MARS EXPLORATION ROBOTICS

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ABSTRACT

Through the development of the Shuttle Remote Manipulators and the Mobile Servicing System (MSS) for the International Space Station, Canada will have invested over $1.2 billion dollars in space robotics. Now that many elements of the MSS have been delivered to orbit, one of the next logical steps for Canada to apply its space robotics expertise is planetary exploration. One of the identified planetary exploration needs is to robotically sample the surface and subsurface of Mars. Canada is in the process of negotiating contributions to international Mars exploration missions and is uniquely positioned to address this opportunity due to its world leadership position in mining automation and in space robotics.

Advanced technology development was performed to position Canada for such opportunities. A 10-meter class diamond-bit coring drill was developed, prototyped and proven to have reached a Technology Readiness Level of TRL-4 as per NASA and JPL’s definition. In addition, a family of manipulators for performing a broad variety of tasks on the Martian surface have been designed. A prototype of such a manipulator was built. It is operational in Earth gravity and 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.

INTRODUCTION

Through the development of the Shuttle Remote Manipulators and the Mobile Servicing System (MSS) for the International Space Station, Canada will have invested over $1.2 billion dollars in space robotics. Now that many elements of the MSS have been delivered to orbit, one of the next logical steps for Canada to apply its space robotics expertise is planetary exploration. One of the identified planetary exploration needs is to robotically sample the surface and subsurface of Mars. Canada is uniquely positioned to address this opportunity due to its world leadership position in mining automation and in space robotics.

Opportunities in the near future for these technologies include NASA’s Scout program that is planning to launch a mission to Mars in 2007, the Mars Science Laboratory (MSL) mission planned for 2009 and ESA’s Exo-Mars mission under the Aurora program. The exact nature of a potential contribution to NASA’s Scout mission is not yet determined since NASA has not yet announced the winners of the Phase A study. However, Canadian researchers and industry are members of several proposals to NASA. For the MSL mission, NASA and the Canadian Space Agency are in the process of finalizing a letter of agreement detailing the nature of Canada’s contributions to the mission. These potential contributions include a subsurface sample acquisition, preparation and distribution system as well as LIDAR sensors for Entry-Descent and Landing, rover navigation, Mars orbit rendezvous and for atmospheric science.

In preparation for participation in such opportunities, technology development projects have been ongoing to address issues specific to Mars exploration. This paper will describe the Canadian activities regarding elements of potential Mars missions that are relevant to space robotics, concentrating on subsurface sample acquisition, preparation and handling.
SUBSURFACE SAMPLING

A prototype was developed for a robotic drill with a capability to sample the Martian subsurface to a depth of 10 meters [1]. The drill prototype is based on hard-rock mining technologies and uses diamond impregnated drill bits to extract core samples. Fig. 1 shows the bit of the prototype drill that was developed and tested. 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.

Fig. 1 - Bit of the 10-m class Martian Drill Prototype

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 characterise 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 [2]. 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 10 cm of limestone, 80 cm of sand, another 10 cm of limestone and finally 10 cm of basalt. The drill successfully penetrated through all layers at penetration rates on the order of 2.5 mm/min in basalt (the hardest rock in the test box) and 10-15 mm/min in sand and dust. Fig. 2 shows a close-up view of the bit tip with a captive rock core brought back to the surface. Fig. 3 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. 2 - Drill bit with captive rock core brought back to the surface](image)

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![Fig. 3 - Set of cores and fine cuttings recuperated throughout the test](image)

Fig. 3 - 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.

**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 1 mm.

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. 4 shows the conceptual design of the sample processing station.
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 [3]. 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.

CONCLUSION

Canada is in the process of negotiating contributions to international Mars exploration missions. Key targets are the subsurface sample acquisition, preparation and handling on NASA’s Mars Science Laboratory mission. Advanced technology development was performed to position Canada for such opportunities. A 10-meter class diamond-bit coring drill was developed, prototyped and proven to have reached a Technology Readiness Level of TRL-4 as per NASA and JPL’s definition. In addition, a family of manipulators for performing a broad variety of tasks on the Martian surface have been designed. A prototype of such a manipulator was built. It is operational in Earth gravity and has undergone
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REFERENCES:

