

AI-based digital twin for safe and sustainable ship operations



Key Characteristics

- Multi-objective digital twin
- Generative artificial intelligent models
- Ship operations in complex conditions
- Safety and sustainability



Motivation

- To reduce emissions of ship operations by embracing artificial intelligence (AI) techniques.
- To bridge the gap of lacking AI-based decision support tools for ship operation safety awareness improvement.
- To provide high-level insights on effectively implementing intelligent technologies in the improvement of ship operation safety and sustainability.

Objectives

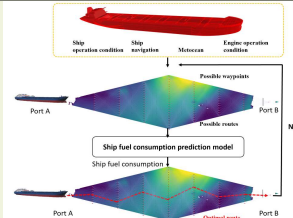


Fig 1. Real-time fuel consumption prediction under different navigational scenarios.

- To establishment a comprehensive database presenting complex navigation scenarios and ship specifications.
- To develop generative deep-learning models to grasp complex features and predict ship motions and fuel consumption.
- To develop a multi-objective AI-based digital twin to accurately represent physical ships under diverse navigation conditions with the aim of safety improvement and emission reduction.

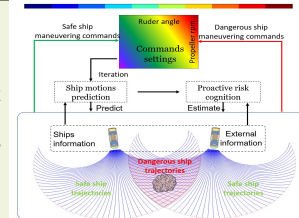


Fig 2. Real-time ship motion prediction under different navigational scenarios.

Methodology

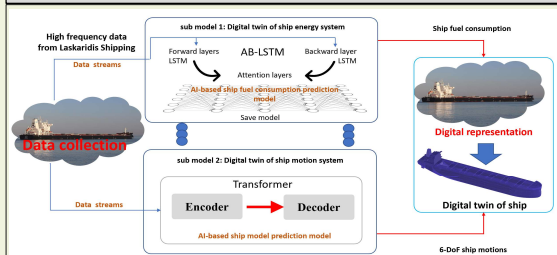


Fig 3. The overall procedure of AI-based ship digital twin.

Step 1: Data fusion and integration for big data streams collection.

Step 2: Sub models training, validation, and generalization.

- (1) Sub-model 1: Bi-directional Long Short-Term Memory (Bi-LSTM) with attention mechanisms for capturing ship energy system.
- (2) Sub-model 2: Transformer with self- and multi-head attention mechanisms for capturing ship maneuvering system.

Step 3: A multi-objective AI-based digital twin establishment.

Results

Sub Model 1: Fuel Efficiency Predictive Analysis

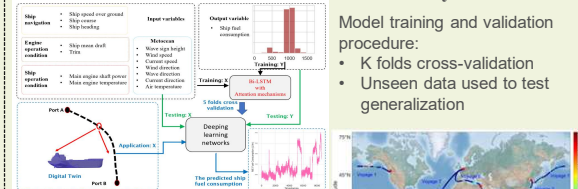


Fig 4. Ship fuel consumption prediction for model training, testing, and application.

Results of the training and validation loss:

- Over 90% of errors are below 4%, with an average error rate of 0.98%.

Fig 5. New data for generalization testing.

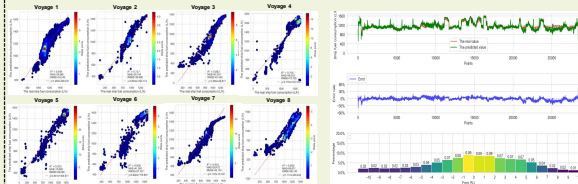


Fig 6. Model implementations on unseen voyages.

Application test:

The average validation loss using Mean Squared Error (MSE) is determined to be 0.0204.

The digital twin model accurately predicts fuel consumption with an average loss range from -0.51% to 5.56%.

Sub Model 2: Ship Motion Predictive Analysis

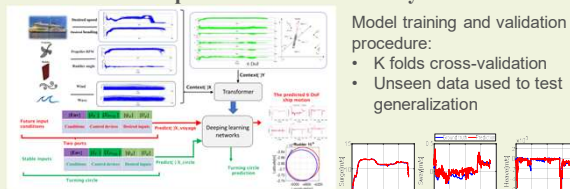


Fig 7. 6-DoF ship motion prediction for the long-term voyage in real conditions and turning circle in calm conditions.

Results of the training and validation loss:

- Ship motion with a loss range from 1.7% to 3.2%.

Fig 8. The Sub model 2 performance evaluation.

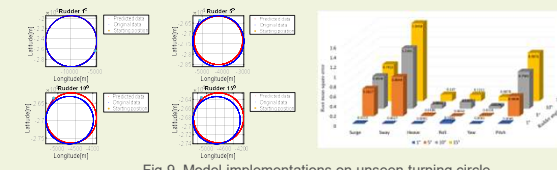


Fig 9. Model implementations on unseen turning circle.

Application test:

	Error	Surge	Sway	Heave	Roll	Yaw	Pitch
Sub model 1	MAE	0.0529	0.0599	0.0003	0.001	0.0001	0.0026
	RMSE	0.0745	0.0734	0.0004	0.0021	0.0001	0.0037

R2 values for surge, roll, and pitch predictions exceeded 0.9.
R2 values for sway and heave predictions are 0.62 and 0.65.

Research Outlook

- The multi-objective AI-based digital twin model can accurately capture ship energy systems and ship maneuvering systems in real operational conditions.
- The innovative use of the multi-objective AI-based digital twin model for predicting ship motions and ship fuel consumption holds significant promise and utility in ensuring safe and sustainable ship operations.

Future work: 1. Extensive testing is necessary to generalize a more advanced digital twin. 2. A comprehensive framework for appropriately utilizing digital twin technology in fleet management.

