ROADEF 2023, Multi-objective ship routing

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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 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, the ocean is 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 the 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 [5].

The interest of investigating this topic is that today, there is no off-the-shelf integrated solution for performing route optimization on sailing, motor, and hybrid-propelled ships. This is a subject of importance as wind propulsion solutions are being pushed on the shipping industry by the IMO2020 international regulations [2], to reduce its carbon footprint.

In our work, we are developing a graph-based algorithm, flexible enough to compute multi-objective time-dependent route optimization for any kind of ship. More precisely, we model time as a continuous variable and compute Pareto-optimal paths with a variation of multi-objective shortest path algorithms. For computational efficiency, we apply approximation methods on Pareto fronts and integrate some speed-up techniques.

After a presentation of our algorithm, we will present some computational comparisons with other state-of-the-art methods such as dynamic programming [3] and other graph-based approaches [4, 1]. Then, we will show experimental results that illustrate how considering two control variables simultaneously enhances the performances of ship routing in terms of consumption reduction. This is an important topic as many approaches optimize one control variable after the other.

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