Advances in telerobotics are making it possible to conduct remote explorations of distant worlds. Human operators can now control their mechanical surrogates from Earth, and will soon be able to do so from space outposts as well. But with the desire for exploration seemingly built into human DNA, will the ‘telepresence’ provided by robotic systems be a satisfactory substitute for truly being there?

Remote Telepresence
A new tool for space exploration?

**Significant strides are being made in** telerobotics, the ability to place human cognition and dexterity in places too perilous for flesh and bone, whether to probe the deepest oceans, dig out resources from mines, or maintain undersea oil pipelines and telecommunications cables. In addition, above our heads, passenger aircraft increasingly share the skies with all manner of unpiloted airborne vehicles, controlled from a distant command center.

Space exploration planners are now contemplating how they can adapt telerobotics to achieve tasks on other worlds. Extending human cognition to the Moon, Mars, near-Earth objects, and other bodies could reduce the challenges, expense, and danger of hurling humans to such hazardous surfaces and deep gravity wells.

Conversely, some believe that sending mechanical surrogates to do an astronaut’s work runs counter to the core value of human space exploration—that crewed space exploration is built into our DNA and answers the call of destiny.

But pitting astronauts against machines is not just contentious; it also overlooks the advantages of combining their attributes to create a true human-robot partnership.

**Early pathfinders**
Momentum appears to be building for future space expeditionary crews who remotely operate systems that are deployed on planetary bodies, doing so from, say, in-space locales. From a habitat circling a planet or in a module situated at a Lagrange point, astronauts could use high-quality telepresence to conduct surface science, piece together infrastructure, or scout out and unearth resources on other worlds.

In some cases, while landing crews on
celestial surfaces may be the ultimate ambition, planting human cognition at these locations via telepresence could be achieved far more quickly and at lower cost. In addition, if remote telerobotic control can be established on the Moon, for example, could this capability help hone future activities at other planetary bodies, particularly at Mars?

"Telepresence has the potential to vastly increase the capabilities for human exploration of the most challenging and revealing locations in the solar system," says Harley Thronson, senior scientist for advanced concepts in the Astrophysics Science Division, Science and Exploration Directorate, at NASA Goddard.

"Landing humans or robots on the surfaces of other worlds and within deep gravity wells is an expensive undertaking. In advance of landing humans on another world, astronauts from orbit operating sophisticated robotic surface explorers may be the far less expensive pathfinders, surveying, testing, and sampling for the humans that would follow," Thronson tells Aerospace America.

This major enhancement of human exploration potential, says Thronson, is enabled by three parallel technological advances: high-bandwidth communication, advanced robotics, and low latency—that is, placing human operators outside the deep gravity wells of other worlds, yet 'close enough' so that the round-trip light-travel time is comparable to time scales associated with the human hand-eye-brain system.

"The key technologies to enable effective telepresence are nearly at hand, first to the vicinity of the Moon, then one day beyond the Earth-Moon system," he says.

"Effective telepresence offers the opportunity for humans to explore worlds..."
Congress buy into an exploration strategy that does not involve humans going all the way to an exploration site? “In many respects,” he suggests, “what telepresence is making us do is redefine what we mean by the word ‘exploration.’ To what extent do we have to ‘be there’ to be explorers? What does ‘being there’ mean? It doesn’t mean what it used to mean,” he contends.

Still, the distances over which robots are exercised impose a time delay on their control. For the Moon, that two-way delay is at least 2.6 seconds; for Mars it is far longer, in the 8-40-minute range.

These delays are, at minimum, what is routinely endured in ‘experiencing’ Mars through rover automatons. What kind of personal experience has you turning your head, then waiting 40 minutes to see the view? Lester asks: Is experiencing distant space destinations through electromechanical surrogates really possible?

Minimizing communication delay time, or latency, says Lester, is a key to achieving telepresence, and that translates into putting human cognition at distant sites. “In order to achieve it, humans need only be close, so the travel problem becomes sending astronauts to the vicinity of exploration sites, and not necessarily landing on them. Landing humans can be almost half the cost of putting human cognition at these sites.”

Thronson and Lester were key organizers of an Exploration Telerobotics Symposium held last May at Goddard that brought together astronauts, scientists, engineers, and robotic specialists from a mix of Earth and space applications fields.

In many respects, Lester says, telepresence is a strategy that challenges traditional definitions of exploration. Can we be explorers without actually setting foot at an exploration site? The space science community is comfortable with that premise, though control of robotic assets from Earth involves serious cognitive compromises. “It was clear to the symposium participants that exploration by telepresence established clear synergy between robotics and human spaceflight, and had a strong generational grounding. The ‘wired’ generation may be far more accepting of such a strategy than an older generation,” he surmises.

Cognitive compromises

Holding a similar view is Dan Lester of the Dept. of Astronomy at the University of Texas in Austin. Lester, who is working with NASA on cis-lunar operations involving science and exploration, notes that there are countless lessons to be learned from the terrestrial telerobotics community. “That’s all happening right now, in a big way, and space exploration has a lot to learn from those endeavors. They don’t use space-qualified hardware. But their operations management and protocols have important lessons for us.”

It is precisely this explosion of technological capability that prompts talk about extending telepresence into space, Lester explains. “Decades ago, when we wanted to put human cognition on the Moon, there was exactly one way to do it…and that was putting people there—boots on the ground. But this is no longer the only option.”

Fast forward to today

Lester underscores what he believes is an important and perhaps overriding question: To what extent do the public and the U.S.
First, it depends on what you run into on Mars, explains John Grotzinger, MSL project scientist from the California Institute of Technology. Curiosity, the size of a small car, is essentially an automated geologist operated by a large team of handlers on Earth. The team is also using orbital imagery of the site the rover is exploring.

Already, Curiosity has shown its robotic right stuff in surveying its surroundings. “With a robot we can actually test the hypotheses, including the alternatives, pretty quickly and efficiently and arrive at a consensus opinion,” Grotzinger says. “I would say it’s simply an issue of signal to noise. If the geological signal of the process is large enough, it’s very easy to build consensus.”

On the other hand, what if Curiosity rolls up to the unexpected, something that has no earthly analogs or is hard to analyze? “I think if you’re working with a robot—and a very large team—it becomes very difficult to reach consensus. Therefore, there’s really no substitute for a human when it comes to exploring very complex situations. The triage that you can do mentally as you pass your judgment over the options and command yourself to walk to different places and make different measurements is really the compelling reason for wanting to do human exploration. It’s just so much more efficient, and you probably will arrive at conclusions that are more likely to be correct than if you had just a robot,” Grotzinger responds.

“But it’s the same problem you’d go through as an individual saying, ‘Do I have enough water, or do I need to go back to the car and refill my water bottle before I go up there?’ So we’re always doing the optimization...there’s always a compromise in terms of how far you go versus the geology you achieve,” he adds.

According to Paul Spudis, senior staff scientist at the Lunar and Planetary Institute (LPI) in Houston, Texas, the extent to which true telepresence is needed for effective geological exploration is unclear. “This is a result of both the lag in telepresence technology—for example, very high bandwidth visual and tactile sensory systems—and our poor understanding of what the field experience entails from a human cognitive viewpoint.”

Spudis says his experience with using remote systems to conduct geology has been less than edifying. “I note both poor situational awareness and a significant diversion of concentration on technical means of the human-robot interface versus conducting surface exploration. In other words, as a replacement for human field exploration, it leaves a lot to be desired.”

**Libration point practice**

There are new studies under way to use an Earth-Moon Lagrange point (E-M L2) to conduct human-controlled telepresence exploration on the lunar landscape.

Last February, NASA’s William Gerstenmaier, associate administrator for human exploration and operations, requested that a team be formed to develop a ‘cohesive’ exploration concept aimed at the E-M L2 spot in space. Libration or Lagrange points are places in space where the combined gravitational pull of two large masses roughly balance each other out, allowing spacecraft to essentially ‘park’ using minimal amounts of propellant.

An earlier appraisal of E-M L2, which is near the lunar far side, labeled this destination the ‘leading option’ for a near-term exploration capability. E-M L2 could serve as a gateway for capability-driven exploration of destinations such as near-lunar space, the Moon, asteroids, the moons of Mars and, ultimately, Mars itself. This capabilities-driven NASA architecture is one that should use the agency’s Space Launch Sys-
An artist’s depiction shows the Earth and Moon as they would appear from an L2 halo orbit reached by an Orion spacecraft. From that site, astronauts would control robotic hardware on the surface. Now under way are discussions on building up a human-tended habitat at the Earth-Moon L2 location to enable telerobotic activities on the lunar surface. Credit: Lockheed Martin.

control robots on the lunar surface. Teleoperated science tasks include snagging rock specimens for return to Earth from the Moon’s South Pole-Aitken basin and robotically unfurling a low-frequency array of radio antennas to observe the first stars in the early universe. The E-M L2 outing would be a stepping stone toward treks to asteroids, and toward human missions to the moons of Mars in later years, he advises.

A Lockheed Martin white paper provided to Aerospace America on the E-M L2 proposal cites a number of benefits that would evolve from such an effort:

- Astronauts on an L2/far-side mission would travel 15% farther from Earth than did the Apollo astronauts—and spend almost three times longer in deep space.
- Each flight would prove out Orion’s life support systems for one-month missions before attempting a six-month-long asteroid mission.
- It would demonstrate the high-speed reentry capability needed for return from the Moon or deep space—40-50% faster than reentry from LEO.
- The mission would measure astronauts’ radiation dose from cosmic rays and solar flares to verify that Orion provides sufficient protection. Currently the medical effects of deep space radiation are not well understood, so a one-month mission would improve our understanding without exposing astronauts to excessive risk.

Meanwhile, NASA strategic space planners also foresee that an E-M L2 waypoint would facilitate assembly and servicing of satellites and large telescopes, among a host of other benefits. As Lockheed Martin notes, if an astronaut-tended E-M L2 waypoint were established, it would also represent the farthest distance travelled by humans since the Apollo 17 Moon landing in 1972. Extended stays at E-M L2 require advances in life sciences and radiation shielding for crews that sojourn outside the protection of Earth’s Van Allen radiation belts.

In a memo written last year, Gerstenmaier added that E-M L2 “is a complex region of cislunar space that has certain advantages as an initial staging point for exploration, but may also have some disadvantages that must be well understood.”

Testing from ISS
Jack Burns, director of the LUNAR (Lunar University Network for Astrophysics Research) Center at the University of Colorado, Boulder, has been spearheading an
factor or time delay, but the specific tasks LPI’s Spudis. Much is made of the latency over controlling them from Earth, says the Moon is possible, but offers no real advan-
tage for export, you are not creating new
ding the L-points, “but they are means to an
cost of the buzz and static emitted on Earth.
With haptic tele-presence, which adds the sense of touch, anyone purportedly can
run operate a robot without training.


drives and habitats.


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Telerobotic control from ISS
A test slated for later this year is designed to
devlop an ISS-to-ground interface for telerobotic
control, to be staged by ESA’s Multi-Purpose
End-To-End Robotic Operation Network (METERON).
This experiment and architecture are key to
validating future human-robotic mission operations
concepts from space, using the ISS. André Schiele,
founder in 2011 of ESA’s Telerobotics and Haptics
Laboratory, is leading the effort.
In the first METERON tests, station astronauts
will operate ESA’s Eurobot prototype from a
computer equipped with special screens and a
joystick. In the next phase, the engineers will allow
astronauts to control a robot that has the sense of
force and of “touch.” It can be connected to robots
like Justin, developed by the German Aerospace
Centre, DLR.
These senses will give astronauts “a real feeling
of the forces that the arms of the robots are
experiencing in their environment,” says Schiele.
“The space station is the perfect orbital plat-
form to simulate very realistic scenarios for human
exploration,” says Kim Nergaard, ESA’s METERON
ground segment and operations manager.

First we have to set up a robust communication
architecture, establish an operations system, and
define a protocol to allow astronauts, robots, and
our ESA control center to work efficiently together.
This is not as easy a task as it seems,” he reports.
What these efforts will accomplish is to prove
out at least the basic operational and communica-
tion concepts and protocols for on-orbit tele-
robotics, which may be used for work on the lunar
or Martian surface, with control from human
operators in orbit above, observes Dan Lester of
the University of Texas in Austin. “It is an important
first step for this kind of work, and makes excellent
use of the ISS.”
That strategy, however, does have some
disadvantages, Lester adds.
“In order to achieve very low latency, you can’t
go through the Tracking and Data Relay Satellite
System, which is what ISS uses for most of its data
communications. You need a direct-to-ground
link. But the problem with that is that such linkages
are only possible when you’re flying overhead.
So for a given single ground receiving antenna,
you’ll only get 5-10 minutes of connect-time... maybe once a day. So while you can prove the
operational concepts and protocols, you sure
won’t be able to exercise them very much,” Lester
notes. “That’s why telerobotic control from ISS
won’t really completely prove out strategies for
on-orbit telerobotics at Mars. Doing work from
Earth-Moon L1 or L2 on the lunar surface will be
far more instructive in this regard.”
One could ask why one even needs to practice
telerobotic control from ISS and not just do it
from the next room?
There are several reasons, says Lester. First,
the communication strategy is an important one.
Orbit-to-ground communication is challenging,
in an error-and-delay-tolerant mode. Second, it
turns out that carrying out telerobotic control in
0-g is not quite like operating it in 1-g. That is,
operating a joystick properly is really helped by
having your arm gravitationally ‘grounded.’
Furthermore, it is not completely clear how good
a sense of telerobotic control one has for a vehicle
in a gravity well, done from a control station in
0-g. “Your brain isn’t quite ‘thinking’ gravity
anymore,” he says.

On the science side, Garvin stresses,
“There is a profound lack of real experi-
ence with low latency telepresence here
on Earth, in geological field situations, with
which to understand how to utilize the ob-
vious benefits of this approach on the
Moon, Mars, asteroids, or beyond.” This
experience gap limits our understanding of
how to develop the engineering and tech-
nology capabilities required for using low
latency telepresence in deep space field
science.
Garvin senses that there is “bona fide
enthusiasm” for low latency telepresence as
part of a “flexible path” approach for deep
space human exploration. Indeed, human
spaceflight can provide significant field sci-
ence and other activities at new destina-
tions without having to initially place hu-
man boots on the ground.

Clearly there are settings and environ-
ments where human field explorers on
other worlds should never go, Garvin
emphasizes. In such places, even very local
low latency telepresence operations, with
robots there and people in nearby safe
havens, could be essential.

“My general feeling is that low latency
telerobotics is a critical capability that must
be investigated so that future human-ro-
botic scientific activities can open up new
frontiers in our scientific understanding of
Mars, the Moon, asteroids, Venus, and other
targets of exploration opportunity,” Garvin
concludes. ▲

The K10 planetary rover has
four-wheel drive and all-wheel
steering on a passive rocker
suspension, a design that allows
operation on moderately rough
terrain.