

Project Title

Open Wave-Energy Control System Development Platform

Federal Agency and Award Number

DOE – EERE

DE-EE0009444

Principal Investigator Contact Info

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Recipient Organization

Monterey Bay Aquarium Research Institute

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DUNS Number

178341772

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Project Period of Performance

10/1/2021 - 3/31/2026

Reporting Period End Date

9/30/2025

Accomplishments

a) Major Goals and Objectives

The primary goal of this project is to create a software infrastructure for the MBARI Wave Energy Conversion buoy that will allow outside collaborators to develop control algorithms that take advantage of all features of the MBARI buoy, and execute these algorithms during the regularly scheduled deployments. The intent of this is to provide an at-sea test-bed for controls researchers that they would not ordinarily have access to, and promote real-world control system research and testing in this manner. The project contains three main activities;

- i) Buoy Software Infrastructure: This is the development of an application programming interface (API) on the buoy system that provides developers consistent access to all sensor data on the buoy and a means by which to programmatically specify control inputs to the wave-energy converter. With this API, developers can concentrate almost entirely on the control algorithm portion of the task, without needing to develop specific expertise in the lower level software and hardware infrastructure of the wave-energy converter. The architecture of the MBARI wave-energy converter buoy is well suited to this abstraction and allows new control code to be uploaded and executed in this model, while the buoy is at sea. It is intended to be routine to perform design iterations in which code is uploaded and run, results analyzed, modifications made and new code uploaded and run, without the need to recover the system.
- ii) Simulation Environment: In order for developments using the API to proceed efficiently, a simulator is also required that allows newly developed code to be tested before deployment on the hardware. A key requirement of this simulator is that it provides an API that is identical to the buoy API. Meeting this requirement means that code that runs in the simulation environment can also run entirely unchanged on the buoy while it is at sea. This simulation environment also will provide some safety checks on code before it is run on the buoy, and allow researchers to do some algorithm performance testing before at-sea testing. The simulator is being developed to run faster than real-time, and will have a range of settings that balance code execution speed and simulation fidelity.
- iii) Marketing and Outreach: The most challenging component of this project is developing engagement with our target users. There are a wide range of potential users and we are targeting academic and non-profit institute researchers as per the funding opportunity announcement. We also envision teaching opportunities for this platform and can imagine a university course in marine hydrokinetic energy harvesting being developed that uses the materials resulting from this project. We are planning a number of activities such as webinars, seminars, and conference events to support this. Additionally, we have included requirements in our software development and documentation specification for ease of use for individuals new to ROS and this type of programming.

To facilitate these activities, this project included Open Robotics Software Foundation (ORSF) as a significant subaward. ORSF develops and promotes the popular “Robot Operating System” (ROS, <https://www.ros.org>) which is a middleware that allows robotics and other real-time software to be divided into a number of processes that share data over a common publish/subscribe message architecture. By developing the required API using this framework, we expect to provide an API that uses a well-documented form and that is approachable for academic researchers. ROS provides language bindings in C++ and Python, which provides some built-in flexibility to meet researchers in their own areas of computing expertise. Although

ORSF was a significant contributor in the first budget period of this project, changes in their organizational structure and the hiring of the requisite skill-sets at MBARI led to a change in the original plan for Budget Period 2. For Budget Period 2 MBARI is providing all needed software engineering, leading to a more cost-effective effort.

Budget Period 1 of this project concentrated on building, testing, and validating the necessary software tools and is complete. Budget Period 2 is focused on marketing the result and helping users make use of the system, this is ongoing and Table 1 highlights the current status of the milestones set out in the original statement of work.

Table 1: Budget Period 2 Milestone Progress

	Milestone	Percent Completed	Completion Month	
			Scheduled	Actual
12.5.1	Attend conference or seminar	100%	36	30
14.2.1	Buoy Deployed	100%	28	28
15.2.1	Successful on-buoy use of user code	0%	33	
17.2.1	Buoy Deployed	100%	40	43
18.2.1	Successful on-buoy use of user code	0%	45	

b) Accomplishments and Developments in this Reporting Period

In this reporting period we have gotten a good start on supporting the University of Washington/Oregon State University BIL supported project that will use the software infrastructure developed in this project. In addition to PI's Jim Thompson, Curtis Rusch, Brian Polayge and Merrick Haller, graduate student Alex Eagan and Post-Doc Brittany Lydon are now actively working with the simulation environment and defining the activities of this effort. Merrick Haller at OSU has also indicated he has identified a new graduate student to join his group as part of this effort and we will welcome that individual to our weekly meetings as soon as it is established. This effort aims to deploy a few wave-measurement buoys in the vicinity of the MBARI wave-energy converter for the purpose of predicting the incoming waves and optimizing control of the WEC. This field activity is now planned for August of 2026, and having the date set is focusing activities. To support this effort, this project needs to add a few required features to the simulation environment immediately to facilitate the research. In particular the wave-measurement buoy behaviors and data need to be added to the simulation and this is underway. Subsequent to that there is some hardware integration work to do on the buoy itself to add the necessary radios for the system to receive the wave-measurement buoy data in real-time during the deployments.

In addition to the UofW/OSU group working with this system, we have received interest from Hannah Walker who is currently completing a PhD in Mechanical Engineering at UCSD. Hannah is interested in working with our

system as part of a postdoctoral fellowship, she is in the process of applying for the MBARI postdoc program as well as the DOE Marine Energy Fellowship administered by the Oak Ridge Institute for Science and Education. Having met with Hannah to discuss the project possibilities we would welcome her at MBARI through either funding route. We have suggested she apply for both opportunities and she is working now on an appropriate research statement that is consistent with utilizing this projects software and hardware resources.

The MBARI wave-energy buoy was recovered on October 16th, concluding it's 2025 deployment (milestone 17). This completes another successful deployment of the system that included testing of new features of the system and supporting a range of science initiatives by powering on-board instrumentation at energy levels not possible from solar-supported buoys of similar size. The deployment did end with a hardware failure that is undetermined at the time of this writing, but we will be opening the system shortly and repairing whatever needs repair. Having the buoy on-shore a bit earlier than expected does provide more time for the integration of the necessary radios for supporting the wave-measurement buoys described above. The buoy will be redeployed in the spring/summer of 2026 to continue to support this project, and that deployment will also support a docking station for autonomous underwater vehicles.

Also during this reporting period, we completed the upgrade of the simulation environment and software to support Ubuntu 24.04, this is now the default installation. This update has resulted in a little bit simpler installation procedure because we are now using an officially supported combination of software, previously we had to do some specific things to use an unsupported combination that enabled all of the features we needed.

Finally, we continue to plan for a no-cost time extension for this project beyond April 2026 to allow more time for us to support the recently started efforts that use this system. We understand that there may be delays in setting this up but would like to continue this discussion.

c) Training and Professional Development Opportunities

The planned BIL funded project with the UofW/OSU groups is the best opportunity to engage students in this project and line of work. As described above, two individuals (Alex Eagan, a master's degree student, and Brittany Lydon, a postdoctoral fellow) have been engaged by the University of Washington and we have begun involving them in this project. Also as part of that funding, there are plans for an additional student to work with Mick Haller at Oregon State University on the drone-measurement component of the plan, and we are told that an individual has been identified for this role. We are also pursuing hosting Hannah Walker at MBARI for a post-doctoral fellowship after she completes here PhD in Mechanical Engineering at UCSD in the spring of 2026.

d) Results Dissemination

The open-source software development in this reporting period represents the bulk of the results dissemination as the public at large has had access throughout the development process. As described above, the wave-body interaction hydrodynamic computations used in this project have been broken out into a stand-alone library that may be useful for several outside efforts.

e) Plans for the Next Reporting Period

In the upcoming reporting period we will be concentrating on implementing the necessary software features to support the UofW/APL research plans. After that, and since the buoy is now on-shore, we will be adding the

necessary radios and software to support the wave-measurement buoys during the field experiments in August 2026.

Products

a) Publications, conference papers, and presentations:

None in this reporting period.

b) Websites:

The following web-sites contain software developed by this project:

The top-level websites for the code and documentation are:

- https://github.com/osrf/mbari_wec
- https://osrf.github.io/mbari_wec/

And the constituent repositories that provide specific functionality are:

- https://github.com/osrf/mbari_wec_gz
- https://github.com/osrf/mbari_wec_utils
- <https://github.com/hamilton8415/FreeSurfaceHydrodynamics>

The first group of these are likely to be visited by users, and the second group by developers.

c) Technologies or Techniques

- Budget Period 1 of this project has spurred changes to the Gazebo simulation framework to properly include added-mass effects in the physics simulation and that work is now complete and available in all the most recent distributions of Gazebo. This is a necessary capability for Gazebo to be used for marine robotics. A second indirect result of this project is the stand-alone free-surface hydrodynamics library (<https://github.com/hamilton8415/FreeSurfaceHydrodynamics>). Although this was developed to support this project, other uses are being investigated and we hope this work can make a contribution to other projects and fields.

d) Inventions, patent applications, and/or licenses

None.

e) Other products

None.

Participants & Other Collaborating Organizations

a) Individuals

1. Name: Andrew Hamilton
2. Total Number of Months: 1
3. Project Role: PD/PI

4. Researcher Identifier: None
5. Contribution to Project: Principal Investigator and Project Manager, directs all activities.
6. State, U.S. territory, and/or country of residence: California, U.S.A.
7. Collaborated with individual in foreign country: No
8. Country(ies) of foreign collaborator: Not Applicable
9. Travelled to foreign country: No
10. If traveled to foreign country(ies), duration of stay: Not Applicable

1. Name: Michael Anderson
2. Total Number of Months: 1
3. Project Role: Other Professional – MBARI Software Engineer
4. Researcher Identifier: None
5. Contribution to Project: Performs Software Engineering, Programming, and Documentation Tasks. Participates in all meetings.
6. State, U.S. territory, and/or country of residence: California, U.S.A.
7. Collaborated with individual in foreign country: No
8. Country(ies) of foreign collaborator: Not Applicable
9. Travelled to foreign country: No
10. If traveled to foreign country(ies), duration of stay: Not Applicable

b) **Change in PI/Senior Personnel**

None

c) **Partner organizations**

None

d) **Other collaborators**

- The collaborative project with Jim Thomson (UofW), Curtis Rusch (UofW), Mick Haller (OSU), and Brian Polagye (UofW) is established. This collaboration has begun and entrained students Alex Eagan (UofW) and Brittany Lydon (UofW).

- We are working to engage Hannah Walker as a postdoctoral fellow at MBARI, starting in the summer of 2026.

Impact

a) **Impact on the principal disciplines**

As part of this project we have developed a general-purpose software library that computes wave-body interaction forces for floating bodies. This is used by this project, and also available to others as it has no specific ROS/Gazebo characteristics. In the future we hope to facilitate research results in the area of wave-energy conversion device control.

b) **Impact on other disciplines**

This project has spurred changes to the Gazebo simulation framework to properly include added-mass effects in the physics simulation. This is a necessary capability for Gazebo to be used for marine robotics. Additionally, in the course of this project three small issues with ROS itself came to light, we fixed those and had the necessary changes accepted into the ROS 2 source-code tree.

c) Impact on development of human resources

None

d) Impact on teaching and education

None yet.

e) Impact on infrastructure

None expected.

f) Impact on technology transfer

None yet.

g) Impact on society

None.

h) Budget percentage spent in foreign countries

0%

Changes/Problems

- a) Changes in approach.
- b) Actual or anticipated problems or delays and actions or plans to resolve.
We continue to work towards finding appropriate users, and need to expand this some as we move forward.
- c) Changes that have an impact on expenditures
None.
- d) Changes in use or care of human subjects, vertebrate animals, biohazards, and/or select agents.
None and not expected to be applicable.
- e) Change in primary performance site location.
None.