Route Planning for Terrain Relative Navigation

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Motivation

- Missions with Limited Navigation
  - TERCOM
  - Planetary Exploration
  - Indoor Navigation
  - Underwater Robotics

- Specific Application
  - Underwater Return-to-Site Mission
  - Plan route to arrive accurately on-site

[Image of TERCOM]

Monterey Bay Aquarium Research Institute (MBARI)

[Image of NASA Mars Rover]

http://upload.wikimedia.org/wikipedia/commons/d/d8/NASA_Mars_Rover.jpg
Underwater Navigation

- **Terrain Relative Navigation**
  - No GPS
  - Non-georeferenced maps
  - Correlate sonar range measurements to Digital Elevation Map

- Successfully demonstrated Return-to-Site Mission

**TRN Return-to-Site Demonstration at Portuguese Ledge**

![TRN Return-to-Site Path](image)

- **TRN Vehicle Path**
- **Target Site**
TRN Route Planning

Suggested Routes on Portuguese Ledge Map

Flat Terrain = Low Information

Path Dependent Navigational Accuracy

Varying Terrain = High Information
Route Planning with Uncertainty

Portuguese Ledge Demonstration

- TRN Vehicle Path
- Vehicle did not fly over planned path due to uncertain position estimate
- TRN Estimate remains inaccurate over flat terrain (low information)
- TRN Estimate improves over varying terrain (high information)
Route Planning Problem

- **Objective:**
  - Maximize probability of arriving at goal
  - Minimize distance traveled

- **Using:**
  - Commanded vehicle position

- **Issue:**
  - Vehicle path and position estimate dependence
Research Goal

- **Goal:**
  - Develop offline route planner to generate optimal commanded path
  - Incorporating path/estimate coupling

![Diagram of Offline Route Generator](image)
Method of Approach

Partially Observable Markov Decision Process (POMDP)

**Advantages:**
- Couples path and estimate
- Established solvers
- Successful in Airborne Collision Avoidance
  - Prof. Kochenderfer

**Disadvantages**
- Difficult to solve/scale
- Requires simplifications
- Onboard computation

- **Implementation**
  - Plant
  - POMDP Solver
  - Optimal Policy
  - Offline
  - Online
  - Dyn. Model
  - Obs. Model
  - Reward
  - Time Horizon

- **POMDP Policy**
  - control
  - probability
Method of Approach

Two-Step Process

1. Offline POMDP Solver
   - Dyn. Model
   - Obs. Model
   - Reward
   - Time Horizon
   - POMDP Solver
   - Optimal Policy

2. Offline Simulation
   - Model
   - POMDP Policy
   - Optimal Route
   - Existing Vehicle Control Structure

POMDP Solution with Practical Implementation
Model Simulation Results

Model Contour with Results

Start

Goal

Planned Path

End Positions

North

East

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Conclusions

- Demonstrated feasibility of two-step approach using POMDPs

Continuing Work

- Refine route extraction with offline simulation
- Quantify route success probability and optimality
- Scale using waypoints
  - Faster POMDP solution
  - Loss of global optimality
  - Implementable on vehicle