

Sailing Vessel Routing Considering Safety Zone and Penalty Time for Altering Course

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ABSTRACT: In this paper we introduce new model for simulation sea vessel routing. Besides a vessel types (polar diagram) and weather forecast, travel security and the number of maneuvers are considered. Based on these data both the minimal travelling costs and the minimal processing time are found for different vessels and different routes. To test our model the applications SailingAssistance was improved. The obtained results shows that we can obtain quite acceptable results.

1 INTRODUCTION

In sailing regattas the success is impacted by crew and sailing vessel parameters. The role of crew is in making decisions to choose suitable directions of sailing, according with weather conditions and sea state. Experience and knowledge of crew are very useful in decision-making, but through time appear solutions that help make the decision. In the last article (Życzkowski, 2016) presented a short review of sailboat routing. Current solutions include e-navigation aspect (Weintrit & Wawruch, 2007) to support the decision to choose the appropriate sailing route. However, some facts are noteworthy, the big regatta yachts such as in the America's Cup, Cowes Races whether Mug Races, have possibility to optimize sailing routes. However the required data and optimization algorithms are not available for sailing society. Lack of sailing vessel parameters for scientists is an impediment. Despite these difficulties in the articles you can find a variety of approaches in the search for the optimal route (Philpott, Sullivan, & Jackson, 1993), (Verwerft & Keuning, 2008), (Dębski, 2016). In this article sailing vessel parameters are achieved due to a simulation modeling of two boats.

However, other result of different vessel modelling can be also used.

The aim of this work is consideration of new different sailing criteria than in the last article (Życzkowski, 2016), which are presented in the following section.

2 OPTIMISATION PROBLEM

The aim of the research is to propose a method, which finds optimal sailing vessel route according to specified criteria, while satisfying given constraints.

The first criteria is taking account of navigation safety in the vicinity of shore and isolated danger marks and all dangerous situations, according with COLREGS and good marine practice (COLREGS, 1972), (Jurdziński, 2003). The second criteria is a penalty time for altering course which increased the total time of the voyage.

Further considerations take into account the impact of these factors on the optimization criterion.

position $P_k = P_{ij}$ and one of next positions $P_{k+1} = P_{i+1, j+1}$. To optimize the next vessel movement to two known criteria such as the weather forecast in points P_k and P_{k+1} and the polar diagram of specific sailing vessel (Stelzer & Jafarmadar, 2012) must be taken into account. These possibilities were implemented in SailingAssistance application (Życzkowski, 2016). Additionally two new criteria can be added: the safety zone and penalty time of the current vessel movement. Moreover we can also consider the possible number of vessel flow direction from point P_k to P_{k+1} . In practice is determined by coefficient wr , which can be one of three values: 8, 16, 32. In further consideration we assume the ambition value $wr = 32$. The penalty time of vessel maneuver from point P_k to point P_{k+1} can be corresponded to angle Ω determined by three vessel positions in points: P_{k-1}, P_k, P_{k+1} (see Figure 3). In the further considerations it is assumed that difficulty of maneuver execution corresponding to value of angle Ω . If angle Ω is higher than difficulty of maneuver is also higher and takes more time. Such time delay can be evaluated by formula (3).

$$\text{PenaltyTime}(P_{k-1}, P_k, P_{k+1}) \quad (3)$$

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{
  X= Pk; Y= Pk-1; Z= Pk+1;
   $\Omega = 180^\circ - \cos^{-1} \frac{\overline{XY} \circ \overline{XZ}}{|\overline{XY}| |\overline{XZ}|}$ 
   $\Omega = \left[ \frac{\Omega \cdot 360}{wr} \right]$ 
  if ( $\Omega > 0.5 * wr$ )
     $\Omega = 0.5 * wr - \Omega \% (0.25 * wr)$ 
  return timeTochangeCourse =  $\Omega * p$ ;
}

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where p be specific coefficient following from characteristics of a sailing vessel. If considered points existing on boundary of basic and safety zone the required calculations of the above parameters are more complicated.

To calculate the next acceptable direction of vessel sailing we consider all possible maneuvers for different possible points P_{k+1} . For each of them we calculate also possible values of penalties time for altering course. Taking into the polar diagram of the sailing vessel and current weather in these points we can evaluate admissible maneuvers basic on algorithm calculating the optimal safety route (Stelzer, 2012). This can be printed out by SailingAssistance. application.

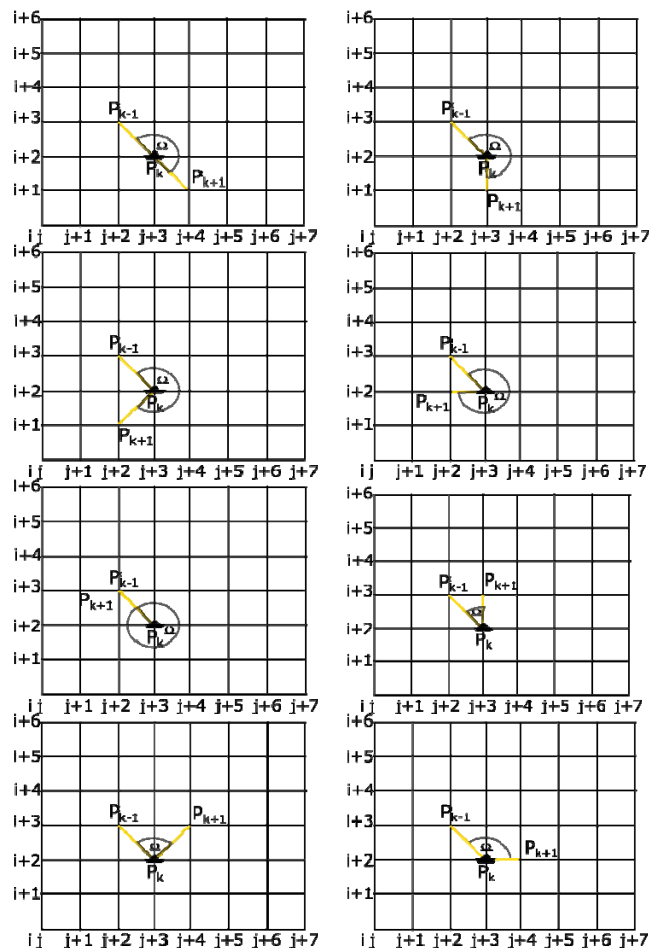


Figure 3 Penalty time for altering course, where possible sailing movement $wr = 8$. Sailing vessel is coming from P_{k-1} to P_k and following to P_{k+1} . For $wr = 8$ sailing vessel possible movement. From picture on the top right to down left : Ω is $0^\circ, 45^\circ, 90^\circ, 135^\circ, 180^\circ, 225^\circ, 270^\circ, 315^\circ$ and penalty time at $p=1$ equals : $0, 4.5', 9', 13.5', 18', 13.5', 9', 4.5'$.

3 ENLARGMENT OF FUNCTIONALITY OF SAILINGASSISTANCE APPLICATION

The present architecture of the application SailingAssistance is shown in Figure 4. It consists of three layers: USERS responsible for cooperation with sailors, ROUTE determining the fast and safety route, DATA allowing to collect the required set of data. Each layer consists of many functions, which some of them are shown in Table 1. Such architecture is flexible and allows to make further modifications.

USER
ROUTE
DATA

Figure 4. SailingAssistance layer structure application

Table 1. SailingAssistance functions.

Function	Layer	Description
Input(SV, A, B, cr)	DATA	Start point A, finish point B, sailing vessel SV, cr criteria fixed.
Create(OB, m, n)	DATA	Create $m \cdot n$ grid of OB specific area.
ChangePD(PD)	DATA	Polar diagram PD transformation to matrix C_{ab}
Area(P_{ij}, t)	DATA	Read area state in P_{ij} point at t time, ie. $S(P_{ij}, t) = Area(P_{ij}, t)$ for $i = 1, 2, \dots, m$; for $j = 1, 2, \dots, n$.
Object (P_{ij}, t)	DATA	Determine object state in point $P_k = P_{ij}$
CreateRoute (A,B,wr,t)	ROUTE	Implementation of Dijkstra's algorithm (Dijkstra, 1959) (Neumann, 2014) for graph G (V, E, O, S) with fixed Parameters (a variant of movement w_r , and with a predetermined criteria. The result is a list of waypoints from start point A to finish point B.
TimeTo(P_k, P_{k+1})	ROUTE	Time from P_k to P_{k+1} , (potential next point in defined route.)
IncGranularity(R, s)	DATA	Increase granularity in safety zone, R is safety zone radius with coefficient s.
PenaltyTime (P_{k-1}, P_k, P_{k+1})	ROUTE	Calculate penalty time for altering course during searching another waypoints.
Display (chart, route)	USER	Display on assumed chart waypoints of designated route

4 THE RESULTS FOR TWO SAILING VESSELS OBTAINED

SailingAssistance application carries out tests for two specific sailing vessels: Conrad and Oceania. Some technical details for these boats are in Table 2.

Table 2. Technical details of Conrad 1200 RT and R/S Oceania

Parameters	CONRAD 1200 RT	R/S *OCEANIA*
Sail area [m ²]	80	520
Sail type	Bermuda rig	Sch. 3 masted
Length [m]	12.00	48.50
Beam [m]	4.04	9.00
Draught [m]	2	3.60
Free board [m]	1.08	2.00
Waterplane [m ²]	32.889	430.133
Lwl/Bwl [-]	3.161	4.711
Bwl/T [-]	4.844	3.000

SAS_VPPN.v03 program (developed in The Faculty of Ocean Engineering) has been used to create a polar diagram based knowledge of sailing vessel design details. The result of program are presented below as Table 3. It is fragment of polar diagram of sailing vessel Conrad. The first row means wind speed equals 1 knot, the second equals 2 knots, the first column means sailing direction equals N, the second NbE at true wind from N. During testing we used the followings settings: granularity gr_1 is equal 293

10^{-6} for 42 n points and 84 m points. The dedicated area is designed by rectangle $\varphi_{min}(\lambda_{min}) = 54.217$ N (18.069 E) and $\varphi_{max}(\lambda_{max}) = 54.936$ N(19.508 E), and granularity gr_2 is equal 73 10^{-6} for 168 n points and 84 m points variants of sailing vessel movement $w_r = 32$. Start point A is $\varphi_A(\lambda_A) = 54.65$ N(19.21 E) and end point B is $\varphi_B(\lambda_B) = 54.60$ N(18.60 E). We measured such parameters: ω number of changes course (if $P_{k-1} P_k P_{k+1}$ is not one straight line then $\omega = \omega + 1$), route time T and the distance voyage D, number of point P_k on designated route and time of work procedure to find route. All simulation results are in Table 4. and are illustrated in Figure 5 to Figure 8 (only Conrad sailing vessel route on chart).

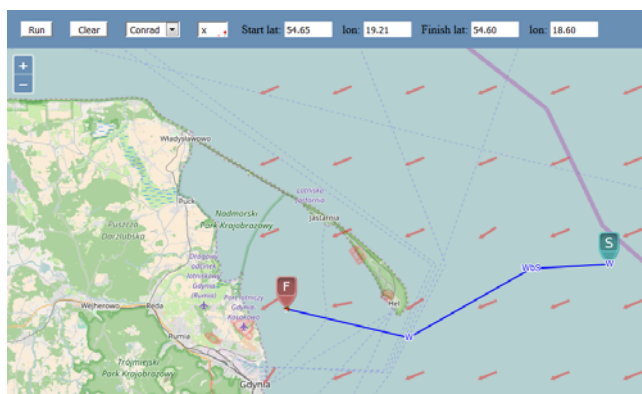


Figure 5. Conrad sailing route for parameters gr_2 po

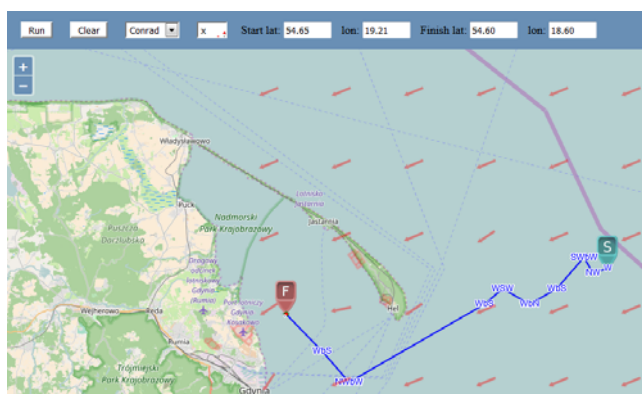


Figure 6. Conrad sailing route for parameters gr_1 p1

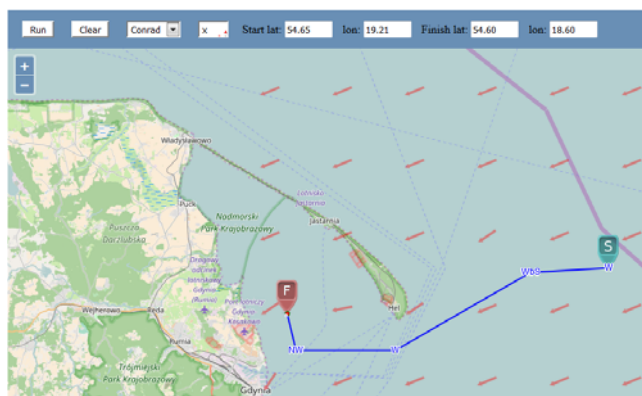


Figure 7. Conrad sailing route for parameters gr_1 po

Table 3. Fragment of polar diagram of sailing vessel Conrad.

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	1.05	2.00	2.96	3.61	4.03	4.31	4.39	4.22	3.92	3.46	2.99	2.46	2.08	1.99	
0	0	0	1.48	2.52	3.57	4.32	4.80	5.11	5.19	5.03	4.70	4.19	3.63	2.98	2.60	2.50	
0	0	0	1.92	3.05	4.18	5.02	5.57	5.91	5.99	5.84	5.48	4.93	4.28	3.50	3.11	3.01	
0	0	0	2.35	3.57	4.79	5.54	6.05	6.33	6.40	6.29	6.01	5.53	4.89	4.02	3.59	3.48	
0	0	0	2.46	3.82	5.17	6.05	6.52	6.75	6.81	6.74	6.53	6.13	5.49	4.54	4.07	3.95	
0	0	0	2.94	4.25	5.55	6.34	6.78	6.99	7.06	7.00	6.83	6.49	5.95	5.04	4.53	4.39	
0	0	0	3.04	4.46	5.88	6.64	7.04	7.24	7.31	7.27	7.12	6.85	6.42	5.54	4.99	4.84	
0	0	0	3.43	4.82	6.21	6.83	7.21	7.42	7.51	7.48	7.35	7.09	6.68	5.92	5.43	5.28	
0	0	0	3.53	4.93	6.34	7.01	7.39	7.61	7.71	7.70	7.57	7.34	6.94	6.31	5.86	5.71	

Table 4 The result of testing of searching sailing route for two sailing vessel depends on penalty time for altering course(p1) or without penalty (p0), lower(gr1) or higher(gr2) granularity, Start point A is $\varphi_A(\lambda_A) = 54.65\text{ N}(19.21\text{ E})$ and end point B is $\varphi_B(\lambda_B) = 54.60\text{ N}(18.60\text{ E})$.

Parameters	CONRAD 1200 RT					R/S OCEANIA		
	gr1 p0	gr2 p0	gr1 p0	gr1 p1	gr1 p0	gr2 p0	gr1 p1	gr2 p1
Route time T [h]	6.22	6.20	7.17	7.12	6.21	6.19	7.30	7.25
Overall distance D [NM]	38.69	38.58	41.89	41.64	38.55	38.35	40.24	39.82
Sum up penalties time to for altering course [h]	0	0	0.68	0.70	0	0	0.81	0.75
Number of Course Changes ω [-]	5	4	10	16	5	5	11	18
The number of P_k points on route [-]	27	54	15	29	28	58	15	28
Processing time to find the route from point A to point B [s]	0.93	1.91	1.06	1.91	0.80	1.54	0.96	1.52

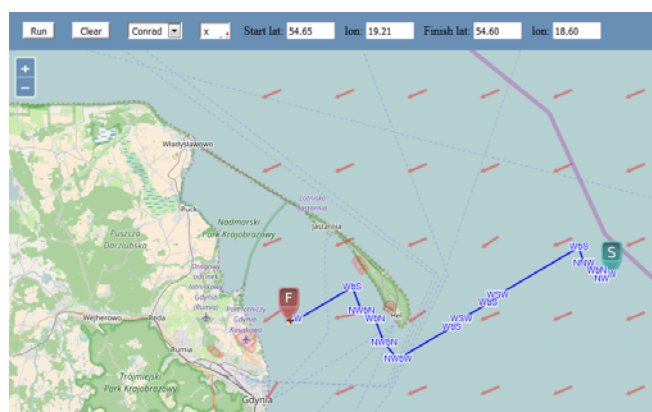


Figure 8. Conrad sailing route for parameters gr2 p1

5 CONCLUSIONS

Modeling of the sailing vessel depends on many factors, but mainly PD, which are difficult to access. The accuracy of PD depends on maneuvers, and consequently the travel time. An important role is played by a granularity of area, which allows a new look at safety as well as the need to modify the algorithms on the border between the two zones: basic and safety. To analyzed more practical situations of vessel sailing the application SailingAssistance were improved and examples of travels modelling of two vessels for different conditions are considered. The paper presents several experiments that confirm the correctness of the developed algorithms and confirm the usefulness of SailingAssistance application.

Of course there is the opportunity to further develop these algorithms in order to strive to

optimize travel time. If knowledge about sailing vessels is deeper, weather forecasting is more true, and sea area description is more realistic our modelling results can be more useful for real user competition.

ACKNOWLEDGEMENTS

The author would like to thank Bogusław Oleksiewicz for providing ship models generated by means of "SAS_VPPN.v03" research software.

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