A SHIP DIGITAL TWIN FOR SAFE AND SUSTAINABLE SHIP OPERATIONS

Mingyang Zhang *and* Spyros Hirdaris
Department of Mechanical Engineering, Marine Technology Group, Aalto University, Espoo, Finland
e-mail: mingyang.0.zhang@aalto.fi

Nikolaos Tsoulakos
Laskaridis Shipping Co. Ltd., Athens, Greece

This paper presents a novel digital twin that can predict ship motions and fuel consumption in real operational conditions. The analysis is based on two optimal Deep Learning Models (DLM) namely (a) a transformer neural network used for the analysis of ship motions and (b) a Long Short-Term Memory (LSTM) network for the prediction of ship fuel consumption. Comparisons of results against sea trial data suggest that subject to further testing and validation DLM could be used as part of a digital twin framework for safe and sustainable ship operations.

Keywords: *digital twins, ship motions, ship fuel consumption, big data science, deep learning*

1. Introduction

Shipping is responsible for more than 90% of the global trade. While it is a relatively safe and clean mode of transportation, it has a significant impact on the environment. Therefore, ensuring the safety and sustainability of ship operations through the proactive utilization of modern technology is a pressing concern.

Digital twins, originally conceptualized by NASA, enable the creation of a digital replica of an artifact to realize and diagnose, critical operational scenarios in real-time [1]. Digital twin technology has been adopted for integrated design and maintenance, as well as performance and safety improvements in modern and increasingly complex ship systems [2]. The traditional format of ship digital twins, which has been used to represent ships as physical entities during design, can be enhanced to monitor and improve ship safety and efficiency, prevent unnecessary outcomes, ensure environmental performance, and minimize downtime. However, it is important to note that the accuracy of physical models may be limited when dealing with complex operational conditions. This is because real operational conditions present unique challenges and factors that may not be adequately captured or accounted for in existing physical models.

Artificial Intelligence (AI) may offer improved predictive capabilities via the integration of deep learning algorithms for the prediction of ship motions [3, 4] and ship fuel consumption [5]. Challenges may arise in selecting a suitable model that matches the data streams, data compatibility and uncertainty modeling. This paper introduces a digital twin that incorporates two optimal deep learning models to achieve accurate predictions of ship motions and fuel consumption for safe and sustainable ship operations.

2. Deep Learning Methods (DLM)

The digital twin presented in this paper comprises two main deep learning Layers namely (a) Layer 1 used to idealise the ship energy system and predict fuel consumption and (b) Layer 2 that can be used to identify ship motions in real operational conditions (see Figure 1).

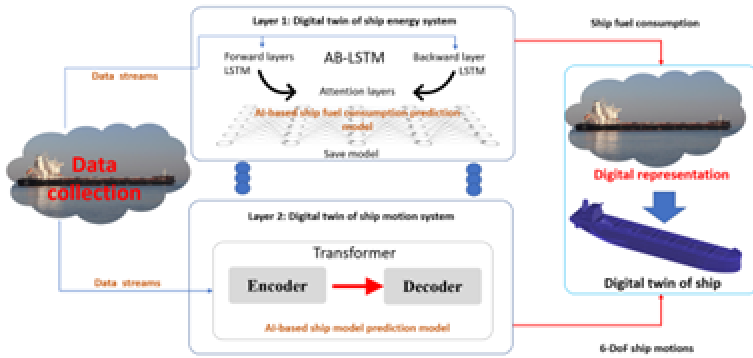

Figure 1: The overall procedure of AI-based digital twin.

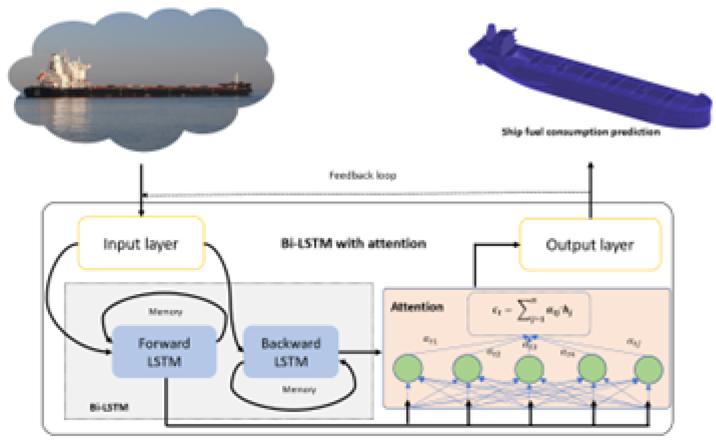

Figure 2: Ship fuel consumption prediction.

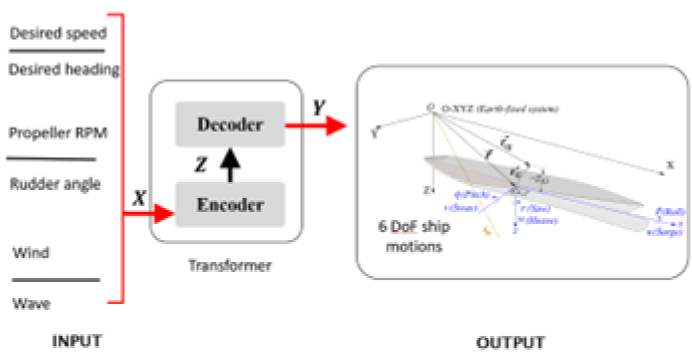

Figure 3: 6-DoF ship motion prediction.

In Layer 1 a wide range of sensors are used to collect navigation data (ship speed, course, etc.), operational/environmental condition data (e.g., draft, trim, wind speed and direction, wave height and direction, etc.), and engine data (fuel flow, propeller rpm, etc.). Then, an LSTM network is used to learn the influence of sailing speed, displacement/draft, trim, weather, sea conditions, etc. on ship fuel consumption (see Figure 2).

In Layer 2 the digital twin utilises Automatic Identification System (AIS), now-cast, and bathymetry da-ta records to extract motion trajectories in real hydro-meteorological conditions (see Figure 3). Then, a rapid Fluid-Structure Interaction (FSI) model and a transformer neural network [4] are employed to generate ship motion patterns while considering the influence of the surrounding water and ship-controlling devices.

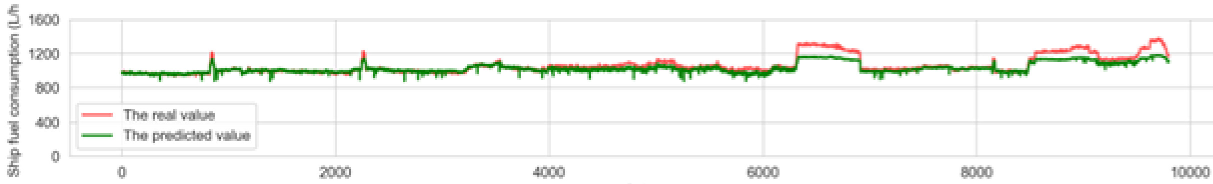

Figure 4: Comparison of fuel consumption from predicted (green line) and real (red line) data.

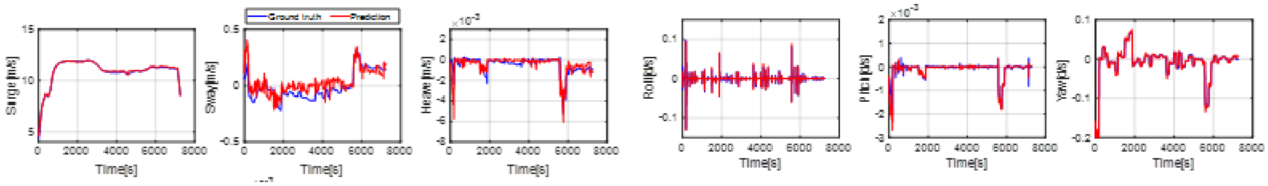

Figure 5: Prediction of ship motion dynamics (blue line is the real data; red line is the predicted results).

3. Results

Layer 1 was trained using big data streams from high frequency sea trial data of a Kamsarmax bulk carrier of Laskaridis Shipping. Comparisons of sea trial records sailing from Canada to Attu Island against DLM suggested that for the selected route the average error in the prediction of the ship fuel consumption during the whole voyage is 2.54% only. These results suggest that subject to further validation over a variety of ships and routes the DLM could be used as an efficient tool for fuel consumption forecasts. Layer 2 was trained by operational data corresponding to Ro-Pax ship voyages and hydro-meteorological conditions between two ports located in the Gulf of Finland. Ship motion predictions indicated that the trained DLM may capture well ship functional behaviour (see Figures 6 and 5).

4. Conclusions

AI-based digital twin models can be used to idealise ship motions and estimate ship fuel consumption. The preliminary results presented in this paper, however promising, are constraint to certain ship types and routes. Hence further testing and validation are necessary with the ultimate aim to develop a framework for the suitable use of digital twin technology for ship operations management (see Figure **??**).

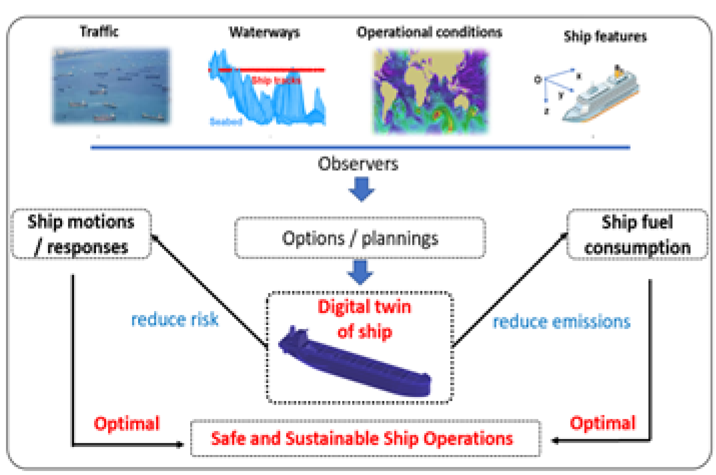

Figure 6: The iterations of digital twins for safe and sustainable ship operations.

ACKNOWLEDGMENTS

All authors acknowledge research funding received funding from Horizons EU 2020 project" RETROFIT SOLUTIONS TO ACHIEVE 55% GHG REDUCTION BY 2030 (RETROFIT55) – Project No.: 101096068".

REFERENCES

1. Allen, B. D. Digital twins and living models at nasa, *Digital Twin Summit*, (2021).

2. Lee, J.-H., Nam, Y.-S., Kim, Y., Liu, Y., Lee, J. and Yang, H. Real-time digital twin for ship operation in waves, *Ocean Engineering*, **266**, 112867, (2022).

3. Nielsen, R. E., Papageorgiou, D., Nalpantidis, L., Jensen, B. T. and Blanke, M. Machine learning enhancement of manoeuvring prediction for ship digital twin using full-scale recordings, *Ocean Engineering*, **257**, 111579, (2022).

4. Zhang, M., Taimuri, G., Zhang, J. and Hirdaris, S. A deep learning method for the prediction of 6-dof ship motions in real conditions, *Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment*, p. 14750902231157852, (2023).

5. Chen, Z. S., Lam, J. S. L. and Xiao, Z. Prediction of harbour vessel fuel consumption based on machine learning approach, *Ocean Engineering*, **278**, 114483, (2023).