

Survey on Maritime Navigation Using AI

Shalini S, Nandini C, K.Mahesh Babu, M.Uday Kiran, R.Siva Karthik Reddy, K.Lakshmi Narayana
Dayananda Sagar Academy of Technology and Management

Abstract- With the increasing complexity of global maritime logistics and the rising impact of unpredictable oceanic weather, there is a critical need for intelligent systems that support safer and more efficient sea navigation. This research addresses that need by offering a data-driven solution that integrates real-time marine conditions into voyage planning. By focusing on ocean-only navigation paths and incorporating dynamic environmental awareness, it helps identify hazardous zones and enables proactive decision-making to avoid risks such as severe weather or navigational obstacles. The system promotes operational safety, reduces fuel consumption by optimizing routes, and enhances overall voyage reliability. It also improves accessibility through interactive visual tools, making it valuable not only for shipping companies but also for port authorities, academic researchers, and disaster management agencies. The research lays the groundwork for future advancements in smart maritime technologies, ensuring that sea travel evolves with greater intelligence, adaptability, and sustainability.

Keywords- Marine Navigation, Interactive Mapping, Vessel Trajectory Forecasting, Maritime Traffic Optimization, Marine Environmental Data, Predictive Modeling.

I. INTRODUCTION

Modern maritime navigation is undergoing a transformative shift through the integration of data centric technologies, artificial intelligence (AI), and machine learning (ML). As global maritime operations become increasingly complex—shaped by dynamic weather conditions, congested shipping lanes, and stringent regulations—traditional navigation methods are no longer sufficient. The demand for precision, safety, and real-time adaptability has fueled the rise of intelligent navigation systems driven by data analytics and geospatial computation.

This survey introduces an advanced, ocean only routing system that fuses real time marine weather analytics, predictive modeling, and interactive visualization to promote safer and smarter seafaring. Leveraging AI powered route optimization and ML based environmental

forecasting, the system responds dynamically to changing ocean conditions. It actively avoids restricted zones, anticipates high risk areas, and adapts navigation paths based on live data streams—such as wind speed, wave height, swell direction, and visibility [1].

An intuitive, browser accessible visual interface—built using layered geospatial mapping—enables users to monitor and interact with live routes, identify environmental risks, and assess potential navigational challenges. These capabilities reflect modern geospatial technology that integrates real time weather, currents, and traffic data to optimize routes for efficiency and safety [2].our solution serves a wide spectrum of stakeholders, including commercial shipping operators, maritime researchers, naval strategists, and educators. Studies have shown that AI-driven systems for vessel navigation can reduce fuel consumption by up to 10% and cut transit times by approximately 5% [3].

AI-based routing systems can further enhance safety by identifying and avoiding hazards like storms, shallow waters, and congested lanes through real-time situational awareness [4]. Underpinning our research is real-time geospatial data streaming from sources including AIS feeds and environmental sensors—enabling dynamic updates and alerts within the visualization platform [5].

II. LITERATURE SURVEY

1. Statistical Analysis-Based Feature Selection for Anomaly Detection in AIS Dataset--(2025)

G. Visky and his team introduced a statistical feature selection technique for detecting anomalies in Automatic Identification System (AIS) data [6]. Their approach leverages Principal Component Analysis (PCA) and Correlation-Based Feature Selection (CFS) to reduce data dimensionality and highlight key features impacting vessel behavior, leading to improved classification accuracy and computational performance. Their model identifies irregular vessel movements, often linked to illicit activities like smuggling or unauthorized fishing, by analyzing spatial and temporal anomalies. However, it functions in a batch-processing setup and lacks real-time capabilities or integration with environmental data.

In contrast, our research emphasizes real-time, interactive maritime route visualization rather than anomaly detection. By incorporating live marine environmental data—such as wind direction, wave height, sea surface temperature, and visibility—our system enables dynamic route adjustments to enhance voyage planning. Unlike Visky and his team's static analysis, our solution uses tools like Folium and Leaflet.js to deliver visually rich, weather-aware routing insights. This makes our system more suitable for operational navigation, offering actionable, real-time decision support rather than retrospective anomaly analysis.

2. AIS Data-Guided Geolocation Correction Method for Low-Orbit Satellite Remote Sensing Imagery--(2024)

H. Wu tackled the issue of spatial inaccuracies in low-Earth orbit (LEO) satellite imagery by developing a geolocation correction algorithm that aligns satellite pixels with AIS data [7]. By combining orbital telemetry, attitude data, and time-synchronized AIS tracks, they reduced geolocation errors to below 50 meters—critical for maritime surveillance tasks such as detecting illegal vessel activity or tracking pollution dispersion. Their approach significantly improves the spatial accuracy of satellite-based maritime monitoring using both optical and SAR imagery.

Nonetheless, Wu's method is confined to static image correction and doesn't offer functionality for interactive route planning or environmental forecasting. In contrast, our system goes beyond image rectification by enabling real-time maritime routing that factors in live oceanic conditions like swell patterns, wind gusts, and current speeds. While Wu's model enhances post-processing accuracy for surveillance, our platform enables proactive, environment-responsive navigation. Through integration with intelligent APIs and geospatial tools, our research delivers dynamic, operationally useful route visualization—ideal for real-time voyage planning and in-transit decision-making.

3. Optimizing Maritime Vessel Trajectory Prediction Using Space-Based AIS Data and PSO-BiGRU--(2024)

D. A. Rahayu and his team introduced a hybrid deep learning framework that integrates Particle Swarm Optimization (PSO) with a Bi-directional Gated Recurrent Unit (BiGRU) [8] to forecast vessel trajectories from historical AIS data. PSO fine-tunes the BiGRU's hyperparameters, boosting both convergence speed and prediction accuracy. By capturing forward and backward temporal dependencies, their model excels at modeling complex, non-linear marine traffic behaviors, especially in densely trafficked areas where precise forecasts can enhance safety and efficiency.

However, their method is focused on trajectory prediction and does not generate routes based on geographic constraints or real-time oceanographic factors. In contrast, our system prioritizes real-time, geospatially bounded routing enhanced with dynamic marine environmental inputs—such as currents, wind, and wave data—to assess navigational risk and optimize voyages. While Rahayu's model forecasts where a vessel might go, our platform determines where it should go under evolving sea conditions. Through API-driven intelligence and interactive HTML-based visualization, our solution enables environment-aware, operational decision-making for real-time maritime navigation, moving beyond historical data forecasting.

4. Multi-sensor Analytic System Architecture for Maritime Surveillance--(2024)

K. Ma and his team developed a scalable multi-sensor analytics framework aimed at enhancing maritime domain awareness by integrating diverse inputs such as AIS, radar, sonar, and meteorological buoy data[9]. Their architecture emphasizes interoperability and supports distributed processing, edge computing, and modular analytics, making it well-suited for large-scale surveillance applications like illegal fishing detection, traffic density analysis, and coastal activity monitoring.

However, Ma's system is primarily backend-focused, concentrating on infrastructure-level sensor fusion without offering real-time, user-facing navigational tools. In contrast, our platform emphasizes interactive, client-side maritime route visualization enriched with live oceanographic data. Designed for end-users like ship captains and port authorities, our system provides immediate, actionable insights through dynamic route mapping and real-time environmental overlays. Unlike Ma's server-dependent setup, our use of lightweight, embeddable tools such as Folium and Leaflet.js enables offline-ready, browser-based access to weather-aware navigation maps. While Ma's framework excels in high-volume data aggregation and surveillance, our solution acts as a frontline decision-making tool, offering direct operational value for voyage planning and execution.

5. Bidirectional Data-Driven Trajectory Prediction for Intelligent Maritime Traffic---(2023)

Y. Xiao and her team proposed a bi-directional deep learning model enhanced with attention mechanisms to predict vessel trajectories using AIS data[10]. By capturing temporal patterns in both forward and backward directions and dynamically weighing critical time steps—such as abrupt course or speed changes—the model achieves high accuracy in complex navigation scenarios, particularly near ports and congested routes.

However, while Xiao's model excels in temporal sequence learning, it lacks spatial awareness of maritime geography and does not incorporate environmental variables like wind, waves, or ocean currents. Our system addresses these gaps by integrating geospatial routing with real-time marine weather data, enabling the generation of environment-sensitive navigation paths. Furthermore, Xiao's model functions as a backend predictive tool without a user interface. In contrast, our platform provides a browser-based, interactive visualization layer that allows users—such as navigators and planners—to explore dynamic, weather-informed routes. This makes our system not only intelligent but also actionable and deployment-ready, bridging the gap between data-driven predictions and real-world navigational decision-making.

6. Deep Learning-Powered Vessel Trajectory Prediction for Improving Smart Traffic Services in Maritime Internet of Things--(2022)

R. W. Liu, M. Liang and their team introduced a deep learning-driven framework for the Maritime Internet of Things (MIoT), aiming to enhance vessel tracking, traffic management, autonomous navigation, and inter-vessel communication[11]. Their system supports key functions like trajectory prediction and anomaly detection, paving the way for intelligent, adaptive maritime operations and connected fleet infrastructure.

However, Liu's model remains mostly conceptual, lacking interactive visual tools or user-facing route planning capabilities. It prioritizes backend

automation over frontend usability. In contrast, our research delivers a practical, user-centric solution by combining real-time meteorological data with geospatial routing constrained to oceanic zones. Designed for operational use, our platform features a visual interface with interactive maps and supports offline functionality through portable HTML outputs—ensuring reliability even in low-connectivity maritime environments. While Liu’s framework advances strategic automation, our system acts as a tactical decision support tool, turning maritime AI into an accessible, actionable resource for real-world voyage planning and execution.

III. IMPACT AND BENEFITS

The fusion of real-time routing with environmental intelligence redefines conventional maritime planning into a data-driven process, greatly boosting both foresight and operational flexibility. Shipping operators benefit through reduced fuel usage by avoiding unnecessary deviations, fewer delays thanks to live weather-informed routing, and better asset deployment via precise ETA predictions. By overlaying key meteorological vectors—such as wind shear, barometric pressure shifts, and ocean currents—along the planned route, the system facilitates sophisticated risk assessments, enabling smarter decision-making in unpredictable sea conditions.

On an industry-wide scale, the project acts as a catalyst for eco-efficient marine logistics and enhances maritime awareness. Its use of open standards and API-based microservices ensures seamless integration with existing Fleet Management Systems (FMS) and Electronic Chart Display and Information Systems (ECDIS). It also supports regulatory adherence with IMO safety protocols and provides realistic training simulations for maritime academy cadets. Additionally, the web-based, offline-capable deployment ensures functional access in low-bandwidth maritime environments—addressing the digital divide in ocean navigation solutions.

IV. CONCLUSION

This survey underscores the accelerating convergence of AI, ML, and geospatial intelligence in advancing maritime navigation. Existing research like statistical anomaly detection, satellite geolocation correction, and deep learning-based trajectory forecasting to infrastructure-level sensor fusion and MIoT frameworks have significantly enriched the maritime domain’s predictive and monitoring capabilities. However, most of these models operate in retrospective, backend-focused, or automation-centric paradigms, with limited user interaction, spatial awareness, or environmental responsiveness.

In contrast, our proposed system bridges this critical gap by delivering a real-time, user-facing, and weather-aware maritime routing solution. By integrating predictive analytics, dynamic environmental data, and intuitive geospatial visualization, it transitions from passive surveillance or static forecasting to proactive, operational decision support. This evolution is particularly vital in an era marked by climate volatility, maritime congestion, and rising security threats.

Ultimately, this work positions itself as a tangible step toward deployable, intelligent navigation—transforming maritime AI from a backend computation model into a frontline strategic asset for safer, smarter, and more sustainable oceanic voyages.

REFERENCES

1. <https://dev.to/navinder/ai-in-marine-weather-prediction-enhancing-forecast-accuracy-for-smarter-maritime-operations-ai2>
2. <https://www.orca-ai.io/blog/when-good-gets-better-from-voyage-planning-to-maritime-route-optimization/>
3. <https://sinay.ai/en/5-ways-to-reduce-operational-costs-in-the-maritime-industry-using-ai/>

4. <https://www.orca-ai.io/blog/when-good-gets-better-from-voyage-planning-to-maritime-route-optimization/>
5. <https://www.esri.com/en-us/capabilities/real-time/partners/data>
6. G. Visky, R. Vaarandi, S. Katsikas and O. Maennel, "Statistical Analysis-Based Feature Selection for Anomaly Detection in AIS Dataset," 2025 IEEE 23rd World Symposium on Applied Machine Intelligence and Informatics (SAMI), Stará Lesná, Slovakia, 2025, pp. 000159-000164doi: 10.1109/SAMI63904.2025.10883201.
7. H. Wu, Z. Huang, Q. Hu, X. Ran and Q. Mei, "AIS Data-Guided Geolocation Correction Method for Low-Orbit Satellite Remote Sensing Imagery," in IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, vol. 17, pp. 18703-18726, 2024, doi: 10.1109/JSTARS.2024.3470903.
8. D. A. Rahayu, Widyawan, I. Ardiyanto and W. Hasbi, "Optimizing Maritime Vessel Trajectory Prediction Using Space-Based AIS Data and PSO-BiGRU," 2024 IEEE International Conference on Aerospace Electronics and Remote Sensing Technology (ICARES), Yogyakarta, Indonesia, 2024,pp. 1-7, doi: 10.1109/ICARES64249.2024.10768074.
9. K. Ma, H. Leung and P. Gouda, "Multi-sensor Analytic System Architecture for Maritime Surveillance," 2024 IEEE International Systems Conference (SysCon), Montreal, QC, Canada, 2024, pp. 1-6, doi: 10.1109/SysCon61195.2024.10553489.
10. Y. Xiao, X. Li, W. Yao, J. Chen and Y. Hu, "Bidirectional Data-Driven Trajectory Prediction for Intelligent Maritime Traffic," in IEEE Transactions on Intelligent Transportation Systems, vol. 24, no. 2, pp. 1773-1785, Feb. 2023, doi: 10.1109/TITS.2022.3219998.
11. R. W. Liu, M. Liang, J. Nie, W. Y. B. Lim, Y. Zhang and M. Guizani, "Deep Learning-Powered Vessel Trajectory Prediction for Improving Smart Traffic Services in Maritime Internet of Things," in IEEE Transactions on Network Science and Engineering, vol. 9, no. 5, pp. 3080-3094,1Sept.-Oct.2022, doi: 10.1109/TNSE.2022.3140529.