Digital twin modelling of floating offshore wind turbine with fully coupled aero-hydrodynamic simulation

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MOTIVATION

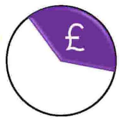
Offshore wind energy demonstrated as reliable energy source over the past decade and contributed to the road of decarbonisation Net Zero 2050. There was 48.2 GW offshore wind capacity already completed by 2021 [1]. Particularly, the Floating Offshore Wind Turbines (FOWTs) have received great attention, and it is expected to have higher potential to harvest wind energy than traditional fix-bottom type offshore wind turbines. In terms of the structural integrity and operational requirements, the mooring systems dictate survivability of FOWT under the extreme wave loading and the required station-keeping performance.

80%

of wind energy resource located in areas where the water depth greater than 60m, floating foundation for wind turbine is required [2]

16.5GW by 2030

Floating offshore wind forecasted based on 2021 [2]



36.6%

of FOWT total lifetime cost refers Operations and Maintenance cost [3]

SHM AND STATE ESTIMATION VIRTUAL SENSING

Structural Health Monitoring (SHM) is a critical asset for all kinds of engineering systems, especially monitoring the internal stress and displacement and providing alarm before any structural failure. Current offshore wind industry mostly adopted load cells, inclinometers and GPS for performing SHM of the prominent mooring system, as shown in the figures on the right. However, they have limitations in practice e.g., low accuracy and fragility problem of underwater sensors and cause high O&M cost and time consuming in repairment under extreme open sea conditions [4].

A common Physics model-based SHM is the use of Kalman Filter (KF) [5], it is widely adopted for state estimation and sensor data fusion, especially for SHM, vehicle tracking and manoeuvring, robotic control, etc. Its recursive algorithm can predict the state dynamics with measurement update, the Augmented KF can be employed for predicting unmeasurable states, in which the real sensor data acquisition is technically challenging, and estimating the unknown inputs e.g. forces and noise disturbance.

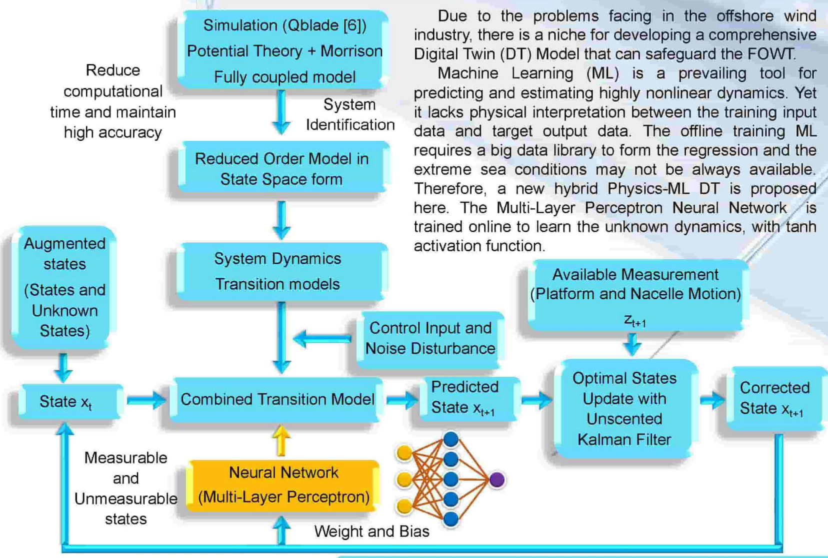
Aerospace NASA Apollo mission for tracking

SLAM for autonomous vehicle

SHM on massive civil infrastructure and failure detection

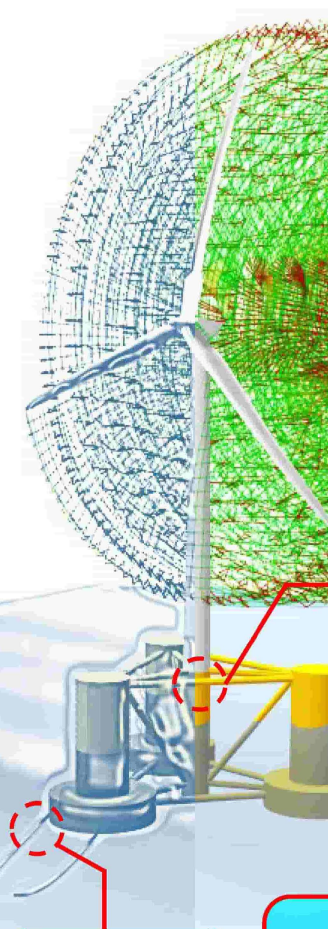
Application examples of Kalman Filter

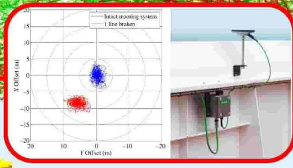
NOVEL PHYSICS – MACHINE LEARNING DIGITAL TWIN



Due to the problems facing in the offshore wind industry, there is a niche for developing a comprehensive Digital Twin (DT) Model that can safeguard the FOWT.

Machine Learning (ML) is a prevailing tool for predicting and estimating highly nonlinear dynamics. Yet it lacks physical interpretation between the training input data and target output data. The offline training ML requires a big data library to form the regression and the extreme sea conditions may not be always available. Therefore, a new hybrid Physics-ML DT is proposed here. The Multi-Layer Perceptron Neural Network is trained online to learn the unknown dynamics, with tanh activation function.





Differential Global Positioning System (DGPS) for floating structures

(Left) vessel offset due to a single broken mooring line. (Right) antenna of a DGPS monitoring system outside the control room of an FPSO. Courtesy: SOFEC

Load pin measurement

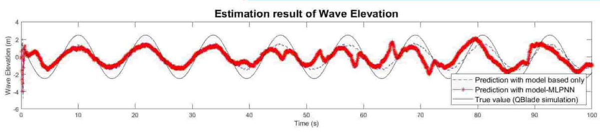
Mooring line termination at the hull of Statoil's (now Equinor) Hywind spar floater. Load monitoring pins mounted on mooring quick release hooks from Mampaey

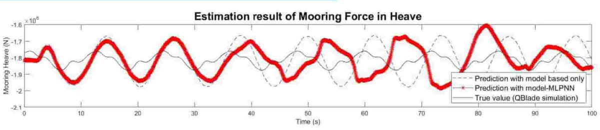
Indirect load measurement

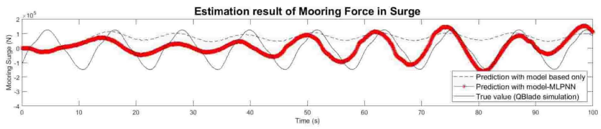
Inclinometers installed on top chain. Courtesy: pulse

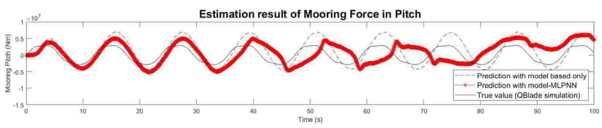
Mooring chain crack failure due to fatigue [4]

INITIAL RESULTS





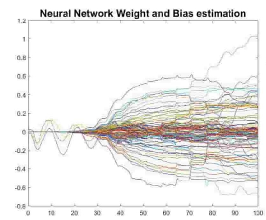




A case study of DeepCwind OC4 semi-submersible FOWT with only hydrodynamic loading considered is presented here. Virtual sensing of the unmeasurable mooring forces based on only the platform motion in surge, heave and pitch noisy measurement (0.05std). Which can avoid the huge cost of underwater sensor installation and maintenance.

Assuming only a dynamic model of moderate sea state wave height 2.5m and wave period 9.63s is known to predict a *"very rough"* sea state of wave height 5m and wave period 11.8s, with reference of LIFE50+ met-ocean [7].

- ***Significant improvement*** of predicting the Mooring Force in Surge with the compensated Neural Network nonlinear dynamics. In general, better estimations are achieved. The DT runs in MATLAB with a computer 11th Gen Intel(R) Core (TM) i5-1145G7 @ 2.60GHz 2.61 GHz, the process time is about ***10*** times faster than the time of data set.



PROGRESS AND FUTURE WORK

- ✓ ***Work accomplished*** was summarised in the publication *Yung, K. H-Y., Xiao, Q., Incecik, A., & Thompson, P. (Paper Accepted). Mooring force estimation for floating offshore wind turbines with augmented Kalman Filter: a step towards digital twin. In Proceedings of the ASME 2023 International Offshore Wind Technical Conference (IOWTC2023) IOWTC2023-119374*
- ***Future work*** will include the modification of KF and enhancement of observer robustness. Different wind, wave and current combinations will be investigated especially for extreme nonlinear Rouge wave and implications on FOWT fatigue life. Also, in-depth ML topics ***Deep learning*** and integration with ***High-Performance Computing*** will be carried out

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