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# INCREASED COST EFFECTIVENESS OF MARS EXPLORATION USING HUMAN-ROBOTIC SYNERGY*

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## ABSTRACT

Mars exploration presents problems not present in the exploration of the moon. The great distance causes prolonged latency as well as reduction of signal strength and bandwidth. The slowed communication limits the speed of movement and rate of data transfer from Earth controlled Mars probes. The area of Mars that can be explored by these probes and the percentage of time their instruments are actually doing science are small. By reducing latency, Mars based human controllers could increase the science performed by robotic probes by several orders of magnitude. An exploration team at one location on Mars could contribute to the exploration of the entire surface of Mars. A low risk, high reward mission would be added to the manned exploration of Mars.
Modifications in the Mars exploration plan necessary to institute this model are discussed. These include development of standard control systems for use by the Mars team, software overseeing division of control of instruments between Earth and Mars based operators, artificial intelligence to facilitate noninterference of the two team's instruction sets, development of minimal and ideal communication satellite systems, and improvements in durability of probes to allow maximal number of probes to be available. Options for training requirements for astronauts, as well as for the scientific team are presented including communication models to limit friction between Earth and Mars based teams.

## INTRODUCTION

**Subject**: Exploration of Mars using an interactive combination of robotic probes and human controllers both on Earth and Mars

**Overview**: In the exploration of Mars, robots and humans each have established advantages.

Robotic missions are relatively inexpensive, and their failure costs substantial loss of time, money, and potential science, but not human life.

Human exploration carries much higher potential costs, both in risk and money, but allows the use of an observer that in the foreseeable future is unmatched in its capacity and flexibility.

**Problem:** In the exploration of Mars or any other object more than a few light seconds from the Earth, on is faced with the problem of latency (among many others), that is the substantial delay in communication between the Earth and the other body. This latency increases the difficulty and reduces of effectiveness of exploration at a distance by robotic missions.

In addition, communication at a distance causes a loss of signal strength and subsequently a reduction of the effective bandwidth with a reduction in the rate of information transfer between the robotic mission and its controllers/scientists.

Both of these problems can be partially ameliorated. Increasing artificial intelligence in the distant robot may allow performance of complex tasks without the immediate intervention of the operator, narrower transmission beams of greater power, better multiplexing, more sensitive receivers etc, can assist in improving the rate of data transmission. Neither the problem of signal strength nor bandwidth can be truly eliminated. The problem of latency is unsolvable within the context of currently known physics.

**Concept:** If astronauts on Mars perform a portion of the control duties of robotic probes distant from their landing site, latency would be eliminated. Mobile robots could move much more rapidly. A much larger portion of the Martian surface could be accessible to more rapid and complete exploration, not only at the area about the landing site, but throughout the entire surface of the planet.

Higher bandwidth and signal strength would be easily achieved. Continuous high resolution visual valuation would be available, possibly in three dimensions, allowing a larger as well as more precise sample selection for scientific evaluation.

The efficiency of robotic and human exploration of Mars would be greatly extended even with this relatively simple contribution. If the astronauts could also perform some of the scientific evaluation under intermittent guidance from Earth, the amount of science performed per unit of time could be increased dramatically even further.

**REQUIREMENTS**

**I. Hardware**

A. The communication system would require at least one, and preferably several satellites capable of transmitting information between robots spread throughout the Martian surface and both the astronauts at the Martian base and to scientists on Earth. Such a communication satellite system is already in the planning, but would require modest modification to support the control and communication paths as outlined above.

B. Some degree of standardization in the control systems of the robots that are to be controlled by the astronauts would be useful. This is not absolutely necessary, but would reduce the risk of error in controlling a group of extremely valuable robots, and would minimize astronaut training time.

There is already precedent for this in aircraft design. Designers of both military and civilian aircraft often have similarities in cockpit design within an aircraft "family" to allow ease of acclimatizing to a new aircraft. This concept has been extended to the pattern of aircraft response to specific input. Airbus in particular has takes the lead in this concept. By using fly by wire techniques, one can have almost the same response to a given input, even in aircraft of dissimilar size and handling characteristics. The pilot's input is the same; the software in the particular aircraft determines the response required.

Many scientific spacecraft, however, are one or a few of a kind. This standardization of communication may be felt to be a severe limitation by the designers of the spacecraft.

This objection may be overcome in one of a number of ways.

1. One could have an astronaut-only instruction set that is standardized for astronaut functions, while leaving the designer of the actual robotic instrumentation to use any set of control instructions he wished. This would also allow for easy differentiation between Earth based and Mars based commands if this was deemed necessary to reduce the chance of error. This would allow the spacecraft designer to preclude the Mars based controllers from using any instructions that he wished to reserve for the Earth based group

2. One could have a common language or instruction set that is used in all astronaut-robot communications, but with different electronic interpretation in each robot. In aircraft, pushing the stick forward has the same meaning (in the general sense) in all aircraft, but each aircraft's fly by wire avionic set uses its own language to deliver the instruction to the control surfaces.

The operator need not know, and in reality doesn't care how the instruction is performed electronically. All he needs to know is that when he performs an operation, the appropriate response occurs. When he says, "Walk there", the robot walks there.

As long as the instruction sets are upwardly compatible (like the instruction sets of successive Intel chips) additional instructions could be added to the set as the technology matures.

C. Experiments whose lifetime could possibly overlap a human presence on Mars, particularly those that are mobile should be designed with astronaut compatible controls from the outset. The concept could also create a movement for more robust and longer lasting robots.

D. If the technology advances to the point where some of the data is evaluated on Mars before being sent to Earth, sensors and receivers of higher capacity may be utilized to take advantage to the increased bandwidth. The advantages of different forms of display and controls are beyond an article of this length.

**II. Human considerations**

A. Astronaut training would have to include, as a minimum, training in the use of the control systems and simulation of the control of robotic movement. Practice would have to continue during the trip to Mars.

Ideally it would also include involvement in the actual experiments when they could be facilitated by the presence of an onsite experimenter, such as a placement of a mechanical arm. If astronaut training were to allow it, or if one of the astronauts had training in one of the biological or physical sciences, it may extend to the choosing of samples for experimentation.

B. The training of the scientists remaining on Earth actually may be more difficult than that of the astronauts. Astronauts have, from the inception of the space program, performed experiments designed by others. Scientists performing robotic missions have had control of the robot and its instruments remain within the "team" There will be a natural resistance to allowing relatively unskilled (from the point of view of the builders of the scientific robots) astronauts to use their truly precious instruments, particularly if the robot was already in the midst of a slow moving but established program prior to the Mars astronauts' arrival.

C. In addition, to have this system function most effectively, there has to be a three way co-operative effort between the artificial intelligence of the robot, the local control of the astronaut, and the more distant, but more expert (from the point of view of the scientific objectives of each experiment and the characteristics of the instruments) scientist-engineer.

The most critical communication is between the scientist and the astronaut, particularly from scientist to astronaut. The scientist has lived with his robot and its instruments for years, and has internalized its abilities, and quirks. He probably has developed a jargon specific for the robot. It is important for him to realize that the recipient of his instructions has a different skill set and as such may need a precision of communication not necessary when speaking to another member of his robotic team
This is accentuated by the latency and attendant inability to have the usual back and forth discussion common in scientific or other teams.

There are excellent models of astronaut-instrumentation interactions either with or without the immediate supervision of the experimenter. That is what our previous and present astronauts do on a routine basis. They perform other people's scientific experiments and in general, do them very well.

Scientist-instrument interactions are also very common even with latency. Once again that is the current state of the art.

Control of a robot with immediate response is also routine, even when the robot is far from the controller.

There are relatively few models of human interactions with latency. Family and business models are too imprecise to be compared with the models at hand.

Three examples come to mind:

1. The current astronauts, particularly those who had been on the Mir. American astronauts are for the most part in relatively unbroken contact with their Earth side counterparts. Mir, however,

was usually out of contact with Russia. Their experiments had to be performed with only intermittent instruction from Earth based resources. The duration of their communication gap was frequently several hours. Their experience is valuable, but not completely parallel

2. The military model comes closer the current concept. Individuals of limited experience have to perform critical tasks created by others with what is often limited ability to contact the creators of the task during its performance. Military training is precise and intense, and obtains a good result.

3. The medical model comes closest to the situation we have here. Often an attending physician must communicate in critical situations with a substantial latency between giving and instruction and obtaining a result. He must relate to individuals with different training (nurses), similar training but less experience (interns /residents) and those with equivalent training and experience but with different skill sets (ER MD talking to surgeon or medical specialist). Once again, medical training is both precise and intense and in general gives a good result.

From both training and personal experience, I have learned that giving instructions in such an environment is neither simple nor obvious. One must be able to give instructions that are both precise and flexible. One must understand that it is the responsibility of the EXPERT to make himself comprehensible, not visa versa. One must be careful to use only terms that have common usage between the two discussants (ex: although Brits an Americans are both nominally English speakers to knock someone has substantially different meanings in the two dialects)

Great scientists are not necessarily great communicators. As with most abilities, some individuals are better at this than others. Some are truly gifted communicators; many are not. The member(s) of the team who are chosen to communicate with the astronaut team should be the most clear, not necessarily the most senior.

Like many skills, training and experience can improve the ability to communicate. The specific training should reflect the experience of the latter two models, with input from other sources that may be relevant (Mir for example) followed by appropriate development via simulation.

**POTENTIAL PROBLEMS**

Some of the potential difficulties in initiating this concept have already been covered. The greatest potential problem in getting this concept off the ground may be that it is an orphan. The human and robotic programs at NASA are in separate subgroups with nominally separate budgets. There is a degree of competition between the two for money and resources. Although the concept could benefit the productivity of both areas of space research, its first effect would to take money and time from what each considers its primary goal, the advancing of either manned or unmanned spacecraft. Unless and until the benefits of combined control are shown in an unequivocal and easily understandable way, it may be difficult to interest NASA in bridging this cultural gap.

**POTENTIAL BENEFITS**

The primary benefit of this concept has already been outlined. The exploration of Mars by mobile robots would be faster probably by several factors of ten if local human control without latency could be instituted. Even robots with mechanical arms or other tools requiring exact placement would have improved productivity using local control of the device.

Two other benefits would also ensue. The early Mars missions must be by their nature conservative in the risks they take. Despite the most careful and complete testing on Earth, no one can be sure of the ability of the suits, rovers, airlocks etc to survive in the Martian environment. This concept would allow a Mars mission to continue to produce meaningful data unobtainable without human presence even if eva was limited or eliminated as an option for the astronauts. In addition, the broadening both the type of human-human interaction, as well as the type of tasks that need be performed, would increase the richness of the social environment of these most isolated of human beings.

**CONCLUSONS**

Using a combination of local (Mars based) and distant (Earth based) human control of robots placed at various locations on distant from the Martian landing site has the ability to substantially increase the amount of scientific information obtained by humans landing on Mars.