Coordinated Detection and Tracking of Hazardous Agents with Aerial and Aquatic Robots to Inform Emergency Responders

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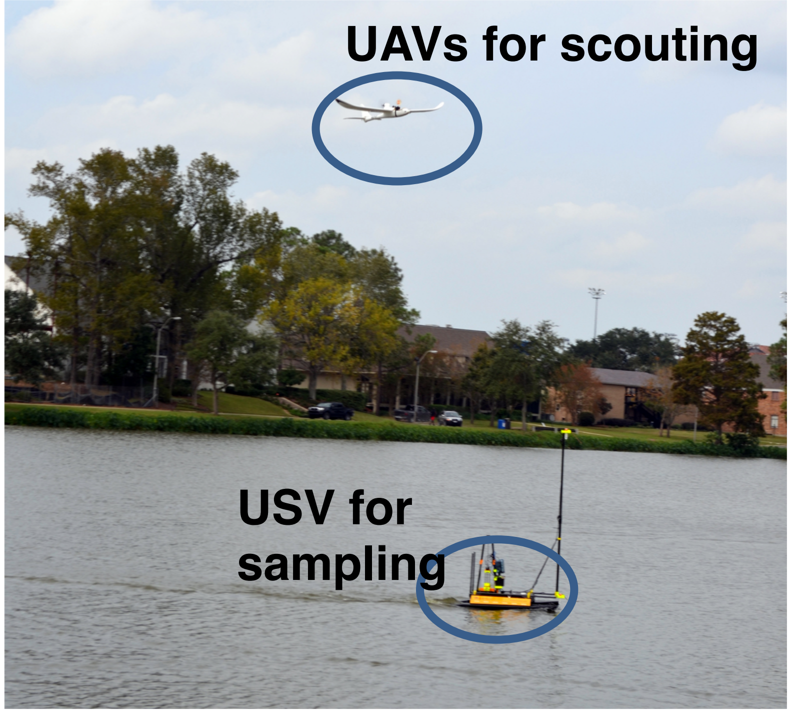
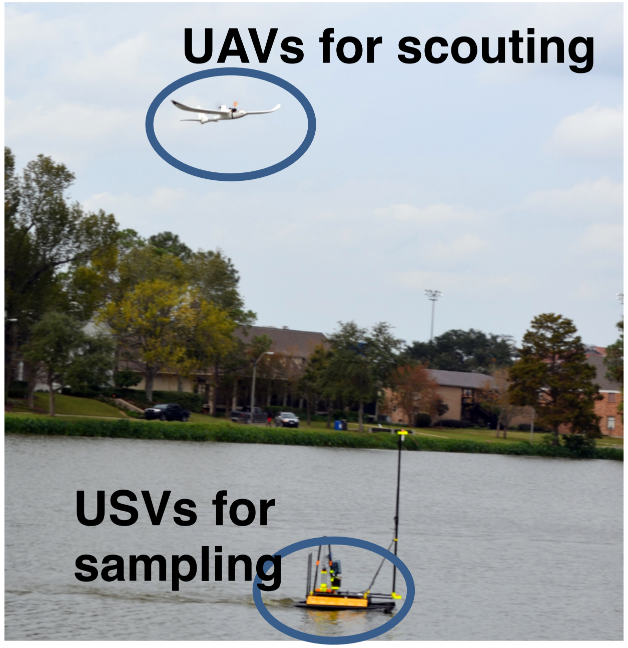
VIRGINIA TECH

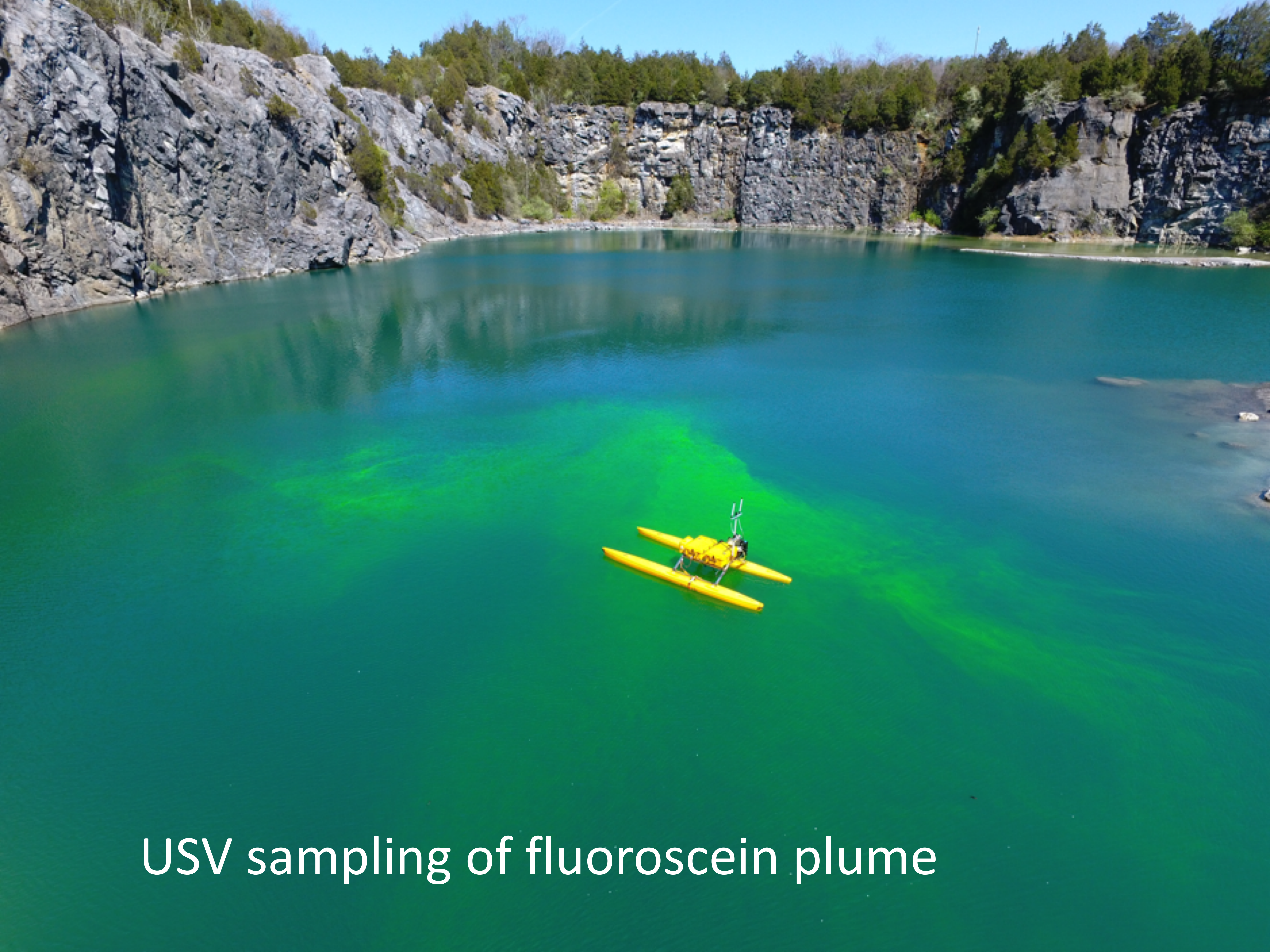
Project Goals

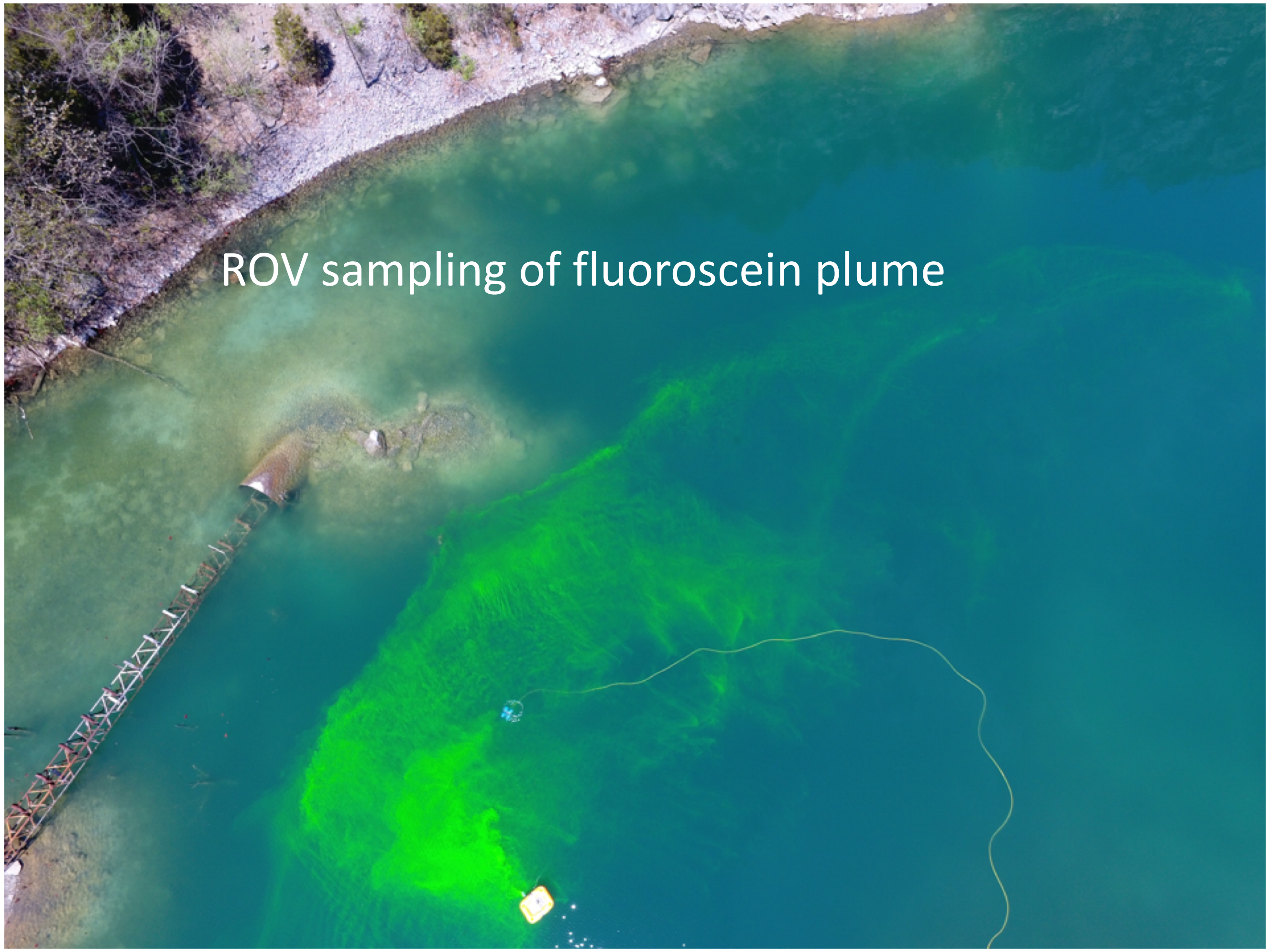
- Enable emergency responders to effectively detect and track hazardous agents that may be rapidly spreading in aquatic environments.
- **Vision:** Coordinated team of UAVs and USVs to detect, track, sample, and diagnose the nature of hazardous agents.



- **Objective 1:** Algorithms for UAV teams to autonomously **map and track** a moving (and possibly bifurcating) plume.
- **Objective 2:** Develop suite of sensors for USVs to **sample and characterize** the nature of the hazards.
- **Objective 3: Selectively deploy the USVs** based on information gathered by the UAVs.



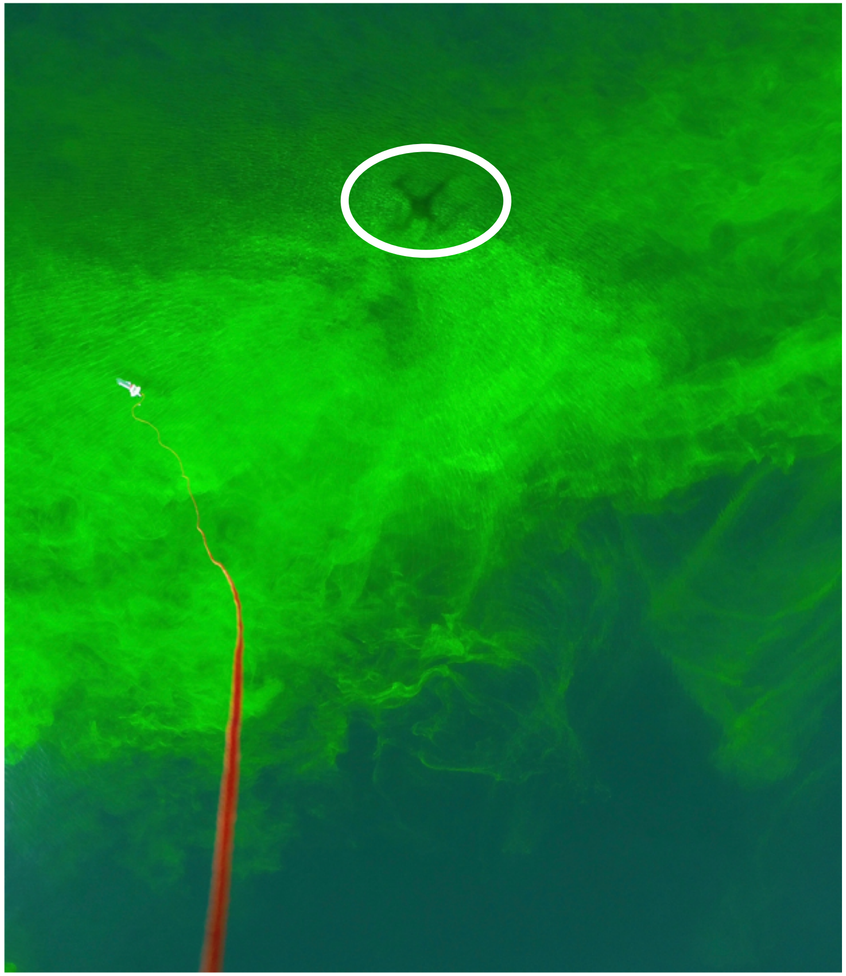

USV sampling of fluoroscein plume



Developed an **underwater robot to monitor dyes** under the surface and collect water samples. The robot was equipped with two fluorometers and a remote-operated sampler to grab 200ml samples of water at specific underwater locations.

Water Sampling with the UAV

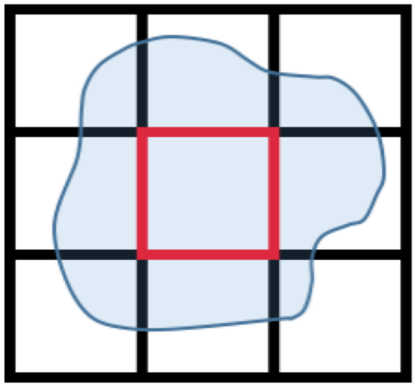
Developed a system to **collect water samples** containing artificial dyes using a 3D-printed sampling device carrying a 50mL sterile **conical tube tethered to a UAV**. The UAV was used to collect surface water samples containing dye in a freshwater lake.



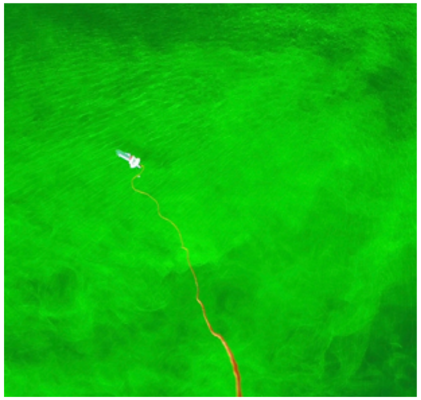
UAVs to determine where to sample?

Multi-Robot Plume Mapping

- Find a tour for R robots to map a plume (of unknown shape) in the least amount of time
- *Similar to classical polygon exploration* problem but
  - robot not restricted to remain inside the region
  - plume may be translating

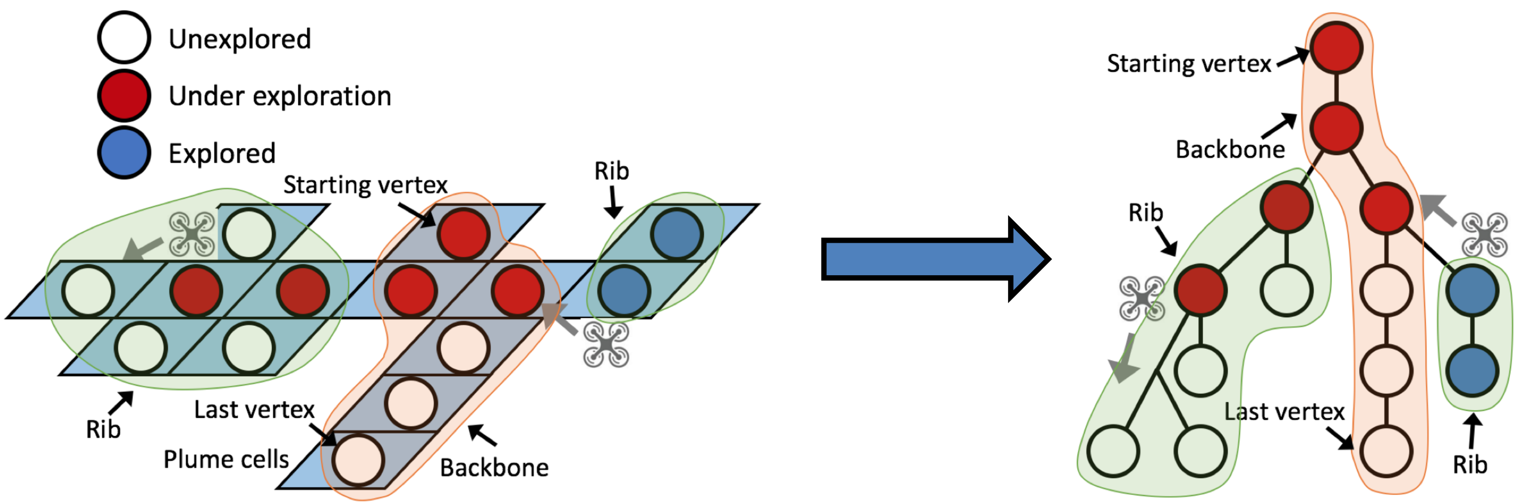


The UAV uses the downwards-facing camera to determine whether the square area in its footprint is part of the plume or not.



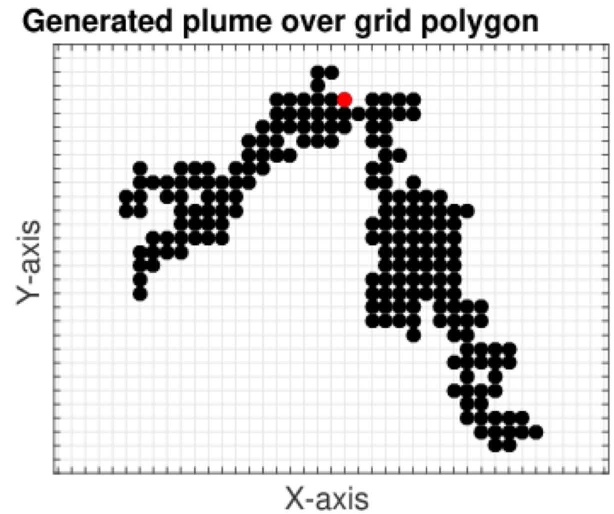
Multi-Robot Depth-First Search

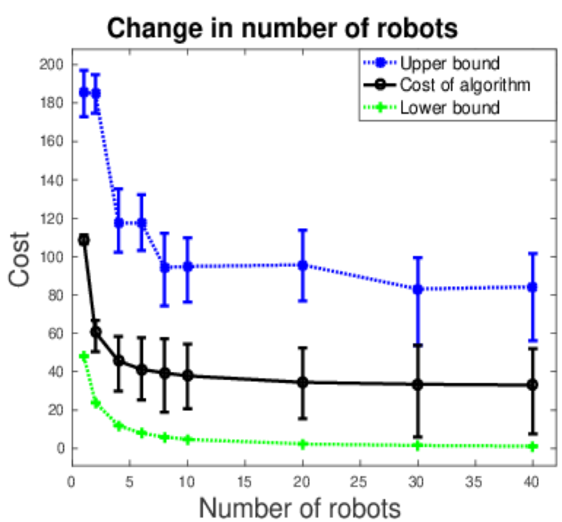
- Mapping an arbitrarily shaped plume → mapping a grid-based plume → exploring a binary tree
- Unknown binary tree, moving vertices
- We propose a depth-first search-based algorithm that finds tours for a team of robots

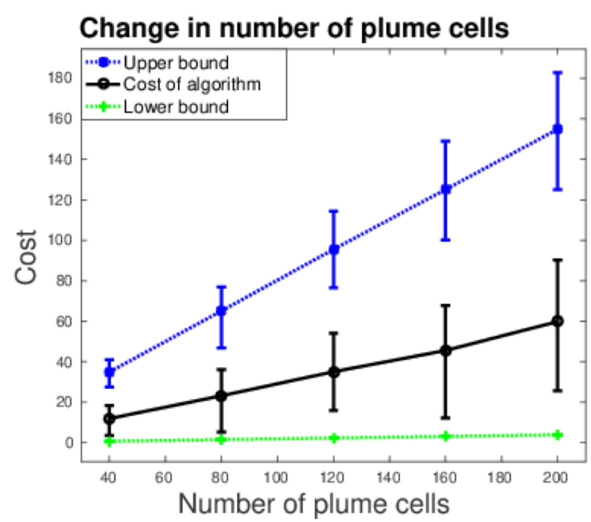


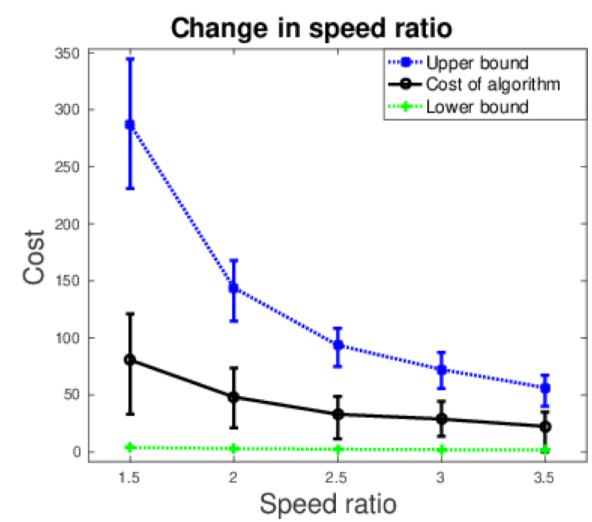
Bounded competitive ratio

$$2\left(\frac{S_r + S_p}{S_r - S_p}\right)\left(\frac{18R + \log R}{1 + \log R}\right)$$





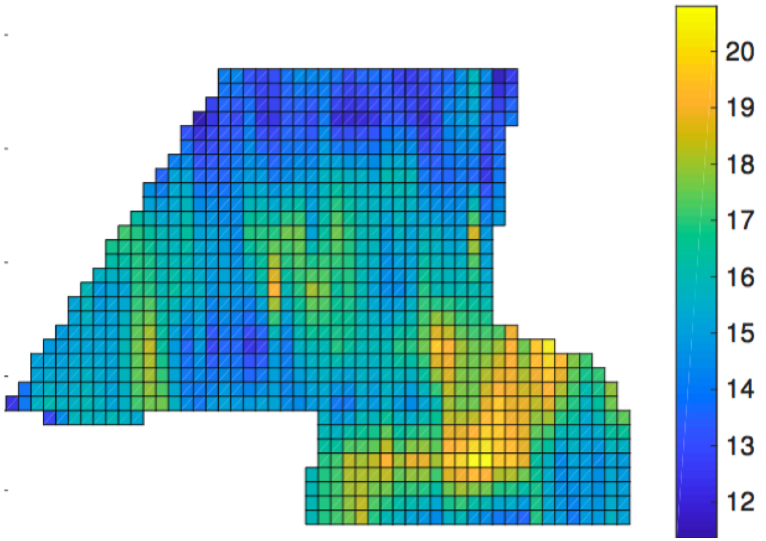




[Sung and Tokekar, *ICRA '19 submitted*]

Mapping Concentration of Static Plumes

- Find a path that **minimizes the time** while guaranteeing a **chance constraint** on the posterior: *prediction for every point is within (1 +/- ϵ) of the true value with probability at least (1 - δ)*
- Constant-factor approximation algorithm

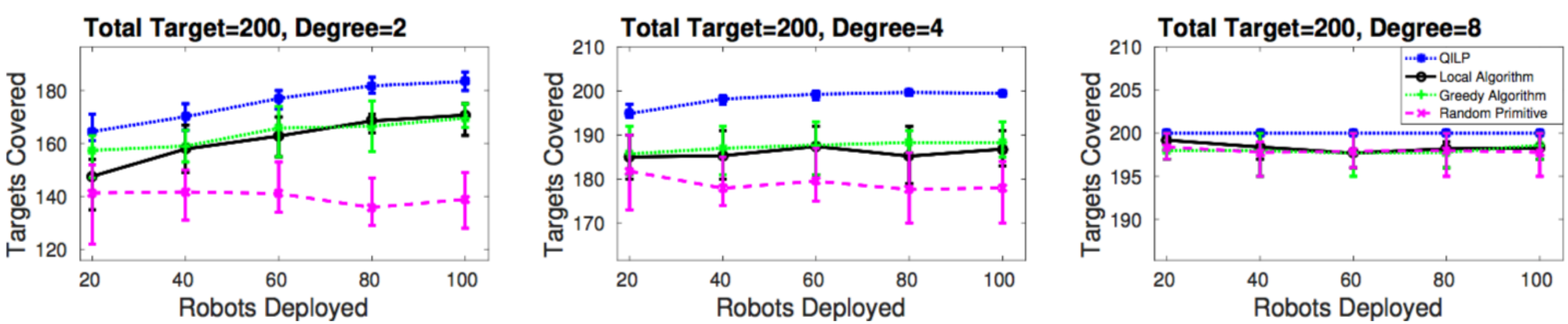


Gaussian Process Regression to estimate the spatial distribution of the hazardous agents in the environment.

[Suryan and Tokekar, *WAFR '18*]

Tracking with Communication Limitations

- **Track key points of interest** in the spatiotemporal field
- Each robot must choose from a set of candidate trajectories to maximize the tracking quality: ***submodular maximization problem*** *subject to a partition matroid constraint.*
- ***Local* algorithm** that requires only O*(h) decentralized communication rounds while yielding a O*(1+1/h)-approximation.



[Sung and Tokekar, *ICRA '18, AURO submitted*]

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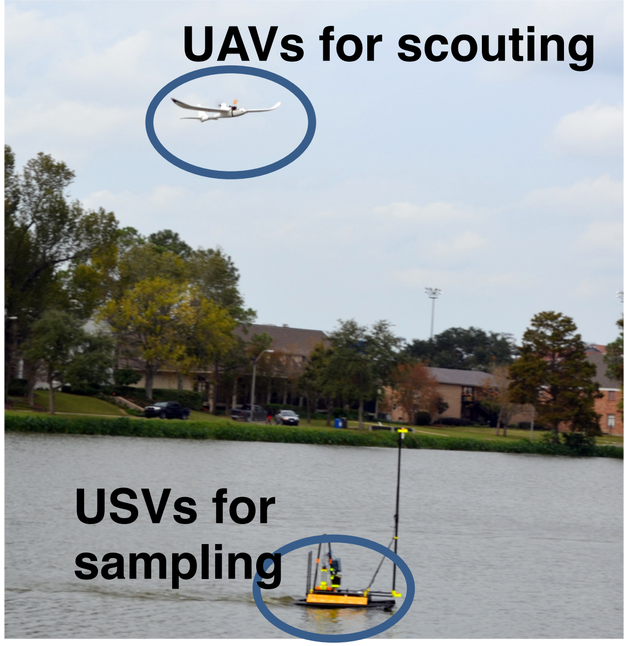

Working with Virginia Tech and Blacksburg Rescue Squads to locate simulated drowning victim

Virginia Tech Rescue Squad
Established 1969

Publications this year

[1] Y. Sung, and P. Tokekar, “A Competitive Algorithm for Online Multi-Robot Exploration of a Translating Plume,” in Proceedings of the IEEE Conference on Robotics and Automation (ICRA), 2019, Submitted.

[2] V. Suryan and P. Tokekar, “Learning a Spatial Field with Gaussian Process Regression in Minimum Time,” in Workshop on the Algorithmic Foundations of Robotics (WAFR), 2018.

[3] Y. Sung, A. K. Budhiraja, R. Williams, and P. Tokekar, “Distributed Simultaneous Action and Target Assignment for Multi-Robot Multi-Target Tracking,” in Proceedings of the IEEE Conference on Robotics and Automation (ICRA), 2018.

[4] Powers, C.W., Hanlon, R., and Schmale, D.G. 2018. Tracking of a fluorescent dye in a freshwater lake with an unmanned surface vehicle and an unmanned aircraft system. Remote Sensing,10(1), 81. doi:10.3390/rs10010081

[5] Powers, C.W., Hanlon, R., and Schmale, D.G. 2018. Remote collection of microorganisms at two depths in a freshwater lake using an unmanned surface vehicle (USV). PeerJ. e4290. doi:10.7717/peerj.4290

[6] Powers, C., C., Hanlon, R., Grothe, H., Prussin, A.J., Marr, L., and Schmale, D.G. 2018. Coordinated Sampling of Microorganisms over Freshwater and Saltwater Environments using an Unmanned Surface Vehicle (USV) and a Small Unmanned Aircraft System (sUAS). Frontiers in Microbiology. 9:1668. doi:10.3389/fmicb.2018.01668

[7] Zhou, Lifeng and Tokekar, Pratap. "Active Target Tracking With Self-Triggered Communications in Multi-Robot Teams," IEEE Transactions on Automation Science and Engineering, 2018. doi:10.1109/TASE.2018.2867189

Thank you!

http://raas.ece.vt.edu/

Poster tomorrow

Yoonchang Sung

Coordinated Detection and Tracking of Hazardous Agents with Aerial and Aquatic Robots to Inform Emergency Responders

Working closely with VT Rescue Squad, > 50 student volunteer based organization

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