Real-time Mercury Characterization for DOE Legacy Facilities Decommissioning Using Mobile Robotic Platforms

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INTRODUCTION

DOE Nuclear Facility Challenge
- Hazardous environments with mercury and toxic vapors
- Unsafe and complex for human inspection
- Require constant monitoring during decommission

Robotic Solution
- Autonomous robots perform inspection and mapping
- Multi-sensor system with AR for human–robot collaboration

Oak Ridge Y-12 Facility Prior to Decommissioning

OBJECTIVES

Autonomous Mapping and Exploration
- Map hazardous nuclear environments in real time
- Enable efficient exploration of unknown areas

AI-Based Characterization
- Estimate contaminant distribution using AI
- Provide semantic awareness of the environment

System Integration
- Multi-sensor fusion (LiDAR, cameras, gas sensor)
- Enable AR-based human–robot interaction

Robotic platform (SPOT) performing inspection in industrial DOE-relevant environment

METHODOLOGY

Platforms
- Boston Dynamics SPOT for mobile inspection
- Ground robots for complementary deployment
- Adaptable to hazardous nuclear environments

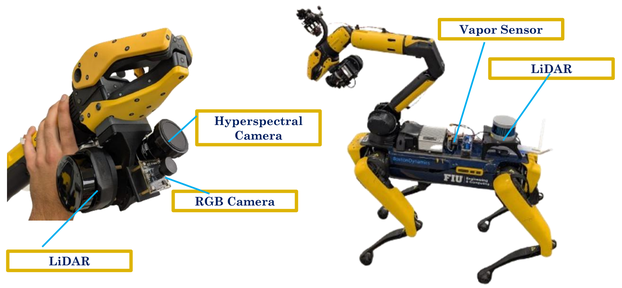
Boston Dynamics Spot

Clearpath Robotics Husky A200

Clearpath Robotics Jackal

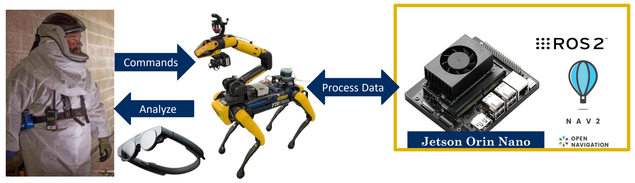
Sensor Stack

Surface Characterization | Field Characterization



Semi-Autonomous System Design

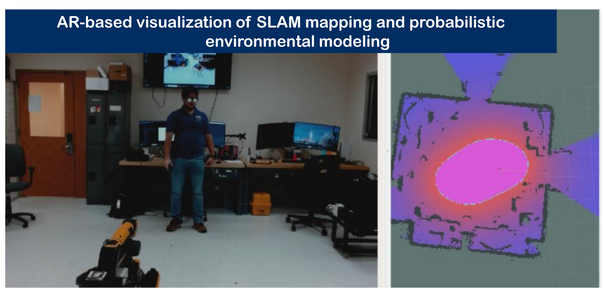
AR-assisted semi-autonomous system integrating sensor-agnostic perception and onboard computing (Jetson + ROS2) for SLAM, open-frontier navigation, and AI-based environmental characterization.

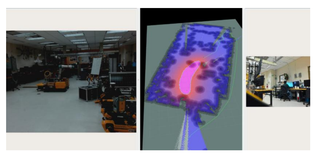


RESULTS

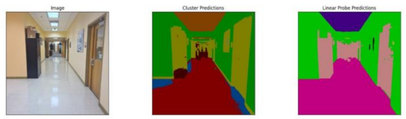
- Real-time SLAM mapping and localization
- Open-frontier autonomous exploration
- Semantic segmentation for scene understanding
- Probabilistic vapor contaminant field estimation (GP)
- Multi-modal sensing for environmental analysis
- AR-assisted human–robot interaction and visualization

AR-based visualization of SLAM mapping and probabilistic environmental modeling

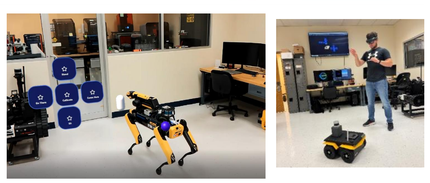




Frontier-based autonomous navigation with real-time SLAM mapping



Real-time AI-based semantic segmentation



AR interface for robot interaction and control

CONCLUSION

- Developed an AR-assisted mobile robotic system for real-time environmental characterization in DOE nuclear facilities
- Integrated multimodal sensing for semantic navigation, contamination mapping, and vapor plume estimation
- Enabled semi-autonomous human–robot collaboration with immersive AR-based supervisory control
- Designed a sensor-agnostic software architecture for scalable deployment across robotic platforms
- Enables safe, data-driven inspection and decision-making in hazardous decommissioning sites

FUTURE WORKS

- Control the robot manipulator using the AR headset
- Extend semi-autonomous capabilities and operator commands to include return-to-base, door opening, object manipulation, and surface swabbing
- Fuse geometric LiDAR with semantics
- Integrate mercury vapor sensor

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