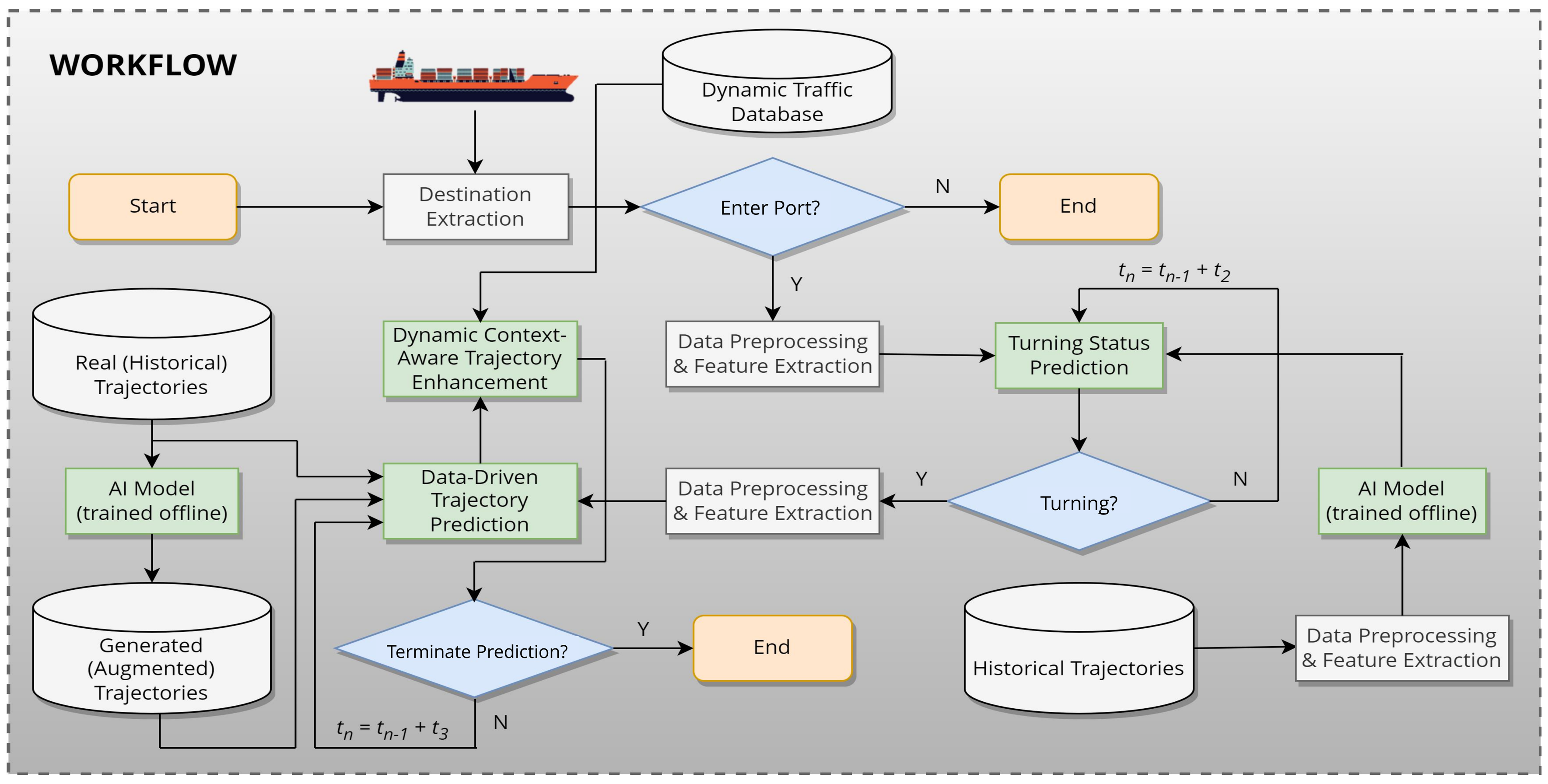
Vessel Trajectory Prediction with an Explainable AI Approach

Introduction

Maritime collision avoidance systems (MCAS) are expected to avoid collisions by providing early warnings to approaching vessels. Predicting the future trajectory of vessels is a fundamental and crucial function of MCAS, and its success has a direct impact on risk assessment in subsequent actions. The widespread deployment of various advanced sensors and systems in the marine and shipping industries has brought the era of big data with the constant accumulation of comprehensive maritime traffic data, which has formed its superiority. Over the last few years, this emerging trend has been propelling vessel trajectory prediction as a research hotspot.

Autonomous ship technology is currently being explored deeply and its implementation has been on the agenda, which is expected to bring forth potential solutions for enhancing vessel navigational safety. Despite the potential benefits of autonomous vessels in the future era, collision avoidance is still one major challenge for accomplishing such intelligent systems. Correspondingly, one of the critical elements in collision avoidance is to accurately forecast the trajectories of surrounding vessels.

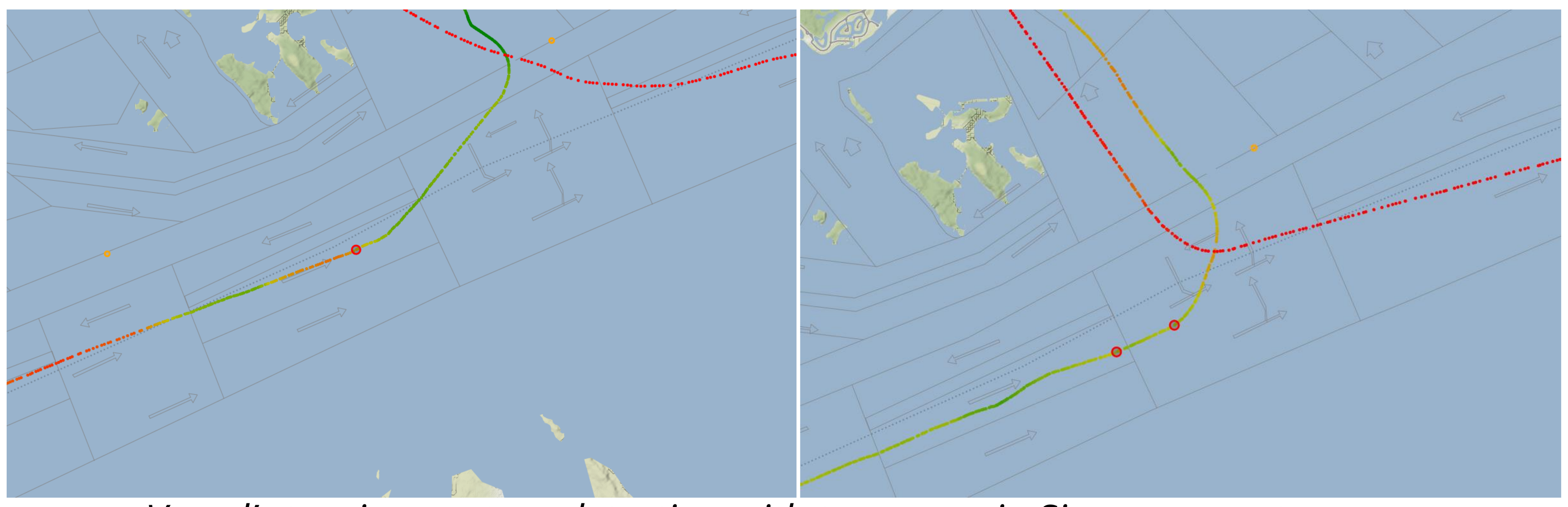
Based on the high-resolution Automatic Identification System (AIS) data collected in the Singapore strait water, we explored the problem of vessel trajectory prediction with an explainable artificial intelligence (AI) solution. The AI approach incorporates multiple stages: (a) The turning posture of a vessel is predicted; (b) The trajectories of vessels are augmented synthetically for the follow-up big data-driven prediction algorithm; (c) The near-future trajectories are predicted with consideration of uncertainty; (d) The predicted trajectories are further enhanced by considering the dynamic interactions between vessels and the surrounding traffic environment.



Vessels' Turning Posture Prediction

The movement patterns of a vessel on a turning track and another vessel on a straight track are significantly different, particularly in the water area where the traffic separation scheme is adopted. Furthermore, a turning vessel may cause unexpected close-encounter situations in busy waterways, which necessitates increased attention.

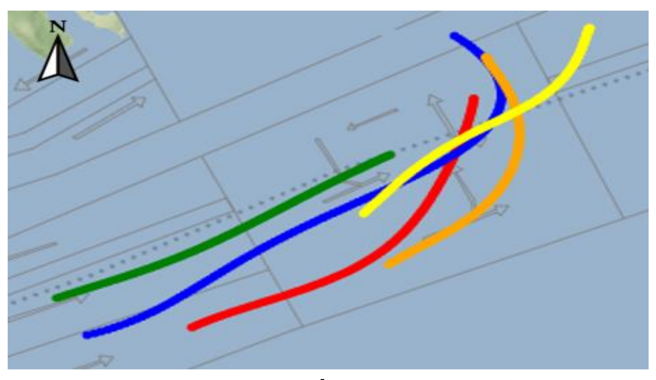
An advanced deep learning algorithm is formulated for vessels' turning posture prediction. The predicted output is the probability of the vessel performing a "turning" operation or maintaining a straight path. The turning posture is predicted in real time to ensure that every significant turning action can be detected. The accuracy and F1-score of our prediction model can reach 92.30% and 92.73%, respectively.



Vessel's turning posture detection with two cases in Singapore waters

Vessel Trajectory Augmentation

Generative deep learning (DL) has been developed to learn the movement pattern of vessels, and then to mimic an arbitrary number of trajectories. The major purpose of it is to augment trajectories that cover diverse scene-consistent motion modes that can facilitate follow-up big data-driven prediction. The randomly generated trajectories by our DL model are shown in the right figure.

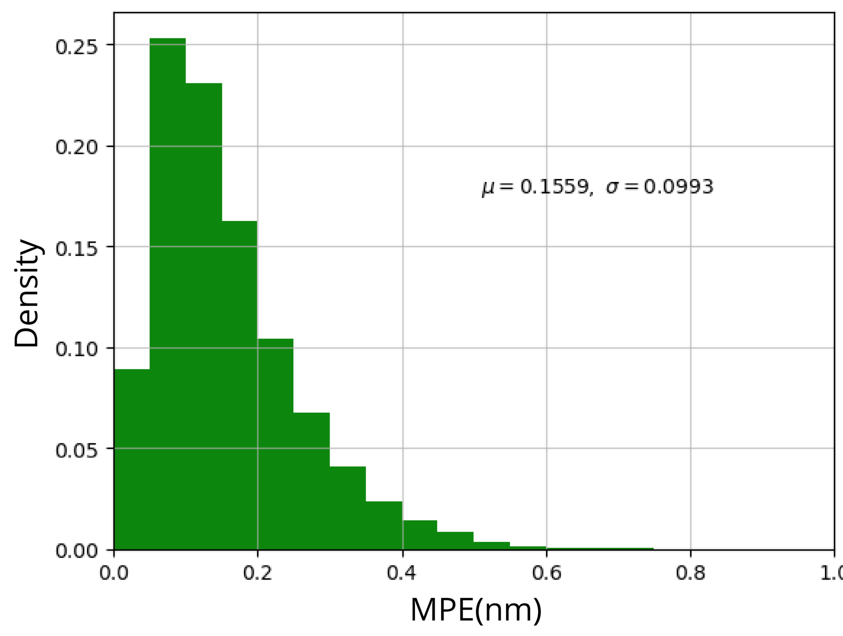


Augmented trajectories

Vessel Trajectory Prediction Considering Uncertainty and Surrounding Traffic Context

A novel prediction algorithm based on multiple steps of nearest-neighbour selection is formulated for vessel trajectory prediction. The primary consideration of proposing such an algorithm is to represent the predicted trajectories with uncertainty. In contrast to the standard machine learning methods which often produce only one trajectory, our algorithm can predict multiple possible trajectories, which gives it an advantage over the machine learning method. Furthermore, comprehensive experiments also prove the superiority of our algorithm over using DL algorithms in terms of prediction accuracy.

The predicted trajectories are further enhanced by considering the dynamic interactions between vessels and the surrounding traffic environment. The incorporation of dynamic traffic context into our model further improves the prediction accuracy by 4.12%. Currently, the prediction positional error can reach as low as 0.1559 nm based on our evaluation in Singapore waters.

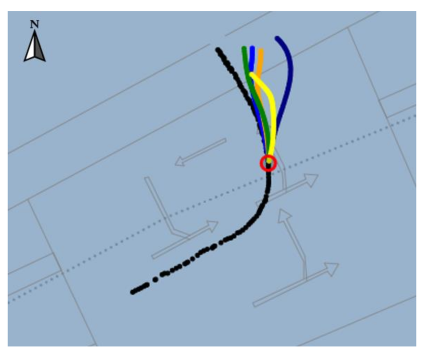


Histogram of prediction errors

A Case Study

We present a case study of the trajectory prediction for a vessel in the Singapore Strait. The vessel is entering the Port of Singapore. First, the turning status of this vessel is predicted every 30 seconds by the model. It is firstly predicted as "turning" status at timestamp 2018-01-15 11:04:00, where the vessel is located at the position labelled by a red hollow circle. Then, a real-time trajectory prediction mechanism at an interval of 1 minute is triggered. For each prediction, the model outputs five potential trajectories as the next 10 minutes' trajectories. The predicted trajectories are encoded by different colours including "navy", "blue", "orange", "green" and "yellow". The actual trajectory is coloured by "black".

At timestamp 2018-01-15 11:09:00, the vessel has reached the traffic separation zone, which is a criterion in this study for terminating the real-time prediction of trajectory; no further predictions are provided after this time.



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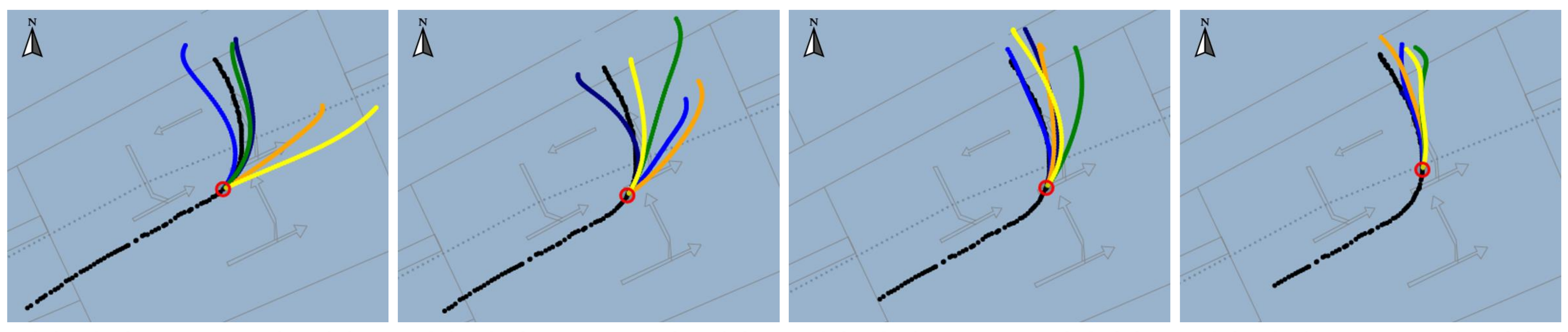

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Summary

An explainable AI-based approach has been proposed for vessel trajectory prediction. This approach involves multiple stages of learning processes to enhance the explainability of prediction. It can achieve high prediction accuracy by considering the uncertainty of predictions. In addition, the vessels turning posture prediction also helps for early warning of the cross-channel vessels in maritime traffic management.

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