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Ship anti-collision,
evolutionary algorithms

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EVOLUTIONARY SETS OF SAFE SHIP TRAJECTORIES: SIMULATION RESULTS

The Evolutionary Sets of Safe Ship Trajectories is a method solving multi-ship encounter situations. For given positions and motion parameters the method finds a near optimal set of safe trajectories of all ships involved in an encounter. The paper briefly presents foundations of the method and focuses on simulation results for selected test cases based on the Baltic Basin. The computer simulations cover both open waters and restricted waters cases. The obtained results confirm correctness and aptness of the method in solving encounter situations at sea.

EWOLUCYJNE ZBIORY BEZPIECZNYCH TRAJEKTORII STATKU: WYNIKI SYMULACYJNE

Metoda ewolucyjnych zbiorów bezpiecznych trajektorii statku służy rozwiązywaniu sytuacji kolizyjnych wielu statków na morzu. Dla znanych pozycji oraz parametrów ruchu metoda znajduje optymalny zbiór bezpiecznych trajektorii dla wszystkich statków biorących udział w spotkaniu. W artykule pokrótce zaprezentowano główne założenia metody i skupiono się na wynikach symulacyjnych uzyskanych w trakcie badań dla wybranych rejonów Morza Bałtyckiego. Przedstawione przykłady przedstawiają sytuacje spotkań na wodach otwartych oraz ograniczonych. Uzyskane wyniki badań potwierdzają poprawność oraz i trafność opisywanej metody w rozwiązywaniu sytuacji kolizyjnych na morzu.

1. INTRODUCTION

Multi-ship encounter situations take place when three or more ships are approaching the same open or restricted water region with headings posing a threat of collision. In such cases general COLREGS [1] rules no longer provide strict anti-collision regulation for the entire set of ships in the encounter. However, still the rules may and should be considered by every ship in the set. This makes the process of planning safe trajectories of all the ships in the encounter complex.

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In general, methods that plan safe ship trajectories in multi-ship encounter situation can be dived into two categories. These are methods based on either differential games or on evolutionary programming. The former (eg. [2]) assume that the process of steering a ship in multi-ship encounter situations can be modelled as a differential game played by all ships involved, each having their strategies. Unfortunately, high computational complexity is its serious drawback. The latter approach is the evolutionary method of finding the trajectory of the own ship (e.g. [3]). In short, the evolutionary method uses genetic algorithms, which, for a given set of pre-determined input trajectories find a solution that is optimal according to a given fitness function. However, the method's limitation is that it assumes targets motion parameters not to change and if they do change, the own trajectory has to be recomputed.

Therefore, the authors have proposed a new approach, which combines some of the advantages of both methods: the low computational time, supporting all domain models and handling stationary obstacles (all typical for evolutionary method), with taking into account the changes of motion parameters (changing strategies of the players involved in a game). Instead of finding the optimal own trajectory for the unchanged courses and speeds of targets, an optimal set of safe trajectories of all ships involved is searched for. The method is called evolutionary sets of safe trajectories and has been already presented in [4]. Applying COLREGS to the method has been already described by the authors in [5].

The method is based on population evolution, where an individual is a set of trajectories (one trajectory for each ship in the encounter). During the evolutionary process, customized for the considered multi-ship encounter problem as described in [4, 5, 6], the individuals are optimized to fulfil the following conditions:

- none of the stationary constraints are to be violated,
- none of the ship domains are to be violated,
- the acceptable course alteration is between 15 and 60 degrees,
- speed alteration are not to be applied unless necessary,
- a ship only manoeuvres, when it is obliged to,
- manoeuvres to starboard are favoured over manoeuvres to port board.

The optimization is performed here for a single-criterion goal function, which depends strictly on a way loss ratio ([4]). When evolutionary process ends its computations the best individual (with the highest fitness value) becomes the resulting set of trajectories.

A software simulation tool implementing the method has been constructed by the authors. Using this tool, comprehensive simulation tests of the method for both open and restricted waters have been conducted and described later in the paper. Section 2 presents the results for open water test cases, divided into basic scenarios (a three-ship encounter per scenario) and complex ones (a six-ship encounter per scenario). In section 3 the results for restricted waters are presented, divided similarly into basic and complex scenarios. The method's summary and conclusions are given in Section 4.

2. SIMULATION RESULTS FOR OPEN WATERS

The following subsections present simulation test results obtained with the software tool for sample open water Baltic Sea regions. There are two basic scenarios with 3-ship encounters and one complex scenario having 6-ship encounter.

2.1 Open water basic scenario *#1*

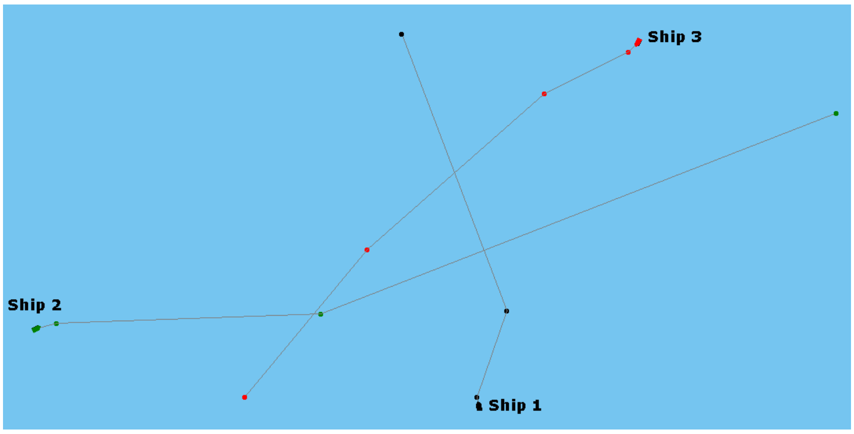

Fig. 1 Open water basic scenario #1 – simulation starting screenshot

Tab. 1 Open water basic scenario #1 – ship positions & resulting fitness values

	Origin position	Destination position	V [kn]	Resulting trajectory fitness value [/]	Resulting general fitness value [/]
Ship 1	20° 34’ 10” E 58° 24’ 29” N	20° 31’ 37” E 58° 36’ 46” E	11.46	0.9595	0.9796
Ship 2	20° 19’ 34” E 58° 27’ 02” N	20° 45’ 58” E 58° 34’ 09” N	14.42	0.9842	
Ship 3	20° 39’ 26” E 58° 36’ 29” N	20° 26’ 27” E 58° 24’ 47” N	12.55	0.9726	

In the scenario presented in Figure 1 all three ships have similar situation of having one ship starboard and one port-board. Thus all these ships have to manoeuvre as follows: ship 1 gives way to ship 3, ship 3 gives way to ship 2 and ship 2 gives way to ship 1. The resulting trajectories assure that all the ships manoeuvre safely and there are no ahead crossings. Due to the specific positions and speeds (Table 2) ship 1 has the largest (the smallest fitness value) and ship 2 the smallest way loss (the largest fitness value).

2.2 Open water basic scenario *#2*

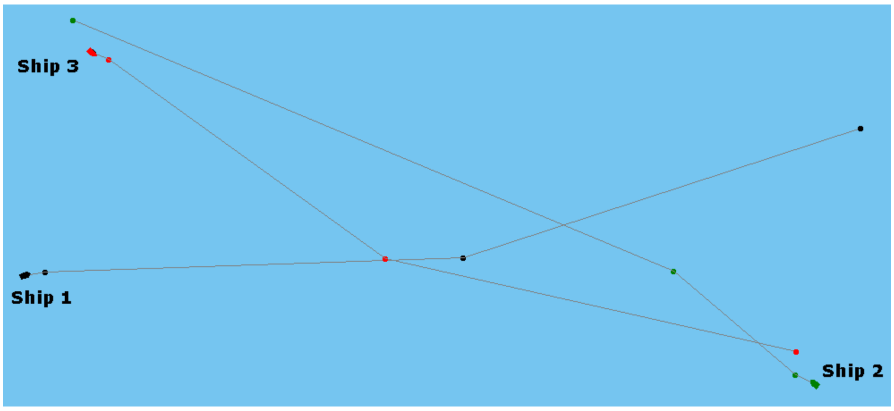

Fig. 2 Open water basic scenario #2 – simulation starting screenshot

Tab. 2 Open water basic scenario #2 – ship positions & resulting fitness values

	Origin position	**Destination position**	**V [kn]**	**Resulting trajectory fitness value [/]**	**Resulting general fitness value [/]**
Ship 1	20° 20' 45" E 58° 28' 28" N	20° 44' 57" E 58° 32' 45" N	12.41	0.9806	0.9821
Ship 2	20° 43' 35" E 58° 25' 21" N	20° 22' 08" E 58° 35' 53" N	14.28	0.9856	
Ship 3	20° 22' 41" E 58° 34' 58" N	20° 43' 05" E 58° 26' 17" N	12.77	0.9591	

In the scenario presented in Figure 2 ship 2 & ship 3 have a head-on encounter while crossing with ship 1. Thus, ship 2 & ship 3 should alter their courses to starboard. Additionally ship 3 should give way to ship 1, while ship 1 should give way to ship 2. The resulting trajectories assure that all the restrictions are met and again there is no ahead crossing. In this situation (Table 2) ship 3 has to take a roundabout way resulting in the largest way loss (smallest fitness value).

2.3 Open water complex scenario

In the scenario presented in Figure 3 (with ship positions given in Table 3) there is a single ship (ship 1) crossing with two group of ships, namely:

- first group formed by ship 2, ship 3 and ship 4,
- second group formed by ship 5 and ship 6.

Ship 1 is a give-way vessel only to the first group of ships, thus it performs a substantial starboard course alteration to avoid ahead crossing. Ships 2, 3 & 4 are stand-on vessels (having no other vessels to their starboard) and due to that their courses remain unchanged until reaching their destination positions (maximum possible trajectory fitness value of 1.0). Unlike group 1, ships 5 & 6 from group 2 must give way to both ship 1 and group 1 ships. Due to mutual relation between origin and destination positions of ship 5 and ship 6 the former alters her course to port board, while the latter – to starboard. This way ship 5 reaches her destination safely bypassing ships 1, 2, 3 & 4 ahead with substantial distance to the ships. On the other hand, ship 6 avoids ahead crossing by her starboard maneuver. If both ship 5 & ship 6 changed courses to starboard, ship 6 would be forced to perform a larger alteration and the resulting way loss of the ships would be greater.

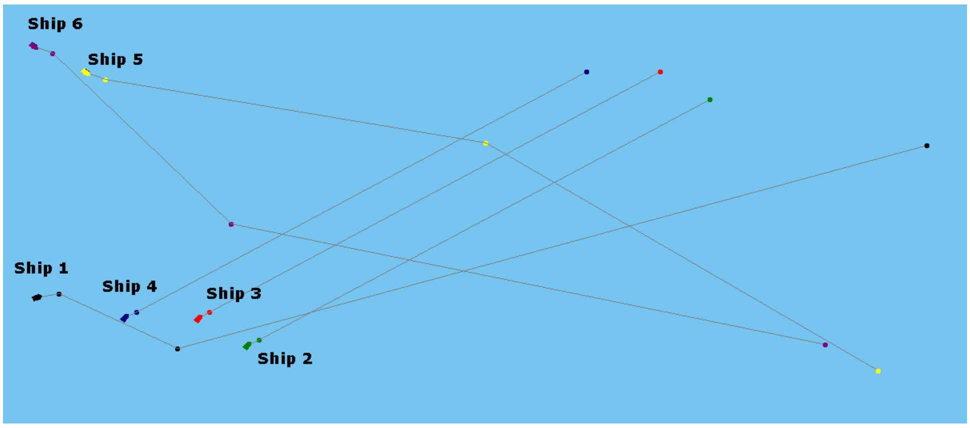

Fig. 3 Open water complex scenario – simulation starting screenshot

Tab. 3 Open water complex scenario – ship positions & resulting fitness values

	Origin position	Destination position	V [kn]	Resulting trajectory fitness value [/]	Resulting general fitness value [/]
Ship 1	20° 18’ 29” E 58° 28’ 08” N	20° 47’ 17” E 58° 33’ 06” N	14.73	0.9275	0.9872
Ship 2	20° 25’ 17” E 58° 26’ 34” N	20° 40’ 14” E 58° 34’ 37” N	10.41	1.0000	
Ship 3	20° 23’ 42” E 58° 27’ 27” N	20° 38’ 39” E 58° 35’ 30” N	10.41	1.0000	
Ship 4	20° 21’ 20” E 58° 27’ 28” N	20° 36’ 16” E 58° 35’ 31” N	10.41	1.0000	
Ship 5	20° 20’ 04” E 58° 35’ 30” N	20° 45’ 41” E 58° 25’ 44” N	15.39	0.9575	
Ship 6	20° 18’ 21” E 58° 36’ 21” N	20° 43’ 59” E 58° 26’ 36” N	15.39	0.8984	

3. SIMULATION RESULTS FOR RESTRICTED WATERS

The following subsections present simulation test results obtained with the software tool for sample restricted water Baltic Sea regions. The regions include landmasses surrounded by some non-approachable areas (safety isobates). There are two basic scenarios with 3-ship encounters and one complex scenario having 6-ship encounter.

3.1 Restricted water basic scenario *#1*

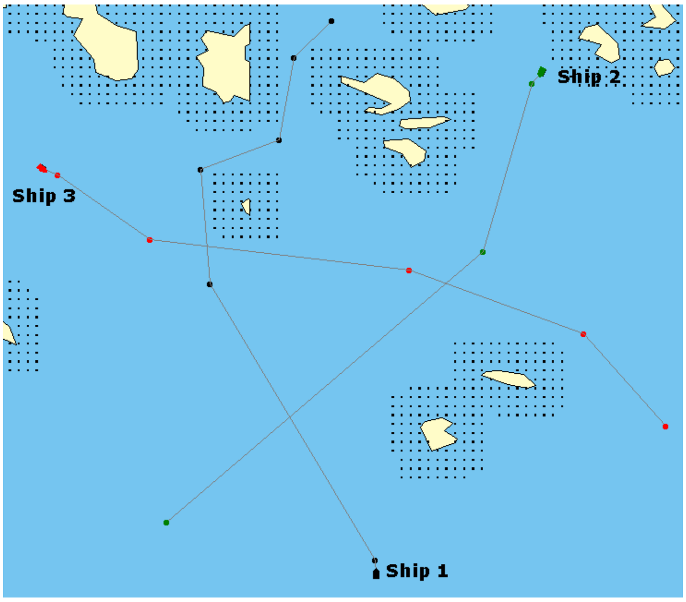

Fig. 4 Restricted water basic scenario #1 – simulation starting screenshot (dotted areas depict non-approachable regions)

Tab. 4 Restricted water basic scenario #1– ship positions & resulting fitness values

	Origin position	**Destination position**	**V [kn]**	**Resulting trajectory fitness value [/]**	**Resulting general fitness value [/]**
Ship 1	21° 03' 33" E 60° 04' 35" N	21° 02' 18" E 60° 20' 05" N	14.39	0.9345	0.9481
Ship 2	21° 08' 11" E 60° 18' 39" N	20° 57' 40" E 60° 06' 02" N	12.78	0.9855	
Ship 3	20° 54' 10" E 60° 15' 57" N	21° 11' 41" E 60° 08' 44" N	10.82	0.9547	

In the scenario presented in Figure 4 (with ship positions given in Table 4) all the ships have one ship starboard and one port board, similar to open water scenario #1, but here ships also have to bypass obstacles (landmasses and areas limited by safety isobate). Ship 1 initially maneuvers to port board, securing safe bypassing of ship 2, ship 3 and obstacle being on her way. Later ship 1 has to change her course three more times to reach her destination hidden behind islands. Ship 2, although having ship 3 on her starboard requires only a small course alteration to port board to safely bypass the other ships. Possible collision threat between ship 2 and ship 3 is diminished also by initial starboard course change of ship 3, made originally due to obstacle bypassing.

3.2 Restricted water basic scenario *#2*

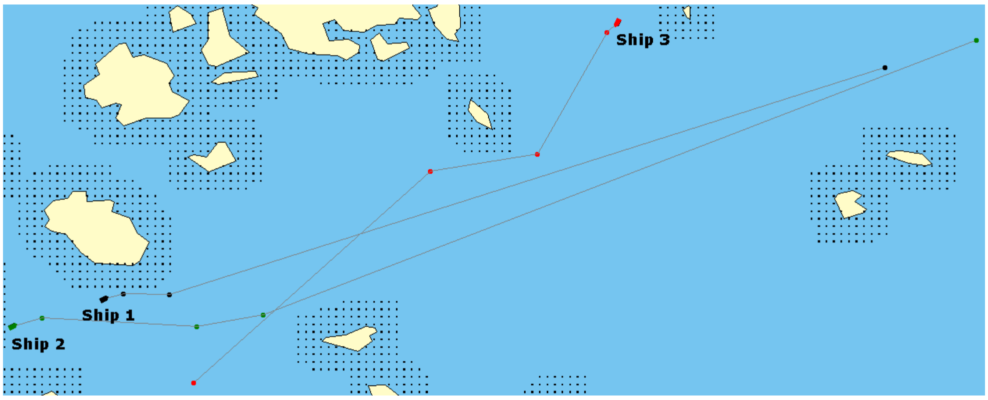

Fig. 5 Restricted water basic scenario #2 – simulation starting screenshot (dotted areas depict non-approachable regions)

Tab. 5 Restricted water basic scenario #2 – ship positions & resulting fitness values

	Origin position	**Destination position**	**V [kn]**	**Resulting trajectory fitness value [/]**	**Resulting general fitness value [/]**
Ship 1	20° 40’ 34” E 60° 05’ 21” N	21° 06’ 28” E 60° 13’ 03” N	14.46	0.9930	0.9716
Ship 2	20° 37’ 32” E 60° 04’ 27” N	21° 09’ 30” E 60° 13’ 57” N	22.05	0.9735	
Ship 3	20° 57’ 36” E 60° 14’ 32” N	20° 43’ 33” E 60° 02’ 36” N	13.00	0.9587	

In the scenario presented in Figure 5 (with ship positions given in Table 5) a group of two ships (ship 1 & ship 2) crosses with ship 3, while in the group ship 1 is overtaken by ship 2. Ship 1 as the stand-on vessel in this case has to perform only a slight starboard alteration to avoid an obstacle and then keeps her course. Ship 2 as the overtaking vessel performs a substantial starboard alteration to safely bypass ship 1. Ship 3 must initially change her course to port board to avoid collision with an obstacle and then gets back to course towards her destination points, having ship 1 and ship 2 safely bypassed astern.

3.3 Restricted water complex scenario

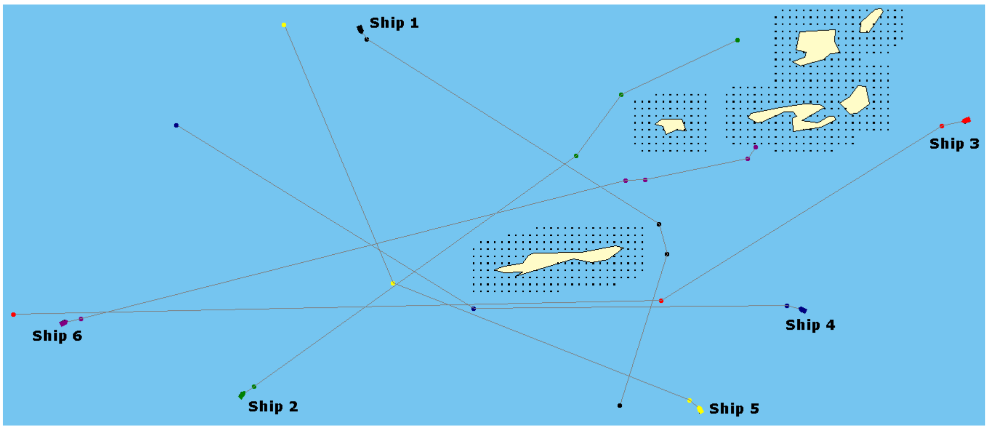

Fig. 6 Restricted water complex scenario – simulation starting screenshot (dotted areas depict non-approachable regions)

Tab. 6 Restricted water complex scenario – ship positions & resulting fitness values

	Origin position	**Destination position**	**V [kn]**	**Resulting trajectory fitness value [/]**	**Resulting general fitness value [/]**
Ship 1	21° 29’ 58” E 59° 58’ 05” N	21° 39’ 13” E 59° 44’ 44” N	13.18	0.9137	0.9565
Ship 2	21° 25’ 45” E 59° 45’ 05” N	21° 43’ 24” E 59° 57’ 44” N	14.54	0.9909	
Ship 3	21° 51’ 33” E 59° 54’ 51” N	21° 17’ 38” E 59° 47’ 58” N	17.67	0.9139	
Ship 4	21° 45’ 43” E 59° 48’ 07” N	21° 23’ 26” E 59° 54’ 42” N	12.43	0.9004	
Ship 5	21° 42’ 05” E 59° 44’ 35” N	21° 27’ 15” E 59° 58’ 17” N	14.61	0.9374	
Ship 6	21° 19’ 24” E 59° 47’ 39” N	21° 44’ 04” E 59° 53’ 56” N	13.32	0.9893	

To facilitate analysis of a scenario presented in Figure 6 (with ship positions given in Table 6) let’s divide the ships as follows:

– ship 3, ship 4 & ship 5, forming group 1, heading westbound,
– ship 2 and ship 6, forming group 2, heading eastbound,
– ship 1 heading southbound.

All group 1 ships must bypass an obstacle and perform this action by port board maneuvers assuring safe astern crossings. In the group 2 alone there a slight crossing threat and ship 2 & ship 6 are forced to minor course amendments. However, still group 2 ships have impact on ship 1 and ship 5 maneuverings. Ship 1 is in the worst situation here: she has to bypass a large obstacle (the same as group 1 & 2 but larger north-southbound than west-eastbound), give way to group 2 ships and make sure her maneuvering won't disturb group 1. Successfully ship 1 makes her so by severe port board course change and astern bypassing trajectories of ship 3, ship 4 and ship 5.

4. SUMMARY & CONCLUSIONS

The paper presents simulation results obtained during test of a method of solving encounter situations – evolutionary sets of safe ship trajectories. The method proves to return safe trajectories which are compliant with international collision avoidance rules ([1]). The trajectories have low way loss, not exceeding 5% way loss for open waters and 9% for restricted waters respectively (for the latter case the way loss is strongly dependent on obstacle positions and concentration). Another advantage of the method is that the trajectories are relatively simple and do not contain unnecessary manoeuvres.

A single test run-time[3] for all the described scenarios varied from 5 sec. for basic open water scenarios up to 26 sec. for complex restricted water ones. Because of its low computational time the method can be applied to on-board collision-avoidance systems and VTS systems. In the former, in case of simple scenarios (where ship priorities are clearly described by COLREGS), the method is able to predict the most probable manoeuvre of a target and plan own ship manoeuvre in advance, so that own manoeuvre could be initiated as soon as the target's manoeuvre is executed. In the latter, due to central planning, it could successfully solve any given scenario involving multiple ships and stationary constraints. The further research on the method is planned and it will focus on VTS-specific issues and on planning ship trajectories on Traffic Separation Schemes with high ship density.

ACKNOWLEDGEMENTS

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5. REFERENCES

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[3] 50 populations run on a standard desktop PC: Intel Pentium D 3.4 GHz, 1 GB RAM

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