Development of an evolutionary routing algorithm

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1 Introduction, previous work

The planning system described in this section (see figure 1 for a system schematic) is mainly based on the one proposed in [1] successively extended in [2], [3] and [4]. A network of dynamic assets equipped with surveillance sensors (e.g. radar) operates to keep the vessel traffic in a given region of interest (ROI) under control. The problem addressed in this work is the coordination of the network by providing an optimal routing plan with respect to given objectives and given operational constraints for a temporal horizon of few days. Specifically, for the sea counter piracy scenario, this work proposes to improve the vessel traffic surveillance by redirecting the moving assets in those areas of the ROI where there is a lack of information (e.g. lack of satellite AIS coverage) and at the same time favorable METOC conditions for piracy activity. To this purpose, a surveillance risk metric is defined and minimized with respect to asset waypoints and speed. This metric is defined by combining satellite AIS performance predictions and piracy activity group (PAG) maps, predicted by fusing METOC forecasts (see figure 2), together with asset sensor performance. A centralized hierarchical fusion architecture is taken into account in defining the metric [3]. Additional conflicting objectives are also taken into account including asset mission costs and network spatial coverage [3]. The problem is constrained by the asset kinematic and operational limits (such as asset endurance). The optimization problem can be also refined by including spatial and temporal constraints such as denied areas and temporal windows in which an asset is available (this capability is not implemented yet). Given the asset initial states (position, velocity and heading), and the constraints, the optimization provides the optimal set of way points and the speed between consecutive waypoints for the navigation of each asset.

The optimization is carried out by using a state of the art evolutionary multi-objective algorithm. The optimizer simultaneously minimizes (or maximizes) conflicting objectives by implementing the concept of Pareto dominance [5]. The algorithm is able to provide a set of solutions which are distributed on the so called Pareto frontier [5] in the multi-dimensional objective space. These solutions represent the optimal trade-offs among the selected objectives; the user of the system can explore the frontier and choose the solution that best fits his/her preferences depending also on the situation at hand [3].

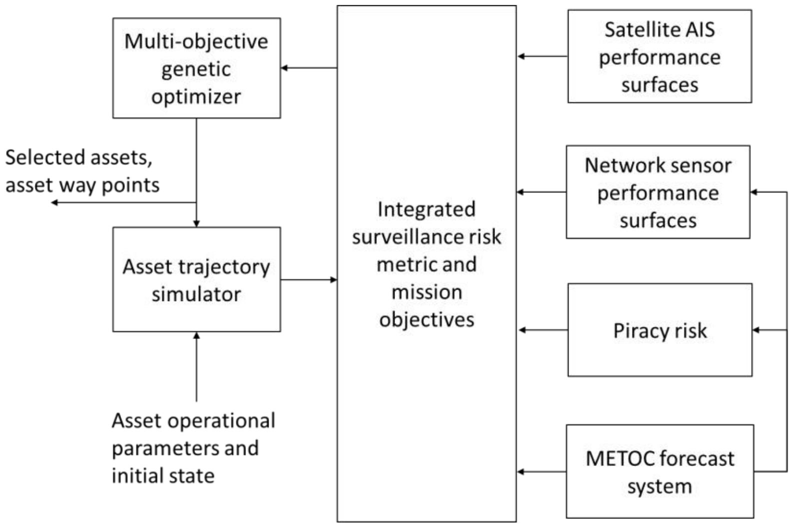


Figure 1: Schematic of the planning system. Predictions of METOC, sensor performance, risk surfaces and simulated asset trajectories are fused to evaluate mission objectives to be optimized by the multi-objective genetic algorithm to provide asset waypoints.

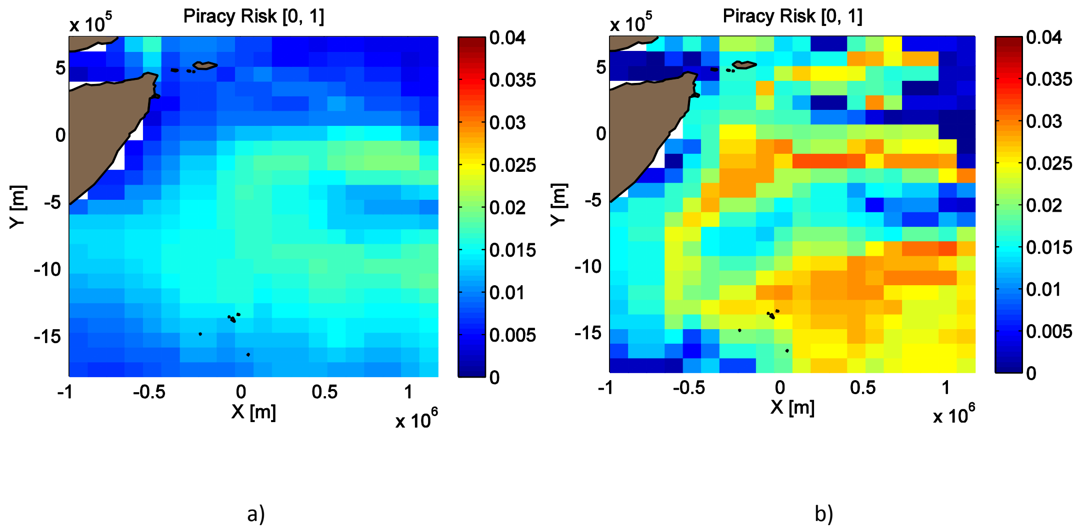


Figure 2: Example of risk map of pirate presence from WAVEWATCH III global model hindcasts. Forecast base time: 10 Oct 2010, 00:00:00Z. Forecasts at a) +00h, b) +72h show increasing risk in the ROI (red color is higher risk than blue).

2 Ship tactical rerouting algorithm.

The system described above can be exploited to provide a tactical ship rerouting algorithm to be used on board a vessel or at a remote command and control center to re-plan the vessel route when sailing through high piracy activity areas in order to reduce the risk of piracy attack. The re-rerouting should optimize the vessel route with respected to estimated risk of piracy attack in the ROI in trade-off with other objectives affecting the journey schedule. In this regard, the approach based on multi-objective optimization is particularly suited to this kind of problems as it is naturally able to provide candidate solutions representing optimal trade-offs among conflicting objectives.

The proposed scenario consists in a vessel following a given pre-planned route. The route is the result of a previous large scale route optimization that minimizes, for example, the total fuel consumption and the time of arrival to the destination port. The vessel entering the ROI needs the route to be re-planned to account for the time and space piracy risk variability due to the dynamic of the METOC conditions over the area. To this purpose, the piracy risk with respect to METOC conditions is first predicted in the ROI, over a time horizon of few days (typically 2 or 3) and then used to calculate a cumulated risk metric along the given route. This value is the reference risk value that is used to define a relative risk metric associated to the new route as the ratio between the risk along the new route and the risk along the reference route. This metric is optimized with respect to the way points and service speed in trade off with relative fuel consumption and relative time of arrival to provide a set of candidate new routes from which choosing the final route.

Figure 3 provides the schematic of the proposed system. The inputs consist in the reference route way points, service speed, fuel consumption and time of arrival, and the forecasts of the piracy risk associated to METOC conditions (2-3 days forecast horizon with a time step of 3h). The system provides a set of solutions, each solution having the associated list of waypoints, the service speed, the relative piracy risk, the relative fuel consumption and the differential time of arrival.

3 Global route planner.

The tactical route planner described in section 2 can be extended at global scale to plan the vessel voyage from the departure harbor to the final destination. The planning is optimized with respect to a reference route. Additional objectives can be considered such as a sea keeping index that can be estimated from METOC data at global scale (using for example forecasts of significant wave height and wind speed). The objectives are evaluated with respect to the reference route as in section 2 (see eq. 1-3).

- Reference route
  - way points
  - service speed
  - fuel consumption
  - time of arrival
- Piracy risk predictions
  (2-3 days, 3h time step)

- Candidate route solutions.
  - way points
  - service speed
  - relative piracy risk
  - relative fuel consumption
  - relative time of arrival

Figure 3: Tactical route planner schematic.

4 Preliminary tests

A first version of the tactical rerouting system is available and is currently under test for further development and improvements. A preliminary version of the global planning system is available as well that needs to be improved for example to add constraints in the route.

Figure 4 shows an example of rerouting plan in the Indian Ocean to avoid high piracy risk areas. The piracy risk map on the right is at +6h since the base time. The picture on the left shows the final Pareto front in the 3D objective space after 30000 iterations of the optimization algorithm. On the right on top the risk map a solution path in blue is compared with the reference route in magenta.

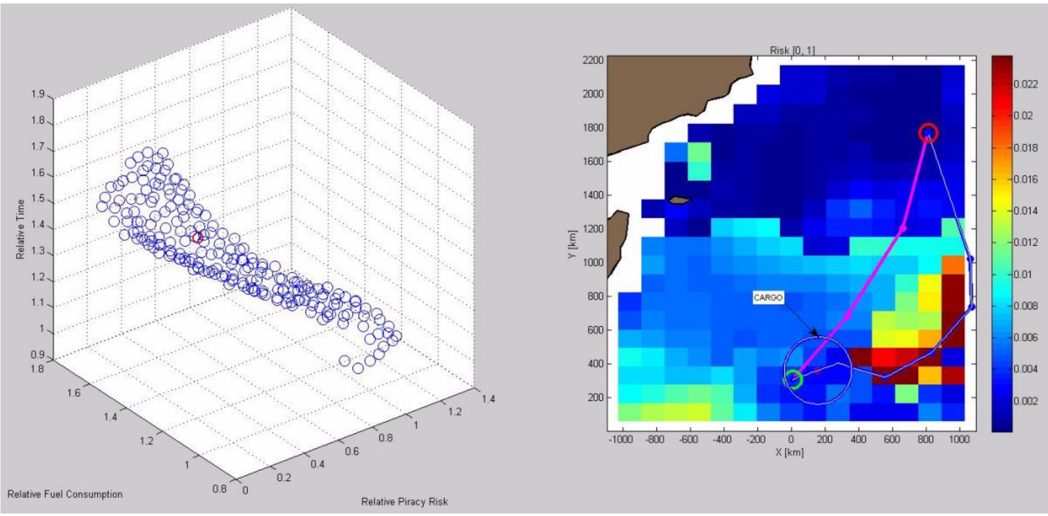
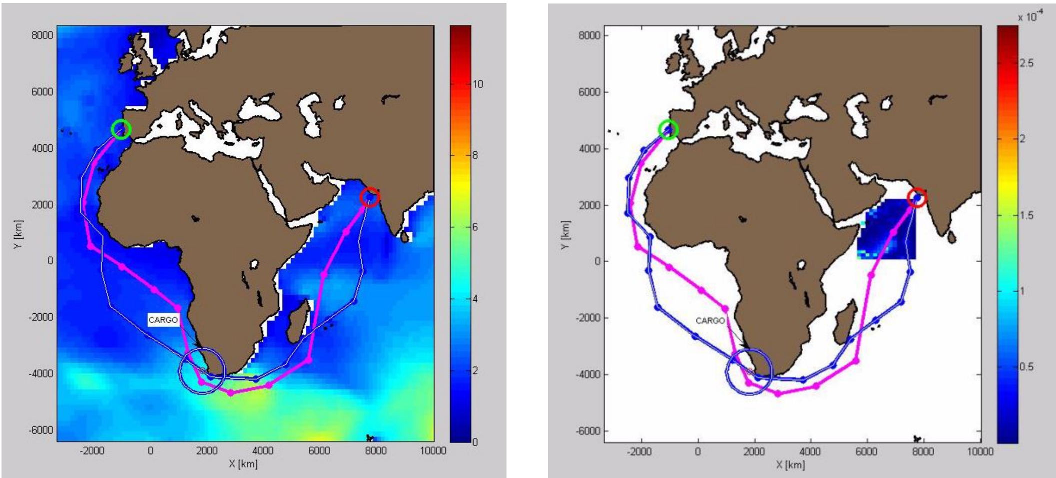


Figure 4: Example of tactical rerouting in the Indian Ocean. The picture on the left shows the final Pareto front in the 3D objective space after 30000 iterations of the optimization algorithm. On the right a solution path in blue compared with the reference route in magenta on the piracy risk map at +6h since the base time.

Figure 5 shows an example of global route planning. In the example provided in figure 5-a), a simple sea keeping index is taken into account in addition to the 3 objectives in eq. 1-3. The index is estimated from significant wave height and wind speed climatological data. The figure shows a map of significant wave height from the WAVEWATCH III hindcast global model with the reference route in magenta and a solution proposed by the planner in blue as an alternative. As depicted in figure 5-b), high piracy risk areas are taken into account by using local piracy risk maps (in the test case the Indian Ocean is considered as the only high risk area).



a) b)

Figure 5: Example of global route plan. A simple sea keeping index is taken into account in addition to the 3 objectives in eq. 1-3. The index is estimated from significant wave height and wind speed climatological data. a) map of significant wave height from the WAVEWATCH III hindcast global model with reference route in magent and a proposed alternative solution in blue. b) high piracy risk areas are taken into account by using local piracy risk maps as showed in the picture for the Indian Ocean.

5 References

[1] Grasso, R., Braca, P., Osler, J., Hansen, J., (2013). Asset network planning: integration of environmental data and sensor performance for counter piracy, 21st European Signal Processing Conference (EUSIPCO), Marrakech, 9-13 Sept., 2013.

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[3] R. Grasso, P. Braca, J. Osler, J. Hansen and P. Willett, (2014). Optimal Asset Network Planning for Counter Piracy Operation Support, Part 1: Under the Hood, IEEE Aerospace and Electronic System Magazine, DOI.No.10.1109/MAES.2014.130181.

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[5] Coello Coello, C., Lamont, G. and Van Veldhuizen, D., “Evolutionary algorithms for solving multi-objective problems,” 2nd edition, Springer, 2007.