**VR SIMULATION TESTBED: IMPROVING SURFACE TELEROBOTICS FOR THE DEEP SPACE GATEWAY.** M. E. Walker, J. O. Burns, D. J. Szafir. Center for Astrophysics and Space Astronomy, University of Colorado, UCB 391, Boulder, CO 80516. michael.walker-1@colorado.edu, jack.burns@colorado.edu, daniel.szafir@colorado.edu.

**Introduction:** Developing new capabilities for surface telerobotics represents a complex, multifaceted problem that typically requires significant time and resource investment. In this work, we describe the design of a virtual reality (VR) simulation testbed for prototyping surface telerobotics that may reduce such barriers and enable more rapid and iterative development processes. Our goal is to create a framework with robust physics and kinematics that provides a platform for advancing algorithms that govern low-level robot autonomy and support interactive trade-offs between teleoperation and supervised control. Further, this testbed may enable explorations into the design of new interfaces that support ground control, and/or crew operation of surface robots from the Deep Space Gateway (DSG) to significantly improve critical NASA lunar exploration missions.

**Virtual Reality Immersive Simulation:** We have constructed a Virtual Reality (VR) simulator with a multiphysics engine core to provide real-time, and robust physics-based environmental model. A VR head-mounted display (HMD), HTC Vive model, allows users to fully immerse themselves within the simulation (see Figure 2). A MER-A rover 3-D model has been integrated within the virtual environment with full teleoperation control with the native VR HMD controllers (see Figure 1). Users can switch between third and first person control of the robot to simulate the teleoperation of the robot on the lunar surface from the DSG.

This work will be extended to create a high-fidelity testbed for rover teleoperation simulations with realistic terrain, authentic rover design and kinematic model, and a state-of-art planning and control interface.

**Environment and Terrain:** Lunar topography will be simulated with high-resolution synthetic terrain modeled after the actual surface of the moon. Surface data will be analyzed to provide us with authentic terrain features (i.e. crater density and distribution, elevation deltas, etc.). Surface optical properties like specularity, reflectivity, albedo, sky-map, etc., will be simulated to give a feel of limitation for autonomous Simultaneous Localization, and Mapping (SLAM) algorithms. As a starting point, HAPKE model [1] parameter maps for moon [2] will be considered. Rover-terrain Interaction, tractive force models and consequent dynamics will be modeled to give a feel of slip, and skid of the vehicle in real-time. Thermal lumped models of the Lunar terrain will be modeled incorporated with Lunar local time as variable input [3].

**Rover Virtual Prototype:** A virtual prototype of a terrain mobility system will be designed, and developed for Lunar terrain. The models to be incorporated into the virtual prototype are as follows: (1) SLAM algorithms will be designed to specifically handle Lunar environment, specifically answering issues like lunar terrain specularity, high reflectivity if terrain, and albedo of the terrain [4]. This data along with auxiliary environment perception sensors and multiple
strategies (visual odometry, wheel odometry, dead reckoning, etc.) will be used for reactive path planning and semi-autonomous avoidance of obstacles [5]. This research will also generate data which will feed into requirements, layout, and placement of on-board sensor systems for perception of environment. (2) Pro-active planning of the path by using existing Lunar terrain high resolution images from multiple missions like LROC, and Clementine will be generated. Using the same in conjunction with absolute landmark based localization algorithms, absolute position of rover on the terrain will be derived on a larger scale [6]. (3) Line of Sight (LoS) from known terrain data will be simulated to suggest better directions of traverse for path planning and potentially provide input to antennae design on lander/rover.

Planning and Control Interface: The interface will be focused on providing real-time situational awareness (latency=0.4s [7]) via multiple modes of sensory feedback (visual, auditory, and haptic), to aid the human-in-loop system (i.e. operators in the DSG) to react and respond quickly. (1) Interface for efficient human-in-loop supervision and intuitively control of the rover will be designed with telepresence capability. We would like to leverage existing research in this area to accelerate development [8]. (2) Absolute navigation on lunar terrain by Landmark matching will be used to localize rover location on terrain, and this will be overlaid on the Digital Elevation Model to give real-time location on lunar terrain [9]. (3) Efforts will be taken to overlay scientific and instrument specific data like spectral, and photogeological mapping [10] on the DTM/derived local map so as to aid in easier scientific exploration.

We propose to use this system for mission training/rehearsal for astronauts on ground. One novel application we are proposing is to utilize this tool for real-time contingency state evaluation. The idea is that in case a contingency comes up like the rover getting stuck in a crater/slipping, the crew and/or ground control may immediately recreate a VR terrain of the local environment from latest derived local map from SLAM, and DTM data to visualize, evaluate, and quickly converge on measures to resolve this contingency by leveraging on the graphic, and physical realism capabilities of the system. Another proposed use of this system is rapidly prototyping user interfaces to ease the primary task of teleoperation as well secondary tasks such as environment navigation, supervisory control and command, and hazard marking and avoidance.

Acknowledgements: This work was directly supported by the NASA Solar System Exploration Virtual Institute cooperative agreement 80ARC017M0006 to J. Burns (PI).

References:


[8] Szafir, Daniel ; Mutlu, Bilge ; Fong, Terrence: Designing planning and control interfaces to support user collaboration with flying robots. In: The International Journal of Robotics Research (2017), S. 0278364916688256
