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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178341772

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Project Period of Performance

10/1/2021 - 3/31/2026

Reporting Period End Date

3/31/2025

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 will be able to 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	0%	40	
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 worked to prepare the buoy system for its upcoming 2025 deployment (Task 17) which is scheduled for May 1st, 2025. As noted in the last quarterly report there was a power-electronics failure in the 2024 deployment that required a significant amount of refurbishment to fix. This has been completed and the system is passing all tests necessary to be ready for deployment. We also took the opportunity while the system was ashore to perform a complete tear-down of the system that includes inspection and replacement of wear items. In this process the cause of a couple of non-critical but annoying anomalies were uncovered and corrected. The system had operated for about 3 years total since the previous such rebuild, so we are optimistic that this system will now be available to meet the goals of this project and other initiatives for several more years without requiring a major service.

Also in this reporting period, we have accepted an invitation to participate in the WPTO software demo days, and are currently scheduled to present this project on June 4th, 2025. As such, we have been attending the demos as they occur and are working on preparing an engaging presentation and demo. Additionally, in preparation for this we are working to improve the documentation and tutorial site for this project, which still has some incomplete sections (https://osrf.github.io/mbari_wec/main/). Hopefully this will be an opportunity to inform at least some of the community about this project and drive interest.

In general, we continue to struggle to gain users of this platform, and have been concentrating on supporting the upcoming Bipartisan Infrastructure Law funded activity to collaborate with faculty and researchers at the University of Washington and Oregon State University (Jim Thompson, Brian Polayge, Merrick Haller, and Curtis Rusch). That project plan involves using the simulation environment from this project to enable development and subsequent at-sea validation of wave-prediction and wave-energy control algorithms, exactly what this project was originally envisioned to facilitate. Unfortunately, it has been a number of years since we heard this work would be supported, but during this reporting period we did respond to a request for an updated sub-award package from the University of Washington grants office, so are hopeful this will finally begin. That sub-award is relatively small and will support some of the on-the-water activities of the program that will take place at the deployment site of the MBARI wave-energy buoy. The BIL project will rely on software support from this project (DE-EE0009444). Unfortunately, the at-sea work will now probably be delayed until 2026, beyond the current project period of performance. It is probably a good time to start discussing options to address this lack of overlap and to make appropriate plans as we are quite interested in supporting this interesting activity.

In spite of the delays, we performed some technical work in preparation for adding the necessary software features to the simulation environment. This involves defining ROS messages in our system that represent the measurements from the SWIFT buoys that will be deployed near the MBARI WEC, and replicating the necessary software interfaces in the simulation environment. We have received a SWIFT wave-measurement buoy from Jim Thomson's lab at the University of Washington and have this set up and have it operating in our lab. Having this direct access to the actual hardware is greatly facilitating us in developing the necessary understanding of this instrument.

Finally, we have been supporting Curtis Rusch at the University of Washington in his selection of graduate students for the BIL work, providing some guidance on the skill-sets that we feel are necessary to succeed with our software and this project.

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. This team has a very strong track record of successful student engagement so we are looking forward to the opportunities that may result.

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

As noted above we are scheduled to highlight this project at the software demo days on June 4th. We will also be deploying the MBARI wave energy converter on May 1st (Task 17 of this project) and will be exercising all of the features of the buoy and this projects software during the 2025 deployment which will likely continue until December or possibly beyond. We will also continue the technical software work needed to integrate the SWIFT buoy data stream into this system, both on the real hardware as well as in the simulation environment. Finally,

we will continue to work to improve the documentation of the system and work on efforts to draw new users to the platform. Although this project will of course end at some point we are planning to continue to support the simulation environment after the end of the project and keep it up to date with the deployed hardware as we continue to expand the use of the MBARI wave-energy system to power instrumentation and under-water vehicles through our docking capabilities.

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

- We have a long-standing collaboration with the Ryan Coe group at Sandia with funding independent of this project. We anticipate this project will benefit that effort and facilitate some of the goals of that partnership. Therefore, we continue to keep the Sandia group apprised of our work here and this project is benefiting from previous modelling work done by Sandia, and their expertise in general.

- 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 is beginning in summer 2025.

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.