VIRTUAL AND COLLABORATIVE EXPLORATION BY THE ARTEMIS SCIENCE OPERATIONS TEAM. José M. Hurtado, Jr., Department of Geological Sciences, The University of Texas at El Paso, 500 West University Avenue, El Paso, TX 79968, jhurtado@utep.edu.

Introduction: As it was with Apollo and other crewed space operations, a role of mission control, and a science operations team (SOT) in particular, is to provide oversight and support of crew activities. Overall, the Apollo science support room (SSR) was certainly an active participant in the missions, in designing and traverses, prioritizing tasks, and assessing science data collected. However, technological and organizational considerations often limited the Apollo SSR to a somewhat passive, reactive support role, watching and listening to the astronauts with few opportunities to directly interact or communicate with them.

Given advancements in imaging, virtual/augmented reality (VR/AR), telepresence, and other technologies, there is an opportunity now to both bring the lunar surface to the Artemis SOT and also to virtually bring the SOT to the lunar surface and the astronauts (the EVA crew) operating there. In the concept proposed here, the SOT can fill both an active support role as well as participate in virtual exploration, both at the tactical timescale (synchronous with EVAs) as well as the longer-term, strategic timescale. This concept provides the SOT with tools to increase their agency to be proactive, collaborative participants in the exploration (when needed) rather than being limited to reactive directors or passive supporters of the exploration.

Concept: During lunar surface EVAs, imagery of the exploration site and the crew activities will be acquired to produce high-fidelity, high-resolution, 3D visualizations of various levels of elaborateness [1], from simple 3D real-time video feeds to preliminary 3D models (real-time to slightly delayed) to complete 3D outcrop and traverse models (slightly delayed to strategic timescale). The input imagery would be obtained by surface assets (crew, robots, or a combination of the two) and would capture the entire EVA, starting with the Artemis equivalent of the Apollo 15-style stand-up EVA. The 3D data stream and derived products would be managed by individuals in a new role in the SOT, the "virtual explorer".

Virtual Explorer: The virtual explorer position in the SOT (filled by a scientist or astronaut) could have the following functions:

(1) Acting as another set of trained eyes to supplement the crews' to maximize science and operational situational awareness: Observations and recommendations would be relayed to the crew via a science communicator or CAPCOM, as necessary. This is largely how the SSR functioned, although the new imaging capabilities would provide better situational awareness.

(2) Over-the-shoulder guidance of crew on specific tasks: At the crew, SOT, or mission operations discretion, the virtual explorer could play a more active, direct role in surface operations. For example, they could verbally assist the crew in following procedures, or, similarly to how field partners interact in geology field work, talk through observations and discuss hypotheses in real time. Again, the enhanced scientific situational awareness provided by high-resolution 3D imagery can be transformative in this regard.

(3) Independent observations and science: Essentially the virtual explorer becomes another EVA crewmember. The extent of interaction with the astronauts would depend on the specific activities being performed. It could be closely linked to crew operations or essentially independent.

Data Acquisition: In its simplest form, the virtual explorer concept could work solely with the use of imagery that would already be acquired from the astronauts' suit cameras and any other imaging assets available. The imaging system, either passively carried by the astronauts (without their interaction) or deployed on a mobile robotic platform (see below), would collect imagery of the EVA site and EVA activities as described in [1].

Eventually, a dedicated roving system that can be controlled in various modes (i.e., by the SOT from Earth, by astronauts on the Lunar Gateway, by the astronauts on the Moon, or autonomously) can be used to obtain image data independently of the crew. The rover need not be large or complex, principally carrying a high-resolution stereo imaging system and, perhaps, one or two other analytical payloads, e.g., an X-ray fluorescence spectrometer (XRF), a visible/near-/shortwave-infrared reflectance spectrometer, thermal infrared camera, etc.

Arguably, having the crew on the lunar surface with the imaging system and/or rover can make the logistics of troubleshooting, etc. simpler. However, when going beyond passive cameras, an important consideration is that these tools are only a benefit for the EVA crew and the SOT, and not a detriment. For this reason, the simpler the platform, and the more transparent and hands-off its operation is to the EVA crew, the better. Ideally, the rover would be multi-purpose and could also be used for carrying tools, samples, etc., not just for virtual exploration. Critically, any failure of this asset must not adversely impact the overall mission architecture, crew timelines, or mission success.

Data Processing: Imagery would be first transmitted to a lunar surface computing hub for preliminary processing (to minimize the amount needed to be transmitted to Earth). The pre-processed data would then be transmitted to Earth where data processing would be completed. The immediate data stream would include stereo video that could, in near-real time, be viewed in 3D by the virtual explorer. Higher level data processing, to include photogrammetric analysis, could be done relatively quickly to produce preliminary 3D models (point clouds, meshes, rasters) in the minutes- to hours-timeframe. Data could be further cleaned, merged, precisely geolocated, etc. within the hours- to day-time frame.

A large volume of data will need to be processed, transmitted, stored, and merged with other data sets. Computational tools for doing this exist but will need to be scaled up and also optimized to decrease processing time. Time-coding the data will be also be important for integration with a time-coded ground data system [e.g., 2,3].

Visualization: For viewing and interacting with the 3D imagery and the derived virtual outcrop and traverse models, visualization systems can be as simple as a 3D workstation or as elaborate as an immersive VR system like a CAVE [e.g. 4]. Mixed reality headsets, such as Microsoft Hololens [5], already used for Mars exploration, are also viable. Data can be used in a real-time, tactical manner. Alternatively, the data can be used in an "offline" strategic manner, collaboratively with crew after EVA (for post-EVA debrief), collaboratively among the SOT (for traverse planning), or collaboratively with other individuals not part of the SOT.

Benefits: This concept will facilitate knowledge and situational awareness transfer among all members of the exploration team (crew and SOT) to maximize science productivity and mission success. The virtual explorer role in the SOT will enable vicarious, virtual, remote, etc. exploration in ways not possible with Apollo. The concept is scalable so that any number of individuals can collaboratively be involved, not all of whom are co-located.

Enabling Technologies and Protocols: Hurtado [1] presented concepts for utilizing miniaturized, high-resolution cameras and photogrammetric data processing for recording field sites and activities in 3D and at high resolution. This concept expands on that imaging capability in three ways: (1) by incorporating a mobile, robotic asset equipped with the imaging system and that could operate independently of the EVA crew; (2) by staffing virtual explorer roles in the SOT to manage and interact with the data stream returned by the imaging system; and (3) by structuring communications pathways and protocols allowing more direct communication between the science operations team and the EVA crew.

Application to Training: The virtual explorer role in the SOT can also be occupied by astronauts in training for lunar missions. This may be a valuable way for those astronauts to: (1) gain visual experience of what the lunar surface is like; (2) observe and participate in EVA science operations; and (3) interact with both mission and science operations personnel in the context of an actual mission. All three of these elements would be important for training purposes.

Application to Education and Outreach: The virtual explorer viewpoint of a high-fidelity, high-resolution, 3D representation of the lunar surface can be used in education and outreach. What better way to engage the public and the next generation than by giving them a front seat view of traversing and exploring the Moon? Opportunities may also exist for using the virtual explorer concept for citizen science as well as in "mining" the inevitable large volume of data returned by the Artemis missions.

References: [1] Hurtado, J.M.(Jr.) (2020) Lunar Surface Science Workshop I (Tools and Instruments), #5130. [2] Feist, B.F. et al. (2019) NESF, NESF2019-005. [3] https://apolloinrealtime.org.
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