National Aeronautics and Space Administration

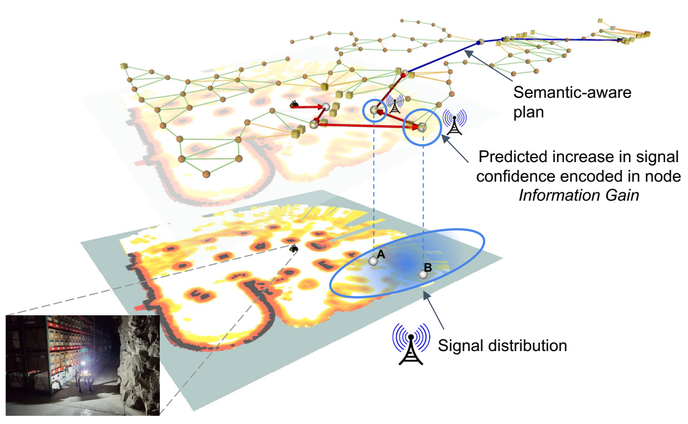
Postdoc Research

Informative Planning for Active Source Seeking in Complex, Unknown Environments

Author: Sangwoo Moon, JPL Postdoctoral Fellow (347T)
Oriana Peltzer[+], Sung-Kyun Kim[+], Joshua Ott[*], Marcel Kaufmann (174C), Mykel Kochenderfer[*], Shehryar Khattak (347J), Benjamin Morrell (347T)

[*] Stanford University, [+] Field AI

Background and Objectives



Background

Autonomous Robotics **exploration** & **signal source localization** in **challenging environments**

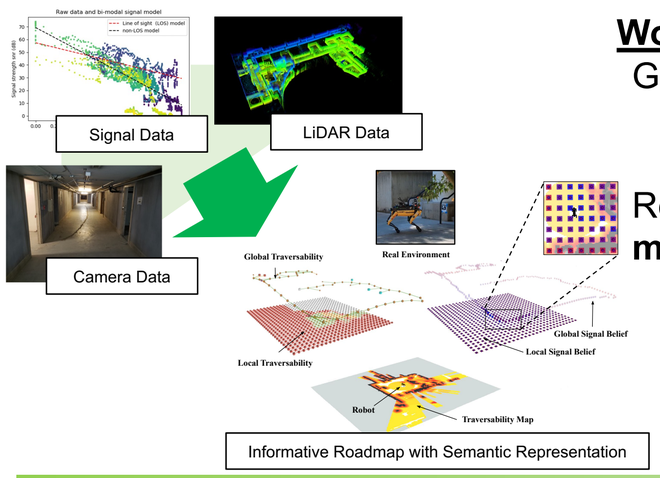
- **Map** complex 3D environments without GPS
- **Navigate** safely in obstacle-laden environments
- **Detect & Localize** objects of interest using visual/RF signatures

Objectives

Develop **an informative planning architecture and its approaches** to take action that maximizes repeatedly

- **Increase in confidence** about the source location
  - Actual signal readings and word semantics
  - Prior knowledge about signal, visual, and geometric sensing modality

Environment Representation



World Belief

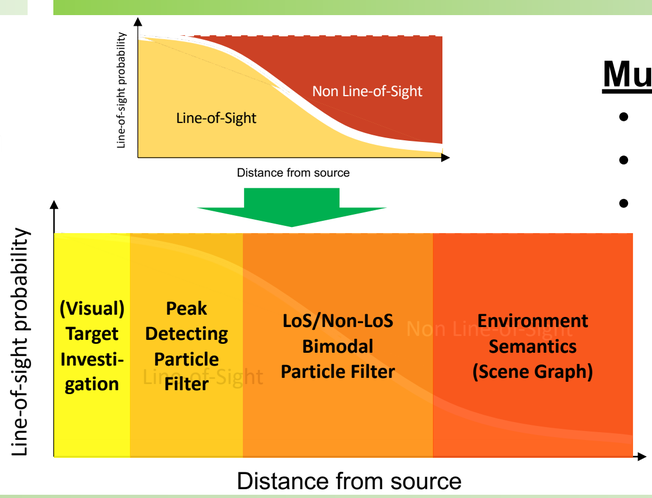
Global + local belief in

- Geometric information
- Signal map

Real-time **belief update** with **multi-modal** sensors

- Signal sensor
- LiDAR
- InfraRed depth
- Camera (RGB-D)

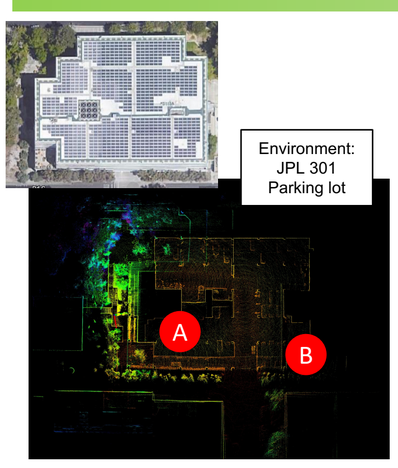
Informative Planning Architecture



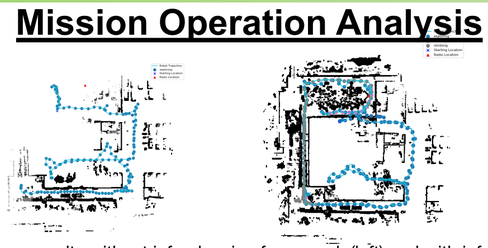
Multi-Stage Reactive Informative Planning

- With respect to distance from the source
- Easier to adapt to various situations
- Planning component:
  - Rough environment encoding : **scene graph**
  - **Signal belief** from multi-modal estimations
  - **Reactive** signal belief tracing max info
  - **Surface coverage** for visual confirmation

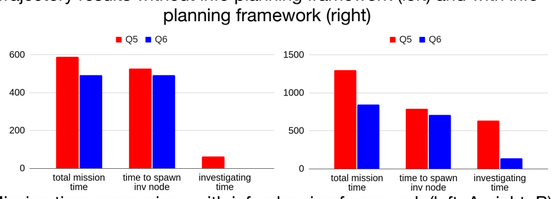
Experimental Results and Analysis



Mission Operation Analysis

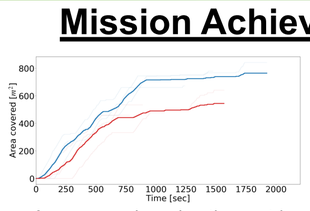


Trajectory results without info planning framework (left) and with info planning framework (right)

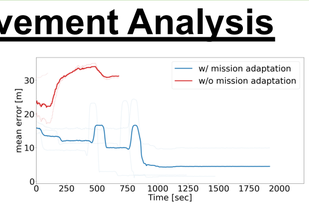


Mission time comparison with info planning framework (left: A, right: B)

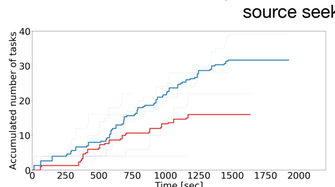
Mission Achievement Analysis



Area covered: exploration metric

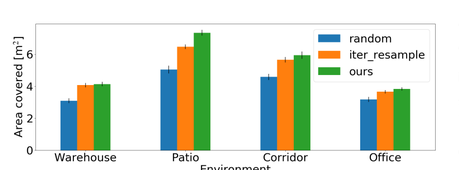


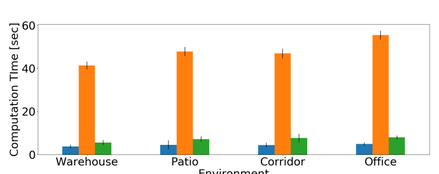
Signal source localization error: source seeking metric



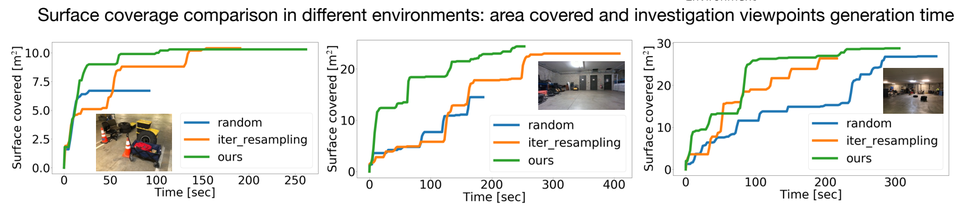
Cumulative accomplished tasks: task achievement metric

Visual Target Investigation Analysis



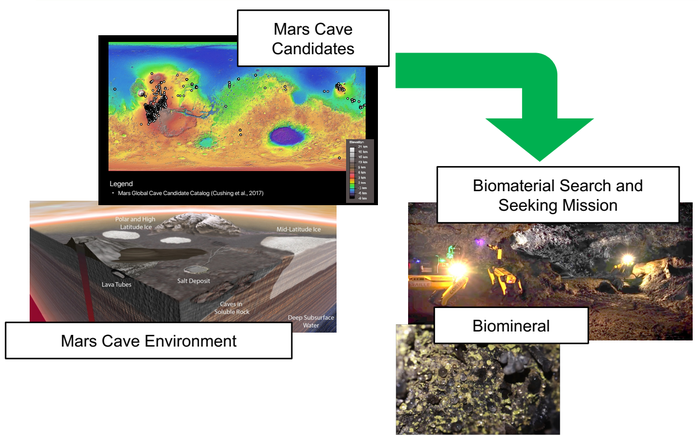


Surface coverage comparison in different environments: area covered and investigation viewpoints generation time



Surface coverage comparison in different environments: surface area covered during mission

Benefits to NASA/JPL



Leveraging **autonomous informative planning** with **challenging environments** for geoscience/space missions

- **Unknown** environment information
- **Dark & hazardous** not for human operations
- **Applicable scenarios**
  - Earth/Moon/Mars exploration with biomaterial searching/seeking
  - Disaster/climate profiling and monitoring
    - e.g., wildfire monitoring, plume detection

Future Work

High-Level Decision-Making

- Exploration & source-seeking in **multi-level indoor & outdoor areas**
- **State machine configuration** for behavior selection

Robust Radio Signal Model

- Universal usage regardless of environment

Scene Graph Utilization

- Leveraging scene graph for information measure

Multi-Robot Operation for Multi-Source Seeking

- Coordination scheme using informative planning

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Publications:

1. Sangwoo Moon, Sung-Kyun Kim, Oriana Peltzer, Mykel J Kochenderfer and Shehryar Khattak, "**Efficient Line-of-Sight Viewpoint Sampling in Complex Environments for Autonomous Surface Inspection** (submitted)," 2024 IEEE International Conference on Robotics and Automation (ICRA), Yokohama, Japan, May 2024.
2. Sangwoo Moon, Oriana Peltzer, Joshua Ott, Sung-Kyun Kim and Ali-akbar Agha-mohammadi, "**Semantics-Aware Mission Adaptation for Autonomous Exploration in Urban Environments**," 2023 IEEE/RSJ International Conference on Robotics and Systems (IROS), Detroit, MI, Oct 2023.
3. Christopher E Denniston, Oriana Peltzer, Joshua Ott, Sangwoo Moon, Sung-Kyun Kim, Gaurav S Sukhatme, Mykel J Kochenderfer, Mac Schwager and Ali-akbar Agha-mohammadi, "**Fast and Scalable Signal Inference for Active Robotic Source Seeking**," 2023 IEEE International Conference on Robotics and Automation (ICRA), London, UK, May 2023.

Author Contact Information:

- email: sangwoo.moon@jpl.nasa.gov
- phone: (720) 481 - 8502