WASP Project

Oregon State University

PIs: Geoff Hollinger and Julie A. Adams

Period of Performance: July, 2025 - December, 2025

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Motivation

- Multi-USV surveillance and reconnaissance



Image: NextGen defense: Ukraine's "Sea Baby" Naval Drone Grows Teeth

Project goal

- **Problem:** Multiple USVs (~3) in lake find and track depth contour in lake (more general feature in simulator)
- Simulator
  - Scalable to 10-100 USVs
  - Runs on standard laptop/desktop computer
- Algorithm
  - Begins with search behavior
  - Transitions to tracking behavior after contour is found
  - Could be applicable to dynamic features
- Demonstration
  - Algorithm implemented in simulation
  - Demonstrate waypoint following on USV hardware

WASP OSU personnel

- Faculty
  - Geoff Hollinger – PI
  - Julie A. Adams – Co-PI
- Students
  - Roger Wienaah – Simulator design and coordination
  - Colin Mitchell – Multi-robot coordination algorithm and hardware

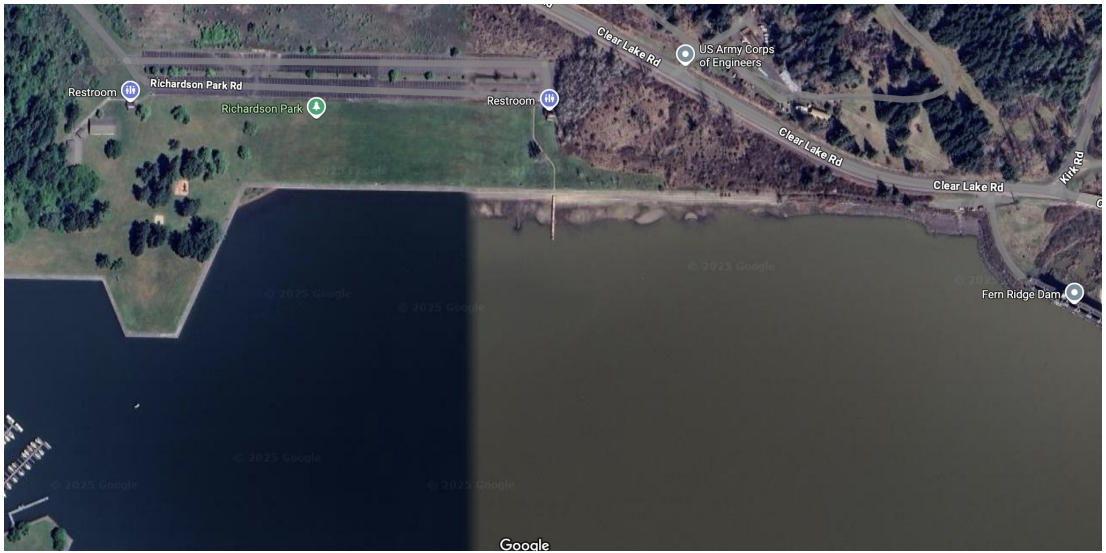
Unmanned Surface Vehicles

- 3 Blueboat USVs
  - **Autonomy:** waypoint navigation
  - **Payload:** multibeam sonar, camera, depth pinger
  - **Comms:** wireless (expandable to cellular and starlink)



Deployment location

- Fern Ridge Lake: about 6-12 foot depth in deployment area
  - **First year goal:** autonomously locate a depth contour with blue boat pingers and take a sonar photo of possible asset



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Timeline (2025)

- **July:** project start, lit review, simulator review
- **August:** Simulator/algorithm conceptualization
- **September:** Simulator/algorithm implementation
- **October:** Simulator/algorithm testing
- **November:** Lake deployments with teleoperation, waypoint following, and comms
- **December:** Final presentations and report

Multi-Robot Coordination

Algorithm and Hardware Implementation

Mission Setup



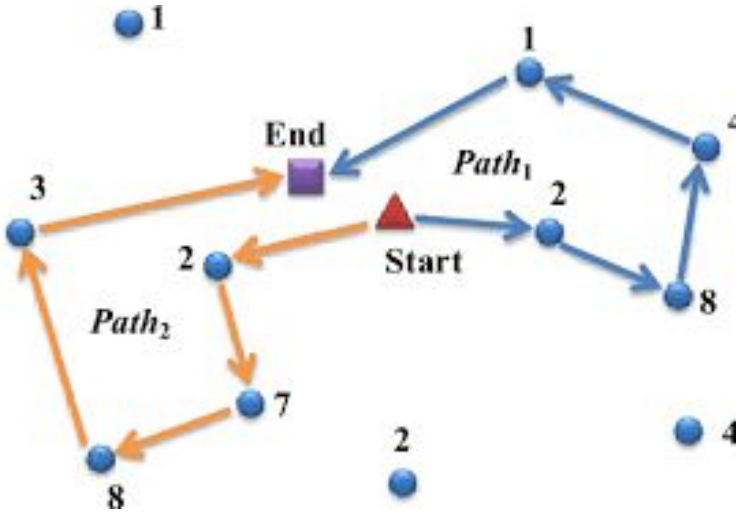
Parameters:

- Boats launched offshore
- Search and revisit behavior
  - Ping for more information
  - Use multibeam to get a better picture of POI
- Sensors:
  - Depth pingers
  - Multibeam sonar

How do we achieve this?

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Team Orienteering Problems (TOPs)



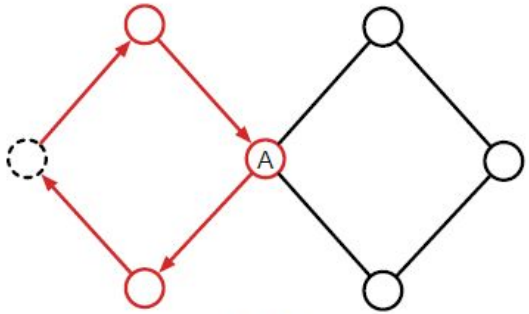
https://www.researchgate.net/figure/An-example-of-solution-for-the-Team-Orienteering-Problem-with-two-paths_fig1_276146351

Given starting and ending points, find routes for each vehicle such that:

1. Aggregate reward is maximized
2. All constraints are met

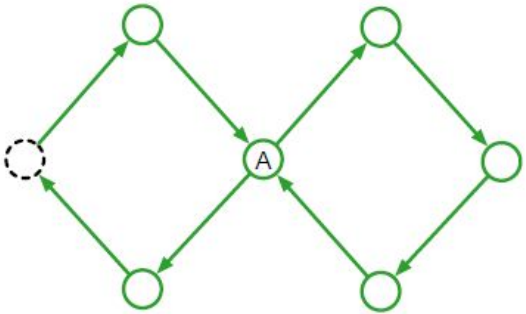
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Team Orienteering Coverage Problem (TOCP)



TOP

- Do not allow repeat POIs in routes
- Does not require any POIs to be visited

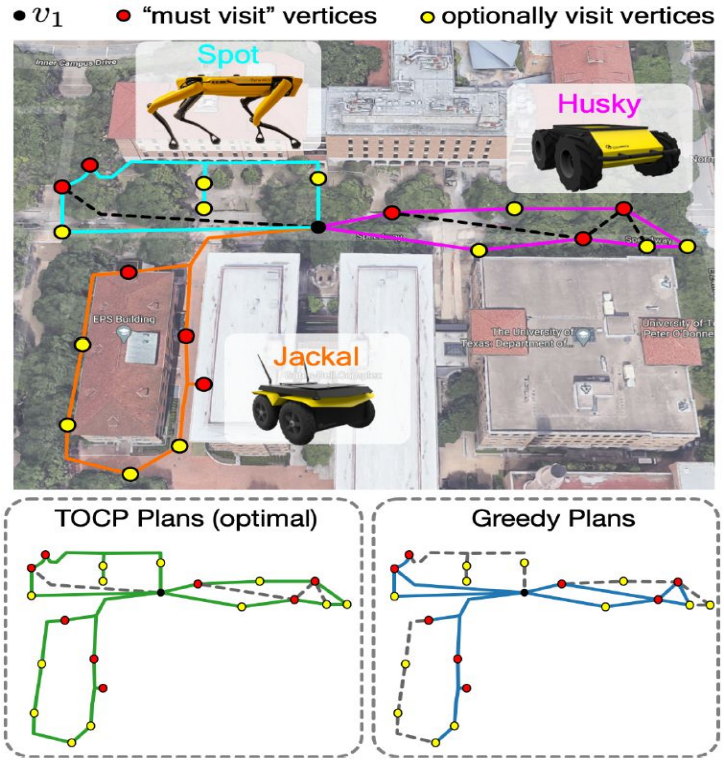


TOCP

- Does allow repeat POIs
- Separates POIs into “must visit” and “optional” sets

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Team Orienteering Coverage Planning with Uncertain Reward (TOCPUR) Algorithm

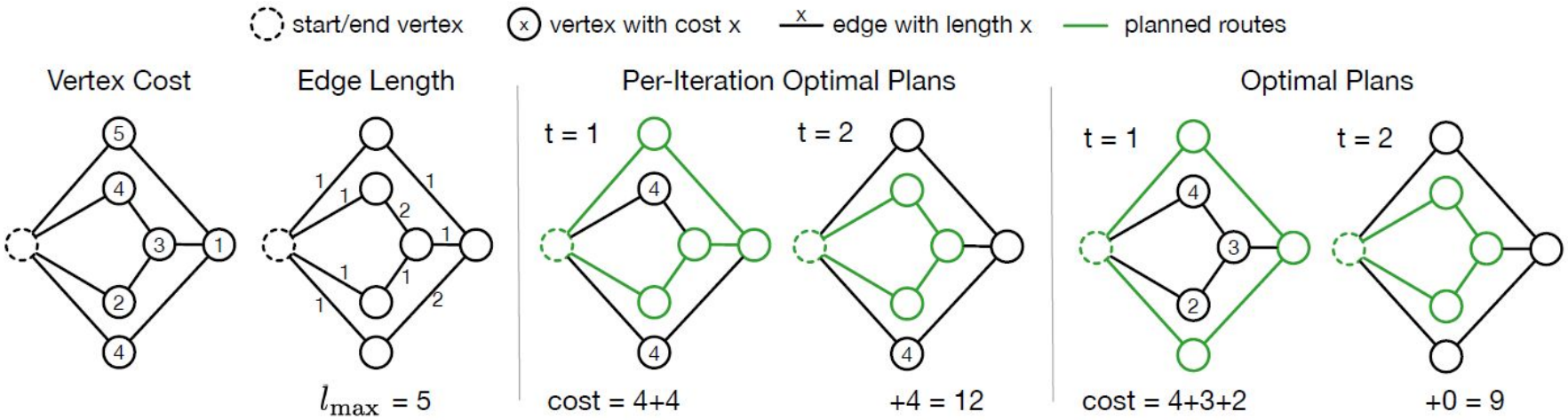


- Heterogeneous team composition (if desired)
- Optimal and heuristic methods for route generation
- Accommodates uncertain rewards

B. Liu, X. Xiao and P. Stone, "Team Orienteering Coverage Planning with Uncertain Reward," 2021 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Prague, Czech Republic, 2021, pp. 9728-9733, doi: 10.1109/IROS51168.2021.9636288.

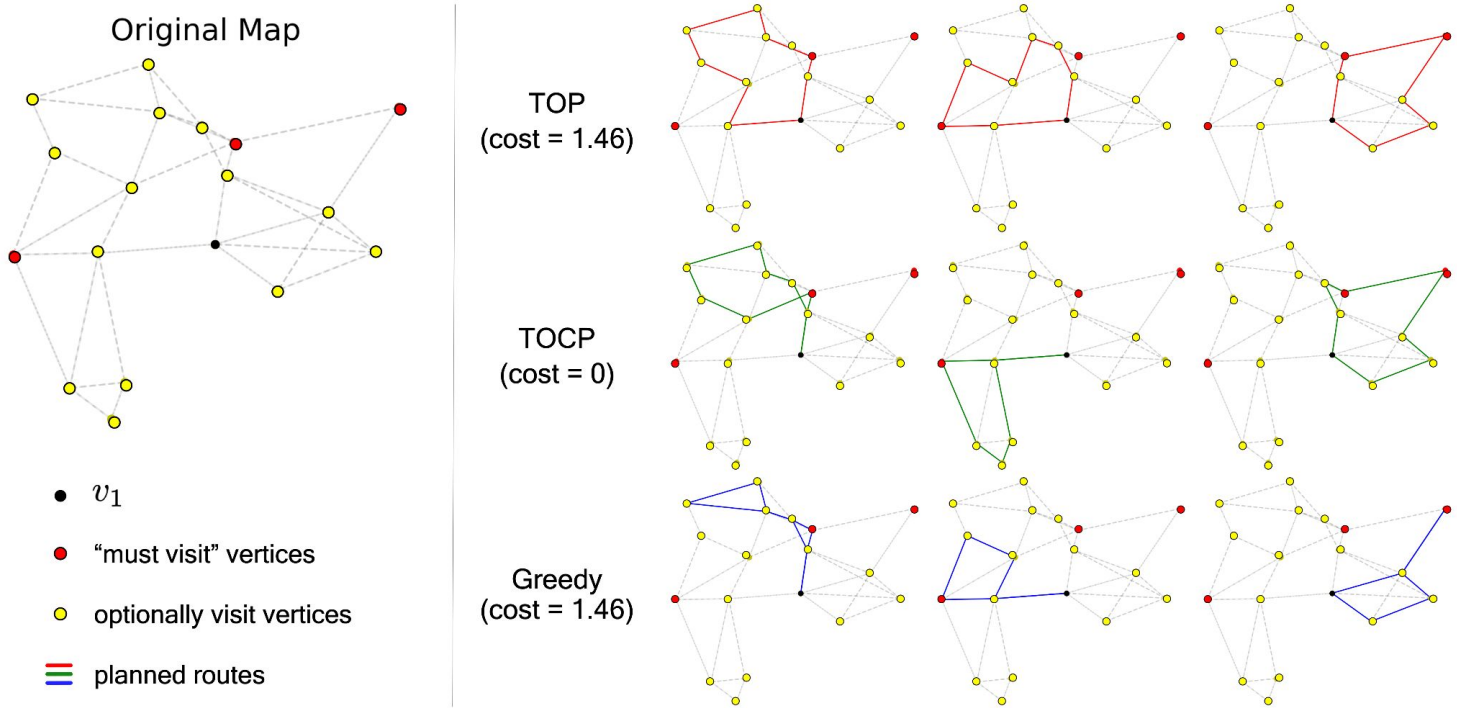
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Per-Iteration Planning



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TOCPUR Greedy

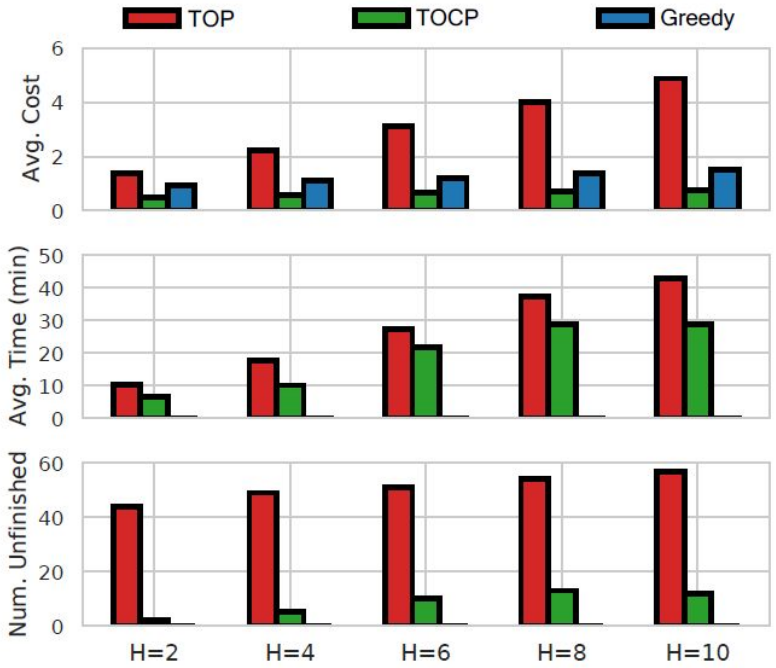


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TOCPUR Greedy

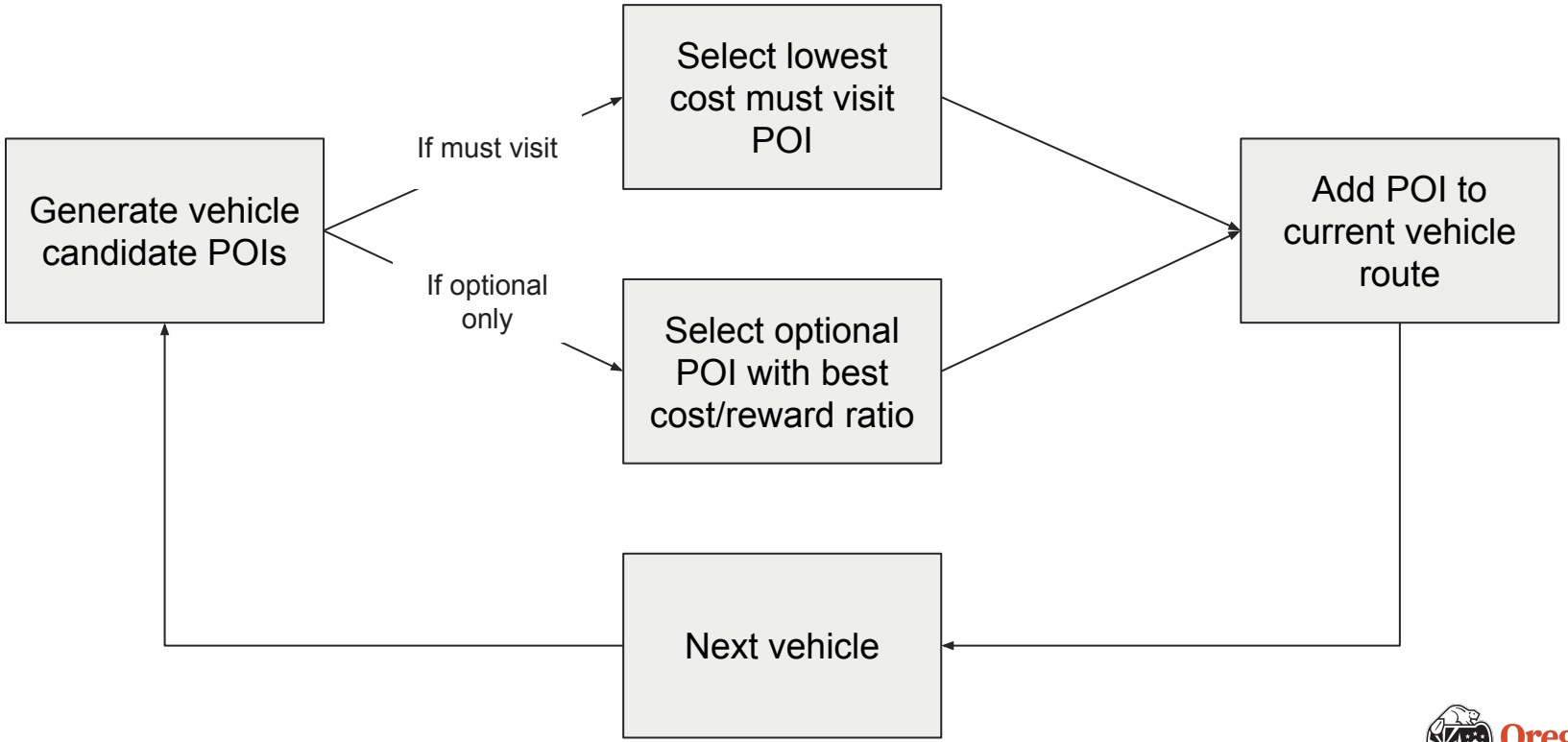
- Always generates a feasible solution
- Avoids computation associated with larger problems

- Trade-off: routes generated aren't always optimal



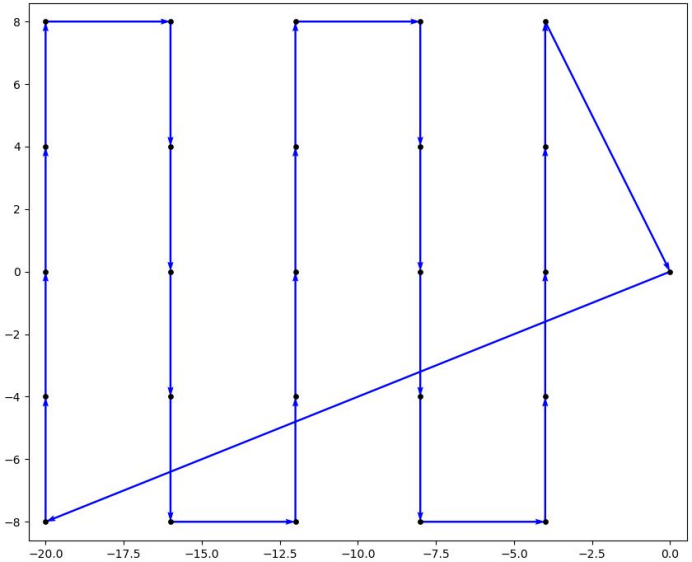
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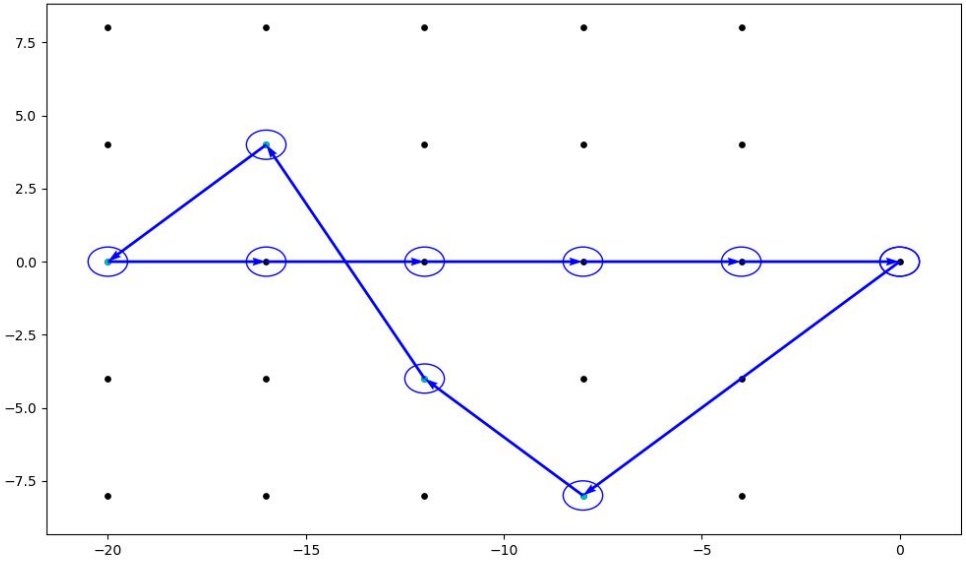
Implementation



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Basic Survey/Revisit Routes

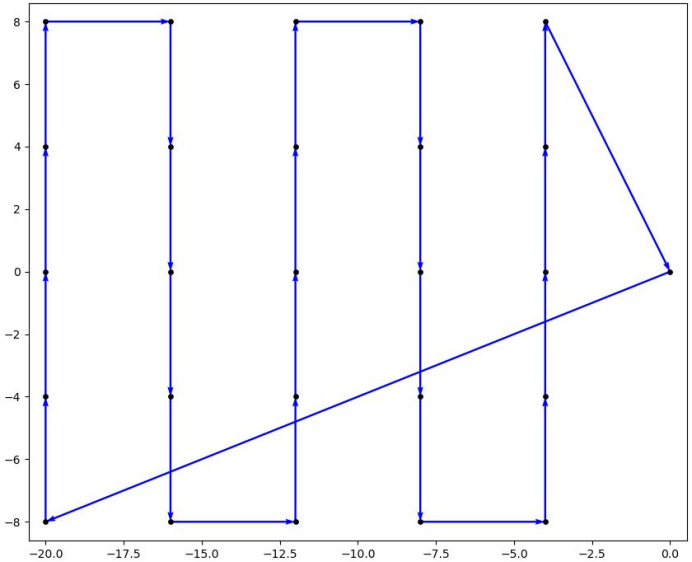


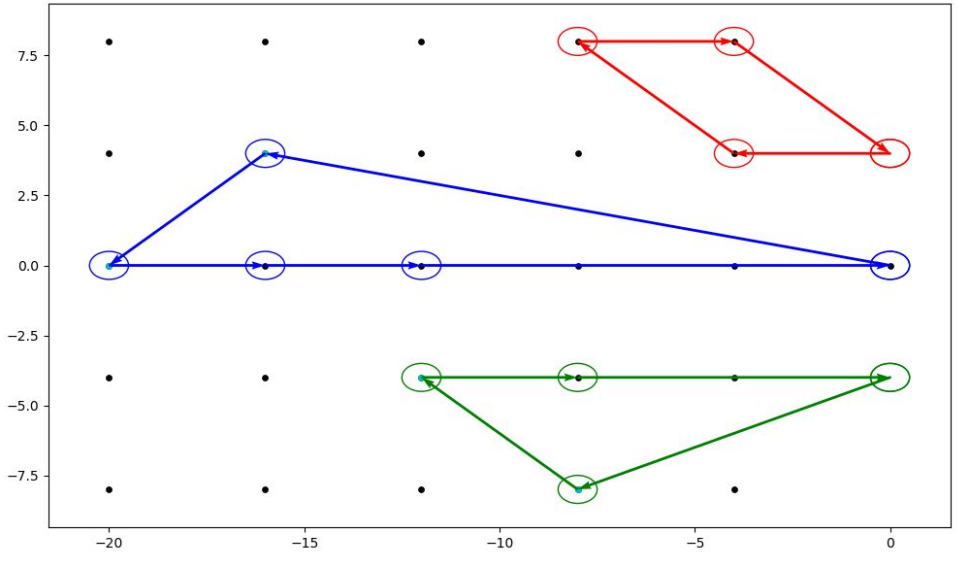


- All POIs in must visit set
- Single vehicle revisit routes
- Must visit POIs in cyan

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Basic Survey/Revisit Routes

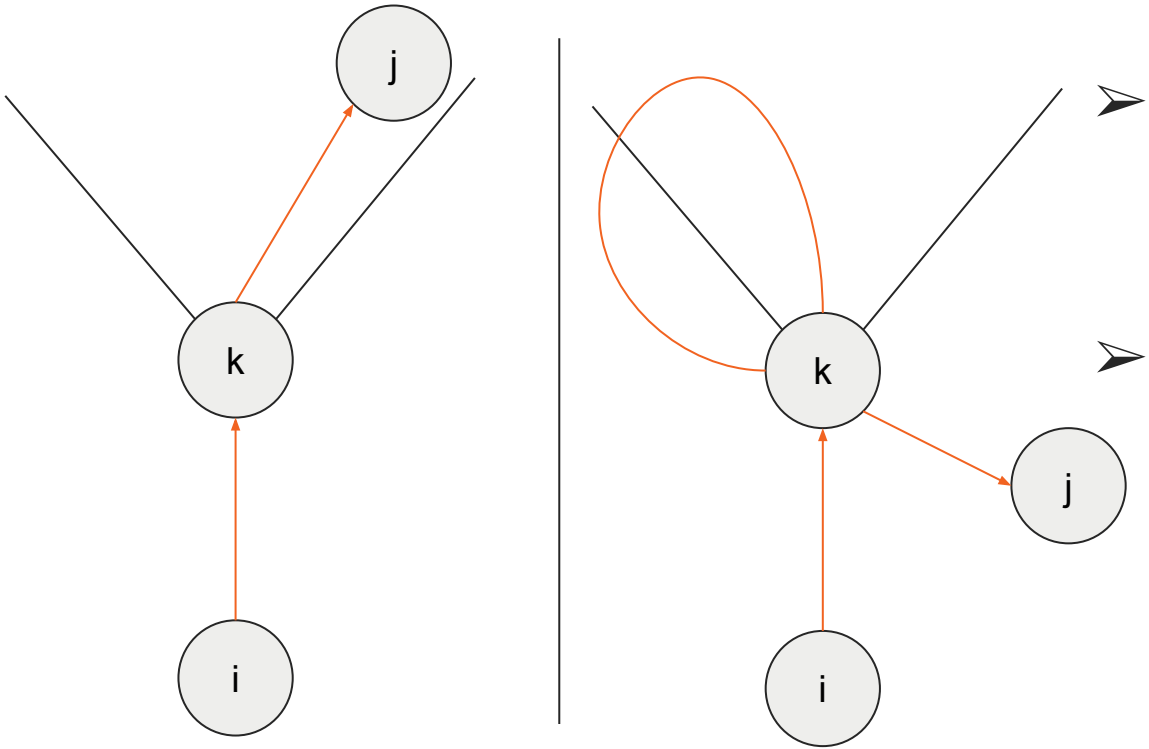




- All POIs in must visit set
- Multi vehicle revisit routes
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Modifications - Vehicle Exit Angles



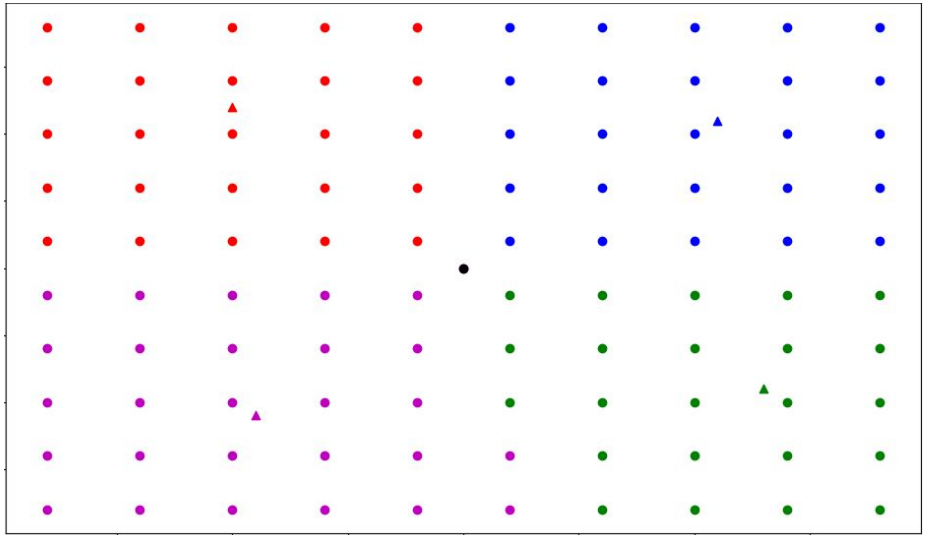
- If angle outside our permitted arc, we add some additional path length cost
- Implemented as a constant for each vehicle
  - Implementation allows for change depending on vehicle

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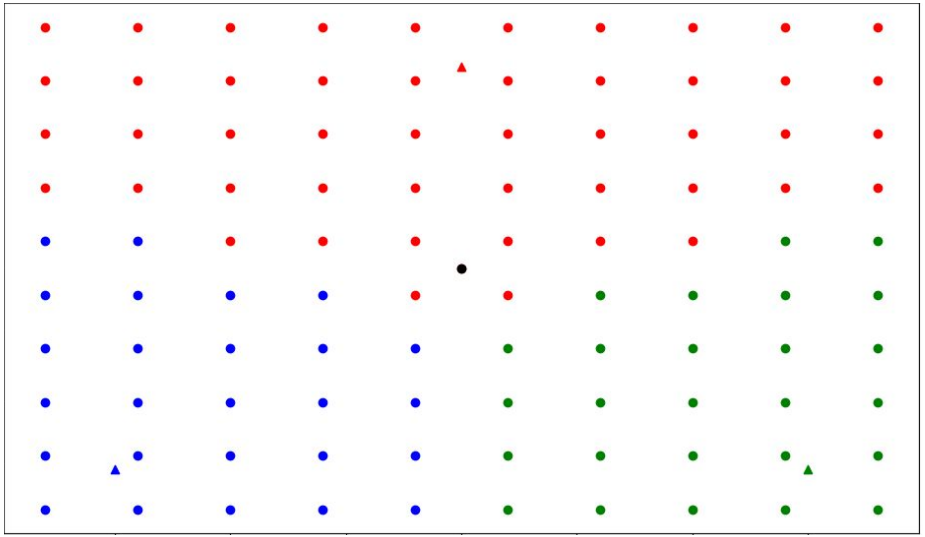
Modifications - Graph Regions

- Black = Home
- Triangle = Vehicle region center

4 Agents



3 Agents



- Could be adapted for sense-and-avoid to follow COLREGS

Field Trials: Fern Ridge Lake

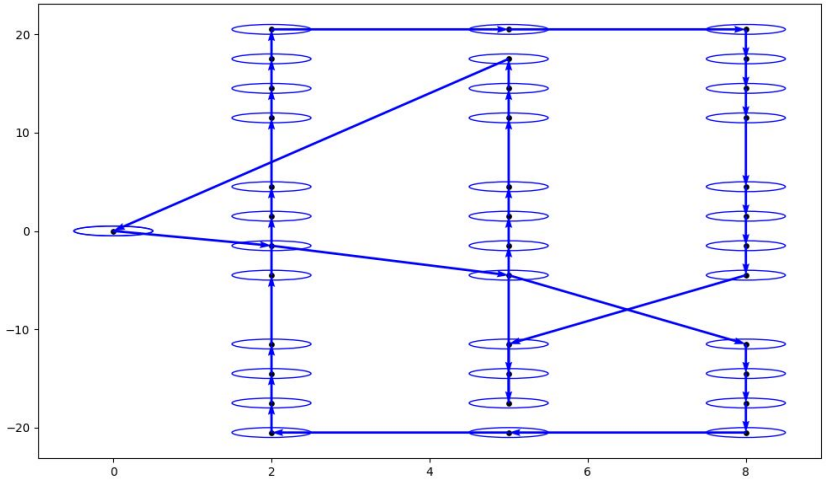




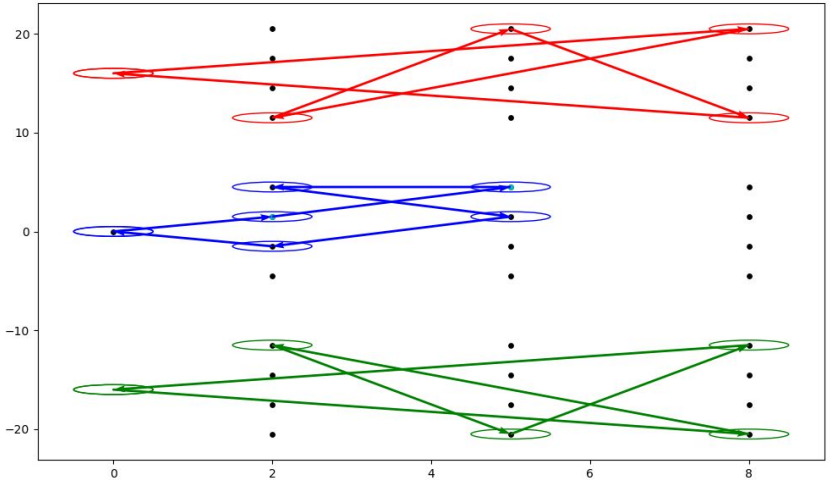
Field Trials: Fern Ridge Lake



Field Trials: Routes



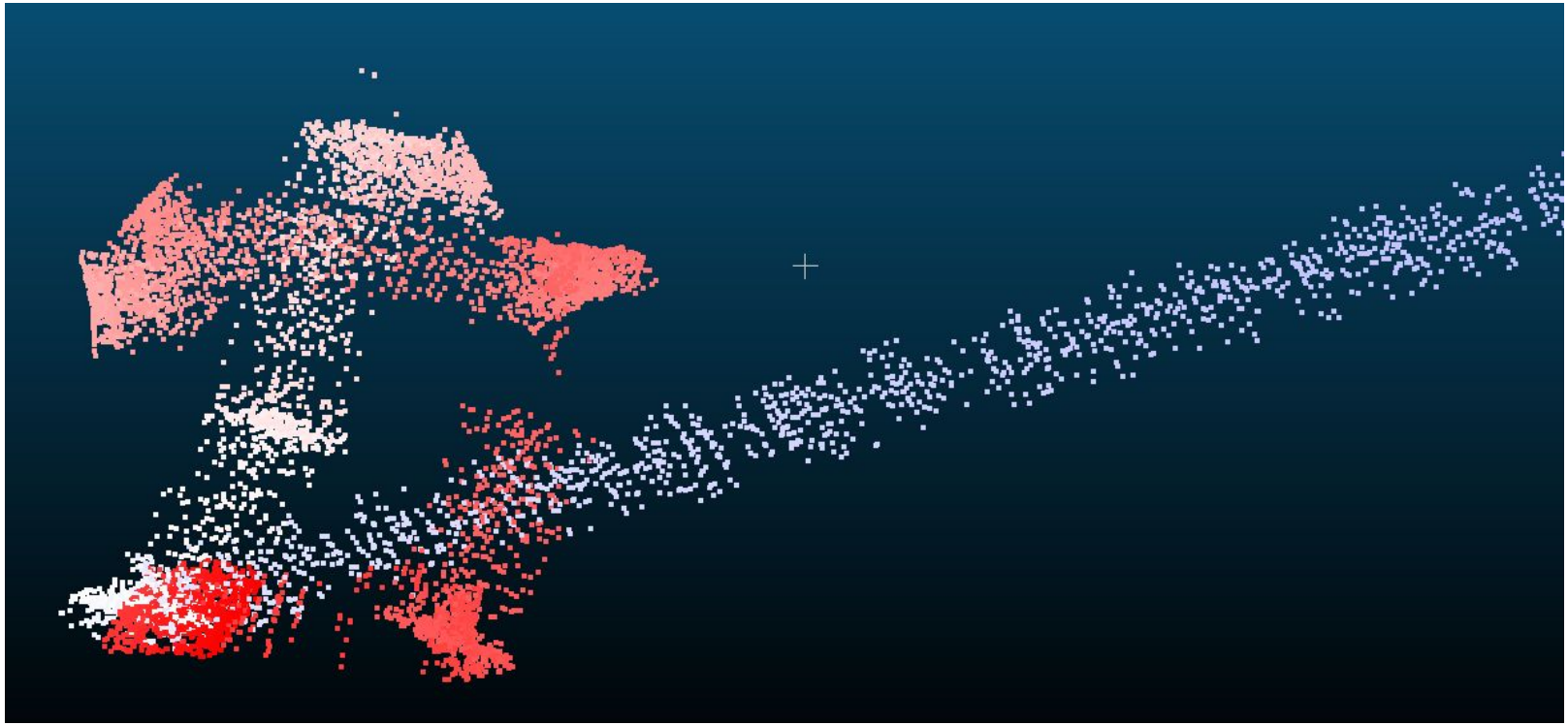
- Single boat survey route



- Multi boat revisit routes
- Red and green routes spend available energy to visit optional POIs

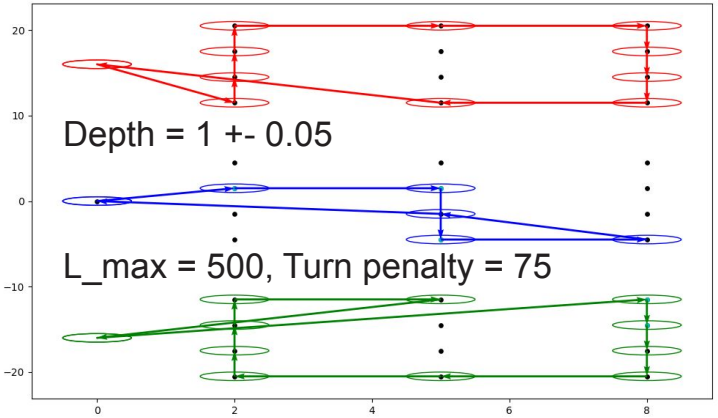
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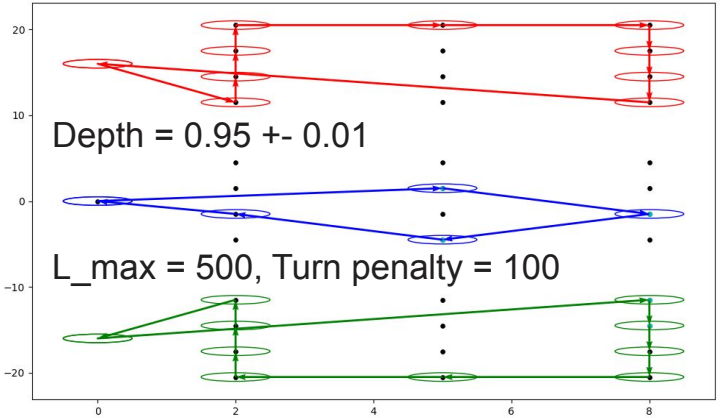
Multibeam Sonar

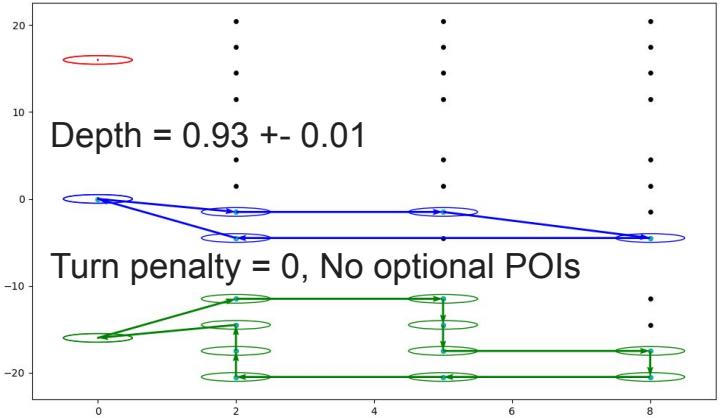


- Red areas correspond to POIs
- Fern Ridge is very flat

Field Trials: Algorithm Capabilities







- Using Fern Ridge data
- Route Optimization
  - Max vehicle travel distance
  - Different reward functions
  - No optional POIs

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Simulator and Algorithm Implementation

HoloOcean

- A high-fidelity marine simulator developed by FRoStLAB at BYU
- Great physics engine
- Support for multiple robot missions
- Mostly used for perception and motion planning tasks



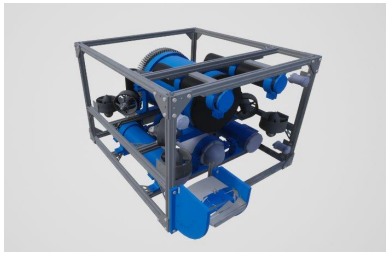
HoloOcean multiple robot underwater scenario

HoloOcean Robots

Underwater Robots



BlueROV



Hovering AUV



Torpedo AUV



Coug UV

Aerial Robot



Surface Vessel



Allows for heterogeneous missions

HoloOcean Sensors and Devices

Sensors

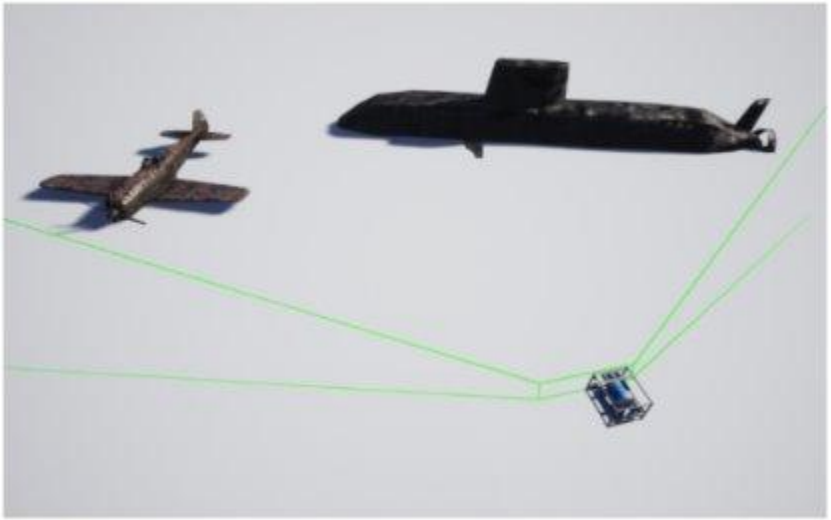
- IMU
- Sonar sensors: singlebeam sonar, multibeam imaging sonar, sidescan sonar, profiling sonar
- GPS
- Doppler Velocity Log (DVL)
- RGB camera
- Depth sensor (AUVs only)
- Range finder sensor

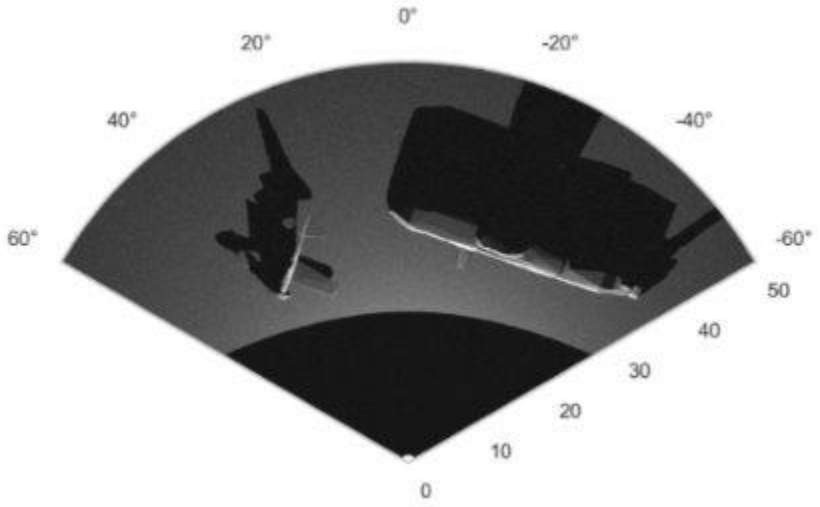
Communication Devices

- Acoustic beacon
- Optical modem

Simulator Capabilities

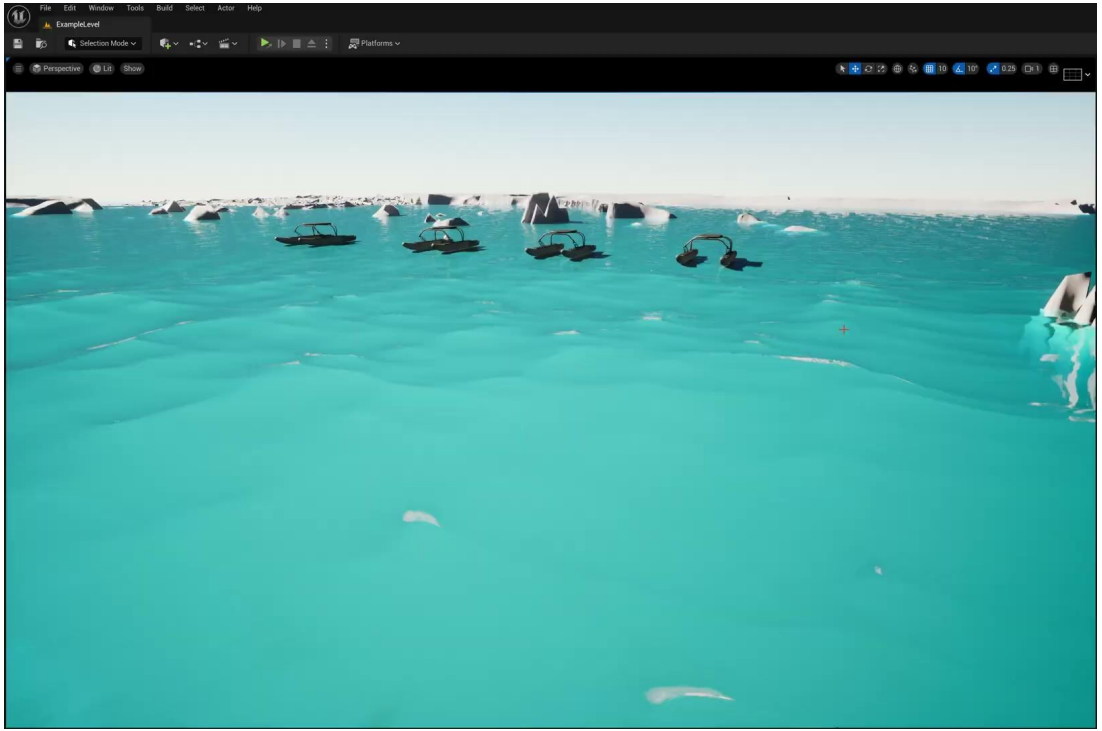
Object recreation with sonar data





Custom Simulation Environment

Fern Ridge Lake Creation in Unreal Engine



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Custom Simulation Environment

Final Fern Ridge Lake in HoloOcean

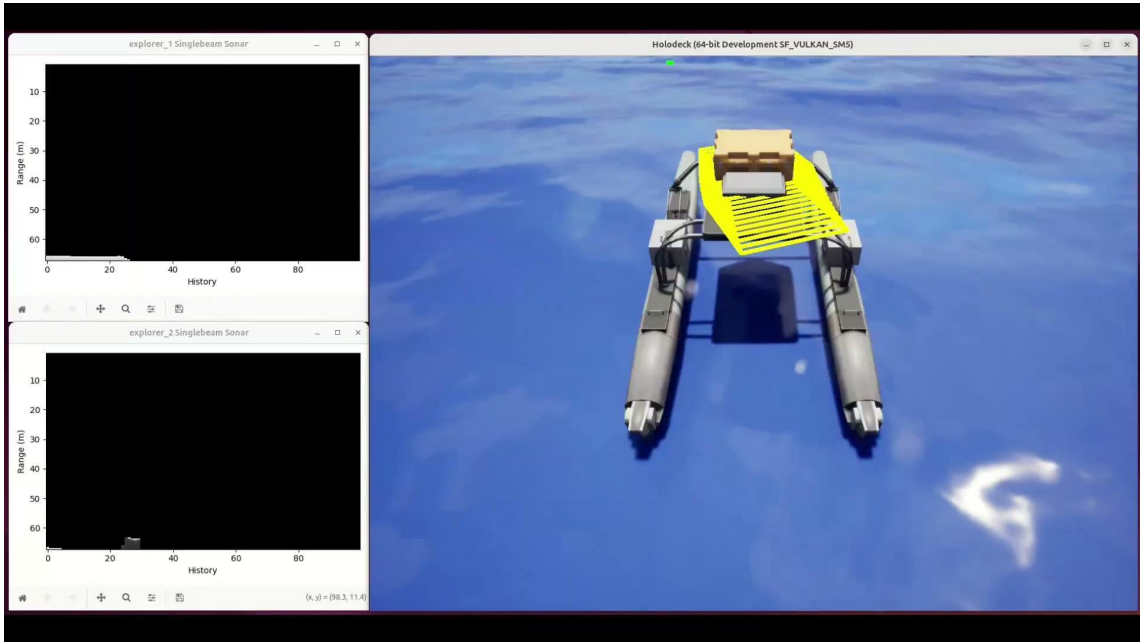


Simulation Setup

- Two types of USVs based on the field experiments
  - Explorers
    - Singlebeam sonar for lake depth measurements
  - Deep Search
    - Same capabilities as Explorers
    - Imaging sonar for recreating objects identified by the explorer agents
- Simple obstacle detection and collision avoidance for all USVs

Fern Ridge Lake Deployment in HoloOcean

Three USVs: two Explorers and one Deep Search

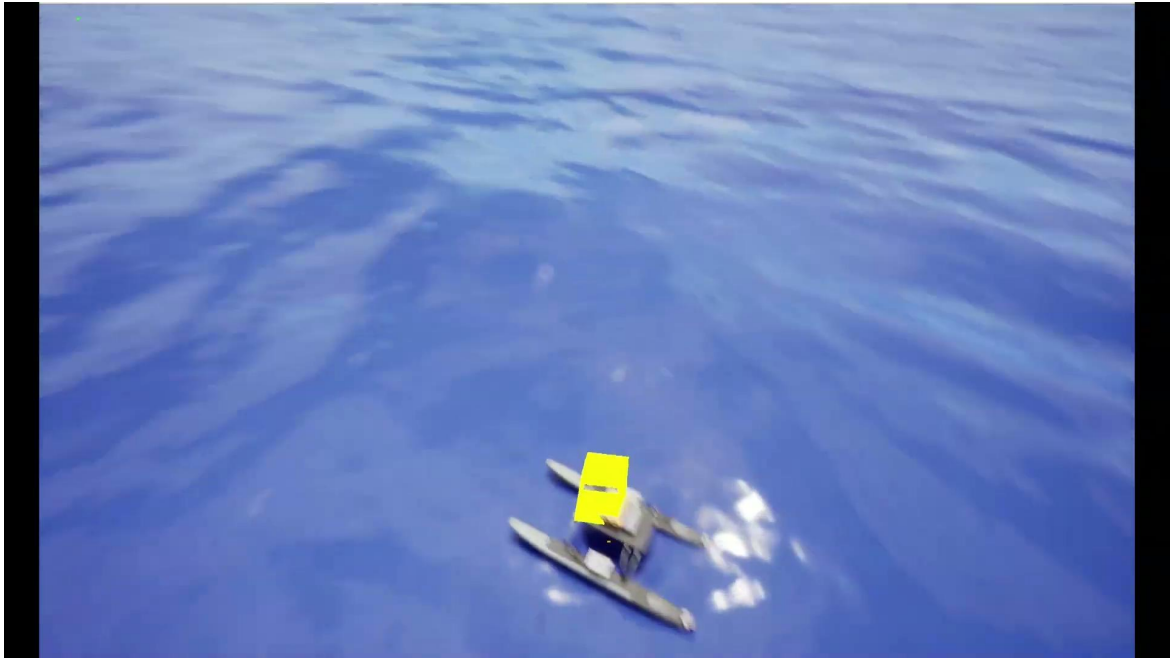


Video speed: x3 in simulation

- Yellow marker: Explorers
- Magenta marker : Deep Search USV
- Green waypoints: coordinates for exploration
- Magenta waypoints: Points of interest for the deep search

HoloOcean: Scaling to 50 USVs

Fifty USVs: thirty Explorers and twenty Deep Search with no sonar sensors



Video speed: X2 in simulation

- Yellow marker: Explorers
- Magenta marker : Deep Search USVs
- Green waypoints: coordinates for exploration
- Magenta waypoints: Points of interest for deep search

HoloOcean: Summary

- Pros
  - Heterogenous multiple robot missions
  - High fidelity graphics
  - Can support up to 50 robots in a single simulation without sonar sensors

- Cons
  - Resource intensive when using sonar sensors with more than four robots
  - Simplified hydrodynamics

Simulation Alternatives

➢ Gazebo VRX

- Pros
  - Modular plugin architecture
  - Native ROS 2 integration
  - Great physics engine



- Cons
  - No multibeam or side scan sonars
  - Low fidelity graphics
  - Difficult to create custom simulation environment (E.g., Fern Rigde Lake)
  - Scales up to 10 USVs without sensors

Simulation Alternatives

➢ **Stonefish**

- Pros
  - High-Fidelity Physics
  - Good graphics
  - Lightweight and more scalable



- Cons
  - Limited support for heterogeneous multiple robot missions
  - Fewer sensors compared to HoloOcean
  - Difficult to create custom environments like Fern Ridge lake

Conclusion