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Editorial

Artificial Intelligence and Its Applications in Intelligent Ship Navigation

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With the rapid advancement of artificial intelligence (AI), maritime autonomous surface ships (MASSs)—also referred to as autonomous vessels—have emerged as an important avenue of research in the maritime industry. Their development is primarily driven by their potential to reduce dependence on onboard personnel, enhance operational efficiency, and improve the overall intelligence of ship navigation. In particular, the application of deep learning, imitation learning, and reinforcement learning techniques provides new approaches for developing highly intelligent navigation systems. These methods enable autonomous vessels to achieve increasingly sophisticated capabilities in environmental perception, navigation decision-making, collision avoidance, and berth-to-berth motion control, with their performance approaching that of human operators. Consequently, AI-based technologies are expected to play an increasingly significant role in intelligent ship navigation and related maritime applications, unlocking the potential to support, augment, or ultimately replace certain functions traditionally performed by onboard or shore-based officers. This technological development is widely regarded as an important direction for the future evolution of autonomous vessels and intelligent transportation systems across inland waterways, coastal regions, and open oceans.

This Special Issue includes 13 research articles, comprising 5 studies on ship navigation, 6 on waterway transportation, and 2 on ocean environmental issues. Most of these studies apply AI-based methods to address specific domain problems and demonstrate satisfactory performance compared with traditional approaches.

(1) AI for ship navigation

With the rapid advancement of artificial intelligence, intelligent ship navigation has become an active research topic. Reliably predicting ship heave motion is particularly important for ensuring navigation safety under complex sea conditions. To improve forecasting accuracy, Liu et al. [1] introduced a hybrid deep learning framework that combines Convolutional Neural Networks (CNNs), Bidirectional Long Short-Term Memory (BiLSTM) networks, and an Attention mechanism. In this framework, CNNs are employed to capture spatial features, BiLSTM networks are responsible for modeling temporal dependencies, and the Attention mechanism dynamically assigns weights to different features, thereby enhancing the prediction performance of ship heave motion in moderate and rough sea states.

Accurate ship trajectory prediction is another key technology for intelligent navigation, as it provides essential support for collision prevention and autonomous decision-making. To address trajectory prediction in congested waterways, Wang et al. [2] proposed



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ShipTrack-TVAE, a prediction framework that integrates a Variational Autoencoder (SocialVAE) with a Transformer architecture. A collision avoidance mechanism was further incorporated by embedding inter-ship safety-distance constraints into the loss function, enabling the model to generate safer trajectories. Experimental results on the Automatic Identification System (AIS) dataset collected from the Qiongzhou Strait demonstrated that ShipTrack-TVAE outperformed the original SocialVAE model, reducing the Average Displacement Error (ADE) and Final Displacement Error (FDE) by 21.85% and 17.83%, respectively, highlighting its effectiveness for autonomous ship collision avoidance.

Since sailing speed has a direct impact on voyage energy consumption and operational expenditure, speed optimization has attracted considerable attention in maritime transportation. Zhang et al. [3] established an energy consumption model based on ship resistance characteristics and onboard energy transfer mechanisms. The Yangtze River waterway was partitioned into multiple navigation segments using the K-means clustering algorithm according to environmental similarities. Under the constraints of the main engine operating limits and the required arrival time, an improved Multi-Objective Particle Swarm Optimization (MOPSO) algorithm incorporating cosine-decreasing inertia weight and Gaussian random mutation was developed to determine the optimal speed for each segment. Simulation results for a fully electric ship navigating the Yangtze River indicated that the proposed strategy reduced energy consumption by as much as 6.18%, thereby lowering both energy usage and operating costs under different navigation conditions.

Improving propulsion efficiency is another important approach for reducing ship energy consumption. Controllable-Pitch Propellers (CPPs) provide enhanced adaptability by allowing blade pitch adjustment under varying operating conditions. Tian et al. [4] proposed an optimization framework to determine the optimal combinations of propeller pitch angle and rotational speed (in RPM) for different navigation scenarios. Their energy performance model incorporated the open-water efficiency characteristics of CPPs under various pitch angles and rotational speeds while considering environmental influences such as current velocity and shallow-water effects. To improve optimization performance, the authors enhanced the genetic algorithm by integrating simulated annealing for population initialization, K-means clustering for population segmentation, and a multi-parent crossover strategy that promotes information exchange among different clusters.

Autonomous collision avoidance remains a fundamental challenge in intelligent ship navigation because conventional reinforcement learning algorithms often suffer from unstable exploration and insufficient compliance with the International Regulations for Preventing Collisions at Sea (COLREGs). To overcome these limitations, Chen et al. [5] proposed the Dynamically Adjusted Entropy Proximal Policy Optimization (DAE-PPO) algorithm. The method introduces a COLREG-compliant and risk-aware reward function together with a quadratically decaying entropy adjustment strategy to improve exploration efficiency and mitigate convergence to local optima. Validation in a UE5-based simulation environment showed that DAE-PPO substantially enhanced collision avoidance performance, increasing the success rate by 45% over every 100 simulation trials while reducing the maximum collision risk by 0.35 compared with the conventional PPO algorithm.

(2) AI for waterway transportation

As one of the most economical and environmentally friendly modes of transportation, maritime shipping plays an indispensable role in global trade. Since uncertainties in vessel arrival times can significantly impair berth allocation decisions, improving arrival time prediction is critical for enhancing port operational efficiency. To tackle this challenge, Fei et al. [6] developed a unified data-driven predict-then-optimize framework that directly couples vessel arrival time (VAT) forecasting with continuous berth allocation optimization. The framework integrates heterogeneous maritime information—including

AIS trajectories, port call records, and vessel characteristics—to estimate VAT, which is subsequently incorporated into a continuous berth allocation problem (BAP) model. In addition, a two-stage evaluation strategy was proposed to validate berth allocation plans using realized arrival times while maintaining the original service sequence. Experimental results demonstrated that the proposed approach reduced the Mean Absolute Error (MAE) from 4.795 h to 2.844 h and the Root Mean Square Error (RMSE) from 7.255 h to 4.934 h while also lowering the BAP objective value by 35.96% compared to a benchmark based on estimated time of arrival (ETA).

Automatic vessel type identification from trajectory information is another important task in intelligent maritime traffic management. To improve recognition accuracy, Ye et al. [7] proposed a multi-graph fusion representation framework that jointly exploits trajectory sequences and their dependency relationships. The method first extracts spatiotemporal and behavioral semantic information from vessel trajectories and then constructs graph representations to characterize trajectory dependencies. Graph Convolutional Networks (GCNs) are subsequently employed to learn behavioral representations for vessel classification. Extensive experiments and ablation analyses verified that the proposed framework consistently outperformed conventional approaches, demonstrating its effectiveness for intelligent vessel type recognition.

NAVTEX (Navigational Telex), an essential component of the Global Maritime Distress and Safety System (GMDSS), automatically distributes critical navigational and meteorological safety information to ships. Recent advances in artificial intelligence have enabled more effective interpretation and restoration of NAVTEX messages. Lee et al. [8] investigated six Bidirectional Long Short-Term Memory with Conditional Random Field (Bi-LSTM-CRF) models to analyze the semantic information contained in NAVTEX navigational safety messages. Their study identified the most suitable architecture for understanding the contextual meaning of individual words, thereby facilitating the automatic delivery of navigational safety information to intelligent ship systems without human intervention. In a related study, Cho et al. [9] introduced a Transformer-based masked language modeling (MLM) approach for restoring corrupted NAVTEX messages. By treating asterisk symbols as masked tokens and exploiting bidirectional contextual information, the proposed model accurately reconstructed missing characters, providing reliable support for Maritime Single Window (MSW) integration while preserving essential safety information under adverse communication conditions.

Accurate long-term trajectory prediction is fundamental to intelligent ship navigation and path planning, particularly in dynamic maritime environments. To improve long-horizon prediction performance, Xiong et al. [10] proposed Informer-TP, a trajectory prediction model built upon the Informer architecture using AIS data. In this approach, AIS records were first segmented into trajectory sequences before being fed into an enhanced Informer model capable of capturing long-range temporal dependencies. Comparative evaluations against several baseline methods under different sequence lengths showed that Informer-TP achieved the lowest Mean Squared Error (MSE), Mean Absolute Error (MAE), and Haversine distance, confirming its superior ability to model long-term vessel movements and improve prediction accuracy for intelligent maritime transportation.

To further capture the diverse motion characteristics exhibited by different vessels, Wang et al. [11] developed MDED-TCNFormer to improve vessel trajectory prediction using AIS data through a motion-decoupled dual-stream architecture for maritime traffic management. The proposed architecture separately models large-scale navigation trends and fine-grained maneuvering behaviors before adaptively fusing these complementary motion features to better represent heterogeneous vessel dynamics. Experimental validation using real AIS datasets collected from the Zhoushan coastal waters demonstrated

that MDED-TCNFormer achieved higher prediction accuracy and more stable trajectory estimation than several representative state-of-the-art methods.

(3) AI for ocean environment

Accurate phase-resolved wave prediction is of great importance for ensuring the safe operation of marine structures under complex ocean conditions. To investigate the performance of deep learning techniques for wave forecasting, Cao et al. [12] systematically evaluated four representative neural network architectures, namely Recurrent Neural Networks (RNNs), Long Short-Term Memory (LSTM) networks, Gated Recurrent Units (GRUs), and Temporal Convolutional Networks (TCNs), through a series of wave-tank experiments conducted under different sea states, directional spreading coefficients, prediction distances, and forecasting lead times. The comparative results revealed that the LSTM-based model achieved the highest overall prediction accuracy under mild and moderate sea conditions, whereas the GRU-based model showed superior performance in the medium- and high-frequency ranges. In contrast, the TCN-based approach demonstrated greater robustness when dealing with severe sea states and extended prediction horizons. Moreover, the study identified sea-state intensity, directional spreading, prediction distance, and lead time as the primary factors influencing prediction performance, providing valuable insights for the practical deployment of deep learning-based wave forecasting methods in marine engineering.

High-quality hydrographic data are equally important for intelligent maritime applications, where data consistency and interoperability directly affect navigation safety and decision-making. To improve the management of hydrographic information, Jeong et al. [13] developed a deep learning-based natural language processing framework for detecting duplicate feature definitions in hydrographic data models standardized by the International Hydrographic Organization (IHO). Unlike conventional manual inspection, the proposed approach automatically identifies duplicate features introduced through frequent data updates and continuous product evolution. Experimental validation discovered 313 previously unidentified duplicate features, demonstrating the effectiveness of the proposed method in facilitating hydrographic data integration, enhancing the reliability of spatial information, and supporting safer smart maritime operations.

Taken together, the studies featured in this Special Issue highlight the growing role of artificial intelligence in intelligent ship navigation and other related maritime applications. The wide variety of topics and methodological approaches presented herein offers readers a useful reference for selecting and applying appropriate models and techniques to different research problems.

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