Lunar Surface Visual Model Rendering Improvements through Image Analysis and Machine Learning Techniques

Dr. Austin Oltmanns, Senior Robotics Engineer, (austin.oltmanns@lunaroutpost.com)

Company Background:

Founded in 2017, Lunar Outpost is a leader in planetary mobility and in-space infrastructure, deploying advanced robotic systems for extreme environments. From enabling the first commercial rover on the Moon, to supporting NASA's Lunar Terrain Vehicle program, Lunar Outpost is leading the way towards a sustainable cislunar economy. In March 2025, Lunar Outpost's commercially funded Lunar Voyage 1 MAPP rover operated at the Moon's South Pole, achieving TRL 9 for key rover systems and subsystems while carrying payloads from Nokia, MIT, Juventus, adidas, and in partnership with LEGO and Castrol. Lunar Outpost has eight missions going to cislunar space before 2030, five of which are lunar rover missions, the most lunar rover missions of any company globally. The company's partners on upcoming missions include NASA, Johns Hopkins University Applied Physics Laboratory, the Australian Space Agency, University of Colorado Boulder Laboratory for Atmospheric and Space Physics, UC Berkeley, University of Central Florida, and more. In 2024, Lunar Outpost was awarded a Lunar Terrain Vehicle Services (LTVS) contract by NASA to develop a human-rated Moon rover as part of the Artemis campaign. Lunar Outpost's Eagle Lunar Terrain Vehicle is designed to build and maintain infrastructure on the Moon, enable Artemis astronauts to conduct research farther from landing sites than ever before, and support commercial objectives when not in use by NASA.

With over a dozen active contracts across commercial, defense and civil space, Lunar Outpost is The Next Leap that will enable humanity to become interplanetary.

Description of Work to be Done:

Vehicles on the Lunar surface operate under harsh conditions and are subject to uncertainty from many factors. Simulation of these vehicles with a digital twin aid in reducing this uncertainty by allowing operational characteristics to be predicted. One of the primary components of a vehicle's operation is capturing images of the Lunar Surface. The accurate simulation of Lunar Surface imaging is important for training ground crews, scientific analysis of the surface, and development of navigational algorithms.

For this project, your team will characterize Lunar Surface images from previous missions like those in the Apollo program and more recent missions like the Chang-E rover. Once we understand what makes the images "moon-like" in a rigorous sense, such as distribution of color, texture, and influence of lighting angles, then we can move to creating a "Lunar Surface Filter" that takes images from our visual simulator and transforms them to better represent the lunar surface according to the metrics you've derived. Sample images are shown below in Figure 1.

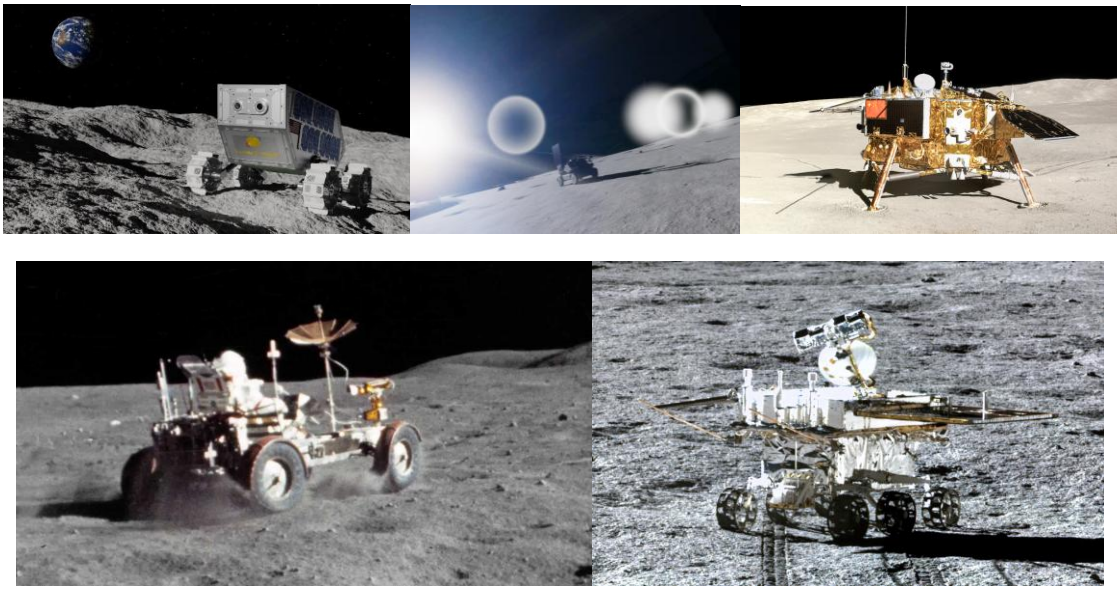

Figure 1: From top left, clockwise: A render of the MAPP rover on the lunar surface, a render of the Lunar Outpost LTV, an image of the Chang'e 4 lander on the far side of the Moon, the Chang'e 4 rover on the Lunar Surface, the Apollo LRV on the Moon. How can you take the rendered images and make them look more realistic?

Students will focus their efforts on four specific areas:

1. Selection and characterization of existing Lunar Surface images.
    a. Selection of key image metrics using image analysis techniques
    b. Application of image metrics to lunar surface images and non-lunar surface images to develop understanding of key visual features
2. Characterization of images from Lunar Outposts visual simulation using the same metrics as the previous step to understand the discrepancies
3. Development of the "Lunar Surface Filter" which transforms a given image to have more moon-like characteristics as determined by the metrics
    a. Application of the filter to images of the lunar surface (control)
    b. Application of the filter to non-lunar surface images
    c. Application of the filter to images from our visual simulator
4. Presentation of these methods and results in a clear and concise manner

Ultimately, this work will be used to characterize the accuracy of our visual model through areas 1 and 2. Areas 3 and 4 will improve the overall accuracy through the filter. After the definition of key image metrics, the methods for implementing the "Lunar Surface Filter" are entirely up to your group. This problem is well suited for both traditional image processing techniques as well as modern machine learning/AI methods. Maintaining qualitative assessment (do the images look moon-like to you?) during the project will also be important.

Reach Goals:

- Comparison of different "Lunar Surface Filter" methods
    - Traditional Image/Signal Processing Techniques
    - Advanced Machine Learning Techniques
    - Investigate tradeoffs for speed vs accuracy of the techniques
- Integration with the real time visual model of our vehicle digital twin
- Render a photo accurate scene from surface geometry and lighting inputs

Desired Skills for Students:

- Familiarity with image processing/analysis: basic image filtering and 2D DFT
- Statistics knowledge: test for significant differences between sample distributions
- Machine Learning: independently set up and solve machine learning problems
- Communication: able to share your results with people from any background

We understand not all the students in the group might have the desired technical skills. However, if they can problem solve and have a willingness to learn, they can excel in this project with the help of our talented engineers.

Preferred Team Size: 3-4 students

Given the scope of this project, a group of 4 students is preferred but 3 students could also excel given they are willing to problem solve and learn.

Internships at the End of the Course:

We are happy to consider offering internships at the end of the course.

Location Where Work Would Be Performed:

We have offices in Arvada, CO. This office is less than a 15-minute drive from CSM campus and should provide a convenient location for the students to meet. We also provide free beverages and snacks to keep the team fueled throughout the day.