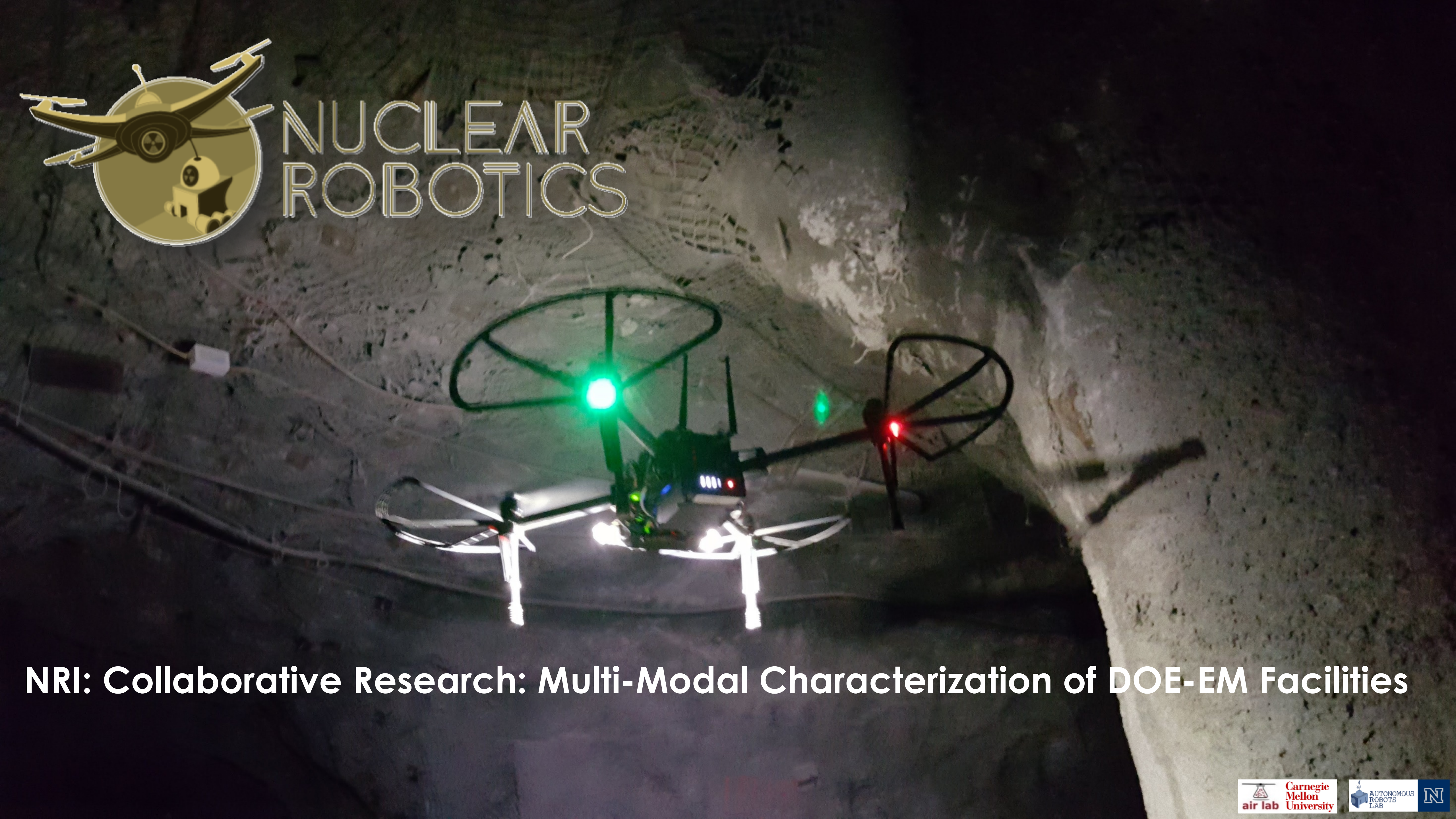
NUCLEAR
ROBOTICS
NRI: Collaborative Research: Multi-Modal Characterization of DOE-EM Facilities
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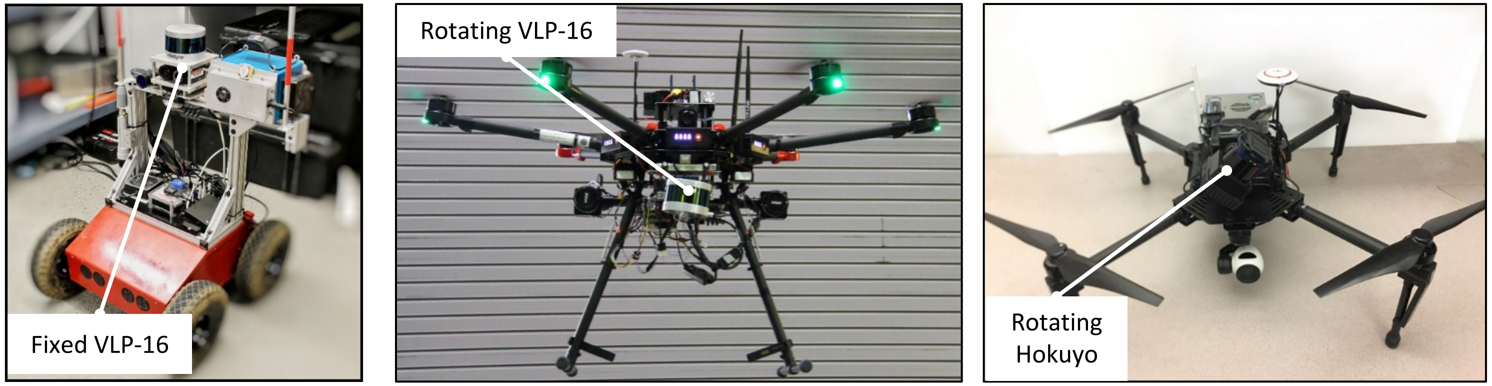
Unified Mapping Framework

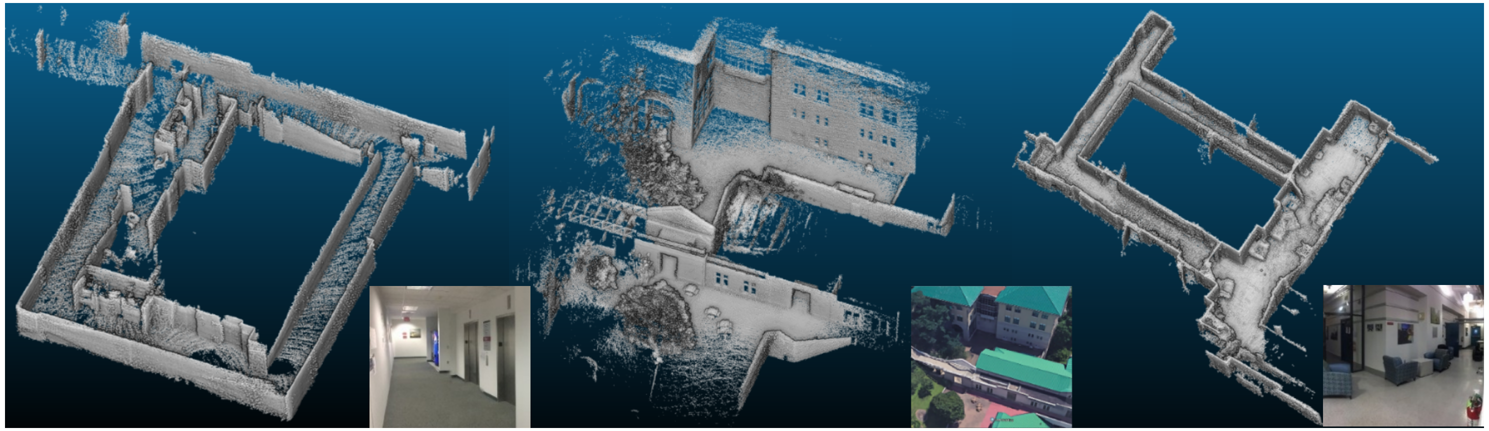
Motivation: A unified LiDAR mapping framework for all developed robots to reduce the efforts of development, deployment and maintenance.

Method: Combining Google Cartographer with a new localization component that uniformly handles data from different LiDAR configurations.



3 robots are developed with different LiDAR configurations. Left: Fixed VLP-16 on a rover; Middle: Rotating VLP-16 on a DJI M600 drone; Right: Rotating Hokuyo on a DJI M100.

Rotating 2D-LiDAR



The mapping framework is tested in multiple environments including indoor and outdoor. Simulation tests are conducted inside the PUREX tunnel model.

W. Zhen, S. Scherer, ***"A Unified 3D Mapping Framework using a 3D or 2D LiDAR"***, International Symposium on Experimental Robotics (ISER), Buenos Aires, 2018

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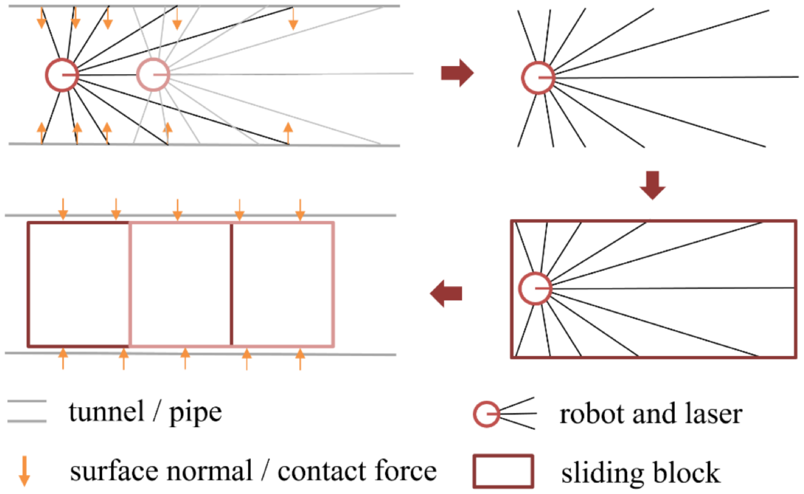
Robust Localization in Tunnels

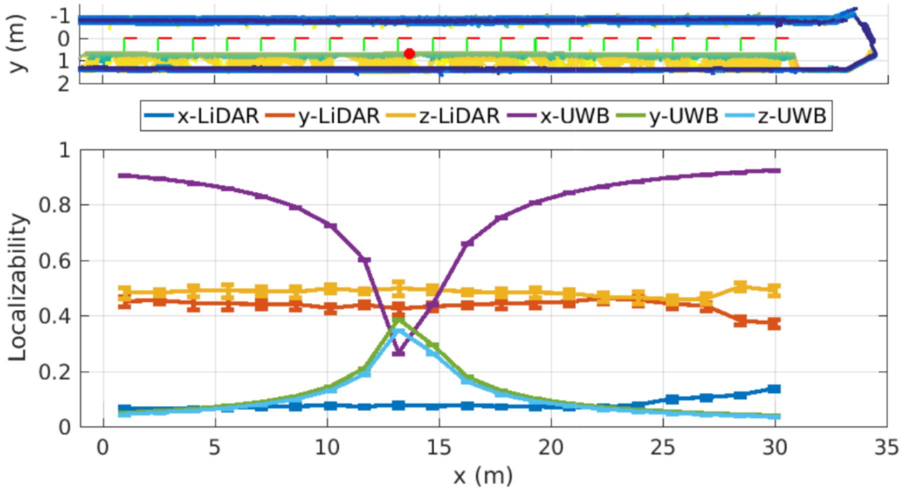
Motivation:
Localization in tunnels that are **geometrical degenerated**.

Contribution:
- A localizability model that predicts localization failure.
- Fusing Ultra-Wide Band (UWB) ranging radio with LiDAR for robustness.

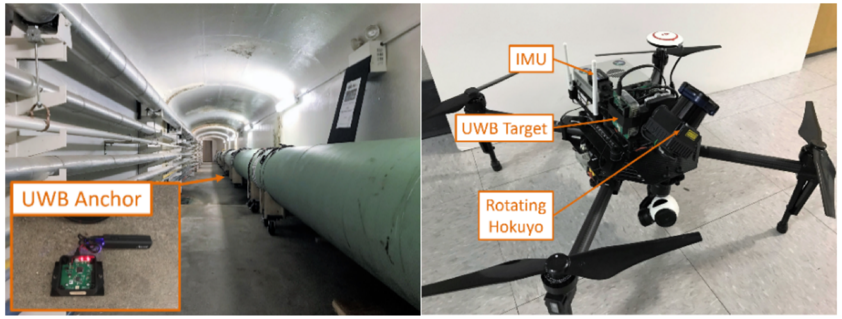
Conclusion:
- Relating **robot localization** & **frictionless-force-closure** will give meaningful explanation of localizability.
- A single UWB ranging radio can improve performance significantly.



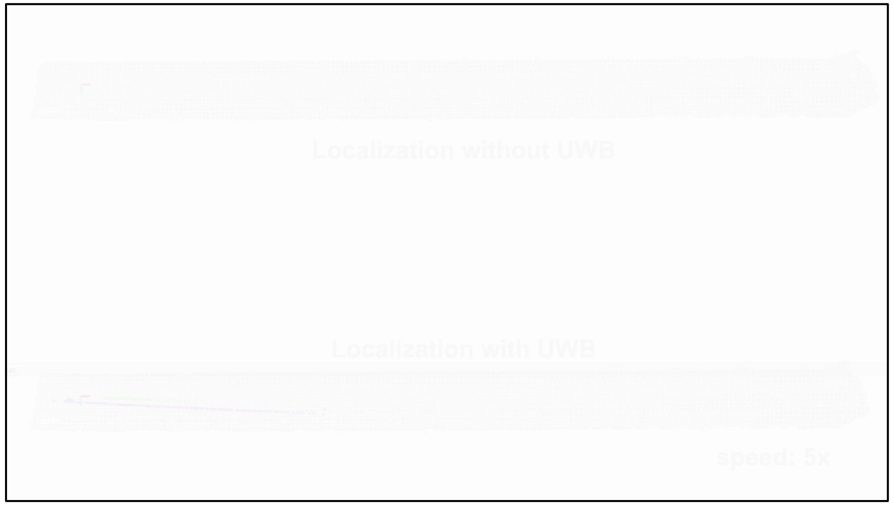
Think of robot localization as a frictionless force-closure problem. The strength of constraints are used to evaluate the localizability.



LiDAR and UWB are complementary in terms of localizability. Therefore, fusion of the two can achieve robust localization.



Experiment is conducted inside a long straight tunnel, which is quite challenging for LiDAR-based localization methods.

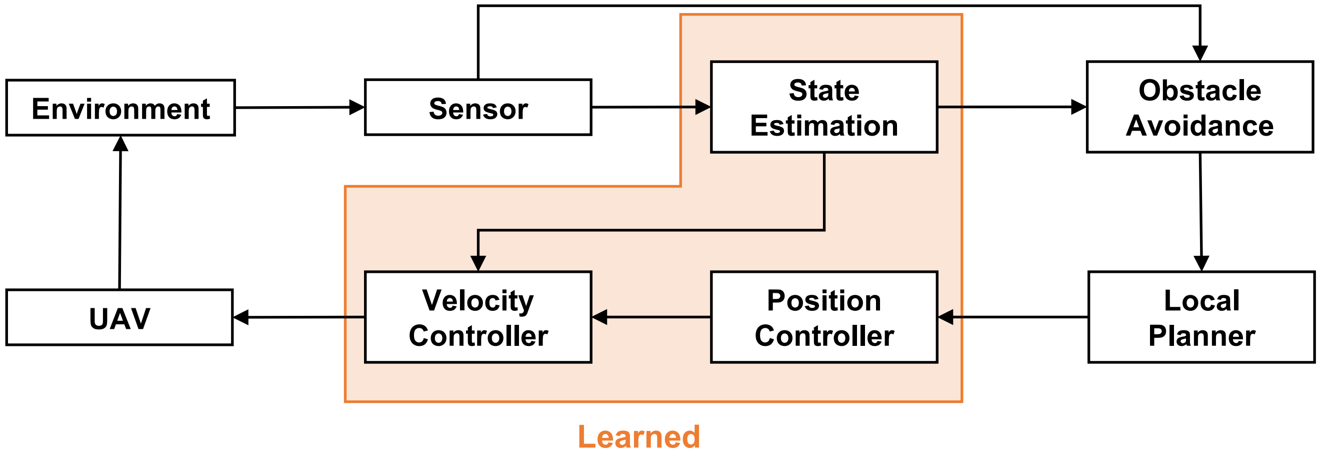


W. Zhen, S. Scherer, ***"Achieving Robust Localization in Geometrically Degenerated Tunnels"***, Robotics: Science and Systems (RSS), Workshop, Pittsburgh 2018

Reactive Obstacle Avoidance

Motivation:
Safe reactive control solution for environments where state estimation is **unavailable**

Method:
Imitation learning techniques are used to train the control policy, which replaces the state estimation and controller.



Conclusions
- Simple target (e.g. go forward) is given to the robot.
- Trained control policy enables safe flight without state estimations.

Real-time tests are conducted inside CMU hallway (left) and mine tunnels (middle and right). The robot is trained to go forward and avoid collisions.

S. Zeng, S. Scherer, ***"Learning Reactive Flight Control Policies: From LIDAR Measurements to Actions"***, Master's Thesis, 2018

Radiation Source Localization

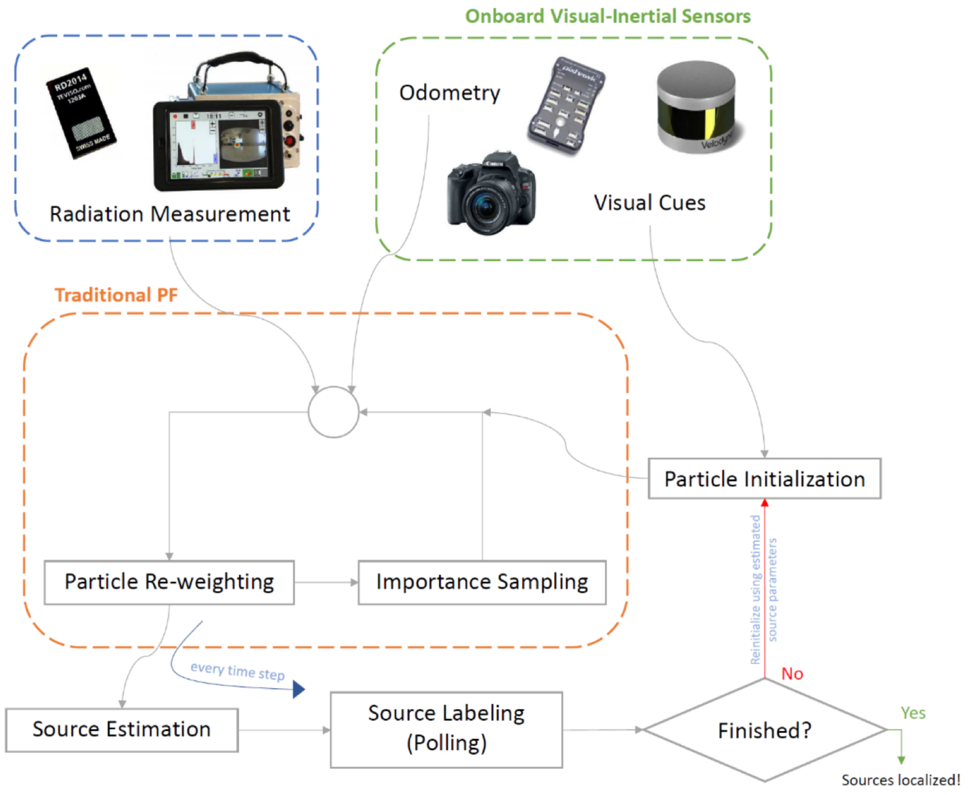
Light-weight detectors (Teviso RD3024) and odometry are combined to localize radiation sources, using a hybrid formulation of a particle filter and clustering techniques.

Contribution

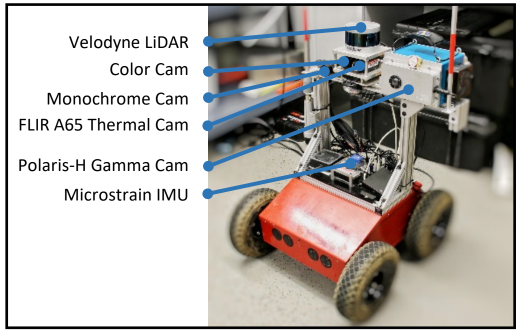
- Resolving large number of sources efficiently
- Scaling to large regions in space
- Localizing bulk radiation sources

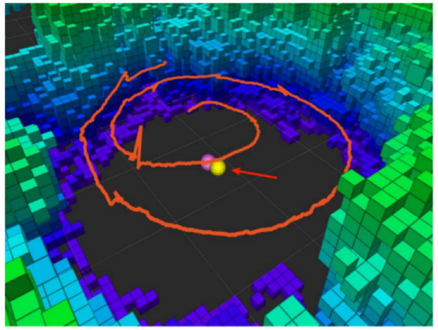
Conclusion

- Improvement over existing methods in terms of convergence rate.
- Scalable to 3D situations without compromising speed or accuracy.
- Extendable to bulk radiation sources

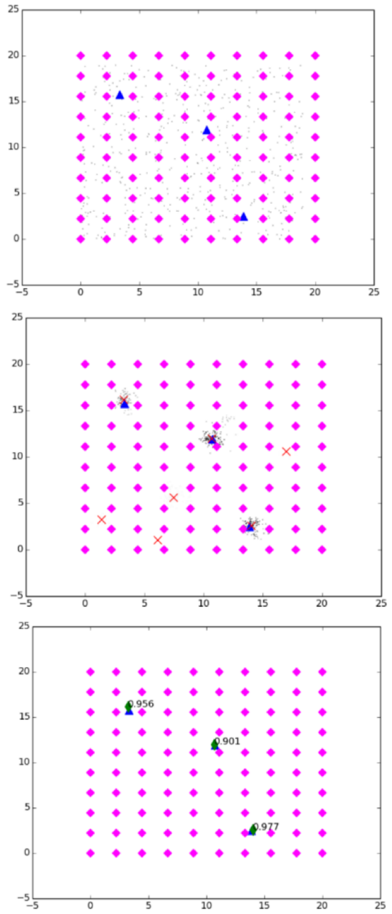


A Particle Filter is combined with clustering algorithm to localize the radiation sources in the environments.





Left: test rover; Right: source localization results (pink: ground truth, yellow: estimated location)



Simulation of source localization. The robot takes measurement at each pink point and finally finds the location of all 3 radiation sources.

D. Shah, W. Zhen, S. Scherer, ***"Robust Localization of an Arbitrary Distribution of Radioactive Sources for Aerial Inspection"***, WM2018

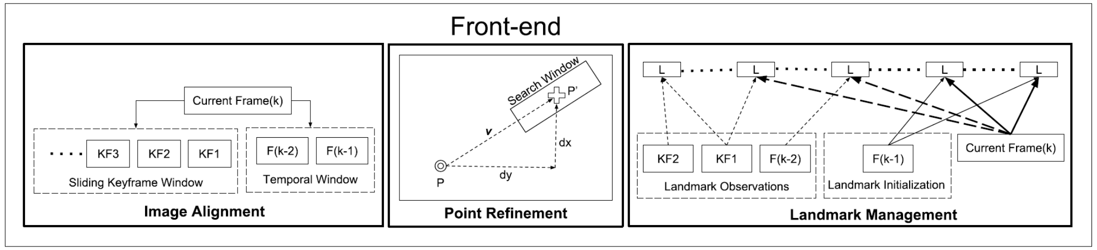
Multi-modal Localization in Tunnels & Underground Mines

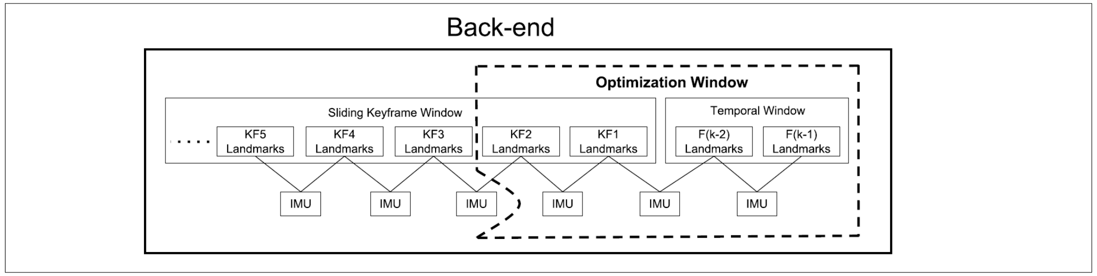
Localization in tunnels and other underground environments can be robustly facilitated through a multi-modal fusion approach.

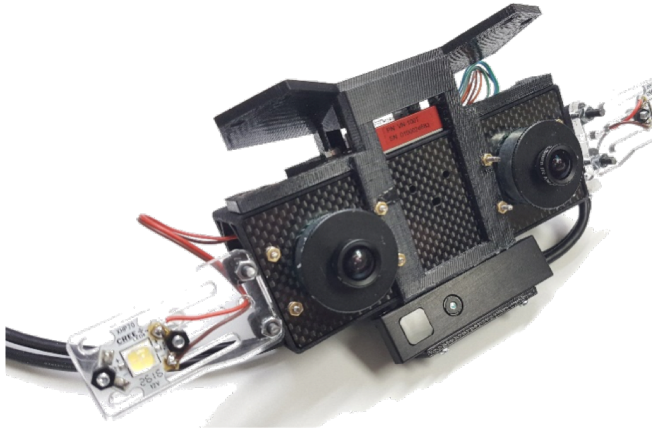
Multi-modal sensor fusion can allow to overcome individual limitations through resourcefulness.

Tight and loosely fused sensing modalities

- Visible-light cameras
- Thermal vision
- LiDAR sensors
- IMU cues
- Force Sensing (ongoing work)







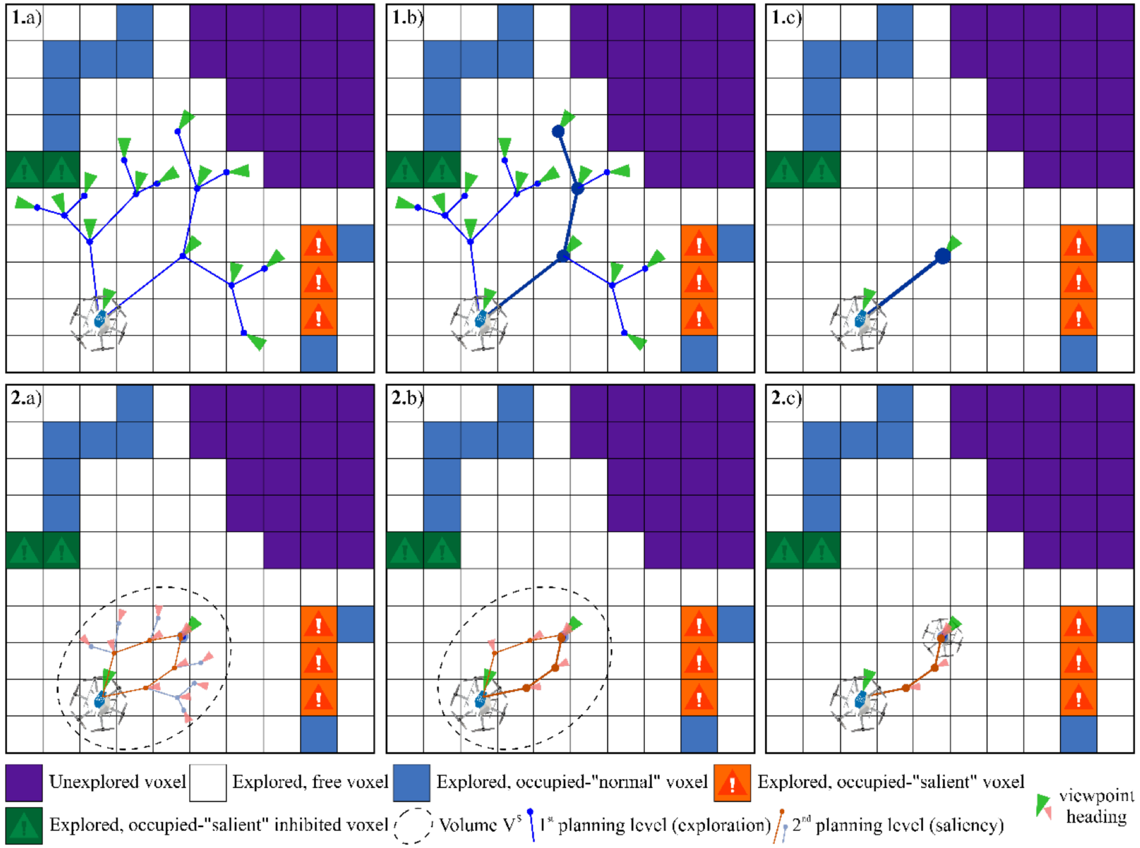
S. Khattak., C. Papachristos, K. Alexis, ***"Keyframe-based Direct Thermal-Inertial Odometry"***, Under Review, & F. Mascarich, S. Khattak, C. Papachristos, K. Alexis, ***"A Multi-Modal Mapping Unit for Autonomous Exploration and Mapping of Underground Tunnels"***, IEEE Aerospace Conference (AeroConf) 2016, Yellowstone Conference, Big Sky, Montana, March 3-10, 2018


50m
0m
KEYFRAME
CURRENT

Attention-driven Informative Path Planning

Attention-driven Informative path planning for high-consequence environment exploration:

- **Explore unknown areas** – extrinsic and mission-relevant objectives to the robot.
- **Account for localization uncertainty** – important for long-term deployment in degraded and high-consequence environments.
- **Account for visual saliency** - proto-objects detected through visual saliency approaches allows for intelligent information gathering in areas for which we lack training data.



Tung Dang, Christos Papachristos, Kostas Alexis, ***"Visual Saliency-aware Receding Horizon Autonomous Exploration with Application to Aerial Robotics"***, IEEE International Conference on Robotics and Automation (ICRA), May 21-25, 2018, Brisbane, Australia,
Christos Papachristos, Shehryar Khattak, Kostas Alexis, ***"Uncertainty-aware Receding Horizon Exploration and Mapping using Aerial Robots"***, IEEE International Conference on Robotics and Automation (ICRA), May 29-June 3, 2017, Singapore

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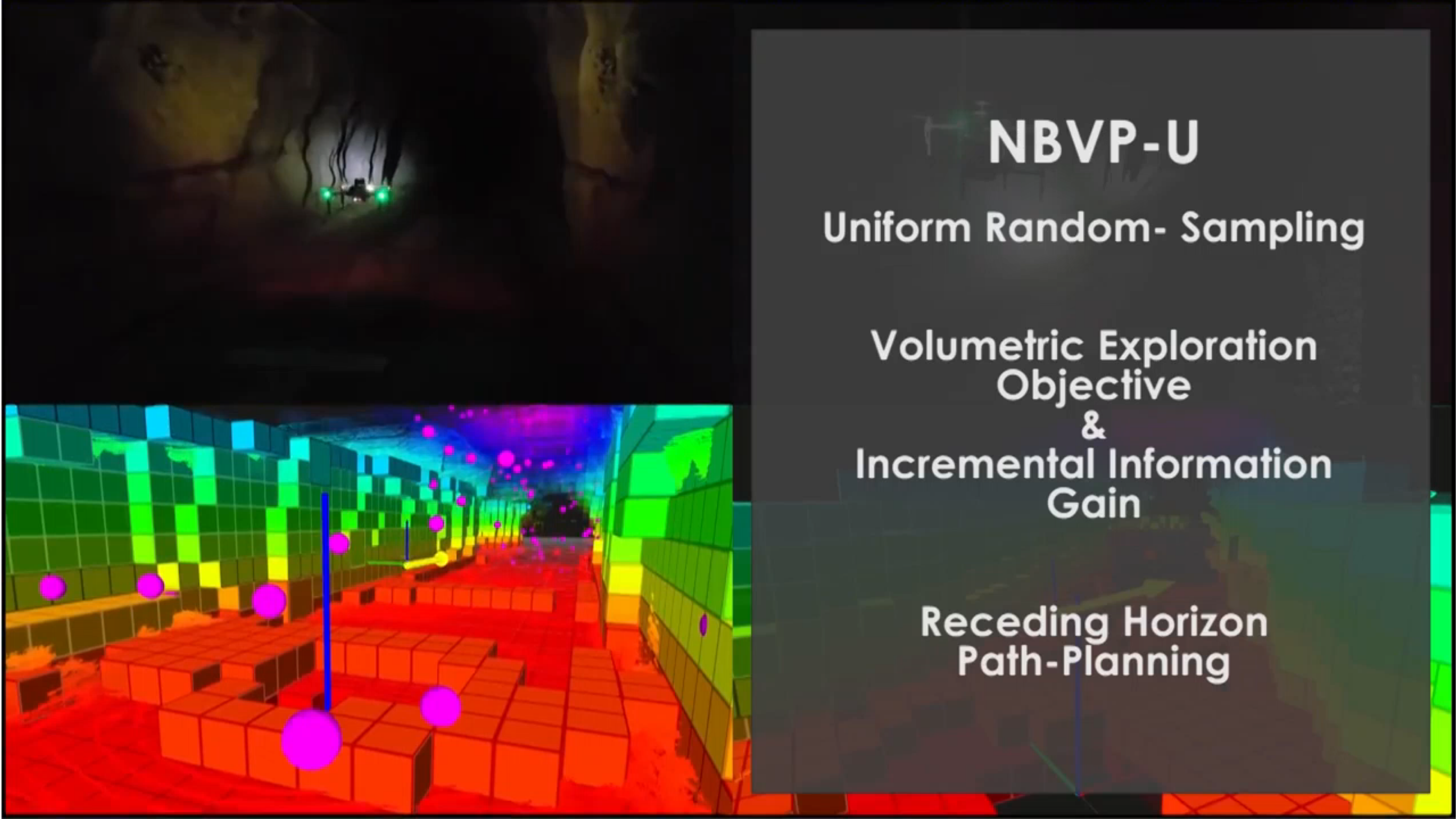
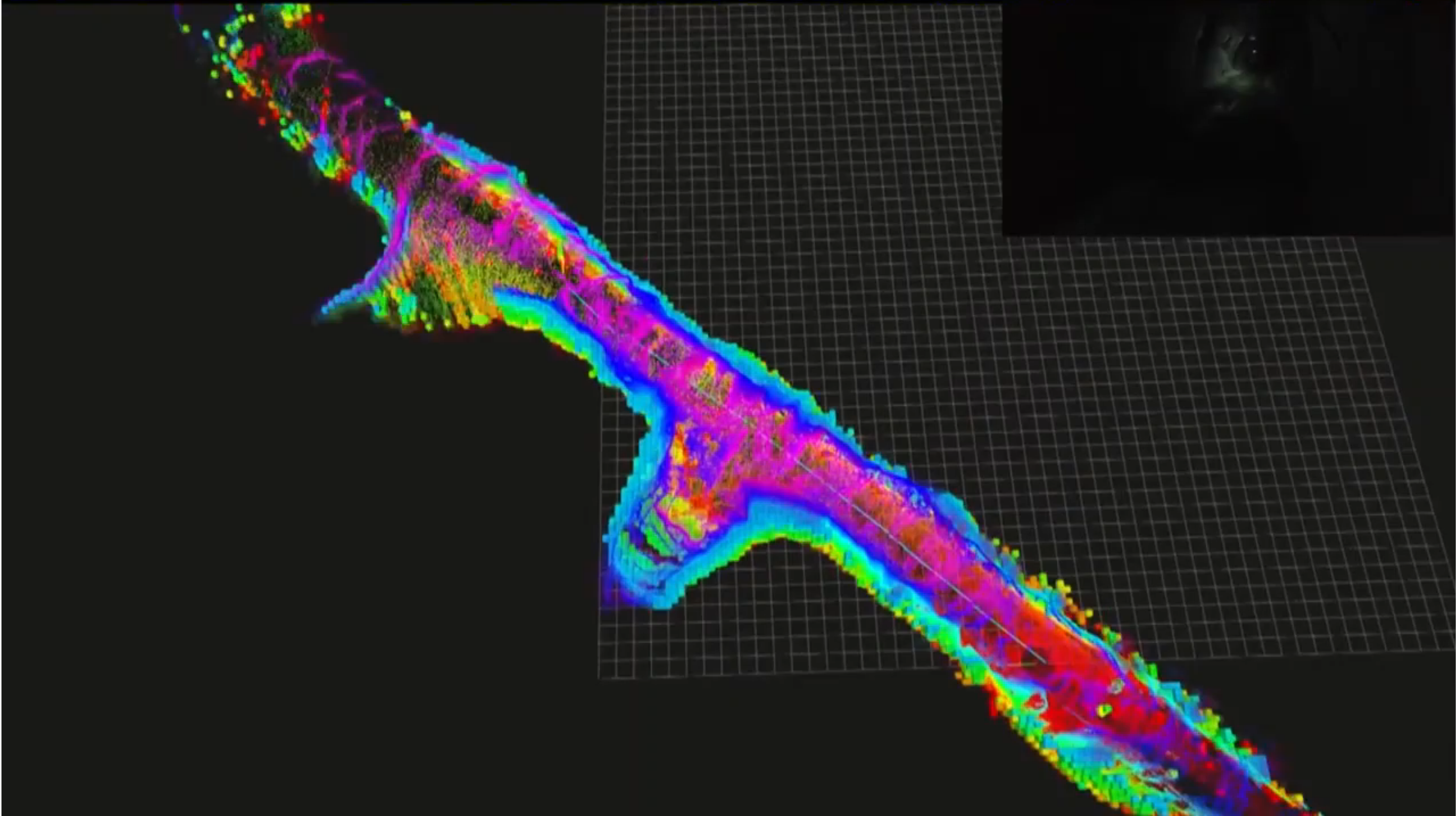

NBVP-U
Uniform Random- Sampling
Volumetric Exploration Objective
&
Incremental Information Gain
Receding Horizon Path-Planning



Radiation Source Localization & Distributed Field Estimation

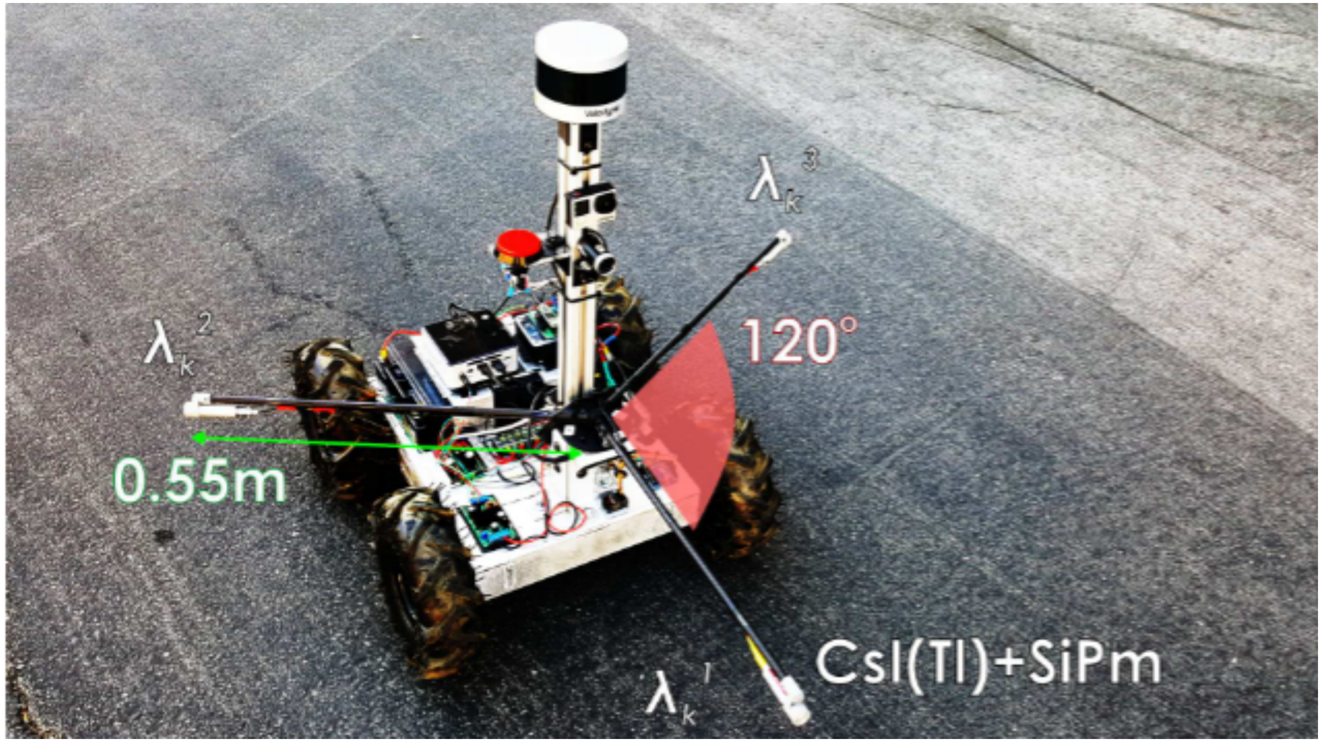
Our work emphasizes on both aerial and ground robot-based radiation characterization including the problem of simultaneous 3D and distributed nuclear radiation field mapping.

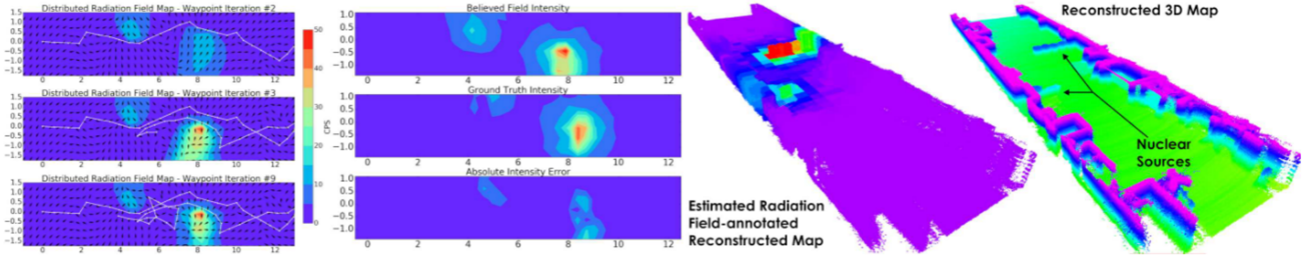
Contribution

- Lightweight apparatus of **3 SCIONIX CsI & CeBr3 scintillators** with Silicon Photomultipliers.
- **Estimate the underlying distributed radiation field** autonomously given no prior information.
- Correlate 3D and radiation data for rapid environment characterization.
- **Informative Path Planning** for optimal next-radiation-measurements.

Field Evaluation

- Verified in variety of scenarios using both aerial and ground robotic deployment and true distributed gamma sources.





Frank Mascarich, Taylor Wilson, Christos Papachristos, and Kostas Alexis, ***"Radiation Source Localization in GPS-denied Environments using Aerial Robots"***, IEEE International Conference on Robotics and Automation (ICRA), May 21-25, 2018, Brisbane, Australia

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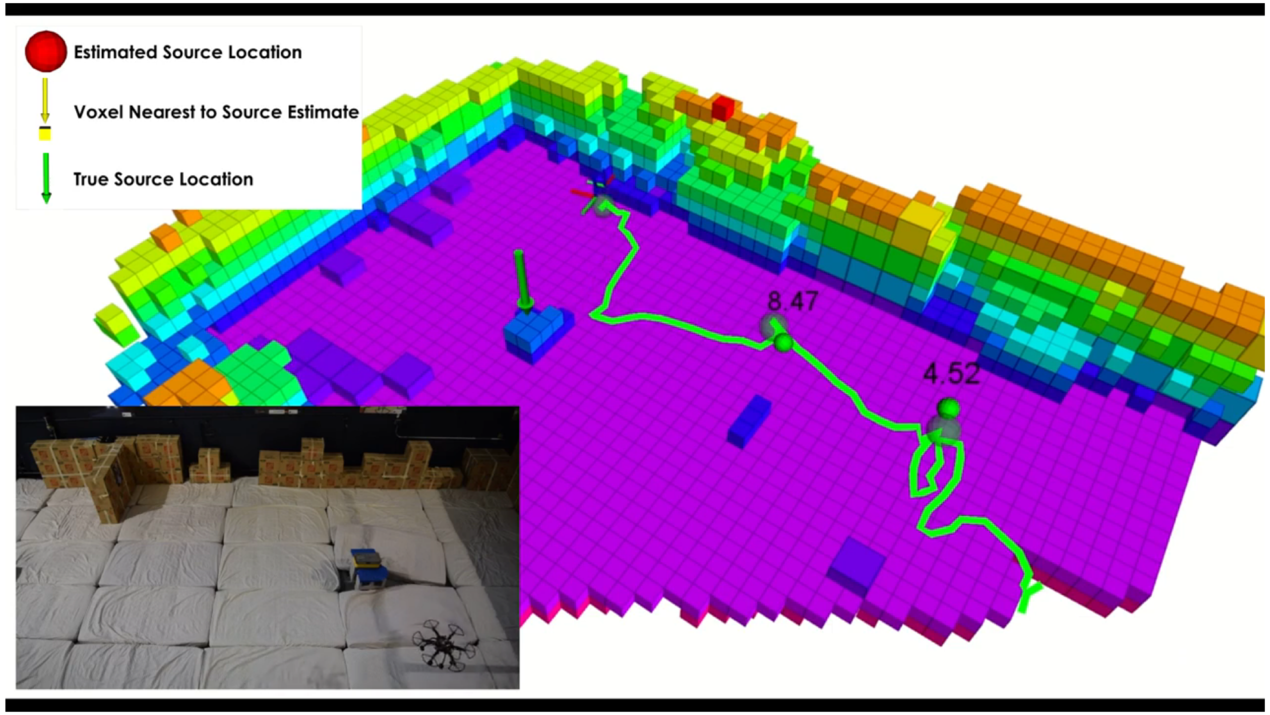
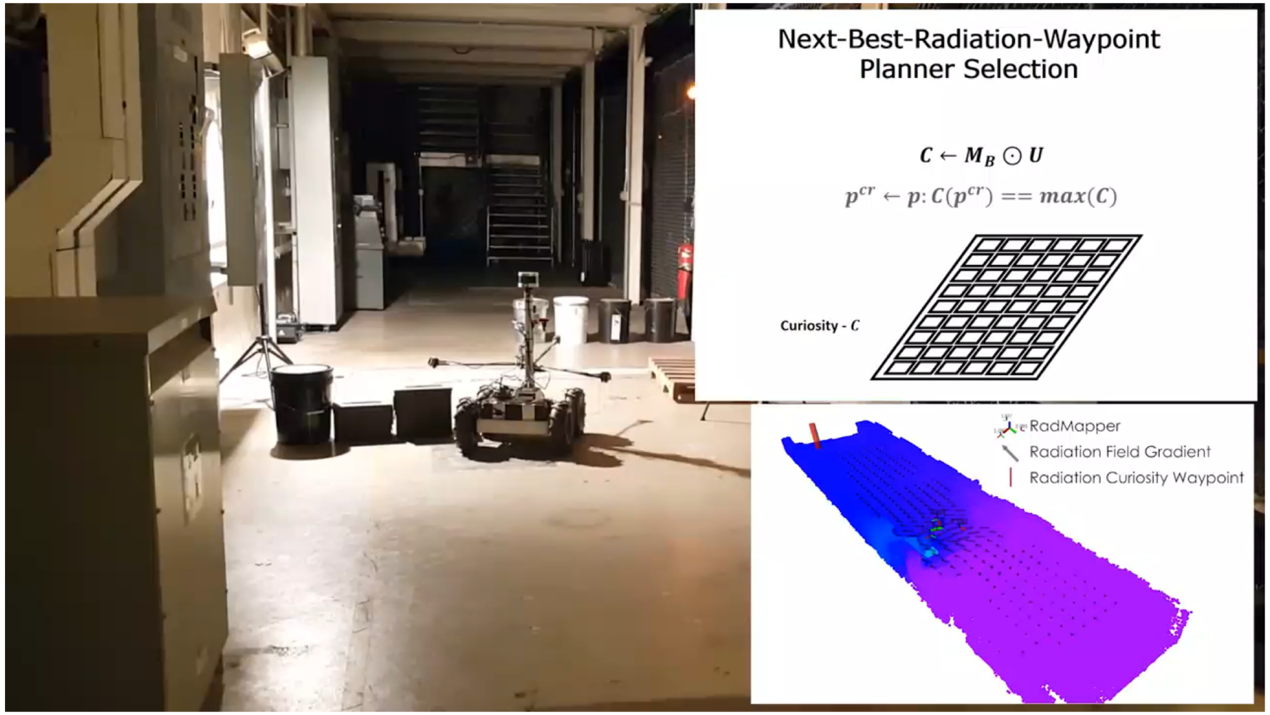
Radiation Source Localization & Distributed Field Estimation

Aerial Robot-based



Single Scintillator (historic reason)
Single or spectra-based multi-source localization
Tested using a Cs-137 source

Ground Robot-based



Distributed complex radiation field estimation
No assumption on number of sources of strength/spectra
Tested based on Uranium/thorium nuclear field

Frank Mascarich, Taylor Wilson, Christos Papachristos, and Kostas Alexis, ***"Radiation Source Localization in GPS-denied Environments using Aerial Robots"***, IEEE International Conference on Robotics and Automation (ICRA), May 21-25, 2018, Brisbane, Australia

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