Optimal UAV Trajectory Planning for Radiological Search

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Project Team

- Collaborative project between Georgia Tech and MIT

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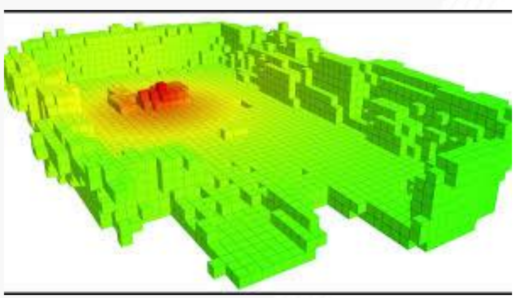
- Joint expertise in path planning, control and optimization for robotic vehicles
  - Extensive experience in UAV prototype development and demonstration

Project Motivation

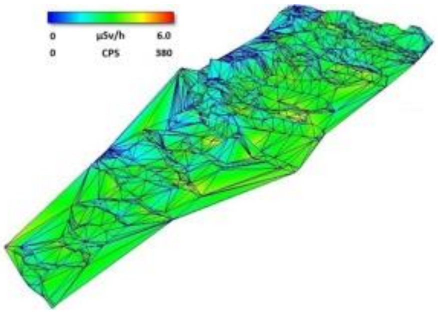
- Two major problems of interest in counter-proliferation:
  - Source localization and characterization
  - Radiation mapping of a 2D or 3D area

Source Localization



- Find source(s) over defined search area
- We can cover search area faster if we use multiple vehicles
- If vehicles are unmanned, deploying more of them (100s?) becomes feasible

Radiation Mapping



- Map radiation intensity over defined area
- UAVs and UGVs allow area to be mapped without exposing humans to radiation
- Ability to circumvent obstacles, reach entire area may benefit from using multiple heterogeneous vehicles

Prior Work

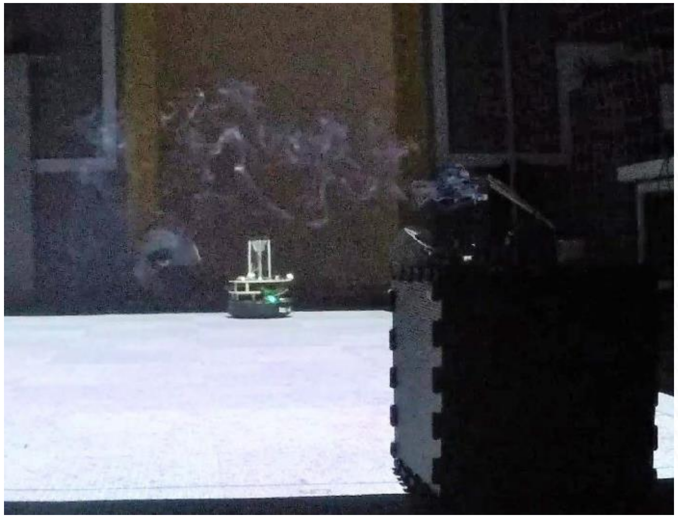
- Current literature can be divided into:
  - Single-agent source term estimation (STE) approaches
  - Multi-agent optimal task allocation
- Single-agent approaches:
  - Goal specifically to estimate location, strength, transmission properties of one or more sources
  - Formulated as partially observable Markov decision processes (POMDPs) with a discrete set of allowable actions
  - Nonlinear Bayesian inference models for estimating source properties
  - Non-parametric approximate measures of information used in path planning cost function
  - **Myopic, computationally intractable for > 1 agent**

Prior Work

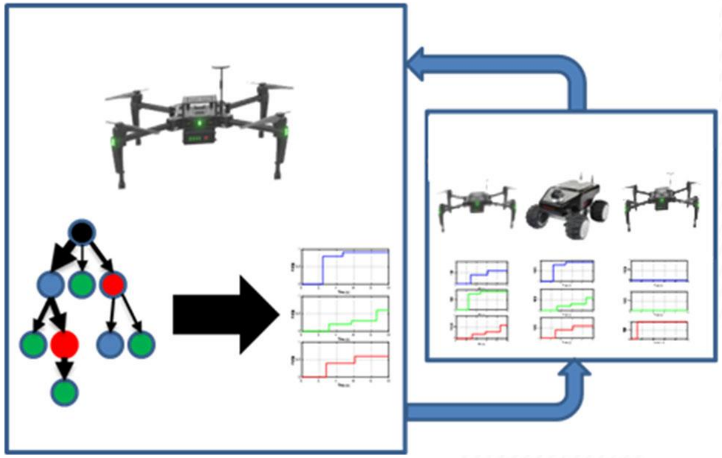
- Multi-agent approaches
  - Focus is on distributed, non-myopic, computationally tractable methods for allocating tasks to a team of robots in real-time to minimize some team-wide cost function
  - Rarely directed specifically at STE problems
  - Planning is sample-based or formulated as a search problem
  - Bayesian inference, if used, generally confined to linear models
  - Either arbitrarily defined rewards or linear information measures used in cost functions
  - **Inference models not sophisticated enough to handle standard STE**

Technical Approach

- Merge inference mechanisms from single-agent STE work with robust multi-agent planning formulations
- Formulate more robust and efficient solution to STE search problem using multiple agents
- Account for idiosyncrasies present in the radiation detection process:
  - Dependency of sensor accuracy on sensor altitude and velocity
  - Omnipresence of background noise from naturally-occurring isotopes



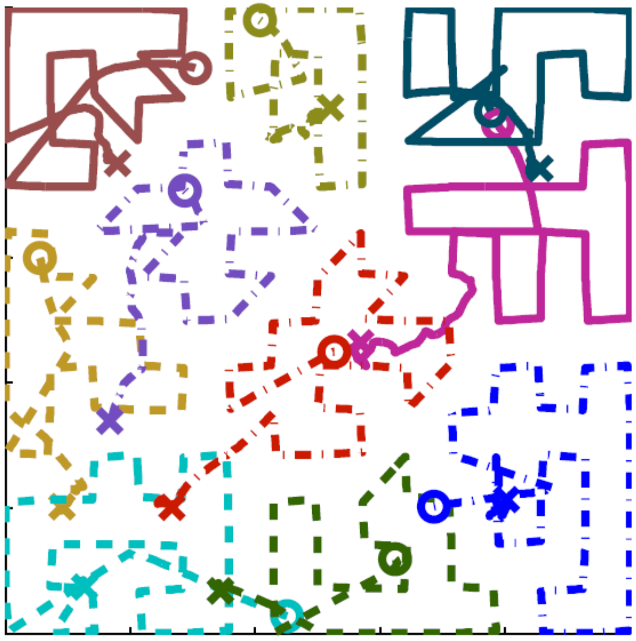
Gas source localization with ground robot.



Inter-agent coordination for optimal task allocation.

Project Approach

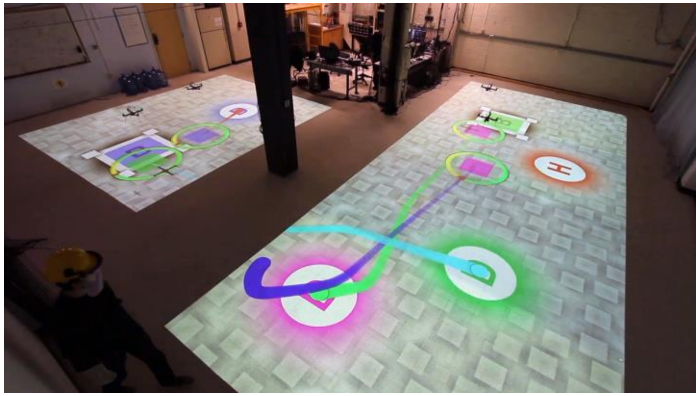
- Proposed solution to STE search problem that is more temporally efficient than single-agent or uninformed planning strategies
  - Non-myopic
  - Distributed
  - Coordinated
  - Information-driven
  - Capable of estimating dispersion behavior
  - Handles sensor constraints
  - Robust to individual agent failure



Robust adaptive coverage control for robotic sensor networks

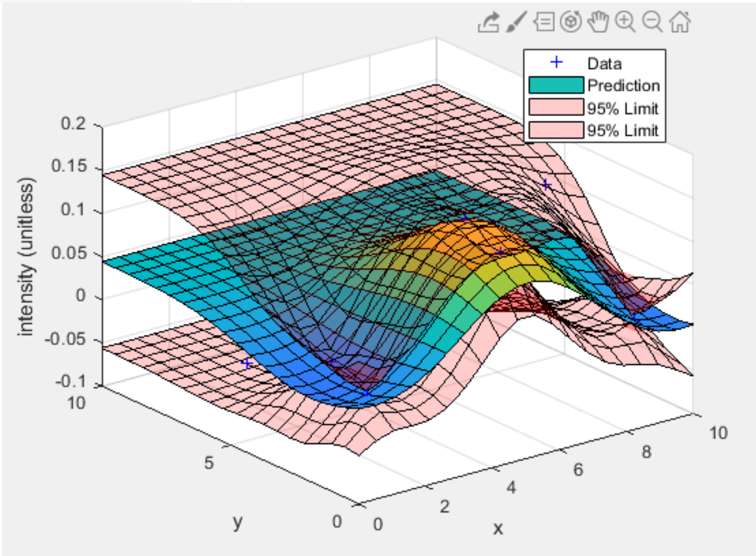
Project Approach

- Emphasis on hardware validation of simulation results
- Experience between labs at Georgia Tech and MIT in experimental UAVs and UGVs
- Experience with multi-agent platforms, information-theoretic search, and performance-constrained sensor models

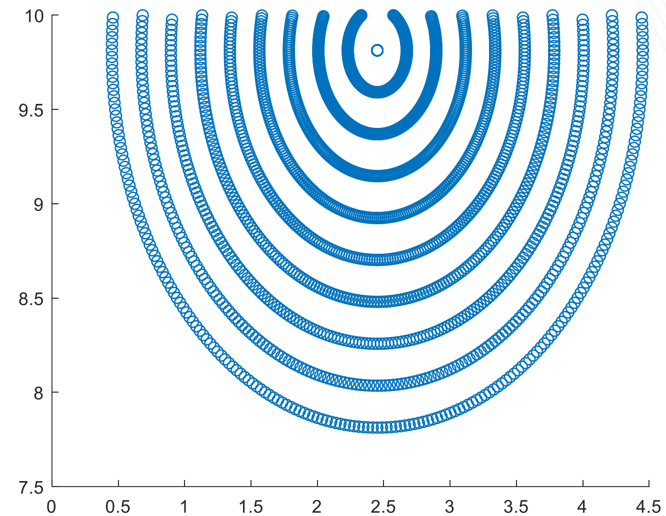


Decentralized Planning Using Macro-Actions (MIT)

Problem Setup and Preliminary Results



Simulation just starting to map the area

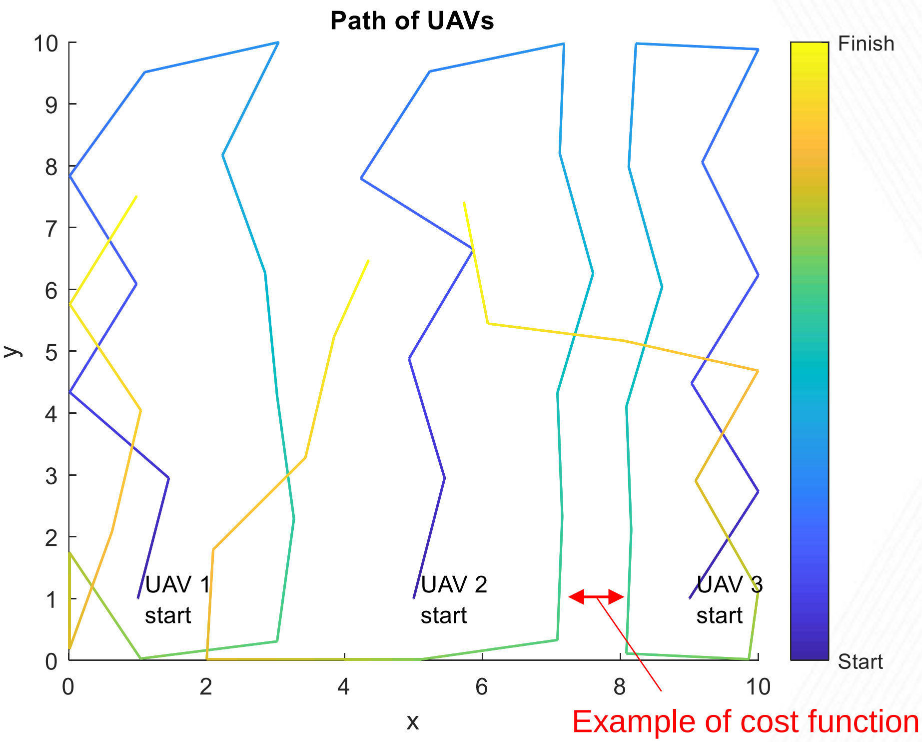


Potential action vectors an agent sees

- We have a simple simulation for single and multi-agent systems that employ active learning.
- Active learning allows us to minimize flight times by searching only areas of uncertainty or interest.
- The sim starts with no prior knowledge of the function it will be discovering.
- Agents start at arbitrary points then propose multiple candidate action vectors.

Problem Setup and Preliminary Results

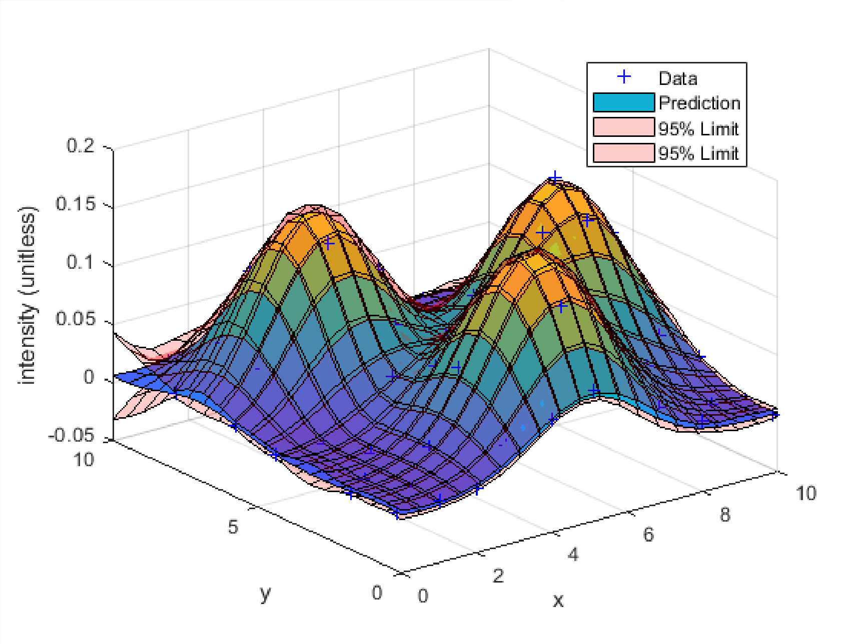
- A centralized controller selects the next action vector for each agent using a cost function.
- The cost function looks for action vectors with the highest discovery that also keep the agents separated.
- Agents keep mapping the area until the Integrated Squared Difference (ISD) is below an arbitrary threshold.

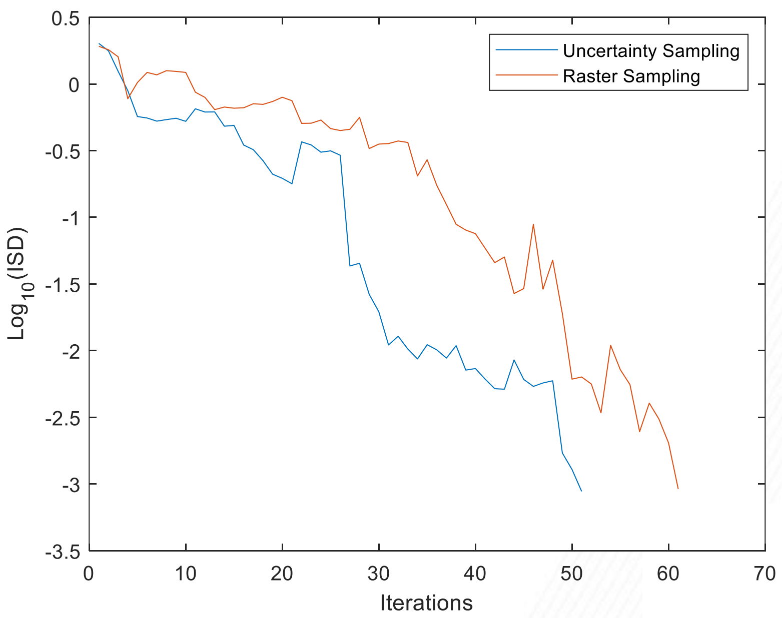


Example of cost function enforcing separation.

Problem Setup and Preliminary Results

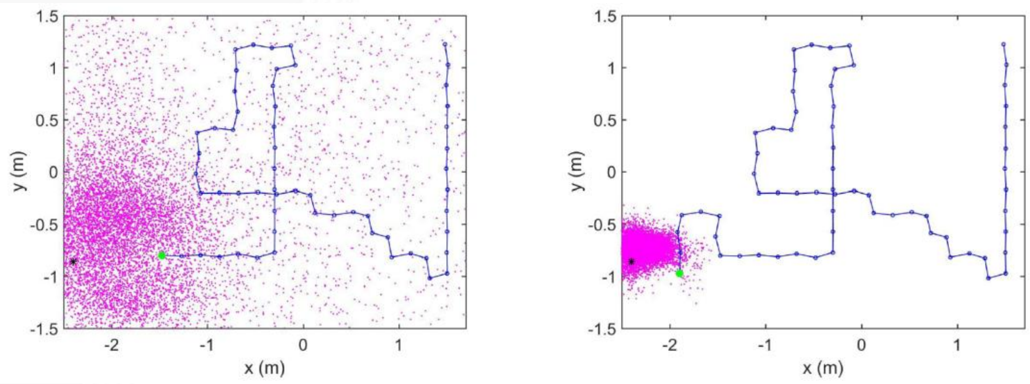
- For a single agent system, the uncertainty sampling (US) method was compared to a raster sampling (RS) method (lawnmower pattern). The raster pattern was generated to use a similar step size as the US method for a fair comparison.
- In cases where the scale of the problem was unknown, the uncertainty sampling method was able to outperform the raster sampling method.
- Without fine tuning, the raster pattern would either be too coarse (not detailed enough) or too fine (too slow), whereas the US method would adapt quickly.
- For a multi agent system, the centralized controller can become overwhelmed when there are too many agents and candidate points to evaluate.





Upcoming Work

- Build on our past work on convex relaxations of the path planning using resource-dependent sensor models
  - Account for effects of altitude and velocity on radiation detector accuracy
- Extend non-myopic multi-agent task allocation strategies for simplified version of the STE search problem
  - Assess need for centralized vs. decentralized inference strategy
  - Investigate incorporating Bayesian inference using nonlinear models
  - Assess computational tractability when included in multi-agent joint planning
- Investigate using segmentation to estimate background noise in real-time (avoid pre-mapping)



Bayesian inference using nonlinear measurement models for point source localization.

Upcoming Work

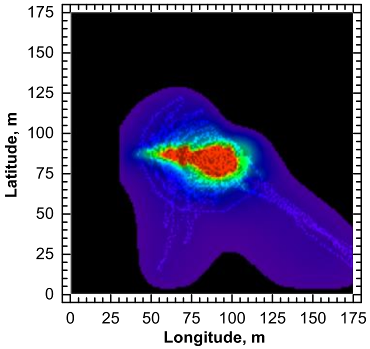
- Develop UAVs with communication and payload capacities suited to our needs.
- Develop sensor package suitable for our UAVs.
- Test systems in simulated radiation fields.
- Test systems in actual radiation fields in partnership with Idaho National Labs (INL).

Multi-agent formation flying experiment performed recently at MIT

DJI Matrice M600 Industrial Drone: Currently used for human piloted radiation mapping at INL

Collaboration with National Labs

- Currently plan to partner with Idaho National Laboratories (POC: David Chichester)
  - Use techniques developed here to take measurements of radiation dispersal events that they conduct regularly
  - Leverage INL expertise in sensing and use of UAVs for source localization



- Possible additional laboratory partners
  - Oak Ridge, others?

Questions and Discussion