J. Szłapczyńska, R. Śmierzchalski - ADOPTED ISOCHRONES METHOD IMPROVING SHIP SAFETY
IN WEATHER ROUTING WITH EVOLUTIONARY APPROACH

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ADOPTED ISOCHRONES METHOD IMPROVING SHIP SAFETY IN WEATHER ROUTING WITH EVOLUTIONARY APPROACH

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Keywords

weather routing, isochrones method

Abstract

The paper is focused on adaptation of an isochrones method necessary for application to a weather routing system with evolutionary approach. Authors propose an adaptation of the isochrones method with area partitioning assuring that the route found by the adopted method would not cross land. In result, when applied to a weather routing system with evolutionary approach, this proposal facilitates creation of initial population, resulting with routes of reduced collision risk and low costs of passage.

1. Introduction

Weather routing services play important role in securing ship safety, especially when ocean-going ships are considered. During such voyages adverse weather conditions may impact not only the passage time, a crucial resource nowadays, but also security of people and commodities on board. Most of recent scientific researches focus on shortening the passage time and avoiding severe weather i.e. tropical cyclones. Though these actions have significantly amended the security level, still more improvements increasing ship safety might be proposed.

One of the first approaches to minimum time route planning based on weather forecasted data was an isochrone method proposed by R.W. James in 1957 [3]. The method, where recursively defined time-fronts are geometrically determined, was in wide use through decades. In late seventies based on the original isochrone method the first computer-aided weather routing tools were developed. However, along with computer implementation a problem arose with so called "isochrone loops". Numerous improvements to the method were proposed since early eighties, with [2], [6], [7] among others.

Evolutionary approach as a natural successor of genetic one has become popular in the last two decades and has been successfully applied to anti-collision manoeuvre modelling [5]. Modern weather routing tools also utilize evolutionary algorithms instead of the deprecated isochrone time-fronts. Yet isochrones can still be utilized for generating initial populations. In such cases special attention must be given to assure that the route found by the isochrone method does not cross any landmasses. Otherwise, land crossings in first evolutionary population may result at least in extended, time-consuming computations or ultimately – in determining a hazardous route. Thus, it is extremely important to adapt the isochrone method in such a way that its resulting route would obey the "no land crossing" rule.

This paper is organized as follows: section 2 introduces classic isochrone algorithms with their advantages and disadvantages referring to computer implementation in evolutionary application. Section 3 presents a possible solution of collision risk reduction in route planning process. Section 4 provides detailed description of a proposal concerning adaptation of the isochrone method with area partitioning. Then in section 5 an example of usage is presented. Finally, section 6 summarizes the material presented.

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2. Classic isochrone algorithms

2.1. Original isochrone method

The isochrone method was originally proposed by R.W. James in 1957 [3]. The method was intended for manual use by navigators as an aid for route planning process. An isochrone introduced by James is a set of connected points that a ship can reach within given time limit starting from one point and going in all possible directions. These points are dependent among other things on weather factors such as wave direction and height. Given this definition the first isochrone visualizes ship's speed characteristic. Then, in order to determine second isochrone, from each point belonging to the first one a perpendicular line to tangent is determined (*Figure 1*). A segment of the line depicting distance that the ship is able to cover within next time limit defines a point on second isochrone. A set of such connected points forms second isochrone. Next isochrones are generated identically.

Main disadvantage of the method when implemented as a part of computer application are so called „isochrone loops" [7]. Such a loop is in fact an irregularity in shape of an isochrone caused by non-convexity of speed characteristic for given weather data. Unfortunately isochrone loops propagate with number of isochrones and as a result make the procedure not applicable for computer programs.
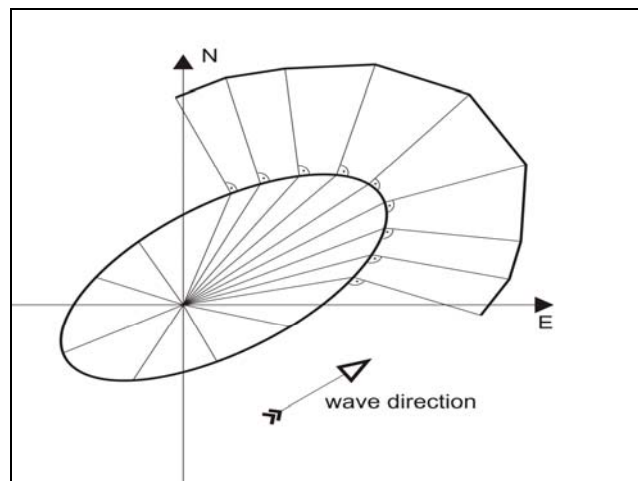
Figure 1. Construction of the first and second isochrone

2.2. Modified isochrone method

Modified isochrone method, presented in [7], removes the main disadvantage of original James' method. The modified method is based on an observation that for a given point on an isochrone the perpendicular to the isochrone is not always the optimal direction. Instead, a course change is required such that its projection on the perpendicular to the tangent is maximized. Not only does this solution remove "isochrone loops" problem, but also is applicable to computer application. However, some problems occur when strict rule of no land crossing should be met. According to the description given by [7], in order to allow the method bypass landmasses it is sufficient to inscribe zero ship velocity with ship's speed characteristic for land points. However, when applied some isochrone points appear to be stuck at landmass shore (*Figure 2*). This behaviour is caused by the fact that when a point of an isochrone is a landmass (e.g. due to not sufficient resolution of weather data) it does not allow creating any new point for next isochrones. In addition to that, inscribing zero velocity for landmass points together with low-resolution weather data may cause isochrone route to cross the land regardless of all other protections.

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Figure 2. Example set of isochrones with a point being stuck at landmass

Last but not least, this method is prone to failure in situation when a ship is about to cross a narrow strait. A reason behind that is that only a single point can be generated from a point on the current isochrone. Thus, if only one point, assuming sufficient isochrone accuracy, is put inside the strait, hardly can it browse the area around.

2.3. Modified isochrone method with area partitioning

Another modified isochrone method was proposed by H. Hagiwara in 1989 [2]. The method with area partitioning assumes that when a new isochrone is to be generated first the search sector's area is partitioned. After a set of calculations the set of sub-areas produce a set of points constructing the new isochrone. For each sub-area sector only one point can be selected, the one having maximum distance from the starting point. Graphical representation of the method is often different than other classic isochrone methods. Here all isochrone points are drawn and, instead of connecting every point from one isochrone like in other isochrone methods, they are connected in such a way that a point is connected with his predecessor and all successors (*Figure 3*).

Due to area partitioning this algorithm is less non-convexity-error prone. It is also more flexible than the previously described method. The method can easily handle narrow strait crossings as well as other crossings. Hagiwara [2] provides only general solution for assuring no land crossings though, giving universal formula for method restrictions including land obstacles. Thus, detailed solutions for "no land crossing" rule should be introduced to the method.
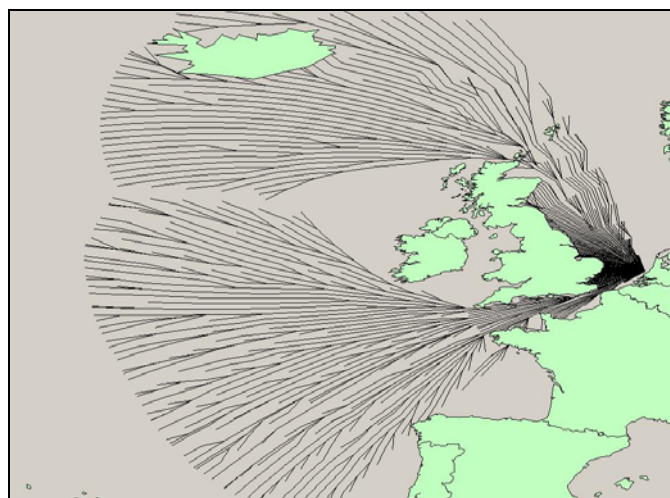

Figure 3. Graphical representation of the modified isochrone method with area partitioning

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3. Reducing collision risk in route planning process

Modern weather routing services focus primarily on achieving low costs of passage by means of either minimization of passage time or reducing transport costs i.e. fuel consumption. Hardly is there any collision risk factor taken into account among the safety criteria in a multicriteria route planning process. It is mostly because collision risk often conflicts with economic criteria. Instead, a trade-off between safety and economic criteria are to be sought. Thus, the authors propose to introduce into the weather routing optimisation procedure another safety criterion, namely traffic intensity factor. When a Pareto-based multiobjective evolutionary algorithm is the main optimisation engine, it is guaranteed that the route found should not cross any high traffic intensity area. In result, the risk of potential collision with other vessels would be significantly reduced. In order to achieve the goal of reducing collision risk while preserving possibly low costs of passage a proper set of initial routes, constituting the initial population, should be determined. These routes must obey all the navigational constraints, particularly the "no land crossing" rule. Thus, an algorithm is required specifying how to determine such routes.

4. Proposed adaptation of isochrone method

As a base for adaptation the modified isochrone method with area partitioning was selected due to it's flexibility and good browsing capabilities e.g. in narrow straits. A focus of research was provided to introduce mechanisms assuring that the final route is free from land crossings.
In order to prevent selecting a route crossing land obstacles following restrictions should be imposed:

1. Neither start nor finish point of the route may lay at landmasses.
2. On creation of a new isochrone candidate point it must be checked whether a line between the point and his predecessor does not cross land (bitmap-based algorithm).
3. If the point in 2. crosses land another candidate point must be found. The new point must not violate ship's speed characteristic or cause land crossing.
4. When selecting the last isochrone point leading directly toward the finish point it must be checked whether land is not crossed (again bitmap-based algorithm).

Next subsections describe in detail the bitmap-based algorithm required to perform steps 2 and 4 as well as the process of new candidate point generation (step 3).

4.1. Bitmap-based algorithm for checking a line for intersection with land area

Let us assume we have a vector-based land map in latitude-longitude projection. The land is defined by a set of polygons (in general they do not have to be convex), with their vertices described by pairs of geographical coordinates: longitude and latitude. Unfortunately, there is no sufficiently fast and robust algorithm that checks a line (defined by start and finish points) for intersection with any polygon, especially non-convex one [1]. Here, for purposes of the isochrone method, complexity of algorithm for checking a line for intersection with land area must remain as low as possible. On the other hand there are some effective algorithms for checking a point inclusion in any polygon, also non-convex one [1].

Having analysed these facts an algorithm may be proposed that performs checking a line for intersection with land area in a twofold way. First a high-resolution bitmap is created covering the entire map. Every bitmap cell holds a boolean "True" or "False" value depending whether land covers entire cell. Due to time consuming process of bitmap creation it is sufficient to be performed once only and its results to be stored in an outer file for future utilization. To keep the file compact it is recommended to store only the boolean values in predefined order of bitmap cells. Once the bitmap is available, algorithm presented below (Figure 4) is able to perform the final check.

The presented algorithm keeps linear computational complexity O(n) ([4]), where n denotes the number of cells. Since the access to the land bitmap is done in constant time (O(1)) it does not affect total complexity of the procedure.

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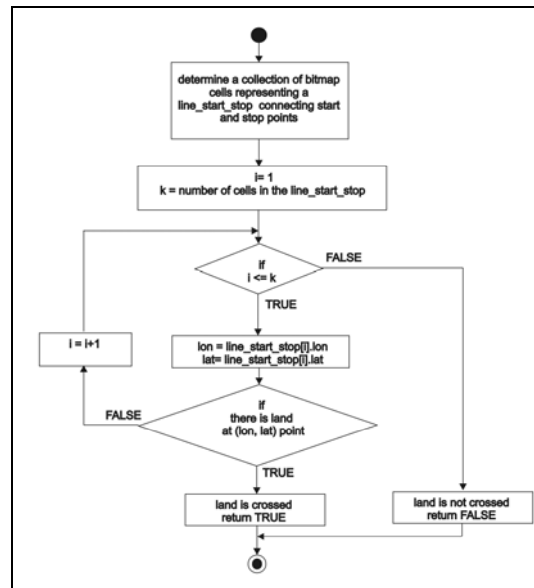
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Figure 4. Bitmap-based algorithm for checking if a line crosses land

Land bitmap resolution is another important issue having impact on calculation accuracy. It is recommended to generate a bitmap with cell size at most equal to the smallest observable map object. Otherwise there is a risk of inaccurate computation due to rough land bitmap data.

4.2. Generation of a new candidate point assuring no land crossings

To generate a new point that does not violate ship's speed characteristic nor crosses land it is necessary to utilize previously described bitmap-based algorithm. Let us assume we have points A and B, where A is a predecessor of B, B was found as a border point of ship's speed characteristic and segment A-B does cross land. Another point C on the A-B segment is sought such that A-C segment does not cross land. In addition to that the C point should maximize the length of the A-C segment. An algorithm presented below finds proper C point for the input parameters: points A and B, distance step and land bitmap.

In the algorithm below (*Figure 5*) a C point is searched such that, starting from A towards B, new points are generated with distance of distance step between them. The first one that causes land crossing breaks the loop. In this moment the previous point (the one that does not cause land crossing) is returned as the C point.
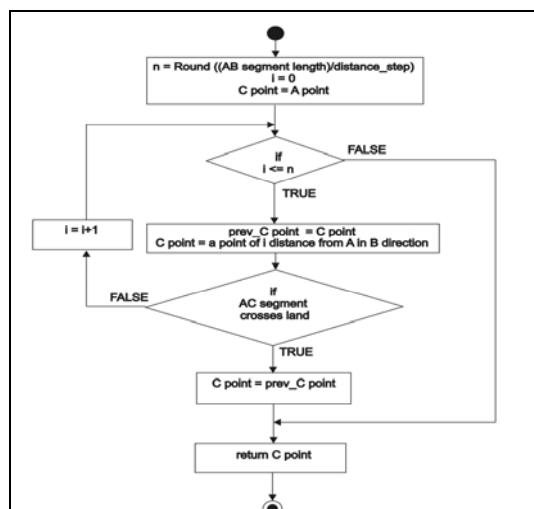

Figure 5. Algorithm for finding new candidate point C on A-B segment
that A-C segment does not cross land

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5. Application example

Following the proposed solution described above an application including applied isochrone method has been implemented. Route determined by the adopted isochrone method will serve as a base for the initial population in a route finding multiobjective algorithm with evolutionary approach.

Let us assume there is a route to be found starting in Plymouth and finishing in New York. Unfortunately classic modified isochrone method [7] fails to find a proper route due to land obstacles as shown in *Figure 6*. When the isochrones come across a landmass, i.e. an island, they tend to stuck in some points (marked by a circle in *Figure 6*). In such points there is no possibility to find another non-land point for given search sector when a new isochrone is being generated. As a result, route found by the classic modified isochrone algorithm is suboptimal.

The adapted isochrone method, as shown in *Figure 7,* does not encounter the problem of isochrone points being stuck at landmasses. Furthermore, it does find time-optimal Plymouth-New York route (*Figure 8)*. Configuration settings of the method are presented in *Table 1*.
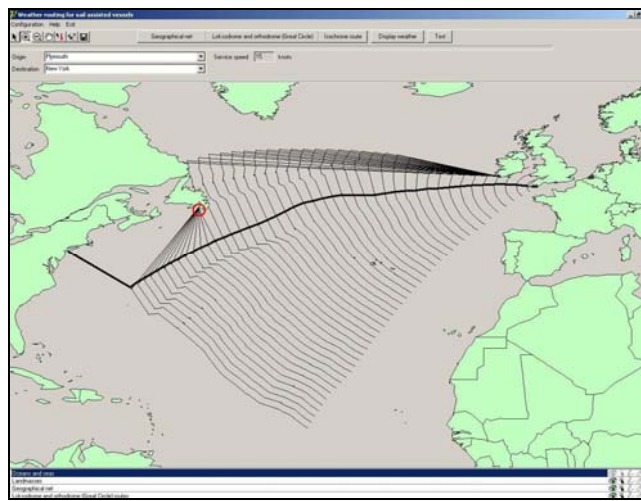
Figure 6. Isochrones and isochrone route (thick solid line) for Plymouth – New York voyage found by classic modified isochrone method

Table 1. Configuration settings of the adopted isochrone method

Parameter name	Value
Search subsector angle	± 60º
Weather data grid resolution (lon x lat)	1.25º x 1.0º
Land bitmap resolution (lon x lat)	0.05º x 0.05º
Time step between isochrones	4 h
Points per isochrone	100

Route Plymouth – New York as shown in *Figure 8* easily bypasses all land obstacles and reaches the destination port. It is worth noticing that the route found is close to the Plymouth – New York orthodrome (Great Circle), the shortest possible geographical route, marked in *Figure 8* by a dashed line. *Table 2* compares length of Plymouth – New York routes determined by classic modified isochrone method, adopted modified isochrone method and the orthodrome as well as their execution times.

Results presented in *Table 2* depict that the route determined by the proposed adopted isochrone method is much shorter (more than 9.5%) than the one determined by the classic modified isochrone method.

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Time required to execute the proposed method is 7 sec. longer than the one for the classic method. It is justified by the necessity of performing additional operations assuring "no land crossings". Nonetheless, the execution time of the proposed method is still acceptable. Of course, both isochrone methods are significantly more time consuming than simple orthodrome determination procedure. It is caused by the fact that the latter is a simplified mathematical procedure, disregarding land obstacles and ship's speed characteristic.
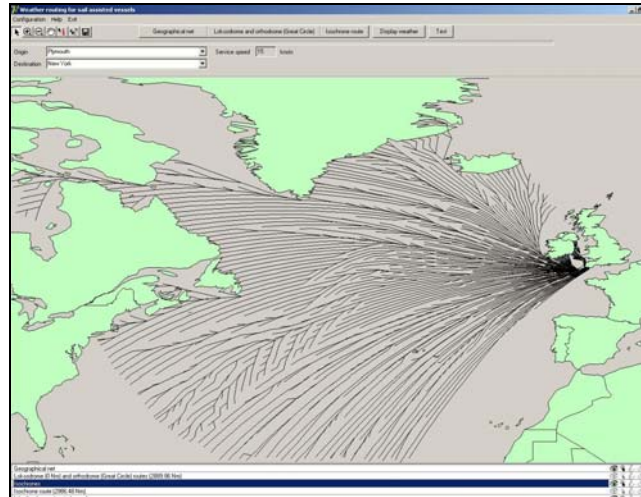

Figure 7. Isochrones found by proposed adopted isochrone method
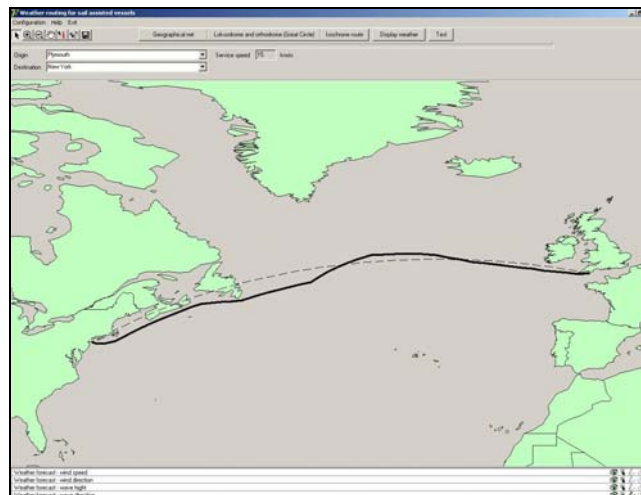for Plymouth – New York voyage

Figure 8. Isochrone route (thick solid line) found by proposed adopted isochrone method
for Plymouth – New York voyage and appropriate orthodrome route (dashed line)

Table 2. Length of Plymouth – New York routes determined by various methods and methods' execution time

Name	Plymouth – New York route length	Method execution time
Classic modified isochrone method	3306.88 Nm	18 sec.
Proposed adapted isochrone method	2986.48 Nm	25 sec.
Orthodrome (Great Circle)	2889.86 Nm	< 1 sec.

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6. Conclusion

Isochrone method, although deprecated as a general route finding tool, still can be utilized in modern weather routing evolutionary systems for initial population of routes. However, special attention must be given to assure that the isochrone method does not produce a route crossing landmasses. Currently, no detailed description of how to meet this requirement is available. Thus, an adaptation proposal of the isochrone method with area partitioning is provided. The proposal improves the classic isochrone method the way that resulting routes are free from land crossings. In result, when applied to a weather routing system with evolutionary approach, this algorithm facilitates creation of initial population, resulting with routes of reduced collision risk and low costs of passage.

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