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Evolutionary Sets of Cooperating Trajectories in Multi-Ship Encounter Situations - Use Cases

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ABSTRACT: The paper discusses the advantages of a new approach to solving ship encounter situations by combining some of the assumptions of game theory with evolutionary programming techniques. A multi-ship encounter is here modeled as a game played by "thinking players" – the ships of different and possibly changing strategies. The solution – an optimal set of cooperating (non-colliding) trajectories is then found by means of evolutionary algorithms. The paper contains the results obtained for different cases of situations including open waters and restricted water regions and the discussion of these results. The already developed version of the method is fast enough to be applied in the real time on-board collision avoidance systems or VTS systems.

1 INTRODUCTION

The main approaches to the problem of planning optimal ship trajectories in encounter situations are the methods based on either differential games and evolutionary method. The methods based on differential games were introduced by Lisowski (Lisowski, 2005). They 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.

The second approach – the evolutionary method of finding the trajectory of the own ship has been developed by Śmierzchalski (Śmierzchalski, 1998). For a given set of pre-determined trajectories the method finds a safe trajectory, which is optimal according to the fitness function – the optimal safe trajectory. The method's main limitation is that it assumes the target motion parameters not to change and if they do change, the own trajectory has to be recomputed.

The approach proposed here 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). Therefore, instead of finding the optimal own trajectory for the unchanged courses and speeds of the targets, a set of optimal cooperating trajectories of all ships is searched for. The early version of this method has already been described by the author in (Szlapczynski, in press). The method had been successfully implemented and tested and the paper presents some representative simulation results covering different use cases.

The rest of the paper is organized as follows. Section 2 contains simulation parameters and is followed by several types of scenarios, where the proposed method is able to predict the behaviour of targets and plan own collision avoidance manoeuvre in advance, even though sometimes there is seemingly no need to perform a manoeuvre at the moment. These scenarios include the following situations: a target changing its course because of landmass (Section 3), a prioritised target changing its course because of another target (Section 4) and finally multi-ship encounters with all ships manoeuvring to avoid collisions on open waters (Section 5) and restricted area (Section 6). The last section contains the paper's summary and conclusions.

2 SIMULATION PARAMETERS

In the scenarios below each stationary constraint is surrounded by a domain of the size specified by the user; the default safe distance of 0.25 nautical mile has been used. As for ship domains – a Coldwell domain (Coldwell, 1982) has been assumed for all ships. Its default dimensions (used in all scenarios) are given in Table 1.

Table 1 The dimensions of Coldwell domain used in the simulation scenarios

	Ellipse's semi axes [n.m.]	**Domain centre moved from the ship's position**	
		Towards starboard [n.m.]	**Towards bow** [n.m.]
Coldwell domain	0.77 0.33	0.1	0.2

The evolutionary parameters values are listed in Table 2.

Table 2 The evolutionary parameters values used in the simulation scenarios

Number of generations	100
Population size	100
Selection method	Truncation selection with the truncation threshold of 50%
Mutation probability (for a single trajectory)	Depends on the trajectory fitness value (from 0% for perfect trajectories to 100% for unacceptable ones)

3 SCENARIO 1: A TARGET MANOEUVRING TO AVOID COLLISION WITH LANDMASS

The positions, destination points and speeds of the ships are given in Table 3.

Table 3 The motion parameters of both ships

	Speed [knots]	**Course** [degrees]	**Position coordinates at the start time** [n.m.]		**Coordinates of the destination point** [n.m.]	
			x	y	x	y
Own ship	12	90	0	2	10	2
Target 1	12	270	10	3	0	3

The current course of the own ship does not collide with neither the landmass (Figure 1) nor the target ship (Figure 2).

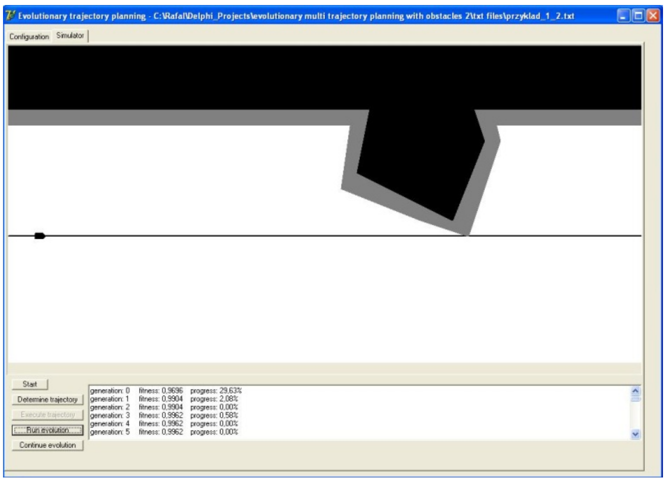

Figure 12 The own ship's current course does not collide with the landmass (black) or its domain (grey).

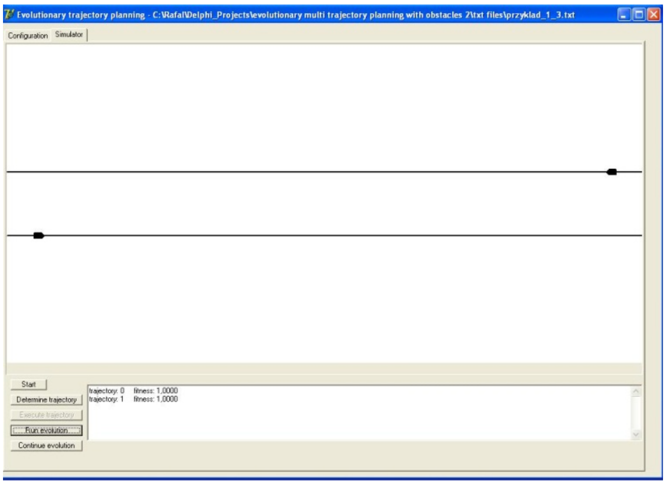

Figure 13 The own ship (left) course does not collide with the current course of the target (right). Landmass is not shown

However, the target's course collides with the landmass and the target will perform a collision avoidance manoeuvre (Figure 3).

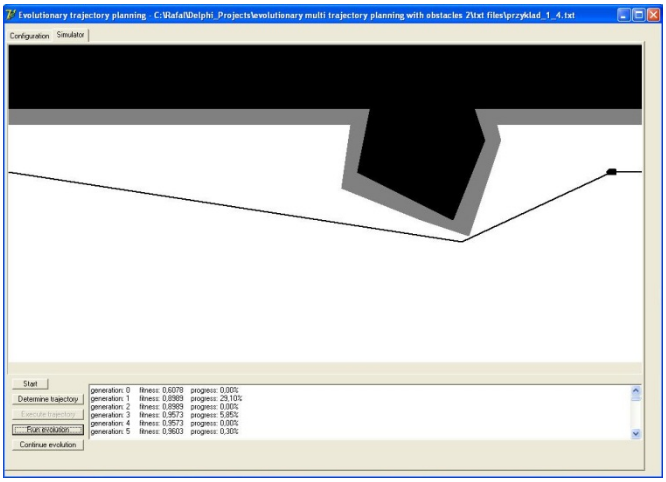

Figure 14 The target's current course collides with the landmass so the target will perform a collision avoidance manoeuvre.

The method predicts the target's manoeuvre and plans the own ship's manoeuvre in advance. The final evolutionary set of two cooperating trajectories of both ships is shown in Figure 4.

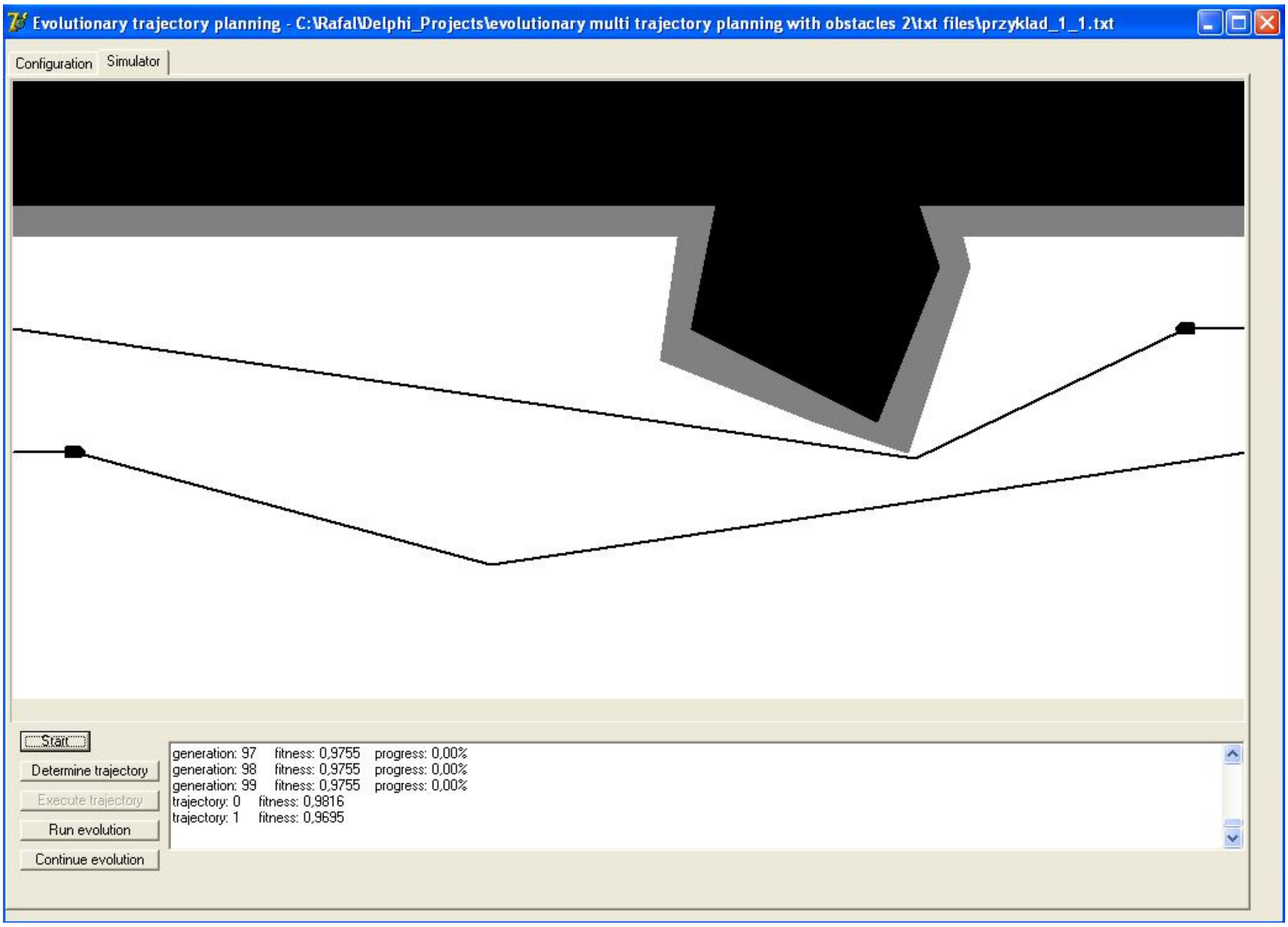

Figure 15 The evolutionary set of the two ships' cooperating trajectories, which avoid collisions with the landmass and each other.

4 SCENARIO 2: A TARGET MANOEUVRING TO AVOID COLLISION WITH ANOTHER TARGET

The positions, destination points and speeds of the ships are given in Table 4.

Table 4 The motion parameters of all ships

	Speed [knots]	**Course** [degrees]	**Position coordinates at the start time** [n.m.]		**Coordinates of the destination point** [n.m.]	
			x	y	x	y
Own ship	12	45	0	0	10	5
Target 1	8	0	5	0	5	5
Target 2	17	270	10	2.5	0	2.5

The current course of the own ship does not collide with neither of the two prioritised ships. The safe trajectories for encounters with either target 1 only or target 2 only are shown in Figure 5 and Figure 6 respectively. As can be seen – no manoeuvres are needed.

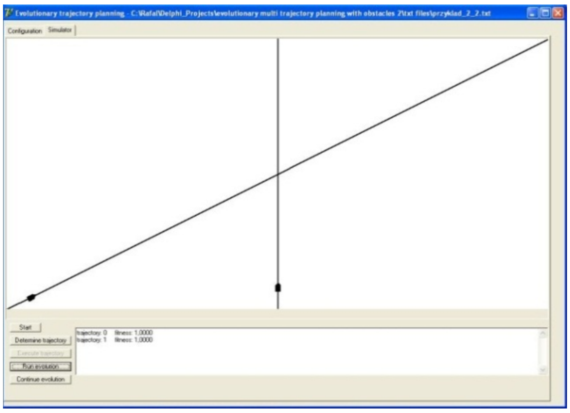

Figure 16 The own ship's current course (left) does not collide with target 1 (right).

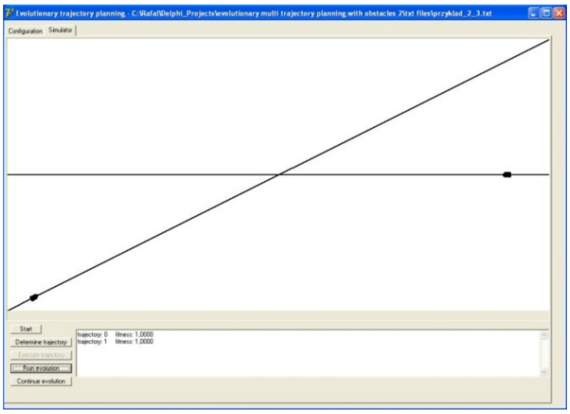

Figure 17 The own ship's current course (left) does not collide with target 2 (right).

However, the first target's course collides with target 2 and the target 2 is a "stand-on vessel" according to COLREGS (Cockcroft, 1993). As a result, the first target will perform a collision avoidance manoeuvre (Figure 7).

The method predicts the manoeuvre of target 2 and plans the own ship's manoeuvre in advance. The final evolutionary set of three cooperating trajectories is shown in Figure 8.

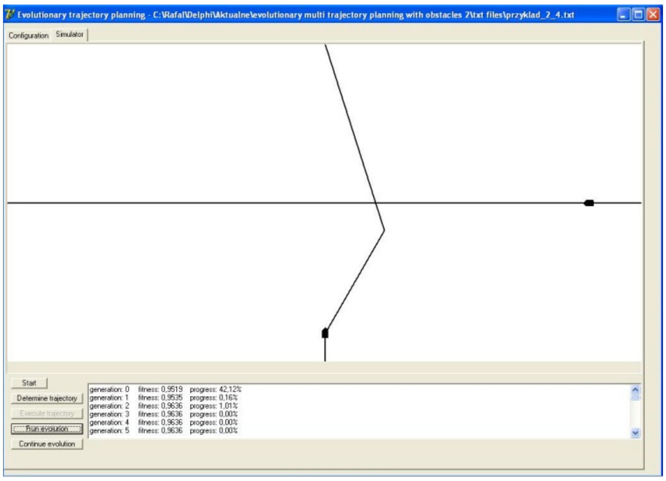

Figure 18 The first target's current course (left) collides with target 2 (right) and target 1 performs collision avoidance manoeuvre.

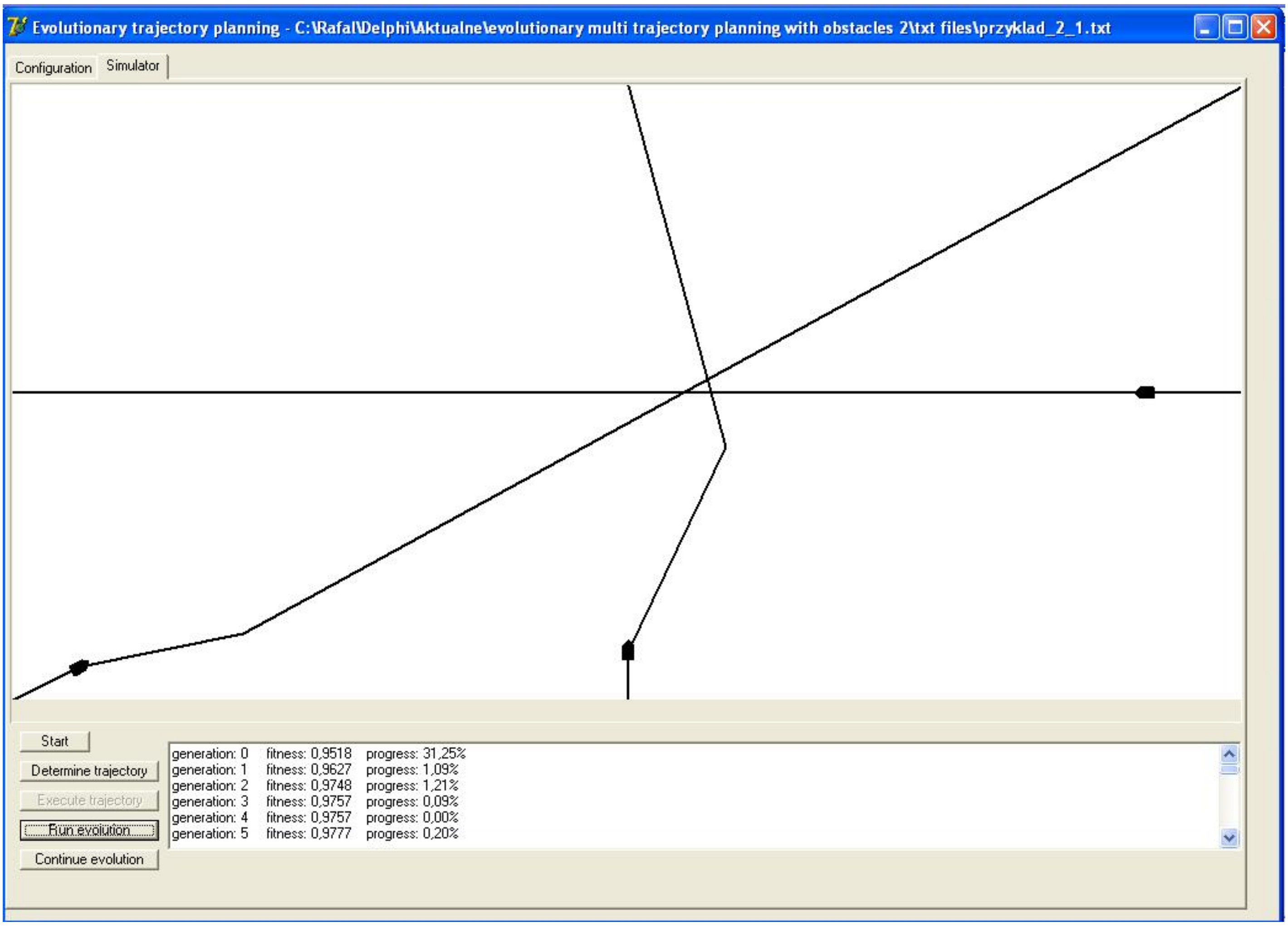

Figure 19 The evolutionary set of the three ships cooperating trajectories, which avoid collisions with each other.

5 SCENARIO 3: A GROUP OF SHIPS MANOEUVRING TO AVOID COLLISIONS WITH EACH OTHER ON OPEN WATERS

The positions, destination points and speeds of the ships are given in Table 5.

The current courses of the ships are such that all of the ships would collide in the central point of the area. The final evolutionary set of the safe co-operating trajectories, which avoid collisions with each other, is shown in Figure 9.

Table 5 The motion parameters of all ships

	Speed [knots]	**Course** [degrees]	**Position coordinates at the start time** [n.m.]		**Coordinates of the destination point** [n.m.]	
			x	y	x	y
Ship 1	5	0	5	0	5	5
Ship 2	14	45	0	0	10	10
Ship 3	10	90	0	2.5	10	2.5
Ship 4	14	135	0	5	10	0
Ship 5	5	180	5	5	5	0
Ship 6	14	225	10	5	0	0
Ship 7	10	270	10	2.5	0	2.5
Ship 8	14	315	0	10	0	5

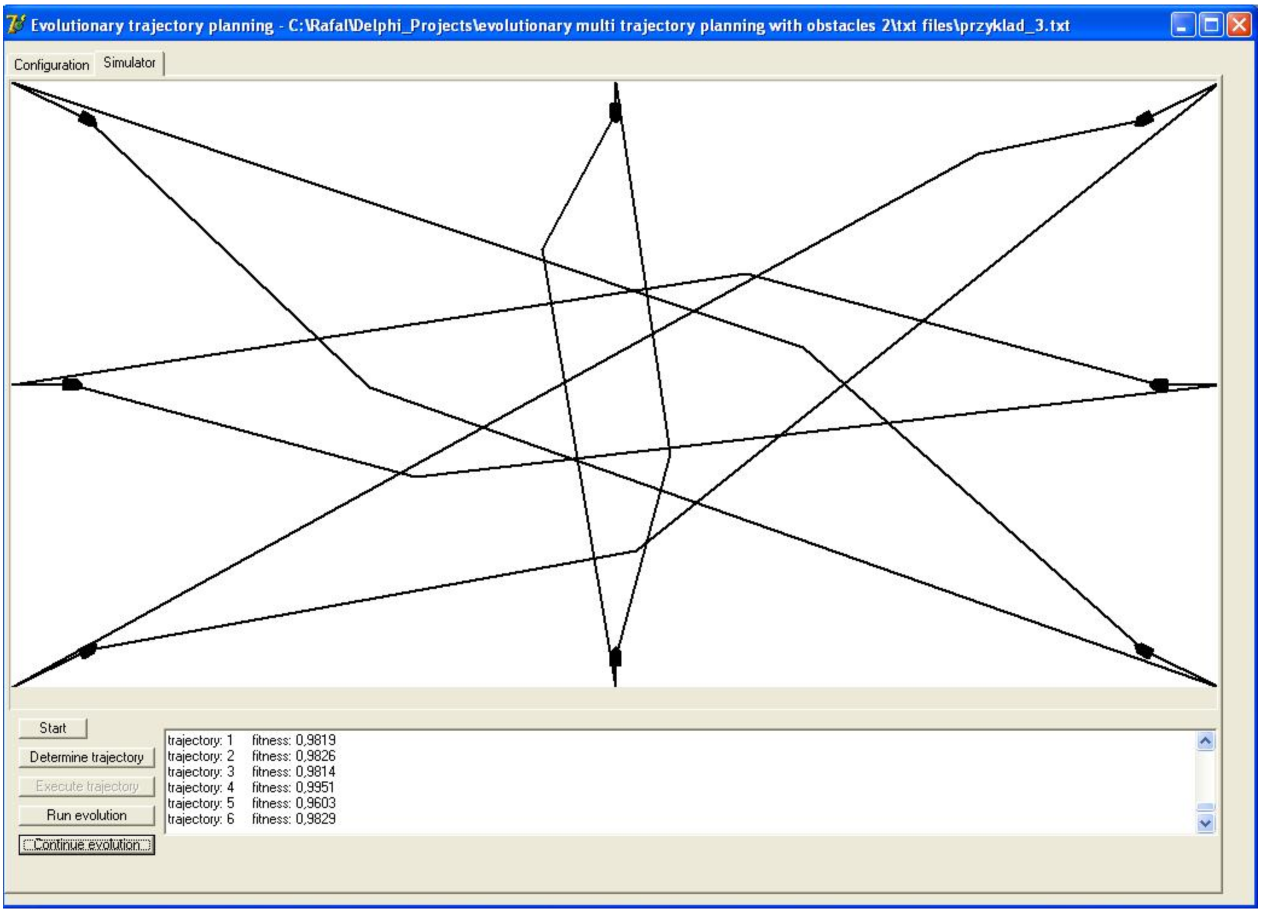

Figure 20 The evolutionary set of the eight ships' cooperating trajectories, which avoid collisions with each other.

6 SCENARIO 4: A GROUP OF SHIPS MANOEUVRING TO AVOID COLLISIONS WITH EACH OTHER AND OBSTACLES

The positions, destination points and speeds of the ships are given in Table 6.

Table 6 The motion parameters of all ships

	Speed [knots]	**Course** [degrees]	**Position coordinates at the start time** [n.m.]		**Coordinates of the destination point** [n.m.]	
			x	y	x	y
Ship 3	10	90	0	2.5	10	2.5
Ship 4	14	135	0	5	10	0
Ship 6	14	225	10	5	0	0
Ship 7	10	270	10	3	0	3

The current courses of all four ships collide with each other or the landmass. The final evolutionary set of four cooperating safe trajectories is shown in Figure 10.

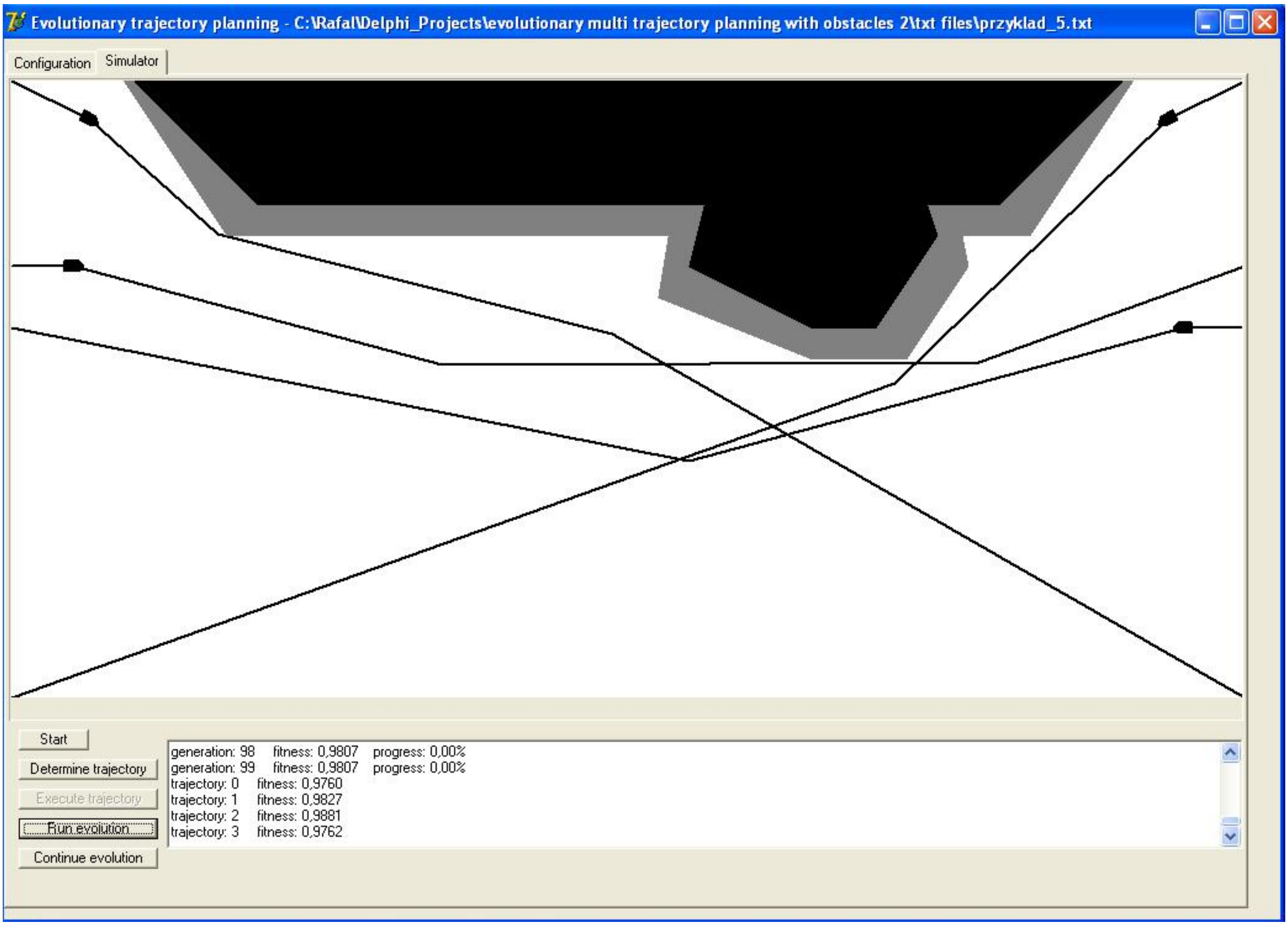

Figure 21 The evolutionary set of the four ships' cooperating trajectories, which avoid collisions with each other and the landmass (landmass in black, landmass domain in grey).

7 SUMMARY AND CONCLUSIONS

In the paper some examples of use of evolutionary approach to solving ship encounter situations have been proposed. This approach is a generalization of evolutionary trajectory determining: a set of trajectories of all ships involved, instead of just the own trajectory, is determined. The method avoids violating the target ship domains and the given stationary constraints, while minimizing way loss and obeying the COLREGS. As has been shown in case of simple scenarios (where ship priorities are clearly described by COLREGS), the method is able to predict the probable manoeuvre of a target and plan own ship manoeuvre in advance. Because of its low computational time the method can be applied to both on-board collision-avoidance systems and VTS systems. In the former it could be used for solving simple scenarios and assessment of more complex ones, in the latter it could successfully solve any given scenario involving multiple ships and stationary constraints.

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