Co-Multi-Robotic Exploration of the Benthic Seafloor

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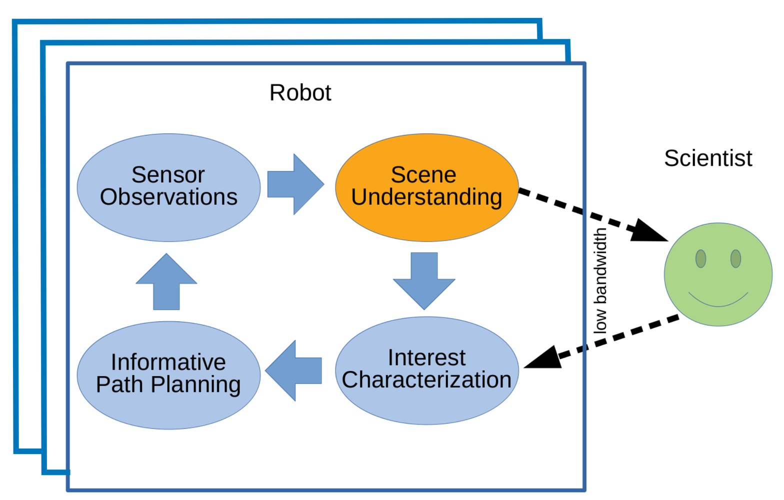
http://warp.whoi.edu/co-robotic-exploration/

Overview

This project is focused on developing new techniques to enable interactive exploration in unknown, low bandwidth environments, with a multi-robot team. The proposed approach enables new types of data collection missions that can target spatiotemporally sparse, and previously unknown phenomena, in extreme environments like the deep sea.



Challenges

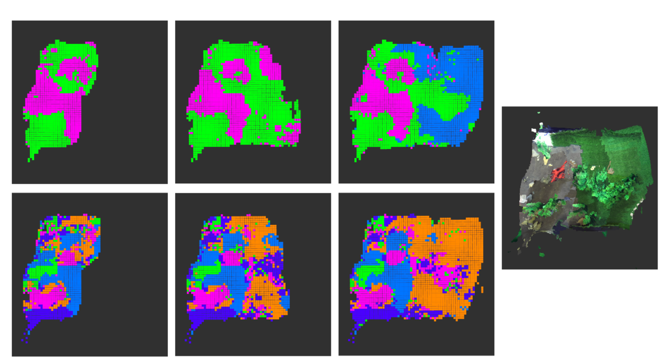
- The primary hurdle in autonomous deep sea exploration is the extremely **low bandwidth communication**.
- A vast majority of the oceans and the seafloor is **unexplored and unknown**, and hence there is very limited amount of data available for targeted autonomous missions.
- The **scale** of the oceans necessitate exploration using multi-robot teams. Strict bandwidth limitations mean they must coordinate with each other efficiently.
- **Informative path planning for robots when observations are categorical**, such as observations of species or tax types, is hard when number of species is large.

Scientific Impact

- The proposed exploration approach **generalized to many other types of environments** beyond the deep sea such as: aftermath of a natural disaster, caves and mines, and other planets, where there exist communication bottlenecks.
- The proposed **distributed unsupervised scene understanding** and **active reward learning** is, to our knowledge, the first to enable interactive exploration in communication constrained environments.
- The proposed generative model for spatially distributed categorical observations is ideally suited for **modeling complex ecosystem**, habitats, and community structures, enabling new applications in ecology.

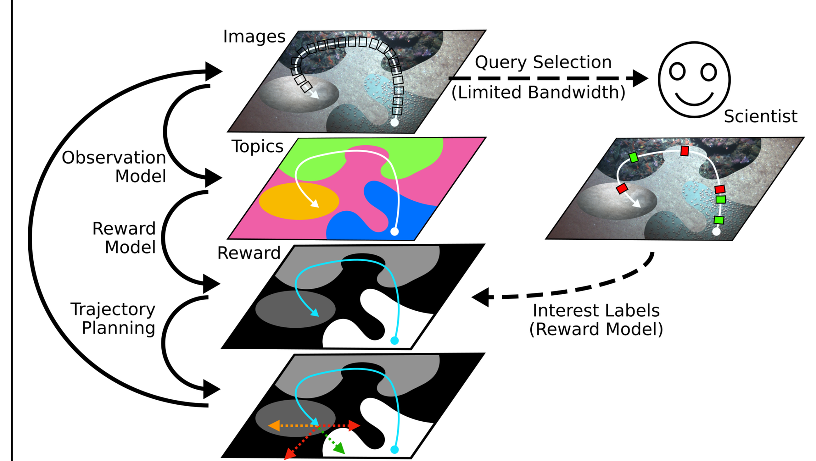
Key Innovations

Unsupervised semantic maps from streaming image data



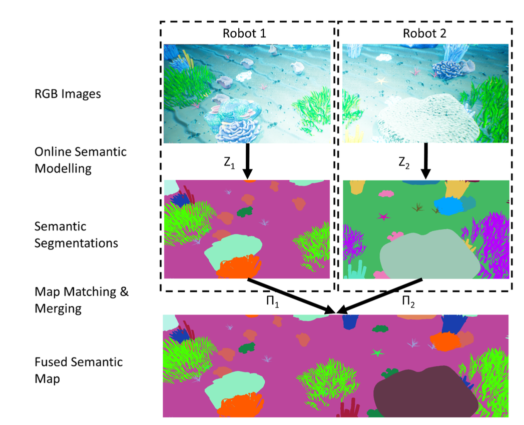
Girdhar, Y. et al. Streaming Scene Maps for Co-Robotic Exploration in Bandwidth Limited Environments. in 2019 International Conference on Robotics and Automation (ICRA) 7940–7946 (IEEE, 2019). doi:10.1109/ICRA.2019.8794132.

Active reward learning over low bandwidth



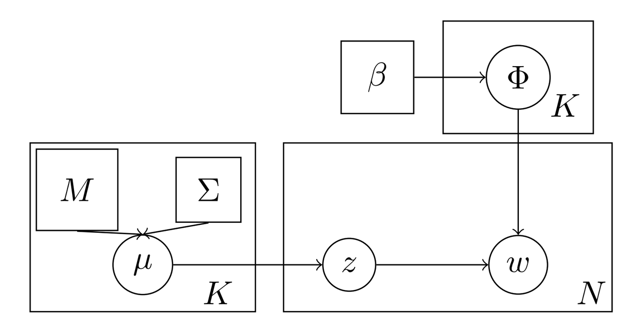
Jamieson, S., How, J. P. & Girdhar, Y. Active Reward Learning for Co-Robotic Vision Based Exploration in Bandwidth Limited Environments. in 2020 IEEE International Conference on Robotics and Automation (ICRA) 1806–1812 (IEEE, 2020). doi:10.1109/ICRA40945.2020.9196922.

Distributed unsupervised semantic maps in low-bandwidth environments



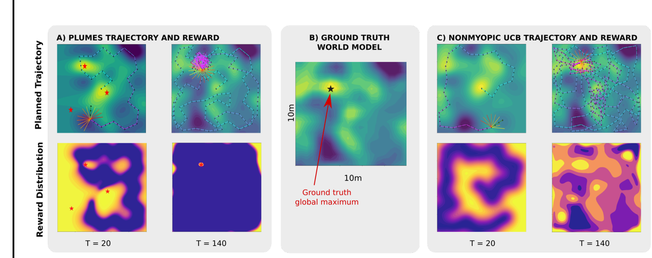
- Doherty, K et al. Approximate Distributed Spatiotemporal Topic Models for Multi-Robot Terrain Characterization. in IROS 2018. doi:10.1109/IROS.2018.8594442.
- Jamieson, S et al. Multi-Robot Distributed Semantic Mapping in Unfamiliar Environments through Online Matching of Learned Representations. in ICRA 2021.

Enabling informative path planning with high dimensional categorical observations using GP and topic models



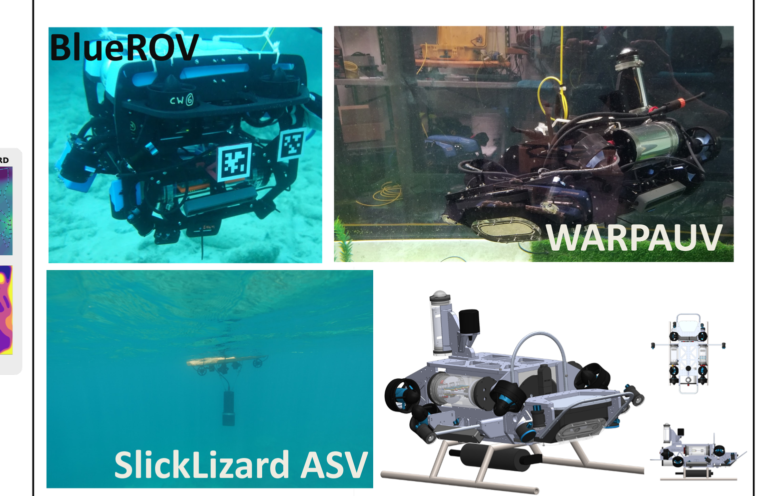
Soucie, J. S., Sosik, H. & Girdhar, Y. Gaussian-Dirichlet Random Fields for Inference over High Dimensional Categorical Observations. in International Conference on Robotics and Automation (ICRA) (2020).

Informative path planning for maximum seek-and-sample missions



Flaspohler, G., Preston, V., Michel, A. P. M., Girdhar, Y. & Roy, N. Information-Guided Robotic Maximum Seek-and-Sample in Partially Observable Continuous Environments. IEEE Robot. Autom. Lett. 4, 3782–3789 (2019).

Robot systems for distributed underwater exploration



McGuire, N., Cai, L., Belani, M., Claus, B. & Girdhar, Y. [poster] WARPAUV: A low-cost, vision-guided AUV for robotics research. in Northeast Robotics Colloquium (2019).

Broader Impacts

Impact on Society

- Potential applications to coral reef health monitoring in the face of climate change. The 2020 field trials will collaborate with coral reef scientists to study endangered stag horn corals
- Cross disciplinary work with marine ecologists.
- Use of methods by third party researchers/robots (NDSF AUV Sentry)
- Lowering barriers to using co-robotics to explore the ocean

Education and Outreach

- Motivating STEM education in high school students through a summer volunteering in the lab.
- Training graduate students
- Robotics field trials with students
- Development of WARPAUV as an open research platform for vision guided AUVs

Quantifiable Impact

- 5 refereed conference papers
- 1 journal paper
- Best paper award in service robotics at ICRA2020
- Finalist for best paper award at IROS 2018.
- First place prize at MIT Mechanical Engineering Research Exhibition 2019.
- 10 students trained (graduate, undergraduate, high school)
- Use of methods by third party researchers/robots (NDSF AUV Sentry)