Fall Project Test Plan

Lunar Autonomous Regolith Excavator

Team C

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1. Introduction

This document outlines the planned functional, integration and validation tests for the LunAR-X project. These are designed to start from testing the smaller units and building blocks of the subsystems, gradually increasing in scale. All of these tests will lead up to a functional autonomous system to be demonstrated in the Fall Validation Demonstration. The included schedule shows the capabilities aimed to be achieved with the help of each of the tests, along with their relation to the previously-defined system requirements. Our Fall Validation Demonstration will display autonomous excavation and building capabilities of the system.

2. Logistics

The equipment and test sites required for the project are enumerated below.

PRL Moonyard: The primary test site for most of our subsystems and the Fall Validation Demonstration. It is a sandbox built in the Planetary Robotics Lab for the purpose of testing and demonstrating different space robotic systems.

MRSD Lab: The site for unit and subsystem bench tests. Situated on the B-level of Newell-Simon Hall.

FARO Scanner: High-fidelity laser scanner for verification of mapping and perception subsystems

Control Station: Required for tele-operated control & monitoring of the system along with the various tests conducted in the Moonyard.

Total Station: External sensor which will be used for the positional localization of the system.

LX Rover: The LunAR-X rover with all of the electro-mechanical assembly and sensor suite attached. This includes the Nvidia Jetson Xavier AGX, Realsense camera(s), Vectornav VN-100, bucket-drum and the lifting assembly

3. Schedule

Identifier	Capabilities	Test(s)	Requirement(s)
Progress Review 8 (27 September)	• Mapping pipeline functional and can build approximate local maps • Tool control approach is verified	• T1 • T2	• M.P.2 • M.P.3 • M.P.7
Progress Review 9 (11 October)	• Mapping pipeline can build accurate maps for navigation • Tool can accurately be controlled autonomously for excavation • Rover can traverse terrain <= 10 degree incline • Rover can autonomously navigate to a given goal coordinate • Task planner can approximately plan a queue of tasks for building berm	• T3 • T4 • T5 • T6 • T7	• M.P.2 • M.P.3 • M.P.5 • M.P.6 • M.P.7 • M.P.8
Progress Review 10 (1 November)	• Mapping & Localization subsystems function together with the Autonomy stack • Task planner can create an efficient plan to build the berm • Tool control subsystem functions integrated with the Autonomy stack • Perception subsystem can accurately evaluate built berm metrics using the map • Task planner can function integrated with the operations handler	• T8 • T9 • T10 • T11 • T12	• M.P.2 • M.P.3 • M.P.5 • M.P.6 • M.P.7 • M.P.8 • M.N.5
Progress Review 11 (15 November)	• All subsystems integrated together can build a berm autonomously	• T13	• M.P.2 • M.P.3 • M.P.4 • M.P.5 • M.P.7 • M.P.8 • M.N.5
Fall Validation Demo (20 November)	• System can autonomously and efficiently plan, excavate, navigate and dump material in order to build a berm	• T14	• All

4. Tests

Test No. 1: Mapping Functional Test	
Objective	Validate if the robot is able to construct a local elevation map
Elements	Mapping subsystem
Location	PRL Moonyard
Equipment	1. LX Rover 2. Total Station
Personnel	Anish
Procedure	1. Flatten Moonyard terrain 2. Place the rover in Moonyard 3. Visualize the local map
Verification Criteria	1. Elevation map must approximately resemble moonyard terrain

Test No. 2: Tool Control Functional Test	
Objective	Validate if rover can excavate and fill the drum to capacity autonomously
Elements	Mechanical subsystem, Autodig subsystem
Location	PRL Moonyard
Equipment	1. LX Rover 2. Control Station 3. Weighing Scale
Personnel	Vibhakar
Procedure	1. Place rover on moonyard ready for excavation 2. Call the autodig ROS action, let the rover excavate material 3. Measure the amount of material excavated
Verification Criteria	1. No chattering sound should be heard during the operation 2. The amount of material excavated should be greater than 7 kgs

Test No. 3: Mapping Accuracy Test	
Objective	Validate the accuracy of the built map
Elements	Mapping subsystem, Localization subsystem
Location	PRL Moonyard
Equipment	1. LX Rover 2. Total Station 3. Control Station 4. FARO Scanner
Personnel	Anish
Procedure	1. Drive the rover around Moonyard by teleoperation 2. Perform one excavation and dumping operation 3. Set up the FARO scanner 4. Obtain the map from FARO scanner and convert to elevation map of the same resolution 5. Evaluate the accuracy of the map generated by rover
Verification Criteria	1. Average least square error must be less than 3cm

Test No. 4: Traversal Test	
Objective	Validate if rover can traverse terrain with <=10 degree incline
Elements	Mechanical subsystem
Location	PRL Moonyard
Equipment	1. LX Rover 2. Shovel
Personnel	Vivek
Procedure	1. Collect sand and build an inclined ramp of 10 degrees 2. Tele-operate rover to climb the inclined ramp
Verification Criteria	1. The rover can successfully traverse the inclined ramp without getting stuck

Test No. 5: Navigation Test	
Objective	Validate the integration of Nav2 package for autonomous navigation of the rover
Elements	Navigation subsystem
Location	PRL Moonyard
Equipment	1. LX Rover 2. Total Station 3. Control Station
Personnel	Dhruv
Procedure	1. Flatten moonyard terrain 2. Initiate LX Rover with a clear static map of moonyard with no obstacles 3. Provide navigation goal of a known measured location within the moonyard
Verification Criteria	1. Rover is able to autonomously navigate to the desired goal

Test No. 6: Task Planning Functional Test	
Objective	Validate planner output for autonomous operation
Elements	Planning Subsystem
Location	MRSD Lab
Equipment	Personal Computer
Personnel	Hariharan
Procedure	1. Start the planning ROS 2 node 2. Input the desired berm top-view shape, and height 3. Check the output sequence 4. Repeat for different input configurations
Verification Criteria	1. Able to decide if the given desired berm configuration is feasible to build 2. Provide reasonable output to each and every test input

Test No. 7: Tool Control Accuracy Test	
Objective	Validate efficiency of tool control
Elements	Autodig subsystem
Location	PRL Moonyard
Equipment	1. LX Rover 2. Weighing Scale
Personnel	Vibhakar
Procedure	1. Place the LX rover ready for excavation 2. Call the autodig ROS action, allow the rover to excavate autonomously 3. Measure the amount of material excavated and the time taken to excavate material
Verification Criteria	1. No chattering sound should be heard during the operation 2. The amount of material excavated should be greater than 7 kgs. 3. The excavation cycle time should be less than 50 seconds

Test No. 8: Global Mapping Integration Test	
Objective	Validate if the robot is able to autonomously build a labelled map of the test site
Elements	Mapping subsystem, Localization subsystem
Location	PRL Moonyard
Equipment	1. LX Rover 2. Total Station 3. Control Station
Personnel	Anish
Procedure	1. Flatten Moonyard terrain 2. Drive the rover around Moonyard by teleoperation 3. Perform one excavation and dumping operation 4. Visualize the built map
Verification Criteria	1. Map coverage must be %100 2. All labels must be present 3. Map must update as the terrain changes

Test No. 9: Task Planning Accuracy Test	
Objective	Validate planner capability for optimal operation sequence outputs
Elements	Planning Subsystem
Location	MRSD Lab
Equipment	Personal Computer
Personnel	Hariharan
Procedure	1. Start the planning ROS 2 node 2. Input the desired berm top-view shape, and height 3. Check the output sequence 4. Repeat for different input configurations
Verification Criteria	1. Able to decide if the given desired berm configuration is feasible to build 2. Provide optimal task sequence to all test cases

Test No. 10: Tool Control Integration Test	
Objective	Validate tool control accuracy post integration with the planning subsystem
Elements	Autodig subsystem, Planning subsystem, Localization subsystem
Location	PRL Moonyard
Equipment	1. LX Rover 2. Total Station 3. Control Station
Personnel	Vibhakar and Hariharan
Procedure	1. Validate enough material is present in the excavation zone 2. Initialize planner with a target of building a linear berm
Verification Criteria	1. The rover should autonomously excavate material from the excavation zone, and dump it at the locations output by the planner 2. No chattering should be heard during excavating material 3. The drum should be filled to near max capacity (> 8 kgs) after each excavation cycle, with an excavation time of < 50 seconds.

Test No. 11: Berm Evaluation Test	
Objective	Validate the berm metrics evaluation capability
Elements	Mapping and Perception subsystems
Location	PRL Moonyard
Equipment	1. LX Rover 2. Total station 3. Control station 4. FARO Scanner
Personnel	Anish
Procedure	1. Build a berm of known measurement using the rover 2. Evaluate the berm metrics using the perception pipeline 3. Evaluate the berm metrics using the FARO scanner 4. Compare the measurements
Verification Criteria	1. The evaluated berm metrics should have an error of less than 3cm in height and less than 5cm in length.

Test No. 12: Planning Integration Test	
Objective	Validate the integration of planning subsystem
Elements	Planning Subsystem
Location	PRL Moonyard
Equipment	1. LX Rover 2. Total Station 3. Control Station
Personnel	Hariharan
Procedure	1. Initiate rover and flatten moonyard terrain 2. Input the desired berm top-view shape, and height 3. Check the output sequence 4. Repeat for different input configurations
Verification Criteria	1. Able to decide if the given desired berm configuration is feasible to build 2. Provide optimal task sequence to all test cases 3. The planner gets an input through the user goal input interface and functions with the ROS2 action client of the operations handler

Test No. 13: Autonomy Integration Test	
Objective	Validate the integration of all autonomy subsystems
Elements	Localization, Mapping, Planning, Navigation, Control subsystems
Location	PRL Moonyard
Equipment	1. LX Rover 2. Total Station 3. Control Station 4. FARO Scanner
Personnel	Dhruv
Procedure	1. Flatten moonyard terrain 2. Initiate the rover and map the initial state of the moonyard terrain 3. Give a desired berm configuration goal 4. Allow rover to execute autonomous operation to build berm 5. Verify the built berm using a high-fidelity laser scanner
Verification Criteria	1. The rover can autonomously build a berm 2. The rover requires minimal to no operator intervention in order to achieve the desired berm goal

Test No. 14: Fall Validation Demo Test	
Objective	System integration and Validation test for FVD
Elements	Full system
Location	PRL Moonyard
Equipment	1. LX Rover 2. Total Station 3. Control Station 4. Visualization Display
Personnel	Vibhakar, Hariharan, Dhruv, Anish and Vivek
Procedure	1. Flatten moonyard terrain 2. Initiate the rover with a map of the initial state of the moonyard terrain 3. Give a desired berm configuration goal 4. Allow rover to execute autonomous operation to build berm
Verification Criteria	1. The rover can autonomously and efficiently build a desired berm

A. Appendix

Table 1: Mandatory Performance Requirements

ID	Requirement	Performance Metric
M.P.1	Receive commands from the user	The system will receive **2** types of commands: start/stop & desired configuration
M.P.2	Map the terrain	The system will update the worksite map at a frequency of ≥ **0.1 Hz**
M.P.3		The system will output ≥ **2** data products of worksite map pre and post operation
M.P.4	Localize within the site	The system will localize itself within a positional accuracy of ≤ **30 cm**
M.P.5	Operate autonomously	The system will operate autonomously with **0** human intervention after the operation starts
M.P.6	Traverse site terrain	The system will be capable of traversing a site terrain with ≤ **10 deg** incline
M.P.7	Excavate material	The system will be capable to excavate ≥ **3 kg** material per cycle
M.P.8	Build berm	The system will build a berm that has minimum dimensions of **15 cm** in height and **30 cm** in length
M.P.9		The system will build a berm with an error tolerance within ±**3 cm** in height and ±**5 cm** in length

Table 2: Mandatory Non-Functional Requirements

ID	Requirement	Description
M.N.1	Appropriate Size	The system will have a size appropriate to the test site
M.N.2	Maintain Traction	The system will be capable of maintaining traction during operation
M.N.3	Environmental Robustness	The system will be able to operate in a dusty environment
M.N.4	Safety Features	The system will operate safely (minimize human hazard)
M.N.5	Evaluate Performance	The system will be capable of generating evaluation metrics