Optimal Path Finding in Dynamic Environment with Application to Vessels and Autonomous Vehicles

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Optimum Vessel Performance in Evolving Nonlinear Wave-Fields Project

A five-year project funded by the Office of Naval Research (ONR) Multidisciplinary University Research Initiative (MURI) Grant
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- In collaboration with:
  - The Department of Naval Architecture and Marine Engineering at the University of Michigan
  - The Department of Electrical and Computer Engineering at the Ohio State University
  - The Applied Physics Laboratory at the University of Washington
The goal of this project is to develop a system that can, in real-time, control the behavior of a vessel, based on real-time measurements and forecasts of the wave-field surrounding the vessel.
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Three objectives:

- Minimize travel time, thus decreasing operational costs
- Minimize fuel consumption, consequently reducing environmental effects
- Minimize vessel motions, thus increasing passengers’ comfort and crew’s efficiency
Optimum Vessel Performance in Evolving Nonlinear Wave-Fields Project

- Real-Time Measurement of Ocean Wave-Fields
Optimum Vessel Performance in Evolving Nonlinear Wave-Fields Project

- Real-Time Measurement of Ocean Wave-Fields
- Short-Term Forecasts of Evolving Nonlinear Wave-Fields

![Radar visible region with symbols R_H and S]
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- Time-Domain Computation of Nonlinear Ship Motions
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- Dynamic Real-Time Path Optimization and Vessel Control
Problem Characteristics

- The cost function (vessel speed) and operability constraints are not available in closed form, and an optimal path cannot be found analytically.

Direction-dependent environment causes cost functions to violate triangle inequality.

Information about the surrounding environment is available up to the radar visibility horizon.

A minimum turning radius function constrains the curvature of feasible paths and problem controllability.

Small run-time of an optimal path finding algorithm is essential for real-time implementation.
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The dynamic programming model evaluates the fastest paths to each point on the border of the radar visible region, then our results for time and space homogeneous environment find the best path to continue to the target point.
As the mobile agent moves along a path, the information about surrounding environment is updated, and an optimal path is continuously reevaluated.
Dynamic Programming Model

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S-175 Containership

- \( R_H = 2500 \) meters
- Nominal ship speed = 11.4 m/s
- Global sea state No. 6.5 (Sig. wave height 7 m)
- Maximum attainable speed range is [8.4, 10.3] m/s
- \( l = 250 \) metres
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Optimal Path Numerical Results

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The DP model not only improves the travel time, but also finds a control-feasible path.
Test Run Number 5: $\theta_{st} = 80$ degrees
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Test Run Number 7: $\theta_{st} = 120$ degrees
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The selected path has to minimize travel time while avoiding dangerous regions, and must dynamically adjust as new information about the surrounding environment is obtained.
Unmanned Aerial Vehicles (UAVs)

- Optimal path finding for UAVs and other autonomous systems while integrating real-time dynamic environment (e.g., wind).
- Uncertainty in the environment and accuracy of the collected data.
Questions?