UNH LunaCats CS | NASA Robotic Mining Team

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Project Overview

NASA Lunabotics Competition
University of Central Florida, Kennedy Space Center

- University teams are tasked with designing, building, and operating a robotic excavator capable of autonomous navigation, regolith excavation, and resource delivery in a lunar environment.

Competition Implementation Overview

- Robot used in competition is implemented using ROS2 node architecture to create a modular and scalable system, both for the current competition and for future ones.
- Utilizes ultrawideband (UWB) distance sensors, lidar, radar, and a behavior tree to create a map of its surroundings, localize itself and navigate to set goals for mining and depositing autonomously.

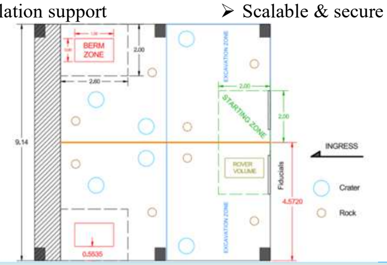
Requirements

Functional

- Autonomous navigation & mapping
- Real-time obstacle detection
- Excavation & deposition
- Manual override capability
- Simulation support

Nonfunctional

- Real-time performance
- Robustness to noise
- Power efficiency
- Reliable network communication
- Scalable & secure design



Software Design

System Objectives

- Designed to meet NASA's autonomous excavation requirements.
- Supports fully autonomous operation with teleoperation fallback.
- Enables seamless transition between simulation and real-world development.

Modular Architecture

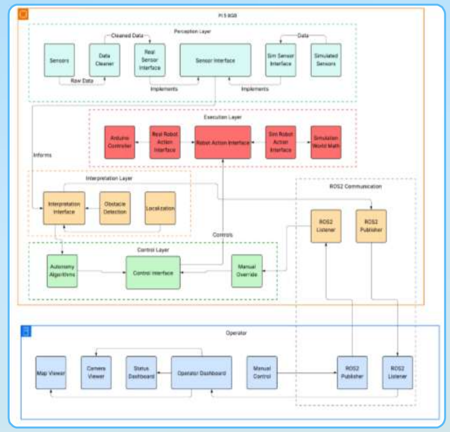
- Decoupled perception, planning, and control layers.
- ROS2-based node architecture for scalability.
- Hardware abstraction layer isolates sensors from planning logic.

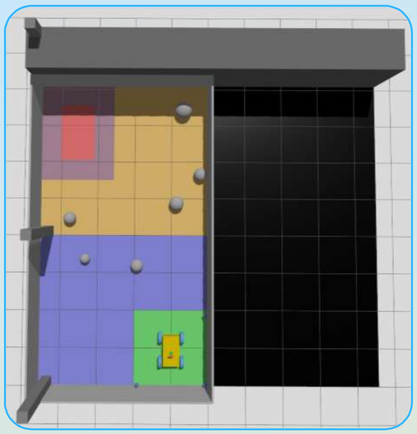
Simulation ↔ Real-World Parity

- Identical software stack used in simulation and field testing.
- Sensor interfaces abstracted for Gazebo and physical hardware.
- Enables rapid validation before hardware deployment.

Localization & Perception Integration

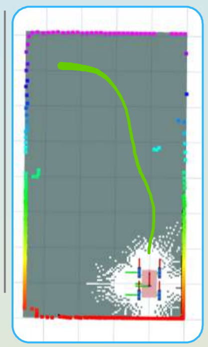
- UWB trilateration fused with SLAM pose estimates.
- LiDAR and radar for real-time obstacle detection.
- Dynamic cost map updates for responsive navigation.





From Sensor Data to Autonomous Action

Real-time LiDAR scans are transformed into a live occupancy map, allowing the robot to localize and navigate without prior knowledge of the environment.



Autonomous Functionality

- **Perception & Mapping**
  - **LiDAR-based SLAM**
    - Real-time occupancy grid generation
    - Handles dynamic dust occlusion.
- **Localization**
  - **Sensor Fusion**
    - SLAM-based pose estimation
    - UWB trilateration for drift correction
  - Reduces cumulative odometry error
  - Maintains centimeter positional accuracy
- **Path Planning**
  - **Global Planner: Timed A***
    - Heuristic grid-based search over occupancy map
    - Minimizes travel cost while avoiding obstacles
    - Replans dynamically when cost map updates
    - Ensures optimal, deterministic path generation
- **Behavior Tree Control**
  - **Mission Phases**
    - Navigate → Excavate → Navigate → Deposit
    - Hierarchal task switching
  - Autonomous failure recovery
    - Replan on obstacle detection
    - Retry navigation on failure
    - Reset localization if divergence is detected

Evaluation

Mission Outcome

- Demonstrated autonomous navigation and localization.
- Integrated UWB-enhanced pose correction.
- Seamless switching between autonomous and teleoperation modes.

Impact

- Enables scalable lunar excavation without continuous human control.
- Demonstrates cost-effective localization for off-Earth environments.

Limitations

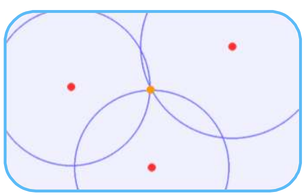
- Limited full-system physical validation due to shared hardware dependencies.

Future work

- Expand full-robot integration testing.
- Improve excavation autonomy refinement.
- Maintain modular architecture for future team development.

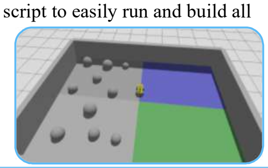
Physical Testing

- Verified LiDAR data transmission via ROS2 topics.
- Validated object detection on final hardware.
- UWB trilateration accuracy testing using beacon array.
- Teleoperation validated on legacy platform prior to final integration.



Simulation Testing

- Gazebo-based arena modeling and obstacle generation.
- Randomized obstacle zones for navigation stress testing.
- Independent subsystem validation. (mapping, planning, control)
- Simulated sensor noise and tested recovery behaviors.
- Enabled rapid iteration prior to hardware availability.
- Utilized quick_start script to easily run and build all simulations



Physical Control

High-Level Control & Telemetry

- **Raspberry Pi 5 (8GB)**
  - Primary onboard compute unit.
  - Executes autonomy and teleoperation logic.
  - Communicates with base station via ROS2.
  - Streams diagnostics & system health data.
  - Enables teleoperation fallback on autonomy failure.

Low-Level Motor & Actuator Control

- **Arduino Mega**
  - Dedicated real-time motor controller.
  - C++ firmware for actuator & sensor control.
  - Serial communication with Raspberry Pi.
  - Isolates hardware timing from autonomy stack.

Acknowledgments

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Abstract

The Lunabotics Computer Science project is an interdisciplinary effort to develop a fully autonomous robot capable of completing a task defined by the NASA Lunabotics department with their goal being utilizing the design in the Artemis missions to the moon and mars. The computer science team integrates hardware systems designed by the electrical and mechanical engineering teams to achieve complete autonomy.

Our system combines LiDAR, ultra-wideband (UWB), and radar data to construct a real-time model of the robot's surroundings. This environmental awareness enables the robot to navigate the arena, avoid obstacles, and operate without teleoperation. Obstacle detection data from LiDAR is processed through a behavior tree architecture, allowing the robot to make intelligent navigation decisions in real time.

Localization is achieved using UWB distance sensors, which continuously measure distances between fixed beacons and the robot. These measurements are used to triangulate the robot's position with high accuracy. By integrating robust localization with reliable object detection, the robot can autonomously navigate the arena, excavate lunar regolith, and construct a berm at a designated location as requested by the challenge.