Spring 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 electro-mechanical system to be demonstrated in the Spring 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 Spring Validation Demonstration will display tele-operated excavation and building capabilities of the system.

2. Logistics

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

Clearpath Husky A200: The mobile platform used for our project. All the subsystems will be integrated with this to provide mobility.

PRL Moonyard: The primary test site for most of our subsystems and the Spring 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.

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.

Nvidia Jetson Xavier AGX: The onboard central compute platform for our robot.

Realsense Camera: The depth camera which will be used to evaluate the berm to be built by the system.

Vectornav VN-100: The Inertial Measurement Unit used for orientation localization of the system.

Bucket-drum: Excavation tool designed by our team. Inspired from NASA's RASSOR designs.

Lifting Assembly: The mechanism designed by our team to raise and lower the bucket-drum for excavation and dumping.

3. Schedule

Identifier	Capabilities	Test(s)	Requirement(s)
Progress Review 1 (15 February)	• Depth cameras functional and can publish a point cloud • IMU functional and can publish data	• T1	• M.P.2 • M.P.4
Progress Review 2 (1 March)	• Lifting assembly can lift a load of at least 10 kg • IMU accurately estimates orientation	• T2 • T3	• M.P.4 • M.P.8 • M.N.1
Progress Review 3 (22 March)	• Excavation tool can excavate and dump at least 3 kg sand • Excavation and lifting subsystems can be controlled by teleoperation • Total station localizes within the Moonyard • Realsense cameras accurately create the berm depth cloud	• T4 • T5 • T6 • T7 • T8	• M.P.2 • M.P.4 • M.P.7 • M.P.8
Progress Review 4 (5 April)	• Husky localizes in the Moonyard using the Total station and the IMU • Husky can be moved using teleoperation • Husky can be teleoperated together with the lifting and excavation subsystems	• T9 • T10 • T11 • T12 • T13	• M.P.4 • M.P.6 • M.P.7 • M.P.8 • M.N.2
Progress Review 5 (19 April)	• System can excavate at least 3 kg/cycle using tele-operation • System can dump at least 3 kg/cycle • Lifting assembly can lift the weight of the drum with excavated sand • System can localize in the Moonyard during operation • System can transport excavated sand to the dump area • Camera can accurately produce a point cloud of the berm	• T14	• M.P.2 • M.P.4 • M.P.6 • M.P.7 • M.P.8 • M.N.1 • M.N.2 • M.N.3

4. Tests

Test No. 1: Sensor Functional Test	
Objective	Validate sensor functionality
Elements	Perception and Localization Subsystem
Location	MRSD Lab
Equipment	1. RealSense 435 Cameras x 2 2. VectorNav VN-100 IMU 3. Personal Laptop
Personnel	Vibhakar
Procedure	1. Interface the sensors with the Laptop 2. Establish and configure sensor interface with ROS 3. Acquire data from cameras and generate a point cloud 4. Acquire data from IMU and generate orientation and acceleration data
Verification Criteria	1. Camera publishes point cloud to ROS 2. IMU publishes orientation and acceleration data to ROS

Test No. 2: IMU Accuracy Test	
Objective	Validate IMU Accuracy
Elements	Localization Subsystem
Location	MRSD Lab
Equipment	1. VectorNav VN-100 IMU 2. Personal Laptop
Personnel	Vibhakar
Procedure	1. Connect the IMU to the Laptop 2. Establish and configure sensor interface with ROS 3. Acquire data from IMU and generate orientation and acceleration data 4. Calibrate and validate the data
Verification Criteria	1. IMU correctly detects yaw (orientation) and publishes on ROS

Test No. 3: Lifting Validation Test	
Objective	Validate lifting capacity
Elements	Mechanical Subsystem
Location	MRSD Lab
Equipment	1. Fabricated Lifting assembly 2. Mechanical Fixture for Testing 3. Linear actuator 4. Power supply
Personnel	Hariharan and Anish
Procedure	1. Design and fabricate a mechanical fixture for testing 2. Mount the lifting mechanism and the linear actuator on the fixture 3. Use a power supply to operate the linear actuator 4. Incremental loading of the mechanism up to the desired weight 5. Lift the mechanism to the desired height
Verification Criteria	1. The lifting tool can lift 10Kg to 50cm height

Test No. 4: Excavation Tool Validation Test	
Objective	Validate Excavation Tool
Elements	Mechanical Subsystem
Location	Moonyard
Equipment	1. Fabricated Bucket drum mechanism 2. Mechanical Fixture for Testing 3. Motors 4. Power supply
Personnel	Hariharan and Vivek
Procedure	1. Design and fabricate a mechanical fixture for testing 2. Mount bucket-drum with the motors on the fixture 3. Use a power supply to operate the motors 4. Excavate and dump material in the sandbox and measure the weight excavated
Verification Criteria	1. Tool can excavate and dump a weight of at least 3Kg

Test No. 5: Electronics bench and teleoperation test	
Objective	Validate Actuation electronics and Tele-operation Software
Elements	Electronics Subsystem
Location	MRSD Lab
Equipment	1. Transistor-driven relays 2. Efuses 3. Current sensors 4. Microcontroller 5. AGX Xavier 6. Power supply 7. Motor drivers 8. Controller for Teleop 9. Control Station
Personnel	Vibhakar, Anish, Vivek and Dhruv
Procedure	1. Connect all the components on a breadboard as per the designed schematic 2. Testing and evaluation of all the interface signals to the actuators 3. Configure the tele-operation software on the laptop and integrate the hardware and software 4. Validate the signals to the actuators using tele-operation
Verification Criteria	1. The electronic circuit powers the actuation. 2. Actuators are correctly controlled using tele-operation

Test No. 6: Total Station Accuracy Test	
Objective	Validate total station accuracy
Elements	Localization Subsystem
Location	Moonyard
Equipment	1. Fixture for mounting reflector 2. Total station 3. Nvidia TX2 with WiFi interface 4. Control Station
Personnel	Vibhakar and Anish
Procedure	1. Design and fabricate test fixture 2. Set up total station and the compute for acquiring data 3. Set up WiFi infrastructure for wireless data transmission 4. Emulate movements of Husky and verify the localization data
Verification Criteria	1. Total station localizes reflector to an accuracy of <30cm

Test No. 7: Excavation & Lifting integrated tele-operation Test	
Objective	Validate Excavation & Lifting integrated mechanisms working with tele-operation
Elements	Mechanical Subsystem
Location	Moonyard
Equipment	1. Test fixture 2. Excavation and Lifitng mechanism 3. Power supply 4. Actuation electronics 5. Microcontroller 6. AGX Xavier 7. Control Station 8. Teleop controller
Personnel	Hariharan, Vivek and Dhruv
Procedure	1. Mount the excavation and lifting mechanism on the test fixture 2. Interface the electronics and the actuators 3. Establish ROS interface for Teleop
Verification Criteria	1. Excavation and lifting mechanisms are correctly controlled together using tele-operation

Test No. 8: Camera Accuracy Test	
Objective	Validate Camera Accuracy
Elements	Perception Subsystem
Location	Moonyard
Equipment	1. RealSense 435 Cameras x 2 2. Camera Mounts 3. Personal Laptop
Personnel	Vibhakar and Anish
Procedure	1. Setup Cameras on the camera mount, and connect wires to PC 2. Build a berm manually in PRL 3. Record a bag file of the camera mount moving around the berm
Verification Criteria	1. An accurate point cloud of the berm can be created using the data from the cameras

Test No. 9: IMU on Robot Test	
Objective	Validate IMU functionality on Robot
Elements	Localization Subsystem
Location	Moonyard
Equipment	1. VectorNav VN-100 IMU 2. Husky A200 3. Xavier AGX 4. Control Station
Personnel	Vibhakar and Vivek
Procedure	1. Connect the IMU mounted on the Husky to the Xavier and start the ROS interface node 2. Record a bag file of the IMU data in two motion types: point turns and straight line movements
Verification Criteria	1. The IMU publishes correct orientation localization of the robot.

Test No. 10: Total Station with Robot Test	
Objective	Validate Total Station Localization with Robot
Elements	Localization Subsystem
Location	Moonyard
Equipment	1. Total Station Setup 2. Husky A200 3. Nvidia Jetson TX2 4. Xavier AGX 5. Control Station
Personnel	Vibhakar and Dhruv
Procedure	1. Setup the total station and its interface with the TX2 2. Mount the total station reflector on the robot and calibrate the total station 3. Move the robot around in the Moonyard in a fixed pattern 4. Record a bag file of the sensor reading
Verification Criteria	1. Output from the total station position localization matches the robot movement

Test No. 11: Localization Integration Test	
Objective	Validate integrated localization from the IMU and the Total Station
Elements	Localization Subsystem
Location	Moonyard
Equipment	1. VectorNav VN-100 IMU 2. Total Station 3. Husky A200 4. AGX Xavier 5. Control Station
Personnel	Vibhakar and Dhruv
Procedure	1. Set up the total station and VN-100 IMU on the robot 2. Calibrate the total station 3. Move the husky around the PRL in a closed loop, record all sensor and localization data
Verification Criteria	1. The start and stop position of the localization output is within 20 cm, and the shape resembles the one made during the test

Test No. 12: Mechanical Subsystem Bench Test	
Objective	Validate mechanical subsystem integration
Elements	Mechanical Subsystem
Location	MRSD Lab and Moonyard
Equipment	1. Lifting mechanism with attached drum 2. Wooden box on a cart 3. Electronics setup
Personnel	Hariharan and Vivek
Procedure	1. Mount the lifting mechanism on a wooden box that resembles the shape of the Husky and place it on a cart 2. Connect the linear actuator and drum motor to the electronics subsystem 3. At the lower configuration, rotate the drum to collect sand while pushing the cart manually around the PRL 4. Lift and lower the mechanism multiple times when the drum is filled 5. At the upper configuration, keep the cart stationary and counter-rotate the drum to dump the collected sand
Verification Criteria	1. The mechanism lifts and lowers the weight and reaches the desired height at the bottom and top of the lift 2. The drum excavates and dumps at least 3 kg/cycle

Test No. 13: Mobility & Excavation Integration Test	
Objective	Validate the mobility and excavation subsystems integrated functioning
Elements	Mechanical & Electronic Subsystems
Location	Moonyard
Equipment	1. Lifting mechanism with attached drum 2. Husky A200 3. Electronics setup
Personnel	Hariharan and Dhruv
Procedure	1. Mount the lifting mechanism on the Husky 2. Connect the linear actuator and drum motor to the electronics subsystem 3. At the lower configuration, rotate the drum to collect sand while moving the Husky manually around the PRL 4. Lift and lower the mechanism multiple times when the drum is filled 5. At the upper configuration, keep the Husky stationary and counter-rotate the drum to dump the collected sand
Verification Criteria	1. The robot can move around in the Moonyard with the lifting and excavation mechanisms operational

Test No. 14: Spring Validation Demo Test	
Objective	System Integration and Validation Test for SVD
Elements	Mechanical, Electronics, Localization Subsystems
Location	Moonyard
Equipment	1. Lifting mechanism with attached drum 2. VN-100 IMU 3. Total Station 4. RealSense 435 Cameras x 2 5. Husky A200 6. Electronics setup 7. Control Station
Personnel	Vibhakar, Vivek, Hariharan, Dhruv and Anish
Procedure	1. Attach the lifting mechanism, electronics, IMU, total station receiver, and RealSense cameras on the Husky 2. Set up tele-operated control over all actuators 3. Place the robot in the Moonyard 4. Operate all actuators by moving the husky in fixed patterns, lifting and lowering the lifting mechanism, excavating and dumping using the drum 5. Press the emergency stop while moving 6. Record a bag file when moving the robot in a closed loop 7. Record a bag file of the camera data while moving the robot around a build berm 8. Execute multiple cycles of excavation and dumping to build a berm
Verification Criteria	1. The system is able to build a berm using tele-operated control 2. Emergency stop button stops all actuation without affecting the computing subsystem 3. Initial and final poses from the localization module are within 20 cm in the loop closure test 4. Pointcloud built using camera data accurately represents the 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