

“Exploration Telepresence : Gateway to Human Engagement with the Solar System”

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What exactly do we mean by “human-robot collaboration”?

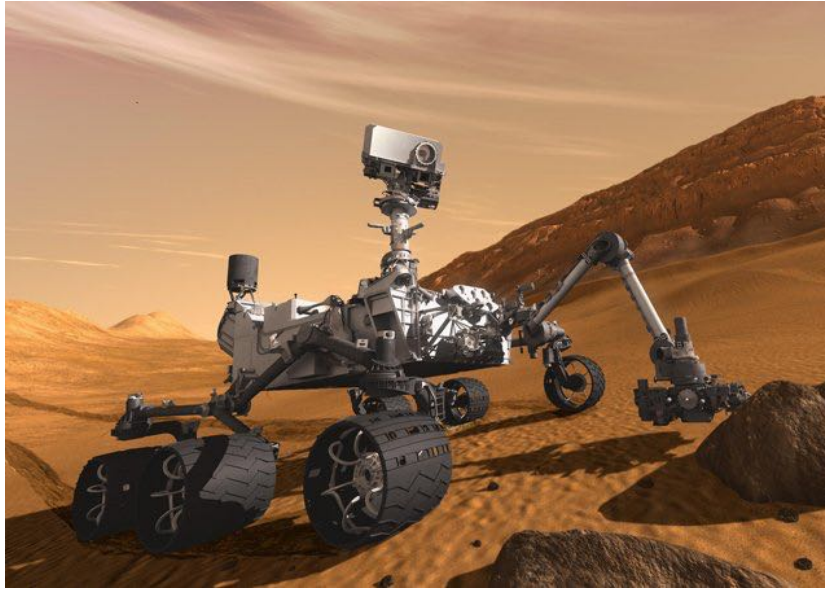


The classic picture is where robots work next to us, helping us out.



“Hold that screwdriver for me please!”

This is an Asimovian perspective on it. Robots are friends and helpers.



Another picture ...

Where robots are tools that
extend human presence.

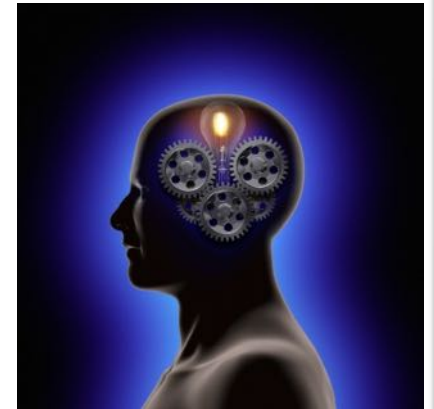
Putting human awareness
and capability in other places.

But space is a big place.
Significant control latency from the Earth.

Human cognition uses “presence” to engage.

“Presence” was once achievable only with bodies.

Don’t need to “be there” to have “presence” at a site.



Telepresence = electronically mediated presence



**Telepresence and human space flight
as enablers for space exploration.**

The cognitive mandate for telepresence depends on

- control latency
- control bandwidth

Recipe for Quality Telepresence (and the cognitive mandate)

Control bandwidth for quality telepresence?

- Human vision ~10 Mb/s per eye
- A bit more with haptics, dexterity, and audio

with compression, and some generosity, let's say 1 Mb/s

Control latency for quality telepresence?

- Threshold for latency detection is ~50 ms but ...
- Human reaction time for visual and aural stimulus is ~200 ms

That defines a “cognitive horizon” of $c * 200 \text{ ms} / 2 \sim 30,000 \text{ km}$

Need to be closer than 30,000 km to have real-time performance.

- Earth-Moon 2.6 seconds
- Earth-Mars 8-40 minutes

WE CAN'T HAVE “QUALITY TELEPRESENCE” AT THESE
LOCATIONS FROM THE EARTH BECAUSE OF LATENCY

So let's talk about latency



Dave Scott's Apollo 15 stopwatch

What's wrong with control latency, if we're doing something?

Piece of telerobotic history (1960s)
-- work of Bill Ferrell (Tom Sheridan).

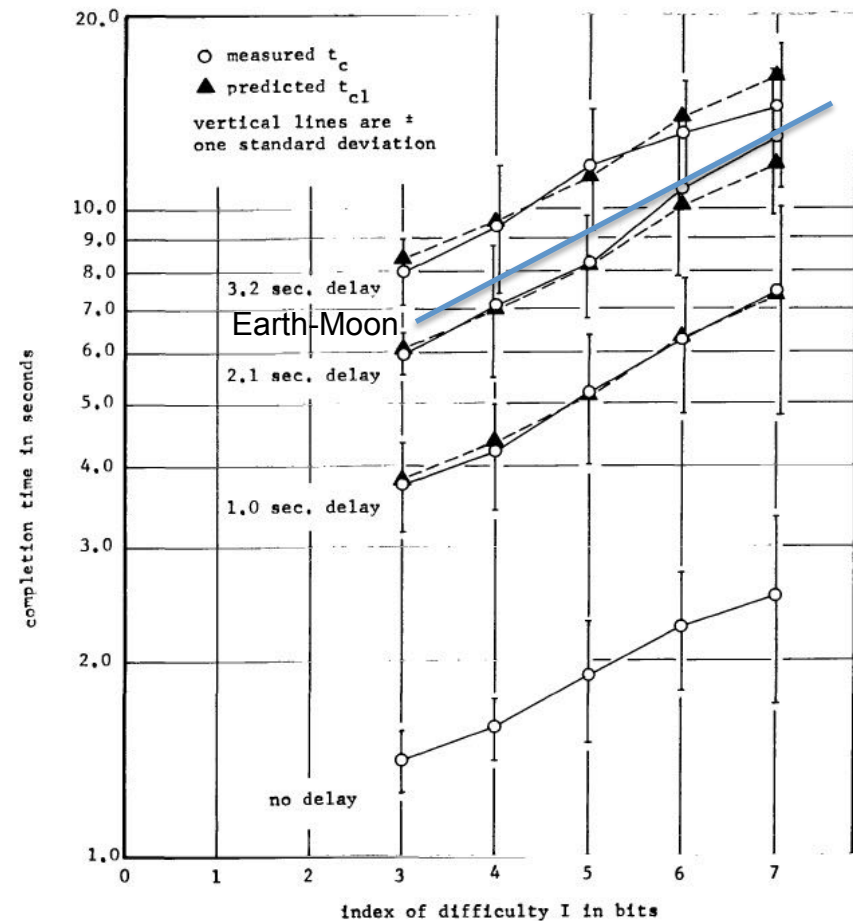
Simple 2D “minimal manipulator”.

Task completion time
versus latency and “difficulty”.

“Difficulty” : how far you move,
divided by how well you got there.

Task completion time depends
critically on latency and difficulty.

THIS IS FOR AN EASY TASK!



What's wrong with control latency, if we're trying to do something?

Manipulations are hard with latency. Sizes, shapes.

Situation awareness is poor with latency.

Haptic feedback extremely intolerant of latency.

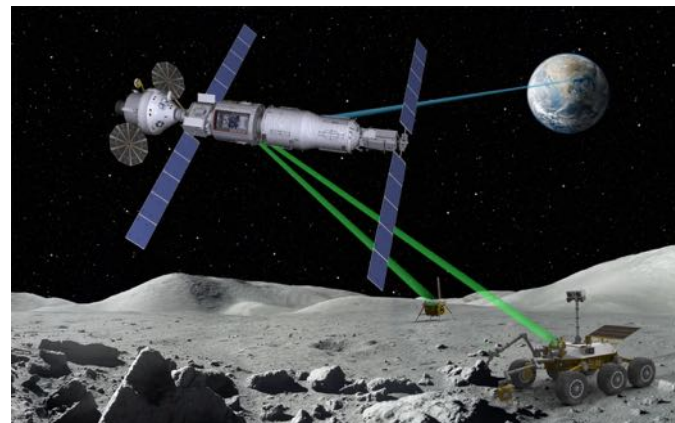
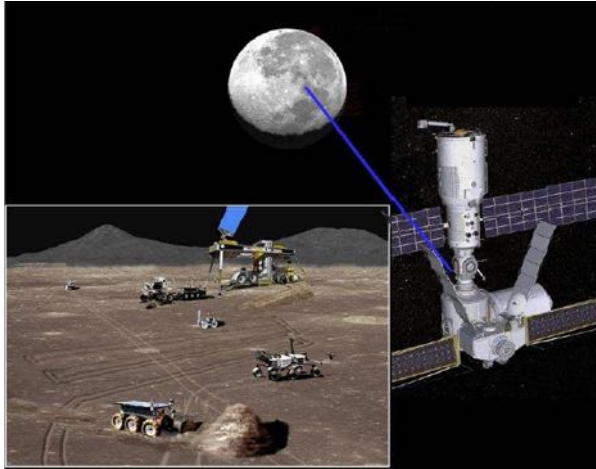
Lessons from high latency telerobotics (MER, MSL) don't transfer well to low latency telerobotics

For field science, we have NO experience with low latency telerobotics.

Analog studies will be essential to understanding.



Exploration Telepresence



Human “presence” from a (short) distance away.
Telerobotics with LOW LATENCY.

(images from Boeing, GSFC, etc.)

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We do low latency telerobotic control on Earth



Drones/UAVs



Undersea oil, gas, cable



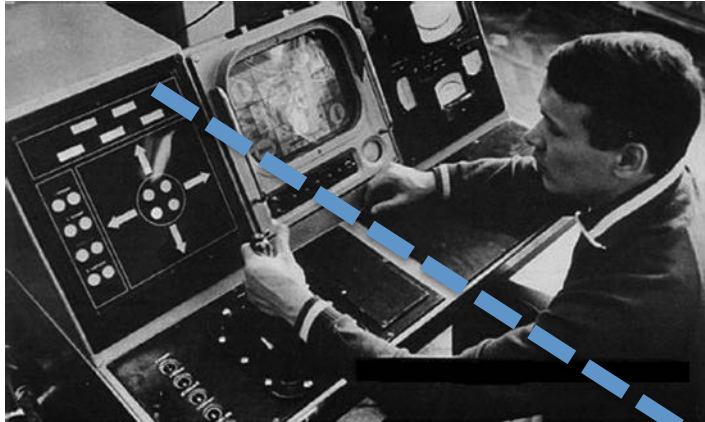
Surgery



Mining

Telepresence isn't R&D anymore.
Commercial reality.

Evolution of space telepresence



Lunokhod control from Earth
(control latency ~5-20
seconds)

***Space
telepresence
enabled***



ISS Remote Workstation^{ISS}
control latency ~ ms)

Lunar workstation at
cis-lunar habitat -
latency ~few x 100 ms



Boeing

Opportunities presented by space telepresence for the Moon and other places, compared with on-site humans

- Reduced cost impact, don't land humans in strong gravity well
 - One party of humans has presence at many sites
 - Exploration duration not EVA-limited
 - Better visual perception (compared with a helmet visor)
 - Better dexterity (compared with EVA gloves)
 - Benefits from commercial terrestrial telerobotic investments.
 - Credible forward planetary protection (as required)
 - Lower human risk, humans in orbit
- >> Increase in the number of potential destinations for human “presence”.
Mercury? Venus? Scuba diving in the lakes of Titan?

That's not to say that we don't want to land humans!

So where do we try to use space telepresence?

Experiment with it, ISS->surface of the Earth (e.g.METERON)

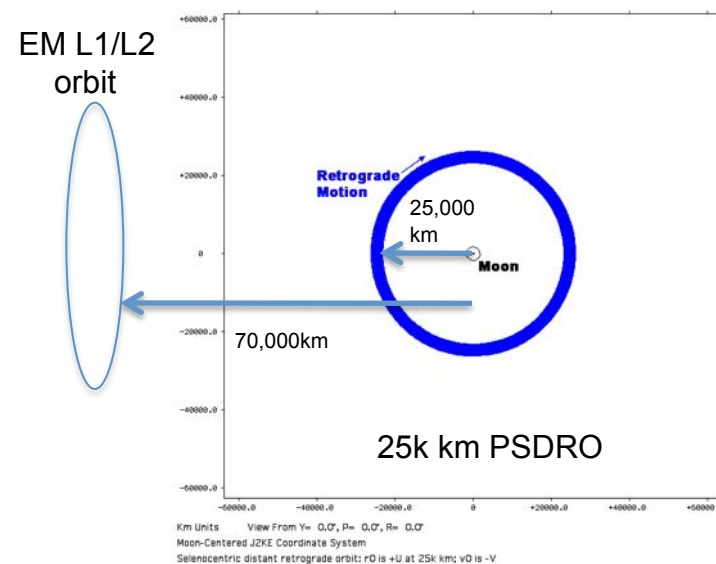
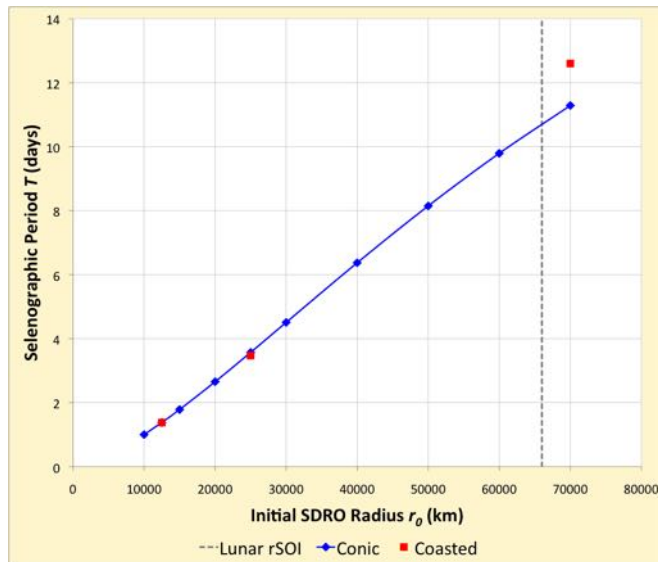
Cis-lunar space -to- Moon
e.g. from Orion or cis-lunar hab



But from where exactly? What kind of orbit?

- LLO? Not good. Unstable orbit. Short duration contact.
- EM L1/L2? Needs stationkeeping, $r \sim 70,000\text{km}$, 500ms latency is a bit large.
- PSDRO “Proximal” Selenographic Distant Retrograde Orbit (SDRO) –
 $70,000 > r > 5,000\text{km}$ -> real-time connectivity.

The value of PSDROs for lunar surface telepresence, ... better than EM Lagrange point orbits?



For example – 25,000km PSDRO, 4 day selenographic period

Proximal Selenographic Distant Retrograde Orbits
characteristics (Adamo et al., AIAA Space2014)
and Jeff Parker at U. Colorado

**Suppose we had a habitat at a 25,000 km PSDRO
– a convenient hab site for lunar telepresence (HERACLES)**

- No orbit maintenance required
- Latencies 15x less than from Earth, real time operations
- Continuous access at a site over a whole workshift, both sides of Moon
- Convenient trajectories to lunar surface – hours, not a day
- Insertion deltaVs for small PSDROs like for EM L1 and L2
- Very short eclipses of Earth and Sun

▪

How could exploration telepresence offer value on the Moon?

With things you'd want humans to do there.

Especially things that might be inefficient to do from the Earth.

- Inspection and assaying of regolith
- Selection, manipulation and collection of samples
- Site surveying and reconnaissance
- Instrument emplacement, maintenance
- Regolith grading, piling, and “paving” for dust suppression
- Deployment of habitats and support facilities

(Yes, you could do this all from the Earth,
but it would take a lot longer for complicated tasks ...)

Most potent long term goal of lunar telepresence is
conops validation for future visits to Mars and beyond

So where do we go from here?

Exploration telepresence is important rationale for in-space habitats

Hab-specific value

- Control functionality?
- Optimal orbit?



Telerobotics-specific value

- Modes for fully immersive telepresence?
- Extensibility to other destinations?
- Sharing low- and high-latency tasks?



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The evolution
of exploration?

