Predictability-bounded control of the Mocean WEC

WES Control Systems Stage 1
Public Report

University of Bath

wave energy SCOTLAND

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1 Project Introduction

This project investigated the feasibility of applying an adaptive control methodology to the Mocean Wave Energy Converter (WEC) in conjunction with a fully electrical rotary Power Take Off (PTO) system. Detailed modelling and simulation activities were undertaken for the WEC and PTO subsystems, and then these were combined in a unified model and the control system applied in order to assess the performance of the complete system against WES target performance metrics. The purpose of the control system is to maximise energy capture within the physical constraints of the WEC and PTO across a wide range of sea states.

The project team consisted of members of the University of Bath Departments of Mechanical and Electrical Engineering, and Mocean Energy. This report summarises the work performed by the consortium under a Stage 1 WES Controls project which ran from October 2nd, 2017 to January 18th 2018.

2 Description of Project Technology

The Mocean WEC is a hinged raft with two bodies connected by a single revolute joint. Wave forcing and the bodies' dynamic responses cause a relative motion about the hinge. A rotational PTO at the hinge transforms the kinetic energy into electricity. Currently Mocean are in a WES Stage 2 NWEC project. In this project Mocean are considering a full-scale model of the WEC with a fully electrical rotary Power Take Off system.

The proposed control methodology is computationally simple and is designed to keep the WEC velocity in phase with the wave excitation (a necessary condition for efficient power conversion) while also accommodating physical constraints such as position limits in a simple and robust manner. The control strategy employs predictability analysis and online nonlinear modelling to maximise usable control bandwidth within irregular seas whilst disregarding frequency components with low estimation certainty. In this way, the performance of the controller is not adversely affected by poor sea state or system model estimation as would be the case for most optimal controllers. There are several advantages to this methodology:

- Very low computational overhead compared to other nonlinear model structures.
- Inherent adaptation as the plant changes due to bio-fouling, ageing and damage.
- Applicability to all WEC/PTO system combinations as they can capture nonlinearities such as dead zones, friction and rate limits.
- Operation on different data types simultaneously, which offers the possibility of including data from weather forecasts or other such sources into the model structures.

3 Scope of Work

The study aimed to demonstrate the feasibility of the proposed control system in terms of the following requirements:

- The control system is stable.
- A performance benefit is seen against target metrics compared to the optimally tuned passive system.
- Implementation is possible using only information that is physically measurable using standard sensors.
- The control system will execute in real time using available hardware.

Dynamic models of the WEC and PTO systems were developed and used to compare the performance of the active control strategy to the optimally tuned passively damped benchmark system. A range of irregular sea states were used to excite the system representing realistic conditions for which the WEC is sized.

All required algorithms to calculate or estimate the quantities needed to implement the control were developed and deployed on standard real-time control hardware to demonstrate feasibility of implementation.

4 Project Achievements

The feasibility of the control system was demonstrated. The main achievements were:

- Development of a comprehensive simulation model of the Mocean WEC
- All required algorithms to calculate or estimate the quantities needed to implement the control were developed and demonstrated to have sufficient accuracy to make implementation feasible
- Implementation of control including realistic restrictions such as torque limits and uni-directional power flow in the PTO
- Up to 80% increase in captured power compared to the optimally tuned passive system
- Demonstration of real time deployability on standard hardware

It has been demonstrated that all required information to achieve control is available from encoders mounted at the PTO drums and from torque sensors at the PTO or current measurement within the generator. It has been demonstrated that this information which is measurable can be used to calculate or estimate with sufficient accuracy all information required to achieve control, assuming that hydrodynamic models have sufficient accuracy. This directly enhances the **integratability** metric. Furthermore, the control strategy does not rely on forward prediction of the wave excitation which would increase uncertainty, reduce robustness and erode **performance, reliability** and **integratability** metrics.

The computational overhead of an algorithm limits the sampling rate which can be used. If the computational burden is too high to permit a sufficiently high sampling rate to achieve control then the algorithm cannot be said to be feasible in terms of real-time implementation. The algorithm was developed in the Matlab/Simulink environment and then extracted and flashed to standard real-time hardware. It was found that the computational overhead was very low as predicted, enabling sampling rates of up to 1.25kHz to be used. Therefore, the control system can be implemented using standard low-cost hardware **[affordability, reliability, integratability]**.

A control system may be feasible but not offer any significant performance benefit over a well-tuned passively damped system. It has been demonstrated that up to 80% more power can be captured in a range of sea states using the active control system as a four-quadrant (4Q) controller. It may not be possible to implement 4Q control, or it may not be desirable. Therefore, it has also been demonstrated that the control system can be implemented with a two-quadrant restriction. This still offers good improvements in power capture (up to 65%) compared to the optimal passive system. Stability has not been an issue, even with the non-linearity of the 2Q restriction. This directly enhances the **integratability** metric.

Overall the study has been successful and feasibility has been demonstrated. It has not been possible to investigate all aspects of the study due to time constraints and underestimation of the system complexity. However, the performance benefits of the control strategy provide a compelling case for further investigation. In particular, the complexity of applying predictability analysis to the problem was underestimated. This aspect of the work was proved feasible to implement, but the benefits of doing so were not able to be explored within the project timeframe.

5 Recommendations for Further Work

While the hydrodynamic parameters of the Mocean WEC should be accurately captured by BEM codes, there could be errors. Further errors could be introduced if fault conditions occur or if the plant changes due to ageing or biofouling. It is anticipated that this is one of the main benefits of the proposed strategy over other control systems, as it can adapt to the changing conditions. Further work could confirm the robustness of the control system to parameter change and uncertainty.

It was envisaged at the outset of the project that the control strategy would employ predictability analysis to maximise control bandwidth within irregular seas whilst disregarding frequency components with low estimation certainty. In this way, the performance of the controller would not assume perfect sea state estimation and would not be adversely affected by poor estimation as would be the case for most optimal controllers. While significant progress was made with this aspect of the study, the complexity of implementation was underestimated. As a consequence, it was not possible to include this aspect of the control strategy within the available time. The consortium still believes there is potential merit in this approach and that further investigation is worthwhile.

A PTO model was generated based on information available and was fit for purpose in Stage 1. Further work will explore possibilities with PTO suppliers to tailor the PTO model to a specific device. This investigation, along with power electronic component modelling, will facilitate the design of a hardware-in-the-loop implementation for physical testing.

These avenues will be explored as part of a stage 2 project should it be granted.

6 Communications and Publicity Activity

Poster presentation at 2nd Annual Wave Energy Scotland Conference, 28th November 2017, Edinburgh, UK.

7 Useful References and Additional Data

[1] Mocean Energy Ltd. Predictability-bounded control of the Mocean WEC: R01 – WEC hydrodynamic model. Wave Energy Scotland Controls 1, 2017. CONFIDENTIAL

[2] University of Bath. Predictability-bounded control of the Mocean WEC: R02 - Power take-off system modelling. Wave Energy Scotland Controls 1, 2017. CONFIDENTIAL

[3] University of Bath. Predictability-bounded control of the Mocean WEC: D01 – Control system feasibility study. Wave Energy Scotland Controls 1, 2017. CONFIDENTIAL