ROADEF 2021, Ship route optimization

Maxime Dupuy[1,2], Claudia d'Ambrosio[2], Leo Liberti[2]

[1] D-ICE Engineering, 1 rue de la Noe, 44321 Nantes, France
maxime.dupuy@dice-engineering.com

[2] LIX CNRS, École Polytechnique, Institut Polytechnique de Paris, F-91128 Palaiseau, France
{dupuy,dambrosio,liberti}@@lix.polytechnique.fr

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1 Introduction

Optimizing ship navigation in function of meteorological and oceanographic forecasts is a crucial issue for the marine industry. Depending on the application, some variations of this problem occur. As an example, for racing sailboats the objective is to minimize the travel time while respecting environmental constraints for safety reasons. On the other hand, for merchant ships the objective often is to minimize voyage consumption while respecting a trip duration and maximum ship motions.

Some of the difficulties that arise with the ship weather routing problem are the following. First, ocean is modeled as a continuous space. Then, as ship behavior (speed, consumption, motions) is impacted by weather conditions, the costs to be minimized are time-dependent. Finally, the set of constraints to be respected can be considerably complicated, and also time-dependent.

The ship weather routing problem is a time-dependent shortest path problem, which can have one or multiple objectives.

2 Problem statement

More precisely, considering a vessel moving on the ocean with a set of control variables modeled as scalars (for example heading angle h and engine power p), we can introduce following vectors: the ship position vector $x(t) = [\varphi(t), \lambda(t)]^T$ where φ, λ are respectively ship latitude and longitude at time t, the control vector $u(x,t) = [h(x,t), p(x,t)]^T$, and the environmental conditions vector $e(x,t)$ composed of wind, waves and (ocean) current variables at ship position x and time t. These vectors have admissible values because of the operational constraints. Ship velocity v can be determined with the ship position x, the control vector u and the environmental condition vector e.

Considering a route from a starting position and time (x_s, t_s) to an arrival position and time (x_f, t_f), with $C(u,x)$ being a k-dimensional vector-valued cost function, the route cost vector can be expressed as:

$$J = \int_{t_s}^{t_f} C(u,x)dt \tag{1}$$

The control problem is to find the optimal trajectory $x^*(t)$ and controls $u^*(t)$ that minimize J. When $k > 1$ (multi-objective optimization), we may have conflicting objectives to optimize, so determining optimality may be impossible: instead, we aim at finding a set of *Pareto-optimal* solutions.

3 Discussion

For each variation of the ship weather routing problem, different approaches have been developed in the past decades [8]. For the single objective time-dependent shortest path problem, the isochrone method is the reference [4, 2, 5]. For multi-objective applications, and especially for merchant ships, dynamic programming [9], graph based approaches [7, 1] and evolutionary algorithms [5, 6] are used.

The interest of investigating this topic is that, today, there is no off-the-shelf integrated solution for performing route optimization on either sailing, motor, and hybrid propelled ships. Developing a flexible enough solution is a challenging issue, as these ships may have a different set of control variables, and also have a different sensitivity to the environment. For example, sailing ships as extremely sensitive to wind forecasts and thus may have optimal routes further from the great circle route than a cargo ship. Also, as mentioned before, usual objectives and constraints differ depending on the ship propulsion. This is a subject of importance as wind propulsion solutions are being pushed on the shipping industry by the IMO2020 international regulations [3], to reduce its carbon footprint.

After a short presentation of the issues of ship weather routing, we will discuss the different state-of-the-art methods to solve these variations of the shortest path problem applied to ship weather routing. Then the ongoing works will be presented, among other a graph based approach to solve the time-dependent multi-objective shortest path problem.

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