Autonomy & Operations Capabilities for Lunar Missions: Highlights of an AI Lunar Surface Demonstration and the ESA-ESRIC Space Resources Challenge

MISSION CONTROL

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Space Resources Roundtable
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We acknowledge the support of the Canadian Space Agency [3CAPDEMO21]

Software for Earth, Moon and Mars

SPACEFARER

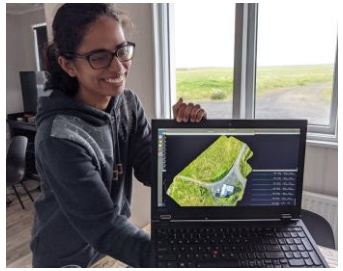
Web-based user interfaces:
operate robots, payloads, and more.

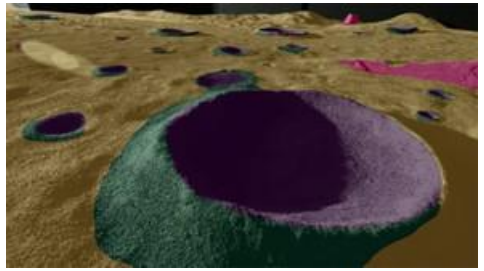
Thousands of hours in analogue use,
now supporting missions to the Moon

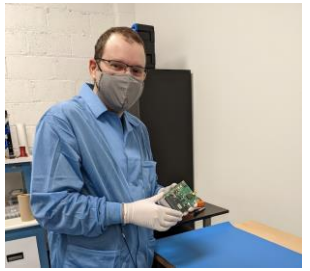
SPACEFARER AI

Enabling autonomy:
Deploy AI for spaceflight

Heritage over 2 flight deployments





Motivation for
Autonomous Perception

MoonNet:
A Lunar Surface Demo

Spacefarer AI:
Our Autonomy Platform

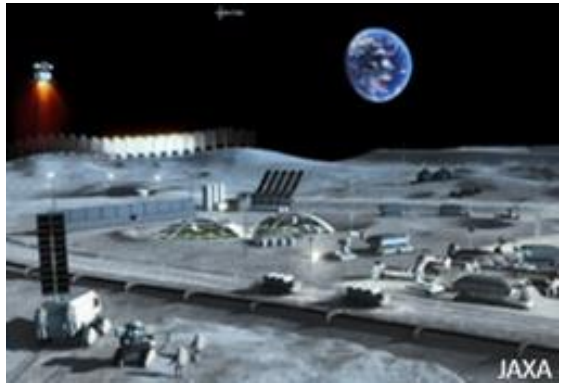
Spacefarer:
Our Operations Platform

Highlight of ESA-ESRIC
Space Resources Challenge

Lunar Exploration Operations Challenges

Mission Scenarios

Exploration (2023-2030)



Construction (2030-2037)

Habitation (2045+)

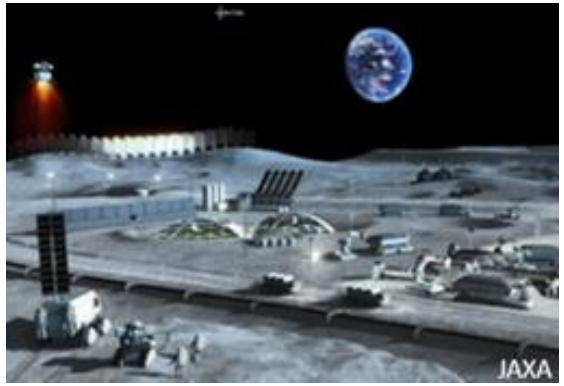
Operational Challenges

- Limited a priori knowledge
- Long latency
- Limited bandwidth
- Communications blackouts
- Human cognitive load
- Missed science opportunities
- Non-scalable operations (costly and cumbersome)

Artificial Intelligence will be required

Mission Scenarios

Exploration (2023-2030)



Construction (2030-2037)

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Onboard intelligence needs:

- Optimize balance of onboard decision making and intelligently select data for downlink
- Help robots perceive their environment
- Localize itself or objects around it
- Interact with its environment and other cooperative (or uncooperative) systems
- Adapt to changes or unforeseen circumstances
- Synthesize and prioritize data for humans consumption & rapid decision making
- Maximize productivity during idle time
- Predictive health monitoring of space system
- Adaptable and automated support for Astronaut HMI, productivity, health and wellness

*In sum, we'll be going to do **more complex operations in space** – and this will require more robots, more autonomy, and better operations*

Barriers to Adoption of Edge AI in Space

*AI **for** Space is common…but not AI **in** space:*

- With good reason, there is a low risk tolerance in relying on new technology for mission critical applications
- Current flight software V&V standards do not apply to stochastic algorithms trained on data
- Lack of training data from real operating environments
- Unknown or early stage development tools & methodologies, testing standards, commissioning & operations for high TRL use
- Hardware limitations of deep space environment limit compute unlike terrestrial production-level ML applications

Critical Enabling Technologies for Edge AI in space

- ML model code

- Agreed upon ML TRL development standards
- Selection of suitable AI applications based on user needs and mission constraints
- Data and model quality control and documentation
- Tools & techniques for accelerating ML model to flight software on low-powered compute
- Verification and validation techniques for statistical learning algorithms
- ML model performance monitoring, ML software infrastructure and in-flight updates
- Graceful failure modes

Autonomy Perception for Mobility

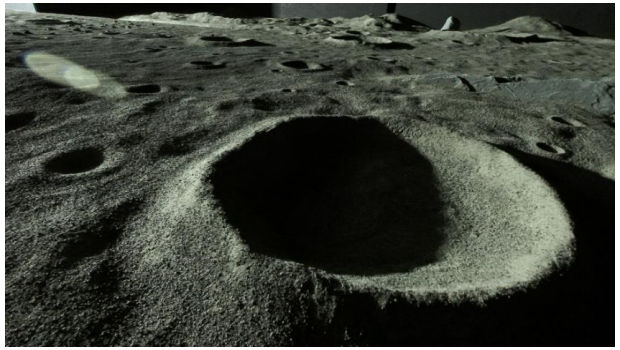
Autonomous Perception

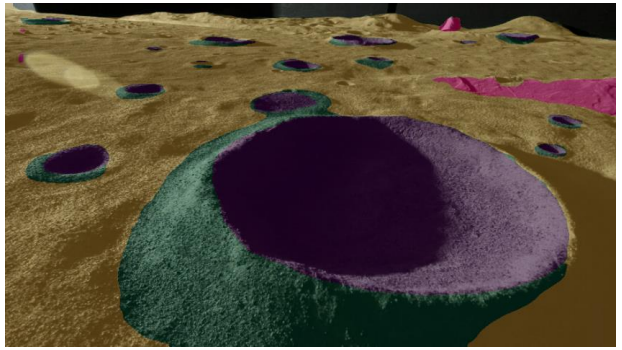
- Obstacle Prediction
- Slip/Energy Prediction
- ID Target of Interest
- Artificial Object Recognition
- Traverse Planning
- Instrument Targeting
- Arm Motion Planning
- Mapping
- Resource Management
- Data Management
- Smart Downlink

Deep Learning based Perception

MoonNet

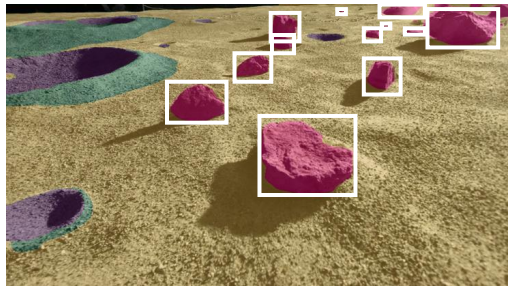
First demonstration of deep learning AI in deep space

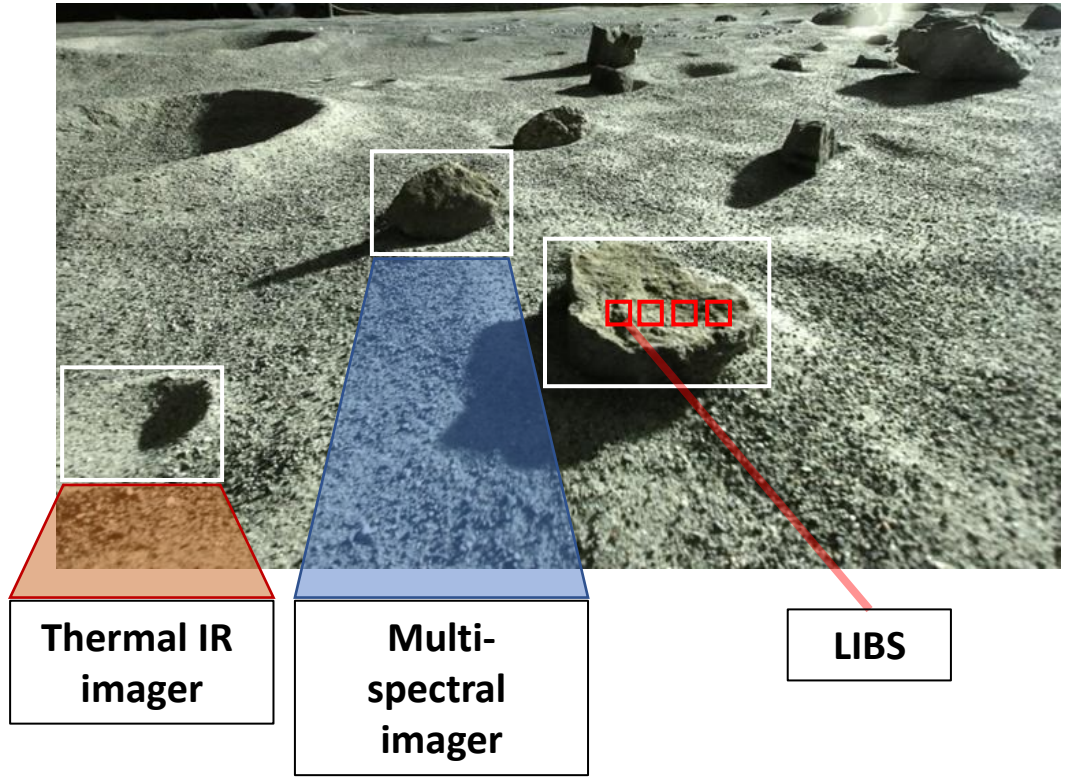




Regolith Crater Interior Crater Exterior Rock Wall

Use Case: Autonomous Targeting





1 Capture Image

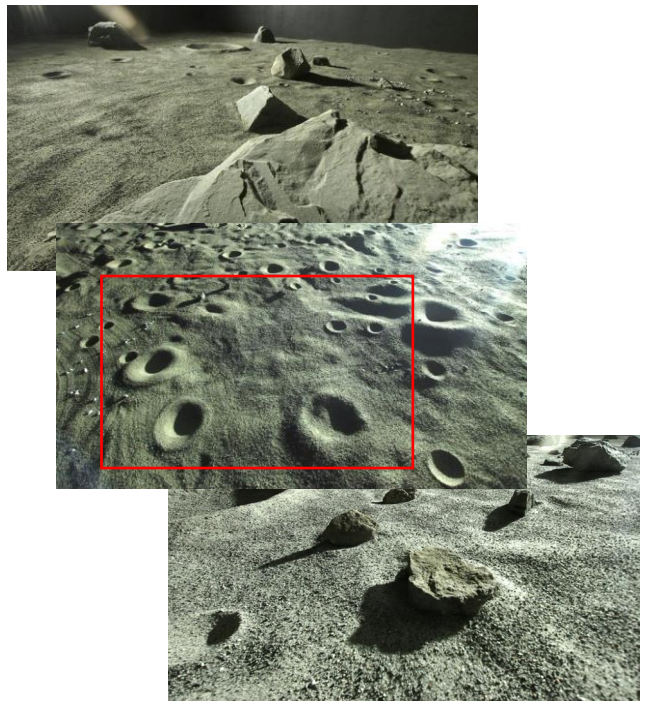
2 Identify Features

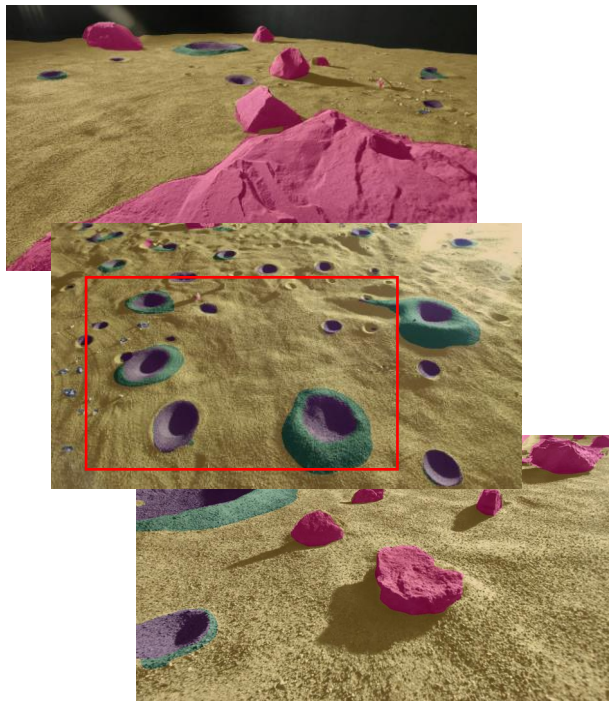
3 Target Instrument

Use Case: Downlink Prioritization

Data priority strategies
- Novel features
- Key target signatures
- Representative sampling

Similar to AEGIS for Mars rovers [Castano et al., 2007]





1 Capture Images

2 Identify & Rank Features

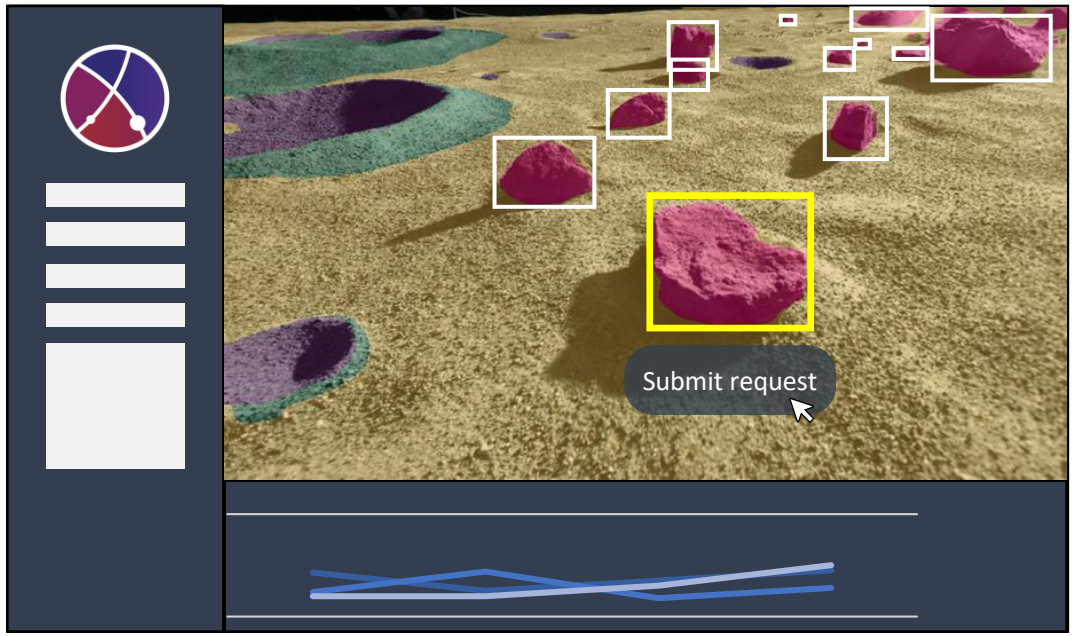
3 Prioritized Downlink

Use Case: Operations Support

Pre-annotated images can save a lot of time

Classified objects allow you to

- Pass object to other consoles
- Intelligent feature query from catalogue of objects
- Add other measurements, data products, metadata to object model
- Enables rapid statistical analysis in real-time
- Integrate into GIS to support mapping



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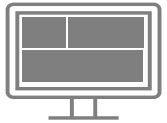


Highlight of ESA-ESRIC
Space Resources Challenge

Lunar AI Demo: ispace Mission Overview

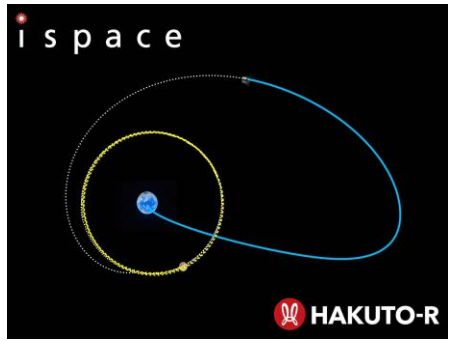
Lander - ispace Hakuto-R M1

Landing site – Atlas crater, Mare Frigoris

Dec 11, 2022 – SpaceX Falcon 9 launched

March 20, 2023 – entered orbit at 9:24 pm

April 25, 2023 – landing attempted



Images: ispace

Lunar AI Demo: ispace Mission Overview

Lander payloads include:

- MBRSC's Emirates Lunar Mission (ELM) Rashid rover
- ***Mission Control's MoonNet***
  - Semantic segmentation convolutional neural network (CNN) for lunar terrain
  - Deployed on: Xiphos Q7 SoC (Zynq-7020)
  - *Spacefarer* operations platform used by our science team
  - Supported by CSA's LEAP Capability Demonstration program

Emirates Lunar Mission

We acknowledge the support of the Canadian Space Agency [3CAPDEMO21]

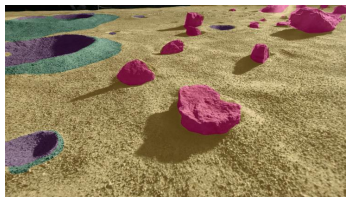
Lunar AI Demo: Architecture

Collaboration with Emirates Lunar Mission

1

Rover acquires images

2

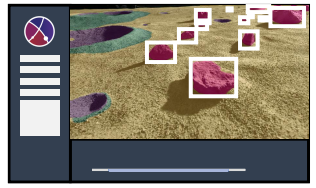


AI on lander classifies images

3

Data downlinked

4



Web-based interfaces for operations

5

Data products Inform Path Planning

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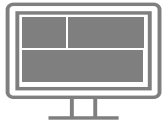
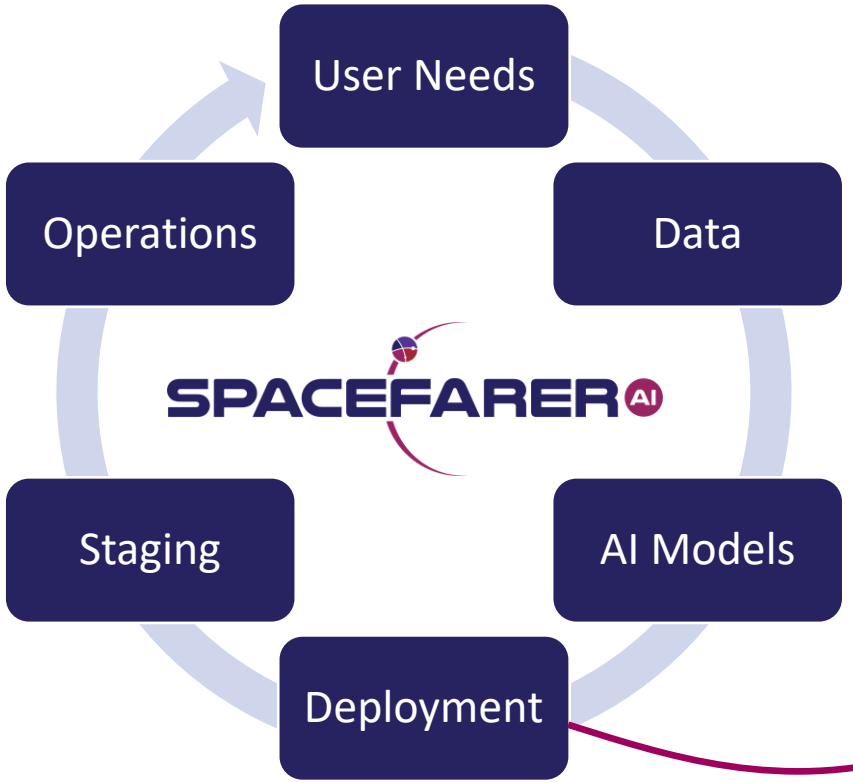


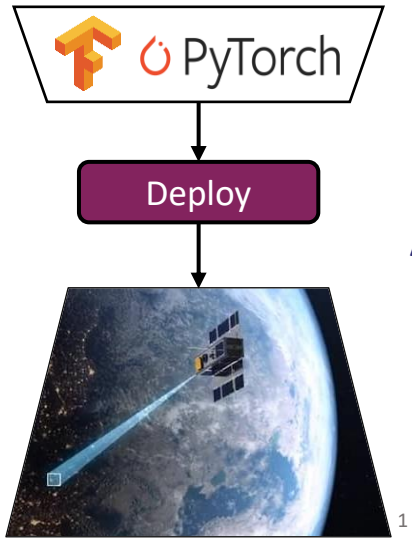
Highlight of ESA-ESRIC
Space Resources Challenge

Spacefarer AI: Enabling Autonomy



Spacefarer AI Deployment Toolkit

Your high-level AI model



Compile AI on flight processors using our **AI Deployment Toolkit**

Your space mission

Image: [1]ESA

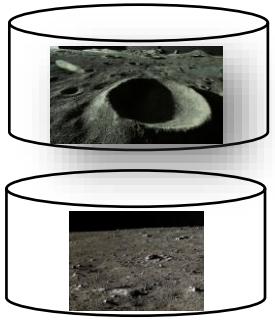
MoonNet: Full Mission Lifecycle Workflow

SPACEFARER Data & Model Pipeline

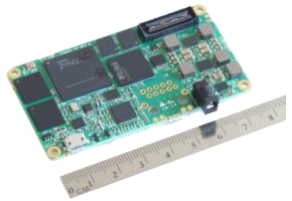
SPACEFARER Deployment Toolkit

User Needs	Data	AI Models	Deployment	Staging	Operations

- Embedded Engineers
- Operations Teams
- Mission Managers
- Data Scientists
- Lunar Scientists



MoonNet



Limited training datasets

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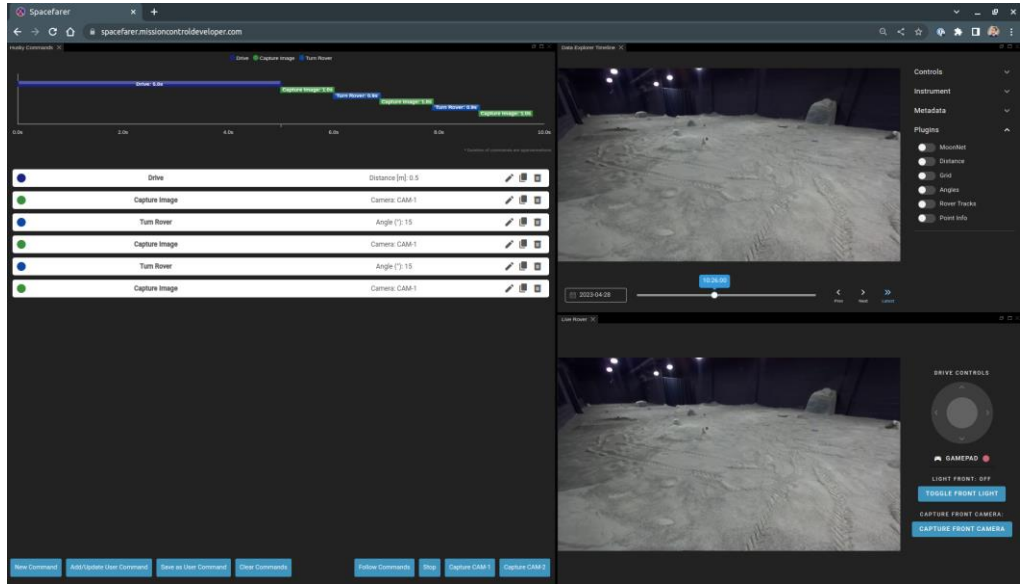
Space Resources Challenge

Spacefarer

Operate Your Mission From Anywhere

Full Mission Lifecycle Support
From Prototyping to Flight Operations

- Live Controller
- Command Builder
- Data Explorer



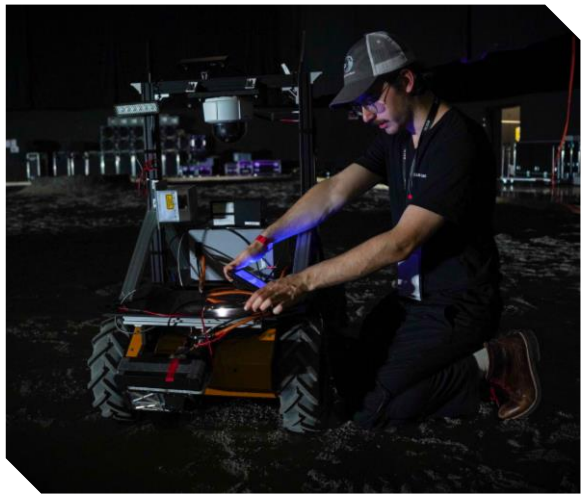
Trusted for thousands of hours in analogue missions on Earth, and is now supporting upcoming missions to the Moon.

ESA-ESRIC Space Resources Challenge

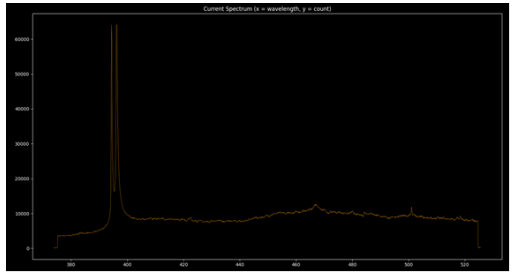
- 2021 Challenge, ESTEC (Netherlands)
  - 13 participants, 5 finalists selected
- 2022 Challenge, ESRIC (Luxembourg)
  - Winner awarded further contracts
- Constraints
  - 2.5s one-way latency
  - Comms dropouts
  - 5 in-person and 3 remote operations team
  - No prior knowledge of terrain

ESA-ESRIC Space Resources Challenge

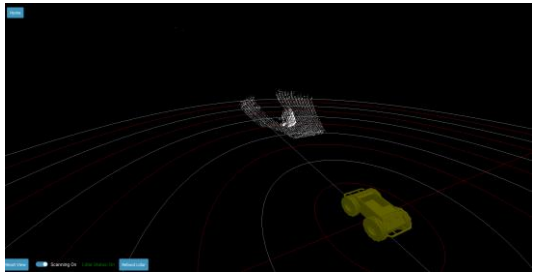
- Our system integrated with Spacefarer
  - COTS rover and GNC sensors
  - mWABS LiDAR from MDA
  - L3VIN LIBS (Laser Induced Breakdown Spectroscopy) from Impossible Sensing

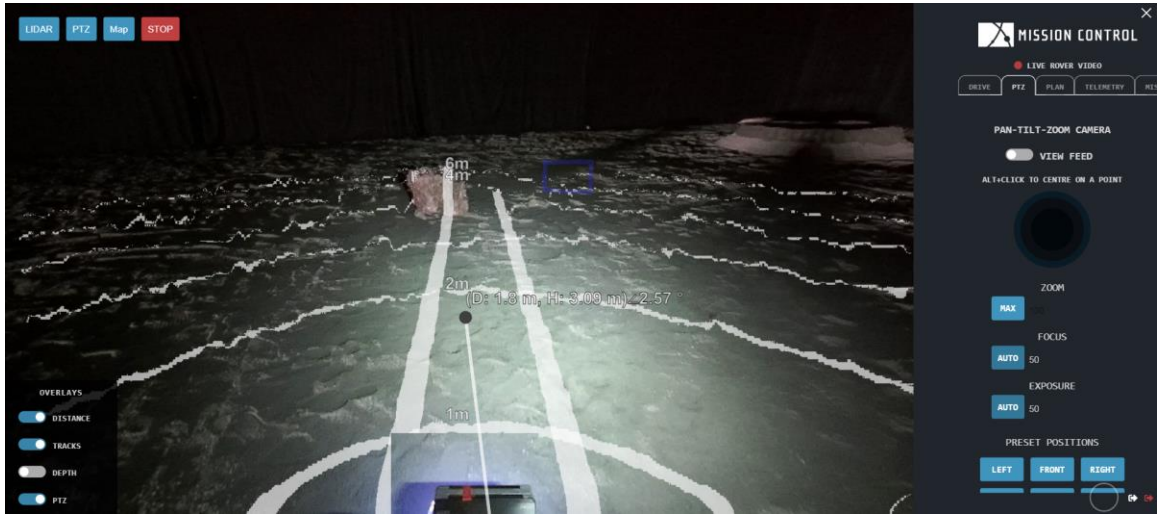


IMPOSSIBLE



MDA

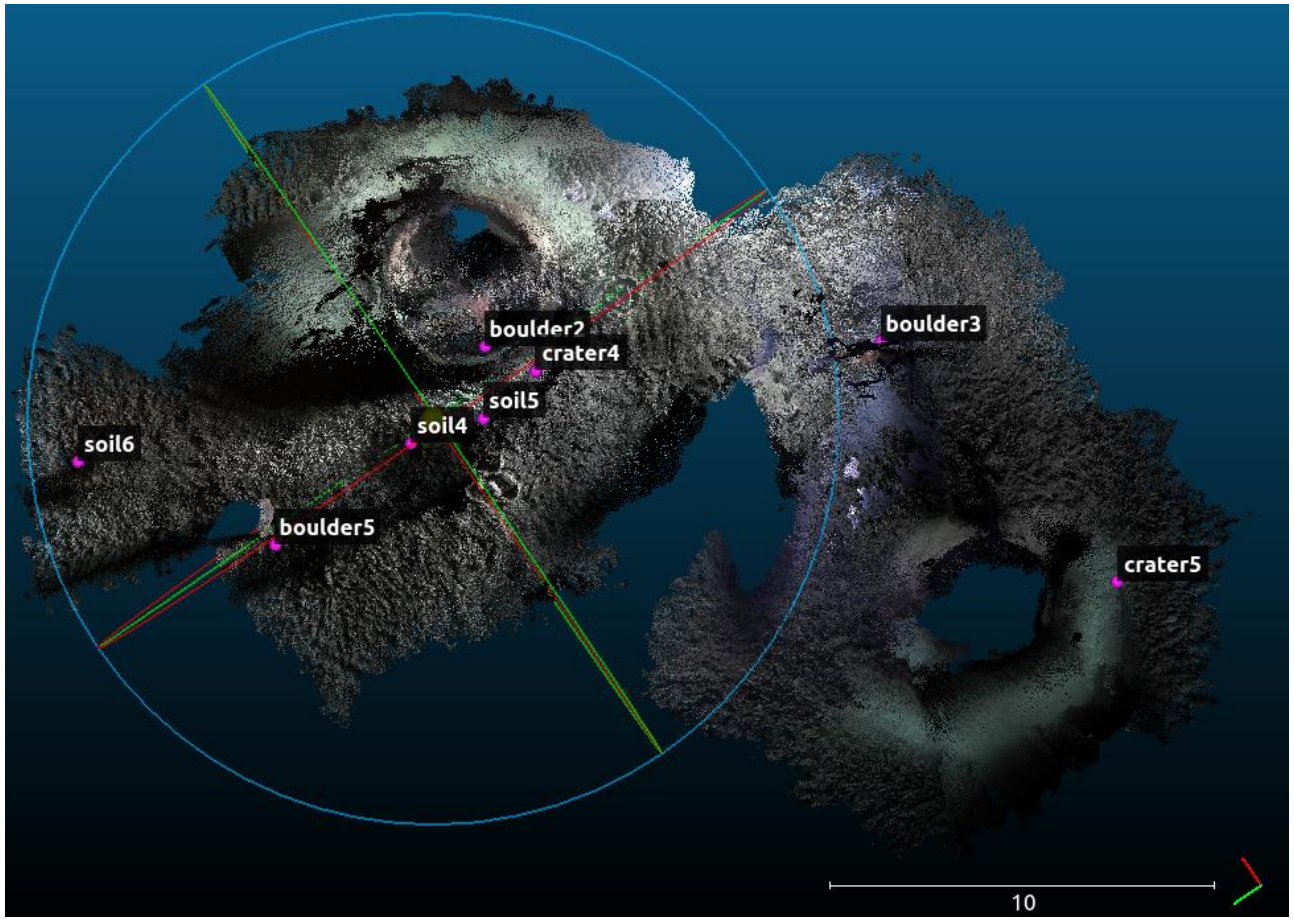




ESA-ESRIC Space Resources Challenge

Our approach

- Spacefarer operations software suite
- Operations readiness
- Waypoint navigation
- Real-time mapping and data labeling



Enabling Operations & Autonomy for Lunar Mobility

- Spacefarer AI used for first deployment of AI for a lunar mission in 2023
- Spacefarer operations software supporting upcoming lunar missions

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