Project Title

Open Wave-Energy Control System Development Platform

Federal Agency and Award Number

DOE – EERE

DE-EE0009444

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Project Period of Performance

10/1/2021 - 3/31/2026

Reporting Period End Date

9/31/2024

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 includes 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.

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

We have continued in this reporting period to look for ways to drive user engagement with this platform, maintain the software platform, and support the at-sea deployment of the WEC as a cost-share to this project.

In early October we presented a seminar at the University of California Santa Cruz department of Electrical Engineering and Computers Science. A significant portion of this seminar was devoted to this project and the opportunities for collaboration. This was well received but we are still lacking in techniques to convert this interest into subsequent engagement. In this case Ricardo Sanfelice (the EECS department chair who invited us) is interested in expanding collaboration activities between UCSC and MBARI in general, and we've identified this project as a possible avenue. We will continue to follow up with him on this going forward.

As we have seen before, the GitHub traffic to this project tends to tick up after these seminar presentations. In the two weeks after the UCSC seminar, there were 23 unique visitors to the main GitHub repository and 8 unique clones of the software were created. This is probably a useful source of information and we will work to better make use of the GitHub statistics in the future.

In a more concrete development, on August 15th the BIL funding for our collaborators at University of Washington and Oregon State University was announced as approved. The project plans for this effort directly involve the use of the software developed in this project, and the staff involved (Jim Thompson, Brian Polayge, Merrick Haller, and Curtis Rusch) have an excellent track record of productive research and student engagement. There have been some delays in getting this effort started, and it is now anticipated that the necessary agreements will be in place in January 2025. Those project plans include at-sea use of the MBARI-Wec platform and software, and may require access to the system into 2026, this is a timing that may require some consideration at some point but we believe can be accommodated.

We have also received reviewer's comments back from the paper submitted to a special issue of Applied Sciences in the area of Dynamics and Control with Applications to Ocean Renewables. The paper is titled *Analysis on Evaluations of MBARI-WEC Field Data using WEC-Sim and Gazebo: A Simulation Tool Comparison* and is the primary characterization of the performance of the simulator developed in this project. The reviewer's comments were useful and will require some updating of the paper, but we anticipate no problems getting this through to publication. At that point it will be a useful reference for this project and we will add it to the documentation site.

The MBARI WEC deployment for 2024 has concluded and the hardware is now ashore. This deployment ended slightly pre-maturely in September with a failure in the systems power electronics. This was surprising as that hardware has years of use to date, failure analysis is ongoing. In any event, we have all of the required components on-site to rebuild this and we are aiming to re-deploy the system in February with a busy 2025 season planned for the device, including again supporting 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. his team has a very strong track record of successful student engagement so we were looking forward to the opportunities that may result. Additionally, Ted Brekken at OSU has indicated he has some funding for a student to get involved in some control-system development in the spring of 2025, so that is a pending possibility.

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

We plan to continue to improve the documentation of the system and work on outreach efforts to spur engagement. Previously discussed but not yet executed is the exploration of the Harvey Mudd "Clinic" senior design project program. This is something MBARI has participated in previously and may have some potential for this project. We have contacts and will be sure to start that process in this next reporting period.

Products

a) Publications, conference papers, and presentations:

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.

- Ricardo Sanfelice, the department chair of the Electrical and Computer Science department and the director of the Cyber-Physical Systems Research Center at the University of California Santa Cruz. (https://cps.soe.ucsc.edu/about-us)

- The collaborative project with Jim Thomson (UofW), Curtis Rusch (UofW), Mick Haller (OSU), and Brian Polagye (UofW) is established. This collaboration should formally start in January 2025.

- Recently, we have a meeting scheduled with the MHKit team for November 20, 2025 to explore possible collaborations relative to this project.

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.