Algorithm for constructing a route to pass a narrow fairway

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Abstract. Modern navigation systems often employ the algorithms for plotting lines for the preliminary route construction. The current conditions of technological development imply the simplicity of constructing routes. However, the most important part was and remains the speed of the system that generates the route. The authors of the paper proposed a universal algorithm for constructing a navigation route in narrow channels of the sea. The presented algorithm identifies the middle of the fairway as the safest point at each narrow segment and connects them with track lines. The problem that can arise is smoothing, as the middle of the fairway can shift significantly. To solve this problem, new relative and absolute parameters that characterize plotting of turning points were introduced. In addition, a unified universal formula was proposed for finding the coordinates of these points on a line perpendicular to the current route of the vessel. It was experimentally proved that correctly selected empirical parameters enable the algorithm to quickly construct a route in any navigation area with a relatively low computational complexity. This approach is appropriate for clearly delineated zones of the fairway, and it is compatible with zone methods.

1. Introduction
According to maritime practice, the water area is considered sufficient for safe passage if the vessel in this water area is able to turn around and head in the opposite direction. In narrow channels, a navigator has no such opportunity. Based on the above, the safety of passage through a narrow fairway can be determined based on whether the vessel is capable of turning around and heading in the opposite direction in the given section of the route.

2. Problem statement
It is quite obvious that in order to be able to deviate from the course and to have water area convenient to respond to emerging hazards, it is necessary to keep away from hazards. However, this is impossible when passing narrow channels, and navigators try to keep the vessel at equal distance from hazards on each side, that is, as close as possible to the middle of the fairway [2].

Thus, it can be argued that the safest place for a vessel at each discrete moment of time when moving in a narrow channel is in the middle of the shortest distance between two opposite sides of the channel, the safest points of the water area at each moment of time t are shown in Figure 1.
Figure 1. The safest points of the water area at each moment of time $t$.

If you connect the obtained points, you get the most suitable route for passing a particular narrow section in terms of safety. However, the route is a set of waypoints with a minimum distance between them. It is inconvenient and often unreasonable for the navigator to use such a route [3]. Therefore, to get a more familiar navigation route, which is a set of turning points connected by straight course lines, it is necessary to smooth a great number of points and filter out outliers.

3. Navigation route acquisition method
The authors propose the following smoothing algorithm.

1. A vessel approaches the entrance to a narrow fairway at a certain heading $K$. Continue the vector of the vessel’s heading until it enters the fairway and draw a perpendicular to the heading at the obtained point $A$, as shown in Figure 2.

2. Determine the middle of the fairway at the next waypoint – point $B$. To do this, divide the fairway into discrete sections with equal intervals $\Delta$ and draw perpendiculars to the vessel's heading, and designate the point of intersection of the vessel's heading line with the second perpendicular $C$, as shown in Figure 3.
Figure 3. Plotting the course to determine the need for setting a new turning point. Point A is the middle of the fairway in the first segment, B is the middle of the fairway in the second segment, C is the point of intersection of the current course with the perpendicular to the current course.

3. Calculate the distance CB and check it by two parameters: relative α (%) and absolute β (kBT) deviation from the perpendicular. The magnitude of these two parameters, when the empirically determined limits are exceeded, will indicate the need for setting a new waypoint, which can be expressed by formula (1):

\[ p = \begin{cases} 
1, \text{at } CB \geq \alpha \mid \frac{CB}{l} \times 100 \geq \beta \\
0, \text{at } CB < \alpha \mid \frac{CB}{l} \times 100 < \beta 
\end{cases} \]  

where: \( p \) is an indicator of the need for setting a new waypoint; \( l \) is the length of the segment between the two boundaries of the fairway and perpendicular to the course of the vessel.

4. If at a given point in space \( p \) is 1, set a waypoint and calculate a new course. Connect the first waypoint to the middle of the fairway in the next segment plotted after the same interval \( \Delta \) and measure the geographic direction of this segment to obtain the course \( K_1 \) of the vessel from the turning point, as shown in Figure 4.

Figure 4. Plotting the course \( K_1 \) of the vessel from the first turning point to the middle of the fairway in the next segment along the vessel route.
5. Continue the line of the new course until the intersection with the next segment and check the need to set a new point according to equation 1. If a waypoint is required, set it and start a new iteration of the algorithm from step 2. If the point is not required, continue the line K1 (length S resulting from summing the discrete distance) to the intersection with the next segment and so on, until the conditions needed for setting the waypoint are met. In this case, the coordinates of the waypoint are determined as follows (2, 3):

$$\varphi = \varphi_0 + \frac{\text{sign}(\text{floor}(CB-\alpha))s \sin(K) + \text{sign}(\text{floor}(\frac{CB}{L-n})s \sin(K))}{\text{sign}(\text{floor}(CB-\alpha)) + \text{sign}(\text{floor}(\frac{CB}{L-n}))}$$

(2)

$$\lambda = \lambda_0 + \frac{\text{sign}(\text{floor}(CB-\alpha))s \cos(K) \cos^{-1}(0.5(\sin(n_0))) + \text{sign}(\text{floor}(\frac{CB}{L-n})s \cos(K) \cos^{-1}(0.5(\sin(n_0))))}{\text{sign}(\text{floor}(CB-\alpha)) + \text{sign}(\text{floor}(\frac{CB}{L-n}))}$$

(3)

After setting a new waypoint and calculating the corresponding new heading of the vessel, the algorithm is repeated iteratively with a new heading and so on until the vessel exits from the narrow fairway.

4. Results
The constructed route might look like the one shown in Figure 5.

![Figure 5. The vessel route constructed by the algorithm.](image)

As indicated above, the parameters $\Delta$, $\alpha$ and $\beta$ can be determined empirically. In the framework of this study, the authors have chosen the following values as the most reliable: $\Delta$ and $\alpha$ equal to 1 kbt, and $\beta$ equal to 25%. When passing the constructed route, it is possible to use decision support systems and automatic keeping of the vessel on the route with regard to deviations from the line [4, 5].

5. Conclusion
In conclusion, the authors of the paper described and proposed a universal algorithm for constructing a navigation route in narrow channels of the sea. Modeling and testing have demonstrated that correctly selected empirical parameters enable the algorithm to quickly construct a safe route in any navigation area with relatively little computational complexity.

References
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