

Autonomous Lunar Rover Digital Twin

FORUM8

14th CPWC

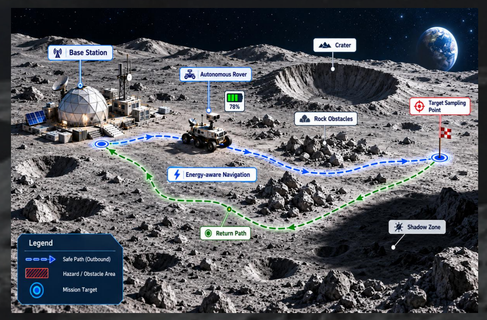
LunaPilot

Background

Autonomous Navigation on Complex Lunar Terrain

Complex terrain, long shadows, limited communications and energy constraints at the lunar south pole require rovers to reach their targets autonomously, avoid hazards along the way and return safely to base.

- Complex terrain / The shortest route may be unsafe
- Limited visibility and communications / Adapt autonomously
- Limited energy / Arrival alone is not mission success



System

Lunar Modeling & Data Support in UC-win/Road

UC-win/Road provides the simulation environment.
Lunar scene modeling, simulation data and external algorithm integration support validation of autonomous navigation and safe return to base.

Scene Modeling
Turn lunar missions into testable scenarios

Data Support
Inputs for perception and evaluation

Algorithm Integration
From planned routes to rover motion

Design → Simulate → Validate → Operate

This workflow connects scene design, mission simulation, performance validation and operational rehearsal within a single digital environment.

Design
Define scenes and missions

Simulate
Run algorithms and test cases

Validate
Assess results and risks

Operate
Rehearse and replay missions

Available Simulation Data

Map simulation data to algorithm needs for perception, vehicle control and mission evaluation.

Data Type	Platform Data	Planned Use
Terrain & Models	Terrain elevation, grids, model geometry and positions.	Build baseline maps; verify terrain and obstacle positions
Onboard Camera Images	Virtual camera images, with UDP output available.	Test perception, visual localization and mapping
Vehicle State	Position, orientation, speed and acceleration.	Evaluate localization errors; provide control feedback
Operation Logs	Vehicle trajectories, steering and throttle records.	Replay missions and analyze performance

From Environmental Observation to Safe Driving

ORB-SLAM3 estimates camera poses and sparse 3D landmarks, which are projected into a 2D map for navigation. A* planning and tracking control close the navigation loop.

Algorithm Pipeline

Mission constraints: ordered checkpoints · mining target · safe return

Simulation Inputs → ORB-SLAM3 → Terrain & Costs → A* Planning → Path Tracking → Mission Evaluation

Observation feedback: update localization, maps and paths as the rover moves

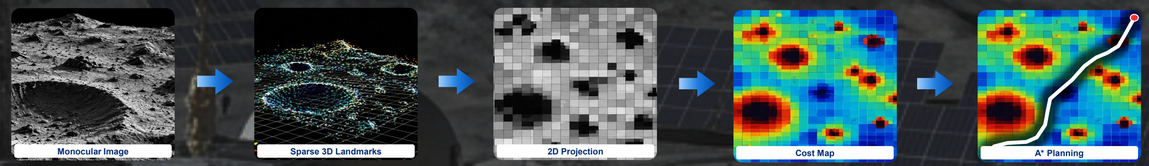
Lunar Autonomous Driving System

1. Monocular ORB-SLAM3 & 3D-to-2D Mapping

Monocular ORB-SLAM3 & 3D-to-2D Mapping Monocular ORB-SLAM3 estimates camera poses and sparse 3D landmarks from follow-camera images.
Projection and grid mapping convert these landmarks and obstacle cues into a relative-scale 2D map for navigation.

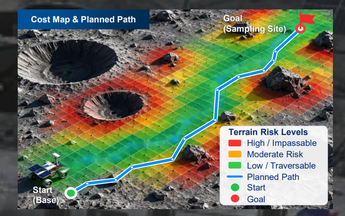
2. A* Path Planning

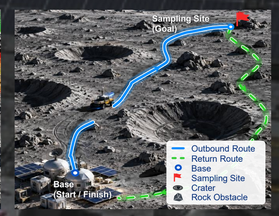
A* searches for routes on a 2D cost map derived from projected SLAM landmarks and obstacle cues.
Planning costs represent obstacle risk and mission constraints along the route to the sampling site.
Mission Navigation & Dynamic Adaptation.



3. Mission Navigation & Dynamic Adaptation

The rover follows its planned path while continuously sensing the environment.
New obstacles or low energy trigger replanning, supporting successful sampling and a safe return to base.

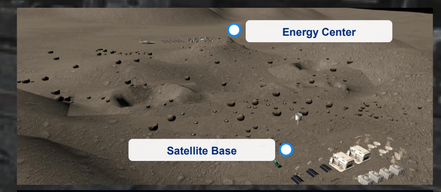




Lunar Autonomous Driving Simulation

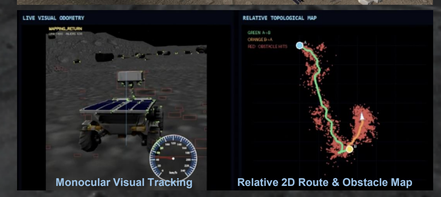
1. Simulation Setup & Mission Execution

A UC-win/Road lunar simulation links Satellite Base A and Energy Center B, supporting route teaching, mapping, planning, and autonomous round-trip navigation.



2. Autonomous Round-Trip Demonstration

After demonstration and route planning, the rover autonomously completes A → B → A using keyframe localization and driving-command replay, with visual correction and a stop-on-localization-loss safeguard.



Innovation & Applications

- Key Features: Supporting the Complete Mission
- Applications: From Resource Transport to Life Support
- Connect Lunar Facilities for Long-Term Habitation

