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

3/31/2024

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 concentrates on building the necessary software tools, and incorporating a few beta users into the system, using the simulation tools in the near term and for on-buoy operations in the second year of the project. Budget Period 2 is focused on marketing the result and helping users make use of the system.

Table 1: Budget Period 1 Milestone Progress

			Completion Month	
	Milestone	Percent Completed	Scheduled	Actual
1.7.1	ROS Running on MBARI WEC Computer	100%	6	5
2.2.1	Simulator selected	100%	5	5
2.8.1	Simulator integrated	100%	8	12
3.4.1	All software packages are published publicly	100%	9	18
4.3.1	MBARI control running in ROS system	100%	9	5
5.3.1	Portal ready to launch	100%	9	20
6.2.1	Webinar completed	100%	11	20
7.2.1	Buoy Deployed	100%	16	17
8.2.1	Successful on-buoy use of user code	100%	21	24
9.1.1	Workshop or online training completed	100%	16	24

b) Accomplishments and Developments in this Reporting Period

The main activity of this reporting period was the preparation, and presentation, of the Go/No-Go continuation report. This report was submitted on January 22nd, 2024, and was followed by a presentation of the material on February 23rd, 2024. A "Go" rating from the program officers was communicated on March 8th, and we have been working since to refine some budgeting details to allow a second award to be made. Budget Period 1 included a six-month no-cost extension which expired on March 31st, 2024, so we are only slightly late in starting Budget Period 2 at this point.

Due to this administrative work, a relatively small amount of technical work has been ongoing in this reporting period. We have continued to maintain the software repositories, involving some work to accommodate changes in the various libraries and repositories the code depends upon. In particular we have added automated daily builds of the software, in this way if a dependency changes or becomes unavailable, the daily build will fail immediately and alert us. This has caught at least one issue so far, and is a good technique to keep these problems from filtering down to candidate users of the software.

The MBARI WEC itself has been ashore for some maintenance through the winter period, and is now fully staged for re-deployment, which is currently planned for May 7th, 2024. This deployment will last through 2024 and the buoy will be on station to support any needs this project has, barring failures.

We continue to work with the UofW/OSU group that is pursuing BIL funding through UMERC to make use of this project's software and hardware. We have not yet heard that this is secured, but have been left with the impression that if the funding is finalized, activities could start in the fall of 2024. This will be good timing for this project. The plan includes a significant amount funding for staff and graduate students at these universities, and the current plan is that this project will provide then necessary support to use our platforms.

Scheduled for May 14th, we will be presenting a seminar the Naval Postgraduate School in Monterey California. This presentation will include an exposition of this project and we aim to try to drive some interest. The date of this seminar has been chosen to accommodate Professor Brian Bingham's schedule. Brian wrote a letter of support for this project originally, has expressed some interest in using this type of platform in an educational setting, and we are looking forward to discussing this in person during the visit.

Finally, we have been contacted by Rebecca Fao and Robert Raye from NREL. They have expressed some interest in this project and we have a meeting scheduled with them on May 1st, 2024.

c) Training and Professional Development Opportunities

Post-doctoral fellow Chris Dizon at Oregon State University (under Professor Ted Brekken) continues to work with the MBARI and Sandia Engineering teams. Chris is now running the simulation developed by this project and working towards a paper that characterizes the performance of the Gazebo simulator developed here as well as the WEC-Sim model of the MBARI system developed by Sandia National Labs. In each case these simulations are being compared to field-data collected from the current deployment of the MBARI system.

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 addition to these outreach efforts, we will continue to improve the documentation of the system to fill in some holes. We will also continue to work towards validation of the systems performance, these results to date have been very promising and we are very close to the submission of a journal paper outlining the comparisons of the simulator performance with the at-sea measurements.

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 and Chris Dizon at Oregon State University as users of this project's products.

- We are working to develop a collaborative project with Jim Thomson (UofW), Curtiss Rusch (UofW), Mick Haller (OSU), and Brian Polayge (OSU). Their efforts would be supported by BIL funds through UMERC, and this project funding would support their work with the MBARI buoy system. Discussions continue but funding is not yet officially secured.

- Recently, we have been contacted by Rebecca Fao and Robert Raye at NREL, they have expressed some interest in this project and we will be meeting with them on May 1st 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.