VIRTUAL REALITY SIMULATOR FOR TELEROBOTICS RESEARCH TO ENABLE ARTEMIS AND THE FARSIDE LOW FREQUENCY RADIO TELESCOPE. Midhun S. Menon[1], Michael E. Walker[2], Daniel Koris[2], Daniel Szafir[2,3], & Jack Burns[1], [1]Center for Astrophysics & Space Astronomy, University of Colorado, Boulder (Email: midhun.sreekumar@gmail.com), [2]Department of Computer Science, University of Colorado, Boulder., [3]ATLAS Institute, University of Colorado, Boulder

Introduction: The second half of this decade has witnessed the rapid resurgence of interest by the world space community in returning humans to the Moon by 2024 & developing a permanent research base on the lunar surface for longer missions. This is part of a larger vision for sustainable deep space exploration.

Future space missions & activities will increasingly rely on robotic systems. One primary reason for this is that robots can reduce safety concerns associated with sending astronauts to hostile & uncertain extra-planetary environments. In addition, robots may improve efficiency in surface construction & assembly tasks in mission operations, which may consume a large portion of astronaut effort & productive time. In this context, robotic systems might aid in teleoperated or semi-autonomous precursor missions as well as provide live human assistance during regular mission operations.

Designing & testing robotic systems for space exploration remains an open challenge. To date, designers have primarily relied on field analogs to evaluate system performance. However, it may not always be feasible to develop analog field environments that can simulate all the critical & unique aspects of the target environments for space operations, such as topography, photometric response, etc. Moreover, obtaining large & diverse training datasets for robust testing of such robotic systems remains another challenging task.

We believe that virtual planetary environment simulators & testbeds will be a pivotal enabling factor for future space missions involving robots in improving algorithm design/testing, operations planning, operator training & mission mock-ups. Simulators can act as virtual analogs, thereby facilitating rapid & cost-effective ways to generate large, diverse, & realistic testing & training datasets. Such simulators will lower barriers posed by hardware & logistics & pave the way for a faster development cycle.

We are developing a simulation framework that generates photometrically accurate lunar virtual environments based on available data from remote-sensing satellites & terrain observations from landed missions. This framework renders the environment using the Unity game engine [1] & tightly integrates with the Robotic Operating System (ROS) [2] to simulate robots interacting with the environment. This type of modular architecture makes the framework scalable & facilitates performance testing of robotic systems under various adversarial conditions.

Although certain high-fidelity simulators are already being used to simulate lunar environments [3], they are not easily extendable. Moreover, they are based on the Gazebo simulation environment, which has been shown to be not as scalable as modern game engines such as Unity [4]. Taking into consideration the advanced rendering pipeline & scalable memory management capabilities, the Unity game engine was chosen as the platform for developing our simulator.

The FARSIDE [5] mission proposal has been chosen for an initial case-study. FARSIDE envisions constructing a 128-node distributed radio telescope array over a 10 km area on lunar far side using a teleoperated rover. Being a robotics intensive mission, this is the ideal use-case wherein a simulator can be used for developing robust algorithms for navigation, teleoperation, assembly, & deployment of antenna nodes using a rover.

Implementation: The environment is modeled in Unity environment. The robotic systems are modeled in ROS. The ROS-Unity communication is implemented by using the ROS# framework [6].

Environment (Unity). The lunar topography is simulated with high resolution terrain modeled by overlaying synthetic super-resolved roughness on the Digital Terrain Models (DTM) generated from the Lunar Reconnaissance Orbiter (LRO)-Narrow Angle Camera (NAC). The super-resolved information is generated by fractal expansion using observed statistical parameters of the terrain roughness from Apollo missions [7,8].

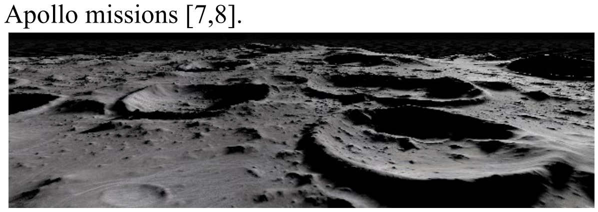

Figure 1: Simulated 1km x 1 km lunar terrain

The surface of Moon shows very specific photometric behavior called Opposition Surge (OS). In our simulator, this is modeled by creating terrain shaders using two Bidirectional Reflectance Distribution Functions (BRDF) for OS, the Hapke model [9] & the Hapke-Lommel-Seeliger model [10]. The parametric values for the shaders are taken from the published literature for Mare regions [11].

Robotic Systems (ROS). The robotic systems are modeled as nodes in ROS which will take inputs from the virtual environment via multiple simulated sensors, including mono/stereoscopic cameras, LIDAR, Inertial Measurement Unit (IMU), odometers etc. The data from the sensors will be utilized by the robotic agents to carry out decision making & planning tasks.

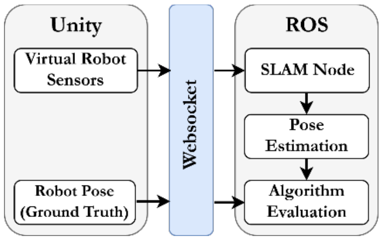

Figure 2: ROS-Unity pipeline architecture

Simulation & Discussion: In this work, the specific algorithms that were tested are the mono & stereo versions of a Simultaneous Localization and Mapping (SLAM) algorithm known as ORBSLAM2 [12]. To test it, the rover is made to traverse a known straight path along X-axis on the terrain of predetermined length (200m) at constant velocity.

During the simulation, the time stamped true pose (ground truth) & simulated camera outputs are sent from Unity to ROS. The SLAM algorithm estimates the trajectory by cross-matching detected features across consecutive image frames. These are compared with the ground truth data using various metrics to evaluate performance. The monocular ORBSLAM2 estimated 2.79 m of X-axis displacement while the stereo version estimated 191.24 m. However, the stereo algorithm also recorded larger drifts in the Y(-47.92m) & Z (-35.75m) directions compared to -0.69m & -0.52m respectively for mono.

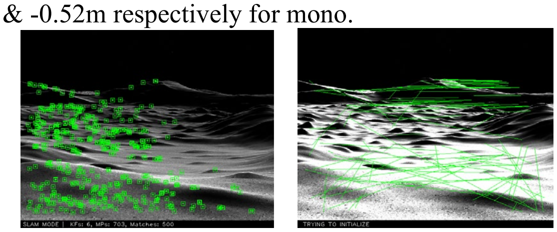

Figure 2: Adversarial shader & illumination parameters in simulator resulting in loss of feature tracking (right) in SLAM when compared with nominal values (left)

An important preliminary observation from these simulations was the delay in initialization & loss of tracking due to the lack of features (due to the barren & smooth landscape of the Moon) across frames due to reduced occurrence of image gradients. Similar loss of features was observed during adversarial testing with shader & illumination parameters (Figure 3).

Conclusion & future work: Initial results indicate the promising potential of the simulator in aiding in multiple studies across areas including telerobotics, designing navigation algorithms, & astronaut training.

We intend to conduct a more extensive comparison among multiple SLAM algorithms & design methods specific to Moon. We also want to make the terrain more realistic by adding boulders and craters in the lower size ranges (0-50cm diameter) which are not captured by remote-sensing data, using observed statistical distributions of such objects from literature.

Acknowledgments: This work is directly supported by the NASA Solar System Exploration Research Virtual Institute cooperative agreement 80ARC017M0006.

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