this development leverages the next year work by the Bioinspiration Lab with their lens-camera-compute modules effort.

  - **Task 3.2**: *3D AI Cam* - Package stereo-structural light system.
    Based on AI techniques, we are working to improve the perception from stereo camera sensors to reconstruct the seafloor better using structural light. In the beginning, a simple eye-safe laser will be used, but we expect to expand it to other light patterns in the future. This work was started this year, and we will move into packaging and testing it in the field next year.

  - **Task 3.3**: Deep-*Open-HSI* - Lab development of a low-cost pushbroom HSI camera.
    A novel open, low-cost, underwater, pushbroom camera that can enable hyperspectral measurements. This approach allows more rich data capture but requires improved image registration techniques to deal with information from a 1D sensor array. The goal is to start with an Open Design available (OpenHSI) and work to validate and package on the field. This effort aligns with the work done by Deep-Sea Coral-Sponge Community Observatory (901904).

- **Task 3.4**: *Paragon ASV* - Field validation of the ASV perception system.
  Many bottlenecks are required to be addressed to enable multi-underwater vehicle operation. One is to deploy multiple vehicles in the field autonomously and to have a support platform for coordination and data transfer. We are planning to start developing the autonomy infrastructure to work in further years with other internal and external groups. During this first tear, we are validating the perception system (cameras, lidar, and navigation) installed on the R/V Paragon. Related to this activity, we are mentoring a student team in Chile that is part of Robot-X, which focuses on developing autonomy for surface vehicles.

Engineering/technology development

- **Task 4**: Research Platforms
  - **Task 4.1**: 6 DOF research field platform for multi-vehicle
    We are planning to continue working on improving our research test-tank platform to enable novel functionalities. These improvements will include better interfaces, and documentation. In addition, extending the work done in the field is necessary to continue expanding our fleets of 6DOF vehicles and spare parts for them.

  - **Task 4.2**: Simulation Environment for navigation and control
    Our simulation environment must be deployed on the cloud to enable a scalable approach for a larger group of users (internal and external) and in multiple scenarios. We plan to continue working with OSFR to support this effort started by the Multi-LRAUV Simulation Environment project (902102).

- **Task 5**: MBARI Operational Platforms
  - **Task 5.1**: Develop the required interfaces for current vehicles at MBARI
    The field validation planned this coming year would require work on some interfaces (hardware and software) to be able to port our navigation and control methods into other vehicles. Much of this work was postponed from the previous year. We propose to start with the MiniROV, ROV Ventana, and LRAUV to integrate future navigation, control, and perception systems.

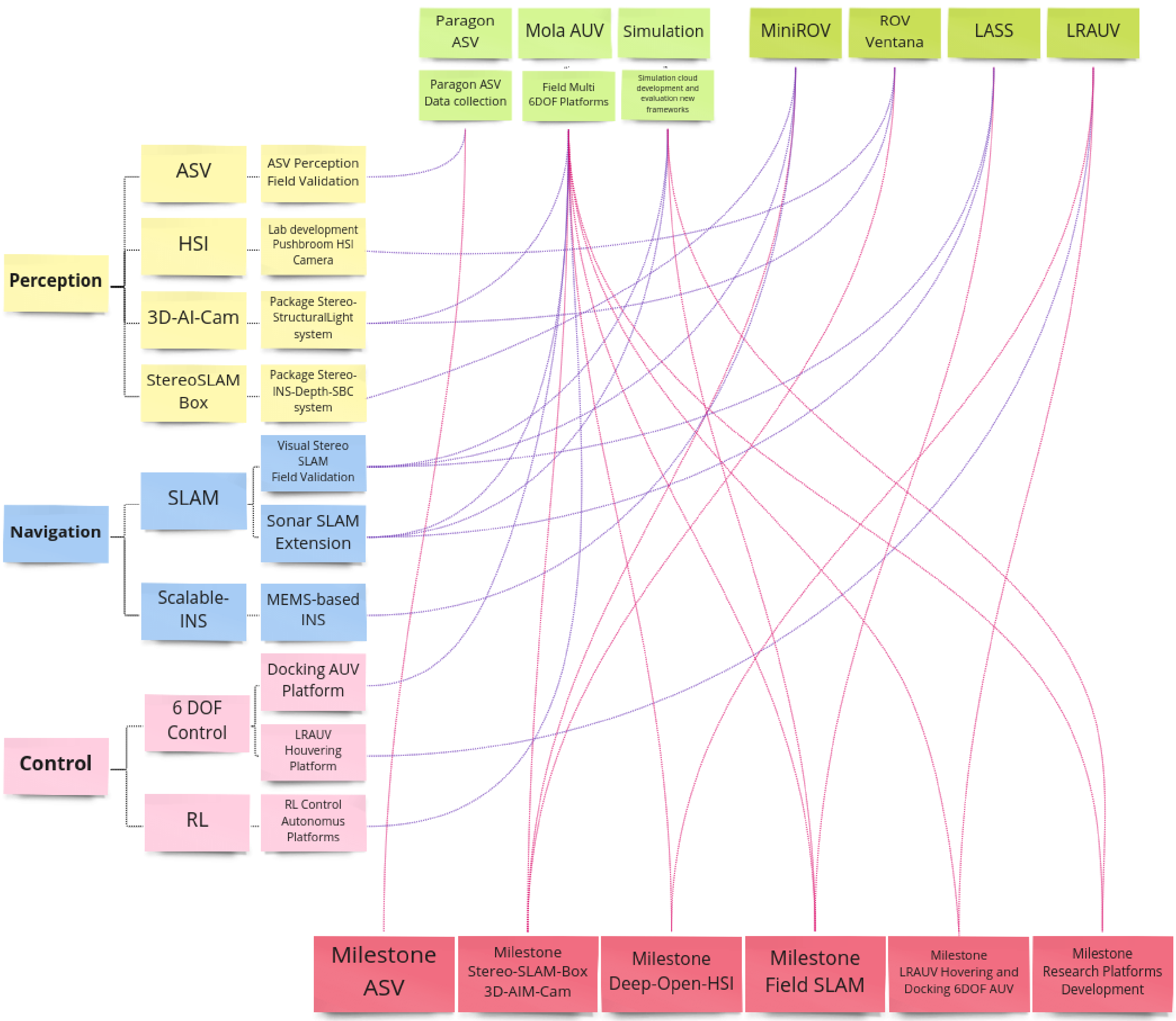
Field programs (detail ship requirements/deployments/diver requirements)
In addition to describing anticipated field programs, please be sure to include requirements for specific platforms and equipment (Dorado AUVs, LRAUVs, Wave Glider, mini ROV, etc.) for each proposed field program so that expectations are clear. Requests must also be entered in the budget entry system.

We are planning a field program during the second year to start transferring our work from the laboratory to the field and eventually to science. Still, we expect to continue using the test tank for development and conduct tests on the R/V Paragon.

Cruise Plan

- MiniROV: Test Tank - February
  - 5 days (Task 3.1) to test the stereo camera navigation
- MiniROV Rachel Carson/Fulmar - March
  - 1 days (Task 3.1) to test the stereo camera navigation box on the field.
  - This activity will be done in conjunction with the Bioinspiration Lab's cruise days to reduce logistics.
- R/V Rachel Carson LASS surveys at Sponge Ridge - late Spring
  - LASS surveys using the mapping toolsled on ROV Ventana
  - 1 day trip to Sponge Ridge to map the sponge and soft coral communities. Both should be done directly following the propose Dave Caress cruise.
  - (Task 1.1) to test the stereo camera navigation
  - (Task 3.2) to test UWOpenHSI camera system and 3D-AI-Cam
- Research Platform AUV/ROV - May/November
  - 5 sea days with the Paragon
- Paragon Perception ASV - All year
  - 10 sea days with the Paragon for engineering testing and data collection.
- Hovering LRAUV
  - 5 days in the test tank to validate the control implementation.
  - 2 days of the field (Paragon) to evaluate the performance.
- MiniROV Rachel Carson/Fulmar - June
  - 2 days to validate task 1.1 with a survey in the canyon area in complex terrain.
  - This activity will be done in conjunction with the Bioinspiration Lab's cruise days to reduce logistics.
- R/V Rachel Carson LASS surveys at Sponge Ridge - Fall
  - LASS surveys using the mapping toolsled on ROV Ventana
  - 1 day trip to Sponge Ridge to map the sponge and soft coral communities. Both should be done in parallel with Dave caress cruise
  - (Task 1.1) to test the stereo camera navigation
  - (Task 3.2) to test UWOpenHSI camera system and 3D-AI-Cam
- External
  - As part of the collaboration with Dave Caress, we expect to be part of the Falkor (Too) cruise in 2023 from San Juan, Puerto Rico.

Diagram connecting Tasks, Platforms and Milestones
(https://bit.ly/3uJheH8)



Specific deliverables

2023 Project Milestones	Milestone Description
1. Paragon ASV Perception	Field validation and data collection of the ASV perception system
2. Scalable stereo nav	Develop and package the scalable stereo-inertial-depth nav box and 3D-AI-CAM to be deployed on the field (ROV Ventana or MiniROV).
3. Open-UW-HSI	Lab development of an open HyperSpectral pushbroom camera.
4. Visual SLAM Field Validation	The goal is to validate the SLAM visual navigation framework developed in the field with the MiniROV. If possible, use the LASS for testing on ROV Ventana with the Dave Caress team.
5. Docking for the 6 DOF AUV platform. Control for the Hovering LRAUV	Control of a 6 DOF AUV for docking. Enable classical techniques in addition to exploring novel methods to improve the controller performance. Also test the controller for the case of a hovering LRAUV (project 902101).
6. Platform development	We will continue to improve our research AUV/ROV Platform. The main goal is to start extending to work on the field deeper and have multi-vehicle solutions related to our research goal in 2024. We will continue using our simulation environment to include other platforms in our simulation, such as the MiniROV and ROV Ventana.
7. Publication and conferences.	Work on publishing some of our preliminary results on sensor calibration, image processing and vehicle navigation. Attend a robotics conference (ICRA or IROS) and visit collaborators in the EU.

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

2023 Project Start Date: 01/01/2023	**Milestone 1**	**Milestone 2**	**Milestone 3**	**Milestone 4**	**Milestone 5**	**Milestone 6**	**Total Resources [5] (in hours)** for each resource category for all milestones listed here
Milestone Date	**June**	**September**	**October 2022**	**November**	**September**	**December**	
Milestone Description	**Paragon ASV Perception**	**Scalable Stereo Nav**	**Visual SLAM Field Validation**	**UW-Open-HSI**	**Docking 6DOF AUV Hovering LRAUV**	**Platform development**	
Electrical Engineer	**Martin (160)**	**Martin (120) Roberts (280) Klimov (80) Sherman (80)**	**Martin (40)**	**Roberts (120)**	**Martin (160)**	**Martin PM (120)**	**EM - 600 PR - 400 DK - 80 AS - 80**
Software Eng-Embedded		**TBD (120)**	**Headley (120)**	**TBD (80)**	**Risi (360) Kieft (120)**	**Risi (120) Headley (120)**	**KH - 240 MR - 480 TBD - 200 BK - 120**
Software Eng-Info Eng			**Barnard (360)**			**Danelle (120) Rueda (120) Barnard (120)**	**KB - 480 DC - 120 CR - 120**
Mechanical Engineer	**Cazenave (20)**				**Hamilton (60) Cazenave (120) Hobson (40)**		**AH - 60 FC – 140 BH - 40**
Mechanical Eng-Division						**Kirkwood (80)**	**BK-80**
Mechanical Eng-Mfg					**TBD (80)**	**TBD (40)**	**TBD - 120**
Associate Engineer							
Electrical Tech	**TBD (40)**				**TBD (60)**		**TBD - 100**
Software Tech							

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

Mechanical Tech	**TBD (40) Flores-Mini (60)**				**TBD (60)**		**TBD - 100 FF - 60**
Machinist	**TBD (40)**				**TBD (60)**		**TBD - 100**
Divers							
MiniROV	**Graves (80)**						**DG - 80**
Paragon Support	**Figurski (80)**						**JF - 80**

Budget justification

More detail can be viewed on the source document: https://bit.ly/3uIJcCY

Milestone	Task #	Subtask	Item	Expenses	Services
1	3.4		Build Bench Testing Mirror System	$1,000.00	
			Monitor & Tools Mounting	$2,000.00	
2	3.1	Stereo Nav Box	Housing wiring for Ventana & Mini (2X)	$4,000.00	
			Housing Manufacturing (2X)	$6,000.00	
			Topside test and interface cable (2X)	$1,000.00	
			Cameras and Lenses (2x)	$6,000.00	
			IMU - VN100 (2X)	$2,400.00	
			Subsea Processing CPU - Jetson Orin (2X)	$6,000.00	
			Suburban Marine		$15,000.00
	3.2	Structured Light	Projector Housing Design	$2,000.00	
			Projector Housing Wiring	$500.00	
			Spare Pattern Projector w/ lenses	$2,000.00	
			Cabling Design for 3 vehicles	$1,000.00	
3	1	Field SLAM	GIM 7 PM (3 WP)		$92,225.00
			GIM +2 PM (+1 WP, optional)		$26,350.00
			Interns (1 by default, ideal 2)		$54,000.00
4	3.3	Hyperspectral Camera	Camera Selection - Ximea	$4,000.00	
			Lens Selection	$600.00	
			Testing rig (80/20)	$500.00	

			HSI Illumination LED Lamp	$2,000.00	
			Calibration Spectrometer	$5,000.00	
			Reflectance Standard Grid	$2,000.00	
			HSI Eval Housing	$2,000.00	
			HSI Eval Housing Wiring & Cabling	$1,000.00	
			HSI Eval Housing Internal Components	$1,000.00	
5	2	6DOF Docking	Design Mola Docking Frame	$6,000.00	
			Purchase Wisub Charger	$7,000.00	
			Dock charger/comms wiring	$3,000.00	
			Adapt dock to AUV Docking project test buoy	$1,000.00	
7	4	Platforms & Control	Consultation Services - OSRF		$15,000.00
			Basic set of thrusters(8)/sensors (DVL/inertial/cameras)	$60,000.00	
NA		Lab Internal Costs	Memberships		$3,000.00
			Publication Fees		$1,000.00
			Conference Fees		$1,000.00
			Travel / Conferences 2 trips	$6,000.00	
			Science illustrations		$5,000.00
			Tools	$1,000.00	
			Computer Hardware	$2,000.00	
			Computer Software	$1,000.00	
				Shipping:	**$1,500.00**
				Expenses:	**$139,000.00**
				Taxes:	**$10,772.50**
				Services:	**$212,575.00**
				Total:	**$363,847.50**

Project team

- PI, Lead Engineer:
    - Giancarlo Troni (1856 hrs)
        - Tasks all
- Research Engineer:
    - TBD (1856 hrs)
        - Tasks 1.1, 1.2, 2.1, 3.2, 4.1, 4.2
- EE:
    - Eric Martin (600 hrs)
        - Tasks 3.1, 3.2, 3.3, 3.4, P.M.
    - Paul Roberts (400 hrs)
        - Tasks 3.1, 3.2, 3.3
- SE Embedded:
    - Mike Risi (480 hrs)
        - Tasks 2.1 and 2.2: control framework for 6DOF platforms
    - Kent Headley (220 hrs)
        - Task 1.2: Drivers for the sonars and data acquisition
    - TBD (200 hrs)
        - Task 3.1, 3.2, 3.3: Support software for cameras and camera calibration support.
- ME:
    - Brett Hobson (40 hrs)
        - Task 2.2: Hovering LRAUV support
    - Andy Hamilton (60 hrs)
        - Docking concept validation
    - Francois Cazenave (140 hrs)
        - Design docking structure
    - Bill Kirkwood (80 hrs)
        - Research platform improvements
- SE Info:
    - Kevin Barnard (480 hrs)
        - Task 1, 4.1: SLAM validation and path planning tools for the AUV platform.
    - Carlos Rueda (120 hrs)
        - Task 4.1: GUI for the research AUV/ROV platform
    - Danelle Cline (120 hrs)
        - Task 4.1: Cloud simulation
- Platforms:
    - MiniROV Team member (220 hrs) - (Dale Graves 80 h, Alana 80 h, Frank Flores 60 h)
        - Task 5: Support sensor integration (120 hrs)
        - Vehicle operation (100 hrs) including 3 at sea days and 10 days in the test tank.
    - LRAUV Team member Brian Kieft (120 hrs)
        - Task 2.2: Support operating LRAUV
    - Paragon, Jared Figurskif
        - Task 3.4: ASV Paragon data collection. Boat operation (60 hrs) and installation/meetings (20 hrs)

This proposal is tightly coupled to David Caress, Kakani Katija, and Steve Rock efforts.

External consultants/contractors
If you propose to engage an external consultant/contractor, please attach a sufficiently detailed SOW and budget proposal from the vendor. If approved, a fully executed Independent Contractor Agreement must be in place before work can begin.

- Contract software support GIM robotics (SLAM architecture)
    - For tasks 1.1, 1.2 is critical to count on their support. We have divided the work into 4 Work Packages (WP) for next year:
        - WP1: Visual navigation support for online deployment at sea
        - WP2: SLAM navigation framework extension for sonar and Lidars.
        - WP3: ASV dataset validation for localization and obstacle detection.
        - WP4: Support MEMS-based INS development and scoping multivehicle extensions (optional).
- Suburban Marine (camera design support)
    - For the software development of Tasks 3.1 and 3.2 is required to count with a software architecture that enables synchronized video to be broadcasted in real-time for data processing.
- Intern 12-month extension (internal structure)
    - Tasks 1.1, 1.2, 2.1, 2.2, 3.1, and 3.2 will be required to be supported by the interns. They have been critical in the interaction with GIM to enable more effective development and other lab-related tasks.

Project lab and office space requirements
In addition to any changes to current space usage, please also include anticipated office and lab needs for students, postdocs, collaborators, etc.

The current laboratory space (B225) is fundamental for conducting this project. In addition, test-tank facilities are required in addition to office space for allocating visiting students and a new research position hired this year.

Risk matrix (development and infrastructure projects only)

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

Compliance Considerations

Please respond "Yes" or "No" to each line item below, and provide details as necessary.

CATEGORY	Yes/No	DETAILS
Isotope Use (see policy and cruise planning) Will the project use stable or radioisotopes?	No	
Battery waste over 4 liters (1 gallon) Indicate type and amount.	No	
Liquid hazardous waste over 60 liters (15 gallons) Indicate composition and quantity.	No	
Export Regulation Foreign collaborations or international travel?	Yes	Graduate students in Chile
Technology access Any potential exposure to proprietary information about export controlled equipment?	NO	
Export controlled purchases Items purchased/in possession or to be purchased that are not on list?	YES	DVL
Export controlled items (hardware, software, tech data) Items to be transferred outside US (temporarily or permanently)? To what countries (including International Waters)?	NO	Other items are part of Seafloor Mapping proposal (Such as Kearfott INS)
Encryption Items Use of non-commercial (specially licensed, non-mass-market) encryption or information security software?	NO	
Work covered by Marine Sanctuary permit? Yes, if work falls under blanket authorization.	YES	
Work conducted in SESAs? ID # for Sanctuary Ecologically Significant Areas	YES	Proposed LASS surveys (with Seafloor Mapping) may edge into SESA 6
Equipment deployed with anchors? Give details for deployment; recovery if < 500lbs	NO	
CA Fish & Wildlife permit required for samples?	NO	
Working in State Marine Protected Area?	NO	
Require Coast Guard PATON for buoys? Private Aid to Navigation. Permit in hand?	NO	
Require Local Notice to Mariners Indicate who will be submitting	TBD	

Permits from other agencies?	NO	
Use of active acoustics not already on list?	NO	DVL and FLS sonars