

Open Robotics MBARI LRAUV 2022

Statement of Work

v1 / December 2021 / Confidential

This SOW shall be governed by the terms and conditions of the Consulting Agreement, dated January 1st, 2021, executed by Open Source Robotics Corporation (Open Robotics / Consultant) and Monterey Bay Aquarium Research Institute (MBARI / Company).

Background

Company requires support for improving their simulation of robotic marine systems. Consultant has expertise in ROS and Ignition Gazebo development as well as integration and testing which will help Company to leverage the software on their platforms.

We propose to continue developing the multi-LRAUV simulation environment in Ignition, and integration with the existing LRAUV software. The work proposed for 2022 will extend the simulation environment to provide full mission profile validation of LRAUV deployments, with an emphasis on multi-vehicle applications and advanced navigation algorithms using bottom-aided sensors. LRAUV's dynamics, hardware, and onboard instrumentation, including inter-vehicle acoustic comms, DVL, and battery will be simulated along with a model of the environment, including surface waves, winds, and bathymetry. The simulator will be operable through a graphical user interface and the TethysDash web interface and will be capable of running in a faster-than-real-time mode allowing users to develop, test, and visualize the performance of their algorithms over the duration of a full deployment offline and then deploy the final product to LRAUV for validation and execution at sea.

The messaging interfaces and simulation tools that we will develop will be open-sourced and made available to MBARI researchers, collaborators, and members of the open-source community. The entire implementation will be packaged using Docker containers that can be deployed by any collaborator or run using cloud services such as AWS. We anticipate that providing general access to the simulation together with an open API for controlling the vehicles will attract researchers and members of the open-source community to collaborate with MBARI, and we intend to actively pursue such collaboration opportunities.

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Open Robotics will be contracted to develop software components needed to support the multi-LRAUV simulation environment. Open Robotics has performed extensive relevant past work, and the proposed tasks build upon the existing open-source software ecosystem supported by Open Robotics, including the Ignition simulator and the ROS 2 programming framework.

Scope of Work

Milestone 1 — Navigation development environment (Q1, 2022)

During the first quarter, Open Robotics will work with the MBARI team to add required software components, simulation plugins, and data to support the development and debugging of navigation software using the Multi-LRAUV Ignition simulation framework. Completing the work proposed under this milestone is required for simulating cooperative navigation missions, such as those proposed by Rock's Precision Control Technologies for ROVs and AUVs (600034). During this milestone we will cultivate an **external collaboration with Brian Bingham's project DAVE funded by DARPA (Naval Postgraduate School)**.

Delivered capability: Upon completion, developers will be able to approximate bottom sensing to test bottom-aided vehicle navigation and advanced algorithms such as collaborative terrain relative navigation (TRN).

Tasks

1. Create a 5x5 km Digital Elevation Model (DEM) of Portuguese Ledge in Ignition from MBARI high-precision octree maps of the area's bathymetry.
2. Create an attitude and heading reference system (AHRS) sensor plugin to Ignition (including noise model) and integrate with the LRAUV main vehicle application.
3. Create a doppler velocity logger (DVL) sensor plugin in Ignition (4 beams velocity and altitude @ 1Hz) and integrate it with the LRAUV main vehicle application. This task will be performed in collaboration with NPS.
4. Add water column velocity sensing to DVL sensor plugin. This task will be performed in collaboration with NPS.
5. Integrate the multi-LRAUV simulator with MBARI staff development workflow. Create run scripts, documentation, and set up the development environment.
6. Software improvements, issue response, and user support.

Goals

1. Ignition world model with DEM of Portuguese Ledge.

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2. Ignition sensor plugin for AHRS.
3. Ignition sensor plugin for DVL.
4. Functioning development environment for MBARI engineering staff.
5. Documentation and associated design documents.

Milestone 2 — Ocean surface and battery simulation (Q2, 2022)

During this phase Open Robotics will improve the simulation performance for the ocean's surface by adding Ignition world model plugins for waves and wind. The work proposed under this milestone overlaps with tasks identified under Hamilton's Open Wave-Energy Control System Development Platform DOE project, and we plan to work in close collaboration with his project. Wind and wave models will lay the foundation for adding support for simulating Liquid Robotics wave-gliders in the Ignition environment (which we hope to add in subsequent proposals).

Delivered capability: Users will be able to visualize the ocean surface, realistically test operations in harsh surface conditions (e.g., vehicle drift due to surface winds), and tune/optimize surface comms to eliminate communication bottlenecks. Realistic battery simulation will support the development of energy management strategies for increased vehicle endurance and edge case testing.

Tasks

1. Add Ignition world plugin for simulation of surface waves (collaboration with Hamilton's DOE).
2. Add Ignition world plugin for simulation of surface winds (collaboration with Hamilton's DOE).
3. Add Ignition sensor plugin for battery energy with realistic battery dynamics model.
4. Integrate the simulation environment with LRAUV's operator training lesson plan (collaboration with Birch and Scholin's 708175.50).
5. Software improvements, issue response, and user support.

Goals

1. Ignition world plugin for surface waves.
2. Ignition world plugin for surface winds.
3. Ignition battery energy sensor plugin.
4. Documentation and associated design documents.

Milestone 3 — Water sampling and development demo (Q3, 2022)

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In this phase Open Robotics will continue to improve the simulation's performance and add Ignition sensor plugins for a water sampler, such as ESP/CANON sampler. At this point, the simulation environment will be mature enough to support a back-to-back development cycle of a new multi-LRAUV application. We will work in conjunction with Hobson's LRAUV Technology Development and Fleet Operations (902101), Zhang's Targeted Sampling (901513), Rock's Precision Control (600034), and/or other to develop a new multi-LRAUV application using the Ignition simulation environment from concept to sea-trail.

Delivered capability: Users will be able to test, validate, and optimize sampling missions with a simulated sampling device in the loop. Devices capable of onboard analysis (e.g., ESP) will be supported with plugins capable of generating data that reflect water conditions of the sampled area in the simulated environment. The Ignition development environment will be capable of supporting a full development cycle for a multi-LRAUV application.

Tasks

1. Add Ignition sensor plugin for ESP/CANON water samplers.
2. Close the loop. Develop a new multi-LRAUV application using the Ignition simulation environment, and demonstrate at sea. The multi-LRAUV application(s) will be developed according to need in Hobson's 902101, Zhang's 901513, Rock's 600034, and/or others.
3. Software improvements, issue response, and user support.

Goals

1. Ignition sensor plugin for ESP/CANON sampler.
2. Demonstration of a new multi-LRAUV application in Ignition.
3. Documentation and associated design documents.

Milestone 4 — Export (Q4, 2022)

In this phase Open Robotics will provide general engineering support and finalize preparation for open-source and release of the Ignition software, Docker images, and associated documentation.

Tasks

1. Cleanup. Prepare for release of the Ignition software, Docker images, associated documentation, and user tutorials.
2. Continue development of new multi-LRAUV application using the Ignition simulation environment.

3. Software improvements, issue response, and user support.

Goals

- GitHub/BitBucket repository containing the open-source Ignition software libraries and docs.
- At-sea demonstration of a new multi-LRAUV application that was developed in Ignition (LRAUV sea time requested in 902101, 901513, and 600034).
- Documentation and associated design documents.

Intellectual Property

Improvements made by Open Robotics to code or documentation for existing open source projects will be contributed back to those projects under an open source license.

Schedule & Budget

Period of Performance

The work will be performed between January 1st, 2022 and December 31st, 2022

Travel and Incidentals

Fixed prices and/or hourly rates do not include any incidental or travel expenses. In the event Company requests Consultant to incur either expense and Consultant agrees, Consultant will be reimbursed in full for any expenses documented with receipts.

Payments

Consultant will keep track of hours worked and submit an invoice at the end of each month payable on NET-30 terms. Work execution will be coordinated between Consultant and Company on an ongoing basis. This coordination will include an estimate of the level of work for each month's performance prior to starting the month.

We will undertake the requested work on an hourly basis, with rates determined by the level of staff who are assigned to the project. Our hourly labor rates are as follows:

Technical staff I:	US\$125
Technical staff II:	US\$170
Technical staff III:	US\$215

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Technical staff IV: US\$260

Technical staff V: US\$370

In recognition of Company's non-profit status, Consultant will discount these rates by 10% for this project.

Based on our understanding of the Scope of Work, we expect to provide an average of 150-197 labor hours / month. In the event that more substantial effort is required, we will work with Company to estimate and schedule such work, subject to our staffing availability at the time and the Company's acceptance of the change.

The minimum monthly billable amount will be \$20,000.

The maximum monthly billable amount will be \$70,000.

The total amount billed is not to exceed \$556,632.

Bank charges will be borne separately by each party for their respective bank.

**MONTEREY BAY AQUARIUM
RESEARCH INSTITUTE**

By: 
Name: Basilio Martinez
Title: CFO

OPEN SOURCE ROBOTICS CORPORATION

By:
Name:
Title: