Algorithm of Trawler Fishing Effort Extraction Based on BeiDou Vessel Monitoring System Data

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Abstract. Performing statistical computations for traditional fishing effort takes much time and effort, and the macro fishing effort cannot be accessed immediately. Through the Beidou satellite vessel position monitoring system, the position, time, speed and other information of vessels can be got and used to data mining. In this paper, the speed threshold of each vessel's fishing state is obtained by the statistics of navigational speed. And fishing state points can be judged by the speed threshold and heading deviation. Via the correction of filtering window, the fishing area grid is calculated by the cumulative fishing time. The cumulative fishing is the product of the cumulative fishing time and the vessel power, such as kW•h. This method has the characteristics of real-time, large-scale, fast and high resolution, which can provide good service in fishery resources protection.

Keywords: Beidou satellite · Vessel monitoring system · Fishing effort · Heading · Speed

1 Introductions

The European Union uses Vessel Monitoring System (VMS) to monitor fishing activities. It has been applied to fishing vessels exceeding 18 m in length [1, 2] as from 1 January 2004 and fishing vessels exceeding 15 m in length [3] as from 1 January 2005. It is mainly used to fisheries management [4, 5]. VMS data have time, speed and heading information. In recent years, there are research on Fishing state judgment [6], fishing effort estimate [7, 8], resource distribution analysis [9, 10], and retrospective fishing boat [11, 12] etc. Fishing effect, the work done in fishing, is an important parameter for researching the variations of fishery resources [13, 14]. The conventional calculation method considers several elements, such as the number of vessels, power, and number of days.

More than fifty thousand fishing vessels had installed the terminal unit of Beidou satellite positing system. After these fishing services carrying out for nine years, the system have recorded billions historical cruising data for each vessel, including the

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time, position, speed, direction, rate of turn, etc. These data can be analyzed deeply by big data mining technology.

2 Materials and Methods

2.1 Data Sources

BeiDou Vessel Monitoring System Data comes from BeiDou data service center which mainly includes ship-card number, latitude, longitude and time. The vessel position information of latitude and longitude has a temporal resolution of 3 min and a spatial resolution of 10 m. Data are managed by SQL Server, because of its superior performance in spatial data's management and analysis. The spatial relationships between geometry instances can be determined and the vessel position can be saved with geometry data type.

Fishing types, vessel powers, vessel names and other information are mainly from official materials which are published by Marine Fisheries Service of every province. By matching official data with BeiDou Vessel Monitoring System Data, the types of 3333 vessels are determined. Most of them are trawling and gill-netting. There are 2212 trawlers, accounting for 66 % of the total. In this paper, it is focus on trawler.

2.2 Methods

Every point position of trawlers includes speed, course, time and other information. With that information, the state of trawlers can be determined. Whether the state is fishing or not can be judged by Formula (1). When the speed and course are in the range of threshold value, the trawler is in the state of fishing.

$$P = F(v, d)\ V_{\min} \le v \le V_{\max}\ D_{\min} \le d \le M_{\max} \tag{1}$$

In Formula (1), V_{min} and V_{max} are the threshold range of speed. D_{min} and D_{max} are the threshold range of course deviation for fishing states.

There may be many trawlers in one fishing grid. One trawler in fishing is divided into many nets. In general, a net lasts a few hours. When a net is over, the next net will get under way after some interval of time. Every net is composed of several discrete point of vessel position. Hence, Formula (2) can be used to calculate the cumulative fishing as kW•h in one grid.

$$Z_i = \sum_{i=0}^{p} \sum_{j=0}^{m} \sum_{k=1}^{n} (P_{i,j,k} - P_{i,j,k-1}) * W \tag{2}$$

In Formula (2), Z_i is the cumulative fishing effort of one fishing grid, in unit of kW•h. $P_{i,j,k}$ and $P_{i,j,k-1}$ are the time of adjacent two position points of one trawler. The difference between $P_{i,j,k}$ and $P_{i,j,k\text{-}1}$ is the length of time, and W is the power of trawler. The first summation is the cumulative fishing for one net. The second summation is the cumulative fishing of one trawler in a period of time for several nets. The third summation is the cumulative fishing of all trawlers in one fishing grid.

Distance inverse weight method is used to generate the thematic map of variation tendency. As long as the positions of trawlers are intensive enough, the thematic map of trend surface can be generated by interpolation, which can assist the trend analyses of global change in resource.

$$Z_0 = \frac{\sum_{i=1}^{n} \frac{z_i}{d_i^r}}{\sum_{i=1}^{n} \frac{1}{d_i^r}} \tag{3}$$

In Formula (3), r is specified exponent. d_i is the distance between control point i and point o. With the increase of distance between forecasted points, the weight of impacts of control points on forecasted points decrease exponentially. Z_o is the estimated value of Point o. n is the number of control points used in the estimation. Z_i is the Z value of Control Point i.

3 State Division of Trawlers

In order to analyze a trawler of Zhejiang Province whose Beidou ship-card number is 300585 (hereafter, it is named Trawler 300585) and report time is Oct 1st, 2013, the time period from 0 a.m. to 24 p.m. is divided into 9 sections. There exist 3 different states. Stage A and stage C is dropping anchor. Stage B and stage D to stage H is fishing. Stage I is sailing. The general process of fishing is as follows. The trawler sails to one fishing ground. Then it casts net in a short-time sailing and begins to tow net. When the quantity of fish in the nets reaches a certain amount, Trawler is slow down and net are pulled.

The course of trawler (azimuthal angle) is the horizontal contained angle between the target direction line and the line drew by centering on the vessel position and lining up from the north direction of it. The course value ranges from 0 to 360°. When varying near 0° or 360°, the variation of course changes largely. To further analyze the actual variation of course, a deviation calculation is performed. The course deviation is the difference between two neighboring report times, that is, the later report time and the former report time. The positive value reacts turning clockwise and the negative value reacts turning anticlockwise. The deviations mainly change near 0°, because the interval of report time in Beidou data is 3 min and the course fluctuation cannot change largely in that short time. Referring to Fig. 1 and according to the statistics of several trawlers, the course deviations of operating states are set as D_{min} and D_{max}. They are $-50°$ and $50°$.

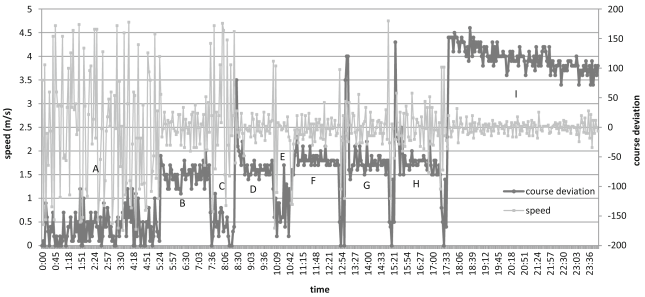


Fig. 1. Distribution map of trawler speed

A navigation path of Trawler 300585 was plotted on Oct 1st, 2013, as illustrates in Fig. 2. Comparing Figs. 1 and 2 an intuitive judgment can be made. In Fig. 2, the points of fishing and sailing are obvious, while the points of anchoring and low speed are covered by the points of fishing and sailing.

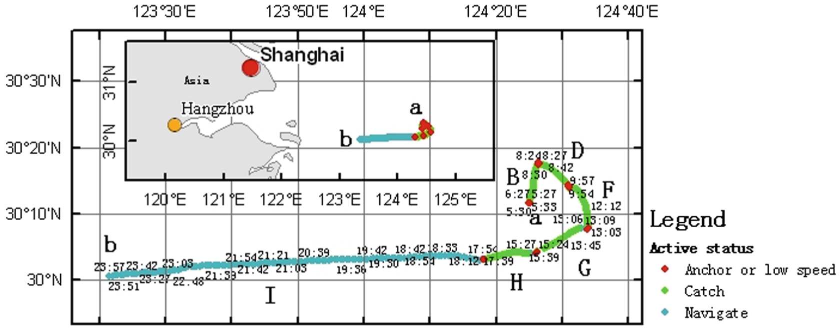


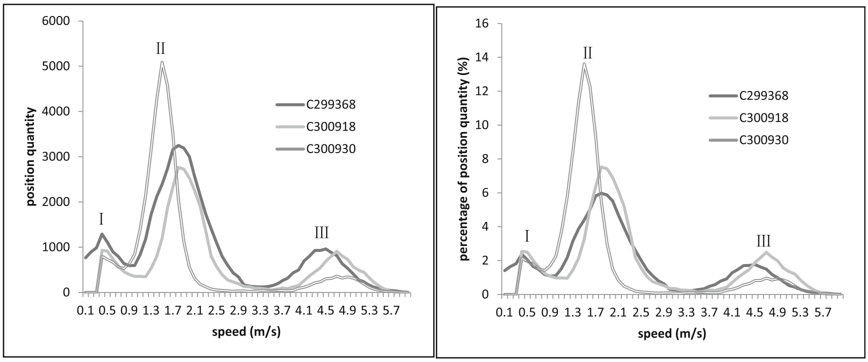
Fig. 2. Tracks of trawler 300585

Through analysis, the path of the trawler from 0:00 to 23:57 is from Point a (30°12′ N, 124°25′E) to Point b (30°6′N, 123°22′E). Point a is in the state of anchoring from 0:00 to 5:27. Segment B, D, F, G and H are in the state of fishing from 5:27 to 17:33. Segment I is in the state of sailing from 17:33 to 23:57.

4 State Judgments of Trawlers

4.1 Determining Threshold by the Statistics of Trawler Speed

Under the circumstances of operating with different power, placing trawl in different water depth and catching different kinds of fish, the speed of trawlers are different. When judging the states of trawlers, Speed threshold should be set for trawlers in fishing. Figure 3 illustrates the quantity of position points changing over the speed with



(a) (b)

Fig. 3. Position record changing with speed in 2013. (a) Position quantity changing with speed (b) Percent of position quantity changing with speed.

performing statistical analysis on position points of twin Trawler 299368, twin Trawler 300918 and single Trawler 300930 in 2013. Since the trawlers anchoring in port also send the position data, large amounts of data with value of 0 m/s are recorded. These data make no influence on judging the states of trawlers, so they are ignored from the statistics.

Through the statistics of vessel position data for a long time, characteristics can be revealed and fishing states can be judged. The speeds of trawlers in Fig. 3 mainly show 3 peaks. The first peak, I, shows that the trawler is in a low speed (e.g. arriving at port, dropping anchor, drifting, proceeding at a slow speed). The second peak, II, shows that the trawler is in fishing state. The third peak, III, shows that the trawler is in sailing. There are striking differences among the quantities of vessel positions. As a positon point obtained by every 3 min, the quantity of points in 10 days to 1 year is 4800 to 170880. In Fig. 3, the position number is 54408 of Trawler 299368, 36716 of Trawler 300918 and 37341 of Trawler 300930.

In order to unify the data of trawlers into the same order of magnitude, marking the total of points with the speed in a range from 0.1 to 6 m/s as 100 %, The percentage of total are used to substitute for the quantity. Figure 3(b) is expressed as a percentage to

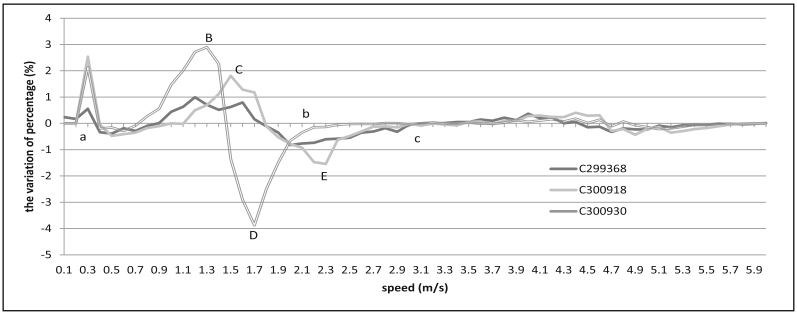


Fig. 4. The variation of percentage in 2013

show the change of point quantity over the speed. As Fig. 1 shows, the states of trawlers can be basically judged by speed. The statistics through the year 2013 for 3 trawlers in Fig. 3 and several other trawlers show that they are in fishing state when their speeds are in the second peak. Figure 4 shows the difference between two adjacent percentages and the interval of horizontal axis is 0.1 m/s, which illustrates the speed variation rate. The maximum and minimum peak of each trawler is between a and c.

The corresponding speed of the first point, on the left of the maximum peak which is 0.1 % larger than the maximum peak, is V_{min} in Formula (1). The corresponding speed of the first point, on the right of the minimum peak which is 0.1 % smaller than the minimum peak, is V_{max} in Formula (1).

Trawlers have a variety of fishing forms, such as single-trawling and twin-trawling, which make all the difference to the power (Fig. 7a). The values of V_{min} and V_{max} for each trawler need to be judged. In Fig. 4, the peak values of single Trawler 300930 are at point B and point D, and the velocity threshold are near point a and point b. The peak values of twin Trawler 299368 and 300918 are at point C and point E, and the velocity threshold are near point a and point c.

In the annual statistics of many trawlers whose speeds are between 0.1 m/s and 0.3 m/s, their position numbers are 0. Hence, there exist exceptions in the statistics. For example, the peak value at point A of Trawler 300918 (Fig. 4) is higher than its peak value at point C. Because the percentage of speed between 0.1 m/s and 0.3 m/s is 0, the change rate will become much larger when the percentage of speed in 0.4 m/s is more than 0. Therefore when the threshold is calculated, the peak value must be captured as when it is larger than 0.4 m/s.

4.2 Modifying the State of Trawlers

In Formula (4), the state of each vessel position can be judged by the combination of speed and course deviation. The threshold of velocity and course deviation can be obtained by the statistical analysis in the preceding paragraphs.

$$S = F(v, d) = \begin{cases} 0 & v \le V_{\min}, D_{\min} \le d \le D_{\max} \\ 1 \quad V_{\min} < & v \le V_{\max}, D_{\min} \le d \le D_{\max} \\ 2 & v \le V_{\max}, D_{\min} \le d \le D_{\max} \end{cases} \tag{4}$$

In this expression, S is the state of vessel position. Its value is 0 for low speed, 1 for fishing, and 2 for sailing.

The trawler 299368 has 724 positions from October 18th to 19th in 2013. By using Formula (4), there are 21 positions misjudged, which is obvious between a and b as well as between c and d in Fig. 5. The error rate of judgment is 2.9 % of the total.

In order to improve the accuracy of states judgment, filter window is used to modify the above results. In the position points of time series, the state of point P at any time can be judged by comparing the states of n points which near the point P.

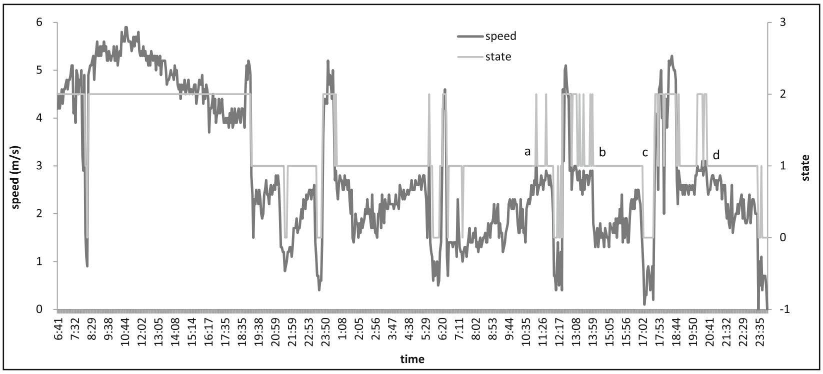


Fig. 5. The states of Trawler 299368

$$S_{front} = F(S_1, S_2, S_3 \ldots S_{m-1})\ S_{back} = F(S_{m-1}, S_{m-2}, S_{m-3} \ldots S_n)\ S_x \in S_1 \ldots S_{m-1}, S_m, S_{m+1} \ldots S_n \tag{5}$$

In Formula (5), S_x belongs to the collection ($S_1 \ldots S_m \ldots\ldots S_n$) which is the states of n points. The state of point P_m is S_m. The most frequency state in [S_1, S_{m-1}] which is earlier than the state of P_m can determine the state S_{front}. The most frequency state in [S_{m+1}, S_n] which is later than the state of P_m can determine the state S_{back}. If there are two states in the same frequency, S_{front} or S_{back} can be determined by the states of the points which is closer to P_m.

$$S_m = F(S_{front}, S_m, S_{back}) = \begin{cases} S_m & S_{front} \neq S_m, S_m \neq S_{back}, S_{front} \neq S_{back} \\ S_m & S_{front} = S_m 或 S_m = S_{back} \\ S_{front} 或 S_{back} & S_f = S_b \end{cases} \tag{6}$$

There are four situations in judging state S_m.
If S_{front}, S_m and S_{back} are different from each other, S_m is kept in the original state.
If S_{front} is the same as S_{back}, S_m is modified to state S_{front} and S_{back}.
If S_{front} is not the same as S_{back} but the same as S_m, S_m is kept in the original state.
If S_m is not the same as S_{front} but the same as S_{back}, S_m is kept in the original state.

After being modified by filter window, states still have 5 misjudgments, where n takes 3 and m takes 1. The error rate is 0.7 % of the total, 724 points, as Fig. 6 illustrates. It is lower than the error rate by only using threshold method in Sect. 4.1. There are 3 stages in trawl fishing. Stage A is casting; stage B is trawling and stage C is pulling. In this paper, we use the time of trawling (stage B) as the time of each net.

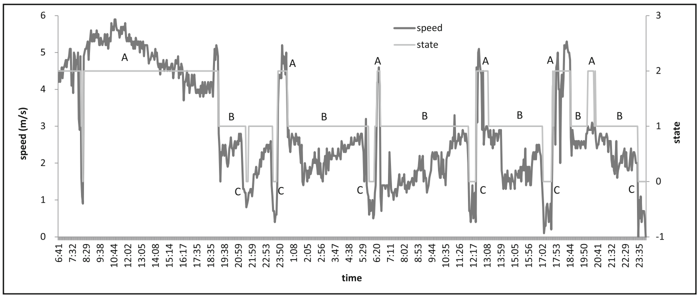


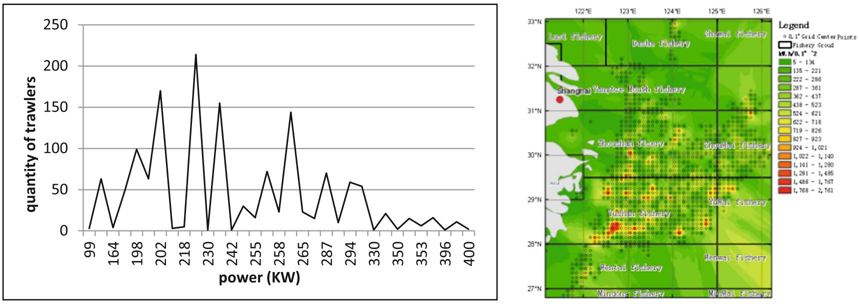
Fig. 6. The states of Trawler 299368

5 Calculation of the Fishing Effort

In 2013, there are 1443 trawlers whose quantity of vessel position is more than 4800 in Xiangshan Harbor. The differences of their power are relatively large (Fig. 7a). Therefore time multiples power as the fishing effort.

With the combination of speed and course deviation, the points in the state of fishing are extracted by Formulas (4) to (6). There are 410949 points in fishing extracted from 1443 trawlers on Oct 10th 2013. These points are putted into a 0.1° × 0.1° grid according to the Formula (2) and calculate the cumulated fishing (kW•h) in each lattice.

The points in Fig. 7b are the center of lattices and the different colors denote different cumulated fishing (kW•h). As the fishing targets are moving fish, the neighboring fishery resources will be affected when we conduct fishing in one area. The stronger the fishing effort is in one area, the faster the neighboring fishery resources decrease. The fishing effort of several adjacent points will prone to a trend surface of resource impact in the surrounding area. The values of lattices are interpolated by Formula (4) and the interpolation figure of Oct 10th 2013 is generated. It reflects the distribution trend surface of trawlers fishing effort from Xiangshan Harbor. As the Fig. 7(b) shows, the strongest fishing effect these days is in Yushan Fishing Area, and then there are Zhoushan Fishing Area and Zhouwai Fishing Area.



(a) (b)

Fig. 7. Calculating the fishing effort (a) Fishing boat power (b) Fishing effort of Xiangshan

6 Conclusion

Via the analysis of speed and course characteristics, the fishing states can be judged and the operating rules can be obtained. According to the statistics of speed for a long period of time, the speed threshold of fishing states can be acquired for each trawler. With the combination of the above speed threshold and course deviation, the position in the state of fishing can be extracted. Then these position data are modified by filter window and calculate the cumulative fishing time according to the state of each trawler in one lattice.

The cumulative fishing is the product of the cumulative fishing time and the vessel power, such as kW•h. The lattice figure of the cumulative fishing is made, and its trend chart generated by interpolation.

In the next phase of work, we will analyze the other types of fishing, explore the methods of distinguishing different types of trawlers by speed and course and produce the complex chart of fishing effect for several fishing types. Analyzing the change rules of cumulative fishing in space and time and comparing advantages and disadvantages with the traditional method, we will improve our method further. Automatic mapping of cumulative fishing for fishing grid will be realized as a business service through programming. The automatic acquisition and business service of cumulative fishing effort will be regarded as a reference and guidance to fishery management and fishing condition analysis.

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