MARITIME RESEARCH CENTER
FOUNDATION FOR UNDERWATER DOMAIN AWARENESS

Research Note

Vessel trajectory reconstruction of missing AIS values

Dhanush Balaji R D[*], Arnab Das[**]

[*] Electronics and Instrumentation, BITS Pilani

[**] Director, Maritime Research Centre, Pune

INTRODUCTION

Automatic Identification System (AIS) is an automatic vessel tracking system that uses digital navigation equipment to broadcast important messages that describe the vessel and its sailing status information. The original purpose of AIS was solely collision avoidance, but many other applications have since developed and continue to be developed [1]. AIS data is generally visualized by constructing individual trajectories, and hence many methods have been devised to construct trajectories from AIS data. However, raw AIS data is usually plagued with a lot of inconsistencies and noise, and thus a sufficient level of data mining and cleaning methods need to be employed before using it for other purposes. Trajectory reconstruction is one particular method that is used to tackle the issue of missing AIS data values.

This study is divided into four sections, and in the first section, some critical applications of ship trajectories are detailed and notable works that have been done for each application are mentioned. In the second section, the latest significant approaches in trajectory reconstruction that aim to improve the quality of AIS database have been discussed. The third section lists some crucial challenges regarding AIS data, and the final section provides some key research directions in this field that can be taken up.

1. APPLICATIONS OF SHIP TRAJECTORIES

1. Mapping shipping density:

Fiorini et al. (2016) [2] presented a complete pipeline for visualizing ship routes from AIS data to improve Maritime Spatial planning. Wu et al. (2017) [3] derived shipping density maps, including the vessel and traffic density maps, as well as AIS receiving frequency maps from AIS data. Shelmerdine R.L. (2015) [4] carried out the density mapping of vessels by deriving them from both point and vessel track AIS data.

2. Characterizing marine traffic patterns:

Breithaupt et al. (2017) [5] delineated vessel routes between ports along the Atlantic coast of the US and processed the AIS data to generate commercial vessel tracks for individual vessels. Altan & Otay (2017) [6] delivered an extensive data analysis of the maritime traffic using AIS data in the Strait of Istanbul. Desouza et al. (2016) [7] developed methods to detect and map fishing activities using S-AIS data to improve fisheries management and conservation measures worldwide. Chen et al. (2015) [8] delineated the principal fairways of ship passages through a strait by identifying cumulative activity patterns of ship groups derived from mass ship trajectories.

3. Anomalous behaviour detection of ships:

Ristic et al. (2008) [9] developed an anomaly detector to be applied to real incoming AIS data by using the extracted motion patterns of the vessel trajectory from its historical AIS data. Pallotta et al. (2013) [10] presented an unsupervised and incremental learning approach to the extraction of maritime movement patterns as a basis for automatically detecting anomalies. Zhen et al. (2017) [11] proposed a method which combines vessel trajectory clustering and Naïve Bayes classifier to detect anomalous vessel behaviour.

4. **Collision risk analysis:**

Chen et al. (2015) [12] established a mathematical model of risk evaluation for an embedded system and proposed a new design of the AIS-based embedded system for ship collision avoidance. Mou et al. (2010) [13] developed linear regression models for collision avoidance based on an AIS data-based statistical analysis of ships involved in collisions.

5. **Investigation of maritime accidents:**

When loss of AIS data transmitted by the ship to the receiver station occurs, especially when an accident happens, the interpolation of the missing AIS dynamic data to reconstruct the vessel trajectory is necessary for analyzing and investigating the maritime accident [14].

6. **Maritime route generation for vessels:**

Tan et al. (2018) [15] presented a method for the automated generation of navigation plans for autonomous or robotic surface vessels. The method computed navigation plans using nearest neighbour-based path retrieval relying on two representations, Ship Feature, and Navigation Feature. Existing AIS records in the form of ship properties and the corresponding routes were pre-processed and stored in the form of Ship and Navigation Feature. Zhang et al. (2018) [16] presented a novel approach to automatic maritime routing algorithm, where a routable road network was inferred by combining data-driven based algorithms on a given a set of ship trajectories.

2. WORKS ON TRAJECTORY QUALITY IMPROVEMENT

1. Sang et al. (2012) [17] divided the vessels' tracks into two classes: stand-on track and turning track. Then AIS messages were parsed, and then the two classes were selected to restore tracks with Piecewise Linear Interpolation, Piecewise Cubic Interpolation, and Piecewise Cubic Spline Interpolation.
2. Sang et al. (2015) [18] proposed a method for restoring trajectories of Class-B AIS data, which sometimes contained garbled messages leading to inaccurate data. The study suggested three rules to identify and cleanse inaccurate data and then designed a novel trajectory restoration method based on navigational features of the vessel.
3. Nguyen et al. (2015) [14] proposed a method that included linear interpolation, cubic Hermit interpolation, and an identification mechanism to interpolate missing AIS dynamic data.
4. Jaskólski (2017) [19] proposed a discrete Kalman algorithm to reduce the unavailability of AIS data by estimating coordinates of the vessel where missing data points exist. The developed algorithm was shown to be useful in patching the AIS data in cases where high-resolution data would be needed but is not available.
5. Mao et al. (2018) [20] proposed a three-step method for path interpolation of missing AIS data values. Firstly, missing data was identified by setting a relevant threshold interval for AIS messages. Then the missing time period was defined as the time range between the missing data pair and the great-circle distance between missing data pair as calculated by the Haversine formula. The computed distance was then divided by SOG of the earlier position, and if it came out to be greater than two, linear interpolation was used to construct the vessel's trajectory in the required time period.
6. Zhang et al. (2017) [21] proposed a method to enhance the availability of AIS dynamic data that was either lost or contained inaccurate values. A set of factors such as the moving distance, speed, acceleration, and course change rate were designed according to the ships' maneuverability to screen the inaccurate AIS data. Then, the piecewise cubic Hermite interpolation and cubic spline interpolation were employed to restore the AIS data.
7. Zhang et al. (2018) [22] proposed a three-step vessel trajectory reconstruction model where outliers were first removed. Then the navigational states were estimated, such as hoteling, maneuvering, and normal-speed sailing. Trajectory reconstruction was done for different navigational states by using linear regression and a B-Spline filtering model.
8. Wang et al. (2018) [23] developed a method to figure out the main routes and associated speed profiles between two distinct locations, from massive historical trajectories based on DTW and HDBSCAN. The proposed method can be used to reduce the uncertainty of trajectories with large path gaps.
9. Yuan et al. (2019) [24] proposed a three-step approach for trajectory reconstruction. Firstly, designed the AIS dataset

was cleaned using an abnormal trajectory data identification algorithm. Then the vessel navigational state was identified considering the navigation characteristics of vessels in that area. Finally, the RNN-LSTM network was employed to construct the vessel trajectory reconstruction model.

10. Liang et al. (2019) [25] proposed a two-step calculation method for vessel trajectory reconstruction. In the first step, the Random Forest method was introduced to identify the missing position records within vessel trajectories automatically.

    The second step involved a Long Short-Term Memory (LSTM)-based supervised learning method to reconstruct the vessel trajectories with missing AIS data.

3. CHALLENGES

1. AIS data reporting intervals not being maintained:

Last et al. (2015) [26] discussed two hypotheses as to the reason behind why the AIS reporting intervals are not maintained as described in ITU [27]. The first hypothesis stated that AIS message loss might be related to the medium which is used to transfer AIS data, which is the very-high frequency(VHF) radio waves. The second one stated that AIS message loss might also be caused by the AIS system itself because of network overload in areas with a high density of vessels.

2. Inappropriate location of AIS base stations:

Lapinski & Isenor (2011) [28] detailed the accuracy of the AIS data depending on the location of the AIS message receiver base stations, which affects the AIS message signal coverage. More specifically, AIS data from the vessels in the port waters was shown to have a higher time resolution than that of the ships in the open sea. Liu et al. (2017) [29] investigated the coverage of AIS base station in the Yangtze River, China. After pre-processing the visual analysis of AIS data indicated distinct features of AIS data loss in the mountainous region of the waterway. Further statistical calculations suggest that the AIS data loss rate falls in a range of 20% to 40%, emphasizing the importance of layout strategies of AIS data acquisition in practical applications.

3. Complexity of ship trajectories:

Lei et al. (2016) [30] showed that extracting movement behavioral knowledge from uncertain AIS trajectories is a challenging task. This is because shipping vessels are free-moving, and thus AIS trajectories are much more complicated than trajectories that are constrained, such as the road traffic networks.

4. Frequency of S-AIS messages:

Guillarme & Lerouvreur (2013) [31] stated that even though S-AIS provides global coverage of the maritime domain including the open sea, its extended range implies some technical issues affect the detection rate and the information update frequency, making it less suitable for real-time applications, especially in high-density areas. Due to the nature of satellite orbits and their trajectories, satellite AIS receivers cannot pick up AIS messages as frequently as terrestrial receivers, which are in a fixed position. Also, VHF signals received by satellite do not use time slots (SOTDMA) [32], meaning that satellite detected AIS data provides valuable but less granular vessel position records than land-based receivers [33].

4. RESEARCH DIRECTIONS

1. Reduce computational time and cost involved in dealing with massive AIS trajectories.

Li et al. (2016) [34] proposed the Douglas-Peucker (DP) algorithm to simplify massive trajectories and used Kernel Density Estimation (KDE)-based vessel density visualization to shorten computation time. Appropriate threshold for DP-based AIS trajectory simplification was chosen to maintain a balance between AIS trajectory simplification and visualization performance.

2. Further study of equipment used to transmit AIS data variables.

Banyś et al. (2012) [35] showed that AIS variables having the highest occurrences of unknown values are those that are calculated externally from the AIS transponder, and have an NMEA connection with the AIS device. Hence to improve AIS data integrity, further studies of the technical conditions that lead to such operation of AIS transponders need to be undertaken.

3. **Taking environmental factors into consideration while constructing trajectories.**

Sang et al. (2015) [18] said that ships navigating along the river are always drifting due to wind, current and environmental conditions. Thus further research in trajectory reconstruction, taking into account these factors/parameters, may be undertaken to restore more accurate trajectories.

REFERENCES

[1] FLIR Systems, Inc. (n.d.). AIS - The Ultimate Guide to Automatic Identification Systems. (2016, September 13). Retrieved June 15, 2020, from https://www.raymarine.com/view/blog/news/details/index-id=15032385552.html

[2] Fiorini, M., Capata, A., & Bloisi, D. D. (2016). AIS data visualization for maritime spatial planning (MSP). International Journal of e-Navigation and Maritime Economy, 5, 45-60.

[3] Wu, L., Xu, Y., Wang, Q., Wang, F., & Xu, Z. (2017). Mapping global shipping density from AIS data. The Journal of Navigation, 70(1), 67-81.

[4] Shelmerdine, R. L. (2015). Teasing out the detail: How our understanding of marine AIS data can better inform industries, developments, and planning. Marine Policy, 54, 17-25.

[5] Breithaupt, S. A., Copping, A., Tagestad, J., & Whiting, J. (2017). Maritime route delineation using AIS data from the atlantic coast of the US. The Journal of Navigation, 70(2), 379-394.

[6] Altan, Y. C., & Otay, E. N. (2017). Maritime Traffic Analysis of the Strait of Istanbul based on AIS data. The Journal of Navigation, 70(6), 1367-1382.

[7] de Souza, E. N., Boerder, K., Matwin, S., & Worm, B. (2016). Improving fishing pattern detection from satellite AIS using data mining and machine learning. PloS one, 11(7).

[8] Chen, J., Lu, F., & Peng, G. (2015). A quantitative approach for delineating principal fairways of ship passages through a strait. Ocean Engineering, 103, 188-197.

[9] Ristic, B., La Scala, B., Morelande, M., & Gordon, N. (2008, June). Statistical analysis of motion patterns in AIS data: Anomaly detection and motion prediction. In 2008 11th International Conference on Information Fusion (pp. 1-7). IEEE. [10] Pallotta, G., Vespe, M., & Bryan, K. (2013). Vessel pattern knowledge discovery from AIS data: A framework for anomaly detection and route prediction. Entropy, 15(6), 2218-2245.

[11] Zhen, R., Jin, Y., Hu, Q., Shao, Z., & Nikitakos, N. (2017). Maritime anomaly detection within coastal waters based on vessel trajectory clustering and Naïve Bayes Classifier. The Journal of Navigation, 70(3), 648-670.

[12] Chen, D., Dai, C., Wan, X., & Mou, J. (2015, June). A research on AIS-based embedded system for ship collision avoidance. In 2015 International Conference on Transportation Information and Safety (ICTIS) (pp. 512-517). IEEE. [13] Mou, J. M., Van Der Tak, C., & Ligteringen, H. (2010). Study on collision avoidance in busy waterways by using AIS data. Ocean Engineering, 37(5-6), 483-490.

[14] Nguyen, V. S., Im, N. K., & Lee, S. M. (2015). The interpolation method for the missing AIS data of ship. Journal of Navigation and Port Research, 39(5), 377-384.

[15] Tan, W. C., Weng, C. Y., Zhou, Y., Chua, K. H., & Chen, I. M. (2018, May). Historical Data is Useful for Navigation Planning: Data Driven Route Generation for Autonomous Ship. In 2018 IEEE International Conference on Robotics and Automation (ICRA) (pp. 7478-7483). IEEE.

[16] Zhang, S. K., Shi, G. Y., Liu, Z. J., Zhao, Z. W., & Wu, Z. L. (2018). Data-driven based automatic maritime routing from massive AIS trajectories in the face of disparity. Ocean Engineering, 155, 240-250.

[17] Sang, L. Z., Yan, X. P., Mao, Z., & Ma, F. (2012, October). Restoring Method of Vessel Track Based on AIS Information. In 2012 11th International Symposium on Distributed Computing and Applications to Business, Engineering & Science (pp. 336-340). IEEE.

[18] Sang, L. Z., Wall, A., Mao, Z., Yan, X. P., & Wang, J. (2015). A novel method for restoring the trajectory of the inland waterway ship by using AIS data. Ocean Engineering, 110, 183-194.

[19] Jaskólski, K. (2017). Two-dimensional coordinate estimation for missing automatic identification system (AIS) signals based on the discrete Kalman filter algorithm and universal transverse mercator (UTM) projection. Zeszyty Naukowe Akademii Morskiej w Szczecinie.

[20] Mao, S., Tu, E., Zhang, G., Rachmawati, L., Rajabally, E., & Huang, G. B. (2018). An automatic identification system (AIS)

database for maritime trajectory prediction and data mining. In Proceedings of ELM-2016 (pp. 241-257). Springer, Cham.

[21] Zhang, D., Li, J., Wu, Q., Liu, X., Chu, X., & He, W. (2017, August). Enhance the AIS data availability by screening and interpolation. In 2017 4th International Conference on Transportation Information and Safety (ICTIS) (pp. 981-986). IEEE.

[22] Zhang, L., Meng, Q., Xiao, Z., & Fu, X. (2018). A novel ship trajectory reconstruction approach using AIS data. Ocean Engineering, 159, 165-174.

[23] Wang, Z., Hu, J., & Fan, Q. (2018, September). Extracting the Main Routes and Speed Profiles Between Two Locations from Massive Uncertain Historical Trajectories. In 2018 International Symposium in Sensing and Instrumentation in IoT Era (ISSI) (pp. 1-5). IEEE.

[24] Yuan, Z., Liu, J., Liu, Y., & Li, Z. (2019, July). A Novel Approach for Vessel Trajectory Reconstruction Using AIS Data. In The 29th International Ocean and Polar Engineering Conference. International Society of Offshore and Polar Engineers.

[25] Liang, M., Liu, R. W., Zhong, Q., Liu, J., & Zhang, J. (2019, March). Neural Network-Based Automatic Reconstruction of Missing Vessel Trajectory Data. In 2019 IEEE 4th International Conference on Big Data Analytics (ICBDA) (pp. 426-430). IEEE.

[26] Last, P., Hering-Bertram, M., & Linsen, L. (2015). How automatic identification system (AIS) antenna setup affects AIS signal quality. Ocean Engineering, 100, 83-89.

[27] ITU-R web. Technical characteristics for an automatic identification system using time-division multiple access in the VHF maritime mobile band [Homepage of International Telecommunication Union]. (2014, February 18). Retrieved June 15, 2020, from https://www.itu.int/rec/R-REC-M.1371-5-201402-I/en

[28] Lapinski, A. L. S., & Isenor, A. W. (2011). Estimating reception coverage characteristics of AIS. The Journal of Navigation, 64(4), 609-623.

[29] Liu, L., Liu, X., Chu, X., Li, J., Jiang, Z., & He, W. (2017, August). Coverage effectiveness analysis of AIS base station: a case study in Yangtze River. In 2017 4th International Conference on Transportation Information and Safety (ICTIS) (pp. 178-183). IEEE.

[30] Lei, P. R., Tsai, T. H., & Peng, W. C. (2016, October). Discovering maritime traffic route from AIS network. In 2016 18th Asia Pacific Network Operations and Management Symposium (APNOMS) (pp. 1-6). IEEE.

[31] Le Guillarme, N., & Lerouvreur, X. (2013, July). Unsupervised extraction of knowledge from S-AIS data for maritime situational awareness. In Proceedings of the 16th International Conference on Information Fusion (pp. 2025-2032). IEEE.

[32] e-Navigation, Marine Information Portal, Canada, Communications Branch. SOTDMA and CSTDMA. (2019, February 26). Retrieved June 15, 2020, from https://www.marinfo.gc.ca/e-nav/docs/sotdma-cstdma-eng.php

[33] Lloyd's List Intelligence, Maritime Intelligence. Understanding AIS (Automatic Identification System) . (2017, March 10). Retrieved June 15, 2020, from https://maritimeintelligence.informa.com/resources/product-content/understanding-the-automatic identification-system

[34] Li, Y., Liu, R. W., Liu, J., Huang, Y., Hu, B., & Wang, K. (2016, October). Trajectory compression-guided visualization of spatio temporal AIS vessel density. In 2016 8th International Conference on Wireless Communications & Signal Processing (WCSP) (pp. 1-5). IEEE.

[35] Banyś, P., Noack, T., & Gewies, S. (2012). Assessment of AIS vessel position report under the aspect of data reliability. Annual of Navigation, 19(1), 5-16.