Robots and Humans in Planetary Exploration: Working Together?

Geoffrey A. Landis

NASA Glenn Research Center
mailstop 302-1
21000 Brook Park Road
Cleveland, OH 44135
geoffrey.landis@grc.nasa.gov

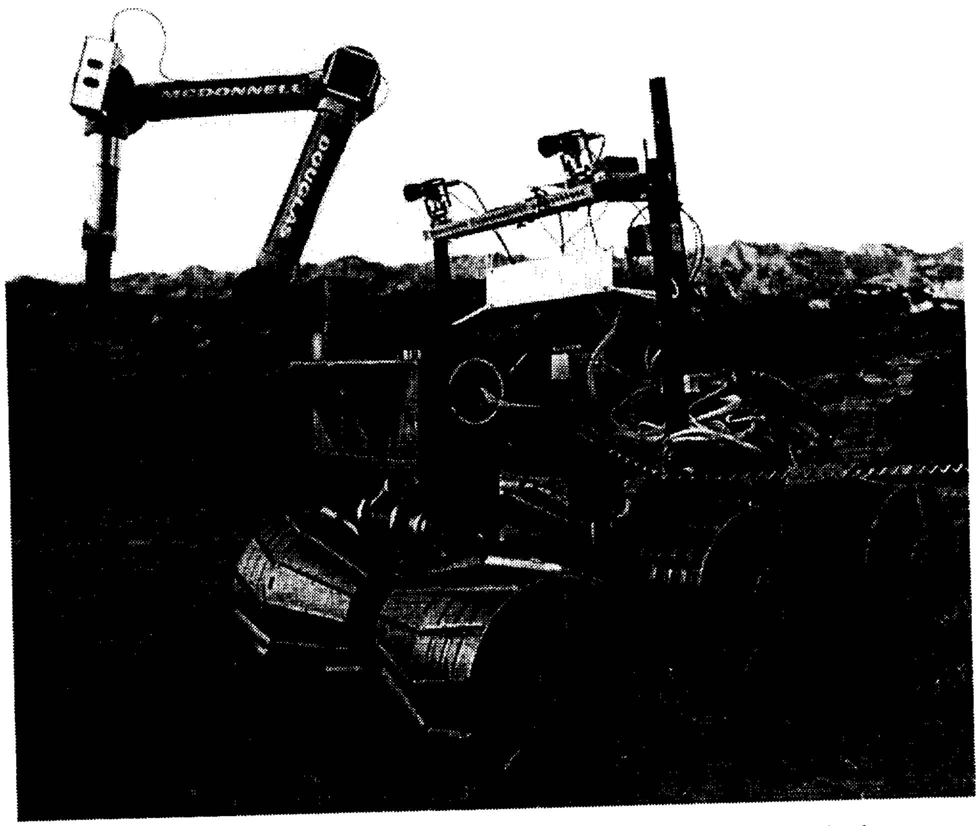
How will humans and robots cooperate in future planetary exploration? Are humans and robots fundamentally separate modes of exploration, or can humans and robots work together to synergistically explore the solar system?

Mars Exploration

Today's approach to human-robotic cooperation in planetary exploration focuses on using robotic probes as precursors to human exploration. A large portion of current NASA planetary surface exploration is focussed on Mars, and robotic probes are seen as precursors to human exploration in:

- Learning about operation and mobility on Mars
- Learning about the environment of Mars
- Mapping the planet and selecting landing sites for human mission
- Demonstration of critical technology
- Manufacture fuel before human presence, and emplace elements of human-support infrastructure

In essence, today's approach accepts a separation of human and robotic missions—first the robots are used to scout, and then the humans explore. This is critical—it is almost unthinkable today to consider sending humans to Mars without first mapping and learning as much as possible by simpler robotic missions.



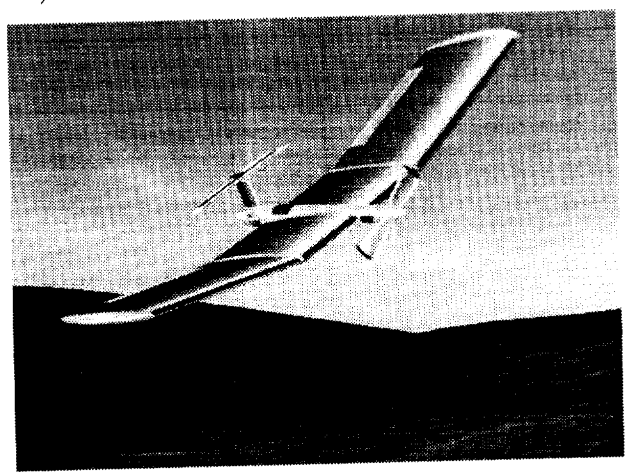
"Marsokhod," an experimental Mars robotic explorer, being tested in the Mojave desert (picture courtesy NASA Ames Research Center)

Robots assisting humans on Mars

Beyond the use of robots as precursors to humans, robots are envisioned as assistants to human exploration while the humans are on Mars. Examples include reconnaissance, robotic "mules", worker robots, and robotic-driven rovers.

Aerial reconnaissance robots help to plan traverses and locate exploration targets. This can be satellite recon vehicles, or real-time local aerial vehicles.

One example of a robotic explorer which can assist humans in exploration by providing reconnaissance is the Mars solar-powered "scout" airplane. The Mars scout airplane is a ten kilogram hand -launchable airplane that flies on solar power. It can carry a camera to get close-up aerial views of the local area, needed for astronauts to plan exploration and traverses, and allows real-time updating of "what's going on"... as well as giving great PR views, suitable for the folks at home.



Solar-powered "scout" airplane

Another example is a robotic "mule" to follows astronauts around. The robot mule can hold tools such as rock-hammers, drills, and cameras, and will carry samples back to the habitat. It will also be ideal to aim the TV cameras for the 11 O'Clock news! This removes the burden of carrying stuff from the human. Robots designed to do the "grunt work" of science can do tasks like setting out remote instrumentations, deploying the solar arrays and radiators, and cleaning off deposited dust after a Martian dust-storm.

Robotic long-range rovers take driving burden off of astronauts on long traverses. Any human landing site will be to some extent a compromise between safety and scientific interest, and many of the most interesting features may require a hundred or even thousand-kilometer traverse to reach. If the rover can be robotically driven, the astronaut effectiveness on site is increases, since the astronauts can use the travel time for rest, recreation, writing reports, answering questions from the IG travel auditor, and so forth.

Robots to replace humans for EVA

What about robots actually replacing humans on the surface? In the telerobotic exploration scenario, the humans remain in a habitat, and use teleoperation to rove across the surface of Mars and explore. This type of exploration will require a high-fidelity, high-bandwidth connection to give the humans a fully-detailed virtual presence in the robotic body.

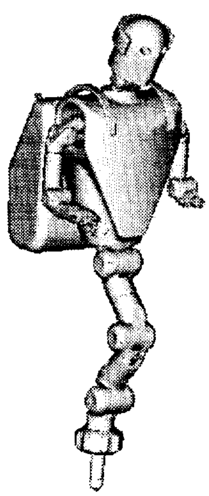
Why explore with telerobots?

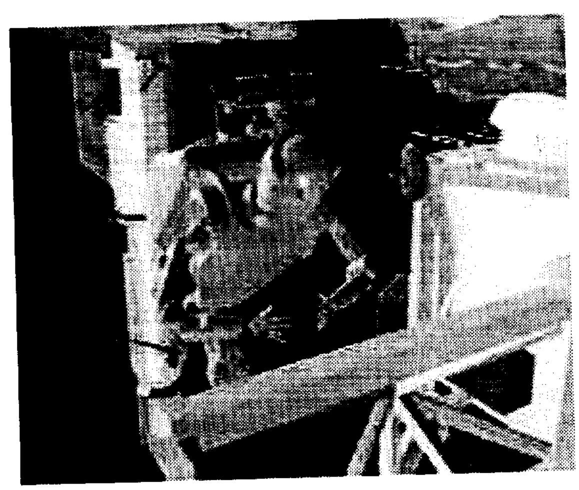
Use of telerobots lowers risk, and thereby allows dangerous exploration. What safety committee will approve cliff-climbing in Valles Marineris? Yet the layers revealed in the canyon may very well be the key to understanding the geological history of Mars. Telerobotic exploration also allows exploration beyond "walk-back" distance.

Use of such telerobotics will also reduce the EVA load on the astronauts. A "Marswalk" will require a time-consuming preparation, involving a lot of time expended for each hour in the field. By having the humans do their "Marswalk in a robotic body, more time can be spent on actual science.

Robots have expanded senses . A robot can easily have radar, infrared, and gamma-ray eyes, and so in principle a robot can see far more than a human can.

Samples can be collected by teleoperated robots, and analyzed by humans in the shirt-sleeve environment of a fully-equipped on-site laboratory. For the most interesting sites, initial forays by telerobots can be followed by detailed "in person" visit by space-suited humans. The purpose is to save the humans for goal-oriented exploration once you know exactly where and what to look at by telerobotic exploration.





Teleoperations real-life example: "Robonaut" for EVA operation on International Space Station

A radical concept: Human Exploration from Mars Orbit

Rather than land humans on the surface of Mars, we could do all of the exploration by telerobotics. What if we send humans to Mars, but don't land the humans on the surface? Instead, explore via telerobot from orbit. Teleoperation of Mars surface robots from a Mars-orbital habitat will operation near "real time" operation with minimum time delay, giving a virtual presence on the surface.

This teleoperation vastly simplifies the mission. We now have no need to develop a human-rated Mars Lander and Mars Ascent Vehicle, and we can send geologists & biologists on the mission; not VTOL pilots. It is a cheaper, simpler, and safer way to explore, and hence it will be a faster way to explore.

Telerobotics has a high human engagement factor: kids are excited by video games, robots, and virtual reality. It has all the excitement of being there, at a fraction of the price.

Tele-exploration from Mars orbit also allows human (virtual) presence at a wide variety of locations. With an orbital base controlling surface telerobotics, the human explorers are not stuck with one base location, but can explore all over Mars. They can explore the polar caps and also near-equatorial canyon regions. This frees the mission from landing site constraints: There is no longer a need to select a "grab bag" site; it is now possible go to all the best sites-- paleolake sites, river beds, volcanic calderas, lava tube sites, layered terrain, canyons, possible shoreline features, the North and South poles-- Mars is a huge planet, so why camp in just one place?

Near-polar exploration sites will need a polar orbit or an inclined orbit for line-of-sight surface teleoperation. A highly-inclined 24-hr 39-minute orbit, for example, will put the orbital station in line-of-sight of a given region for about 8 hours per day-- one teleoperation shift.

Why explore from Orbit? Scientific rationale

Planetary protection is a significant (and difficult) constraint on human exploration. The most exciting question on Mars is: is there life? To answer this question, we need to explore and collect samples with no Earthly biological contamination. But all space suits are at least slightly leaky! If we explore by telerobotics, we keeps the surface of Mars sterile for biological quarantine, so when we find life, we can be sure that it is not life that we brought with us.

Since present day life could exist on Mars, planetary protection is also needed to preserve the (possible) fragile Mars biosphere from competition from ferocious Earth life. Isolated biospheres on Earth have been devastated when they have been exposed to alien life forms introduced—accidentally or deliberately-- from another continent. If there is life on Mars, we will wish to protect it from having to compete with introduced Earth biota.

Reverse planetary protection—protecting the Earth biosphere from exposure to Mars microorganisms—is also an important consideration. While many biologists argue that life adapted for Mars conditions could have no possibility of infecting terrestrial life, nevertheless, from public policy alone, protecting the Earth from Mars is a primary goal. Exploring from orbit will reduce biological risk by keeping humans from exposure to possible Mars microbes. A telerobotic mission will need no quarantine on return to Earth, and avoids the difficult human question of how to isolate Mars mission astronauts infected by Martian microorganisms.

Beyond Mars: Human Exploration of Venus by Telerobot

Venus, the greenhouse planet, is a scientifically fascinating place. In many ways it can be considered "Earth's evil twin." A huge number of important scientific questions remain to be answered:

- Before the runaway greenhouse effect, was early Venus temperate?
- Did Venus once have an ocean?
- What causes the geological resurfacing of the planet?
- What is the "snow" on Venus mountaintops? (certainly not ice!)
- Can we learn about Earth's climate from Venus?

The surface is far too hostile to land the humans, but we can put humans in the atmosphere to explore the surface via rugged telerobot.

The surface robot will require new technologies; specifically, it will require electronics, scientific instruments, power supplies, and mechanical linkages designed to operate at a temperature above 450 C—hot enough to melt the solder on a standard electronic circuit board. This will require devices made from advanced semiconductor materials, such as silicon carbide, or even new approaches, such as micro-vacuum tube electronics. Such materials are now being developed in the laboratory.

In the Venus atmosphere, at the one-bar pressure level, temperatures are fine for humans-- 0 to 20 C. At this level, there is plentiful solar energy. Atmospheric carbon dioxide is a plentiful resource for life support, and although humans cannot breath the atmosphere, no pressure vessel is required. Further, oxygen and nitrogen are lifting gasses on Venus: you can actually fill the envelope of an aerostat with gas you can breathe.

So it should be possible to float in the atmosphere, and explore the surface of Venus remotely.

Human Exploration of the Jupiter and Beyond by Telerobot

Why stop at Mars and Venus? With telerobotic exploration, the whole solar system is exciting!

Humans will want to explore the Jovian moons, some of the most interesting territory in the solar system. However, the moons of Jupiter orbit in an intense radiation environment. In the Jupiter system, humans will need radiation protection. Human exploration can be done with expendable radiation-tolerant robots, bringing (remote) human presence into protected habitats buried beneath the surface of one of the moons. Such an approach will expand human exploration from the sulfur volcanoes of Io to the oceans of Europa, and explore Jupiter's atmosphere by (tele-) nuclear ramjet.

Beyond Jupiter, the outer solar system is exciting, but one-way trip times of years to decades makes it unlikely to be a place for exploration within the 40 year horizon of this study. To explore the outer solar system, we need robots to send back detailed Virtual Reality models.

With VR models, humans can explore in the comfort of their own planet.

Each robot sends terabits of data-- and we can send hundreds of robots. Critical to this mission is high-bandwidth laser communications—but the technology for this is here; it needs only to be adapted to space exploration.

Engage the entire population of Earth-- everybody can be an explorer!