



MOTIVATION / OBJECTIVE

The Problem:

- Satellite remote sensing of the Moon offers wide-area data but lacks direct, on-site validation called ground truthing.
- Traditional ground-truth instruments are heavy and expensive.

The Proposed Solution:

- A previous mars sample-return concept demonstrated deploying small, auxiliary payloads alongside main mission objectives.
- Sensor packages detach from ASTROJACK and deployed across a designated lunar-area, providing direct ground-level measurements.

<u>Objective</u>: Provide a proof-of-concept for low-cost, lightweight distributed sensor packages capable of:

- Ground Analysis: classifying ground hardness.
- Communication: maintaining robust, drop-node-tolerant data-transfer between nodes.
- Localization: computing relative node locations.



SYSTEM REQUIREMENTS

Key Milestones

- Implement ground-hardness classification via accelerometer data and onboard software.
- Develop peer-to-peer communication protocol over SDRs.
- Build RSSI-based distance estimation between two nodes.
- Extend localization and communication to a network of 3+ nodes. Design and fabricate enclosure to house and protect system electronic components from dropping.

High Level System Requirements

- Classify surface hardness (soft/hard) via ≥ 1 kHz accelerometer sampling and onboard machine learning algorithm.
- Communicate wirelessly across \leq 500m with reliable, low-latency transmission and error checking.
- Determine relative location of each node using RSSI-based distance estimation and localization within 50m of uncertainty per 100m.

SYSTEM DIAGRAM



*In the event that the central node goes offline, the next available ARM will take it's place



ELECTRICAL & COMPUTER ENGINEERING

UNIVERSITY of WASHINGTON

ASTROJACKS: A.R.M.S. (Autonomous Remote Mapping System)

GROUND ANALYSIS



highlighted in purple.

DAQ

Base

Station

Ground Analysis

- Detect free-fall/steady-state acceleration for start/stop conditions.
- Record ≥ 1 kHz accelerometer data via microcontroller. Determine drop characteristics including peak acceleration and impact duration. Soft Landing



Machine Learning

• A TensorFlow-based linear neural network serves as the base model. While typically power-intensive, it is optimized into a low-power TinyML format suitable for deployment on resource-constrained platforms like the Raspberry Pi.

COMMUNICATION

- Wireless Communication is implemented through a peer-to-peer, multi-nodal mesh network. Each node: • Sends and receives 25-packet bursts containing local ground classification (*soft_or_hard*).
- Stores *soft_or_hard* majority bit from all peers.
- Stores and sends distance estimations of all peers through packet-extracted, averaged RSSI values (rssi_log). Stores *rssi_logs* from peers (*rssi_peer_log*) to form distance matrix used for localization.

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soft_or_hard: 0/1 from Metro)	2 soft_or_hard: 0/1 from I
rssi_log = { J2: rssi (dB) received from J2, J3: dB, J4: dB, J5: dB }		rssi_log = { J1: rssi (dB) received fi J3: dB, J4: dB, J5: dB }
rssi_peer_log = { J2: {rssi_log from J2-J5 }, J3: {}, J4: {}, J5: {} }		rssi_peer_log = { J1: {rssi_log from J1 J3: {}, J4: {}, J5: {} }
ground_log = { J2: soft/hard (0/1 bit) from J2, J3: 0/1, J4: 0/1, J5: 0/1}		ground_log = { J1: soft/hard (0/1 bit) J3: 0/1, J4: 0/1, J5: 0/1

LOCALIZATION

Node to Node Distance

- Distance approximation between nodes utilizes **received** signal strength indicators (RSSI) from packet data.
- This method requires experimental calibration to the desired environment (path loss exponent: n).

$$Distance = d_0 \cdot 10^{\left(\frac{RSSI_0 - RSSI_{measured}}{10 \cdot n}\right)}$$

Location Equations

 $(x-p1_x)^2+(y-p1_y)^2+(z-p1_z)^2=d1^2$ $(x-p2_x)^2+(y-p2_y)^2+(z-p2_z)^2=d2^2$ $(p-p3_x)^2 + (y-p3_y)^2 + (z-p3_z)^2 = d3^2$

- Takes in a node-to-node distance matrix as an input. • Passes distances and nodes through systems of location equations. • Uses the calculated distance to output (x,y,z) coordinate points.

ADVISERS: RUSSELL G SMITH, PAUL E GLICK, JONATHAN SAUDER, SAMUEL PRAGER **SPONSOR:** NASA JET PROPULSION LABORATORY

STUDENTS: ERNST ANDERSON, MAXWELL FIELDS, BRADEN HOLGATE, AARON HUSIN, CHRISTOPHER LAM, JERLEN VEGA







Figure demonstrates the relation between dBm (RSSI) and the meters both observed and predicted by our model

Mapping Package Locations: Multilateration

DATA ACQUISITION AND VISUALIZATION

File Reception

ingestion pipeline.

Data Visualization

- A Grafana dashboard dynamically tagging.

PHYSICAL IMPLEMENTATION & TESTING

Ground Analysis Testing:

- Initial drop tests were conducted by mounting fragile electronics inside a suspended milk crate.
- An accelerometer is secured to the base to capture impact data.

Comms & Localization Testing:

custom wire harnesses.

Final encasing:

• The final casings were 3D printed using ABS filament due to its availability, impact resistance, and researched thermal stability.

We aimed to design a lightweight, low-cost system that could autonomously characterize lunar soil and support future NASA missions with real-time, groundtruth data.

- classification using onboard ML.
- sensor data.

Future Works & Improvements

Sincere thank you to our sponsors and mentors at the NASA Jet Propulsion Laboratory for their guidance and support throughout this project.

Jet Propulsion Laboratory California Institute of Technology

• Sensor data logged in real-time by uploading structured CSV files received from sensor packages to an InfluxDB time-series database via python

visualizes acceleration data from each node with drop-specific filtering and timestamp



Node 2

Node 1

• 2D or 3D spatial telemetry rendered on an interactive map interface for remote monitoring and analysis of sensor package locations.



• Compact, self-contained telemetry units were assembled by integrating a battery, Raspberry Pi, and SDR into a single package connected through



CONCLUSIONS

Ground analysis: Captured impact characteristics and implemented surface

Communication: Enabled wireless transmission and visualization of gathered

Localization: Accuracy of localization is \mp 25m per 100m, limited by the RSSI implementation as it is dramatically affected by multipath.

• **Improving localization accuracy** by exploring alternative distance approximation methods: Time of Flight, Ultra-wideband. **Reducing power consumption** through duty cycling or hardware level optimizations for longer field deployment. **Enhancing communication resilience** to reduce dropped telemetry.