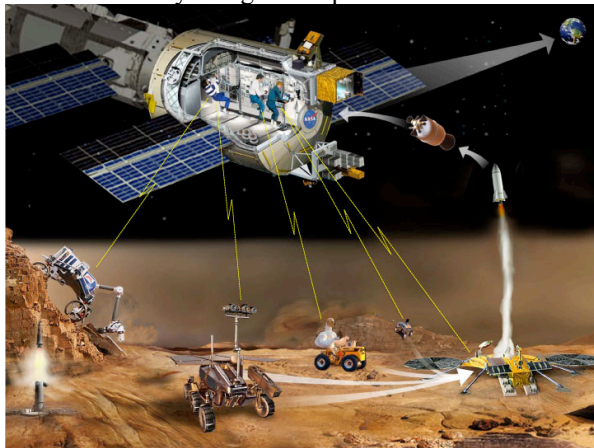## LOW-LATENCY TELEROBOTICS FROM MARS ORBIT: THE CASE FOR SYNERGY BETWEEN SCIENCE AND HUMAN EXPLORATION

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Introduction: Initial, science-directed human exploration of Mars will benefit from capabilities in which human explorers remain in orbit to control telerobotic systems on the surface (Figure 1). Low-latency, high-bandwidth telerobotics (LLT) from Mars orbit offers opportunities for what the terrestrial robotics community considers to be high-quality telepresence. Such telepresence would provide high quality sensory perception and situation awareness, and even capabilities for dexterous manipulation as required for adaptive, informed selection of scientific samples [1]. Astronauts on orbit in close communication proximity to a surface exploration site (in order to minimize communication latency) represent a capability that would extend human cognition to Mars (and potentially for other bodies such as asteroids, Venus, the Moon, etc.) without the challenges, expense, and risk of putting those humans on hazardous surfaces or within deep gravity wells. Such a strategy may be consistent with goals for a human space flight program that are currently being developed within NASA.

Figure 1*: Artist's conception of a low-latency telerobotics exploration approach at Mars emphasizing selection, acquisition, and transfer to orbit of critical surface samples for analysis and return to Earth [1] by humans orbiting the Red Planet.*

Although landing humans on the Martian surface may remain our ultimate goal [2], extending human cognition/dexterity to local surface sites with high science potential in this way can be achieved on a shorter timescale and at a far more modest cost, and may ultimately serve the needs for humans on these surfaces

[2] [3] [4]. Moreover, with sufficiently low latency – *round-trip light-travel time between operator and robot* – astronauts in a suitable Mars orbit can have the full experience of exploration in dangerous or challenging environments at little risk to themselves. These types of capabilities are being developed and refined on Earth in deep-sea exploration and development, tele-surgery, and remote mining operations, as well as for military drone aircrafts.

Scientific Exploration of Mars via Low-Latency Telepresence (LLT): Scientific exploration via this revolutionary approach is not only limited to field geological exploration of the Martian surface (e.g. biogeochemical sampling, deep drilling, etc.) via low-latency tele-opereated robots, but also includes critical aspects of on-orbit sample recovery and return to the crewed orbiting facility for immediate scientific analysis by resident astronauts. This possibility, for example, would enable rapid analysis of volatile-bearing samples without requiring long-term cryogenic storage.

Discussions at the First Exploration Telerobotics Symposium held recently at NASA Goddard Space Flight Center (http://telerobotics.gsfc.nasa.gov) around current state-of-the art capabilities for terrestrial telerobotics exploration suggest that many existing capabilities can directly apply to telerobotics in Mars orbit. Additionally, lessons from the Mars Exploration Rovers (MER) and Mars Science Lander (MSL) experiences can be incorporated to provide field-validated tactics for enhanced telepresence strategies associated with field scientific activities. Current capabilities, as will soon be demonstrated via MSL's surface exploration of Mars, are semi-autonomous and involve what is called high-latency telerobotics (HLT). Further, MSL's field operations will be inherently bandwidth-limited, preventing what field scientists here on Earth describe as "flexicution" as they adapt quickly to changing hypotheses and circumstances *(observation by Prof. Kip Hodges, ASU)*.

One possible scenario for surface exploration of Mars via LLT could be the deployment of twin telerobotic rovers on the surface with high-definition visual tools to allow low-latency communication and rapidly adaptable operation from an on-orbit crew for field astrobiology. Such "tele-rovers" could be equipped with instruments for detailed *in situ* reconnaissance and capabilities for recovering and sending selected samples to the human-tended on-orbit spacecraft
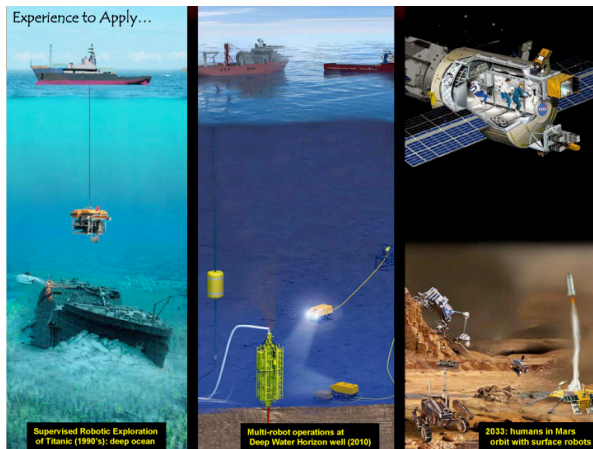
Figure 2: *Terrestrial telerobotics examples and their application in Mars orbit (rightmost panel).*

for preliminary screening by means of lab analysis by resident astronauts. In the case of samples of biological significance, very rapid encapsulation and recovery of the sample materials at the spacecraft in orbit are required and this is enabled by this approach. Most of the required technology already exists for terrestrial telerobotics exploration of Earth, although the TRL would have to be advanced and validated for operations on Mars.

It is entirely feasible that surface exploration of so-called *Special Regions* (on Mars) will require higher fidelity and more adaptable science activities that all but precludes human access at any time, and hence low-latency telerobotics may be a formal requirement to achieve science goals in such important locales. At such sites, LLT methods could include human orbiting or human operators on the surface at a safe standoff distance to allow appropriately prepared telerobots for access and exploration.

Enabling Features of Proximity Telerobotics: Proximity telerobotics operations have numerous advantages. These include: lower communication latency, high communication bandwidth (i.e. allowing larger collection of data), better communication quality of service (e.g. less jitter, more link availability, less loss of signal), and allowing larger mass and volume of samples for Earth return. In addition, proximity operations allow flexible execution or "flexicution" which includes real time "data collection" decision-making, and continuous and flexible operations which enables the potential for more serendipitous discoveries.

Current Work: Although many related terrestrial systems exist, no crew-controlled surface telerobotics system has yet been tested in a fully operational manner, in a high-fidelity space environment, and characterized using detailed performance metrics. Thus, both NASA and ESA are planning to conduct tests in 2013 with astronauts on the International Space Station re-

motely operating planetary rovers on Earth [5]. Astronauts will use the robots to perform surface work including site survey, instrument deployment, and servicing. The primary objectives of these tests are to: collect data from system operation under a variety of test conditions; validate key functional issues; and develop requirements for future mission systems.

Next Steps: As a consequence of two days of discussions with a broad range of planetary science, robotics, and human spaceflight experts at the GSFC Exploration Telerobotics Symposium, some specific near-term activities to advance development of Mars-relevant capabilities were suggested: 1) In order to synergize science and human exploration, it is essential to engage the scientific community in topical workshops to develop specific scenarios for scientific exploration of Mars using low-latency telepresence and tied to the NRC Decadal Survey goals; 2) A number of state-of-the-art capabilities based on current terrestrial telerobotics exploration activities (deep-sea operations and mining, tele-surgery, etc.) are already within reach. Operations feasibility assessment at analog field sites should be conducted with telerobotic systems similar to those that could be developed for use at Mars; 3) Investments in key robotics technologies such as sensing and perception, mobility, manipulation, human-systems integration and autonomy are needed; 4) A mission of the caliber described, synergizing science and human exploration, requires public/private as well as international collaboration and these partnerships must be fostered as soon as possible. The strong work throughout the international community on space telerobotic technologies bears on these efforts, and provides a clear path to fruitful partnership.

We believe that using telerobotics to extend human cognition can be highly advantageous in achieving Mars science priorities. This kind of human-robot partnership additionally offers opportunities for many future space destinations. The public appeal of such a mission scenario (humans to Mars orbit tele-operating robots on the Martian surface) will inspire the next generation of American scientists and engineers.

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