

Reachability Prediction and Optimal Path Planning for Autonomous Ocean Vehicles

by

Ellen M. Mulé

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Authored by:	Ellen M. Mulé Joint Program in Applied Ocean Science and Engineering, MIT-WHOI August 14, 2025
Certified by:	Pierre F.J. Lermusiaux Professor of Mechanical Engineering and Ocean Science and Engineering, MIT Thesis Supervisor
Accepted by:	Alexandra H. Techet Professor of Mechanical and Ocean Engineering, MIT Chair, Joint Committee for Applied Ocean Science and Engineering
Accepted by:	Nicolas Hadjiconstantinou Professor of Mechanical Engineering, MIT Graduate Officer, Department of Mechanical Engineering

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ABSTRACT

For intelligent ocean exploration and sustainable ocean utilization, the need for smart autonomous underwater vehicles (AUVs), surface craft, and small aircraft is rapidly increasing. Creating time-optimal navigation routes for these vehicles has wide-ranging applications, including ocean data collection, transportation and distribution of goods, naval operations, search and rescue, detecting marine pollution, ocean cleanup, conservation, and solar-wind-wave energy harvesting. In this thesis, we employ the Massachusetts Institute of Technology – Multidisciplinary Simulation, Estimation, and Assimilation Systems (MIT-MSEAS) time-optimal and hazard-time-optimal path planning theory and schemes based on exact Hamilton–Jacobi partial differential equations (PDEs) and Level Set methods. We apply this methodology to ocean gliders and floats during several real-time sea experiments—the Mini-Adaptive Sampling Test Run (MASTR) and Grand Adaptive Sampling Experiment (GRASE) in the Gulf of Mexico, and the New England Seamounts Acoustic (NESMA) experiment in the North Atlantic. Using the MIT-MSEAS multi-resolution ocean modeling and data assimilation system to provide deterministic and probabilistic ocean current forecasts, we compute time-reachable sets as well as time-optimal paths for a variety of ocean vehicle missions. The governing differential equations for reachability analysis and time-optimal path planning were numerically integrated in real time, forced by our large-ensemble ocean forecasts. We illustrated deterministic and probabilistic forward reachability analyses, glider recovery planning, time-optimal routing for gliders in distress, and planning of future glider and float deployments. Results show that the actual paths of gliders were contained within our reachable set forecasts and in accord with the dynamic reachability fronts. These forecasts were successfully employed for glider recovery and informed strategic decisions for future missions. Additionally, we demonstrated the ability to incorporate risk such as severe weather or vessel traffic into hazard-time-optimal path planning for simulated collaborative air-sea drone missions. Overall, the integration of data-driven multi-resolution ocean modeling with exact reachability theory and numerical schemes enables principled, operationally relevant path planning for diverse ocean missions.

Thesis supervisor: Pierre F.J. Lermusiaux

Title: Professor of Mechanical Engineering and Ocean Science and Engineering, MIT

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