Operational Constraints of Low-Latency Telerobotics from the Deep Space Gateway Due to Limited Bandwidth.
B. J. Mellinkoff[1], M. M. Spydell[2], and J. O. Burns[3]. [1]Center for Astrophysics and Space Astronomy, University of Colorado, UCB 391, Boulder, CO 80516, benjamin.mellinkoff@colorado.edu; [2]Center for Astrophysics and Space Astronomy, University of Colorado, UCB 391, Boulder, CO 80516, matthew.spydell@colorado.edu; [3]Center for Astrophysics and Space Astronomy, University of Colorado, UCB 391, Boulder, CO 80516, jack.burns@colorado.edu.

Introduction: The new era of space exploration will begin in the 2020's by sending humans beyond LEO and beginning the development of the "Deep Space Gateway" (DSG) [1]. The DSG will serve as a base of operations for humans in cis-lunar space and enable operations on the Moon and research about humans ability to perform beyond the protection of LEO. It will also serve as a proving ground for future missions that will go on to Mars. The DSG will have the capability to maneuver between many different cis-lunar orbits via an electric propulsion module. One possible location would be an halo orbit of the L2 Lagrange Point roughly 65,000 km above the lunar farside during some portion of its operation [1]. This position allows for constant low-latency communication down to surface assets on the Moon's surface while maintaining line-of-sight with Earth. Astronauts located on the DSG will serve as a perfect opportunity to perform low-latency surface telerobotics for scientific objectives (e.g. deployment of a low-frequency radio telescope). The benefit of the DSG in regards to teleoperation is establishing low-latency communication and creating a virtual "human presence" on the surface [2]. A virtual human presence is promising but the operational constraints necessary have still not been explored fully. We identify two constraints on space exploration using low-latency telerobotics and attempt to quantify these constraints.

Figure 1. Modified COTS rover operated by human via low-latency teleoperations in search of exploration target.

Low-Latency Operational Constraints: The first operational constraint associated with low-latency surface telerobotics is the bandwidth available between the DSG and a ground asset. Bandwidth will vary depending on line-of-sight conditions between the antenna on the DSG and the antenna on a ground asset. This variation means it is critical to quantify the necessary video conditions for an effective virtual human presence. We designed an experiment to quantify the threshold frame rate required for effective operations; frame rate is just one aspect affected by reduced bandwidth. Our experiment simulated geological exploration using low-latency telerobotics. We had operators identify exploration targets under various video frame rates and used time to discovery as the metric of success. The experiment used a modified COTS rover in a lunar analog environment using painted rocks with symbols as exploration targets (Figure 1). The results indicate that the mean time to discovery (MTD) significantly increases when the frame rate drops below five frames per second (Figure 2). In other words, the threshold frame rate for an effective virtual human presence is five frames per second [3].

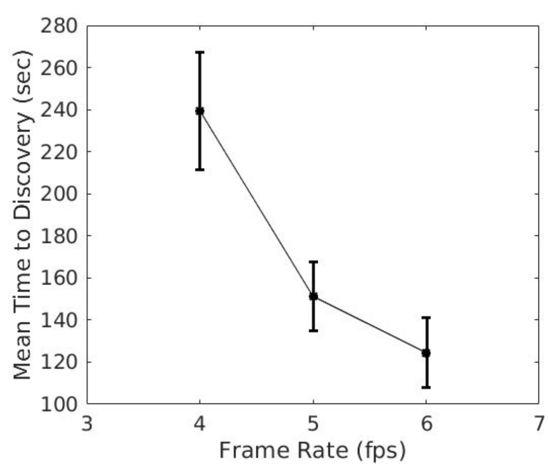

Figure 2. The MTD and associated error bars for the following frame rate: 6, 5, & 4 fps. Note: the lines connecting the data points serve as a reference for the eye.

The next constraint we attempted to quantify was latency threshold. In particular, we compared the latency condition that would be present between the DSG and a lunar ground asset and the best-case latency condition present from Earth to the DSG and down to a lunar ground asset. Specifically, we compared 0.4 seconds and 2.6 seconds of latency (Figure 3). The purpose of this experiment was to determine the significance of a small increase in latency. The results from this experiment show a 150% increase in exploration time when latency changes from 0.4 seconds to 2.6 seconds with all other video conditions remaining the same [3]. This drastic increase in exploration time indicates that 2.6 seconds of latency is too high to produce effective low-latency telerobotic operation using real-time exploration strategies. This means that teleoperation from the DSG is required in order to utilize real-time exploration strategies. Thus, teleoperation from the DSG is necessary to achieve an effective virtual human presence on the surface of the Moon.

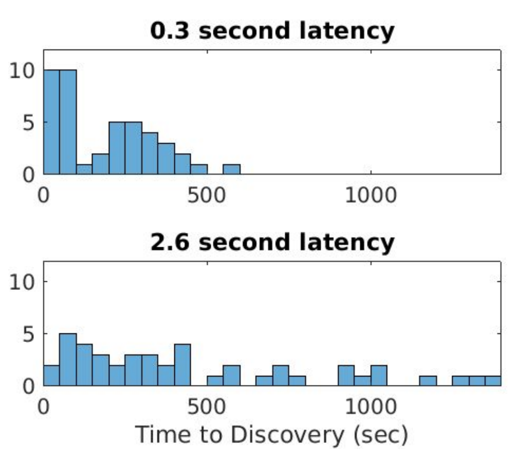

Figure 3. Distribution of the time to discovery for the following latencies: 0.3 & 2.6 seconds. The dispersion clearly increases with the 2.6 second latency.

Low-Latency Assembly Tasks: Low-latency teleoperation from the DSG will allow real-time supervision of the rovers performing autonomous assembly tasks on the lunar surface. While the astronauts will primarily oversee the rovers performing autonomous tasks, the low-latency conditions allow for immediate human intervention when an anomaly occurs in the autonomous task. This is one of the more promising aspects of teleoperation from the DSG because it will allow quicker and more efficient assembly of scientific instruments, such as a low-frequency radio array and infrastructure for future human surface missions. It is critical to conduct experiments on Earth to study the effects of decreased bandwidth on the ability to use low-latency teleoperation for assembly tasks. In particular, it is necessary to identify the threshold video conditions required for humans to efficiently perform telerobotic assembly tasks. We plan to conduct a low-latency assembly experiment aimed at identifying the threshold video conditions for telerobotic assembly tasks. This experiment will involve humans remotely operating a rover equipped with a robotic arm in order to assemble a simple antenna array. The rover is a COTS Parallax rover titled Advanced Rover for Lunar Operations (ARLO). ARLO is capable of zero-point-turning due to two independently powered wheels and two caster wheels. A modular 6-DOF robotic arm will be mounted onto the front section of ARLO. This robotic arm will have a gripper end-effector which will allow human operators to remotely grab components for assembly. The experiment will consist of deploying four antenna units to form an array. The antenna unit is defined as a pre-assembled case with an antenna and a software defined radio USB fastened to the case. The deployment of each antenna unit will consist of two distinct tasks. The first task will be the physical placement of the antenna unit to the designated location on a defined grid. This will require that the human teleoperate the rover and arm to grab the antenna unit from its initial deployment location and transport it to the designated operating location. The second task will be completing the USB electrical connection between the antenna unit and the main computer. The trial will be complete once the operator successfully places and connects the four antenna units to the main computer. Observation of signals from all four antennas will signify a successful antenna array deployment.

References:

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