Busy Fishing Area Recognition based on Improved K-means with Random Walking Centroid

H. Xue，H. Zhu*，F. Tian and T. Chai

Abstract—**To overcome the sensitivity of the initial value generated by the K-means algorithm, the selection method of an initial clustering center is improved in this paper. The clustering algorithm of a random walking centroid is used to improve the efficiency, stability, randomness, and diversity of the iterative process and prevents convergence to the loacl optimal solution. The identification model of busy water in fishing areas is developed and applied to the Minnan fishery. The proposed model can accurately identify the to overcome the sensitivity of the initial value generated by the spatial distribution and scale of busy fishing areas. It can also adjust the algorithm parameters according to the merchant ship scale, and generate the targeted recommended route. The results can help maritime security departments. Furthermore, the identification method helps novel safety supervision of the maritime department.**

Index Terms—**Fishing boats, Cluster, K-means method**

I. Introduction

In recent years, fishing area in China has been developed rapidly, and the number of fishing boats is increasing. The navigation density of coastal merchant ships in China is growing along with the country's economic development. This has resulted in location overlap between merchant shipping routes and fishing areas. There have been many ship collision accidents along the coast of China, especially for commercial ships and fishing vessels. The Taiwan Strait and other sea areas are concentrated fishing areas. Navigation through the fishing areas is challenging for merchant ship drivers. Although the National Maritime and Fishery Authorities attach great importance to the safety of commercial and fishing vessels at sea, commercial and fishing vessel collision accidents are unfortunately inevitable.

There are a considerable number and wide range of fishing vessels in China. The echoes of fishing vessels often cover the whole radar screen, and the lights of fishing vessels illuminate the entire sea surface. The centralized operation area of fishing vessels stretches for several to dozens of nautical miles. Because of the overwhelming number of fishing vessels, it is difficult for commercial vessels to clear up completely. The fishing boats in the fishing ground are dense. The fishing gear for single towing, pair towing, purse seine, drift net, net opening, rope fishing, and other operations is complex, making it impossible for commercial ships to prevent a collision.

To continue, China's coastal sea fog has high concentration, long duration, and wide coverage, making it a serious threat to navigation safety. China's coastal areas have been affected by typhoons and monsoons for a long time. Therefore, fishing boats, especially wooden fishing boats, cannot be easily found during rainstorms or conditions involving big waves.

The merchant ships are negligent in the navigation and management of the fishing boat operation area, the personnel on duty at the bridge are insufficient, and the lookout is ignored. At present, the company and ships still arrange for only one pilot to be independently on duty. To continue, no safe speed has been adopted, and the pilot on duty rarely adopts speed change measures, with most of them only turning the rudder to avoid other fishing boats. The officer on duty is often inexperienced and unfamiliar with the type of lights displayed by fishing boats, especially at night. The judgment of various light signals of the fishing boat is inaccurate, or the distance is judged only by the brightness of the fishing boat light rather than the overall observation of the clarity of the light.

Moreover, the officer on duty relies too much on the action rules of ships in mutually meeting the international maritime collision avoidance rules to avoid a collision. The officers do not fully understand the collision risk, actions to avoid a collision, or deviation clauses. The officer on duty does not correctly use the light and sound signals and does not give sufficient warning to the fishing boat. There are bad driving habits in duty driving, and autopilot is often used to avoid a close-range collision. The shift handover of the officer on duty is insufficient, especially at night, and the crew on duty does not have enough time to adapt to night vision. The officer on duty was lucky that he did not grasp the situation of crossing the fishing boat area and did not ask the captain to deal with it in time.

Fishing boats have bad habits when managing ships. For example, the fishing crew's level of driving the ship is irregular, and there is still a superstitious idea of "grabbing the bow of the big ship, don't worry about eating and drinking." The crew members of fishing boats are not familiar with collision avoidance rules, lack systematic

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calculation for collision avoidance, and avoid collision only by feeling. When the fishing vessel is engaged in fishing operations, the fishing vessel crew is busy with operations, neglecting to look out for other boats and driving the fishing vessel. The display of fishing boat lights is not standardized, and there is even the phenomenon of not putting on lights at night. The fishing boat crews have high labor intensity and often fall asleep when driving the ship, making the ship enter the "free navigation mode." Although many fishing boats have been equipped with GPS, Automatic Identification System (AIS), and Beidou Positioning System, there are obstacles to the communication between fishing boats and commercial ships.

Effectively excavating the intensive area of fishing boats is conducive to monitoring the behavior of ships and controlling the speed of ships near the fishing area, ensuring the safety of ship navigation and promoting economic development. The idea has significance for the research and application of fishing area mining, pattern recognition, and running track of AIS ship data under the background of big data.

With the rapid development of the shipping industry in recent years, many traditional fishing areas in China have become navigation areas. Especially during the fishing season, the traditional fishing areas outside the Yangtze River Estuary mostly overlap with the channel, making commercial ships and fishing boats coexist in parallel. In addition, most fishing boat crew do not understand the collision avoidance rules. Many fishing boat crews even have the superstitious psychology of "there is no need to worry about crossing the bow for three years," forcibly rushing through the bow of the merchant ship. In addition, many commercial ship drivers have little coastal navigation experience and lack experience in avoiding fishing boats, resulting in frequent collision accidents in this water area.

The technical contribution of this work is summarized as follows:

(1) The selection method of the initial clustering center is improved to overcome the sensitivity of the initial value generated by the K-means algorithm.

(2) The clustering algorithm of a random walking centroid is used to improve the iterative process's efficiency, stability, randomness, and diversity and prevents convergence to the local optimal solution.

(3) Its convergence is proved.

(4) The identification model of busy water in fishing areas is developed and applied to the Minnan fishery. The proposed model can accurately identify the spatial distribution and scale of busy fishing areas, adjust the algorithm parameters according to the merchant ship scale, and generate the targeted recommended route decision for the fishing area.

The rest of this paper is organized as follows. Section 2 reveals the related work. Section 3 describes the preliminaries and problem statement. Section 4 introduces the proposed algorithm to identify and model busy water. The simulation results are reported in Section 5. Finally, Section 6 concludes the paper.

II. Related works

The process of dividing a collection of physical or abstract objects into multiple classes composed of similar objects is called clustering. The cluster generated by clustering is a set of data objects. These objects are similar to those in the same cluster and different from those in other clusters. Wu studied cluster analysis for investigating road recovery in Fukushima Prefecture following the 2011 Tohoku earthquake[1]. Chen studied short-term wind speed forecasting based on singular spectrum analysis, fuzzy C-Means clustering, and improved SSABP[2].

There are three kinds of clustering algorithms: clustering methods based on partition, hierarchical clustering methods, and density-based clustering methods. In K-means , k points are specified, and different sample points are divided into the set of the nearest point to divide all samples into k categories. Liu proposed geological identification based on the K-means cluster of a data tree of shield tunneling parameters[3]. Ma designed a method for establishing a tropospheric atmospheric refractivity profile model based on multiquadric Radial Basis Function and K-means clustering[4].

By classifying the sea state and ship operation state into multiple models, K-means clustering was used to analyze the influence of the sea state and ship operation state[4]. The privacy protections in the process of K-means clustering and K-nearest neighbor classification were studied[5]. The clustering accuracy of K-means from outlier removal and distance measurement was improved[6]. The particle swarm optimization algorithm was implemented to optimize the K-means clustering center to prevent the K-means clustering algorithm from relying on the initial clustering center[7]. Furthermore, a practical protocol for K-means clustering in a cooperative manner was proposed[8]. A method bootstrap mean value was also proposed, where blocks were generated by substitution in the dataset[9]. Considering the estimation of the average of random variables, the bootstrap median of the average had a better collapse point than the median of the average if enough blocks were generated. The algorithm performed Lloyd type iteration and used bootstrap mean and median strategy. The integrated K-means Laplacian with 12 different kernel functions was improved to form paired similarity matrices[10]. Their effects on the performance of existing algorithms and proposed algorithms were studied.

In the studies related to fishery resources in China, some researchers use the cluster analysis method based on the vessel monitoring system to study the temporal and spatial characteristics of fishery activities and the impact of the fishing operations on water areas. In the marine transportation field, the primary purpose is to cluster the ship trajectories and guard against the abnormal behavior of ships by obtaining their main motion trajectories. In navigation production, with the development of modern navigation aids, the spatio-temporal data generated by ships in the process of operation begins to be recorded and collected. AIS is the primary source of ship dynamic information. These large, rich, and real-time data are widely used in ship navigation law extraction, potential behavior feature mining, and so on.

The ship position data is extracted from the received AIS information. The large amount of data has good connectivity and density. The data set can also be divided according to the region and time. Combined with the advantages of regional density connectivity of the Density-Based Spatial Clustering of Applications with Noise (DBSCAN) algorithm, the clustering of fishing vessel positions with high density can be achieved. The clustering results can be adjusted through the parameters related to the density.

Due to the difficulty of navigation in merchant shipping fishing areas, combined with the theory of marine traffic engineering[10], a busy water identification model for fishing areas using the density clustering algorithm based on ship AIS data is developed in this paper. In addition, it identifies and judges the fishing areas that highly affect the navigation of merchant ships and determines the spatial distribution and scale of busy water. Finally, it provides decision-making suggestions on route design for merchant ship pilots.

III. Preliminaries and Problem Statement

K-means randomly initializes location of each cluster center. Each point is assigned to the cluster with smallest distance to the cluster's center. The cluster center is moved to the average value of its sample points. The above operations are repeated until the loss function reaches its smallest value. The objective is to minimize the sum of the distances from all sample points to their center they belong to, that is,

$$J = \sum_{i=1}^{M} \sum_{y_j \in C_i} \| y_j - c_i \| , \quad (1)$$

where y is the samples to be clustered, M is the number of clusters, C is a cluster, c is the centroid of the cluster, and J is the cost function.

The center of the cluster is updated as follows:

$$c_{i,k} = \frac{1}{\| C_{i,k} \|} \sum_{y_j \in C_{i,k}} y_j . \quad (2)$$

IV. Main Results

A. Initial cluster centroid

The track with the minimum distance to other tracks is selected as the first initial center track. The distance between the remaining tracks and the first initial center track is calculated and sorted. The track furthest from the first initial center track is selected as the second initial center track. The sum of the distance between the remaining trajectories and the first and second initial center trajectories is calculated and sorted. The track farthest from the sum of the first and second initial center tracks is selected as the third initial center track. This operation is continued until K initial centers are selected. These selected initial centers are used to improve the efficiency of the clustering. The method is given in Algorithm 1.

Algorithm 1 Initial cluster centroid.

Input: Trajectories to be clustered.

Output: k initial cluster.

Begin:

1: Select the track with the minimum distance to other tracks as the first initial center track.

2: For all $i = 2 : k$ do

3: Calculate the distance between the remaining tracks and the selected initial center track.

4: Sort the distance.

5: Select the track furthest from the selected initial center track as the i-th initial center track.

6: End for.

End

B. New centroid selection mechanism

In the K-means with random walking centroid (RWC-K-means) algorithm, when iteratively updating the centroid, random walk is introduced. To increase diversity and prevent falling into local optimization, the new centroid is selected as follows:

$$\| \hat{c}_{i,k} - c_{i,k} \| = r_{i,k} \| c_{i,k-1} - c_{i,k} \| , \quad (3)$$

where $0 < r_{i,k} < 1$.

Figure 1 depicts the new centroid selection mechanism.

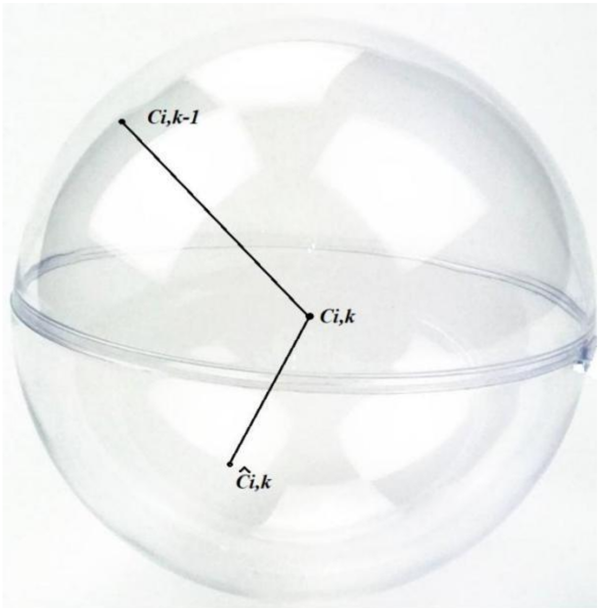

Fig. 1. New centroid selection mechanism.

The algorithm process is shown in Figure 2.

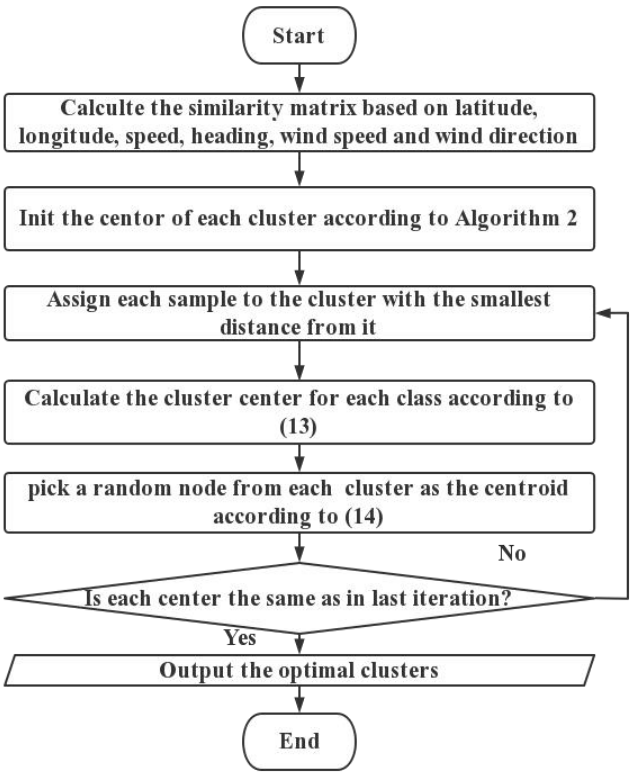

Fig. 2. Architecture of RWC-K-Means algorithm.

The RWC-K-Means is provided in Algorithm 2.

Algorithm 2 RWC-K-Means.

Input: Problem description and algorithm parameters.
Output: The optimal clusters.
Begin:
1: Calculate the similarity matrix based on latitude, longitude, speed, heading, wind speed, and wind direction.
2: Init the center of each cluster according to Algorithm 2.
3: Assign each sample to the cluster with the smallest distance from it.
4: Calculate the cluster center for each class according to (2).
5: Pick a random node from each cluster as the centroid according to (3).
6: Repeat steps 3-5 until the termination condition is satisfied.
End

V. SIMULATIONS

A. Dataset

Considering that the broadcasting and receiving distance of the AIS equipment is limited, the water close to the coastal base station is preferred. Accordingly, the water on the west side of the Taiwan Strait is selected for fishing vessel data sampling. In this paper, the fishing vessels affecting the passage of merchant ships near the middle route of the Taiwan Strait are analyzed. In addition, the individual dredging is performed for a long time. Small ships with particular operation types are also included in the analysis to further reduce the impact of insufficient data. In terms of sample data time nodes, the seasonal regularity of the fishing operations of fishing vessels is followed, and the data of one month in the fishing period is taken to ensure the data capacity and adaptability of the model.

Figure 3 presents the distribution of fishing ship length.

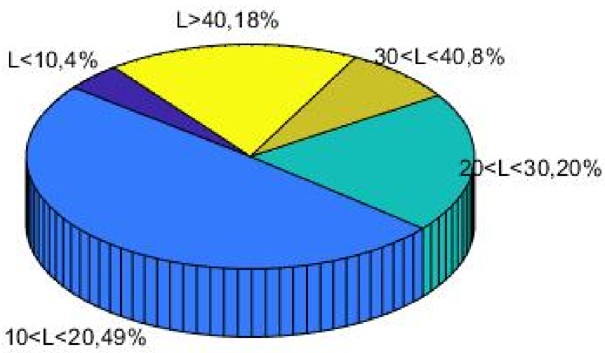

Fig. 3. Distribution of fishing ship length.

Samples of ship AIS data, including Maritime Mobile Service Identity (MMSI) is listed in Table 1.

TABLE I
SHIP AIS SAMPLES

MMSI	Longitude	Latitude
700050977	119.022855	24.795085
700050977	119.022395	24.794678
700050977	119.021918	24.794253
700050977	119.021468	24.793803
700050977	119.021017	24.793362
700050977	119.020157	24.792468
700050977	119.019702	24.792052
700050977	119.019230	24.791632
700050977	119.018253	24.790808
700050977	119.017763	24.790402
700050977	119.017280	24.789987
700050977	119.016773	24.789580
700050977	119.016232	24.789200
700050977	119.015723	24.788802
700050977	119.015220	24.788403
700050977	119.014193	24.787640

Information of fishing boats, including MMSI, call sign, and length is listed in Table 2.

TABLE II
INFORMATION OF FISHING BOATS

MMSI	Call sign	Length/m
200012308	35559	26
412000032	00032	30
412000999	60997	28
412123464	12345	34
412343658	1234567	26
412344602	66881	26
412440111	803	13
412440678	BZUX9	66
412444117	6879202	30
412444128	60997	30
412444357	66753	30
412444363	6860097	30
412444371	60849	27
412444459	6589	28
412444502	6879498	30
412444543	09872	21
412444611	60884	22
412444624	63196	20
412444665	09873	26

The Minnan fishing ground is located in the south of the Taiwan Strait, starting from the vicinity of Beitao Island in the north, to the south of Taiwan Shoal in the south. It faces

Taiwan in the east and the East Guangdong fishing ground in the west. There are many islands, reefs, sandbanks, and shoals scattered throughout the fishing ground, with complex terrain and large changes in water depth, generally between 20-90 m. However, the nearshore is shallower, the depth in the middle increases, and the water depth becomes shallower to the Southeast Taiwan Shoal. The planning of the South Fujian water functional area is shown in Fig. 4. The two fishing areas, namely Gaoqi Fishing zone and Oucuo Fishing zone, are marked with blue circles.

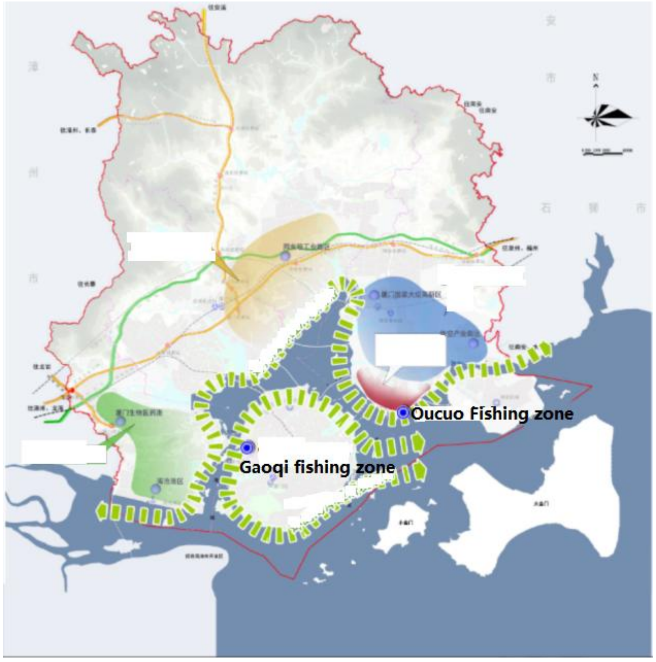

Fig. 4. Planning of South Fujian water functional area.

B. Clustering Result Display

The algorithm results are presented in Fig. 5.

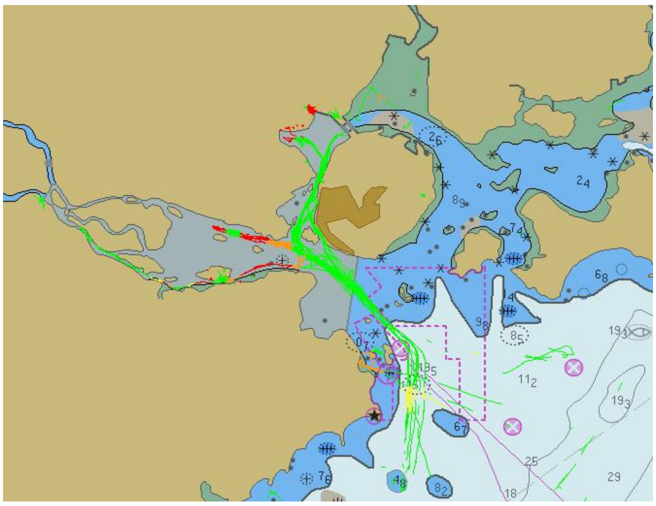

Fig. 5. Clustering result of data set.

From clustering results, the activity rules of fishing vessels in Xiamen are summarized as follows:

(1)There are many fishing boats in the waters near Jiujie reef in the deep-water route, and fishing boats may cross the deep-water route more frequently, especially in cold wave and windy weather.

(2)The waterway on the east side of Xiamen is curved, with many shoals, reefs and other obstacles. Fishing boats often occupy the waterway for fishing and anchoring.

(3)The fishing operations and navigation density of coastal fishing vessels in the waters near the 201 light buoy and the TB3 light buoy are relatively high.

(4)The Minnan fishing ground and the main channel of the strait overlap in the waters near Dongding island, Nanding island and Xiamen Bay. A large number of fishing boats gather to operate during the spring and summer fishing seasons.

(5)Ships entering and leaving the main channel and Houshi port area all meet in the waters near Y6 light buoy. Sand boats and fishing boats cross the channel at will. During the fishing season, many fishing boats gather and operate near the channel.

(6)Wuyu island is an important fishing port, where many fishing boats stop. There is a newly built fishing boat shelter to the west of Qingjiao island, where a large number of fishing boats often berth. These fishing boats all enter and leave the port from the Wuan waterway. Some fishing boats in the lower reaches of the Jiulong river in the Bay often choose to enter and leave the port from the Wuan waterway.

(7)There are many cross river cables and bridges in Shima channel, which is prone to ship damage accidents. A large number of fishing boats often anchor, sail or operate on both sides of the channel. There are many anchored ships on both sides of Shima channel, and a large number of fishing boats often occupy the channel for fishing operations or set up breeding nets in the channel and nearby waters, resulting in a greater risk of ship collision and ships entering the breeding area by mistake.

(8)In the waters near Haimen island in the Jiulong river, a large number of fishing vessels often occupy the channel for fishing operations or set up aquaculture nets in the channel and nearby waters.

C. Discussion

The Minnan fishing ground in the waters near Dongding Island and Nanding Island at the mouth of Xiamen Bay overlaps with the main channel of the Taiwan Strait. During the fishing season in the spring and summer, many fishing boats gather and operate, which are greatly affected by fog, making it easy for collision accidents to occur between sailing ships and berthing guide fishing boats in Shangxiamen Bay.

Sand boats and fishing boats in the waters near Jiujie Reef in the deep-water route cross the deep-water route more frequently (cold waves and windy weather make it even more challenging to navigate). Some inbound sand vessels keep sailing and entering the port on one side of the departure channel. It is difficult for small sand vessels and fishing vessels to accept vessel traffic service (VTS) coordination and control, not listening to very high frequency (VHF), making it challenging to ensure the freshness of the deep-water route. Furthermore, there are many fishing boats near Jiujie reef, and the background light may also submerge the navigation lights of some small fishing boats in the port. When entering the port, the ship should pay special attention to observing the trend of small fishing vessels operating in the port.

The ship position visualization results demonstrate that the fishing boat operation area is very extensive, and there is no apparent law to follow. In addition, the driver cannot intuitively judge the ship operation and avoidance time when passing through the water area. An improper avoidance behavior may lead to an incomplete or impossible avoidance[15]. Since the accurate operation of avoiding fishing vessels requires very high ship operation experience from commercial ship drivers, when commercial ships encounter a group of fishing vessels with intensive fishing operations during navigation, it is recommended that ship drivers consider the fishing area as busy waters and take measures to bypass them to avoid direct crossing. This can improve the adaptability of the decision-making model.

D. Results of ship route recommendation

The planned way points of ship routes in the Dongshan sea area are listed in Table 3.

TABLE III
ROUTE TURNING POINT INFORMATION IN THE DONGSHAN SEA AREA

No.	Latitude/°	Longitude/°	Course/°	Distance/nm
1	23°44.60′N	117°31.38′E	060º.8	0.09'
2	23°44.64′N	117°31.46′E	060º.8	0.09'
3	23°44.46′N	117°31.94′E	112º.6	0.48'
4	23°44.27′N	117°32.29′E	121º.5	0.37'
5	23°43.17′N	117°31.65′E	208º.1	1.25'
6	23°42.62′N	117°31.44′E	199º.3	0.58'
7	23°39.41′N	117°30.12′E	209º.8	3.63'
8	23°34.79′N	117°26.36′E	211º.3	5.49'
9	23°34.53′N	117°24.33′E	262º.1	1.88'
10	23°33.71′N	117°21.93′E	249º.6	2.35'
11	23°34.21′N	117°18.93′E	280º.2	2.80'
12	23°34.54′N	117°18.46′E	307º.6	0.54'
13	23°37.02′N	117°20.28′E	033º.8	2.99'
14	23°38.87′N	117°19.17′E	313º.36	2.12'

Figure 6 shows the kernel density estimation (KDE) of the ship trajectory.

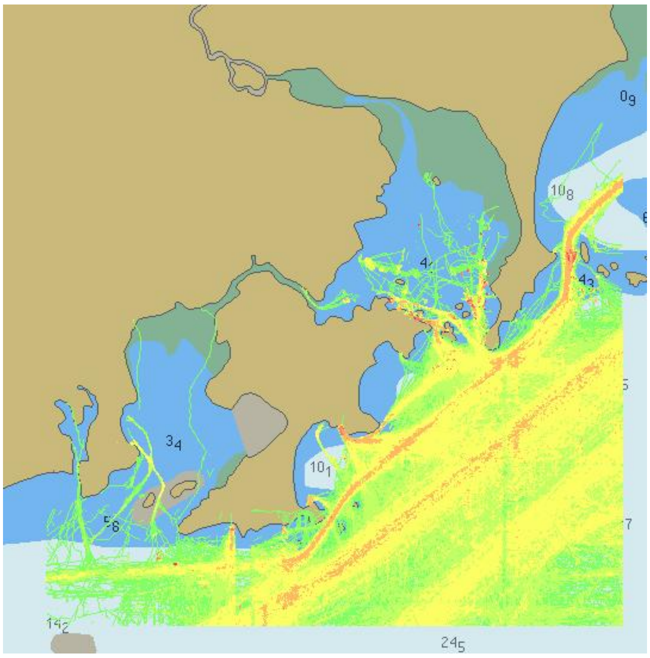

Fig. 6. KDE of ship trajectory.

Figure 7 shows the ship path planning result in Zhangzhou. The horizontal axis represents longitude, while the vertical axis represents latitude.

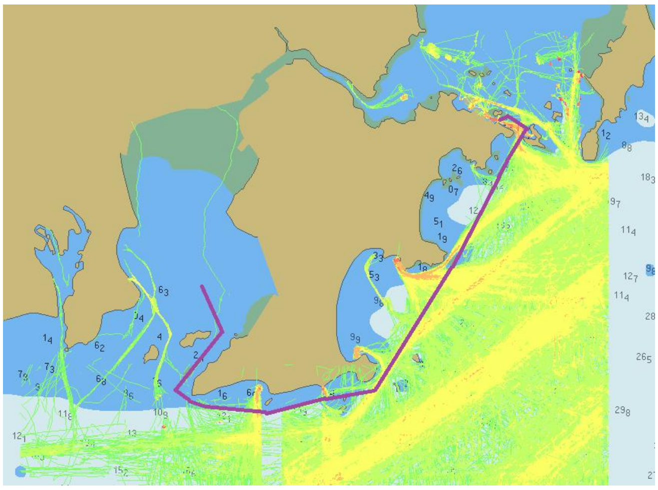

Fig. 7. Path planning result.

It is shown that the ship's original route crosses the busy waters of the fishing area. During the non-fishing moratorium, the centralized operation of the fishing vessels affects the navigation safety of the ship. The cargo ship is large, the residual speed is difficult to control, the manipulation is not convenient, and some difficulties in avoiding fishing vessels exist at a close range. Therefore, to ensure the safety of the ship operation, the recommendation decision is given based on the original planned route of the ship.

E. Comparison of Different Algorithms

There are many evaluation indexes of the clustering performance, such as accuracy and mean absolute error (MAE). MAE is used in this paper. The MAE can reflect the difference between the classification of the data set and the real classification. The cost comparison of different algorithms are listed in Table 4.

TABLE IV
COST COMPARISON OF DIFFERENT ALGORITHMS

Bay	Algorithms	Best	Worst	Average
Nanmen	K-means	1.187	1.236	1.190
	Ours	0.954	0.996	0.974
Maluan	K-means	1.345	1.390	1.367
	Ours	1.116	1.157	1.129
Jinluan	K-means	1.230	1.302	1.290
	Ours	0.790	0.823	0.803

The results show that this proposed algorithm has smaller time complexity than K-means. Compared with K-means, the new algorithm requires an additional operation. However, the new algorithm convergences faster and can reach the optimal solution in fewer searching iterations. Therefore, it still takes less time to obtain the results.

The Xiamen Bay is located in the fishing ground in Southern Fujian, and many fishing boats are sailing nearby. These fishing boats often do not hang the required number of lights according to the regulations when sailing. So it is difficult to observe their movements. Ships passing through this water area should be paid attention to. A radar-assisted lookout should be done during night navigation. Sometimes the ships should give way as early as possible. When navigating in fog weather, the ships need stay away from the dense area of fishing vessels and use long-range radar to find nearby fishing vessels.

VI. Conclusions

Based on the AIS data of fishing vessels in 2016, a identification model of busy fishing area through the DBSCAN clustering algorithm is developed in this paper. This model is applied to the water of the Minnan fishing around the Taiwan Strait. The busy fishing area around the sea route in the Taiwan Strait is identified and judged based on the simulation of real traffic flow from September to October in 2016.

With the scale expansion of the ship trajectory data, the time consumption of the algorithm will also increase. Therefore, optimizing the algorithm and effectively reducing the overhead of the algorithm may be explored in future research.

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