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Ship Routes Planning Based on Traffic Clustering

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Abstract. This work is about navigation safety of marine traffic at sea areas. In addition to traditional approach of danger situation detection based on vessels approaching, the current paper introduces another metrics derived from kinematic parameters of the vessel to identify whether it follows patterns (rules) of the traffic at a certain sea area. Authors focused their efforts on analyzing existing traffic schemas in order to identify its danger level in general rather than scrutinizing individual cases. Along with the traditional approach of sea traffic schema identifications, we propose an original method of automated identification of sea traffic schemes based on clustering of movement parameters using historical AIS data. For the clustering decomposition subtraction clustering algorithms were considered. The historical AIS data of sea traffic at Tsugaru strait is used for identifying traffic schema and ship routes planning with the model designed under presented research.

1. Introduction

The classical concept of the maritime safety includes three tasks solved by shipmasters and coastal services operators: collision risk assessment, ship collision avoidance and ship path planning [1]. One of the elements of areas traffic organization under heavy (intensive) traffic is the system of establishing routes for ships [2], [3]. It is a set of restrictions imposed by a certain traffic pattern ("traffic rules") adopted in a particular water area. From the point of view of classical concepts, vessels that violate traffic rules in the water area may not present a danger now. However, vessels can lead to an intractable dangerous navigation situation after a while.

The three classic tasks are complemented by planning a vessel's route for long-range sailing. The purpose of this planning is traffic optimization. For example, sailing along the shortest possible path, in the shortest time, with minimal fuel consumption, etc. [4], [5]. The planning of the route for the passage of the vessel should be carried out considering the specified restrictions when moving through the waters with established routes. A promising way of identifying these restrictions is to isolate the established patterns of movement of a particular sea area developed by operational practice from retrospective information about its traffic. Model representations of such a problem can be formulated based on the idea of clustering the parameters of ship traffic.

In this paper, we consider the problem of planning a route for a ship to cross water areas with heavy traffic. The task seems to be relevant due to the promising development of unmanned marine vehicles. It is proposed to introduce the function of "desirability" of a particular course of the vessel for each point of the water area, considering the identified patterns of movement. A weighted graph of possible routes of the vessel is built considering this information. Thus, planning the route of the vessel is reduced to finding the shortest path on the graph. This report is devoted to assessing the

possibility of solving the closed problem of identifying movement patterns and planning ship routes in this way.

2. Method and materials

Planning a vessel's route through a busy water area includes the following steps:

1. Partitioning a section of a water surface by graph vertices.
2. Determination of the set of edges of the graph.
3. Estimation of the weight of the graph edges.
4. Finding the shortest path on the graph.

Splitting the graph vertices. Consider the *xy* coordinate system, where the *x*-axis corresponds to the geographic longitude and the *y*-axis corresponds to the geographic latitude of the vessel. We introduce a set of *N* points p_i with coordinates x_i, y_i. In this case, one of the points - p_1 - corresponds to the point of the beginning of the movement of the vessel, and one of the points - p_N - to the end point of the route. Let the set of possible routes of the ship lie on the *xy* plane inside a square with a side equal to the length of the segment with vertices at the starting and ending points of the route (p_1 and p_N, accordingly). In this case, the point p_1 lies in the middle of the side of the square, and the point lies p_N in the middle of the opposite side (that is, the segment p_1 p_N divides the square into two halves). Fill this square with dots so that they form a regular rectangular grid. Let *n* be the number of points dividing a segment p_1 p_N, and *m* - the number of rows of points to the right and left of this segment.

Determination of the set of edges of a graph. In the problem under consideration, it is proposed to resort to the well-proven approach of "layer-by-layer" formation of edges [6], [7], which considers the navigational specifics. Let is call the vertices of the graph, lying on the segments perpendicular to the segment, the layers of the vertices p_1 p_N. Suppose that when the ship moves, transitions from only one layer of vertices to the next nearest layer are possible, and movements between the vertices of one layer or between the vertices of far-apart layers are prohibited. Figure 1 illustrates the idea of forming a graph. There are *n* layers with *m + 1* vertices in each, as well as the beginning and end vertices. It is also advisable to limit the maximum rib length. Specific values of *n, m* and maximum rib length are determined based on the specifics of a particular water area.
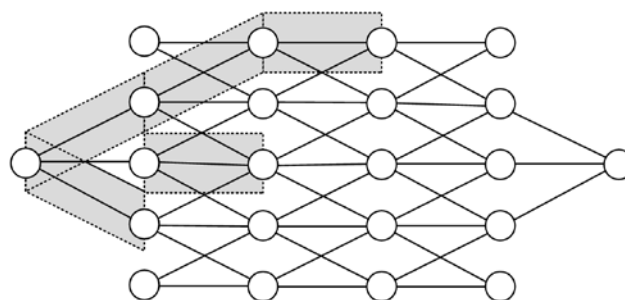

Fig. 1 – The idea of forming a graph of possible routes for a vessel

Estimating the weight of the graph's edges. The collective movement of vessels is usually characterized by typical (recommended and / or realizable) values of the course and speed in certain parts of the water area [8], [9]. It is convenient to use model representations of clustering to describe the pattern of movement in the water area [9]: objects with the "most typical" characteristics are identified, taken as the centers of clusters; the rest of the objects are assigned to the corresponding subsets if they are "similar" to the selected centers. To solve the clustering problem of this type, the subtractive clustering algorithm has proven itself well, which does not require specifying the number of clusters [10]. The central element of clustering is the definition of the distance metric between objects. Vessel traffic data is a set of *LON, LAT, SPEED, COURSE* tuples - longitude, latitude, speed

and course, respectively. In the described problem, it is advisable to resort to decomposition. It is necessary to divide the water area into sections and carry out clustering for each of the sections separately. It should be considered that only courses are signs of objects. This view is consistent with practical industry specifics.

Let there be data on the movement of ships for a certain period. There is a region that corresponds to one or another edge of the graph in Figure 1 (gray rectangle around the edge). It has many ships and has a distance matrix D_{ij} that sets the degree of proximity between objects with indices i and j. The metric of the distance between objects with indices i and j is specified as $D_{ij} = \sqrt{(COURSE_i - COURSE_j)^2}$ (the difference in rates is determined with regard to the periodicity of the angle values). Courses specific to the selected area (centers and sizes of clusters) are found by subtractive clustering. Let us introduce the function of "desirability" of this or that course of the vessel as follows. If the course corresponding to the direction of movement along the edge of the graph corresponds to the found clusters, then such a movement is considered "desirable" (the "desirability" function is taken equal to 1). Otherwise, the movement is "undesirable" (the "desirability" function is 0.01). The weight of an edge is considered equal to its length divided by the "desirability" function. If one of the vertices or a part of the edge incident to them falls on a prohibited area (for example, on land), the edge weight is taken to be infinity. If in the considered area the clustering of objects is impossible (for example, too little data), it is an area with unregulated movement and the desirability function is taken equal to 0.1. Thus, the edges have the least weight since they correspond to the patterns of movement in the water area.
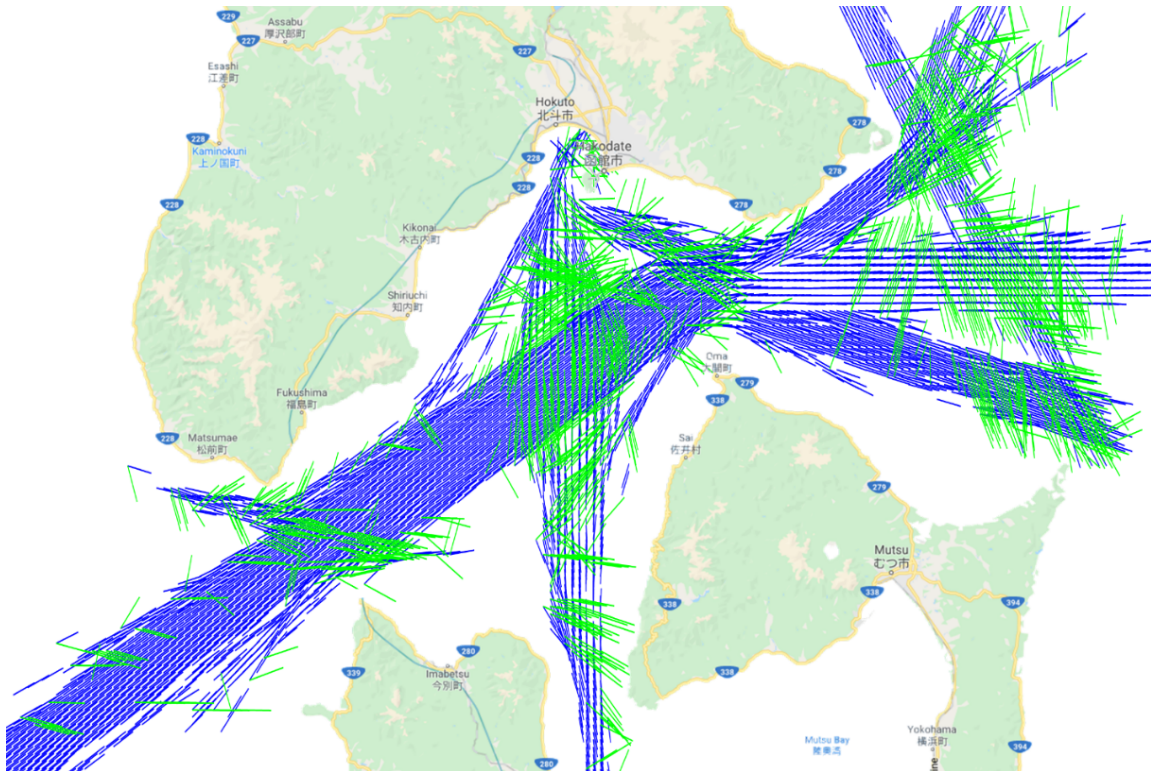

Fig. 2 - Centres of the first, second (blue) and third, fourth (green) clusters in the ship heading data
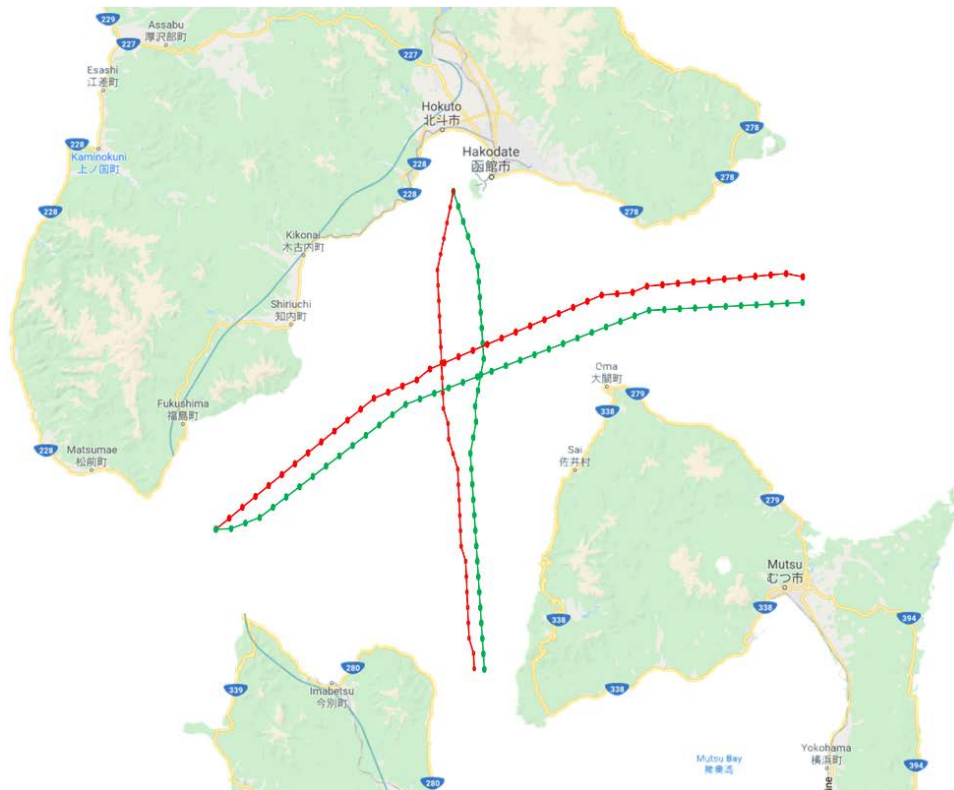
Fig. 3 - Results of planning the route of the vessel in the Tsugaru Strait
(Hakodate – Mutsu Bay and Japan Sea – Pacific Ocean)
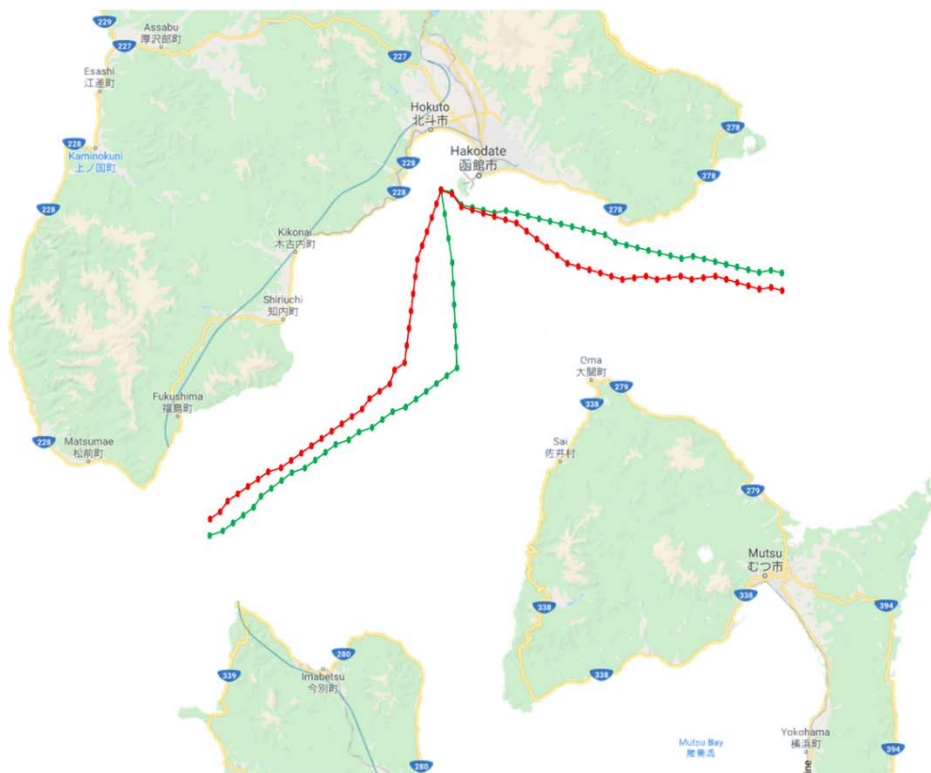

Fig. 4 - Results of planning the route of the vessel in the Tsugaru Strait (Hakodate – Pacific Ocean and Hakodate - Japan Sea)

Finding the shortest path on a graph. The search for the shortest path from vertex p_1 to vertex p_N can be carried out by any known general-purpose algorithm (Dijkstra, Bellman-Ford, etc.). The choice of values for m and n depends on the geographical features of the area and the scale of the discontinuities in the traffic data. It should be noted that the complexity of the most efficient algorithms for finding a path on graphs is proportional to the number of edges and the number of vertices (or their logarithm) [11]. And it is necessary to limit the values of m and n so that the time for solving the problem remains acceptable for practice.

3. Results

The study was carried out on real data on the movement of ships, collected from the resource [12] using a specially developed software system [13]. An example of solving the problem for the Tsugaru Strait is given. Traffic data was taken for one week. There are about 1.5 million records in total. The standard subtractive clustering method was used. The values of the method parameters were selected to correctly identify the clusters of the reference sample. As a result, the characteristic radius of the cluster of ship courses was determined to be 16 °. The courses were considered to belong to the cluster if they lay closer than 20 ° from its center (1.25 · 16 °). The iterative procedure for searching for cluster centers ended if the potential of the next cluster did not exceed 10% of the potential of the first cluster. The remaining clusters were considered insignificant.

In Figure 2 segments show the courses corresponding to the found clusters: the first and second (blue lines), the third and fourth (green lines). It should be noted that the found course values fully correspond to the direction of movement of real traffic flows.

In Figure 3 lines show the results of route planning: Pacific Ocean - Sea of Japan (east - west) and the port of Hakodate - Mutsu Bay (north - south, red lines) and back (green lines). Figure 4 shows the results of route planning: Hakodate Port - Sea of Japan (North - West) and Hakodate Port - Pacific Ocean (East - North, red lines) and back (green lines). It can be seen that the routes found fully correspond to the direction of movement of real traffic flows. In a particular case, they take the "correct" side of the movement (right-hand traffic is accepted in marine navigation).

4. Conclusion

Researchers now have the opportunity to work with large amounts of data on the real movement of ships, as the technologies and services of the Automatic Identification System, the concept of e-navigation [14] and cloud computing technologies have been developed. This has led to the appeal to safety models for the collective movement of ship groups and in the water area as a whole with the allocation of problems of recognition, classification, clustering and forecasting, i.e. tasks of "big data". In this paper, we propose a method for solving the problem of planning the routes of ships when they move through water areas with a saturated traffic flow, based on clustering of courses. The problem is solved as follows:

1. Formation of a database of retrospective data on the movement of vessels in the selected area of the water area.

2. Formation of the graph of possible routes of the vessel.

3. Evaluation of the characteristic values of the courses of ships in certain parts of the water area.

4. Estimation of the weight of the edges of the graph of possible routes of the vessel, finding the shortest path on the graph.

Studies carried out on traffic data from real water areas have confirmed the applicability of the proposed method.

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