Scientific and Social Research, 2026, Volume 8, Issue 5
http://ojs.bbwpublisher.com/index.php/ssr
Online ISSN: 2981-9946
Print ISSN: 2661-4332

Research on Cargo Ship Trajectory Based on Time Window Smoothing Filter Algorithm and Transformer Model

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Abstract: With the flourishing development of maritime transportation, the safety of cargo ship navigation cannot be overlooked. To ensure the safety of cargo ship navigation and improve the prediction accuracy of cargo ship trajectories, the Transformer model is utilized to predict cargo ship navigation trajectories, enabling the anticipation of spatial and temporal location information of cargo ships in the near future. This facilitates proactive operations and early warnings, thereby ensuring the safety of cargo ship navigation. Previously, predictions of cargo ship navigation trajectories were mostly based on statistical and traditional machine learning methods, which exhibited poor model adaptability and high constraints, making them unsuitable for the current complex and thriving maritime traffic patterns. In the modern era, the rapidly developing Automatic Identification System (AIS) enables researchers to obtain vast amounts of cargo ship trajectory data, providing favorable conditions for mining data characteristics of cargo ships. Therefore, this paper, based on AIS data, combines the time window smoothing filter algorithm and employs the Transformer model to predict, research, and analyze cargo ship navigation trajectories. Furthermore, an early warning mechanism for cargo ships is established to alert to deviations from the planned route, thereby ensuring the safety of cargo ship navigation.

Keywords: Time window smoothing filter algorithm; Transformer model; Trajectory research

Online publication: June 5, 2026

1. Introduction

Maritime transportation is the primary means of economic and trade exchanges between countries, characterized by its large carrying capacity, low cost, and extensive coverage. According to trade volume estimates, 85% of global trade is transported by sea [1]. However, maritime transportation also poses greater risks compared to other modes of transportation, making ensuring the safety of cargo ship navigation a fundamental requirement of maritime transportation [2].

2. Research content

Most current research has delved deeply into predicting cargo ship navigation trajectories. However, during the processing of AIS data, there are erroneous points in the AIS trajectory data that deviate from the actual trajectory, resulting in non-smooth sequences of AIS trajectory points [3]. When removing outliers, only those with significant deviations are eliminated, without further processing those with minor deviations. Addressing the existing issues, this paper fully explores the spatiotemporal correlation of AIS data, processes it using the time window smoothing filter algorithm, and studies cargo ship navigation trajectories using the Transformer model [4]. The Self-Attention mechanism in Transformer can capture not only the relationships between elements at the source and target ends but also the intrinsic relationships within the source and target ends themselves [5]. By leveraging the advantages of Self-Attention in the Transformer, the prediction accuracy is further enhanced. In the experimental section, data from the main channels of the Ningbo Zhoushan Core Port Area, namely the Luotou Channel and Xiazhi Gate Channel, are used for training and prediction, fully demonstrating the feasibility and superiority of deep learning prediction models in predicting cargo ship navigation trajectories. Based on this, this paper establishes an early warning mechanism for cargo ship deviations from the planned route using predicted points as references, ensuring the safety of cargo ship navigation and promoting the intelligent and digital development of the maritime transportation industry.

3. Trajectory prediction

The instance data from the main channels of the Ningbo Zhoushan Core Port Area, namely Luotou Channel and Xiazhi Gate Channel, after undergoing data preprocessing and time window smoothing filter algorithm processing, are depicted in **Figure 1**.

Figure 1. Trajectory map of cargo ships in the selected water area

Selecting the trajectory of a cargo ship with the MMSI number 21252**** in this area and mapping its latitude and longitude onto a planar two-dimensional coordinate system results in **Figure 2** below. From the figure, it can be observed that the predicted values from the Transformer model exhibit a high degree of fit with the actual values of the cargo ship, fully demonstrating the high prediction accuracy of the Transformer model.

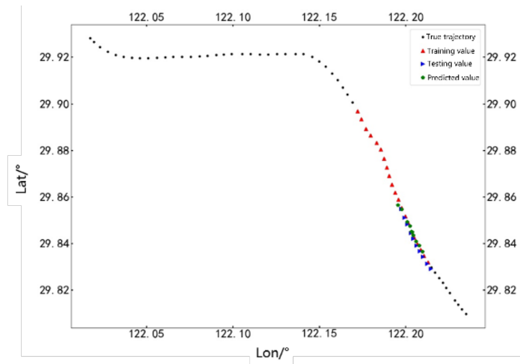

Figure 2. Trajectory prediction by the transformer model result diagram in two-dimensional coordinates

The trajectory of the cargo ship with MMSI number 21252****, selected as mentioned above, is mapped onto an electronic nautical chart, as shown in **Figure 3**. From the figure, it can be observed that the model's predicted values not only conform to the motion trend of the cargo ship but also exhibit a high degree of fit with the actual values, accurately predicting the motion trend and spatiotemporal position of the cargo ship in the near future, thereby adding a layer of security to the cargo ship's navigation.

Figure 3. Trajectory prediction by the transformer model result diagram on an electronic nautical chart

4. Practical application

According to the relevant provisions of the "Special Plan for Waterways and Anchorages in the Zhoushan Port Area," the width of the main waterways in the Ningbo Zhoushan Core Port Area ranges from 1000 to 1300 meters. Furthermore, this study is conducted based on cargo ships with a length of over 90 meters. Combining this with the navigation data from the Ningbo Zhoushan Port, it is evident that the lengths of large cargo ships navigating in the main waterways of Ningbo Zhoushan mostly range from 90 to 300 meters, with widths mostly ranging from 12 to 60 meters.

Considering factors such as the width of the main waterways and the range of cargo ship widths, this paper sets two thresholds for the deviation range to issue warnings for cargo ship deviation behavior. The low-level threshold is set at 250 meters, and the high-level threshold is set at 400 meters. These thresholds can be adjusted based on actual navigation conditions. Based on these threshold ranges, the warning mechanism is categorized into three scenarios: “normal position”, “slight deviation”, and “severe deviation.”

To better demonstrate the cargo ship warning mechanism, the actual motion trajectory of the cargo ship and the predicted values from the Transformer model are mapped onto an electronic nautical chart platform, as shown in **Figures 4, 5**, and **6** below. These figures respectively display the electronic nautical chart representations when the cargo ship trajectory is “normal”, “slightly deviated”, and “severely deviated.” The dashed box represents the low-level threshold, while the solid box represents the high-level threshold.

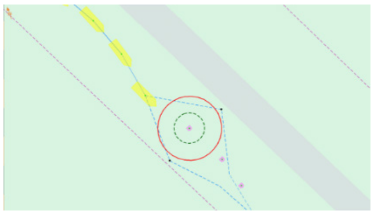

Figure 4. The electronic chart display of the cargo ship’s track position under normal conditions

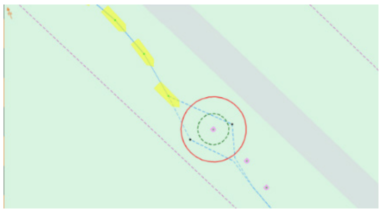

Figure 5. The electronic chart display when the cargo ship’s track exhibits a slight deviation

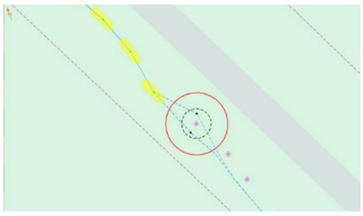

Figure 6. The electronic chart display when the cargo ship’s track exhibits severe deviation

5. Conclusion

This paper relies on AIS data processed by a time-window smoothing filtering algorithm and employs the Transformer model to predict the future trajectories of cargo ships within the core port areas of Ningbo-Zhoushan. Based on the predictive results of the reference model, a cargo ship early warning mechanism has been constructed. Using the model’s predictive points as a reference, it provides cargo ships in transit with insights into their future spatiotemporal positions, offering early warnings for deviations from their intended routes. This serves as a preparatory step for collision avoidance warnings, ensuring the navigational safety of cargo ships. However, there are still some shortcomings in the current article, which can be improved in future research from the following two aspects: Firstly, while maintaining prediction accuracy, consideration can be given to increasing the time interval, thereby extending the duration and distance of the predicted cargo ship trajectories and enhancing the practical significance and application value of trajectory prediction.

Secondly, for cargo ships that frequently change direction, the model should strengthen its learning from large amounts of high-quality data and improve its performance to ensure prediction accuracy. In the next phase of research, predictive studies can be conducted on the navigation trajectories of cargo ships that frequently change direction. In the context of the current prosperous and complex maritime traffic, combined with the surge in deep learning, this aims to promote the digital and information-based development of the maritime shipping industry.

Funding

2024 School-level Scientific Research Project of Liaoning University of International Business and Economics, "Research on Cargo Ship Trajectories Based on the Transformer Model" (Project Number: 2024XJLXQN007)

Disclosure statement

The author declares no conflict of interest.

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