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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10/30/2026

DUNS Number

178341772

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Project Period of Performance

10/1/2021 - 3/31/2028

Reporting Period End Date

9/30/2026

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 (OSRF) as a significant subaward. OSRF 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

OSRF 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 work 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	100%	33	50
17.2.1	Buoy Deployed	100%	40	43
18.2.1	Successful on-buoy use of user code	30%	45	

b) Accomplishments and Developments in this Reporting Period

Activities in this reporting period were focused on preparing for the planned fieldwork with our University of Washington and Oregon State University collaborators. As of this writing, this fieldwork was successfully completed in early October, due to the preparation work performed in this reporting period. In particular, software updates to both the simulator environment and the buoy computers have allowed the wave-prediction algorithms under investigation to be run in real time on both the simulator and the buoy hardware. This involved adding the SWIFT buoy data stream to the simulator as well as adding the messaging infrastructure to feed the wave motions from those devices into the ROS messaging infrastructure alongside the wave-energy device telemetry. The work done by this project enabled the collaborators to develop and test their algorithms in the simulation environment prior to the at-sea work. This work highlighted that the existing computer infrastructure onboard the buoy was insufficient to perform the needed computations in real time. To address this, a faster computer (NVIDIA Orin) was installed on the buoy alongside the required radios to receive data from the SWIFT measurement buoys in real time. All of this work together set the project up well for the planned October 2026 field programs.

The MBARI WEC was deployed in Monterey Bay on September 29th, including the radio and compute infrastructure upgrades described above and upgrades to support underwater-vehicle docking. This deployment

went smoothly and the WEC remains onsite, supporting this project and other activities. The latest basic telemetry for the system can be viewed here: https://ftp.mbari.org/pub/Hamilton/LatestQuickViewPlot.pdf

c) Training and Professional Development Opportunities

Hannah Walker joined MBARI in September as a postdoctoral fellow, with specific plans to work with the software and capabilities developed by this project. Hannah will be with us for three years, supported initially by the DOE ORISE fellowship program and then subsequently by the MBARI postdoctoral fellowship program. Her ambitions are to explore machine-learning techniques for optimal wave-energy control. She has immediately become integrated into the growing group of researchers using this platform and was able to meet the UofW and OSU participants when they were here in October.

The University of Washington and OSU groups also continue to be active, performing research and participating in weekly calls with us. In particular, graduate student Alex Eagan at the University of Washington continues to be a strong contributor and we believe will continue to use this system through his planned PhD work. Emma Speyrer at Oregon State University is also becoming more involved as we proceed through the fieldwork.

We have recently been contacted by Professor Geoff Hollinger at Oregon State University, who has expressed some interest in this project and is looking at our products as potentially being useful for his graduate student projects.

d) Results Dissemination

As an addition for this deployment, the collected data specific to the University of Washington's work is now also being mirrored from the buoy onto an FTP site that they can draw from as needed: https://ftp.mbari.org/pub/Hamilton/PMEC_October2026/

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.

e) Plans for the Next Reporting Period

The next report will cover the actual fieldwork in October 2026, and subsequent results collection and analysis. We anticipate this will lead to new desires and requirements for both software and hardware aspects of the effort, which we look forward to implementing to support the users of the system. Also, in the next reporting period we expect to recover the wave-energy converter itself and begin to prepare it for a longer deployment in 2027.

Products

a) Publications, conference papers, and presentations:

None in this reporting period.

b) Websites:

The following websites contain software developed by this project:

Field data from deployments related to this project are maintained here:
- https://ftp.mbari.org/pub/Hamilton/PMEC_October2026/

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 of these are likely to be visited by users, and the second two groups 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. Traveled 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. Traveled 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 entrained students Alex Eagan (UofW) and Emma Speyrer (OSU).

- Hannah Walker has joined MBARI as a postdoctoral fellow.

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.
None.

b) Actual or anticipated problems or delays and actions or plans to resolve.
None.

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.