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Editorial

Data/Knowledge-Driven Behaviour Analysis for Maritime Autonomous Surface Ships—2nd Edition

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This Special Issue, entitled "Data/Knowledge-Driven Behaviour Analysis for Maritime Autonomous Surface Ships—2nd Edition", is the sequel to "Data/Knowledge-Driven Behaviour Analysis for Maritime Autonomous Surface Ships", including five contributions [1–5] published from 2023 to 2024.

The analysis of ship behaviour is crucial for the development of maritime autonomous surface ships (MASS) and the new-generation Waterborne Transportation System (N-WTS). The **data-driven behaviour analysis** of historical data (e.g., radar data, AIS data, CCTV data, etc.) via statistics and machine learning methods is one fundamental method that help researchers learn the behaviour of a ship in a real-life scenario. **Knowledge-driven behaviour analysis**, on the other hand, is another method used to extract information from navigation rules and regulations, offering valuable prior knowledge about ship behaviour according to such rules. Both methods are important for understanding the traffic behaviour of a ship and can be used to aid the situational awareness of officers on watch onboard, operators in Vessel Traffic Service (VTS), and intelligent machines in MASS or N-WTS.

This Special Issue aims to collate studies that provide new insights on data/knowledge-driven behaviour analysis for MASS and N-WTS, including but not limited to data-driven behaviour modelling, knowledge-driven behaviour modelling, multisource heterogeneous traffic data fusion, risk analysis and management of MASS, etc. A brief overview of all the contributions, emphasizing the main research topics and outcomes of the analysis, follows.

Data-driven behaviour analysis is a powerful tool for learning ship behaviour from large amounts of data, and four papers collated in this SI explore this method.

To support intelligent fishery management and the sustainable development of fishery resources, the recognition of fishing behaviour from massive AIS data is essential. A group of researchers from China and the Netherlands, Zhang et al. [1], proposed a multi-scale behaviour analysis method for fishing behaviour recognition, which is based on historical AIS data. Firstly, the stop points (SPs) and points of interest (POI) of each trajectory were identified, allowing the voyage information of each vessel to be discovered based on the identified SPs and POI. Then, combining the motion and morphological features of the entire trajectory, a logistic regression model for fishing behaviour detection was developed. To verify the proposed methods, fishing log data from ocean squid fishing vessels in Argentine waters (collected in 2020) were used, and the results show that (1) the proposed method provides robust and accurate recognition results; (2) the seasonal changes in squid fishing activities can also be detected. The results reveal the potential of the proposed method for the intelligent management of fishery activities.

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The group behaviour of ships sailing in dense waters has attracted widespread attention from researchers in recent years. Zhou et al. [3] proposed a feature-driven spatiotemporal companion pattern (STCP) mining method, which could be used to recognize and detect the activities of groups of ships. Firstly, the trajectory of the ships was rasterized into a set of individual pixels, called spatiotemporal trajectory grid sequences (STTGSs); secondly, filtering rules incorporating constraints on range, time, and distance were designed to define a set of basic pattern candidates; thirdly, a similarity measure was proposed to evaluate the similarity between STTGSs and the basic pattern candidates, and then the behaviour of the ship was recognized by comparing the similarity and the confidence threshold. To validate the proposed method, trajectory data from Taiwan Strait were used, and results show that (1) 825 pairs of associated ships and 225 pairs of accompanying ships were recognized when the grid size was set as 0.05° and the confidence level was set as 0.5; (2) larger grid sizes could contribute to more associated ship pairs and a higher confidence level of the behaviour; (3) accompanying behaviour such as cooperative operation, companion navigation, etc., could be detected using the proposed method. The results demonstrate the performance of the proposed method for identifying group activities in certain waters, indicating its potential in the N-WTS.

Liu, Yuan et al. [2] proposed a self-stabilized Stewart platform that can be installed onboard ships and relies on the updating of motion parameters based on off-line and online data. The proposed self-stabilized Stewart platform could reduce the swing behaviour of the platform in complex sea conditions. The cores of the platform are the motion prediction of the ship and subsequent compensation control of the platform. To predict the future behaviour of the ship, an auto-regressive model of the ship was established, and the parameters were initialized using off-line historical data and updated using online sensing data; based on the predicted states of the ship, the six electric cylinders on the proposed Stewart platform were controlled to counteract the extra motion variables of the ship. To validate the proposed platform, various experiments in a simulation environment were conducted, and the results show that (1) the average one-step motion prediction error was less than 1%; (2) the maximal and average self-stabilizing control errors were 1.6° and 0.7°, respectively. The results indicate that the platform could be stabilized via the proposed platform in simulated wave conditions, which would be useful for equipment that requires a relatively stable working environment on MASS, for example, a telephoto camera.

The motion prediction of a ship carrying out various manoeuvres is crucial for autonomous navigation on MASS. Song, Hao et al. [4] proposed an off-line black box modelling method for unmanned surface vehicle (USV) trajectory predictions, based on a sparrow search algorithm-based weighted-least-squares support vector machine (SSA-WLS-SVM). First, the platform of the testing USV was introduced, with the process of obtaining experiment data being described. Then, the least-squares support vector machine (LS-SVM) framework was introduced to identify parameters in the proposed prediction process. Following this, to improve the stability and robustness of LS-SVM, the weighted-least-squares (WLS) method and the sparrow search algorithm (SSA) were incorporated into the original LS-SVM. Finally, the random manoeuvring dataset generated by the simulator was fed into the proposed black box model for training. To validate the performance of the proposed method, a dataset with random manoeuvring and 25° turning manoeuvring is employed. The results show a strong generalization performance of the proposed method.

Knowledge-driven behaviour analysis is another powerful tool for learning ship behaviour in the context of regulations, and one paper collected in this SI explores this method.

The detection of anomalous ship behaviour (such as sudden acceleration, deceleration, etc.) is important for waterborne traffic surveillance. Li, Zhang et al. [5] proposed a ship anomalous behaviour detection method based on text similarity and kernel density estimation. Firstly, a traffic pattern density model for in/outbound behaviour was developed to estimate the density value of different motion states; secondly, the trajectory was converted to trajectory pattern text via a semantic transformation method, and then the text similar-

ity was employed to identify the in/outbound behaviour of the ship; thirdly, abnormal behaviour was identified by comparing the estimated real-time density value of the ship motion and the threshold of anomaly behaviour. The simulation data were employed for validation, and the results indicate that the accuracy of the proposed method in abnormal behaviour identification is more than 90%, which shows its future potential in waterborne transportation management.

Conflicts of Interest: The authors declare no conflicts of interest.

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