AVATAR FOR LANDED LUNAR IMMERSIVE EXPLORATION. K. D. Runyon, C. A. Hibbitts, D. A. Handelman, M. E. Nord, J. I. Núñez, K. D. Seelos. Johns Hopkins APL, 11101 Johns Hopkins Rd., Laurel, MD, USA. (kirby.runyon@jhuapl.edu).

Introduction: Planetary rovers are scientifically extremely capable and autonomy/AI is increasing that capability but current rovers are intrinsically limited by a design approach that hasn't fundamentally changed in 40 years and communication is limited to the speed of light. At Johns Hopkins APL, we are working toward a solution to both these limitations, both of which are unexplored. Our proposed solution will provide a totally different experience and approach to designing a rover for exploration, in this case the Moon, as this solution is needed to support upcoming human lunar surface exploration. APL's Avatar for Landed Lunar Immersive Exploration (ALLIE) is a real-time operated (tele)robotic rover that uses anthropomorphic manipulators with haptic-feedback and a "real" immersive environment for operation that is latency-free, giving the operator the feeling and perspective of being "teleported" into rover. It is operated through natural operator motion (ALLIE mimics the body motions of the operator) with the immersive interface being a 3D environment of pictures (not VR) updated in near real time, but model mediated to eliminate latency so that ALLIE is responding smoothly albeit multiple seconds later than the operator (Fig. 1). ALLIE is designed to act as a human robot and to react at human speeds; it imbues teleported human control into an anthropomorphic robot operated without latency by the use of a teleported environment around the operator.

A foundation of NASA's new strategic vision is the exploration of the lunar surface to understand the extent to which materials on its surface can be used as resources to support its exploration and eventual habitation by astronauts. Extracting in-situ resources from the regolith such as water, oxygen, and raw material for building construction can replace prohibitively expensive shipments from the Earth. This is going to take may years to realize and will be a continual need as long as humans are present on the Moon, and will require advanced robotics to efficiently operate.

ALLIE is designed to support exploration. In contrast to scientific missions, exploration is the process of searching for a (often specific) thing of value; it is both focused while at the same time dynamic because of unpredictable unplanned for situations that can result from the fast pace of operations commonly associated with exploration. For these reasons, humans are generally considered the ideal explorer, capable of discerning and focusing on important objectives, while being aware of the greater surrounding context, and able to deal with the unexpected and unplanned. ALLIE enables much of the human capability of an astronaut compared to current robotic technology, through a telerobotic interface for which the deleterious effects of latency on operations are largely eliminated, an immersive operational environment that provides an effectively real-time situational awareness with surrounding environmental context, and an anthropomorphic robotic arm/hand with a natural motion control interface to enable intuitive and rapid human-robotic interaction also in near real time (Fig. 2). We will discuss size, mass, power, and crew resources.

Figure 1. Allie on Earth controlling ALLIE on the simulated surface of the Moon. Concept only. We propose to develop the architecture addressing design, control, and operation.

Mission Scenario: We baseline a lunar mission scenario that requires the rapidity of operations, complex interactions with the environment, and ability for the operator to interact as if personally there, as if an astronaut on the Moon. To support human settlements, resource ores must be found. They can't be found from orbit on the Moon any more than one can find where to mine on Earth from orbit. Instead, exploration of the surface is required, with detailed mapping of areas in size from a few km^2 to as large as 100 km^2 (Carpenter et al., 2016). Because the heterogeneity of the lunar surface with respect to volatile resources is on the order of 1 to 100 m laterally (Hurley et al., 2015); to characterize even a 1km x 1km region thoroughly would require a minimum of 100 traverses, each 1km long for a total of 100 km! A rover will need to not only traverse but will need to stop every 100 m, to sample the near surface. This is because the linkage between the surface composition, which could be measured from orbit at the relevant scales, to that of the near surface composition is not understood and even models provide equivocal answers (e.g. Hibbitts et al., 2011; Jones et al., 2018).

Tele-operated rover(s) will scour the lunar surface in the region of interest, prospecting for resources broadly speaking, and interacting with the Moon when guided to do so. Multiple ALLIE rovers can link to explore large regions of the Moon. ALLIE rovers equipped with AI enable operation autonomously, mapping potential resources, driving to them while avoiding obstacles or dangerous conditions, and even performing some basic measurements. This level of autonomy has largely been demonstrated by the Mars Curiosity and MER rovers (Francis et al., 2017). Although that level of autonomy is much slower than needed here, it does not need significant development and is being considered in even greater extent by current science rover mission concepts supported by NASA SMD. Interacting with the lunar surface through a robot, but as an astronaut would, is new. Thus, at this point the teleoperator can allow the ALLIE rover to continue basic standard operations or take over exploring the site of interest through a reconstructed reality interface. It is almost already possible for tele-astronauts to drive around on the virtual rovers. ALLIE enables the operator to identify a sample (e.g., rock) of interest, use the prosthetic arm to grasp and pick up the object and feel it, pull out tools from a tool belt, and do all the things a human astronaut would do.

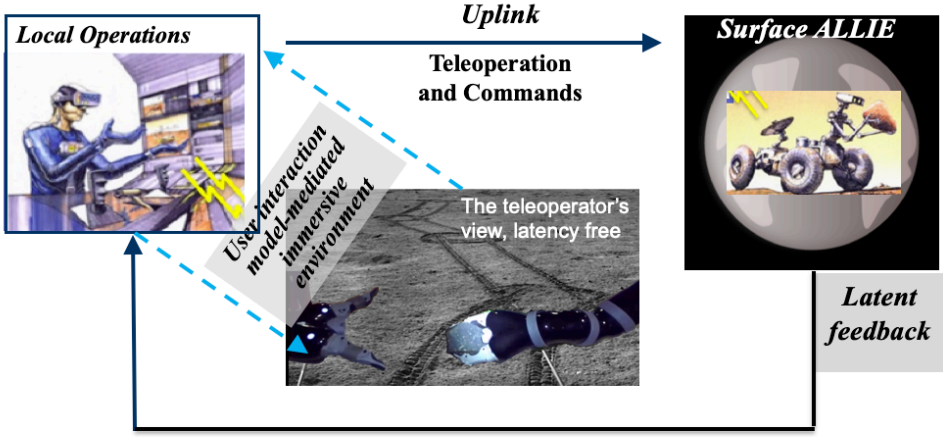

Figure 2. CONOPS. The operator will control ALLIE through a latency-free model mediated immersive interface. The lack of latency, the contextual information, and natural ergonomic control through simply moving one's limbs will increase efficiency by many-fold (imagine anthropomorphic hands). Also, the surrounding environment updated in near-real time (not shown), will enable the operator to scan and decide in real time, where to explore next.

Sustained human exploration of the Moon will also involve the construction and subsequent maintenance and upkeep of the facilities. Instead of risking human astronauts for mundane tasks on the surface of the Moon, a teleoperated ALLIE controlled from Earth, lunar orbit, or the surface of the Moon can perform maintenance tasks requiring the dexterity of a human without risk to or expense of sending an astronaut onto the surface. While the tasks to support a lunar habitat have yet to be defined, the ability to interact with the lunar surface, to manipulate tools, and operate at a high cadence are likely the types of qualities a robotic habitat assistant would need as well.

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