EXPLORATION TELEPRESENCE FOR SPACE SCIENCE, AND OPTIONS AT THE DEEP SPACE GATEWAY.

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Introduction: Exploration telepresence is the strategy of using low-latency telerobotic control to achieve a high level of human cognition for exploration. Most optimally, such latencies are small compared to the human reaction time, which is about 200 ms, allowing real-time human involvement. The speed of light requires that such activity take place in the vicinity of the region to be explored, perhaps in orbit overhead. This bears on the use of a Deep Space Gateway (DSG) for science on the Moon. Low latencies promote a sense of real human presence. Whether the telerobotics are implemented with direct or semi-autonomous control they would offer not only awareness but improved performance for dexterity and mobility.

This contribution is not aimed at any particular flavor of space science, but rather to call out a strategy that can economically bring real-time human presence to many kinds of scientific pursuits in space.

The Promise of Exploration Telepresence: Exploration telepresence (otherwise known as low-latency telerobotics) has been an acknowledged strategic asset for space exploration for many years, taking an important role in the decades-old Paine and Stafford reports. But advances in telerobotic control now make the strategy wholly credible. While the advantage for the Moon is notable, since the two-way control latency from the Earth is at least 2.6 seconds, the advantage for Mars is enormous. In this respect, while low-latency telerobotics on the surface of the Moon controlled from a DSG can be scientifically advantageous, such efforts are especially promising in that they exercise protocols for doing science in this way at Mars.

It is clear that modern imagers provide vastly more resolution, sensitivity, spectral and pixel information than does an in situ human eye behind a helmet visor. It is also clear that modern dexterous tele-manipulators provide better control than an EVA-gloved human hand. While EVA-suited astronauts may currently have an advantage in mobility, telerobots that can reach, climb, jump, and even fly are becoming realizable.

To the extent that high quality human presence can be electronically mediated, exploration telepresence on the Moon can allow astronauts to explore from the comfort, safety, and convenience of the DSG. We currently do telerobotics across the solar system from the Earth, but the latencies involved produce a very low quality sense of presence. Astronauts in orbit in one habitat overhead can explore many different sites on the planet below, including those that might be considered risky for human visits, with exploration not limited by EVA times for suited humans. The prospect of doing biological space exploration in this way shows great potential by avoiding forward contamination. [1]

Low latency telepresence is a strategy that is well exercised on the Earth, with military UAVs, mining and agricultural telerobots, hazardous environment telerobots, and telerobotic surgery. In fact, it is the enormous investment in such commercial effort that makes this a powerful space exploration strategy.

This Isn't Humans Versus Robots: Exploration telepresence requires astronauts travelling to distant sites in order to mediate light-time latencies, and is an excellent example of the spirit of human-robotic partnership that now guides exploration policy. In principle, it can be used to scout sites for eventual human visits, and even develop on-site infrastructure for those visits. This is about using robots to put human presence and real-time awareness on other worlds. Programmatically, comparison with human spaceflight is more appropriate than comparison with high latency robotic spaceflight because the latter cannot put high quality human presence anywhere. The question is whether low latency telerobotics is a more opportunistic way of doing it than putting boots on the ground.

New Thinking About Exploration Telepresence: In 2013, we organized a symposium at GSFC about opportunities presented by exploration telepresence (http://spacenews.com/exploration-telerobotics-symposium/). We have managed a Keck Institute for Space Studies study on *"Space Science Opportunities Augmented by Exploration Telepresence"*. (http://kiss.caltech.edu/programs.html#telepresence) A study report is now being developed. These efforts have attempted to develop modern perspective on low latency telerobotics, and its value for space science. For the latter study, field geology was considered with some care. A short review of the conclusions has been recently published [2].

The Problem With Latency: The importance of low latency control to human accomplishment can be assessed in a number of ways. Even very early work by Sheridan and Ferrell [3] considered the impact of transmission delay on manipulative control. They found that completion times of tasks scaled with command latency, with each component of an iterative task taking of order a human reaction time. Reaching out to pick up a rock can be a multi-step procedure, in which the hand and fingers are iteratively positioned. Each iteration suffers the same command latency. Simple manipulation tasks with Earth-Moon latency (2.6 s) required 6-8 s to complete. Clearly, the tasks whose completion times will suffer most from control latency are dexterous tasks that require fine control and iteration. It is well understood that surgical telerobotics, with incisions and stitching in a compliant medium, is completely intolerant of control latencies over 500 ms [4]. Telerobotic surgery on the Moon will not be done from the Earth.

To the extent that science is an iterative process, control latency is a serious handicap. That a human in situ could accomplish more in a day than a MER could accomplish on Mars in a month is largely the result of Earth-Mars control latency.

What We Don't Know:

In the case of, for example, doing field geology with low latency telerobotics, it is easy to make presumptions about efficiency and opportunity. In fact, we have no idea how to do it. We don't do field geology on the Earth telerobotically, because it is cheaper to send people. In order to make the best use of this strategy, analog studies are required that will better define protocols and requirements, and establish the penalties of latency for this kind of work. We need to assess which scientific tasks are most latency intolerant, and to what extent real-time human presence is necessary to do them. That being said, we're actually pretty good at doing high latency field geology on Mars.

Current Work on Low-Latency Space Telerobotics:

Current work, in which ISS astronauts control telerobots on the Earth with low latency, are being carried out by NASA [5], and by ESA [6]. These tests are important for establishing communication functionality from orbit to ground, and provide information about procedural and design requirements for operations with the DSG, as well as future Mars operations from orbit.

The DSG As a Control Node for Lunar Exploration Telepresence:

Of principal importance for doing exploration telepresence from a DSG is the surface-to-control node communication link. The attributes of this link are highly dependent on the orbit. High quality imaging will require of order 1 Mb/s for the link, and engineering it will determine the power and antenna configurations needed. Simple link budgets suggest that for an EM Lagrange point orbit, a pointed meter scale antenna on the DSG will serve a telerobot on the lunar surface with a MSL-type transmitter and HGA. The orbit will also determine the two way latency that the operators must cope with. A Lagrange point orbit will result in a fixed 400 ms latency, which is probably not uncomfortably large for what can be considered real-time operation. A proximal distant retrograde orbit (PSDRO) could be much better in this regard [7]. A Lagrange point or DRO orbit may not, however, be optimal for polar exploration. A high inclination near-rectilinear halo orbit (NRHO) can offer much smaller latencies at perigee, but the control latency will vary enormously, which could complicate operations.

The scientific methodology of field geology has been articulated in detail [8]. It requires systematic observations, and the process is a progressive one, where on-the-fly interpretive synthesis of an ensemble of observations generates results. This methodology is strongly enhanced with real-time human presence, whether achieved with in situ humans or electronically mediated by nearby humans. Certainly mobility is an asset, and telerobotic systems can achieve that mobility over great distances, and over extended periods of time, unlike an astronaut in an EVA suit. The ability to climb and reach is something that astronauts may have an advantage with, however. The process requires high quality pointable imaging, ideally with telescopic and microscopic capabilities, and even with spectroscopic discrimination. These capabilities are easily achieved with contemporary imaging systems, and not so easily achieved with the human eye inside a space helmet. Regolith will need to be manipulated – cleaved, scraped, as well as sampled. This requires some measure of dexterity that can be achieved with modern telerobotic systems which, as noted, can be done with a precision exceeding that of a hand in an EVA glove.

An important factor for science by exploration telepresence or by in situ humans will be the extent to which operations can be shared and supported with a larger population of scientists on Earth. The "science backroom" used by high latency telerobotic science, as well as for the Apollo lunar program, was critical for providing scientific perspectives above and beyond what a semi-autonomous telerobot or a limited number of scientist-astronauts are able to provide. Exploration telepresence should allow sharing of observations over a higher latency link, and can even allow telerobotic control over that link during astronaut down-time.

References:

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