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A novel ship trajectory reconstruction approach using AIS data

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ABSTRACT

AIS data plays an increasingly important role in collision avoidance, risk evaluation, and navigation behavior study. However, the raw AIS data contains noise that can result in wrong conclusions. We propose a multi-regime vessel trajectory reconstruction model through three-steps processing, including (i) outliers removal, (ii) ship navigational state estimation and (iii) vessel trajectory fitting. This model allows for vessel trajectory reconstruction in different navigation states, namely hoteling, maneuvering, and normal-speed sailing. The normal-speed navigation trajectory is estimated with a spline model, which can fit any types of the trajectory even with circles. Then, the proposed model is tested and compared with other three popular trajectory reconstruction models based on a large AIS dataset containing the movement of more than 500 ships in Singapore Port. The results show that the proposed model performs significantly better than the linear regression model, polynomial regression model, and weighted regression model. The proposed model can decrease the abnormal rate of speed, acceleration, jerk and ROT (Rate of Turn) from 43.42%, 10.65%, 59.25%, 50.33%–0.00%, 0.00%, 17.28% and 15.81%, respectively. More importantly, the navigational behavior, such as turning operation, could be clearly shown in the trajectory reconstructed by the proposed model.

1. Introduction

Automatic Identification System (AIS) is an automatic ship self-reporting system used for the maritime transportation safety purpose. The AIS system broadcasts the vessel sailing status information, such as the position, speed, loading status, which can be received by the other ships or Vessel Traffic Service (VTS) centers (Harati-Mokhtari et al., 2007). According to the Safety of Life at Sea (SOLAS) of the International Maritime Organization (IMO), AIS is mandatory for the international voyaging ships with Gross Tonnage (GT) more than 300 and all passenger ships. As its wide application in the shipping industry, AIS data have become increasingly important for the navigational safety and maritime traffic management (Szlapczynski and Szlapczynska, 2016; Wang and Chin, 2016; Xiao et al., 2015; Zhang et al., 2016).

Vessel trajectory information indicated by the AIS data is one of the most important data sources for ship collision study. First, with real-time AIS data, a vessel can track the movement of the neighbor vessels and use the collision avoidance decision-making models to improve the navigational safety (Li et al., 2012; Mazaheri et al., 2016). For example, Su et al. developed a fuzzy logic theory based system using AIS data to optimize the rudder steering decision for the give-way ship (Su et al., 2012). Moreover, the historical AIS data is useful for vessels' movement analytics and collision risk evaluation. For instance, Mou et al. investigated the actual behavior of collision-involved ships off the Rotterdam Port in Europe, and analyzed the vessel collision using the AIS data (Mou et al., 2010). Weng et al. evaluated the vessel collision frequency in Singapore Strait by calculating the product of the vessel conflicts number and the causation probability using the real-time vessel movement data from the Lloyd's Marine Intelligence Unit (Lloyd's MIU) database (Weng et al., 2012). More recently, AIS data are used to predict the vessel trajectory for the maritime safety management using the machine learning methods (Borkowski, 2017; Shangbo Mao et al., 2016). For example, Borkowski (2017) developed a trajectory prediction model using multiple neural networks learning from the maritime fusion data. All these applications depend on the accurate vessel trajectory information from the AIS data.

The quality of the AIS data depends on the AIS equipment, the navigational state of the vessel, and AIS message receiver base station (Lapinski and Isenor, 2011). There are two types of shipborne AIS equipment, namely Class A and Class B AIS equipment. Class A AIS equipment is usually installed in the international cargo ships and passenger ships, while Class B AIS equipment is mainly installed in the inland waterway ships (Xiao et al., 2015). The Class A AIS equipment is

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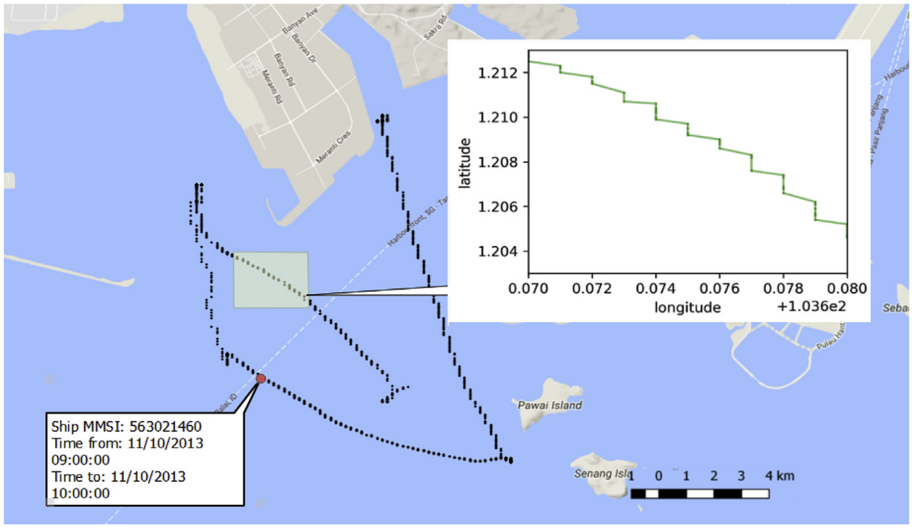
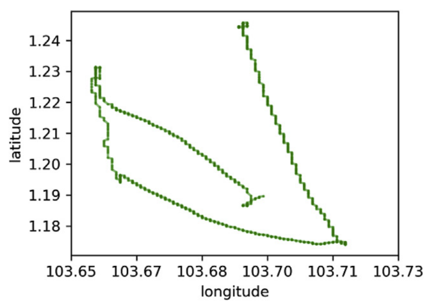
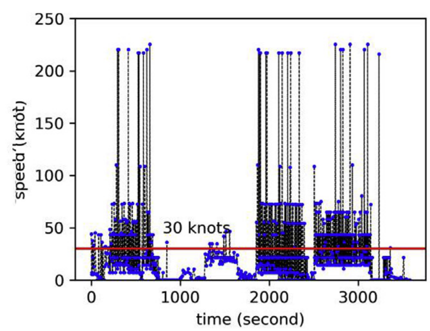


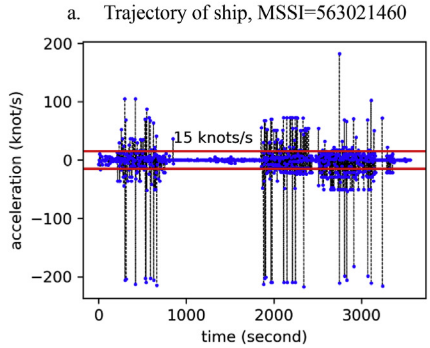
Fig. 1. The vessel trajectory of the AIS data.



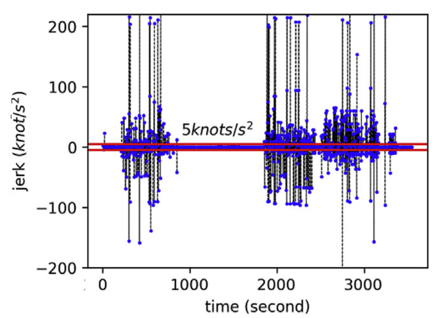
a. Trajectory of ship, MSSI=563021460



b. Speed analysis



c. Acceleration analysis



d. Jerk analysis

Fig. 2. Ship speed, acceleration, and jerk analysis.

usually more expensive and has higher accuracy compared with the Class B AIS equipment. The accuracy of the AIS data also depends on the location of the AIS message receiver base stations, which affects the AIS message signal coverage (Lapinski and Isenor, 2011). The navigational state also affects the AIS data quality. More specifically, the AIS data from the vessels in the port waters have a higher time resolution than that of the ships in the open sea (Lapinski and Isenor, 2011).

A number of works have been reported for the accuracy evaluation of AIS data. For example, Harati-Mokhtari et al. investigated the AIS errors considering the navigational states, and found that 30% of ships were displayed incorrectly (Harati-Mokhtari et al., 2007). Just as the GPS data, the AIS data is also suffered from the data noise of position information. This can be illustrated by an example of a vessel sailing in the Singapore Port on October 11, 2013, as shown in Fig. 1. It can be seen in the zoom window that the trajectory of the vessel is zigzag caused by the noise data, which should be a smooth curve according to the mechanisms of movement. If this kind of data with noise is used for grounding risk evaluation or the vessel navigation behavior study, which depends on high accurate trajectory data, will result in wrong conclusions. Thus, there is a need to quantify the quality of the AIS dataset, and reconstruct the real ship trajectory based on the sampling vessel position information with noise from the AIS data.

Very few attempts in the literature review have been conducted for the AIS data noise elimination and vessel trajectory reconstruction based on the AIS data. Qu et al. presented a data cleansing procedure to eliminate the noises and update those inaccurate records according to Newton's laws of motion (Qu et al., 2011). More specifically, the traffic speed can be calculated based on the AIS trajectory, which is then used as an