Extraterrestrial Sample Manipulation

VT LUNA (Team 13) - AOE 4105 Fall Final Presentation

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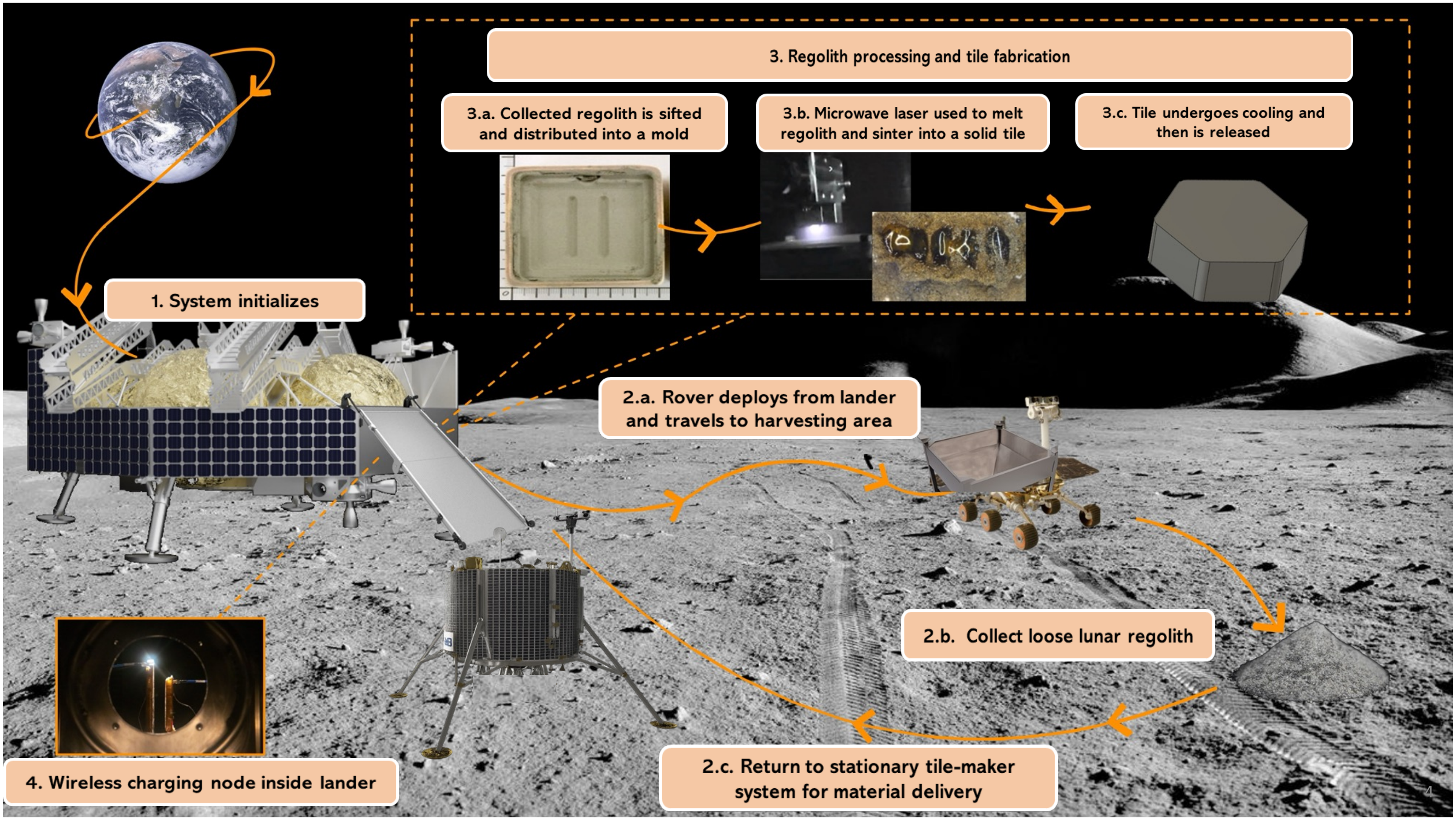
Agenda

1. Introduction: Project Definition
2. Project Overview & Motivation
3. Experiment Definition & Setup
4. Experiment procedure and test cases
5. Expected results and how they will be useful
6. Budget Sheet
7. Timetable

Project Definition

We will design and construct a rover capable of collecting and storing a regolith simulant and then transporting it to a holding container. Once at the holding container it will scale a ramp before depositing the simulant into the top of the container.


3. Regolith processing and tile fabrication
3.a. Collected regolith is sifted and distributed into a mold
3.b. Microwave laser used to melt regolith and sinter into a solid tile
3.c. Tile undergoes cooling and then is released
1. System initializes
2.a. Rover deploys from lander and travels to harvesting area
2.b. Collect loose lunar regolith
2.c. Return to stationary tile-maker system for material delivery
4. Wireless charging node inside lander

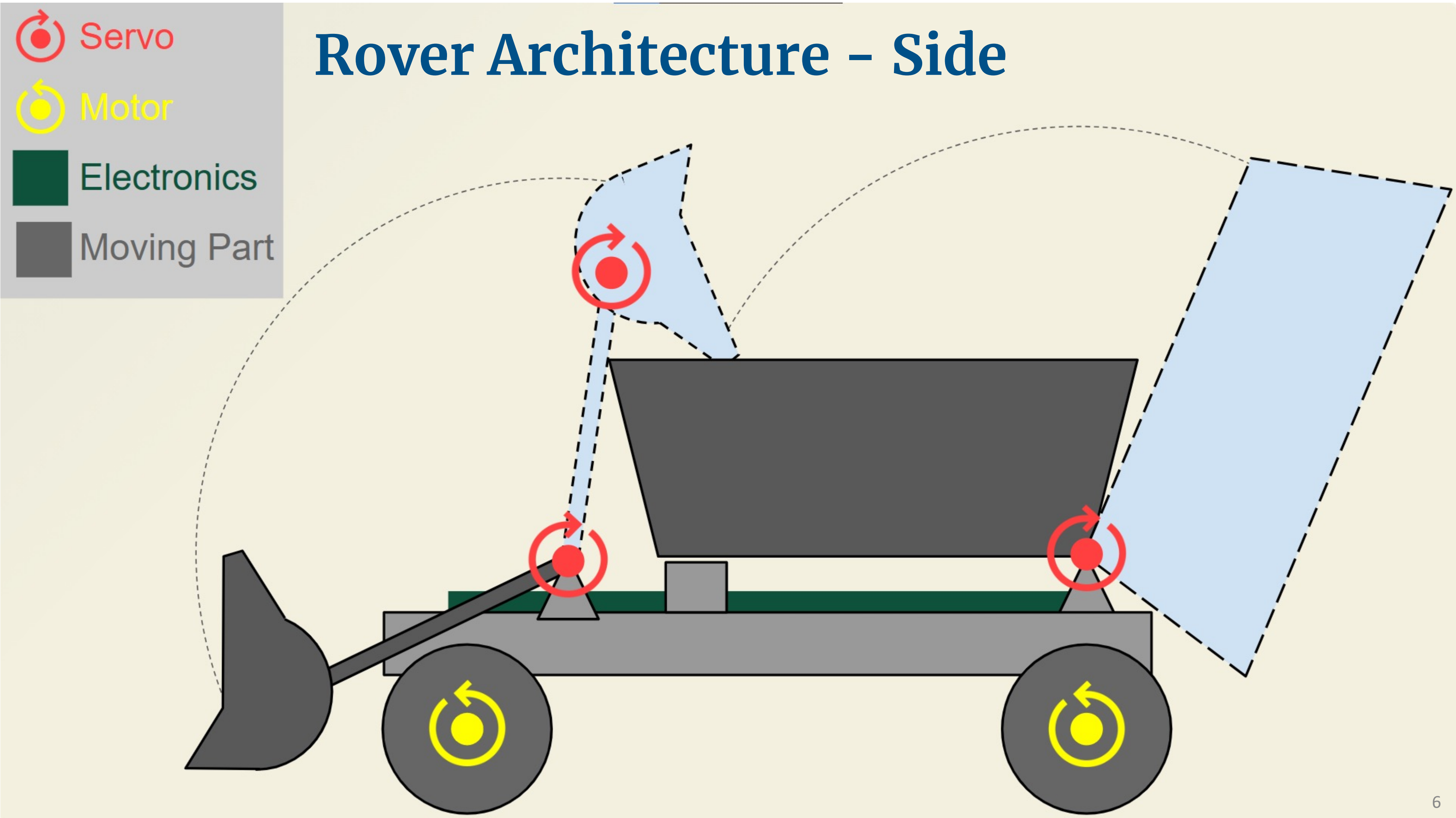
Project Relation to Senior Design

Lunar Landing Pads – Our Senior Design project entails the construction of lunar landing pad tiles using the concept of microwave sintering as a means of manufacture.

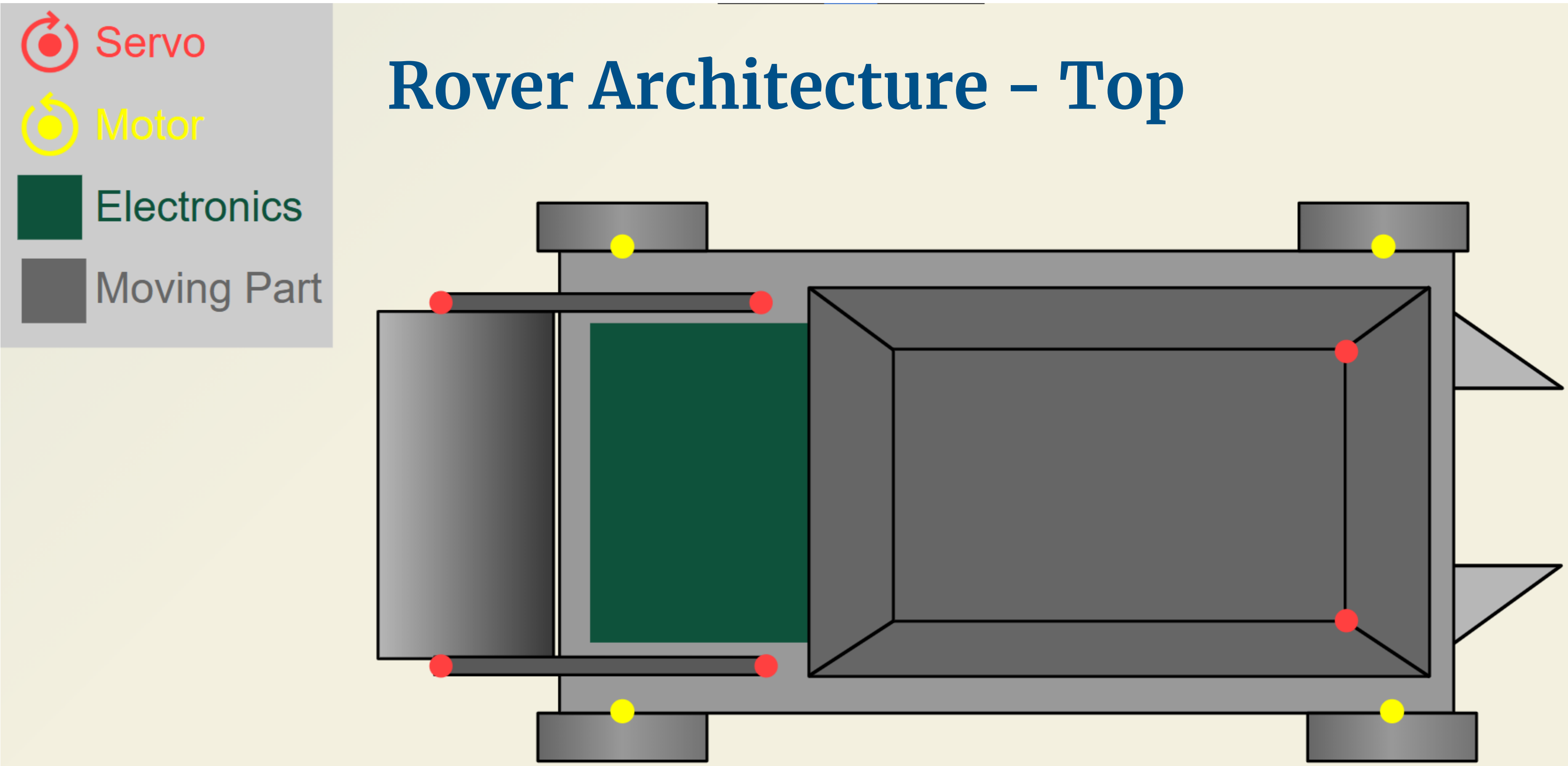
Rover System – Our design will include a rover system capable of gathering the regolith and returning it to the stationary tile maker

Experiment – Our experiment will be to simulate the rover system process here on Earth. We will design and automate a rover to collect a lunar regolith simulant and return said simulant to a large bucket serving as the "stationary tile maker"

Rover Architecture – Side

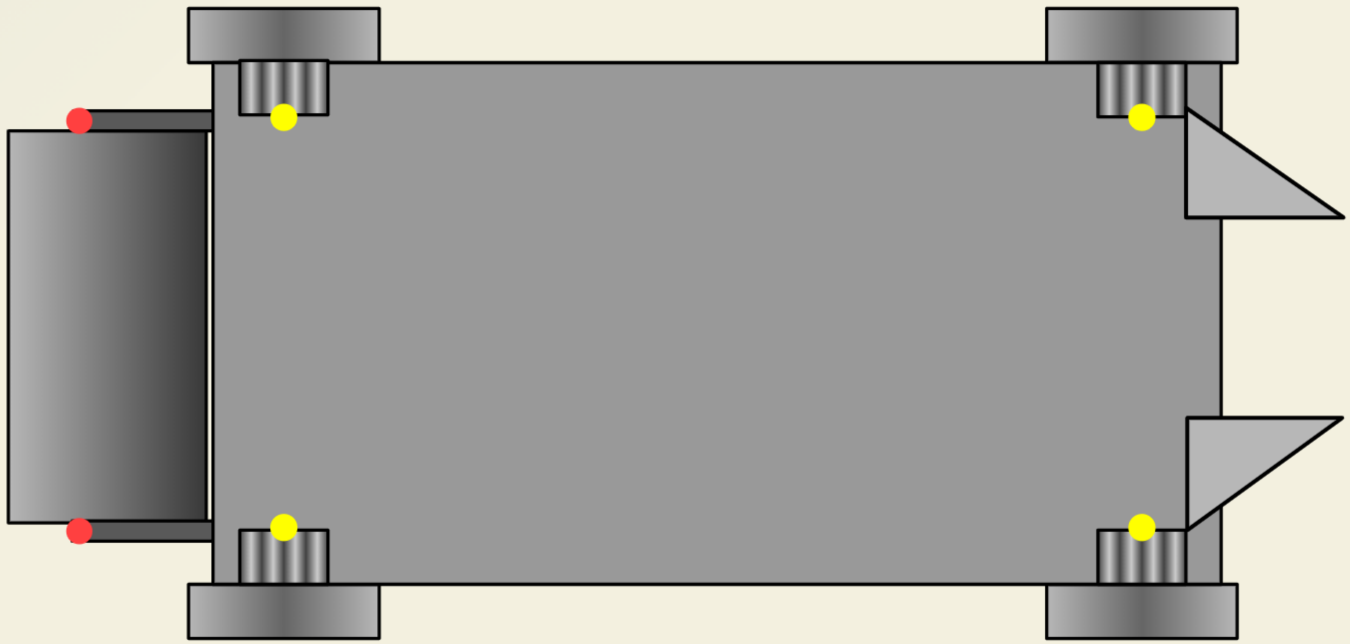


Rover Architecture – Top



Servo
Motor
Electronics
Moving Part

Rover Architecture – Bottom



Motivation and Impact

This technology is essential for planetary missions, including robotic-led missions like Moon/Mars Sample Return, as well as mining missions to eventually build infrastructure on other planets/moons. The efficiency of the robotics demonstrated in this mission directly impacts the time and energy efficiency of a mission that relies on this technology.

Literature Review

Literature Review:

Primarily focused on rover architecture and extraterrestrial excavation techniques. Touches on excavation efficiency, regolith selection, and rover size power optimization.

Literature Review

Best Practices for the Testing of Planetary Roving Vehicle Mobility Systems and Tires

- Compiles a list of best practices for testing rover mobility systems
- There are benefits to testing on the full system
- Regolith simulant should be chosen based on specific test needs

Parametric review of existing regolith excavation techniques for lunar In Situ Resource Utilization (ISRU) and recommendations for future excavation experiments

- An overview of research on lunar regolith excavation methods
- Methods included: Scraper, Front loader, bucked wheel, bucket drum, backhoe, and pneumatic
- Excavation rate, traverse speed, and power consumption should be considered when choosing an excavation method

Creager, Colin, et al. "Best Practices for the Testing of Planetary Roving Vehicle Mobility Systems and Tires." (2025)

Just, G. H., et al. "Parametric review of existing regolith excavation techniques for lunar In Situ Resource Utilisation (ISRU) and recommendations for future excavation experiments." *Planetary and Space Science* 180 (2020): 104746.

Literature Review

Automating the Short-Loading Cycle: Survey and Integration Framework

- Analyzes the short loading cycle and determines the steps required to automate it
- Cycle: Approach the pile, Loading, Retract from the pile, Approach the dumper, Dumping, Retract from the dumper
- Proposes a solution that switches between a neural network, a rule-based system, and a trained agent based on the needs of each step

Borngrund, Carl, et al. "Automating the Short-Loading Cycle: Survey and Integration Framework." *Applied Sciences* 14.11 (2024): 4674.

Configuring Innovative Regolith Moving Techniques for Lunar Outposts

- An overview techniques for excavating, transporting, and building with regolith
- Production per unit weight is highest with smaller vehicles
- Smaller robots are less power efficient because of a smaller battery and similar idle power usage
- Adjusting driving speed and angle of the excavation blade can decrease the task completion time

Skonieczny, Krzysztof, et al. "Configuring innovative regolith moving techniques for lunar outposts." *2009 IEEE Aerospace conference*. IEEE, 2009.

Literature Review

- Most research surrounding regolith collection is focused on collecting samples for testing instead of construction
- Most research around collecting regolith for construction is an overview of the entire process instead of specifically focusing on collecting and moving the regolith
- Most research involves larger scale and far more expensive rovers

Experimental Setup

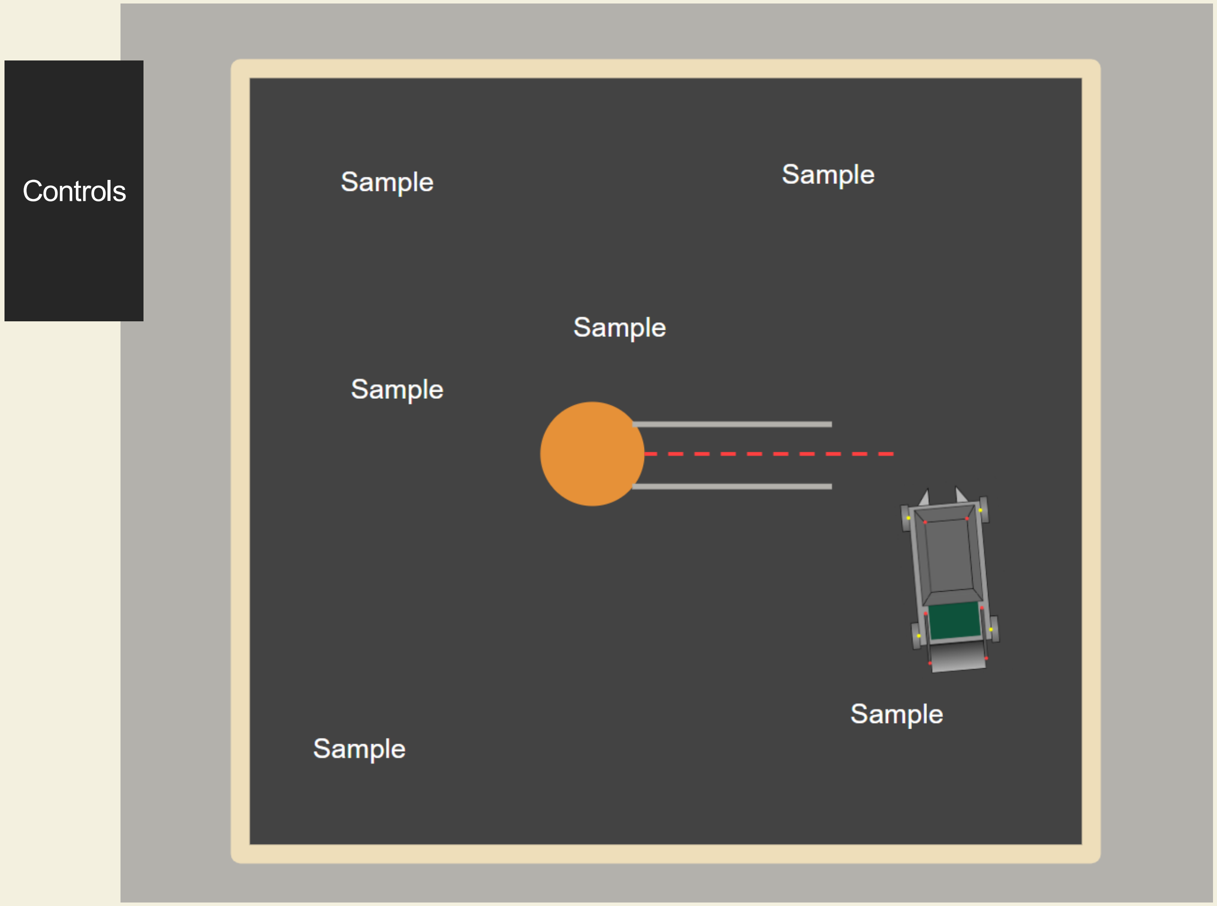
Lab Facility

Autonomous Aerospace Systems (A2Sys) Lab, Room 237 VTSS

3 by 3 meters

Core Components

Motion capture system for precise, real-time tracking of samples.


Controls
Sample
Sample
Sample
Sample
Sample
Sample

Expected results and usefulness

EXPECTED RESULTS:

- Successful scoop–transport–dump cycle with sand
- Controlled dumping with minimal spillage
- Demonstration of stable ramp climbing under load (1.15 Nm of torque required per wheel)
- A collection rate of 1.2 kg/min
- Minimal sample loss rate ~5%

This experiment will be useful to assess rover performance in regolith handling and guide future lunar rover design

Parts list

Component	Cost	Link
Servo x6	$150	150KG Digital RC Servo
Chassis	$700	https://www.servocity.com/strafer-chassis-kit-104mm-gripforce-mecanum-wheels/
Assorted Screws	$60	https://www.servocity.com/m4-socket-head-screw-assortment-pack/
Raspberry Pi 4 Model B/4GB x2	$60	https://www.pishop.us/product/raspberry-pi-4-model-b-4gb/?src=raspberrypi
Arduino Giga R1 WiFi x2	$67	https://www.jameco.com/z/ABX00063-Arduino-Arduino-Giga-R1-WiFi-Dual-Core-with-Bluetooth-and-WiFi_2352183.html?CID=BINGMC
12V battery	$25	https://www.amazon.com/Tenergy-Capacity-Rechargeable-Replacement-Equipments/dp/B077Y9HNTF
Motor x4	$120	Amazon.com: BRINGSMART 12V 12rpm DC Worm Gear Motor 70kg.cm High Torque Self-Locking Reversed Mini Turbine Geared Motor for DIY Robot Rotating Table Door Lock Curtain Machine (12V 12rpm) : Electronics
Motor Controller	$125	https://www.superdroidrobots.com/shop/item.aspx/sabertooth-dual-25a-motor-driver/822
regulator	$10	https://www.amazon.com/Weewooday-Regulator-Voltage-Converter-Transformer/dp/B08JZ5FVLC
PWM Breakout	$15	HiLetgo 2pcs PCA9685 16 Channel 12-Bit PWM Servo Motor Driver
Wiring	$30	
Misc. (Fuses, switches, bulk capacitors, power distribution blocks.)	$100	
Basalt Sand	$20	https://www.homedepot.com/p/45-lb-Basalt-Sand-5-cu-ft-1042015/202084896
Tarp	$15	https://www.homedepot.com/p/BOEN-10-ft-W-x-10-ft-L-All-Purpose-Blue-Tarp-BLU-1010/204091346?source=shoppingads&locale=en-US&fp=ggl
Total	$1345	

Components that need to be 3d Printed/CAD Modeled

Component	Basic Information
Rover Hopper Bucket	Our custom Rover Hopper needs to be able to hold 4.2 kg of sand. Designed with Lunar gravity in mind with steep angles and conductive metal.
Rover Bulldozer Blade	Our custom Bulldozer Blade needs to be able to scoop 1.3 kg of sand and load it into the Hopper Bucket.
Mount for Arm	Custom machined arm servo mounts and assemblies will give us full control over size, weight, and torque requirements.
Mount for Hopper	Our hopper mount will be designed to fit our custom Hopper and attach it to our frame.

Timetable

Dates	Plan
12/08/25	Ordering parts such as Raspberry pi and Arduino (2 of each) and work on CAD models through out the break.
1/20/26 – 2/9/26	Order parts for the rover (some computers already ordered) and complete training to get access to the lab. Start setting orders to print parts using Aero Fabrication Facilities.
2/9/26 – 2/27/26	Begin constructing the rover as well as early programming steps (getting some electronics to talk to each other).
2/27/26 – 3/31/26 (Before Spring Break)	Finish construction of the rover and begin programming functions of our experiment (using motion capture system, scooping of sand, dumping of sand).
3/31/26 – 4/17/26	Work on running the experiment and collecting sand autonomously. Improve on design if possible.
4/17/26	Have a working experiment we can share with others.

Questions?

Ramp Climbing

Assumptions:

- 25 lb (conservative estimate)
- 30-degree inclined ramp
- 0.05 rolling resistance coefficient of the ramp (conservative estimate)
- Movement speed of 1 ft per second
- 70% motor efficiency (conservative estimate)
- 3’’ radius wheels (conservative estimate)

Math:

25 lb = 11.3 kg

11.3 kg mass is about 111 N of force due to gravity

55.6 N pull downwards

96.3 N pulls horizontally

4.8 N pulls horizontally when factoring in the rolling resistance coefficient

Thus 60.4 N is the total force required

Power = F * V = 60.4 N * 0.3 m/s = 18.4 Nm/s = 18.4 W

Factoring in motor efficiency, **26.3 W**

Our battery can supply 24 Wh meaning the rover could in theory climb for almost an hour (much longer than we need)

Each wheel should be able to produced 15.1 N of force, or 15.1 N * 0.076 m (3 in) = **1.15 Nm torque required**

Rpm = 60.4 N * 0.3 m/s (1 ft/sec) / 2*pi*0.076 = **38 rpm**

Calculations

Assumptions:
Scoop shape: half cylinder
r=6.5cm
d=21 cm
L=30cm
80% scoop fill
Density =1.5 g/cm^3
Scoop and arm mass =1kg

Torque=force x distance
Force = mass x acceleration
Mass = volume x density

V=1394 cm^3
M=2.1 kg
Mfill=1.7 kg
Mt=2.7kg
T= 2.7kg x 30cm = 81 kgcm
Ta = 150kgcm x 2 = 300kgcm
FS = 300 / 81 = 3.7

Assumptions:
Pivot time: 10s
U=.5 m/s
25s per scoop
M = 1.6 kg

Known:
Ta= 150 kgcm
w = 250 deg/s (unloaded)
X=3m
Ramp length = .8m

Pivot time: 10s
Transport time = X / U = 6s
Time to load = number of loads x time per load = 3 x 25 =75s
Transport time = X / U = 6s
Pivot time: 10s
Climb ramp: ~25s
Deposit material ~12s
Descend ramp ~10s
Dead time ~60s
Total time:3.2min
1.3 kg/min

Component	Cost	Link
Arduino Giga R1 WiFi	$67	https://www.jameco.com/z/ABX00063-Arduino-Arduino-Giga-R1-WiFi-Dual-Core-with-Bluetooth-and-WiFi_2352183.html?CID=BINGMC
Raspberry Pi 4 Model B/4GB	$60	https://www.pishop.us/product/raspberry-pi-4-model-b-4gb/?src=raspberrypi
Home Depot 5 Gallon Bucket	$4	https://www.homedepot.com/p/The-Home-Depot-5-Gallon-Orange-Homer-Bucket-05GLHD2/100087613
Linear Actuator	$40	https://www.amazon.com/RVMARINEPAT-Linear-Actuator-Electric-Waterproof/dp/B0CX8Y49JN?c=ts&dib=eyJ2IjoiMSJ9.lIKk90GnuzDfOO5lU2Oo1C3Un9KWq1zHk70C2WqOl2U-fg6Kse6CMd8g90-RsgpfAe4qav0EewrQwudM4D4jX7rELbCIzK6ZCoqoiBnMeKvnFiiwBC6yez9XjdkaWYDv6r6ZeA3lZKsMKTMerFSsbhpCuo2TIRFqFquSowqoU13xqfdQST9nd_gndYTYiRCiW7CG67Yc23v-oZ56aqKokrHgpJxzwAqu_oVItQehIcfPbS9B_nBUUk2_tiL0i9Sbgj_HcQQ4hjzvLh7h5kKyWMALe9BfwvgYMO-M6RzYGLk.7vhHF9z4RgUiPHg803pk0Zrz913r6ycpbnAr8QNz2BQ&dib_tag=se&keywords=Linear%2BMotion%2BActuators&qid=1765043855&s=industrial&sr=1-3&ts_id=350654011&th=1
Hiwonder 4WD Mecanum Robotics Chassis with Large Metal Bracket, Encoder Geared Motor Kit,	$150	https://www.amazon.com/Hiwonder-Vehicle-Chassis-Bracket-Raspberry/dp/B0BB72LPDH?th=1
2500mAh 11.1V High Capacity Battery Pack	$65	https://www.amazon.com/2500mAh-Capacity-Replacement-Extended-Quadcopter/dp/B07TVCMMF9
6DOF Robot Arm (Open source)	$159	https://www.amazon.com/LewanSoul-Robotic-Arduino-Software-Tutorial/dp/B074T6DPKX/ref=pd_lpo_d_sccl_2/139-9994314-9186956?pd_rd_w=S5TbD&content-id=amzn1.sym.4c8c52db-06f8-4e42-8e56-