NRI-FND: Human-Team-Supervised Autonomy with Application to Underwater Search and Rescue

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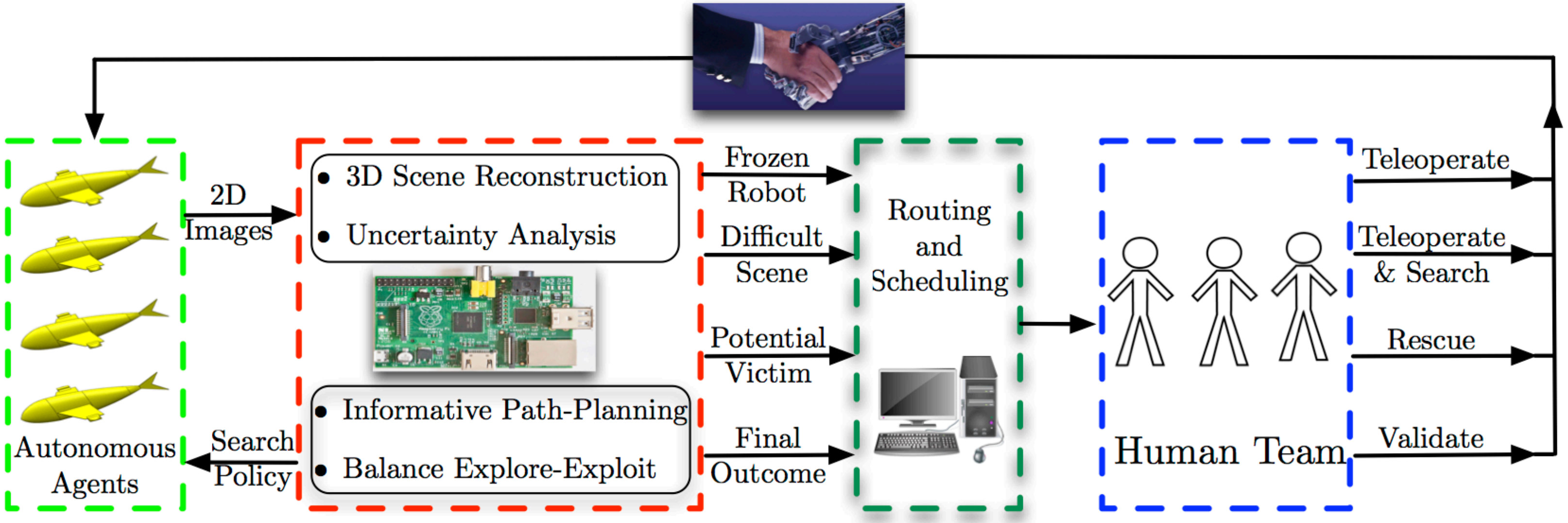
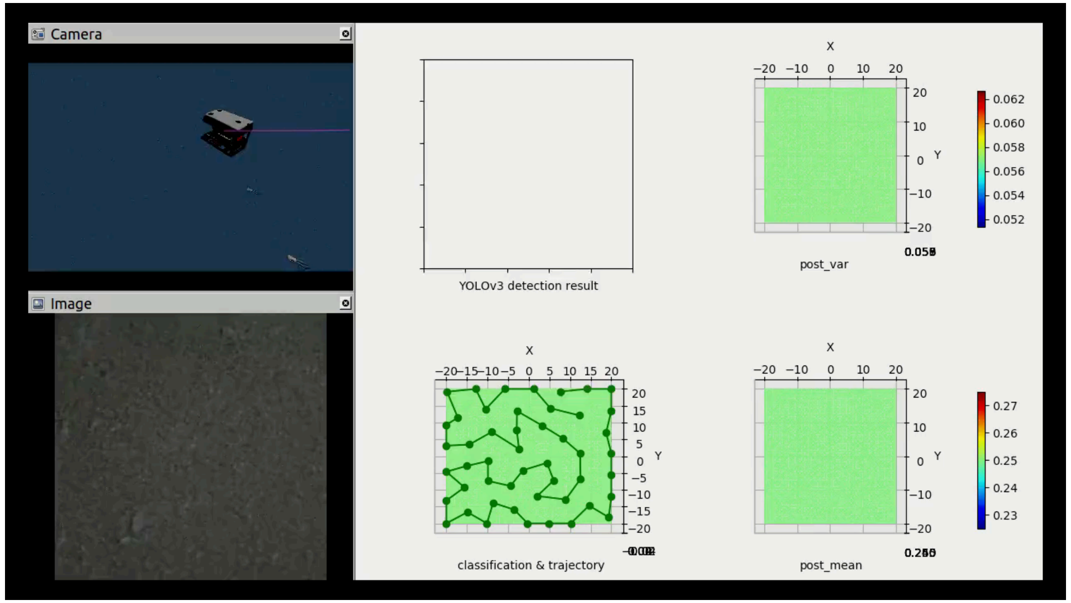
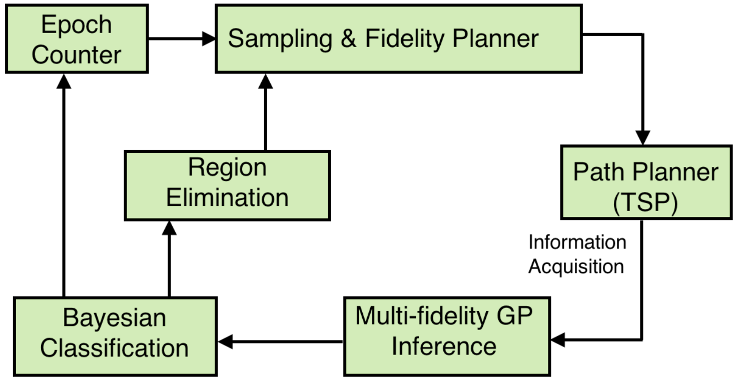
Project Objectives



- Informative path planning for search for targets of interest
- Optimal task allocation and scheduling for human-team supervision
- Development of a heterogeneous group of gliding robotic fish, ROVs and a robotic boat
- Experimental evaluation in field trials emulating underwater search and rescue

Multi-fidelity Informative Path Planning for Expedited Target Detection





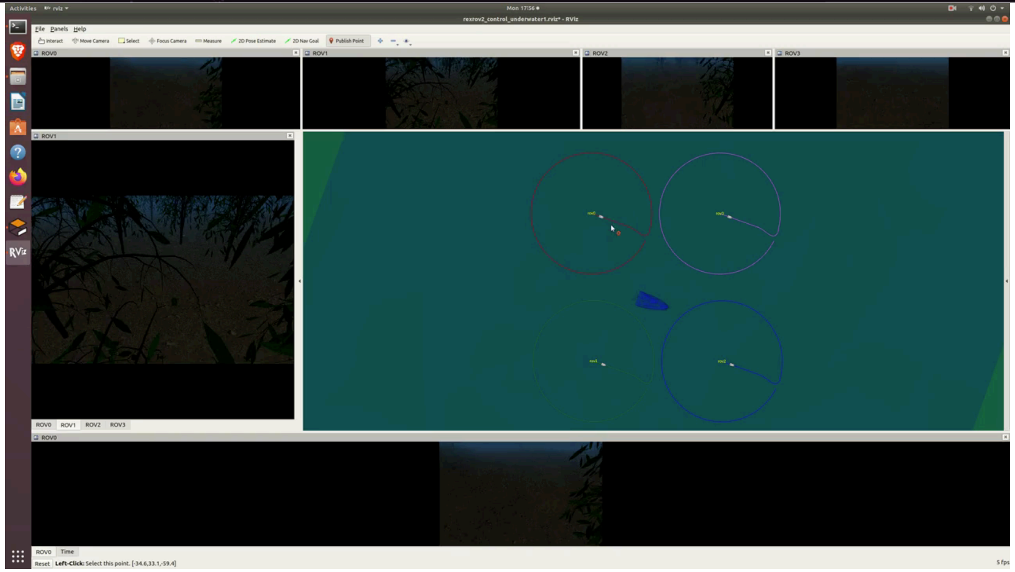
Multi-fidelity Search Algorithm Architecture

- Objective: Expedited detection of unknown number of targets
- Sampling at lower (higher) depths provides more coverage but lower(higher) fidelity
- A multi-fidelity GP model for sensing performance

$$\boxed{g_m(x) = a_{m-1} g_{m-1}(x) + b_m(x)}$$

- $g_m(x)$ = processed sensing output at fidelity m
- $b_m(x)$ = sensing bias at fidelity m modeled as a GP
- Greedy sampling at each fidelity and a fidelity switching rule
- Formal guarantees on expected detection time

Human Supervisory Underwater Search Experiments

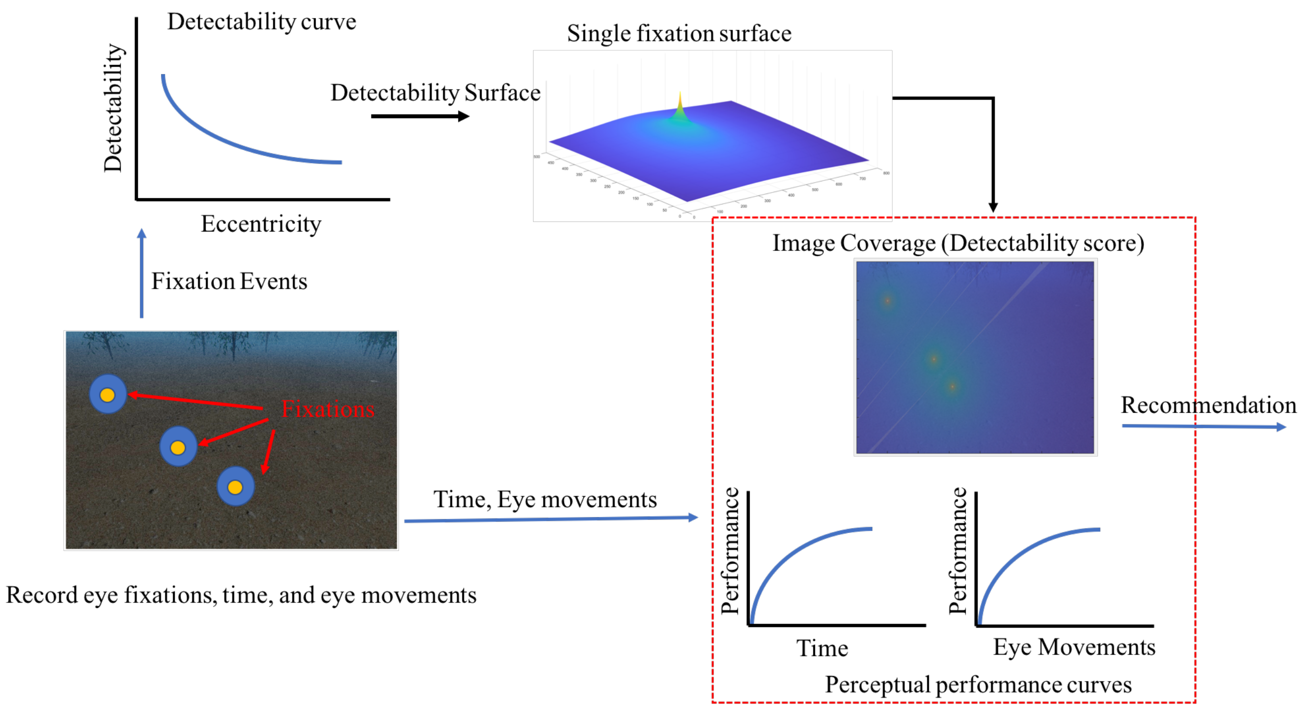


Experiment 1: Search and Possible Tele-operation

- Human monitors feed from multiple ROVs
- Human can tele-operate them as needed
- Using EEG to assess cognitive load and assign ROVs to operator

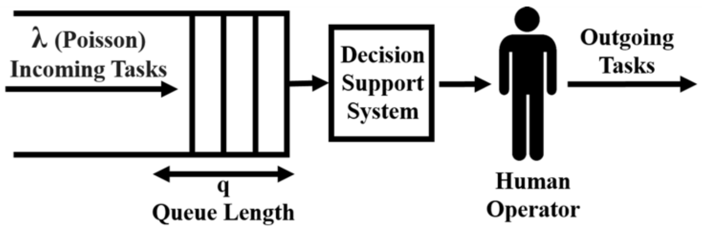
Experiment 2: Searching for Victims

- Using eye-tracker to observe fixations and estimating detectability performance
- Recommendation to monitor unexplored areas of image

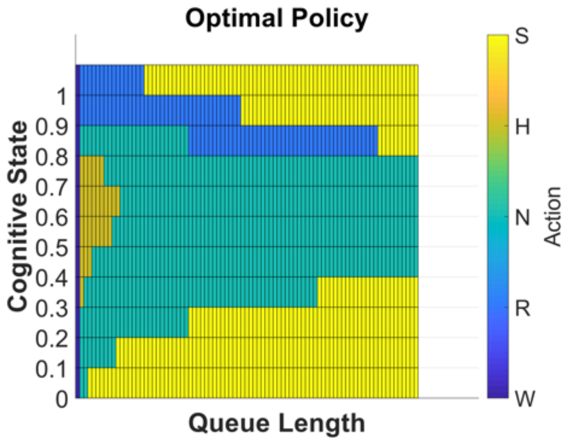


Task Allocation for Human-Team Supervision

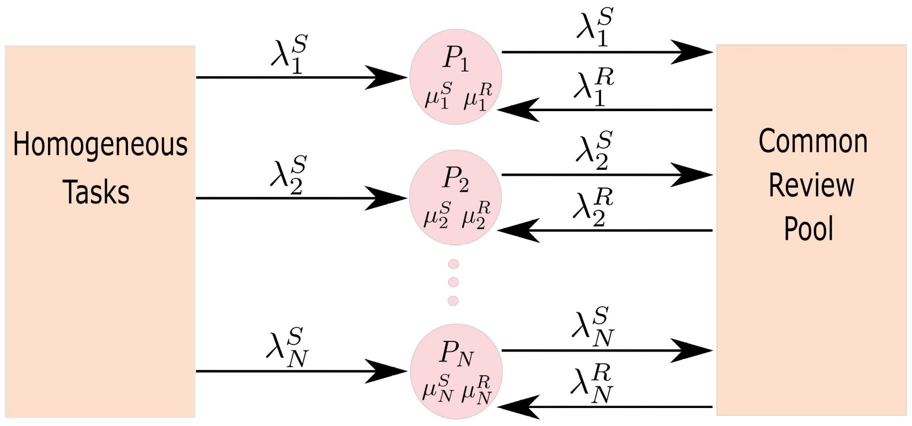
Optimal attention allocation for human operator



- Queuing framework for human servicing search tasks
- Service time function of lumped cognitive state
- Semi-MDP for computing optimal policy for human



Common Pool Resource Games For Efficient Collaboration

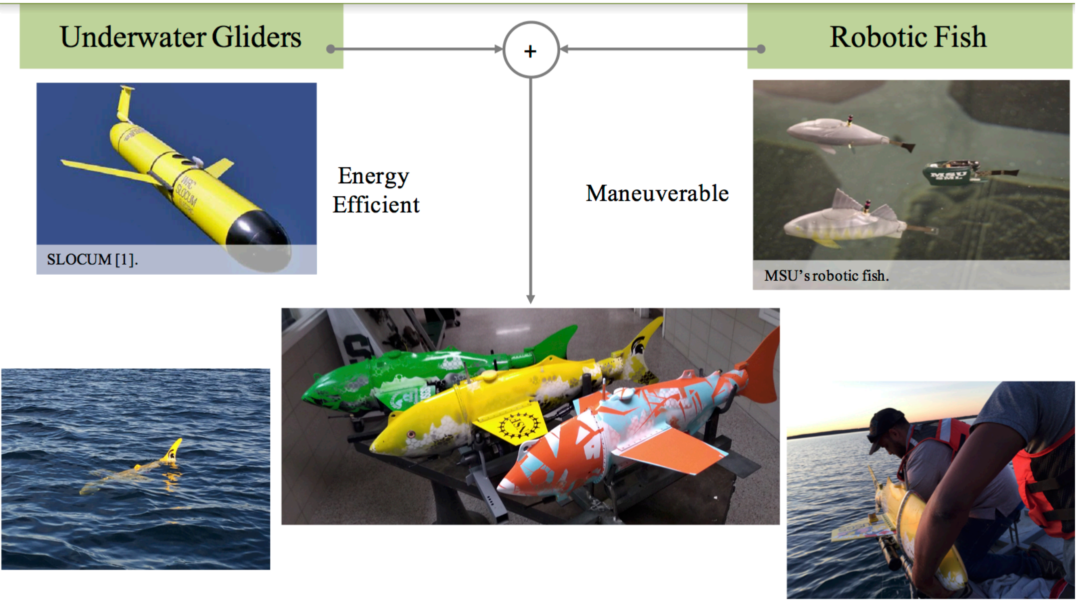


$$\frac{\mu_1^S}{\mu_1^R} \leq \frac{\mu_2^S}{\mu_2^R} \leq \cdots \leq \frac{\mu_N^S}{\mu_N^R}$$

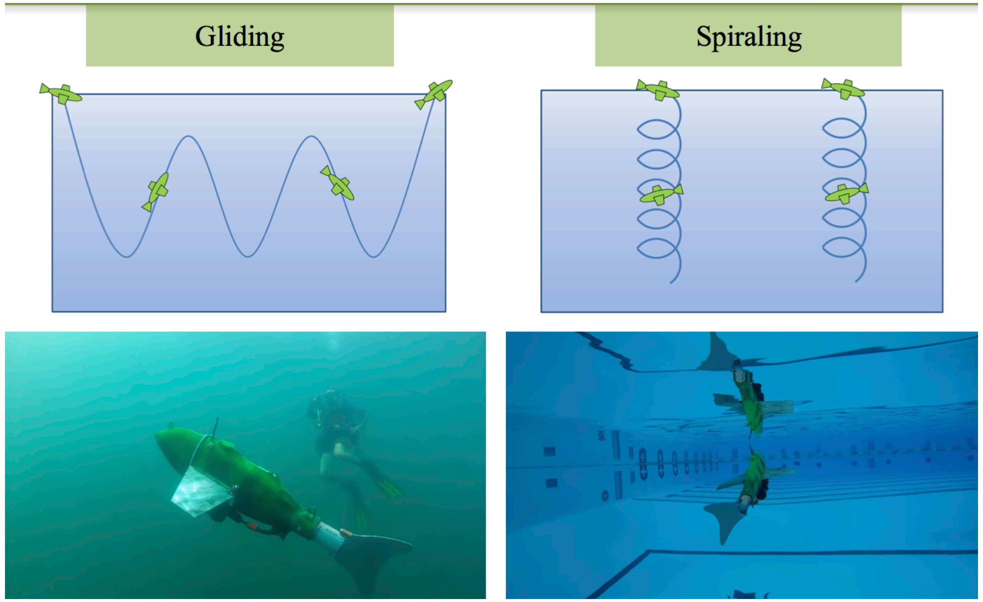
- Team servicing and reviewing (from CPR) tasks
- ***Heterogeneity***: Different service and review capabilities
- ***Objective***: Incentivize team collaboration
- Establish existence of unique PNE; *Price of Anarchy* ≈ 1
- Best response dynamics converge to PNE

Advances in Gliding Robotic Fish

Robotic Platform: Design Concept



Robotic Platform: Working Principle



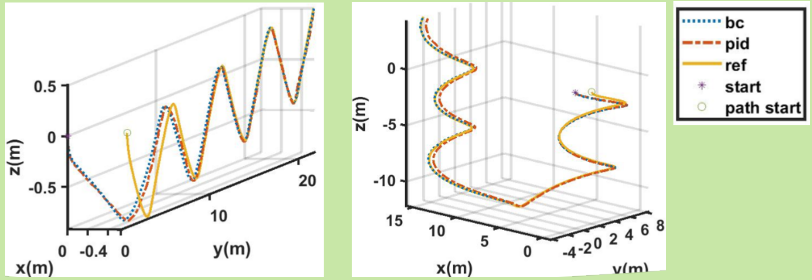
Next Generation Design improvements

(a) Modular mechanical design
(b) Modular actuator configuration
(c) Individually sealed modules
(d) Faster development and maintenance
(e) Vectored thruster propulsion

Electronics improvements

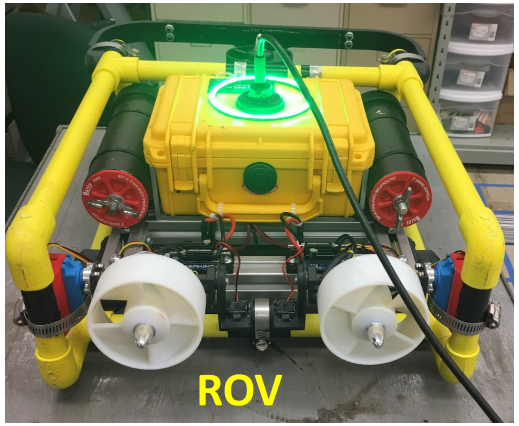
- Iridium Satellite Communication
- Wi-Fi Communication
- Improved computational power
- 32 GB on board Storage
- Larger battery capacity

Trajectory Tracking Control Simulations



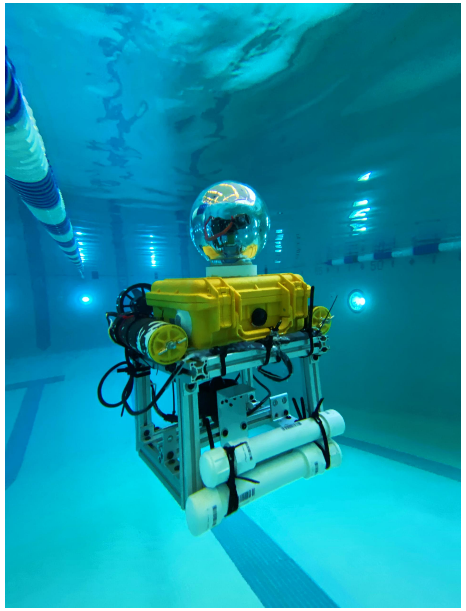
[1] D. C. Webb, P. J. Simonetti, and C. P. Jones, "SLOCUM: An underwater glider propelled by environmental energy," *IEEE Journal of Oceanic Engineering*, vol. 26, no. 4, pp. 447–452, 2001.

ROV Platform and Robotic Boat

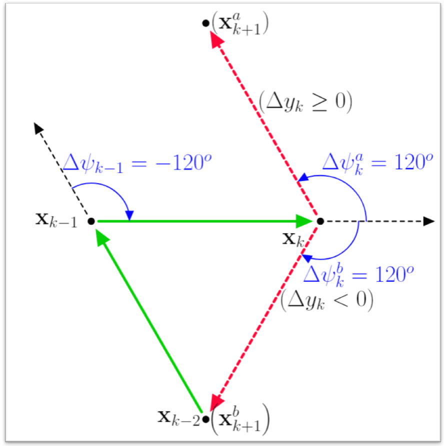


- ROV communicates through a buoy that floats on the surface of the water
- Boat carries assistive devices and can perform autonomous waypoint tracking
- Side-scan sonar unit is designed to operate remotely while being towed by the boat

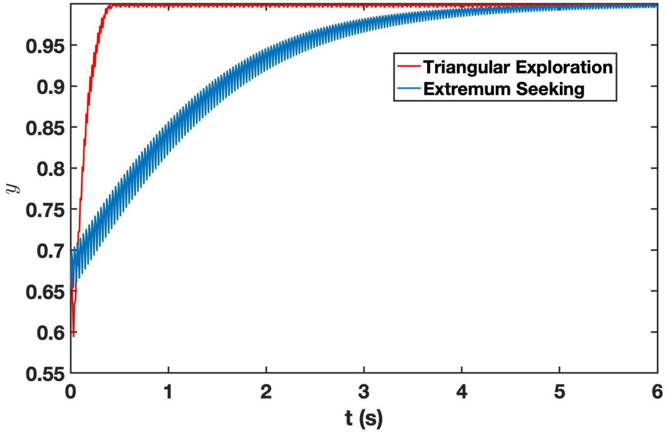
Optical Communication for Underwater Robots



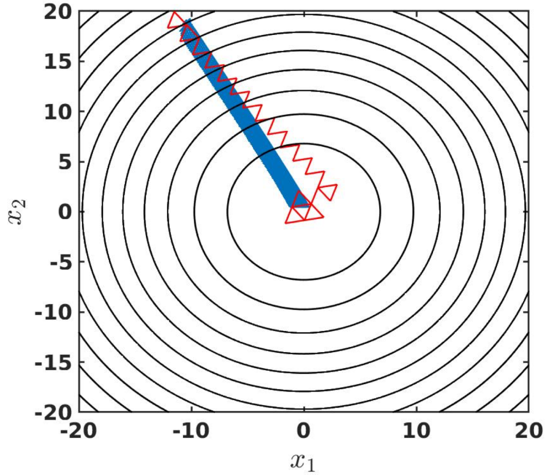
Triangular exploration

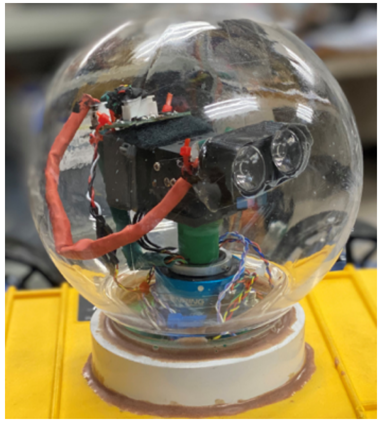


Convergence rate



Trajectory in $\boldsymbol{x}$ plane

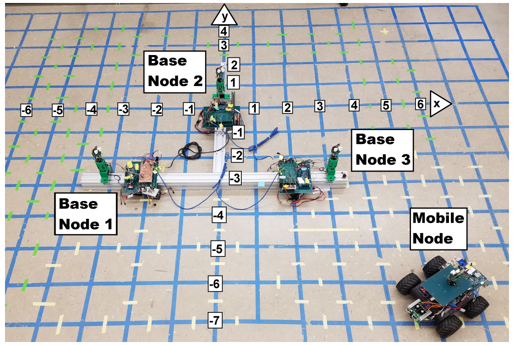




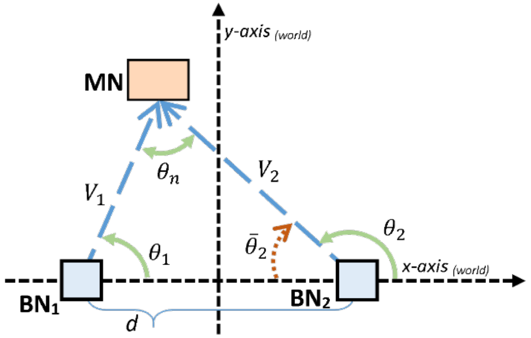
- Objective is to achieve Line of Sight (LOS) between two underwater optical transceivers
- $\boldsymbol{x}_k$ represents the LOS direction in spherical coordinates attached to receiver frame
- A novel geometry-based algorithm that achieves quick alignment of transceiver with LOS

Optical Localization for Underwater Robots

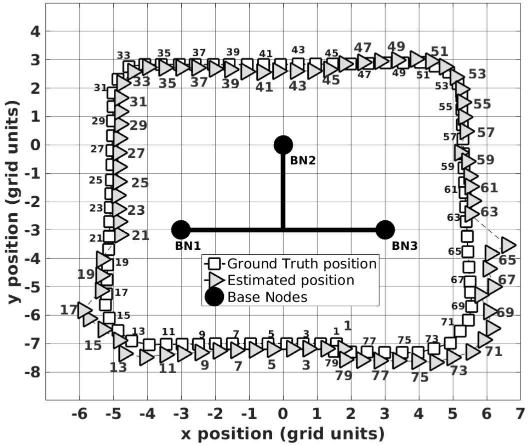
Experiment Setup



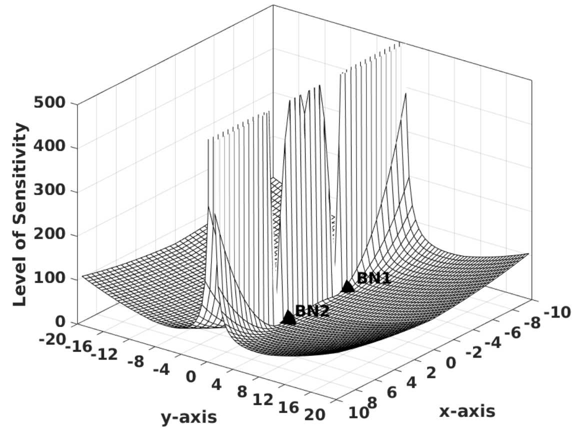
Triangulation Concept



Experiment Results



Spatial Sensitivity Visual



- Localization of a mobile robot using the bearing angles, for establishing Line of Sight (LOS) between the robot and two base nodes, to triangulate the position
- A spatial sensitivity metric of the two-base-node triangulation method is developed
- The sensitivity metric is used to determine the most robust base node pairing
  - Smaller sensitivity value correlates to higher confidence in the measurement accuracy

Current Directions

- Underwater search experiments in tank and swimming pool
- Multi-robot coordination for multi-fidelity search
- More comprehensive human supervisory underwater search experiments
- Active alignment for bi-directional optical communication

Thank You