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Technology Development for the Canadian Mars Exploration Program

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Abstract

Canada is in the process of negotiating contributions to international Mars exploration missions. The most important mission opportunities are NASA Mars Science Laboratory mission planned for 2009 and the NASA Scout mission planned for 2007. Advanced technology development is performed to position Canada for these and future opportunities.

Examples of such technology development include subsurface sampling systems, robot manipulators, a sample processing station, lidar sensors and autonomous robotics algorithms.

1 Introduction

With the delivery of the Space Station Remote Manipulator System (SSRMS) and its mobile base to the International Space Station (ISS), and the near-completion of the Special Purpose Dextrous Manipulator (SPDM), the Canadian Space Program must start to consider its next major space endeavour. The Space Exploration component of the Canadian Space Program will enable Canada to participate in, and contribute to, the international effort aimed at understanding our solar system in relation to the origin of life and evolution of our environment. [7]

Mars, our closest planetary neighbour, is considered to hold the answers to our many unanswered questions. Indeed, the international space community has recognised Mars as a research target of the highest scientific value. Mars is a planet very similar to Earth. It has undergone changes that may help us understand the evolution of our own home planet. Mars may have supported life in the past, and may indeed still support life in simple forms. Answering the fundamental question of whether life exists or has existed elsewhere than on Earth is of the high interest to society. Mars can also provide clues about the formation of the Solar System and about geological and atmospheric phenomena that also occur here on Earth.

The opportunities currently being pursued by the Canadian Mars exploration program are driven by the need to satisfy the interests of the Canadian planetary science community. During the recently held fourth Canadian Space Exploration Workshop [7], the Canadian science community has re-iterated its interest to study the Martian environment with a particular emphasis on the shallow subsurface. This is particularly relevant in light of the recent discovery by the Odyssey spacecraft of traces of hydrogen in the top meter of Martian regolith leading to belief that ice may be present in the Martian regolith at depths easily accessible from the surface. [3]

In addition to meeting science requirements, Canadian contributions to the international Mars exploration program are shaped capitalize on recognised industrial strengths in Canada. An example of such capabilities is space robotics, in which Canada has invested over $1.2 billion through the development of the Shuttle Remote Manipulators and the Mobile Servicing System (MSS) for the International Space Station. Other examples are mining automation, lidar sensors and Synthetic Aperture Radar imaging: three areas for which Canada is a recognised world leader.

The most significant mission opportunity in the near future is NASA's Mars Science Laboratory (MSL) planned for launch in 2009. This landed mission will conduct geology and astrobiology experiments and will have a strong component of science studying the suitability of the Martian environment to support the existence of past or present life. Potential Canadian contributions to this mission include a system to acquire process and distribute rock and regolith samples, a lidar sensor for entry, descent and landing as well as science instruments.

Other mission opportunities in the near future include participation to NASA's Mars Scout program planned to launch in 2007. Canadian teams are part of two out of four mission concepts that have been selected for feasibility study: One of the contenders is the Mars Volcanic Emission and Life (MARVEL) mission for which Canada could contribute a multi-channel imager and star trackers. The other Scout opportunity is the Phoenix mission to which Canada could contribute an atmospheric lidar.

In preparation for participation in such opportunities and future ones, technology development projects are ongoing to address issues specific to Mars exploration.

2 Canadian Mars Technology Development Projects

In the recent past, technology development has been performed under CSA funding to develop technologies that would enable Canada to capture a meaningful role in international Mars missions. Development work included the design and prototyping of a 10-meter class drill for subsurface sampling, a manipulator for sample handling and instrument deployment and a lidar sensor for planetary landing. Currently, mission-specific technology development is being performed to address the needs of the MSL mission and to prepare Canada to capture longer-term opportunities. The MSL-specific technology development is focussed on sample acquisition, preparation and distribution, and on lidar sensor development.

2.1 Subsurface Sampling

In answer to the needs of a broad portion of the planetary science community, a prototype was developed by the Northern Centre for Advanced Technologies (NORCAT) and MD Robotics for a robotic drill with a capability to sample the Martian subsurface to a depth of 10 meters [2]. The drill prototype is based on hard-rock mining technologies and uses diamond impregnated drill bits to extract core samples. Several modifications were made to the basic drilling technologies to make them usable in a Martian environment. Terrestrial units are typically hydraulic-powered, use thousands of Watts of power, have a mass of several thousands of kilograms and can rely on vertical thrust forces on the order of 30-40 kN.

The prototype unit developed uses only electrical power. It is driven by two DC motors with power comparable to what could be expected in a typical Martian mission. Two important modifications were made to the drilling process to reflect usage from a Mars exploration platform: the drilling process uses low thrust on the drill bit and does not use any fluids to lubricate/cool the rock-bit interface or to carry cuttings back to the surface. Instead, a special design using auger flights is used to carry the drill cuttings away from the bit-rock interface. The most important impact of dry-drilling on the process is the fact that the process must be slowed down considerably to avoid over-heating the core sample and the drill bit. Fortunately, this is consistent with the level of power available to drive the drill. Another important consideration of dry drilling has to do with the transport of drill cuttings away from the rock face. Some types of rock, such as limestone, have a tendency to remain at the rock-bit interface, thus clogging the cutting edge of the bit.

From a scientific perspective, the selected technologies have several advantages. First, the usage of core drilling has the advantage of preserving the stratigraphy of the terrain for later analysis by scientific instruments. It is possible to know with great accuracy the exact depth at which each sample was acquired. In addition, by preserving all samples brought back to the surface, it is possible to preserve a complete, indexed set of every drill hole.

Core drilling is a very energy-efficient method of penetrating rock since it grinds away only the outer edge of the core. This results in less waste rock and in less energy being injected in the system in order to reach a given depth. It also has the advantage of being able to penetrate diverse lithologies: it can deal equally well with unconsolidated material, such as sand or dust, with soft sedimentary rock, or with hard rock such as is expected on the surface of Mars.

Another important advantage is that diamond core drilling provides samples in two forms: solid cores and finely ground material, which is the product of the drilling process happening around the periphery of the core. Unlike the solid core, the exact provenance of the fine cuttings is known with less precision and is more prone to contamination. However, it offers the advantage that the material needs no further processing to be fed to most scientific instruments.

The solution selected for bringing cores and fine cuttings back to the surface has the advantage of minimizing cross-contamination between the samples extracted at different depths. This is specially important for the Martian subsurface, which is expected to be highly oxidized down to an unknown depth. Proper prevention of cross-contamination would help scientists partially characterize the oxidation process on Mars.

The prototype unit was tested and demonstrated to meet a Technology Readiness Level (TRL) of 4 as per NASA/JPL's definition [1]. Testing of the unit involved drilling down to a depth of 2.1 meters in unconsolidated and consolidated material under laboratory conditions. A representative set of rock and regolith types was selected for the test soil sample. The top layer consisted of 10cm of a mixture of dust and sand. This was followed by a layer of 30cm of dried clay and then 60 cm of sand. Below this were a layer of 10cm of limestone, 80cm of sand, another 10cm of limestone and finally 10cm of basalt. The drill successfully penetrated through all layers at penetration rates on the order of 2.5mm/min in basalt (the hardest rock in the test box) and 10-15mm/min in sand and dust. Fig. 1 shows a close-up view of the bit tip with a captive rock core brought back to the surface. Fig. 2 shows the set of cores and fines cuttings that were retrieved during the testing cycle. Over the entire test campaign, the drill successfully penetrated through more than 78 meters of rock and regolith. Despite this, the drill bit showed virtually no sign of wear and could have endured at least an order of magnitude more use in terms of drill depth.

Fig. 1 - Drill bit with captive rock core brought back to the surface

Fig. 2 - Set of cores and fine cuttings recuperated throughout the test

To complement the 10-meter class drill, a 1 to 2-meter class drill is currently being prototyped by NORCAT. Such a unit could be used for rover-based subsurface sampling such as might be expected on the Mars Science Laboratory (MSL) mission.

2.2 Sample Manipulator

Prior to the development of the subsurface sample acquisition, processing and handling system, a technology development program had funded the development of a family of small manipulators for operations in the Martian environment [10]. These manipulators are designed to perform a wide variety of tasks such as acquiring surface samples, handling a variety of payloads, including instruments and tools or conduct contingency operations.

The activities undertaken under this project include the development of and end-to-end system design. Sub-systems that were considered high risk were prototyped. Specific components developed under this program include robotic joints, avionics, flight software, ground control software, the cable harness and a lightweight end-effector. The robot joints were prototyped with motors, gearboxes and joint position sensors that have an upgrade path to space qualified equivalents. Similarly, all electronics was designed to be used directly in space. Lower grade electronic components were substituted in certain cases for the ground-based prototype unit.

The point design solution that was designed was selected for its fit with the original MSR 2003 mission requirements. It has a reach of 2.8 meters and a payload capability of 5 kg (at a 2 m reach). The prototype is functionally equivalent to a Mars solution but has an upgraded shoulder and elbow to operate in Earth's gravity. It has a mass of 10 kg and its power consumption is on the order of 35W continuous, 50W peak.

Many lessons that have been learned from the design of the manipulator are directly applicable to the design of a subsurface sampling and sample processing system. For example, the actuators, gearboxes and sensors used in the joints are directly usable for the drill deployment mechanism and the sample handling system. They are also applicable to the drill itself and the sample processing station. The avionics and elements of the flight software designed for the manipulator are applicable to any Martian electromechanical system. Similarly, the mission planning, rehearsal, execution and analysis tools developed for the ground station are also portable.

2.3 Sample Processing

To complement the subsurface sampling equipment prototyping, a sample processing station is currently in its early concept development phase. This sample processing station is designed to meet the requirement of the MSL mission. The basic functionalities being investigated are cutting of rock core, grinding and crushing. The particle size at the output of the sample processing station is driven by the requirements of the scientific payloads expected on the science laboratory of MSL. At the moment, the minimum particle size is assumed to be on the order of 1mm.

The sample processing station is capable of handling samples coming from every expected sampling mechanism: loose regolith from a scoop, solid rock cores from a mini-corer and regolith/rock core from a drill. It allows analysis of the sample at various stages throughout the processing. Such analysis could serve as a primary set of measurements on the sample or as a triage station to determine whether further processing or analysis would be worthwhile pursuing. Fig. 3 shows the conceptual design of the sample processing station.

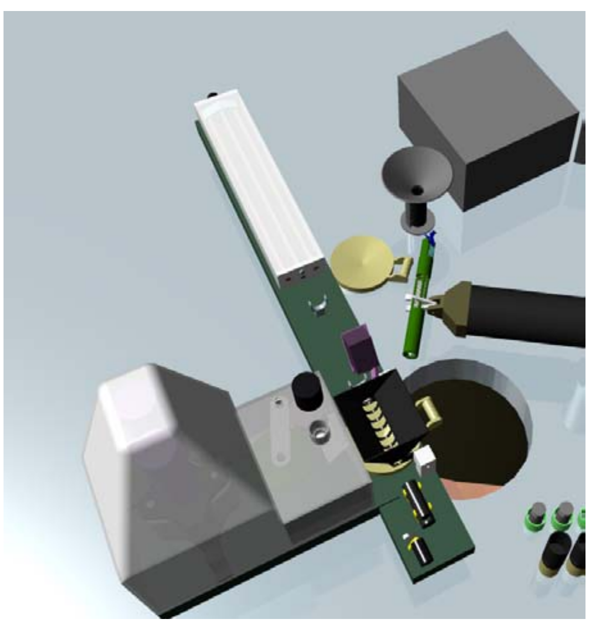

Fig. 3 - Conceptual Design of Sample processing Station

2.4 Lidar-based Planetary Landing System

A lidar-based Planetary Landing System (LAPS) was developed to provide an obstacle detection capability during the terminal phase of Entry, Descent and Landing for Mars missions. This capability enables landed missions to access rougher, more geologically interesting terrain than the more conservative approaches relying on the limitation of landing sites to areas where the landing error ellipse is contained in safe, flat terrain.

To develop LAPS, Optech upgraded one of their commercial scanning lidar units by using space-qualifiable components. By retrofitting the unit with new scanning optics, a new laser source and space-qualified electronics, a technology readiness level beyond TRL-4 [8] has been achieved.

The LAPS lidar offers the potential to dramatically change the terminal phase of EDL scenarios since it can generate three-dimensional terrain measurements with range accuracy better than centimetre starting at an altitude of over 2 kilometres. Its accuracy in azimuth and elevation is on the order of 250 micro-radians. It has a 20 degrees by 20 degrees field-of-view and a scan rate between 10 kHz and 20 kHz. Using different scan patterns, it can then map out areas around the landing site to a varying resolution.

The team led by Optech is also developing guidance and navigation software to gain a complete understanding of the planetary landing problem from a systems perspective. [4]

2.5 Mobile Robotics and Autonomy

In preparation for capturing longer-term opportunities, the Canadian Space Agency is also performing R&D in autonomy and mobile robotics. Although missions such as Pathfinder used very little autonomy, it is widely recognised that missions in the coming years will require more autonomy to maximize the number of operations that can be conducted per sol and thus the science return on investment. Missions beyond the horizon of the current planning process may require autonomous navigation over large distances with relatively little operator interaction or may involve fleets of robots performing operations in a cooperative manner.

To this end, the ROSA[6] ground control architecture developed by the CSA and MD Robotics was adapted to conduct autonomous operations scenarios using mobile robots in uncertain environments. A first implementation demonstrated autonomous navigation in a known but uncertain terrain. The capabilities that were implemented included the ability for a mobile robot to localize itself, to plan a path to a final destination, to detect obstacles and react to anomalies in the environment. Upcoming developments include the incorporation of much more capable environment sensors (such as a lidar) and the capability for multiple robots to coordinate their actions in order to conduct a complex task.

3 Conclusion

Canada is in the process of negotiating contributions to international Mars exploration missions. The most important mission opportunities are NASA Mars Science Laboratory mission planned for 2009 and the NASA Scout mission planned for 2007. The potential Canadian contributions to the MSL mission are the sample acquisition, preparation and handling and potentially a lidar for hazard avoidance during terminal descent. Advanced technology development is performed to position Canada for these and future opportunities.

Examples of such technology development include the design and prototyping of a 10-meter class diamond-bit coring drill that proven to have reached a Technology Readiness Level of TRL-4 as per NASA and JPL's definition. Another example is the design of a family of manipulators for performing a broad variety of tasks on the Martian surface. A prototype of such a manipulator was built and is operational in Earth gravity. It has undergone functional testing in laboratory conditions. Most of the lessons learned through the development of this manipulator are directly relevant to the development of the sample acquisition, preparation and handling for the MSL mission.

Similarly, the technology investments in lidar sensor development have matured the space qualifiability of such sensors for future missions such as the MSL and potentially a NASA Scout.

Finally, some efforts are geared towards developing technologies for longer term applications, that are currently beyond the planning horizon of the Mars mission queue. These technologies include the development of autonomous operations algorithms for planetary exploration robots.

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