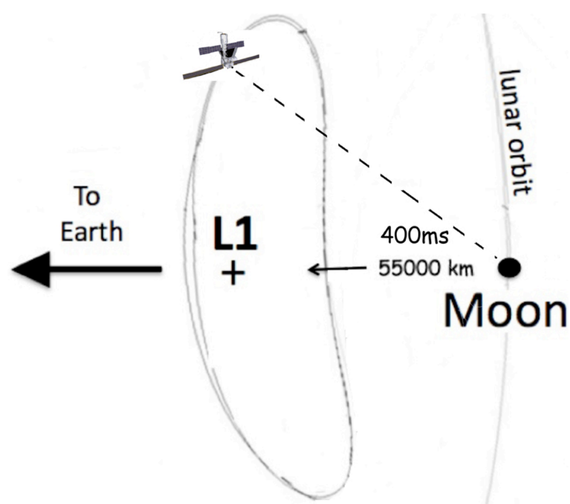
ON-ORBIT TELEROBOTICS AS A STRATEGY FOR LUNAR EXPLORATION. D. Lester[1], K. Klaus[2], K. Hodges[3] , C. Ower[4] and P. Jasiobedzki[4], [1]Dept. of Astronomy, University of Texas, Austin TX 78712 (dfl@astro.as.utexas.edu), [2]The Boeing Company, 13100 Space Center Blvd, Houston, TX 77059 (kurt.k.klaus@boeing.com), [3]School of Earth and Space Exploration, Arizona State University, Tempe AZ 85287 (kvhodges@asu.edu), [4]MDAInc., 9445 Airport Road, Brampton, Ontario, Canada, L6S 4J3 (cameron.ower@mdacorporation.com, piotr.jasiobedzki@mdacorporation.com)

Introduction: We present a new strategy for near-term lunar exploration that optimizes human-robot partnership. It is consistent with current space flight plans, provides for high quality field science at many sites, and is highly extensible to other destinations. Telepresence in space is considered to be one of NASA's technology grand challenges. This concept minimizes control latency so that humans can achieve real telepresence on the surface, putting human cognition, if not flesh, at the exploration site. Modern technology, including high dexterity manipulators, mobility platforms and high bandwidth communications makes this increasingly credible. This strategy obviates the need, in the near term, for astronauts to descend to the surface [1,2].

On-Orbit Telerobotics from Earth-Moon Lagrange Points: We propose high quality telepresence on the lunar surface by controlling telerobots there from within what we call the cognitive horizon [2]. A control station in lunar orbit would offer this capability, but would require orbit maintenance for any but highly restricted frozen orbits, and would go in and out of lunar shadow. Exploration sites would also rise and set. Earth-Moon L1 (nearside) or Earth-Moon L2 (far side) offer important advantages in this regard. These locations entail two-way latencies of just 400ms to the lunar surface, provide for 24/7 control of surface assets across an entire hemisphere, and are almost consistently sunlit, simplifying power management [1]. The two-way latency from these locations is six times smaller than from Earth. While control from Earth offers economical control of surface robots by large numbers of workers, control from Earth-Moon Lagrange points offers cognitive coupling that, in terms of task completion time advantage, is thought to significantly exceed that factor of six.

Lagrange Point Architecture: We envision a habitat facility at Earth-Moon L1/2 as a sensible scenario for on-orbit telerobotic control of assets on the lunar surface. Such a facility has been considered by HAT, and has been endorsed with some enthusiasm in the Global Exploration Roadmap by prospective international partners. Such a facility was originally proposed by the Decadal Planning Team in 2000 [4], though for uses that did not include on-orbit telerobotics. A habitat that builds on technologies and even piece parts from ISS, as in the ISS-EP concept, appears to be an affordable approach [5]. See also the paper by Raftery, Hoffmann, and Klaus in this session. To be effective as a control node, such a habitat needs simply to have high bandwidth communication. It need not have multiple docking ports, airlock, or even a truss for materiel storage. As such, on–orbit telerobotics from EM L1 or L2 is very much a first-use application for a first-generation habitat.



Telepresence and Surface Science : The Mars Exploration Rovers (MERs) demonstrated surface science from teleoperated assets on another planet. What telepresence with lower latency can offer is much greater efficiency, the potential of doing significantly broader and deeper exploration, and the prospect of real field geology [6]. A capable robotic agent with instruments that go beyond what a human alone can bring (multi-spectral imaging, highly dexterous manipulators, high resolution magnification) coupled with a human in the loop from close proximity would greatly increase the science return compared to the many minute latency we experience today with MER.

With the goal of creating an effective and efficient surrogate field geologist, controlling a lunar telerobot within the cognitive horizon will enable the application of telepresence technologies which have been developed for telerobotic applications on Earth in hazardous environments. A good terrestrial analogue to this planetary field geologist application is the use of telerobots in current Chemical, Biological, Radiological and Nuclear (CBRN) investigations by first responders. The investigators attempt to identify CBRN threats in new or potential crime scenes using teleoperated robots. Early telerobots for these applications provided limited situational awareness to the CBRN robot operators with feedback being a limited field-of-view video feed and some time-stamped sensor readings.

However more recent developments such as the CBRNE Crime Scene Modeler (C2SM) [7], provide a mobile real-time mapping and high situational awareness operating environment for first responders. Operating on board a teleoperated security robot, it provides localization in GPS-denied environments and uses a suite of cameras (stereo, high resolution, IR) as well as chemical and radiation detectors to provide real-time situational awareness and threat detection capability to the remote investigator. All data is geo-located and time-stamped, stored in an on-board database and transmitted to the operator's station via a wireless link; compressed images are sent in real-time, while the complete data sets are transmitted as a slower background process or upon request. Live data is displayed on the operator's console enabling real-time decision making, while the data stored in the database is used for post-event analysis and planning. This data is displayed either as a global 2D map or a 3D model of a site of interest augmented with icons representing measurements and coverage of various devices.

This C2SM architecture can be applied to enable control of a surrogate field geology robotic agent on the lunar surface from an EM L1 or L2 habitat via a low-latency communications link. The first responder's goal of assessing the scene in real-time for threats while storing time and geo-referenced data for later analysis and planning has parallels with the actions of geologist operating in the field. An application of this approach to planetary exploration has occurred in an on-going Canadian Space Agency (CSA) Analog Mission project "Impacts and Ice: Lunar Sample Return from the South Pole" where a C2SM-like system is used to support lunar-like science investigations. The basic C2SM architecture has been extended to include support for planning of focused geological data acquisition: importing field data, and extending the database and visualization tools. Initial 3D models and high resolution images are used by Mission Control to analyze the scenes and plan acquisition of close-up images, and deployment of spectroscopic (XRF and Raman) and contact instruments (mini-corer). The system records spatial locations of where measurements and samples were taken, allowing the new measurements and close-up images to be imported directly into the system for analysis. The core samples are labeled using unique identifiers generated by the system, which enables both tracking and subsequent analysis, such as a microscope, to be imported at a later stage. The operator station provides access to all the geolocated data in graphical 3D context. Thus far, the system has been field tested by field geologists in an analogue site in Sudbury, Ontario (2011) and Mistastin, Labrador (2011).

Analysis of the LEAG Lunar Exploration Roadmap shows that many of lunar science goals can be achieved telerobotically until a human outpost on the surface is achievable. High order science goals are chemistry of major geochemical provinces, variations within each unit, both laterally and vertically, geologic context of in situ measurements, ground truth of orbital observations, resource potential for ISRU and comprehensive broad scale sampling. Objectives include mineralogy, elemental abundance, characterizing the environment and regolith structure. We envision this as an opportunity to engage the public with participatory exploration, though with higher latency.

Extensibility of On-Orbit Telerobotics: A major advantage using cis-lunar on-orbit robotics is that it can be used to prove out the strategy for more distant destinations, where communication latency with Earth is far larger. On-orbit telerobotics and exploration telepresence is the basis for the "Human Exploration using Real-time Robotic Operations" (HERRO) concept for Mars, which focuses on sending piloted spacecraft and crews into orbit around Mars where they can control, with low latency, robotic agents on the surface [8]. See the paper by Schmidt et al. in this session. Such a strategy could also be of value for a human trip to a NEO, minimizing the need for EVAs.

In fact, on-orbit telerobotics is highly extensible even to destinations that are quite unfriendly to humans. Putting human cognition on the surface of Venus, for example, has been proposed in this fashion. This strategy therefore can dramatically increase the number of destinations for human cognition, if not human flesh.

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