AUTONOMY & OPERATIONS CAPABILITIES FOR LUNAR MISSIONS: HIGHLIGHTS OF AN AI LUNAR SURFACE DEMONSTRATION AND THE ESA-ESRIC SPACE RESOURCES CHALLENGE.

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Introduction: As lunar commerce takes seed and grows this decade following initial technology demonstration and scientific missions delivered via the CLPS program, there will be a growing demand for enabling autonomy and streamlined operations capabilities for lunar surface missions. To enable autonomy, missions will need to deal with increasingly large volumes of sensor data and onboard decision-making independent of direct human oversight. With novel technology to deploy and maintain the use of Artificial Intelligence (AI) in spaceflight, Mission Control is pioneering how lunar missions can embed AI in their systems and make use of streamlined operations software to support their missions. In this abstract, we provide an overview of two events: an upcoming lunar surface demonstration of AI-based image processing for lunar rovers, and Mission Control's participation in the Space Resources Challenge organized by the European Space Agency (ESA) and the European Space Resources Innovation Centre (ESRIC).

Artificial Intelligence for Lunar Missions

Within the field of AI, Deep Learning techniques are the leading standard in terrestrial applications that require computer vision and natural language processing [1]. However, they are power intensive so they must be customized for space hardware. The software tools hardware vendors currently ship are difficult to install and use, and represent a pain point in developing and deploying AI models. This fragmentation of the software landscape into hardware vendor specific run-time tools and compilers prevents innovations from spreading broadly within the AI community [2]. To address these challenges, Mission Control has developed the Spacefarer AI Deployment Toolkit, a multi-stage deep learning compiler and corresponding runtime for accelerating neural network inference. The Deployment Toolkit is a key component of Spacefarer AI: Mission Control's emerging product line of tools to facilitate deployment of AI models in spaceflight and enable autonomy capabilities in missions for lunar prospecting and mining.

AI-powered applications can enable autonomous tasks for lunar systems such as:

- Autonomous perception of the lunar environment can support autonomous navigation for lunar rovers and other ground vehicles, as well as autonomous targeting for onboard scientific payloads and actuation such as scooping, drilling, and robotic arm operations.
- Detection of anomalies/faults for any system ranging from an excavator vehicle to an ISRU processing plant.
- Intelligent prioritization of data to downlink to Earth for improving the efficiency of missions that produce high volumes of data but need to extract relevant information in a timely manner.

Demonstration of AI-based Perception in a 2023 Lunar Surface Mission: On December 11th 2022, Mission Control's MoonNet AI payload launched onboard the first ispace mission M1. Slated to land and begin operations in Q2 2023, MoonNet will be the world's first demonstration of Deep Learning on the lunar surface, a historic milestone for space exploration. It will classify lunar surface features visible in images from the Rashid rover in the Emirates Lunar Mission (ELM). Mission Control will also participate in the international science collaboration of ELM, led by the Mohammed Bin Rashid Space Centre (MBRSC). Following this critical demonstration of AI-based autonomy, Mission Control is eager to deploy this technology for future lunar surface prospecting and ISRU missions.

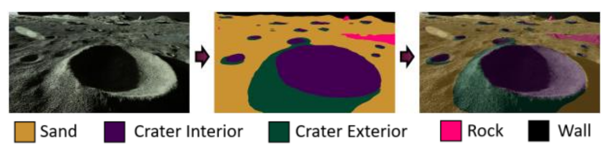

Figure 1. Example output of our MoonNet lunar terrain classifier, trained on images of our lunar testbed, that is slated to be the first demonstration of deep learning on the lunar surface.

Mission Control is currently also engaged with the European Space Agency to complete an AI demonstration onboard ESA OPS-SAT, a satellite already in space and launched specifically for AI experimentation and demonstration. More details on these flight demonstrations can be found in recent publications [3-5].

Operations Software for Lunar Missions

To aid operations teams get the most value out of their constrained missions, Mission Control has developed Spacefarer, a user-friendly and modular operations platform. Spacefarer enables distributed teams to interface with their assets which can range from robotic systems to onboard payloads such as scientific instruments. Spacefarer is designed from the ground-up to be used throughout a mission lifecycle as it enables the operator to control devices in real-time in Earth-based networks for purposes such as data collection and analogue mission testing, as well as to control spacecraft in a high-latency and data-restricted network in command sequence fashion.

Demonstration at the ESA-ESRIC Space Resources Challenge

In 2021, Mission Control was selected among 13 teams to compete in the Space Resources Challenge organized by the European Space Agency (ESA) and the European Space Resources Innovation Centre (ESRIC) in Luxembourg. The challenge took place close to ESA's ESTEC facility in the Netherlands, in November 2021. With a strong team well-versed with lunar rover operations, our team was selected among the top 5 teams to move on to the second phase of the challenge, which took place at ESTEC in Luxembourg in September 2022.

The second phase of the Challenge required a 2500 m^2 region of interest (ROI) to be explored, mapped, and prospected for resource potential within 4 hours. The ROI was set up as a south lunar pole analogue with challenging lighting conditions, and various features of interest to investigate. A 2.5-second latency in each direction and random communications drop-outs were incorporated to emulate a lunar mission scenario, allowing judges to evaluate the approaches taken by teams to handle the communications challenges.

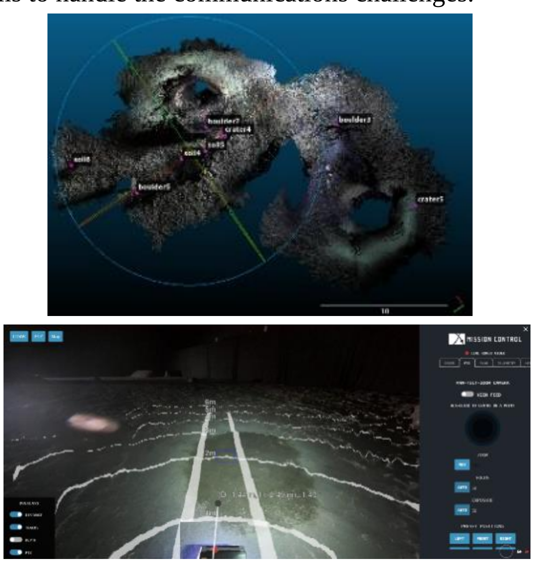

Figure 2. Top; Map generated from traverse at ESRIC. Bottom: A screenshot of a previous version of the Spacefarer UI used for rover and payload operations.

As a software-focused company, Mission Control entered the Space Resources Challenge with a solution based on three elements:

- Focus on operations software technology and strategies based on our Spacefarer platform
- Rigorous practice and operational readiness by the team, leveraging our easily accessible indoor lunar analogue testbed.
- Leveraging reliable COTS hardware components, such as the Clearpath Robotics Husky, NVIDIA Xavier developer platform, a Pan-Tilt-Zoom camera, and Zed-2 stereo camera.

We also used instruments from key partners:

- The mWABS, a compact, next generation, 2-axis scanning LiDAR, from Canadian space robotics and sensing company MDA, and
- The L3VIN LIBS (Laser Induced Breakdown Spectroscopy) from US-based Impossible Sensing.

Mission Control developed a mapping tool that also integrated with our Spacefarer software for generating and visualizing the 3D environment (Fig 2). The map was auto-populated with data labels when measurements were captured during the mission, which significantly contributed to operator situational awareness and rover localization. All systems testing prior to the Challenge was conducted in Mission Control's Moonyard, our indoor lunar analogue terrain. Using our Spacefarer software, our team frequently and iteratively tested the system under varying operational parameters, including a lunar communications emulator that allows for control of time delays, bandwidth restrictions and network dropouts, and to practice operational procedures under expected Challenge conditions. Operations were conducted by a team of five team members on site and three remote participants, thereby demonstrating the utility of remote and distributed mission operations with the Spacefarer mission operations software.

Acknowledgements:

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References: [1] Zhang D. et al. (2022) AI Index 2022 Annual Report [2] Lattner et al. (2019) [3] Raimalwala K. et al. (2022) IAC 2022. [4] Ahmed. R. et al. (2022) IAC 2022. [5] Macdonald A. et al. (2022) ASCEND 2022