Abstract

Currently, a significant effort in global research is focused on finding efficient solutions for a carbon-free energy supply. World energy demand has increased significantly over recent decades, making clean and efficient energy production one of the most crucial challenges. In the context of renewable energy, ocean wave energy has emerged as one of the most promising sources. With its vast yet untapped potential, properly exploiting wave energy could make a substantial contribution to the overall energy supply. Despite the abundance of ocean waves as a resource, the levelised cost of energy for wave energy systems still cannot fully compete with other renewable technologies, primarily due to the high costs associated with their conversion process. In this context, the development of energy-maximising control strategies is crucial for the economic viability of wave energy technology. These control strategies are responsible for maximising the energy absorbed by wave energy devices while ensuring the safety of all mechanisms involved in the conversion chain, and adjusting their action to the wave resource whose characteristics are continuously changing.

At the state of the art, most strategies developed to control wave energy systems adopt a control-oriented model, which is the result of simplifying assumptions on the system equations that could affect the optimality of the computed action or even jeopardise the safety of operations. Given the specific nature of wave energy systems control and control-oriented modelling, the motivation behind this thesis is to contribute to the development of reliable, energy-maximising, and accurate control strategies, aiming to leverage data-driven and data-based modelling and control design approaches.

This thesis presents two main contributions. Firstly, different data-based approaches (frequency-domain, time-domain, and set-membership identification) to solve the control-oriented modelling problem of wave energy systems are presented and assessed using real data obtained from two experimental campaigns on different devices. The obtained models are successfully validated in both controlled and uncontrolled conditions, ensuring a mitigation of the modelling errors associated with the standard modelling approach.

Secondly, the adoption of data in the synthesis of optimal control strategies is investigated. A robust output feedback predictive control strategy able to robustly guarantee stability, handle constraints, and maximise energy is proposed and robustly compared to state-of-the-art control strategies (impedance-matching-based controllers and standard model predictive control). Following this, an adaptive predictive controller that can efficiently identify a model of the system online and reduce the conservativeness associated with robust approaches is proposed and compared to the other analysed control strategies. These two proposed control strategies exploit data in different ways and provide various tools to successfully deal with control-oriented model uncertainties in the wave energy system control framework.

The presented results obtained by exploiting data within the processes of control-oriented modelling and optimal control synthesis demonstrate the potential of the proposed approaches in contributing towards the development of reliable, energy-maximising, and accurate control strategies.