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A Method of Fairway Boundary Extraction Based on AIS Data

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Abstract: Due to the limitations of existing fairway extraction methods that not take the width of the fairway into account, a method of fairway boundary extraction based on AIS data is proposed. Firstly, in order to express the density of AIS track points, the Voronoi diagram is constructed. Secondly, the density difference between both sides of the fairway is quantitatively analyzed, and the index of it is proposed. Finally, using the AIS track points that selected by the former index, the Delaunay irregular triangulation network is constructed, and then the boundary of the fairway can be extracted. The experimental results show that: using this method, the boundary of the fairway can be automatic extracted, which provides a new idea for the semantic analysis of AIS data.

1.Introduction

With the development of information technology, the Automatic Identification System (AIS) has been widely applied[1,2]. AIS data can not only provide a collision avoidance reference for ships but also contain a large amount of information. Among these data, the track data record the trajectory of the ship's navigation[3], which contains rich information about fairway. With track data, the geometric boundary and distribution trend of the fairway can be reflected.

In order to obtain the fairway information timely, many scholars have researched the mining method based on AIS data. The typical method that used to solve this problem is track clustering and image processing: Through the Density-Based Spatial Clustering of Application with Noise (DBSCAN) method and the track distance model, calculating the track similarity, and complete the clustering of the ship's track, then, the result of trajectory is regarded as fairway[4,5]. Similarly, some scholars research also use the DBSCAN method to cluster the track points from AIS data and regard the connection of points as fairway[6]. Moreover, part of scholars had rasterized the ship's track and used the Hough transform to extract the linear channel in an image processing way[7]. In addition to these methods, some other methods had proposed by scholars, such as K-means clustering[8], nuclear density[9] and grid statistics[10]. However, the existing method can only extract the fairway line. Similar to the road, the fairway also has a certain width. Current methods will be greatly limited for further semantic analysis of the track data (such as traffic separation).

To solve the above-mentioned problems, a method for extracting the fairway boundary based on AIS data is proposed in this paper. The Voronoi diagram is constructed to express the density of AIS track points, and the index of the density difference between both sides of the fairway is quantitatively analyzed. Then based on the track points that selected by former index, the Delaunay irregular triangulation network is constructed. Finally, the boundary of the fairway is extracted from the Delaunay irregular triangulation network.

2.Methodology

2.1 Distribution of track point density supported by the Voronoi diagram

The key method of road boundary extraction is to identify the boundary of trajectory points distribution[11]. As the boundary of the fairway, it is obvious that the distribution of track points on both sides with a significant difference. Moreover, this difference in the density of distribution is an essential feature for identifying the boundary of the channel.

The difference in spatial density of point features is an important index of generalizing point elements in the theory of cartography. Each point in space has its "influence domain" or "competition domain" and need to acquire its "living space." The competition result of the adjacent point in spatial distribution is equivalent to the equalization of space division[12]. In practical applications, weighted or unweighted Voronoi diagrams are constructed based on the difference in point properties to achieve generalization of point groups. For track points, for there is no difference between them, the distribution density of the track points can be expressed by the unweighted Voronoi diagram.

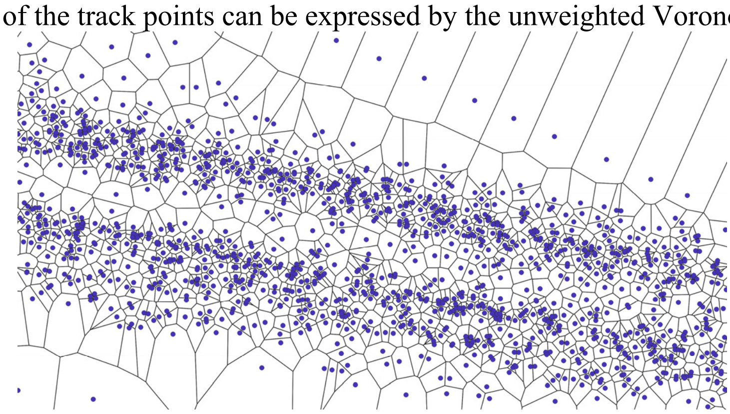

Figure 1. the Voronoi diagram of track points

As shown in figure 1, the area of Voronoi diagram elements outside the fairway is larger than the area that inside the fairway. Therefore, the value of the track point distribution density D can be set as the reciprocal of the Voronoi diagram elements area, which can be described as:

$$D_i = \frac{1}{S_v} \tag{1}$$

Where D_i represents the distribution density of i th track point, S_v represents the area of this Voronoi diagram element.

2.2 Identification index of fairway boundary

After the generation of Voronoi diagram, a quantitative analysis of distribution density of track points is required. As shown in figure 1, the distribution density of the track points inside the fairway is higher than outside. Set the threshold value of the distribution density of the track points, if the density value greater than the set threshold, the track point is located inside the channel. Otherwise, it is located outside the channel. For the fairway is an important channel for maritime navigation, the movement of the ship is frequently, on the timescale, the spatial distance between track points must be smaller than the safe distance of ship collision avoidance. Therefore, this paper takes the average safe distance of the ship collision avoidance as radius and determines the area of the circle generated by this radius as the threshold to complete the extraction of Voronoi elements that inside the fairway.

According to the difference in distribution density of the track points inside and outside the channel mentioned in Section 1.1, the channel boundary Voronoi elements can be identified. However, the elements of the Voronoi diagram are often irregular polygons, and there are multiple adjacent elements. It is difficult to find the different "side" directly. To solve this problem, considering the Delaunay irregular triangulation network and the Voronoi diagram are mutually opposite, adding the distribution density of the track points as an attribute to the data structure of the triangle edges in the

Delaunay irregular triangulation network.

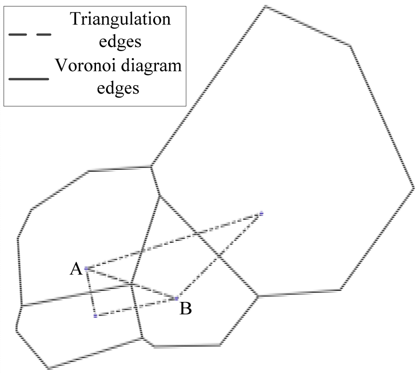

Figure 2. the Voronoi elements divided by triangle edges

As shown in figure 2, with the triangle edge *AB*, the Voronoi elements can be divided into "left" and "right" side. Using the formula (1) in Section 1.1, the track point density on both sides of the Voronoi elements is calculated. Then, setting the rate of the distribution density on both sides of triangle edges as an index R_D, and R_D can be described as:

$$R_D = \begin{cases} \dfrac{D_L}{D_R}(D_L \le D_R) \\ \dfrac{D_R}{D_L}(D_L > D_R) \end{cases} \tag{2}$$

where D_L represents the "left side" of distribution density of track point, D_R represents the "right side" of distribution density of track point.

The larger the value of R_D is, the higher the difference in the distribution density of the track points, and the probability of Voronoi elements is the fairway boundary area is also higher. On the contrary, the Voronoi elements may be inside or outside the areas of the fairway. By setting different threshold values, different classification of fairway boundary identification can be realized. The smaller the threshold is, the lower level fairway can be extracted. The larger the threshold is, the higher level fairway can be extracted. After that, selecting the track points that at boundary areas or inside the fairway as the preparation for the extraction of the channel boundaries.

2.3Fairway boundary extraction based on Delaunay triangulation

As a method to construct the topological relationship of point elements, Delaunay triangulation is widely used in the fields of mapping synthesis, data mining, and pattern recognition. In the research of road identification, the Delaunay irregular triangulation network can be used to identify the boundary information from taxi trajectory data [11,13]. Therefore, this paper also extracts the channel boundary based on the Delaunay triangulation. The flow diagram of the extraction method is shown in Figure 3. The specific flow is as follows:

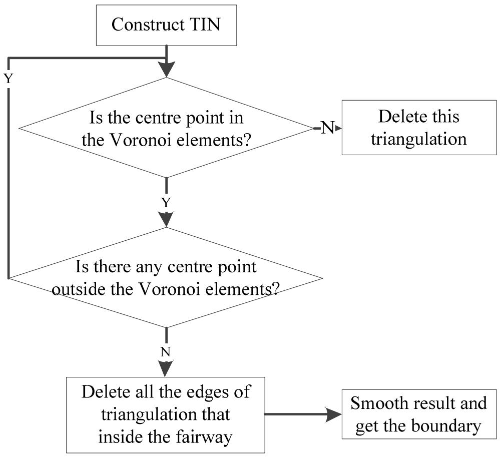

Figure 3. the flow diagram of the extraction method

(1) Based on track points selected by the method of Section 1.2, the Delaunay irregular triangulation network is constructed.

(2) Find the center point of all the triangles in the Delaunay irregular triangulation network, and judge the positional relationship between the center point and the Voronoi elements identified by the method of Section 1.2 that inside or boundary of the fairway. If the center point is not in the Voronoi element, delete this triangle, until no center point outside the selected Voronoi elements.

(3) Delete the triangle edges in the Delaunay irregular triangulation network if each of its points is the track point that inside the fairway.

(4) Smoothing the extracted line features, and finishes the extraction of fairway boundary.

3.Experiments and Analysis

In order to verify the effectiveness of the proposed method, the Hangzhou Bay area was selected as the experimental area for experiments. The experimental data were derived from the AIS data of the shores of China and its adjacent waters from September 1st to September 3rd, 2017. The distribution of data is shown in Figure 4.

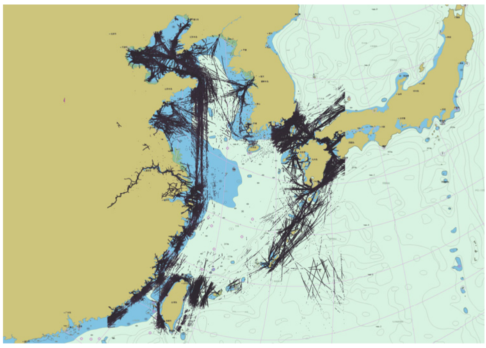

Figure 4. the distribution of all experimental data

The experimental data mainly includes Maritime Mobile Service Identification (MMSI), time, latitude and longitude and some other information, totaling 3,452,012 track points, and the time interval is 5s~ 2 minutes. After cleaning, sorting and selecting, the number of track points in the experimental area is 57,988. The experimental area data is shown in Figure 5.

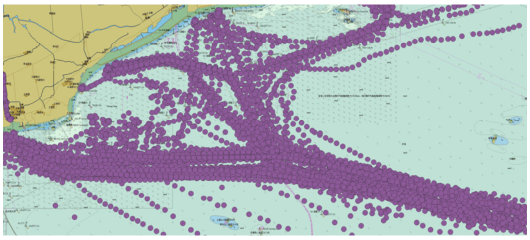

Figure 5. the distribution of data in the experimental area

Based on the experimental data in the experimental area, the fairway boundary is extracted by the proposed method. The basic parameters of the PC used for the experiments are shown in Table 1, and the extracted boundary is as shown in Figure 6.

Table 1 Hardware configuration for the experiments

Equipment	Processor	RAM	Hard Disk	Graphics/Memory	Operating system
PC	Intel core i5-3230M 2.60GHz	8GB	1TB	AMD 7400M/1GB	Windows7 X64

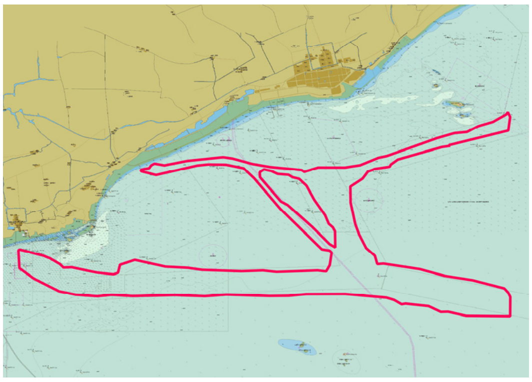

Figure 6. the fairway boundary extracted by the proposed method

To further verify the accuracy of the experimental results, quantitatively evaluate the experimental results. The public released chart of the Hangzhou Bay is selected (Chart Number: C1413310; Chart Name: Hangzhou Bay; Scale: 1:150,000), and the fairway features in the chart are compared with the fairway extracted by the proposed method. Referring to the evaluation method of road network extraction[7], the percentage of the number of track points inside the fairway is taken as the quantitative analysis index. The results are shown in Table 2.

Table 2 the percentage of track point inside the fairway

Method	Point Number	Percentage
Fairway extracted from chart	40743	70.26%
Fairway extracted by the proposed method	45530	78.52%

Based on the above experimental results, it can be seen that the percentage of track points falling inside the fairway extracted from the chart is slightly different from that from proposed method, but the difference is not significant. This may due to experienced fairway sometimes not reflected on the chart and some special tracks caused by collision avoidance and so on. Meanwhile, some fairway on the chart has not been extracted under the proposed method. This is because these parts of fairway have fewer passing ships in experimental data and the density of the track points is insufficient.

4.Conclusions

In order to solve the limitation of the existing fairway extraction method which cannot take fairway width into account, a fairway boundary extraction method based on AIS data is proposed. By constructing the Voronoi diagram, the distribution density of track points is expressed. Then, the difference of distribution density between both sides of the fairway is quantitatively analyzed. Finally, using the selected track points, the Delaunay triangulation is constructed to extract the fairway boundary. Experiments show that the proposed method can achieve the extraction of fairway based on AIS data with accurate and reliable.

Additionally, the method proposed in this paper only considers the extraction of fairway boundary. How to conduct further semantic analysis such as collision avoidance and traffic separation from AIS data will need to be further studied.

Acknowledgments
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Reference

[1] 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.
[2] Last P, Bahlke C, Hering-Bertram M, et al. (2014) Comprehensive Analysis of Automatic Identification System (AIS) Data in Regard to Vessel Movement Prediction. Journal of Navigation, 67(05): 791-809.
[3] Cao J, Cambria E, Lendasse A, et al. (2016) Proceedings of ELM-2016. Cham: Springer.
[4] Wang, J.S., Liu, Y.X., Yang, K., et al. (2016) Extraction Method of Main Routes in South China Sea Based on Spatial Cluster analysis. Journal of Traffic and Transportation Engineering, 16(6): 91-98.
[5] Mou, J.M., Chen, P.F., He, Y.X., et al. (2018) Fast Self-tuning Spectral Clustering Algorithm for AIS Ship Trajectory. Journal of Harbin Engineering University, 39(3): 428-432.
[6] Xiao, X., Shao, J.P., Pan, J.C., et al. (2015) Ship Trajectory Clustering Model Based on AIS Data and its Application. Navigation of China, 38(2): 82-86.
[7] Chen, H.K., Cha, H., Liu, L.G., et al. (2018) Vessel Traffic Pattern Extraction Based on Automatic Identification System Data and Hough Transformation. Journal of Computer Applications, 38(11): 3332-3335.
[8] Guo T, Iwamura K, Koga M. (2007) Towards High Accuracy Road Maps Generation from Massive GPS Traces Data. Barcelona: IEEE, 667-670.
[9] Wang J., Li M., Liu Y., et al. (2014) Safety Assessment of Shipping Routes in the South China Sea Based on the Fuzzy Analytic Hierarchy Process. Safety Science, 62: 46-57.
[10] Halpern B S, Walbridge S, Selkoe K A, et al. (2008) A Global Map of Human Impact on Marine Ecosystems. Science, 319(5865): 948-952.
[11] Yang W., Ai T.H., (2017) The Extraction of Road Boundary from Crowdsourcing Trajectory Using Constrained Delaunay Triangulation. Acta Geodaetica et Cartographica Sinica, 46(2): 237-245.
[12] Ai. T.H., Liu Y.T., (2002) A Method of Point Cluster Simplification with Spatial Distribution Properties Preserved. Acta Geodaetica et Cartographica Sinica, 31(2): 175-181.
[13] Yang W., Ai T.H., (2016) Road Centerline Extraction from Crowdsourcing Trajectory Data. Geography and Geo-Information Science, 32(3): 1-7.