A Framework for Wave-to-Wire Simulation of Wave Energy Converters for Autonomous Underwater Vehicle Recharging

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Abstract

Wave energy converters (WECs) generate the necessary power to recharge an autonomous underwater vehicle (AUV) to enable a persistent and sustainable mission performance at remote locations. This research aims to develop a comprehensive framework for modeling the hydrodynamics of a WEC-AUV dock system, optimizing the AUV homing and docking trajectory, and predicting the power status of a docking station and AUV. The main objectives are to (1) develop WEC-AUV dock system hydrodynamic model for analyzing the WEC and dock dynamic responses and estimating the power output, (2) couple AUV homing and docking autonomous algorithms to determine the optimized trajectory, and (3) to integrate a power model for prediction of real-time power production and consumption.

The WEC-AUV dock hydrodynamic model is developed using a commercial time-domain analysis software package, ProteusDS. The hydrodynamic forces are calculated using hydrodynamic coefficients provided by the frequency-domain boundary-element method (BEM) solver (e.g., WAMIT). Other force components (e.g., power-take-off (PTO) force, mooring force) could be included in the linear or nonlinear expression. This model is used to perform a wave-to-wire simulation of WEC for AUV recharging. The prediction of dock dynamic responses is applied to couple of AUV navigation algorithm to determine the optimal homing and docking trajectory. The power generation estimation is used to couple the power model to perform power tracking.

With the goal of reaching the docking station from an arbitrary location, the AUV must be able to navigate autonomously through unexplored obstacle-free environments considering nonlinear and differential constraints. To accomplish this, a navigation framework that couples flow state estimation with a closed-loop model predictive control (MPC) is designed and developed. The objective of this controller is to perform precise and reliable docking by predicting the optimal control input that accounts for the influence of ocean current disturbances. This navigation framework could be integrated in simulation to provide real-time AUV thrusters force to control the vehicle homing and docking.

The power model provides a framework in which possible mission characteristics and limitations may be identified. This model takes into account expected or observed sea states, modeled WEC efficiency, expected power draw from on-board instrumentation, and the power consumption of the AUV, which depends on its mission duration and profile. This framework may be used for different purposes. For example, based on a given sea state, this framework may provide an estimate of the frequency at which the AUV may perform a given mission. Alternatively, if integrated in simulation, it could provide real-time guidance that directs the system to recharge the AUV, begin an AUV mission, or recharge WEC batteries.

The AUV navigation algorithm and power model are integrated into the WEC-AUV dock hydrodynamic model through the application programming interface (API) of ProtuesDS and applied to model and analyze the WEC-AUV docking and charging system to demonstrate its modeling capability. The ocean environmental conditions at PacWave south location are characterized and employed in the simulations. A point absorber device is used as a representative WEC to produce the power. Two dock conditions including seafloor mounted and floating 3rd body dock are simulated. The dynamic responses of the WEC and dock are analyzed. The optimal homing and docking trajectory is determined based on the dock location predicted from the hydrodynamic model. The real-time power at the docking station and AUV are predicted.