Anomaly Detection of Ship Navigation Based on AIS Signal with Long short-term memory(LSTM)

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Abstract

My plan is to study a method of judging the ship's speed anomaly and position anomaly.

With the continuous prosperity of shipping trade around the globe, the density of maritime traffic increases gradually. The abnormal behavior of ships will hinder the normal progress of shipping trade and increase the hidden danger of personal and property safety. In order to reduce the risk of maritime traffic accidents and crack down on illegal smuggling behaviors, the effective anomaly detection of ship navigation has become a hotspot. AIS data contains a wealth of ship movement information, which provides great convenience for the effective identification and supervision of abnormal behavior of ships. Therefore, this paper is to determine whether the ship's speed and passing position belong to normal navigation according to longitude and latitude data provided by AIS signal with DP and LSTM.

Introduction

Because of the growth of global trade and the expansion of the shipping industry, the number and scale of ships are increasing, which brings new difficulties and challenges to maritime monitoring and management, and also has higher requirements for the efficiency and safety of shipping traffic. As the cornerstone of the development of economic exchanges, the importance of ship transportation efficiency and safety is self-evident, and people are paying more and more attention. Ships may encounter many abnormal situations during operation at sea, such as mechanical failure of internal parts of ships, inclement weather that prevents normal navigation, attacks by pirates, illegal transactions, accidents caused by improper operation caused by crew mistakes, etc., which will seriously affect the safety and transportation efficiency of ships.
In order to ensure the safety and economy of maritime trade, ship anomaly detection technology came into being and gradually developed into an important national strategic research field. Its purpose is to improve the level of information, digitization and automation of the government's maritime monitoring and management departments, optimize the management mode, and enhance the efficiency of supervision to reduce illegal acts and accidents. Effective detection and identification of ship abnormal behavior is of great significance for protecting Marine navigation safety and reducing the risk rate of water traffic accidents. Therefore, ship abnormal detection technology has been widely used in ship operation management, Marine environment monitoring, maritime law enforcement and other fields, and has become an important support technology for the development of shipping industry.
LSTM can solve the problem of gradient disappearance and gradient explosion during the training of long sequences, and has better performance in longer sequences.

Related work

With the increasing success of data-driven approaches (Provost 2013)in various fields and the growth in the volume of maritime transport data, the adoption of data-driven approaches holds great promise in the field of effectively identifying and monitoring abnormal behavior of ships. The Automatic Identification System (AIS) provides abundant data sources for ship location and trajectory, which provides great convenience for the research work related to the detection of ship abnormal navigation behavior.The ship motion feature extraction and prediction method based on AIS data has become a hot research direction in the field of global shipping traffic engineering.

- K-nearest neighbor algorithm and DBSCAN algorithm constantly need to calculate the similarity measure. A commonly used similarity measure in trajectory clustering is DTW distance, which requires the trajectory data points to be arranged in a time series, but does not require that the different tracks be perfectly aligned in time.DBSCAN clustering algorithm is based on density. It has a good effect on the region clustering of arbitrary shape and the recognition of outliers. A article(HAN X 2021)points out the shortcomings of this algorithm: uneven data distribution and the shortest distance calculated by using Euclidean distance cannot accurately describe the trajectory of complex scenes at sea. To this end, they

[*]With help from the teacher named LuYang and his assistants.

thought of similar Mahalanobis distances to replace Euclidean distances, characterize the shortest distances, and describe trajectories in complex scenarios.

- Another common similarity measure is Hausdorff distance. Unlike DTW distances, Hausdorff distances do not require logarithmic points to be arranged in chronological order
- Some people(RONG H 2022, 2019)used clustering and Gaussian models to extract the starting point, end point and sailing path of ships in a certain area. They used four independent variables, course, turning rate, ship speed and ship type, to predict the probability of a ship belonging to a different route. When a ship is classified as a low-probability route, it is considered to have engaged in unusual behavior.
- In this paper(PALLOTTA G 2013), a dynamic anomaly detection method based on ship motion characteristics is proposed, which extracts the motion track from historical data, uses the latitude and longitude information and speed information of the ship in the specified observation area to predict the path area that the ship will pass with a high probability, and can immediately update the sailing state and prediction results following the ship's movement, and decide whether to alarm according to the deviation degree.
- In the literature(Wang Zhengxing 2021; WANG Z X 2021), by introducing a neuron construction model that represents the amount of special environmental disturbance, researchers applied the short-duration algorithm to judge the ship trajectory, which has a better effect than the traditional neural network. The paper(Xiang Huaikun 2013), researchers used particle swarm optimization algorithm to optimize the parameters of the network and took into account the degree of traffic congestion. The experimental results show that the recognition accuracy and recognition speed of the improved neural network are better than the traditional neural network. In a literature (hcr 2015), initial critical values and weighting coefficients were generated on the basis of genetic algorithm, and a preliminary classifier was established. Next, they used the AdaBoost algorithm to optimize the critical values and weighting coefficients, thus forming a strong classifier. In the case of this classifier, they classify the data in order to monitor the occurrence of exceptions. Literature(MA X 2015)proposes a long and short term neural network to solve the attenuation of backpropagation errors, which greatly increases the time to predict the trajectory motion. The motion anomaly recognition by statistical method is to obtain the probability distribution of the past ship data, and distinguish the normal and abnormal data according to the confidence of the distribution. The algorithm proposed in the paper(W Y 2017)obtains the standard of similarity measurement through training trajectory data, and uses this standard to calculate the similarity of test data and make judgment. In the literature (KOWALSKA K 2012), Gaussian regression and active learning algorithms are used to predict the ship's next behavior, and the difference between the real motion and the predicted value is compared to determine whether there is any anomaly. A literature(H 2021)optimized the general density-based clustering algorithm, clustering the position, speed and heading of ship trajectory. However, the method based on statistical modeling has some limitations, mainly relying on historical information and failing to fully consider environmental factors. For example, when a ship is sailing at a speed within a high probability interval, if the speed of the surrounding ships is much lower than or higher than the ship, the ship's motion state may have problems.
- A paper(ZHANG T 2020) uses similarity measurement to judge whether two abnormal trajectories belong to the same trajectory and evaluate the possibility of deliberately shutting down the navigation system according to similar normal trajectories. The paper(D'AFFLISIO E 2021) uses the hypothesis testing formula of deception parameters to evaluate whether the received data trajectory is trustworthy.
- Complex abnormal behavior. These are often composed of several fundamental anomaly events, and most of them are not easy to detect directly from the raw data. At present, the research of complex ship incidents mainly focuses on smuggling, drug trade, theft and fishing in forbidden areas. Different basic anomaly identification methods should be combined to systematically detect anomalies. The paper(ZHANG Z 2020) integrates a variety of recognition methods and gradually builds an identification library, allowing users to select identification modules according to their own priorities and combine them into event streams according to their choices, so as to facilitate the identification of more chaotic situations later. Literature(SHAHIR H Y 2015) uses Hidden Markov Model (HMM) to divide abnormal behavior into different scenarios, and adds more environmental information to determine which kind of anomaly it is.(Huang Chen 2022)

Proposed Solution

Long short-term memory (LSTM) is a special kind of RNN, mainly to solve the problem of gradient disappearance and gradient explosion during long sequence training. Simply put, LSTMS can perform better in longer sequences than ordinary RNNS.Whereas RNN has only one transmission state, LSTM has two transmission states, cell state and hidden state. The passed cell state changes slowly, and the output is usually the previous state Add some numbers. hidden states, on the other hand, often differ greatly in different nodes. This is the main difference between the two. The internal structure of LSTM is shown in Figure 1. There are three main stages of operation:

- Forget phases. This stage mainly involves selective forgetting of the input passed in by the previous node. Forget the unimportant and remember the important. Specifically, the calculated value is used as a forget gate to control whether the previous state needs to be retained or forgotten.

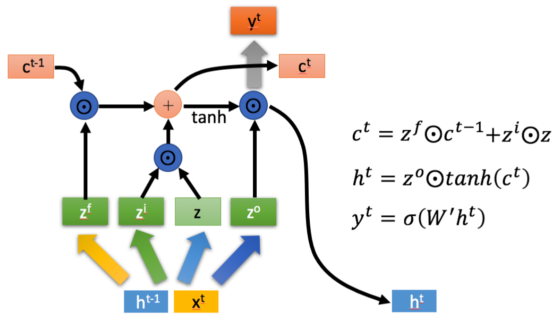

Figure 1: The internal structure of LSTM

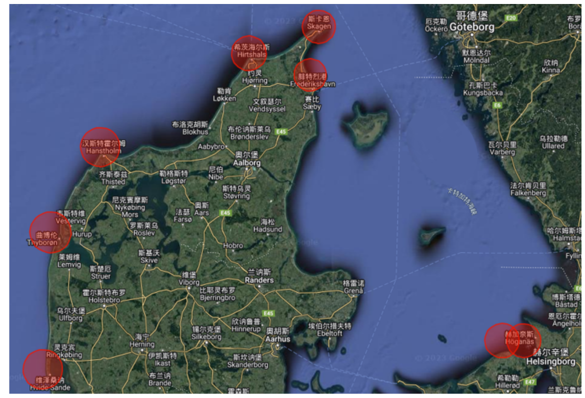

Figure 2: The locations of some of the ports in Denmark included in the data set, circled in red.

- Select the memory phase. This stage selectively "memorizes" the input from this stage. It mainly selects memory for the input. Write down what is important, and write down less what is not. Add the results obtained in the two steps above to get the transfer to the next state
- Output phase. This phase determines what will be considered the output of the current state. The results obtained in the previous stage are also reduced by a tanh activation function.

Experiments

Our goal is to detect abnormal behavior of ships, including speed anomalies and position anomalies.

Data set. The AIS data of ships used in this paper are from The Kingdom of Denmark, located in northern Europe. Denmark is committed to becoming the world's leading maritime power. Its geographical location is advantageous, surrounded by the sea on three sides, with a long coastline and many islands, it owns more than 7 percent of the world's merchant fleet and contributes about 10 percent of the world's shipping services. As a highly developed country, Denmark's merchant fleet has a large number of new ships, a high degree of modernization of ship interior design, and advanced control technology. Maritime operations are more efficient, have a greater advantage in maritime safety, and are a shipping center capable of providing a full range of services from maritime engineering to financial services. Figure 2 shows the locations of some of Denmark's ports in red circles.

Data preprocessing. The original AIS data was sampled at very short intervals and contained many data types, but many data entries had partially missing fields, which was not conducive to further analysis. Therefore, filtering and data cleansing are required to improve data integrity. Since the main purpose of this paper is to develop a ship anomaly detection method through trajectory clustering, and a large amount of data needs to be processed, we focus on the trajectory of a single type of ship arriving at the target port and passing through the target area within a certain period of time, and filter and clean the original AIS data through the following steps.

(1) Data filtering. Filter the raw data and only retain the data that dates from around 2018, the vessel type is a fishing vessel, and the destination is the target port.

(2) Eliminate logical errors. For example, the longitude is not in the range of (-180, 180), the latitude is not in the range of (-90, 90), and the speed value is not realistic.

(3) Trajectory extraction. The data filtered in the previous step is first grouped by MMSI, and then sorted according to the time stamp. After sorting, the time continuity of the data is checked for each MMSI group in turn, and a continuous set of points with a maximum time gap of less than two hours is extracted as the candidate trajectory. Since data loss can occur due to, for example, faulty reception by the base station or failure of data storage, the complete trajectory to the destination can be split into multiple segments.

(4) Track integrity check. For each candidate trajectory, first check whether the end point is within a certain distance (within 10 km) from the destination port. If this condition is not met, then the candidate locus is eliminated. The remaining part of the trajectory is checked again for time integrity to see if it has sufficient time length (that is, time length 6h). If this condition is met, the trajectory is retained for further analysis.

(5) Downsampling. The time granularity of the extracted trace is about a few seconds. Since ships do not move very far in a few seconds, changes in state in such short intervals tend to be small. This means that there is still a large amount of redundancy in the extracted data. To reduce redundancy, we downsample each trajectory using linear interpolation so that the time interval between two adjacent points is 150 seconds. Then the trajectory needs to be checked again for integrity and points that are clearly not in the trajectory are eliminated.

Speed anomalies. There are two types of abnormal speed behaviors that may occur in the course of ship operation: too slow speed and too fast speed. Too slow speed may be the ship encountered a variety of mechanical problems, such as bearing failure, fuel accidental leakage and lack of power, and so on. By monitoring the operation data of the ship, these faults can be checked in time, and then maintenance

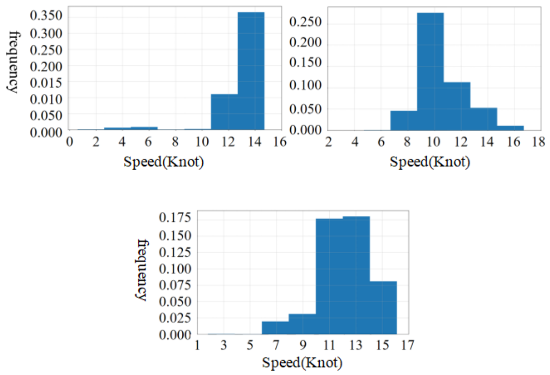

Figure 3: Skarn port speed and course statistical histogram

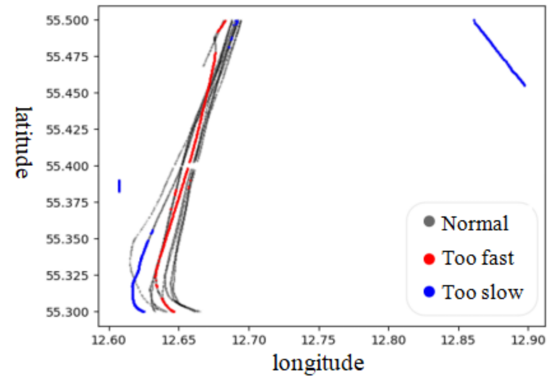

Figure 4: Determine the speed anomaly diagram

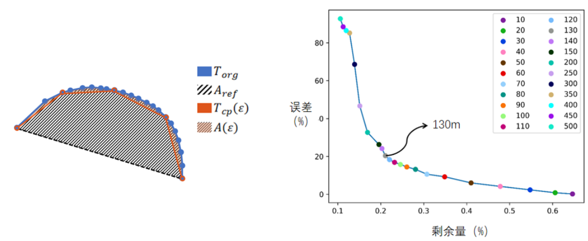

Figure 5: Similarity measurement method

measures can be taken to adjust and optimize the speed and route of the ship, avoid further deterioration of the fault, and ensure the safety and transportation efficiency of the ship. Too slow for a long time also means that the ship may be wandering in a sea area, is carrying out illegal activities, such as smuggling, dumping illegal chemicals, etc., should attract the attention of maritime regulatory authorities. Excessive speed may be due to improper operation of the ship's personnel due to mistakes, or based on their own past experience to make a wrong judgment. Another possibility is a pirate attack and a need for land support. By monitoring the operation data of the ship, the crew can be warned in time, errors can be corrected, hidden dangers can be eliminated, and the safety and transportation efficiency of the ship can be guaranteed. First of all, the speed and course of ships going to various ports are analyzed statistically. Taking Skarn Port as an example, Figure 3 shows the speed statistical histogram of ships going to Skarn port passing through different areas.

Then, the quantile is used to judge the anomaly. For speed anomaly detection, we focus on the speed of the ship passing through the same sea area, without distinguishing the port of destination of the ship. Therefore, once a ship has passed through the target area, it counts as an experimental sample. If the speed exceeds 95 percent of the total, it is considered to be too fast, and if the speed is lower than 5 percent of the total, it is considered to be too slow. As shown in Figure 4, the normal speed of the original track is black, the track with too fast speed is red, and the track with too low speed is blue.

Position anomalies. In traditional maritime operations, the choice of channel is very limited, because the channel that the ship passes through is based on the experience of the captain, which is called the experience channel. If you enter an unknown area, the ship may collide with potential shipwrecks, fishing fences, and wooden piles, and striking the reef may damage the hull and greatly increase the risk of transportation. If the water depth near the channel changes greatly, leaving the experience channel too far may cause the ship to run aground. Therefore, it is very important and challenging to develop channel position anomaly detection that can achieve high accuracy in a short time interval. The core idea of the method proposed in this paper is to first carry out data mining on historical AIS data sets to identify reference routes.

Since the original trajectory extracted from AIS data generally contains a large number of points, the Douglas-Peucker (DP) algorithm is adopted to reduce the number of points in each trajectory, so as to reduce the computational complexity and obtain key points that can represent the entire trajectory.While achieving greater compression rate, it is necessary to ensure that the similarity between the compressed trajectory and the original trajectory is large enough. Since the point of the compressed trajectory is a subset of the original trajectory, distance-based similarity measures such as DTW distance and Hausdorff distance cannot accurately capture the similarity. Inspired by the local intermediate polyline, the area surrounded by the trajectory is used as a measure of similarity.In order to minimize the error and residual amount, and increase the compression rate and similarity, an appropriate threshold should be selected, as shown in Figure 5.

The shipping routes of large ports are more concentrated, and the data points formed are very dense, and the trajectories are clear. The channel can be expressed without too many points, so the compression force can be increased. The shipping routes of small ports are more dispersed, the data points are sparse, and the tracks look a little messy, so the degree of compression needs to be reduced to prevent the loss of track characteristics. Figure 6 shows the compressed results. Then LSTM algorithm is used to connect the compressed points into a channel. The parameters in the algo-

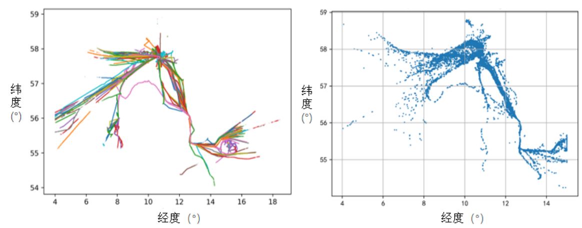

Figure 6: The DP algorithm obtains the compression result of the reference trajectory

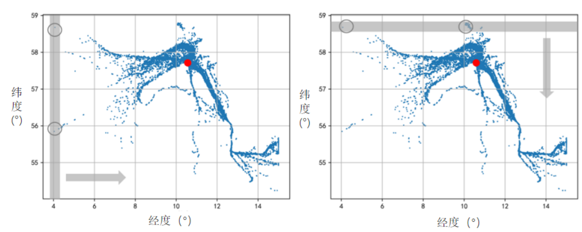

Figure 7: The space fitting line is carried out through the vertical and horizontal sliding window

rithm are adjusted to make the channel conform to the characteristics of the real trajectory. Taking Strandby Port as an example, Figure 8 shows the process of optimizing parameters. Similarly, the results for other ports are shown in Figure 9. The trajectories are divided into sub-trajectories by hour, and the distance from sub-trajectories to the reference channel is calculated. If the distance exceeds 90 percent of the total, the trajectory is considered to be a positional anomaly, as shown in Figure 10.

Conclusion

Firstly, this paper expounds the background, purpose and significance of the research on abnormal behavior detection of ship navigation, and points out that the effective detection and identification of abnormal behavior of ship is of great significance to protect the safety of Marine navigation and reduce the risk rate of water traffic accidents. This paper describes the research status in this field at home and abroad, introduces the development and application of AIS data, and summarizes the types of abnormal behavior and common detection methods. Secondly, the theory and algorithm related to the method used in this paper are introduced. The content, data type and data characteristics of the signal sent by the AIS system are explained. Important algorithms are explained. Then, the method of judging ship speed anomaly and position anomaly is presented in detail. The first step is to filter and clean the original AIS data to extract the movement trajectory through the specified area during a certain period of time to the target port. The second step is to use statistical methods to judge ship speed anomalies. In the third step, DP algorithm is used to further compress the trajectory, and the ”key point” which can represent the trajectory shape is obtained. The LSTM algorithm is used to synthesize the reference channel in both vertical and horizontal directions of the ”key point”, and finally

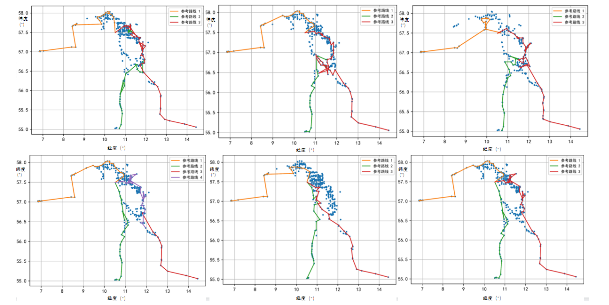

Figure 8: The reference channel diagram of the port is extracted by optimizing parameters

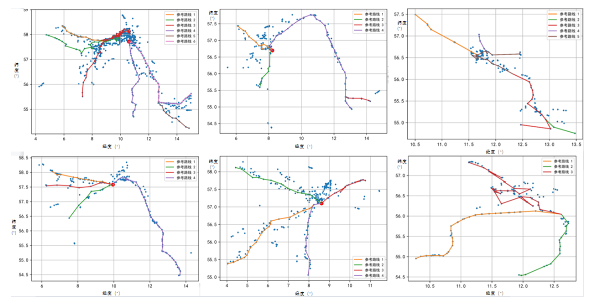

Figure 9: Reference channel for other ports

the location anomaly is detected by the track similarity measurement.

There are many shortcomings in this paper, which need to be continuously improved and improved in the follow-up work: mainly in the following aspects:

(1) In practical application scenarios, the information that can play a warning role is preferably real-time feedback. Compared with the analysis of historical data, online processing and analysis of real-time data, human-computer interaction, dynamic early warning is more practical significance.

(2) Although the data used in this paper is rich in types, it comes from a single source and lacks environmental information. The addition of information such as hydrometeorology on the sea surface and the status of hardware facilities on the ship can more comprehensively evaluate the sailing conditions of the ship, so as to judge abnormal behaviors more accurately.

(3) Although the statistical method used to judge the ship speed anomaly has high efficiency, its accuracy is insufficient. A suitable probability distribution model should be adopted to improve the detection accuracy.

(4) The data objects analyzed in this paper are mainly speed and latitude and longitude, so there are fewer types of anomalies that can be detected. More types of data should be focused on, more types of data should be analyzed in a unified manner, and more complex anomalies can be identified. For example, the use of the ship's speed, course Angle, longitude and latitude three variables to determine whether the ship is wandering in a certain sea area.

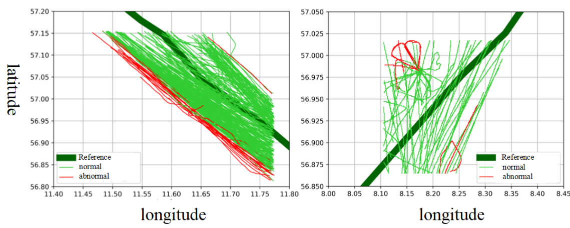

Figure 10: Location anomaly detection diagram

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