National Aeronautics and Space Administration

Uncertainty-aware and semantics-cognizant safe exploration of unknown environments

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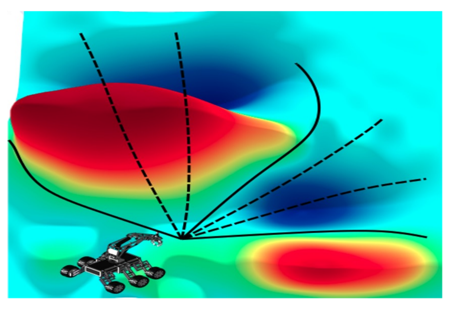
Program: FY22 SURP
Strategic Focus Area: Localization and Mobility

Objectives

- Develop situational awareness algorithms that **encode the uncertainty and semantics** of the environments
- Develop **perception-aware decision making methods** for safe exploration of unknown environments

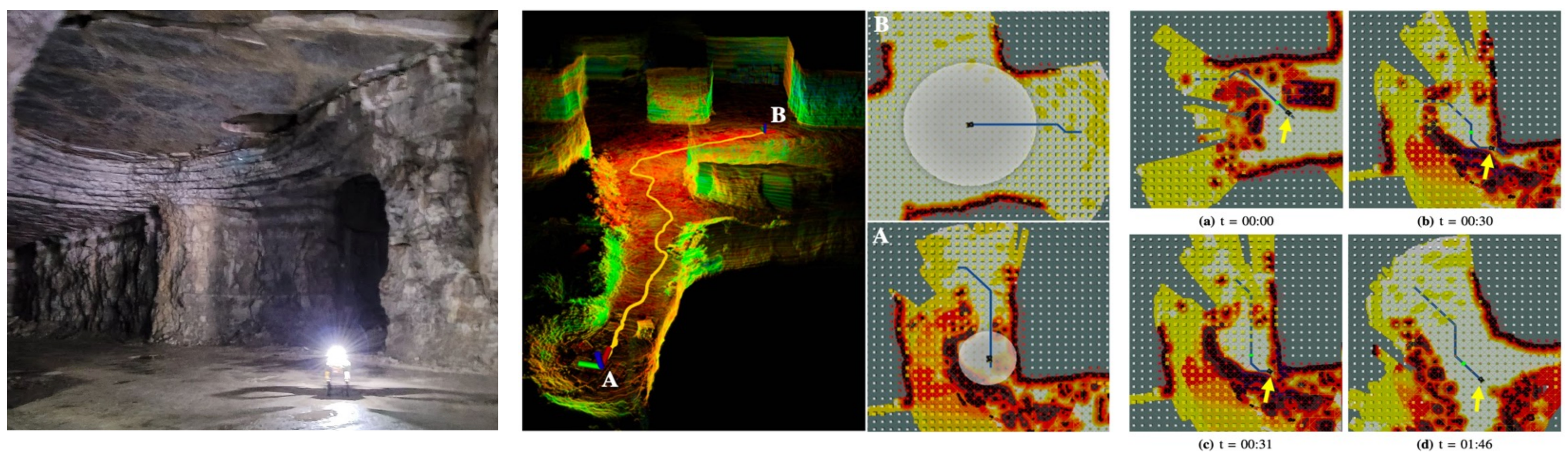


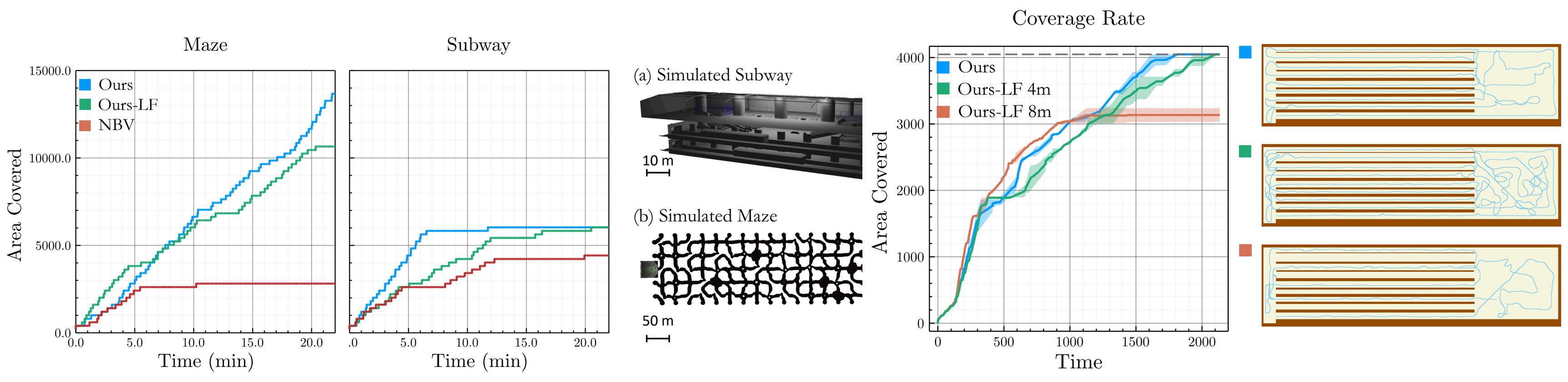
Background

Key capabilities required for lunar concept missions (Design Reference Mission (DRM), Decadal Survey, and Lunar Surface Innovation Initiative (LSII)):

- Long traverse and wide-area sampling
  - For volatile and magnetic field mapping (long-duration, high speed)
- Exploration into comm-denied areas (lunar pits, skylights, tubes)
  - Wide-area/multi-site sampling in the Marius Hills volcanic crater

Results



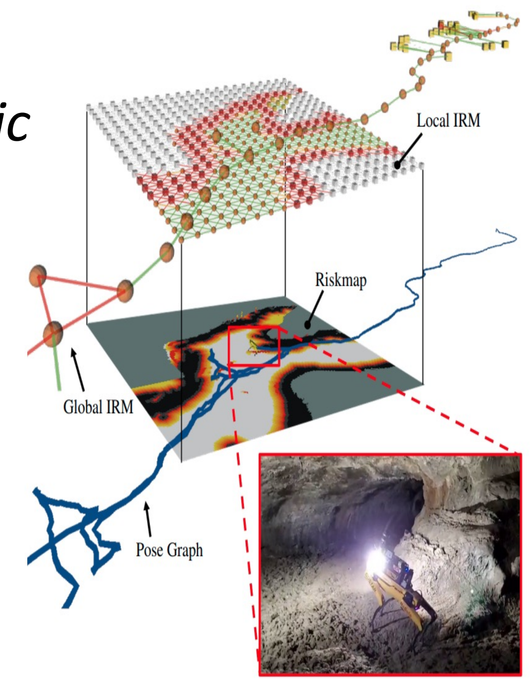


- Achieved efficient coverage rate and high resiliency to diverse environmental characteristics via semantics detection and online adaptation in decision making

Approach

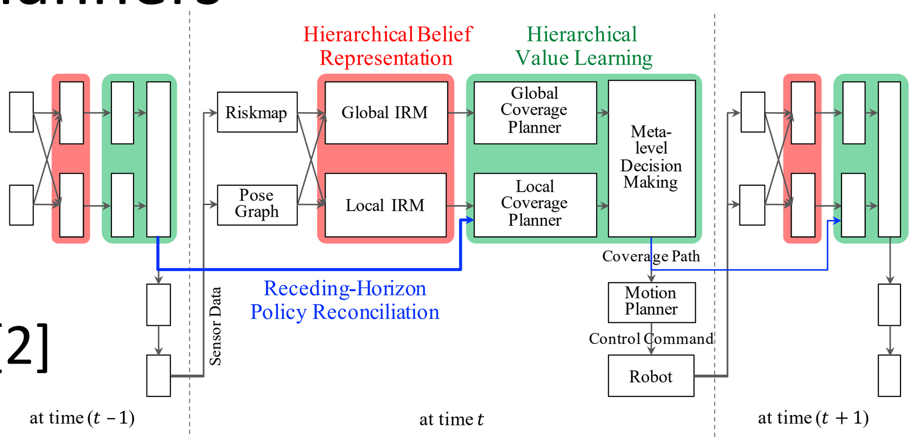
Uncertainty and Semantics Representation

- Information RoadMap (IRM)
  - Generic graph representation with *probabilistic* attributes [1]
  - Detect and encodes *semantics*, including spaciousness and traversability
- Hierarchical Representation
  - Local IRM to capture high-fidelity semantic information
  - Global IRM to scale up to very large environments (~kms)



Semantics-Cognizant Planning under Uncertainty

- Hierarchical Coverage Planners
  - Finds a path on Local/Global IRMs that maximizes info gain and minimizes traversal cost
  - Leveraged a multi-heuristic dynamic programming solver [2] and an orienteering solver [A]



- Semantics-based Online Adaptation
  - Adjust the coverage field of view based on the spaciousness [B]
  - Switch between local/global plans based on the traversability

Significance/Benefits

- Enhanced situation awareness
  - Autonomous semantics detection and its scalable representation
- Semantics-aware safe exploration capability
  - Real-time multi-resolution planning under uncertainty
  - Hardware validation both in large and narrow spaces

[1] Kim, et al., "PLGRIM: Hierarchical value learning for large-scale exploration in unknown environments," ICAPS, pp. 652-662, 2021.

[2] Kim et al., "POMHDP: Search-based Belief Space Planning using Multiple Heuristics," International Conference on Automated Planning and Scheduling (ICAPS), 2019.

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Publications:

[A] Peltzer et al., "FIG-OP: Exploring Large-Scale Unknown Environments on a Fixed Time Budget," IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 2022. *To appear.*

[B] Bouman et al.,, "Adaptive Coverage Path Planning for Efficient Exploration of Unknown Environments," IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 2022. *To appear.*

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