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

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Project Period of Performance

10/1/2021 - 3/31/2028

Reporting Period End Date

3/31/2026

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 (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	30%	33	
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

In this reporting period we have worked significantly with the University of Washington/Oregon State University BIL supported project that will use the software infrastructure developed in this project. This group has set a date of mid-August 2026 to do field testing with their software and hardware in conjunction with the MBARI Wave Energy Converter. To facilitate this, we have made considerable software infrastructure additions to support the array of SWIFT wave-measurement buoys they intend to deploy nearby the WEC. This work includes both the addition of software to ingest the real-time wave-measurement data over a radio network, as well as a port of the NextWave wave-prediction algorithm (https://www.researchgate.net/publication/380623684_The_Next_Wave_Buoy_Arrays_for_Deterministic_Wave_Prediction_in_Real-time) to run on board the buoy and interact with the WEC behaviors. Features have also been added to the simulation environment so that all of this can be tested prior to deployment. This capability has required the addition of some hardware to the buoy as well. In addition to a radio and appropriate antenna, the computational demands of the NextWave algorithm require a more powerful computer than is currently on-board the buoy. To address this we have added an NVIDIA Jetson AGX Orin computer to the buoy. This high-performance computer designed for edge computing has proven to be able to predict the incoming waves in real-time, while consuming 12 Watts of power doing so. This is well within the energy budget of the buoy system, but is wired through a remote-control relay so it can be powered only when needed.

In addition to PI's Jim Thomson, Curtis Rusch, Brian Polayge and Merrick Haller, graduate student Alex Eagan and Post-Doc Brittany Lydon continue to work on this effort, and Merrick Haller at OSU has also added graduate student Emma Speyrer to work on the planned lidar wave-height measurements. Joe Tablert and Amy Larson from University of Washington are also joining our meetings and contributing technical help with organizing the planned field experiment.

In addition to the UofW/OSU group working with this system, Hannah Walker has received funding from the ORISE program to work with this system at MBARI as a postdoctoral fellow, and will be joining us at MBARI in September of 2026. Hannah also received funding from the MBARI postdoctoral fellowship program, and MBARI has agreed to delay her funding to allow her one-year of ORISE funding to be completed first. This therefore means Hannah will be with us working on this project for three years total.

As reported previously, the wave-energy buoy itself was recovered in October of 2025, and is currently in our facility undergoing routine maintenance. The system is being re-assembled now after service, and with new features to enable a connection to an AUV dock, an important demonstration of the utility of small-scale wave-energy harvesting.

Finally, we are pleased that the no-cost time extension for this project has been completed, allowing us to continue to support our collaborators with technical contributions until early 2028.

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, Emma Speyrer has been added to the effort, working with Mick Haller at Oregon State University on the drone-measurement component of the plan, and she is also getting involved in some of the wave-prediction algorithm details. We will also be hosting Hannah Walker at MBARI for a post-doctoral fellowship, starting in the fall of 2026.

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.

PI Hamilton gave an invited talk on this project at the University of California Berkeley Department of Mechanical Engineering as part of the Graduate Ocean Engineering Seminar series. This took place on April 10th, 2026, and was well received.

d) Plans for the Next Reporting Period

In the upcoming reporting period we will be preparing the software and hardware systems to support the field experiment components of the UofW/APL research plans, scheduled for August 2026. This includes software integration to support the SWIFT buoy data and processing, and hardware additions to support the needed radios and surrounding SWIFT buoys themselves.

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 entrained students Alex Eagan (UofW) and Brittany Lydon (UofW), and Emma Speyrer (OSU).

- Hannah Walker will be joining us at MBARI as a postdoctoral fellow, starting in the fall 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.