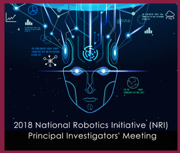

1637915: Coordinated Detection and Tracking of Hazardous Agents with Aerial and Aquatic Robots to Inform Emergency Responders

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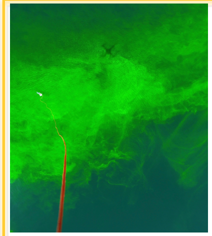
VIRGINIA TECH

Motivation

- The goal of this project is to enable emergency responders to effectively **detect and track hazardous agents** that may be rapidly spreading in aquatic environments using a coordinated team of UAVs and USVs to detect, track, sample, and diagnose the nature of hazardous agents.
- Objective 1: Develop algorithms for using a team of UAVs to autonomously **track a rapidly expanding** (and possibly bifurcating) plume using downwards facing sensors.
- Objective 2: Use USVs fitted with a unique set of sensors to **sample and characterize** the nature of the hazards.
- Objective 3: Deploying a USV is a time-consuming operation. **Selectively deploy the USVs** based on information gathered by the UAVs.
- By visualizing the spatiotemporal flow along with annotated information from the USVs, the emergency responders can find and localize the sources of the hazardous thread.

Sensing Hazardous Agents with USVs

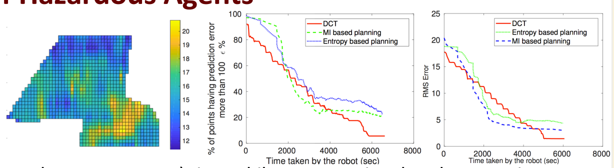


- The Schmale Lab worked with members of the VT Rescue Squad and the Blacksburg Rescue Squad to **locate a sunken rescue manikin** using an ROV tethered to the USV.
- We developed a system to **collect water samples** containing artificial dyes using a 3D-printed sampling device carrying a 50mL sterile **conical tube tethered to a drone**. The drone was used to collect surface water samples containing dye in a freshwater lake.
- We 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 precise underwater locations.
- We designed a **bioaerosol-sampling system onboard USV** to collect microbes and monitor particle sizes in the atmosphere. The system includes a series of 3D-printed impingers, two optical particle counters, and a weather station. A UAS was used in a coordinated effort with the USV to collect microorganisms on agar media 50 m above the surface of the water.

Learning and Tracking Hazardous Agents

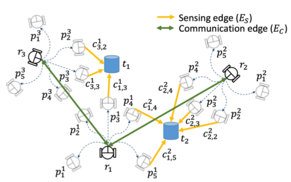
Learning the Distribution of Hazardous Agents

- We use **Gaussian Process Regression** (GPR) to estimate the spatial distribution of the hazardous agents in the environment.

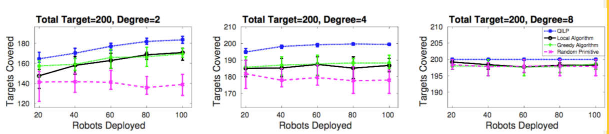


- Problem: Find a path that minimizes the (travel + measurement) time while guaranteeing that the posterior prediction for every point in the environment is within (1 +/- ϵ) fraction of the true value with probability at least (1 - δ).
- We exploit the smoothness properties of the squared-exponential kernel to present a **constant-factor approximation algorithm**.

Tracking with Multi-Robot Teams

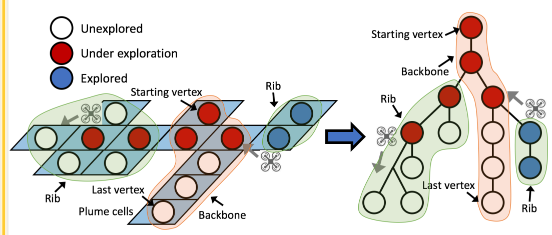


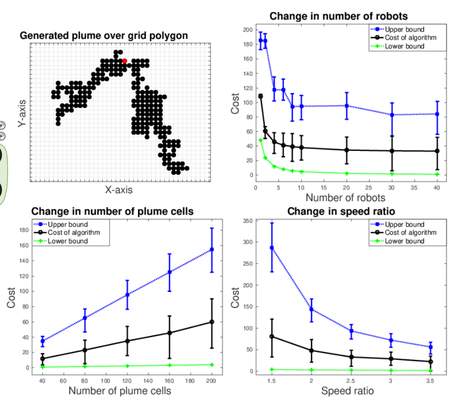
- The goal is to **track key points of interest** in the spatiotemporal field (e.g., local maxima of the field) using the team of robots.
- We formulate this a **multi-robot trajectory assignment problem**. Each robot must choose from a set of candidate trajectories to maximize the overall objective (e.g., tracking quality) which is a **submodular maximization problem** subject to a partition matroid constraint.
- A sequential greedy algorithm yields a 2-approximation but can require n communication rounds.
- Instead, we use a ***local* algorithm** that requires only O(h log 1/ϵ) decentralized communication rounds while yielding a O((1+ϵ)(1+1/h))-approximation.



[1] 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.
[2] 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.
[3] 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.

Multi-Robot Mapping of Plumes





- The goal is to **explore and map a translating plume using a team of aerial robots** where the shape and the size of the plume are not given a priori.
- We propose a **recursive depth-first search-based planning algorithm**. All robots start from the same location and collaboratably generate tours that **completely explore** the plume.
- We solve **two versions of the problem**; the first version is to map **the plume based on the grid map** whereas in the second version we consider **the plume with an arbitrary shape**.
- **The competitive ratio for the grid map-based plume** is $\frac{2(S_r+S_p)(R+\lfloor\log R\rfloor)}{(S_r-S_p)(1+\lfloor\log R\rfloor)}$ (R is the number of robots, S_r and S_p are the robot speed and the plume speed), and **that for the plume with an arbitrary shape** is $\frac{2(S_r+S_p)(18R+\lfloor\log R\rfloor)}{(S_r-S_p)(1+\lfloor\log R\rfloor)}$.

[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.
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[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.