Open Wave-Energy Control System Development Platform

FOA/Topic

Marine Energy Foundational Research and Testing Infrastructure
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Topic Area 1 (Foundational Research and Development)

Team Member Organizations

Monterey Bay Aquarium Research Institute
Open Robotics

Technical Points of Contact

Andrew Hamilton, Ph.D.
Monterey Bay Aquarium Research Institute
hamilton@mbari.org

Tully Foote, Community & Business Development Manager
Open Robotics
tfoote@openrobotics.org

Business Point of Contact

Danielle Haddock
Monterey Bay Aquarium Research Institute
danielle@mbari.org

Background and Aims

The wave-energy conversion field has a rich history of control system research that has characterized the possibility of dramatic performance and reliability improvements for wave-energy systems based on a variety of optimal control strategies. The technical problem is characterized by a miss-match between the natural frequencies of the devices and the lower frequency of wave-excitations found in the ocean [1]. This is especially true for smaller devices envisioned for "Powering the Blue Economy" applications. Any control system that can effectively narrow this gap increases power capture and a wide variety of approaches to do this have been investigated. Existing research commonly highlights that a 3-5 times increase in energy capture may result from careful control system design when compared to linear damping control [2]. These insights are from sophisticated work that has been done in this field, but are mostly based on computer simulation due to the high cost of at-sea hardware. There is a pressing need to investigate what is possible in real-world conditions, which introduce a myriad of interfering factors. Unfortunately, most existing wave-energy hardware is part of commercial developments that are generally not available to the academic research community.

The aim of this project is to help reduce the barrier to real-world testing by making an existing wave-energy converter currently operating at the Monterey Bay Aquarium Research Institute (MBARI) available to any research group that is interested in applying promising control-system techniques and measuring the resulting performance improvement. To achieve this MBARI and Open Robotics will collaborate to develop an interface based on open source software for the existing buoy system such that a wide variety of researchers can develop implementations independently. We will also include a simulation capability that will enable researches to quickly iterate and validate the performance of their algorithms. In addition to established experts, we aim to draw in researchers that are not traditionally engaged in wave-energy technology. The process and tools chosen for this effort are familiar to the most recent generation of researchers who will bring new perspectives and skills to the problem.

Research Plan and Methodology

In this project we will create a software interface based on the popular *Robot Operating System* (ROS) for control of the MBARI wave-energy converter. ROS is the de-facto standard for development in most robotic domains and has hundreds of thousands of active monthly users [3, 4]. Open Robotics leads the development of ROS, and their extensive experience using this software will be critical for the success of this project (see addendum). MBARI has completed many deployments of the target system and is committed to continue to do so in the coming years to advance our goals of demonstrating wave-powered oceanographic science and autonomous underwater vehicle recharge. These activities require the buoy system to be at sea for extended periods of time, which will provide an opportunity to test control system software without the cost of dedicated deployments.

MBARI wave energy buoy

The MBARI wave-energy converter is a 250 W (average) system designed to support oceanographic research and is suitable for other "Powering the Blue Economy" applications. MBARI typically performs up to two deployments of this system each year, each with a duration of 3-8 months. MBARI's focus for the next several years is to increase the reliability of this system and use it to perform demonstrations of remote and autonomous oceanographic science. MBARI

plans to continue to refine this system through repeated deployments in Monterey Bay and it is therefore available without requiring support from the proposed project for the full cost of deployment, recovery, maintenance and operation. The existing wave-energy converter is a complete system and includes a four-quadrant power take-off device, extensive instrumentation and telemetry, as well as on-board battery storage and computing infrastructure. There is 4G cell-phone coverage at the deployment site, which enables real-time interaction with the on-board computing network. With the planned software infrastructure in place, it will be routine to upload and test new control software on a regular basis.

Robot Operating System and Simulation

ROS is a widely used open source robotics framework that allows systems to be architected as a collection of independent processes and to re-use software components that solve common tasks in the field of robotics. The use of this technology in MBARI's wave-energy conversion system will result in an API (Application Programming Interface) to the buoy hardware that any researcher could interact with in a predictable and uniform way. Additionally, the buoy dynamics, hardware, and on-board instrumentation will be simulated so that algorithm development and testing can be performed offline and the result uploaded to the deployed buoy for execution. This code-commonality is a very successful paradigm in ROS and Open Robotics has extensive experience with this approach. In addition to the instrumentation and telemetry systems on the buoy, the buoy dynamics must also be included in the simulation. ROS contains simulation and visualization tools that can be used for this project. External models and domain specific simulations, such as WEC-Sim, can also be integrated into ROS as needed.

Project Phasing

The proposed project will be split into two phases. The first phase will include the ROS infrastructure and simulator integration, and release of the resulting tools into the open source world to solicit participation by outside research groups. Activities during this phase will be the development of the ROS infrastructure, including sufficient documentation and examples such that a researcher new to the field will be able to download, install, and experiment independently. MBARI and Open Robotics will also provide some technical support and review of results during this phase. The first phase will not involve the hardware system and can be accomplished without in-person interactions. The second phase will be to deploy promising candidate codes on the buoy hardware system at sea. Selected external participants will be given the opportunity to run their algorithms on the buoy at a scheduled time. The second phase will require some involvement and oversight from MBARI, including scheduling, software upload, monitoring, and data dissemination.

Risks and Mitigations

There are both programmatic and technical risks to be considered. Programmatically, there is a chance that the expected group of outside researchers will require encouragement to participate. This may need to be addressed through sufficient marketing and presents a good opportunity to engage the Foundational Research Network Facilitator described in Topic Area 3 to expand the network of research entities involved in marine energy research. Additionally, the outcomes of this project would provide an opportune platform for software competitions, which have proven to be an effective way to drive interest in the robotics community. As some evidence of interest to date, MBARI is currently collaborating with two outside groups on projects similar to what we envision

in this proposal. First, Umesh Korde (Johns Hopkins University) and MBARI are funded by the National Science Foundation to perform on-buoy radar integration and testing to measure incoming wave characteristics for control purposes. Second, Ryan Coe's group (Sandia National Laboratories) is working with MBARI to deploy at sea the control approaches they have been demonstrating success with in a wave-tank [5]. We view both of these collaborations as exciting test cases for our plans of making our system available for outside research purposes. Due to the lack of open software infrastructure at this time, these collaborations require significant MBARI engineering assistance to execute and are therefore not scalable to a larger number of researchers, a situation this proposal addresses.

Technically, it needs to be considered that often control system development is most fruitful when incorporated early in the design process of a wave energy converter, and that we are not operating in that ideal situation. To address this issue, the first step in our collaboration with Sandia National Laboratories has been to extend the numerical modelling performed to date for the MBARI system to include a more detailed model of the specific electro-hydraulic power take-off hardware. We plan to evaluate and implement appropriate changes to the system as needed to accommodate the specific control system approach under consideration. This analysis will be publicly available and will be a good reference for any outside groups performing control-system research under the proposed effort. Similarly, our work with Umesh Korde will result in additional sensing capabilities on the buoy system that will become part of the infrastructure available to all users. As exemplified by these efforts, changes to the existing system are possible and we are prepared to add additional instrumentation if the simulation phase of this project highlights the need for such measures.

Impact Potential and Relevance of EERE Funding

In addition to advancing control-system technology for wave-energy conversion, this project will recruit a wider range of researcher and technologies from the academic and robotics community than are traditionally involved in this field. ROS has been chosen as the technology infrastructure specifically because of its appeal to the target community and the stature Open Robotics enjoys in that community. By engaging students and early-career researchers the efforts proposed here will train the next-generation workforce in the technologies, challenges and opportunities of wave-energy conversion. Finally, this project will provide a research platform that will support activities of the Topic Area 3 Foundational Research Network Facilitator.

By supporting this project, EERE funding will be leveraged with MBARI's internal grants from the David and Lucille Packard Foundation to provide an open research and development platform for wave-energy converter control-systems. We anticipate that this situation will create an incentive for researchers to pursue additional funds from other sources. Similarly, we predict that follow-up projects will be attractive from a cost point of view to grant making organizations that typically would not embark on a hardware development project due to the high cost of such work. To achieve the goals outlined here, the involvement of Open Robotics is critical and funding will be necessary, as external collaborators are not eligible for Packard Foundation funding.

References

[1] Falnes, J. (2002) Cambridge University Press. [2] Hals, J. et al. (2011) JOMAE, 133, 031101:1-12
[3] www.openrobotics.org [4] http://download.ros.org/downloads/metrics/metrics-report-2019-07.pdf
[5] Coe, R.G. et al. (2018) Report Number: SAND2018-12858

Addendum

Monterey Bay Aquarium Research Institute

MBARI has been developing and fielding small-scale wave-energy conversion devices since 2009 and has all of the requisite skills and hardware in place to continue to do so. MBARI is motivated by a desire to bring the promise of wave energy to oceanographic science and is actively working on this application alongside the development of the wave-energy conversion technology. The existing wave-energy conversion hardware is complete in its ability to support the proposed software infrastructure development. MBARI as an organization recognizes the importance of expanding the field of researchers working in the wave-energy control systems area and therein lies the motivation to support this project. MBARI is located in Moss Landing, California and operates three research vessels in and beyond Monterey Bay throughout the year. MBARI has all the engineering and manufacturing personnel and capabilities on site to complete the proposed effort.

Open Robotics

Open Robotics is extremely well suited to the tasks envisioned. In addition to developing and supporting ROS, this group has a long track record supporting open competitions to facilitate community-based innovation. Open Robotics has worked with DARPA, NIST, NASA, ONR, NPS, and Toyota to facilitate competitions with hundreds of competitors and millions of dollars in prize money. These competitions have ranged across all types of platforms, from cars, to drones, to boat, to humanoid walking. They have simulated many different environments from the ocean to underground, to factories, to orbital space and Mars. Open Robotics specializes in building software to facilitate the growth of the global robotics community. The community has grown to be many hundreds of thousands of users worldwide.

Selected Resources for further reading:

- https://www.ros.org
- https://www.osrfoundation.org/ros-gazebo-at-the-drc-finals
- https://spectrum.ieee.org/automaton/robotics/robotics-software/coordinated-robotics-winner-nasa-space-robotics-challenge
- https://www.openrobotics.org/blog/2019/3/18/new-virtual-robotx-competition