LEVERAGING VIRTUAL REALITY FOR THE BENEFIT OF LUNAR EXPLORATION. R. S. McCandless[1], E. D. Burke[2], and V. T. McGinley [1]Lunar Experiences, [2]Nova Realities, [3]Lunar Experiences

Introduction: Lunar exploration, whether for scientific, economic, or other purposes, is in a stage of infancy. Even with several missions scheduled, only a tiny fraction of the lunar surface will be visited in the next few years. Surface coverage can be done from orbit (e.g., LRO) but detailed vetting for science, habitation, or resource extraction is best done on the surface. What combinations of technologies will enable widespread exploration? We propose a set of intersecting and collaborating technologies that will exponentially increase scientific and exploration productivity starting with simulated environments.

Leveraging Virtual Reality: One such set of emerging technologies is collectively called immersive reality (IR) – virtual (VR), augmented (AR), and mixed (MR) – which will give us new opportunities for exploration, collaboration, outreach, and much more in ways we are just starting to imagine, especially for space generally and specifically lunar scientific exploration. Of the IR technologies, VR has the earlirest near-term use and strong long-term potential. Today's state of VR technologies gives us a hint of where they will be in just a few years that will dovetail with our increased ability to reach and operate on the lunar surface. Most think of VR in terms of games, yet VR has a multitude of industry uses. Venture Radar has identified 25 major use cases for VR for both consumer and workplace tasks. VR hardware is getting rapidly cheaper and more capable, which will drive how it can be used both here on Earth and in space missions. For instance, lightfield technology will give the user a much clearer and realistic look anywhere the camera goes, which is very useful for remote exploration. Camera components are getting smaller, weighing less, and provide higher quality data. For upcoming robotic lunar exploration missions, including some associated with the Google Lunar X Prize, VR data will be sent back from rovers and stationary payloads, which will require ground processing ("stitching") into usable video for researchers and eventually for public consumption. These data will provide much improved simulated environments for upcoming mission training and concept of operations validation. Additionally there are coming technologies, not only in VR but in other supporting areas, that will dramatically enhance our ability to explore the Moon in near real-time and involve more people in the scientific process.

Emerging Technology Infrastructure: What if we could cover large surface areas with instruments, provide data back to Earth and cis-lunar space in near-real time, and involve trained citizen scientists to help with analysis? VR and collaboration technologies have the potential to accomplish this, which is orders of magnitude better than today's situation. There is a set of enabling technologies that are needed to make VR effective for lunar surface exploration. They include improved cameras, better data storage and transmission, practical teleoperation, use of swarm devices, and advanced artificial intelligence (AI). Lightfield technology in small, lightweight cameras in space VR applications will give the user unprecedented views of the lunar terrain and conditions near operational sites. Collecting massive amounts of high quality data will be very useful, but how will that data reach humans in a timely manner? Laser communications technology that is being pioneered by NASA and companies such as ATLAS will be needed to collect and transfer data in real time for viewing. As this technology improves, it will open up the possibility of near real-time teleoperations where operators on Earth or even from lunar orbit (e.g., NASA's Deep Space Gateway) can not only analyze data, but can control devices on the lunar surface for further investigation. Small, agile, smart, rechargeable lunar drones outfitted with VR cameras such as those under development by SpaceTREx Lab could be deployed to areas for closer exploration of sites of interest, provide support to humans and rovers on expeditions, and monitor ongoing operations (e.g., drilling) to provide status, health, and safety functions [1] . SpaceTREx drones will utilize advanced AI that learns from errors and helps organize swarm activities for specified exploration objectives. Large swarms of drones can be used to quickly gather data in specific lunar regions. Having vast amounts of near real-time VR data will provide opportunities for citizen scientists to get involved in analysis in the spirit of today's Moon Zoo and Galaxy Zoo projects. VR and the aforementioned companion technologies will exponentially improve our ability to explore the Moon.

Broader Impact: With the coming ubiquity of VR (>100 million headsets by 2020), bringing the Moon to anyone will not only be possible, but probable, through science, educational outreach, entertainment and games, film, and other experiences. Making the Moon a VR destination will help popularize space and lunar exploration, enabling even more scientific endeavours.

References: [1] Thangavelautham, J., Robinson, M., and McCandless, R. S. (2016), NASA RFI NNH17ZCQ001L.