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Determination of the shortest path as the basis for examining the most weather favorable routes

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Abstract

Generating initial population of evolutionary algorithms used in the process of weather ship route optimization requires the determination of the area where it may find the points of designated routes. The problem may be a need to sail around the continent, circumnavigate the islands, and the restrictions from the ice fields and other closed areas. Comparing routes to the rhumb line or great circle may be also impossible. It is proposed to determinate the preliminary route using Dijkstra's algorithm using land / ocean data of the GFS model. It will be used during generation an initial population on the ocean area in these cases.

Introduction

When performing the calculations for selecting the best ship ocean routes when considering current and forecasted weather conditions in addition to the accuracy of the calculations is also important the time of calculations. Too long waiting for the calculation makes it difficult or even impossible eventual verifications of the results, and developing alternative solutions.

On the accuracy of calculations itself affected mainly:

– accuracy and reliability of weather data;
– adjusting the speed characteristic of the vessel;
– type of calculation algorithm and size of the selected parameters.

Computation time will be conditioned on the one hand by the power of computing machines, on the other hand by the accuracy and type of computational algorithms. Practical application for an example on the ship bridge will be restricted by computing power of an average PC. Thus, greater weight is given for the choice and parametrization of the calculation algorithm. The required solution will be a satisfactory solution, so far as is the sub-optimal result. From a practical point of view, deterministic defining of the absolute minimum time of travel for selected conditions is not necessary if the solution worked out slightly different from it. Minute difference in travel time lasting several days or even longer, has no special meaning.

While the searching for ship route on the open ocean is an issue solving without major difficulties, whereas the appearance of constraints in the form of land areas, prohibited areas, or fields in the form of threats such as tropical cyclones significantly complicates the problem.

In this paper an example of the ship voyage from Montevideo in Uruguay to Valparaiso in Chile is presented.

Attempt to make this calculations without creating intermediate way-points using a commercial system SPOS based on the isochrone algorithm, regardless of the assumed parameters of the track width and density of issued points, fails and system shows the message "destination unattainable" (Fig. 1).

The authors propose a preliminary designation of a route linking the starting point with the destination point using Dijkstra's algorithm [1], and then use it to generate an initial population of routes for an evolutionary algorithm [2, 3, 4] which will be carried out the rest of the calculations. It should allow to avoid difficulties in calculating the route avoiding prohibited areas, while fast reaching the final solution.

Fig. 1. An attempt to establish a route around the continent using SPOS system

Determining an initial route and generating the initial population

Initial route

The basis for the generation of initial population was to determine the path from the origin to the destination. For this purpose Dijkstra's algorithms [1] based on greedy strategy were used. It is used to find the shortest path between two vertices of a graph with non-negative edge weights. The input data for the algorithm was undirected graph created on base of information regarding the configuration of the analyzed area, obtained from the GFS model [5].

These data are available as a grid with elements in the shape of a square in dimension of 0.5º × 0.5º. They contain:

- coordinates of each element;
- row and column indices, at the intersection where there is an element;
- information regarding the position of the land / ocean.

In order to reduce the amount of analyzed data and calculations time, preliminary analysis and selection of input data were carried out, limiting it only to the area needed to determine the route between the desired points. The elements of a grid located on land were also eliminated, allowing further reduction in the number of nodes of the graph.

Route selection procedure was performed for two different options for calculating weights for the connections between the nodes. In the first case the weights were the distances between points. In the second case, the weights were a function of two variables: the distance and the need of changing course with respect to the direction of transition between nodes in the previous step of route selection algorithm.

The first option allows to find the shortest path, but does not limit the number of course changes. In the second case founded route is a bit longer, but the number of course changes necessary to execute has been significantly reduced.

In an example presented below, the road between Montevideo, Uruguay (34°53'S; 56°10'W) and Valparaiso in Chile (33°04'S; 71° 38'W) was found. If the values of weights are the distance only, the route run through the 99 elements of the grid. In the second case, calculated route consisted of 104 nodes (Fig. 2).

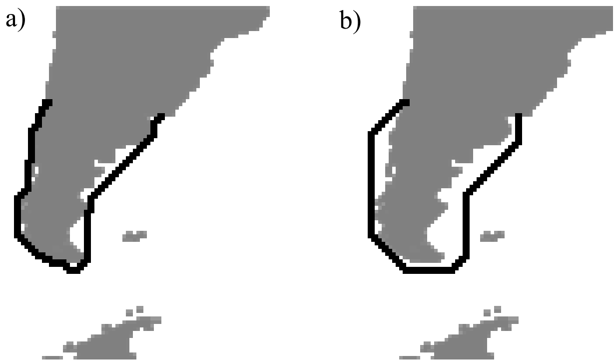

Fig. 2. Found routes: a) the weights are a distance only, b) the weights are a function of distance and the need to change the course

For further calculations, the route taken in the variant "farther from the shore" (b) as giving greater strip for search was chosen. The run of this route based on the coordinates describing the grid squares of the GFS model and is presented on figure 3.

Generating the initial population

Generating initial population of evolutionary algorithms used in the process of weather ship route optimization, to speed up the calculations, require to determine the area where it may place the points of designated routes. Proper selection of operands may be important for the speed of obtaining final solutions [6].

Initial populations for genetic algorithms were generated randomly based on data obtained from Dijkstra's algorithm. Number of points generated for the given population was the same as the number of elements of the grid, through which ran the route developed by Dijkstra's algorithm.

It was assumed that the coordinates of successive points should be randomly generated such that the point was in the:

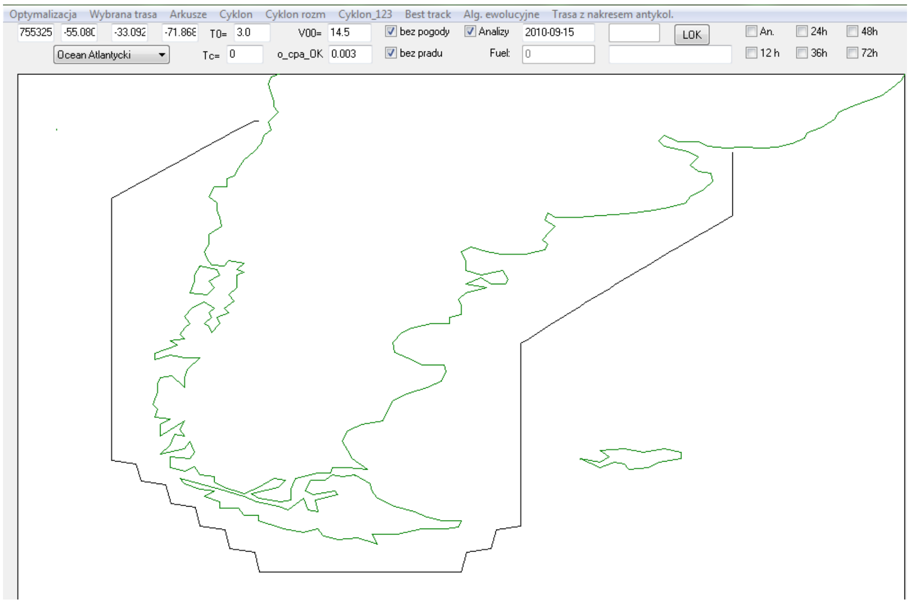

Fig. 3. Initial route "farther from the shore" (b)

– grid element for which we generate a point, or
– a square of side n-times longer then the length of one side of the grid, for the purposes of this calculation the $n = 3$.

If in the area of the square, in which a point was generated, elements of the grid located on land were included, drawn point was accepted only in cases where the item was selected as in the grid element located on the water.

Initial population of 50 individuals shows the figure 4.

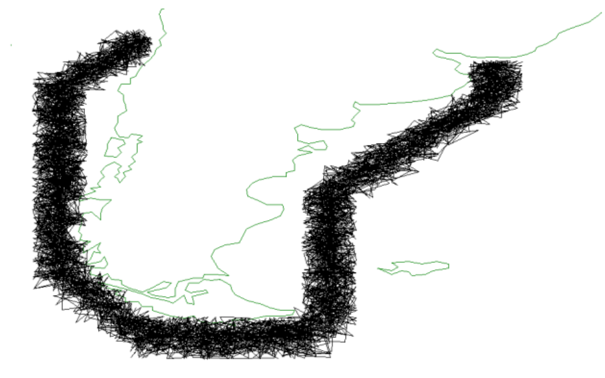

Fig. 4. Initial population of 50 individuals

Calculations and results

For the calculation of a preferred route on given weather conditions, speed characteristics of the merchant vessel of a medium size with the calm water speed of 14.5 knots were used [7].

The following data from the model WaveWatch III [5] were taken into consideration:

– wave height;
– wave direction;
– u-component of wind vector;
– v-component of wind vector.

Weather analysis for each day of the period of September 15–25, year 2010 (00UTC time) were used. Currents conditions were not taken into account.

Mutation operand randomly choosing a point of each route [3, 4] and changing its location to within ±1° in latitude and ±1° in longitude was applied. A side effect of its action might be the formation of groups of points in identical or close positions (Fig. 5).

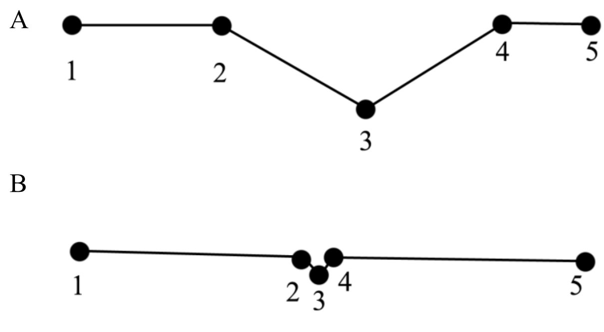

Fig. 5. Group of points formation

In the situation "A" the change of the position of point 3 can lead to shortening the route and obtaining better results, while in the case of grouping the points (situation B) changing the position of point 3 will lead to a route lengthening through the route "clinging" by the near points.

Therefore, the operand of removing neighboring points was applied. If two consecutive points differ by latitude and longitude less than 0.5°:

$$\Delta\varphi < 0.5^{\circ} \text{ AND } \Delta\lambda < 0.5^{\circ}$$

the first of the points was removed after checking the condition of not crossing the land by the so revised route. The result of calculations after 1000 generations (mutation and removing) shows the figure 6.

It can be noted that the route is more smooth, but it is not yet an acceptable solution. The calculated duration of the voyage was 239h 36'. The maximum wave height recorded on the route was 7.9 m. The length of this route is 3085 NM and the average speed of 12.9 knots.

To get close to the optimal solution without having to increase the amount of generations and a significant increase of calculations time, therefore the crossover operand were also used. Crossover were subjected to whole populations, and thus 25 pairs of the two individuals, establishing randomly one point of crossover.

Such a worked out route after 1000 generations with the use of a mutation removing, and the crossover operands are shown in figure 7. The time of such a calculated route is 220h 48'. Maximum wave

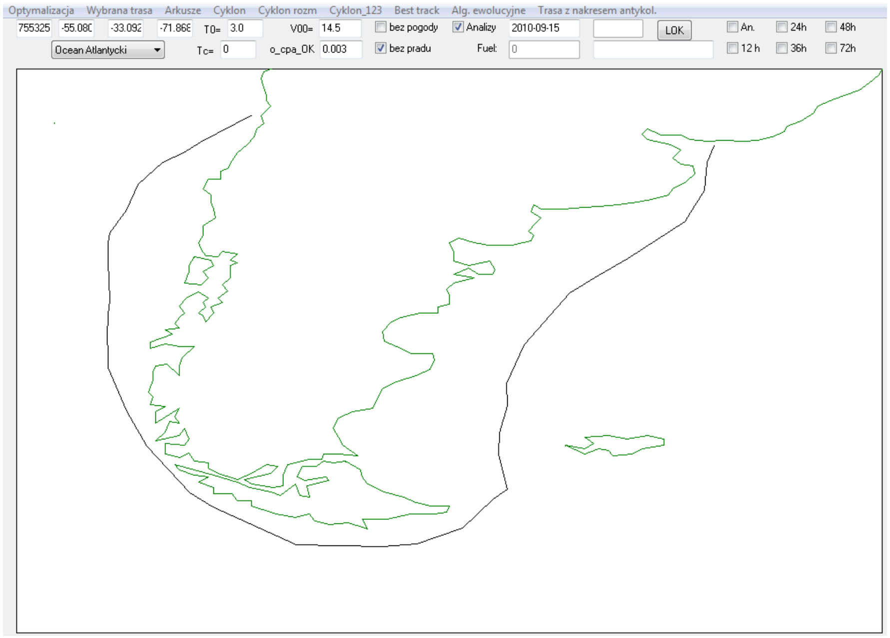

Fig. 6. The result of the initial route after undergo the operation of mutation and removing operands after 1000 generations, taking into account weather conditions

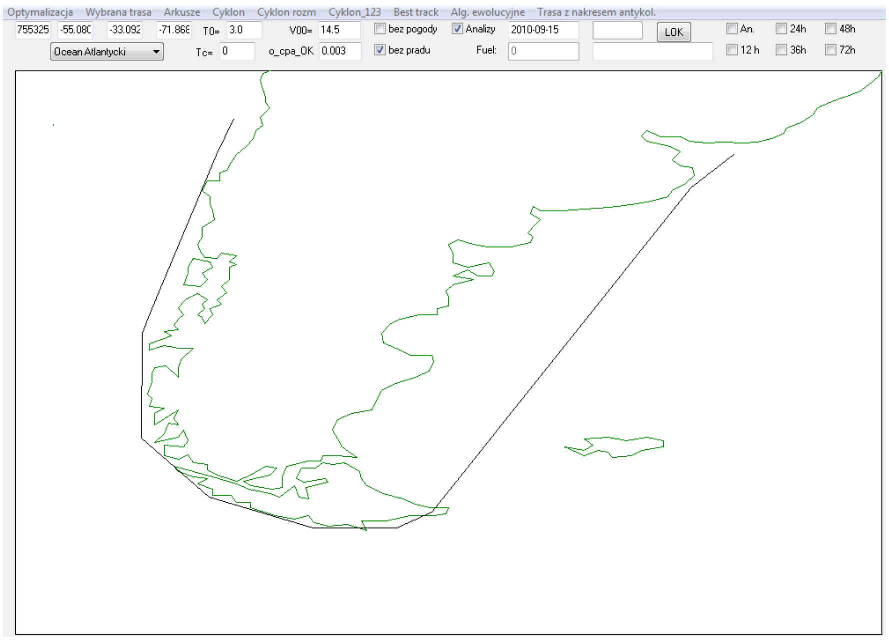

Fig. 7. The results after 1000 generations from the initial population after using the mutation, removing and crossover operands taking into account weather conditions (land plotted schematically)

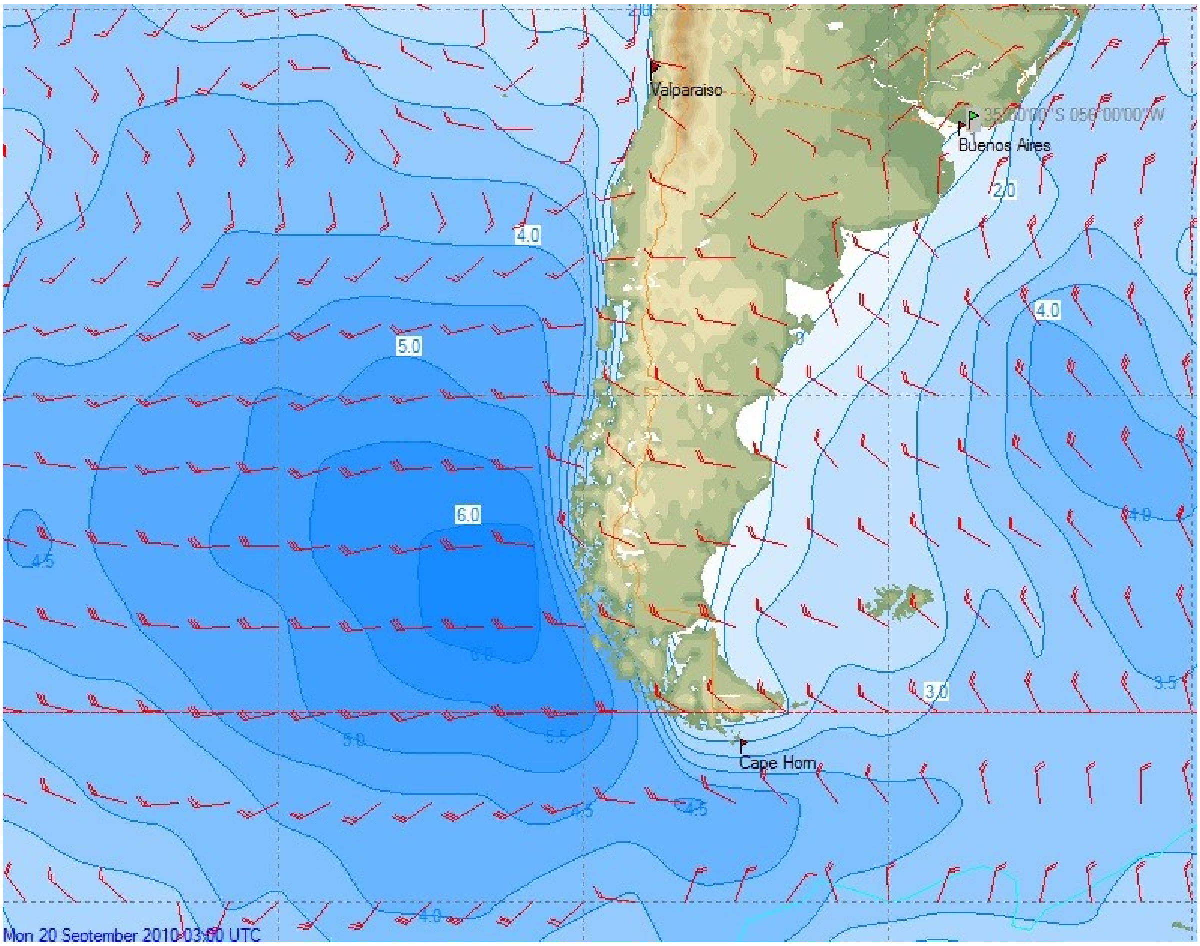

Fig. 8. Weather conditions – 20th September 2010 [SPOS]

heights encountered on the route is 7.2 m. Distance traveled is 2855 NM, the average speed achieved is 12.9 knots.

The ship correctly chooses the route near the western coast of South America, as the weather conditions (Fig. 8) do not allow entirely avoid the large wave field located on the south-east Pacific, the wave heights exceed of 6 meters and the accompanying westerly wind speed achieves 30 knots. Weather conditions on this area are the main cause of speed loss of the ship on the calculated route.

Conclusions

The adopted procedure based on a combination of Dijkstra's algorithm with evolutionary algorithms gives satisfactory results. It allows to calculate the route avoiding obstacles, which in this case was extended meridionally land area. A short calculation time of several minutes allows for route calculation in operational mode.

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