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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Project Period of Performance

10/1/2021 - 3/31/2026

Reporting Period End Date

6/30/2025

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

			Completion Month	
	Milestone	Percent Completed	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

This project presented an online seminar and software demonstration as part of the Water Power Technology Office and PRIMRE "Software Demo Days" series on June 4th. This presentation was an overview of this project, some demonstrations of the systems capabilities, and can be reviewed here: https://youtu.be/dDWNg4U4FoE?si=n0H4dFD5tOneypPR. Our aim was to highlight what this system is capable of and drive interest and engagement. We felt the presentation was well received and did see an uptick in GitHub visits and downloads subsequent to the event. During a previous presentation by the MHKit team, they had expressed some interest in gaining access to a dataset from one of our long-term deployments. This was revisited after our June 4th presentation and we are working with Andrew Simms at NREL to identify the exact data they need, and determine how best to transfer that data. For institutional requirements we may need to determine how we license that data-set, but anticipate no issues with that part of things.

On May 1st, the MBARI wave-energy buoy was deployed for its 2025 deployment (milestone 17). This deployment is ongoing through much of the rest of 2025 and the software features developed to date in this project are operational on-board. In the original project planning this was to be the final deployment, but internal MBARI plans rely on the wave-energy being maintained at sea over the next few years, so the features enabled by this project will remain available during those deployments. We are also upgrading the buoy system

with an improved Lithium Ion battery pack that will make the energy storage on board the buoy more efficient, which could be relevant in some control scenarios.

We are very pleased that in this reporting period, the Bipartisan Infrastructure Law activity to collaborate with faculty and researchers at the University of Washington and Oregon State University has begun. The sub-award is in place now with MBARI and we are beginning weekly meetings to determine the specific work plans. This is a very positive development that will provide opportunities to use the MBARI-WEC system and the associated software. Graduate student Alex Eagan and Post-Doc Brittany Lydon have been recruited to work on this project at University of Washington. They have successfully installed the simulation environment and are eagerly learning about the system and asking questions. We have established a regular weekly meeting with this group and this project will support them however needed, both in using the platforms and suggesting research directions. Also related to these efforts we have begun work to integrate the specific SWIFT wave-measurement buoys and other instrumentation into the simulation environment.

We have also received an inquiry from our collaborator Ted Brekken at Oregon State University, he has a student looking for post-doctoral opportunity and is interested in our program. Currently Ted has not identified funding for this student but we are looking for opportunities. One possibility is to advertise an opportunity as part of the MBARI post-doctoral program that would be funded by MBARI (applications open in September 2025). In this case a post-doc would be mentored by Hamilton at MBARI, possibly with some co-mentoring from Ted Brekken if appropriate.

We have completed the necessary software maintenance to support the simulation environment under Ubuntu 24.04. Previously we had supported ROS and Gazebo versions that ran on Ubuntu 22.04 but the nature of these software tools is that they are fairly tightly coupled with the operating system versions. 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. In this reporting period we completed this maintenance work and tested the new versions together. Shortly this will become the default installation on our GitHub site, consistent with the fact that Ubuntu 22.04 is fading in prevalence.

At the previous project quarterly review meeting, we discussed the prospects of extending the time available to this project to support outside users of the software and platform. As time is passing and the current April 2026 conclusion of the project approaches, it becomes clear that a no-cost time-extension is sensible, provides support for the late-starting funding described above, and is the best way to efficiently and effectively use the remaining funds allocated to this project. We are interested to know how to finalize this decision and move the official decision forward.

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 fello) 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, a role that may or may not involve use of our simulator tools.

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 getting the University of Washington collaborators up to speed. This involves helping the install and understand the software components, providing some test data from our field-deployments, and integrating new features into the simulator that reflect the behaviors of the SWIFT wave-measurement buoys that are planned for field testing in a year or two.

Products

a) Publications, conference papers, and presentations:

Presentation at the Software Demo Days, viewable here:
https://youtu.be/dDWNg4U4FoE?si=n0H4dFD5tOneypPR

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

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- We continue to develop a relationship with Ted Brekken at Oregon State University as users of this project's products. Ted has some funding to support a student and is interested in involving this project with that work, probably starting spring 2025.

- 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).

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.