FOREWAVE

WES Control Systems Stage 1 Public Report

Innosea Ltd

This project has been supported by Wave Energy Scotland

1 Project Introduction

Project FOREWAVE aims at developing a set of methodologies to provide high quality inputs for several types of control techniques. These methodologies will be based on the device motions and states alone. Providing better methodologies to generate the inputs required by all type of control methodology will benefit the WEC industry as a whole.

For most WECs, control laws parameters can be mapped with respect to the average incident sea state (H_S, T_E, others), therefore a reliable real-time sea state estimation with no need to rely on external wave measurement or forecast will be beneficial for all WECs. Such methodology will also be able to integrate into the estimation the reflection of waves in array deployment. Additionally, WEC performance could be greatly enhanced if short term wave force were available, by applying several control techniques needing this input (e.g. optimal control, latching control, MPC, others).

The project is divided in two main parts, the first addresses sea state estimation, by linking the device motion parameters to the sea main parameters, whereas the second part focusses more on the estimation and prediction of wave forces via real time dynamical modelling.

Benefits expected from such techniques regard mainly WEC developers, that will be able to obtain the present wave state as an input for their device and reduce therefore the WEC development cost. Additionally, by obtaining the wave force prediction it will be possible to implement a series of high performance control logics maximizing the energy yield of the WEC single device and farm.

2 Description of Project Technology

2.1 Sea state estimation

Two different techniques for the estimation of the sea state conditions from onboard measurement were explored during Stage 1.

The first technique makes use of the response amplitude operator (RAO) associated with a degree of freedom of the WEC which is not affected by the PTO. The spectrum of motion of the unaffected degree of freedom is estimated and combined with the RAO to obtain an estimate of the incoming sea state spectrum. The sea state parameters that are used as inputs for WEC control strategy are estimated from the estimated incident spectrum. The deployment of this strategy requires one of the degree of freedom from the WEC to be independent from the PTO action and to have a fairly linear behaviour over a wide range of operational conditions (the RAO must be valid for the technique to be applied successfully).

The second technique involves the establishment of formal link between the observed motion and the sea states characteristics for the full range of operational conditions. There is no assumption on the WEC behaviour, and all the onboard observation are potentially considered. The timeseries of the onboard observations are first reduced to parameters similar to the sea state parameters that should be estimated (significant wave height, period estimator and broadness). Then, using a dataset obtained from simulations, tank tests data or real measurements at sea, a multilinear regression model is fitted between the onboard parameters and the incident sea states. The models are then reduced to keep only the significant parameters. Once the multilinear regression models are established, they can be used to estimate the sea states parameters using onboard measurement during the device deployment.

2.2 Short term wave forcing prediction

The short-term wave prediction is focused on providing an estimation of the wave forcing on the system for the 10 to 20 second forecast horizon. The algorithm developed by Polito makes use of a neural network and auto-regressive model, which is trained for each considered sea state:

- The forecasting is performed through an auto regressive filter, and this auto regressive filter is fed with an estimation of the wave pitch force obtained through a feed forward neural network using the onboard available signals such as PTO position/velocity/force, hull accelerations and velocities.
- The neural network training is performed with simulations, and that involves limitations regarding the accuracy of the WEC model. In future evolutions, the neural network will be retrained with real values.

Providing estimation to the wave forcing for up to 10 to 20 second could be very beneficial for WEC which control strategy relies on MPC type controller increases in the order of 20-25% could potentially be achieved with even a few seconds of prediction.

3 Scope of Work

In Stage 1, the work undertaken for the three techniques described above was focused on preliminary feasibility assessment. An exhaustive assessment of limitations and hypothesis involved in the deployment of each technique was produced. The principal technical hurdles were identified, and initial work was carried out to lift them out. In all three techniques, the ISWEC device was considered as a case study (www.waveforenergy.com/tech/iswec).

For the first technique, the heave motion of the ISWEC device is considered, as it is fairly independent of the other degree of freedom and of the PTO action. The heave RAO of the device was obtained through potential flow theory modelling. Experimental data from the deployment of ISWEC at the Pantelleria site were then used for the feasibility assessment. Three records were selected from the available data based on the recording quality. For those three sea states, the spectrum of the heave motion was extracted from the onboard measurement, and the sea spectrum was then computed using the heave RAOs. The estimated sea spectrum was compared with the incident sea spectrum recorded on site during the deployment. The impact of several parameters entering the estimation of the heave spectrum was also assessed.

For the second techniques, a large body of simulation is required to establish the multi-linear regression models. As such a body of data was not available from experimental sources, numerical simulation results were used. 228 irregular waves simulations capitalising on the partner experience with the ISWEC device were generated. Once filtered for suitability, a subset of 117 simulations was used to define the models. Models linking the onboard WEC state observations to the significant wave height, the energy period and the spectral bandwidth of the incident sea state were established. A separate subset of 20 sea states selected randomly from the initial dataset was then used to tests the models and obtain a first estimation of the forecast errors.

In the short-term prediction techniques, an algorithm tailored to the ISWEC device was developed. Eight sea states representative of the ISWEC deployment site at Pantelleria were selected for the feasibility analysis. The neural network was trained, and the results were tested using some of the simulation data generated for the second work-package. As real-time implementation of the prediction is crucial in the context of short term prediction, the algorithm was then ported into LabView and implemented on a CompactRIO real-time processor as used on the ISWEC for control algorithms. The performance of the algorithm was monitored as well as the load on the CompactRIO's CPU.

4 Project Achievements

The project achieved its aim for the three techniques investigated.

For the first technique, the results were good on the three selected sea states, with errors in the prediction of the sea state parameters in the +/- 10% range in most cases. For the second technique, the initial work conducted shows that, within the limitations of the work (limited by the representability of the numerical model), models could be fitted to the data successfully. However, due to the relation between the period of resonance of the device in pitch and the range of sea state studied, there remains a doubt on the possibility to find suitable models covering the entire range of periods encountered.

For both techniques, the project uncovered a lack of clear metrics available to define the success of the forecast. First and foremost, the forecast obtained from this method should be of similar quality to the forecast obtained by other means. Second, the forecast quality should be good enough in the sense of the acceptable level of errors is the one that does not induce significant errors in the setup of the parameters of the control strategy making use of such forecast. There isn't clear definition related to these two conditions.

The work on short term prediction of wave forcing demonstrated that it is possible to define an algorithm based on a neural network and to train it to provide a good estimation of the wave forcing in the 10-15 second forecast horizon. There is still some limitation that must be lifted, and the method must be validated for a wider range of sea states.

The work also demonstrated the applicability of the method in a real-world environment by implementing the algorithm on a real-time controller similar to what will be available in a deployed full scale WEC. As for the sea state estimation, the team lacked from a clear definition of success for the short-term forecast.

5 Recommendations for Further Work

Future activities should:

- Dedicate time to define suitable metrics for the evaluation of the results of the project through engagement with the potential users of the forecasts.
- For the sea state estimation, it is necessary to factor the rate of change of the sea states parameters into the assessment of the methods accuracy and success. As the sea states are constantly changing, the estimation of the future sea state (the one for which the controller must be adapted) using the previous timeseries should indeed factor in the uncertainty due to changing sea state characteristics.
- Linked with the previous points, an exploration of the record length impact on the forecast quality should be conducted. Frequent update on the sea state estimation would potentially alleviate issues regarding fast changing sea states.
- A comparison of the two methods implemented to estimate the incident sea states is required. For the WEC type that can implement both, this could show that a combination of both might be required to obtain best results, or that one of the methods is a clear winner.
- For all the techniques employed, using a wider range of sea states is required to validate the models. This includes different spectral shape, not only variation over Hs and Te. When numerical simulation is required to set up the algorithms, using real spectra with the desired spectrum parameters would be useful for validation. This will allow a proper mapping of the methods capabilities as a function of the considered sea states.

- For the second method employed to estimate the sea states, it is necessary to widen the range of period considered in order not to have the resonance period of the device at the edge of the range. This will allow the fitting of more robust statistical models.
- For the short-term description, it will be interesting to have a demonstration of the method while it is used. In other words, it will be necessary to demonstrate the wave forcing prediction while using the wave forcing prediction to control the device. This will however only become possible at later stages, where the forecast techniques studied in FOREWAVE will be incorporated within the WEC control strategy themselves.
- For all the methods, it is important to apply the techniques to other type of WECs to demonstrate their possible application to a wide range of devices.

6 Communications and Publicity Activity

During the short time of the stage 1 project, the publicity activity undertaken was the presentation of a poster describing the project during the annual WES conference.

7 Useful References and Additional Data

More details are provided regarding the work conducted in the confidential reports of the project:

- D02_FOREWAVE_Sea state estimation from unaffected DoF motions [version 2, 20180319]
- D03_FOREWAVE_Sea State Estimation from internal measurements [version 2, 20180305]
- D04_FOREWAVE_Short-time wave force prediction [version 1, 20180119]