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Robots and humans: synergy in planetary exploration

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Abstract

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? It is proposed that humans and robots can work together in exploring the planets by use of telerobotic operation to expand the function and usefulness of human explorers, and to extend the range of human exploration to hostile environments.

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1. Robots and humans for mars exploration

1.1. Introduction

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 focused on Mars, and robotic probes are currently seen as necessary precursors to human exploration in the areas of 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 on Mars, and possibly for the manufacturing of fuel before human presence and emplacement of 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. Robotic precursor exploration 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. An example of Mars “precursor” robot is shown in Fig. 1. However, the choice between human and robotic exploration does not need to be an exclusive dividing line, with an entirely robotic initial phase of exploration yielding entirely to exploration by astronauts. Humans and robots can be used together for effective exploration.

1.2. Robots assisting humans on Mars

Beyond the use of robots as precursors to humans, robots are envisioned as assistants to astronaut exploration while the humans are on Mars [1]. Examples of tasks that could be done by robots to assist human exploration include reconnaissance, robotic “mules”, worker robots, and robotic-driven rovers.

As an example of robotic assistance, aerial reconnaissance robots can be used to help to plan traverses and locate exploration targets. This reconnaissance can be by orbital reconnaissance satellites, or real-time local aerial vehicles—winged or rocket-powered robots.

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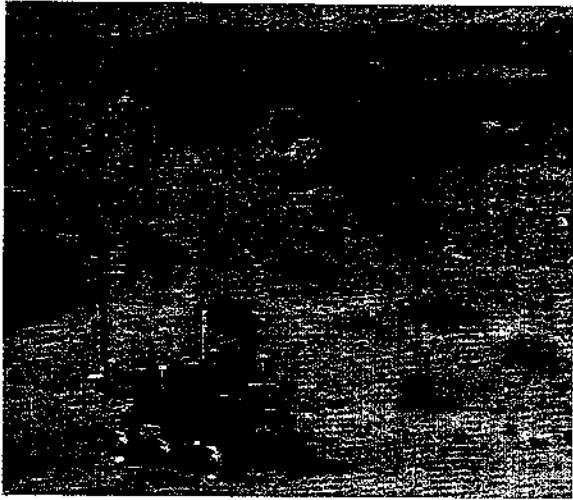


Fig. 1. Field-Integrated Design and Operations (FIDO), a prototype Mars robotic explorer, being tested in the Mojave desert (picture courtesy NASA).

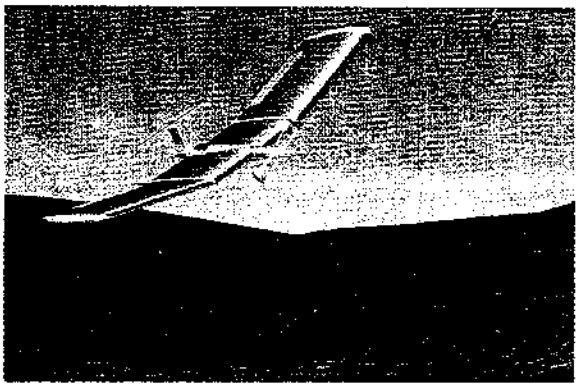


Fig. 2. One concept for a lightweight solar-powered Mars airplane. Such a vehicle could serve human exploration by providing local reconnaissance, as well as by making aerial photography of operations available (artist's conception courtesy NASA).

One example of a robotic explorer to assist humans in exploration by providing reconnaissance is the Mars solar-powered “scout” airplane, shown in Fig. 2. The Mars scout airplane is a 10 kg 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 “outreach” views, suitable for the folks at home.

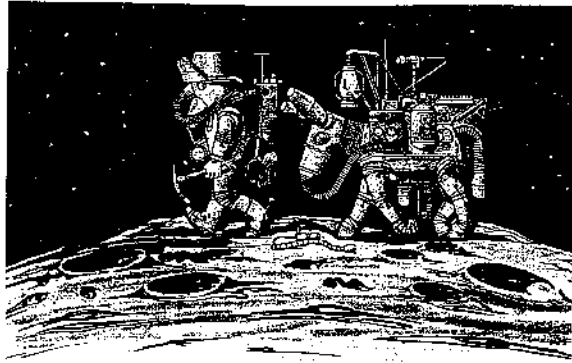


Fig. 3. A robotic “mule” to follow astronauts with equipment could extend the capability of humans prospecting space in the same way that mules provided support for prospectors searching for gold and precious minerals in the American west (cartoon by NASA, courtesy Diane Linne).

Another example is a robotic “mule” to follow astronauts around (Fig. 3). 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 routine and repetitive jobs of science can do tasks like setting out remote instrumentation, deploying solar arrays and radiators, and cleaning off deposited dust after a Martian dust storm.

Such cooperative exploration by astronauts working with robots has been demonstrated in field geology tests by the Astronaut Robot Field Experiment (“ASRO”), discussed by Cabrol et al. [2,3].

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 100 or even 1000 km traverse to reach. If the rover can be robotically driven, the astronaut effectiveness on site is increased, since the astronauts can use the travel time for rest, recreation, writing reports, answering questions from the public, and so forth.

1.3. Robots to replace humans for EVA

What about robots actually replacing humans on the surface? Most roboticists make a distinction between



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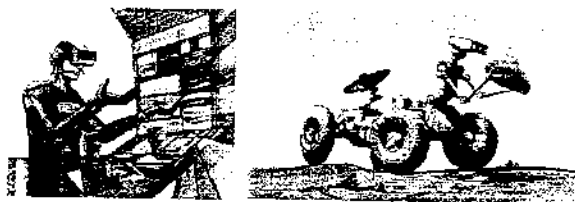


Fig. 4. Telerobotic operations on Mars concept (painting by Carter Emmart, courtesy NASA Ames Research Center [4]).

teleoperated and remotely operated robots [4]. A teleoperated rover, as shown in Fig. 4, has a real-time operator interface, such as the joystick control that is routinely used for operating underwater vehicles. Often, teleoperation is assumed to include an immersive “virtual” environment, so that the human views the scene from the robot’s point of view. On Mars, true teleoperation requires humans to be close enough to the robot that the speed-of-light delay is short enough that the human can operate the rover in real time.

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.

Tools for human telepresence in orbit are already being developed, such as the “Robonaut” [5,6] shown in Fig. 5. The concept uses a humanoid interface, allowing the operator to use the telerobot in the same way that the human body operates. Such a human-like interface could also be used on a mobile body, as shown in the “Centaur” concept shown in Fig. 6, for robotic exploration [6].

1.4. 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

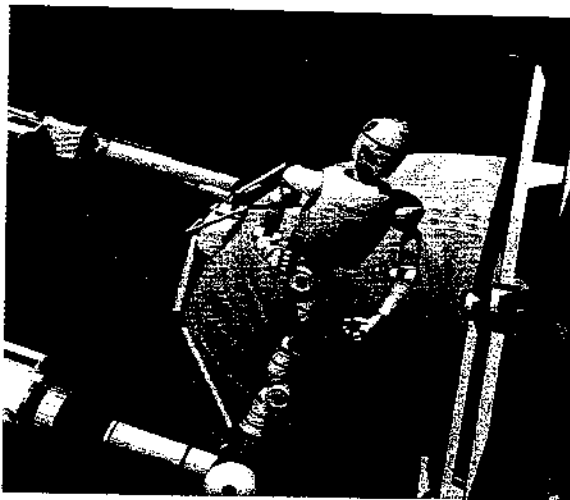


Fig. 5. Teleoperations real-life example: “Robonaut” telerobot for EVA operation on International Space Station [5,6]; visualization by John Frassanito and Associates, courtesy NASA).

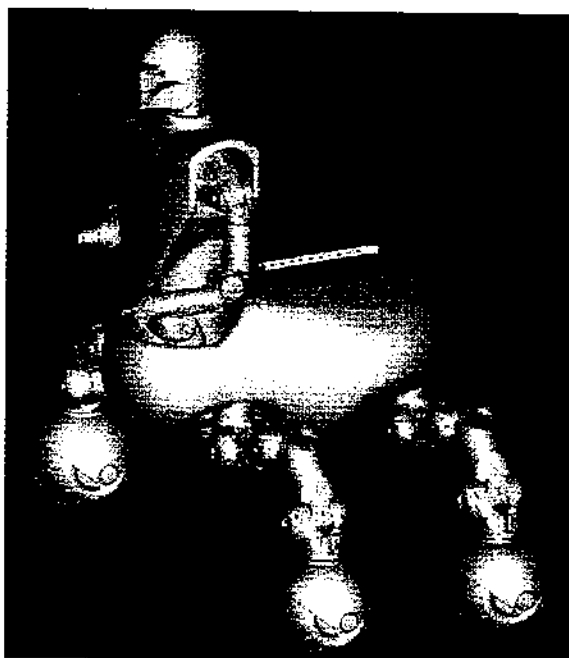


Fig. 6. “Centaur,” a wheeled humanoid telerobotic concept for planetary exploration based on the “Robonaut” technology [6].

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. Furthermore, robots

can 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.

2. A radical concept: human exploration from Mars orbit

2.1. Exploration from orbit: concept overview

Rather than land humans on the surface of Mars, we could do *all* of the exploration by telerobotics. What would be the result if we send humans to Mars, but do not in fact land the humans on the surface? Instead, humans could explore Mars via telerobot from Martian 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 [7–9].

By use of teleoperation, it is possible to vastly simplify the surface exploration 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. Indeed, as discussed by Minsky [10], telerobotics has at least as high human engagement factor as direct astronaut exploration: kids are excited by video games, robots, and virtual reality (VR). 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, 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, from the same orbiting base. This frees the mission from landing site constraints.

With no need to select a “grab bag” site that contains a large number of geologically diverse features at or near a single location; 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 to be operated from a Mars-polar orbit (or at least a highly inclined orbit) to allow direct line-of-sight communications for surface teleoperation. A near-polar inclination 24-h 39-min period Mars orbit, for example, will put the orbital station in line-of-sight of a given region for about 8 h per day—one teleoperation shift.

2.2. 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 biologically pristine samples, with no terrestrial organic 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 most biologists argue that life adapted for the extreme conditions of Mars 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

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3. Beyond Mars: human exploration by Telerobot

3.1. 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 1-bar pressure level, temperatures are fine for humans—0–20°C. At this level, there is plentiful solar energy. Atmospheric carbon dioxide is a plentiful resource for life support, and although humans cannot breathe 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 [11].

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

3.2. 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 VR 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 ability to perform this mission in high-resolution virtual reality will be the ability to send high-bandwidth data by laser communications—but the technology for this is here; it needs only to be adapted to space exploration.

With VR, we can engage the entire population of Earth—everybody can be an explorer!

4. Conclusion

The current approach to planetary exploration views exploration and human exploration as dichotomy: exploration is either by robots, or by humans. The primary cooperation envisioned is the use of robotic probes as precursors to human exploration. However, robots and humans can in fact be seen as systems which, when used together, can expand the effectiveness of human exploration. Humans and robots together can explore more effectively and investigate a wider range of environments than either robots or humans alone. With the use of telerobotics and virtual reality, everyone on the Earth can be an explorer.

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