Development of a Novel Wave-force Prediction Model based on Deep Machine Learning Algorithms

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ABSTRACT

The future knowledge of the waves and force is indispensable for the model identification and the real-time control of ocean engineering devices. In order to effectively control the motion of the offshore structures in a real-time manner, it is required to have an accurate and efficient prediction of the waves. Machine learning has been widely applied in ocean engineering field as it offers compromise between prediction accuracy and computational cost. The present study focuses on wave-force prediction of offshore structures based on deep machine learning algorithms. A novel wave-force prediction model is proposed, which makes full use of the efficient processing characteristics of Long Short-Term Memory Recurrent Neural Network (LSTM RNN) and Nonlinear Autoregressive Exogenous Feedback Neural Network (NARX FNN) for time series data processing. The relationship between the wave height and the wave height is non-causal and nonlinear which need future wave height knowledge for current wave excitation force. Therefore, The LSTM RNN is firstly utilized for multi-step prediction of the time series of wave elevation. The NARX FNN is used to address the model system identification between the wave heights and the wave force. Then, the LSTM RNN is further applied to predict the future force of offshore structures for the real-time control of the structure motions. After that, the proposed deep machine learning algorithm is utilized for wave-force prediction based on the experimental data obtained in Kelvin Hydrodynamic Laboratory and the optimal horizon can be specified for the test model by comparing the performance of different prediction horizons. The results indicate that LSTM-NARX model can successfully predict the time series of the waves and force.

KEY WORDS: wave-force prediction, deep machine learning, LSTM RNN, NARX FNN.

1 INTRODUCTION

Wave energy as a dense and stable renewable energy resource is forecast to have the potential to supply 10% of European electricity needs or to generate the equivalent of up to 20% of UK electricity; about half today’s total renewable generation. WECs convert the oscillation of kinetic and potential energy carried by ocean gravity waves to electrical energy that can be delivered to the electrical grid through a mechanism known as power take-off system (PTO) (Anderlini, 2019). Wave energy drives two or more parts move relatively then energy is captured by hydraulic mechanic or direct drive. However, there is no wave energy converter reaching commercial stage due to its high levelised cost of energy (LCOE).

There is one of the ways to move a step forward by improving the power absorption efficiency under real-time control. By controlling the force exerted from PTO system, such as latching control, it is possible to tune the velocity of WEC with the excitation force of incoming wave for achieving the maximum energy absorption. The wave excitation force is regarded as the combination of incident component and diffraction component from the view of linear potential theory (LPT).

There are myriad reasons to explain why predicting wave is important, from surfer and swimmers to shipping route planning, from offshore structure protection in extreme condition to stabilising renewable energy electrical grid. There are also reasons for wave prediction in WECs operation: as illustrated in (Garcia-Abril, 2017), for implementation of many energy maximising control strategies, there are two processes requiring future knowledge of the incoming wave experienced by WEC. Falnes (Falnes, 1995) described the non-causal characteristic of wave excitation force deduced by wave elevation, and future wave elevation is necessary information as well. It is a open problem to predict wave excitation force for decades. Fusco and Ringwood (Fusco, 2012) assumed that in-coming wave elevation is known fully or in the near future, as well as Son and Yeung (Son, 2017). Also there are researchers realise wave force prediction in alternative methods, for example linear superposition (Li, 2012), Kalman Filter (Ling, 2015) and Artificial Neural Network (Li, 2018) and these mentioned prediction methods have been used in control implement of WEC. These methods are based on physical fundamamation or processing statistics. Because of the complicate nonlinear relation between wave height and wave excitation force, data extrapolation performance of existed prediction tools is not accurate enough for a long short-term prediction of Model Predictive Control (MPC). The accuracy of the model of the body dynamics strongly affected the performance of real-time control methods (Anderlini, 2017). Only if an accurate wave prediction is obtained, the real-time control makes sense. The predicted wave force with unsatisfactory performance may cause negative effects with control commands. As wave force prediction plays an important role in real-time MPC control of WEC, a prediction algorithm with high accuracy and low computation cost is necessary to be developed, calibrated, and validated with the rapid development of wave energy engineering.

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