Time-Optimal Multi-Waypoint Mission Planning in Dynamic Flow Fields

by

David Ferris

B.S. Systems Engineering, United States Naval Academy (2008)

Submitted to the Department of Mechanical Engineering
in partial fulfillment of the requirements for the degrees of

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and

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Author . . . .
Department of Mechanical Engineering
May 11, 2018

Certified by. . . . .
Pierre F.J. Lermusiaux
Professor of Mechanical Engineering and Ocean Science and Engineering
Thesis Supervisor

Accepted by . . . .
Rohan Abeyaratne
Chairman, Department Committee on Graduate Theses

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Abstract

This thesis demonstrates the use of exact equations to predict time-optimal mission plans for a marine vehicle that visits a number of locations in a given dynamic ocean current field. The missions demonstrated begin and end in the same location and visit a finite number of locations or waypoints in the minimal time; this problem bears close resemblance to that of the classic "traveling salesman," albeit with the added complexity of a continuously changing flow field. The paths, or "legs," between all goal waypoints are generated by numerically solving exact time-optimal path planning level-set differential equations. The equations grow a reachability front from the starting location in all directions. Whenever the front reaches a waypoint, a new reachability front is immediately started from that location. This process continues until one set of reachability fronts has reached all goal waypoints and has returned to the original location. The time-optimal path for the entire mission is then obtained by trajectory backtracking, going through the optimal set of reachability fields in reverse order. Due to the spatial and temporal dynamics, a varying start time results in different paths and durations for each leg and requires all permutations of travel to be calculated. Even though the method is very efficient and the optimal path can be computed serially in real-time for common naval operations, for additional computational speed, a high-performance computing cluster was used to solve the level set calculations in parallel. This method is first applied to several hypothetical missions. The method and distributed computational solver are then validated for naval applications using an operational multi-resolution ocean modeling system of real-world current fields for the complex Philippines Archipelago region. Because the method calculates the global optimum, it serves two purposes. It can be used in its present form to plan multi-waypoint missions offline in conjunction with a predictive ocean current modeling system, or it can be used as a litmus test for approximate future solutions to the traveling salesman problem in dynamic flow fields.

Thesis Supervisor: Pierre F.J. Lermusiaux
Title: Professor of Mechanical Engineering and Ocean Science and Engineering

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