Spring Test Plan

Lunar ROADSTER

Team I

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1 Introduction

This document details the test plans for the Lunar ROADSTER system throughout the spring semester, aimed at validating compliance with functional requirements. The testing framework follows a structured, incremental approach, beginning with fundamental assessments and progressively advancing in complexity as subsystem development progresses. Additionally, this document outlines a timeline for achieving each key functionality, ensuring systematic evaluation and refinement. Test results will be reviewed during scheduled progress reviews. By the spring validation experiment, the system will demonstrate a minimum viable product, showcasing autonomous crater grading in the Moon Yard. A milestone schedule is also provided to track progress toward key objectives.

2 Logistics

The equipment and test sites required for Lunar ROADSTER are listed below:

2.1 Equipment

1. **Lunar ROADSTER Rover:** The CraterGrader Workstation was modified to the project's requirements. The improvements include a front-mounted dozer, an improved sensor stack, and wheels suited to the Lunar Terrain.
2. **Leica TS16 Total Station:** An external sensor which will be used for localization of the robot's position.
3. **VectorNav VN-100 IMU:** An onboard Inertial Measurement Unit which will be used for localization of the robot's orientation.
4. **Zed 2i Depth Camera:** A stereo depth camera will be used to validate the environment manipulation being performed.
5. **Wheel Prototypes:** A series of 3D-printed wheel designs will be tested until the optimal design is decided.
6. **Dozer Assembly:** An actuated assembly that will be mounted to the front of the rover and used to manipulate the Lunar environment.
7. **NVIDIA Jetson AGX Xavier:** The onboard central compute for the robot.
8. **Arduino Due:** The onboard microcontroller interfaces the motor controllers and fans.
9. **Operations Terminal:** The main control centre of the Lunar ROADSTER mission. This is used to tele-operate and monitor the rover during all tests.
10. **Jetson TX2 Relay:** As a part of the external infrastructure, the Jetson TX2 board will connect to the Leica TS16 Total Station and obtain the measured data.
11. **TP-Link Router:** A personal LAN network will be created to connect the Jetson AGX Xavier on the rover, the Jetson TX2, and the Operations Terminal.

2.2 Testing Sites

1. **Planetary Robotics Lab Moon Yard:** The sandbox is the primary test site for most tests and the Spring Validation Demo.

2. **CIC LL67 Lab:** Our primary working area and the site for all small-scale unit tests.

3. **MRSD Project Lab:** Site for presentations and for testing any MRSD project course-related assignments.

3 Schedule

Date	Event	Capability Milestones	Tests	Requirements
02/13	PR1	• Rover can adequately maneuver • IMU accurately gives pose • Camera outputs video stream	T01 T02 T03	M.F.3 M.F.4 M.F.8
02/27	PR2	• Dozer can adequately grade and level • External infrastructure can interface with the rover • Wheel traction is adequate for dozing in regolith • Hardware setup is adequate for dozing task • Obtain map of the Moon Yard	T04 T05 T06 T07 T08	M.F.1 M.F.3 M.F.4 M.F.5 M.F.7
03/20	PR3	• Rover can localize itself accurately • Sensor placement do not block tool operations • Rover can navigate autonomously • Tool can operate autonomously	T09 T10 T11 T12	M.F.2 M.F.3 M.F.4 M.F.6 M.F.7
04/08	PR4	• Subsystems and units operate when integrated • Integrated subsystems do not hinder each other • Rover is operable as a system • Failing or degraded parts on rover is replaced	T13 T14	M.F.2 M.F.9
04/17	PR5	• System can operate autonomously • System can localize itself • System can navigate autonomously • System can traverse the Moon Yard without getting stuck • System can grade suitably sized craters and dunes • System updates the operations terminal regarding progress	T15	M.F.2 M.F.3 M.F.4 M.F.5 M.F.7 M.F.9

4 Tests

4.1 T01: Teleoperation Test

Teleoperation Test	
Objective	Validate the mechanical systems and navigation control software stack by CraterGrader is functional.
Elements	Wheel motors unit, navigation unit
Location	Planetary Robotics Lab Moon Yard
Equipment	Crater Grader chassis, teleoperation joystick controller, 2 AA batteries, 3 DeWatt 12V batteries, operations terminal laptop
Personnel	Boxiang, Bhaswanth
Procedure	
1. Put in the batteries for the joystick and rover.	
2. Power up the rover and SSH into Crater Grader's docker on the rover from the operations terminal.	
3. Run the teleoperation launch file and verify that the joystick topic is running and publishing commands.	
4. Validate the Jetson is receiving the commands and sending them to the motor controllers.	
Verification Criteria	
1. The rover moves forward and backward depending on the movement of the right trigger button.	
2. The rover turns left and right depending on the movement of the left trigger button.	
3. The rover's tool moves up and down depending on the movement of the shoulder button.	

4.2 T02: IMU Interfacing and Connectivity Test

IMU Interfacing and Connectivity Test	
Objective	Validate the interfacing of the IMU and publish data to ROS2 topics
Elements	Localization Unit
Location	CIC LL67 Lab
Equipment	VectorNav IMU VN-100, NVIDIA Jetson Xavier
Personnel	Ankit, Deepam
Procedure	
1. Connect the IMU to the Jetson Xavier via serial port.	
2. Run a ROS2 package interfaced with the VectorNav SDK to begin reading IMU data.	
3. Verify if the data is being published correctly to the ROS2 topic.	
4. Perform bias calibration on the IMU after finalising its mounting point on the rover.	
Verification Criteria	
1. IMU sends readable bias-corrected data via serial port and it is published on a ROS2 topic.	
2. The IMU data is bias-corrected and readable.	

4.3 T03: Depth Camera Connectivity Test

Depth Camera Connectivity Test	
Objective	Validate camera drivers are working and can be read by the Jetson.
Elements	Perception and localization subsystem
Location	CIC LL67 Lab
Equipment	NVIDIA Jetson Xavier, operations terminal laptop, ZED 2i stereo camera
Personnel	Boxiang, Bhaswanth
Procedure	
1. Connect the ZED 2i stereo camera to the Jetson Xavier via serial port.	
2. Run the ZED 2i stereo camera SDK on the Jetson.	
3. Acquire data from the SDK and convert the camera readings to video format via OpenCV packages.	
Verification Criteria	
1. Stereo camera sends its readings via serial connection to the Jetson.	
2. The video output is clear and human readable.	

4.4 T04: Dozer Assembly Test

Dozer Assembly Test	
Objective	Validate the functionality of the dozer blade assembly
Elements	Dozer blade, arms, linear actuator
Location	Planetary Robotics Lab Moon Yard
Equipment	Lunar ROADSTER Rover, teleoperation joystick controller, 2 AA batteries, 3 DeWatt 12V batteries, operations terminal laptop
Personnel	Ankit, Deepam, Bhaswanth, Simson
Procedure	
1. Mount the dozer assembly on the rover.	
2. Put in the batteries for the joystick and rover.	
3. Power up the rover and SSH into Crater Grader’s docker on the rover from the operations terminal.	
4. Run the teleoperation launch file and verify that the joystick topic is running and publishing commands.	
5. Prepare Moon Yard with a crater.	
6. Tele-operate rover to the crater and grade the crater using dozer blade	
Verification Criteria	
1. The dozer lifting mechanism is working as per design.	
2. The dozer is successfully grading the craters.	

4.5 T05: External Infrastructure Test

External Infrastructure Test	
Objective	Setup the robotic total station to track a prism mounted on the rover for localization, and an external TX2 setup to publish the total station commands via the router
Elements	Localization subsystem and teleoperation unit
Location	Planetary Robotics Lab Moon Yard
Equipment	Lunar ROADSTER Rover, Leica TS16 Total Station, Jetson TX2 Relay and TP-Link Router Setup
Personnel	Bhaswanth, Boxiang
Procedure	
1. Setup the Leica TS16 Total Station In the Moon Yard.	
2. Calibrate the total station with the mini prisms using the ”Orientate to Line” method.	
3. Mount a prism on the mast of the rover and track it using the total station.	
3. Setup the TP-link router, power up the Jetson TX2 and connect it to the total station via the RS232 cable.	
4. Inside the TX2, run the total station launch file to publish the measured data.	
Verification Criteria	
1. The total station sends the measured x, y, z readings of the prism to the TX2, which should be read by the Jetson on the rover via SSH.	

4.6 T06: Wheel Tests

Wheel Tests	
Objective	Continuously test wheel design iterations until design is finalized. Validate the functionality of the final design
Elements	Drive System
Location	Planetary Robotics Lab Moon Yard
Equipment	Lunar ROADSTER rover, Tele-operation Setup
Personnel	Ankit, Deepam, Bhaswanth, Simson
Procedure	
1. Mount the manufactured iteration onto the rover	
2. Note down performance of the wheel on the basis of traction, drawbar pull and sinkage.	
3. Iterate over designs and repeat until wheel performance is satisfactory.	
4. Manufacture all wheels and validate final functionality on the basis of traction, drawbar pull and sinkage.	
Verification Criteria	
1. The iterated wheel improves performance from the previous design and the test gives inputs for the next iteration's design.	
2. The final wheel design's performance is satisafactory.	

4.7 T07: Complete Hardware Test

Complete Hardware Test	
Objective	Validate the performance of the complete hardware system - sensors, electrical connnections, communication and mechanical elements
Elements	Sensors, Electrical Connections, Drive System
Location	Planetary Robotics Lab Moon Yard
Equipment	Lunar ROADSTER rover, Tele-operation Setup, Communication Setup
Personnel	Ankit, Deepam, Bhaswanth, Simson, Boxiang
Procedure	
1. Complete the full hardware setup of the rover - sensors, power connections, micro-controllers, wireless devices, mountings and drive system	
2. Tele-operate the rover to perform the required SVD/FVD tasks in the Moon Yard .	
3. Validate all working requirements - sensor outputs, connectivity, battery consumption and stress-test the drive system.	
4. Repeat 5 times and note down any potential points of failure. Develop a plan to handle these failures.	
Verification Criteria	
1. The rover's hardware functions as per requirements.	
2. A plan is developed for any potential points of hardware failure.	

4.8 T08: Mapping the Moon Yard

Mapping the Moon Yard	
Objective	Scan the Moon Yard to generate point cloud data, which will be processed into a 2D costmap for navigation
Elements	Mapping Subsystem
Location	Planetary Robotics Lab Moon Yard
Equipment	Nvidia Jetson Xavier, Operations Terminal laptop, Zed 2i Stereo Camera
Personnel	Simson, Boxiang
Procedure	
1. Connect the ZED 2i Stereo Camera to the NVIDIA Jetson Xavier.	
2. Run the ROS 2 package from the ZED 2i SDK to obtain point cloud data.	
3. Verify that the point cloud data is correctly published on the ROS 2 topic and visualize it in RViz.	
4. Record the point cloud data in a ROS 2 bag file for future use.	
5. Adjust parameter values in configuration files as needed and execute the required ROS 2 launch files to generate the costmap.	
Verification Criteria	
1. The point cloud data is successfully visualized in RViz and can be accessed by ROS 2 packages.	
2. The generated costmap correctly identifies obstacles and navigable areas, ensuring its accuracy for navigation.	

4.9 T09: Localization Test

Localization Test	
Objective	Validate the rover's localization stack by fusing data from the VectorNav IMU and Leica Total Station, ensuring precise real-time position tracking.
Elements	Localization subsystem
Location	Planetary Robotics Lab Moon Yard
Equipment	Lunar ROADSTER Rover, Leica TS16 Total Station, VectorNav IMU VN-100
Personnel	Bhaswanth, Boxiang
Procedure	
1. Power up the rover with the NVIDIA Jetson AGX Xavier.	
2. Connect the IMU to the Jetson via serial port.	
3. Setup the total station and track the prism mounted on the mast of the rover.	
4. Run the localization stack on the rover to localize the rover using data from the total station and the IMU.	
Verification Criteria	
1. Data from the IMU and the total station are correctly fused.	
2. The localization system runs in real-time without any delays or lag.	

4.10 T10: Optimal Mast Depth Camera Placement

Optimal Mast Depth Camera Placement	
Objective	Determine the optimal placement of the mast-mounted depth camera to ensure its field of view remains unobstructed by any robot or dozer components
Elements	Perception Subsystem
Location	CIC LL67 Lab
Equipment	Nvidia Jetson Xavier, Operations Terminal laptop, Zed 2i Stereo Camera
Personnel	Simson, Boxiang
Procedure	
1. Connect the ZED 2i Stereo Camera to the NVIDIA Jetson Xavier.	
2. Run the ZED 2i stereo camera SDK on the Jetson.	
3. Acquire data from the SDK and convert camera readings into a video stream using OpenCV.	
4. Mount the depth camera on the mast and adjust its position to ensure an unobstructed field of view.	
Verification Criteria	
1. The mast-mounted depth camera's field of view is completely free from obstructions caused by any robot or dozer components.	

4.11 T11: Autonomous Navigation Validation

Autonomous Navigation Validation	
Objective	Ensure that the localization and autonomous navigation subsystems function correctly, allowing the rover to navigate accurately to a goal point while avoiding large craters
Elements	Localization and Navigation Subsystem
Location	Planetary Robotics Lab Moon Yard
Equipment	Lunar ROADSTER rover, Communication Setup, Operations Terminal
Personnel	Simson, Boxiang, Bhaswanth, Ankit, Deepam
Procedure	
1. Connect all rover components and subsystems.	
2. Set up the external infrastructure such as the total station in the corner of the Moon Yard, the LAN router and the Jetson TX2 relay.	
3. Place the rover in the Moon Yard and calibrate its localization.	
4. Power on the rover and establish an SSH connection to the Lunar ROADSTER Docker on the operations terminal laptop.	
5. Run the required ROS 2 navigation and localization packages.	
6. Open RViz to visualize the rover's position and send goal points.	
7. If the global and local paths are not formed accurately, fine-tune the Nav2 parameters in the configuration file and re-run the navigation until performance is satisfactory.	
Verification Criteria	
1. The localization and navigation subsystems work together seamlessly.	
2. The rover avoids large craters and successfully reaches the designated goal location.	

4.12 T12: Tool Planner Test

Tool Planner Test	
Objective	Validate the tool planner is working in tandem with the navigation stack and is controlling the tool (dozer assembly) as per requirements
Elements	Tool Planner, Dozer Assembly, Localization and Navigation Subsystem
Location	Planetary Robotics Lab Moon Yard
Equipment	Lunar ROADSTER rover, Communication Setup, Operations Terminal
Personnel	Deepam, Ankit, Simson, Bhaswanth, Boxiang
Procedure	
1. Connect all rover components and subsystems.	
2. Set up the external infrastructure such as the total station in the corner of the Moon Yard, the LAN router and the Jetson TX2 relay.	
3. Prepare Moon Yard with appropriate craters and dunes.	
3. Place the rover in the Moon Yard and calibrate its localization.	
4. Power on the rover and establish an SSH connection to the Lunar ROADSTER Docker on the operations terminal laptop.	
5. Run the required ROS 2 tool planner, navigation and localization packages.	
6. Open RViz to visualize the rover's position and send goal points.	
7. Monitor autonomous mobility of the rover and autonomous tool movement based on the environment encountered. Fine-tune parameters until satisfactory operation achieved	
Verification Criteria	
1. The tool planner, localization and navigation subsystems work together seamlessly.	
2. The rover avoids large craters and successfully reaches the designated goal location, and moves the tool (dozer) accordingly based on the height and depth of sand.	

4.13 T13: Integration Test

Integration Test	
Objective	Validate all the components and subsystems are integrated correctly.
Elements	Navigation subsystem, localization subsystem, perception subsystem, tool subsystem
Location	Planetary Robotics Lab Moon Yard
Equipment	Lunar ROADSTER chassis, operations terminal laptop, total station, Jetson TX2 relay, LAN router, 3 DeWatt 12V batteries
Personnel	Ankit, Deepam, Bhaswanth, Simson, Boxiang
Procedure	
1. Attach and connect all the components and subsystems of the rover.	
2. Set up the external infrastructure such as the total station in the corner of the Moon Yard, the LAN router, and the Jetson TX2 relay.	
3. Prepare the Moon Yard with a suitable crater and dune.	
4. Place the rover in the Moon Yard and calibrate its localization.	
5. Turn on the rover and SSH into the Lunar ROADSTER docker on the operations terminal laptop.	
6. Switch the rover to autonomous mode and run the start-up procedure.	
7. Observe the rover autonomous grade the crater and level the dune. If anything unexpected occurs press the emergency stop button.	
Verification Criteria	
1. Execute end-to-end tasks in the Moon Yard by successfully grading one crater and leveling one dune autonomously.	

4.14 T14: Maintenance, Reliability and Quality Assurance Test

Maintenance, Reliability and Quality Assurance Test	
Objective	Carry out maintenance of the entire system, replace degraded parts and run all subsystem and system tests multiple times to validate repeatability, reliability and quality of the output
Elements	Navigation subsystem, localization subsystem, perception subsystem, tool subsystem
Location	Planetary Robotics Lab Moon Yard, CIC LL67 Lab
Equipment	Lunar ROADSTER chassis, operations terminal laptop, total station, Jetson TX2 relay, LAN router, 3 DeWatt 12V batteries
Personnel	Ankit, Deepam, Bhaswanth, Simson, Boxiang
Procedure	
1. Check all mechanical and electronic components for any failures or degradation.	
2. Replace/repair the degraded components and prepare for rigorous testing.	
3. Attach and connect all the components and subsystems of the rover.	
4. Set up the external infrastructure such as the total station in the corner of the Moon Yard, the LAN router, and the Jetson TX2 relay.	
5. Prepare the Moon Yard with a suitable crater and dune.	
6. Place the rover in the Moon Yard and calibrate its localization.	
7. Turn on the rover and SSH into the Lunar ROADSTER docker on the operations terminal laptop.	
8. Switch the rover to autonomous mode and run the start-up procedure.	
9. Observe the rover autonomous grade the crater and level the dune. If anything unexpected occurs press the emergency stop button.	
10. Monitor localization, navigation, mobility, and tool operation across multiple tests. Adjust the height and placement of components if needed, and fine-tune software parameters to achieve reliable results.	
Verification Criteria	
1. Maintenance is carried out on the Lunar ROADSTER rover.	
2. The rover is performing satisfactorily as per requirements multiple times.	

4.15 T15: Spring Validation Demo Test

Spring Validation Demo Test	
Objective	Perform a dress rehearsal for the Spring Validation Demonstration.
Elements	Navigation subsystem, localization subsystem, perception subsystem, tool subsystem, external environment
Location	Planetary Robotics Lab Moon Yard
Equipment	Lunar ROADSTER Rover, Operations Terminal Laptop, Leica TS16 Total Station, Jetson TX2 Relay, LAN Router
Personnel	Ankit, Deepam, Bhaswanth, Simson, Boxiang
Procedure	
1. Attach and connect all the components and subsystems of the rover.	
2. Set up the external infrastructure such as the total station in the corner of the Moon Yard, the LAN router, and the Jetson TX2 relay.	
3. Prepare the Moon Yard with a suitable crater and dune.	
4. Place the rover in the Moon Yard and calibrate its localization.	
5. Turn on the rover and SSH into the Lunar ROADSTER docker on the operations terminal laptop.	
6. Switch the rover to autonomous mode and run the start-up procedure.	
7. Observe the rover autonomous grade the crater and level the dune. If anything unexpected occurs press the emergency stop button.	
Verification Criteria	
1. The rover will climb gradients up to $15°$ and have a contact pressure of less than 1.5 kPa.	
2. The rover will fill craters of up to 0.5 meters in diameter and 0.1 meters in depth.	
3. The rover will localize itself and follow the planned path to a maximum deviation of 10%.	
4. The rover will operate autonomously and communicate the robot state and mission status to the user.	

5 Appendices

5.1 Mandatory Requirements

5.1.1 Mandatory Functional Requirements

Table 17: Mandatory Functional Requirements

Sr.No.	Mandatory Functional Requirement (Shall)
M.F.1	Perform **trail path planning**
M.F.2	Operate **autonomously**
M.F.3	**Localize** itself in a GPS denied environment
M.F.4	**Navigate** the planned path
M.F.5	Traverse **uneven terrain**
M.F.6	Choose craters to **groom and avoid**
M.F.7	**Grade** craters and **level dunes**
M.F.8	**Validate grading** and trail path
M.F.9	**Communicate** with the user

5.1.2 Mandatory Performance Requirements

Table 18: Mandatory Performance Requirements

Sr.No.	Performance Metrics (Will)
M.P.1	Plan a path with **cumulative deviation of** $\leq 25\%$ from chosen latitude's length
M.P.2	**Follow planned path** to a maximum deviation of **10%**
M.P.3	**Climb gradients up to** $15°$ and have a **contact pressure of less than 1.5 kPa**
M.P.4	**Avoid craters** ≥ 0.5 **metres** and **avoid slopes** $\geq 15°$
M.P.5	Fill craters of **up to 0.5 meters** in diameter and **0.1 meter** in depth
M.P.6	Groom the trail to have a **maximum traversal slope of** $5°$

5.1.3 Mandatory Non-Functional Requirements

Table 19: Mandatory Non-Functional Requirements

Sr.No.	Parameter	Description
M.N.1	Weight	The rover must weigh **under 50 kg**
M.N.2	Cost	The cost for the project must **be under $5000**
M.N.3	Computing Capacity	The onboard computer should be able to **run all required tasks**
M.N.4	Size/Form Factor	The rover should measure **less than 1 meter** in all dimensions

5.2 Desirable Requirements

5.2.1 Desirable Non-Functional Requirements

Table 20: Desirable Non-Functional Requirements

Sr.No.	Parameter	Description
D.N.1	Technological Extensibility	The system will be **well documented** and designed so that future teams can easily access and build on the work
D.N.2	Aesthetics	Requirement from sponsor, the rover must **look presentable and lunar-ready**
D.N.3	Modularity	To enable **tool interchangeability**, the tool assemblies must be modular and easy to assemble/disassemble
D.N.4	Repeatability	The system will **complete multiple missions without the need of maintenance**