**Lidar and mSM as scientific tools for the geological mapping of planetary surfaces.** G. R. Osinski[1], T. Barfoot[2], N. Ghafoor[3], J. Tripp[4], R. Richards[4], P. Jasiobedzki[3], T. Haltigin[5], N. Banerjee[1], M. R. M. Izawa[1], P. Furgale[2], [1]Depts. of Earth Sciences/Physics and Astronomy, University of Western Ontario, London, ON, N6A 5B7 (gosinski@uwo.ca), [2]University of Toronto Institute for Aerospace Studies (UTIAS), Toronto, ON, M3H 5T6, [3]MDA Space Missions, 9445 Airport Road, Brampton, ON, L6S 4J3, [4]Optech Incorporated, 300 Interchange Way, Vaughan, ON, L4K 5Z8, [5]Dept. of Geography, McGill University, Montreal, QC

**INTRODUCTION**: Several technologies are currently being developed for long-range rover navigation. Among them, LiDAR and Mobile Scene Modeling (mSM) have received considerable attention [1]. LiDAR technology uses time-of-flight principles to measure ranges to objects within its field of view, which allows 3D information about a spacecraft or rover's environment to be measured in detail. LiDAR is specifically suited for long-range (>1 km) and is less susceptible to ambient lighting variations than stereo cameras. As such, LiDAR provides the capability to operate at night and within permanently shadowed zones of planetary surfaces [2]. A complementary vision system is mSM developed by MDA, based on a stereo camera system. This technology autonomously generates rapid 3D models from sequences of stereo images obtained from a mobile stereo camera pair [3]. The cameras may be mounted on various platforms (e.g., rover, lander robotic arm, astronaut glove/helmet). This is possible as mSM recovers the camera ego-motion (6 degrees of freedom) and integrates the 3D data using only the images without the need for any positional (e.g., GPS) tracking. The system creates calibrated 3D models in situ and automatically within minutes, producing a photo-realistic 3D surface with mapped colour texture.

The use of LiDAR and mSM as vision systems for planetary exploration is, therefore, becoming well established, but are there also scientific applications for these technologies? Space-based LiDAR has many terrestrial applications, including mapping of geological structures, forest canopies, and various geomorphological landforms, such as landslides and gullies (e.g., [4, 5]). In terms of rover- and lander-based surface operations, ground-based LiDAR has been used extensively for atmospheric studies on Earth [6] and, recently, with the Phoenix mission, for Mars [7]. But can LiDAR and mSM be used as a scientific tools for the rover-based geological exploration of planetary surfaces? Very few studies have addressed this question [8], despite the likely potential use of these technologies for rover navigation.

**ANALOGUE FIELD TESTS:** We conducted a series of field tests at the Haughton impact structure (Devon Island, Canadian High Arctic) in July 2008. Haughton is a well-preserved, well-exposed 23 km diameter, 39 Myr old meteorite impact structure [9] and it represents an ideal terrestrial analogue [10]. Several sites of geological interest within the Haughton impact structure were imaged: (1) impact melt breccia hills near the centre of the structure; (2) a site of impact-associated hydrothermal mineralization (Fig. 1); (3) polygonal terrain (Fig. 2); (4) gullies and channels developed on impact regolith (impact melt breccias); (5) a slump/collapse feature developed within impact regolith.

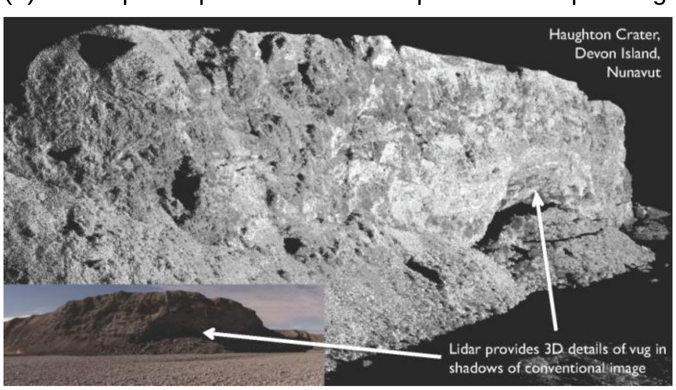


**Figure 1.** LiDAR scan and panoramic image (inset) of an impact-hydrothermal site. It is notable that the LiDAR scan can provide valuable information about a hydrothermal vug in the shadowed region.

For the tests, we used an ILRIS3$_6$D-ER (Intelligent Laser Ranging and Imaging System on pan-tilt unit) LiDAR developed by Optech Inc. [11] with a range of up to 1 km. It is field portable and is capable of running from a portable battery pack. Software enables the user to pan, zoom, and tilt the images, and to view from multiple angles. Two stereo camera systems were used – one in a rover-mounted configuration, another simulating astronaut handheld or robotic arm deployment. Both were the Bumblebee XB3, manufactured by Canadian company Point Grey Research (PGR). This is an integrated fixed-baseline stereo camera with a motorized base to allow for panning and tilting. The handheld mSM system was also configured with a ruggedized embedded portable computer.

**RESULTS AND DISCUSSION:** One of the fundamental techniques in field geology is the ability to capture a visual record of the terrain, from the regional (km) to outcrop (m to cm) scale, and of sites visited. For centuries, the field geologist has used sketches in a field notebook for this purpose later augmented by slide and film photography and, more recently, digital photography. However, major drawbacks of these techniques are that they do not capture 3D relief and they are often difficult to reference and correlate, which results in difficulties if a geologist wishes to recreate the situational awareness that existed in the field. This is important on Earth – where much of the interpretation can occur subsequent to the field season – and will be critical for lunar and Martian exploration, where scientists may be operating from a habitat, a rover or back on Earth. Thus, a key strength of LiDAR and mSM is in the 3D record of a site(s), providing the ability for a geologist to virtually revisit sites, perform measurements, and view from multiple directions and angles; the latter is something that is not always possible in the field. The 3D models may furthermore be augmented with geo-tagged multi-media data such as geologists' annotations in the field, high resolution close-up images, measurements from additional detectors and results of laboratory analysis of samples.

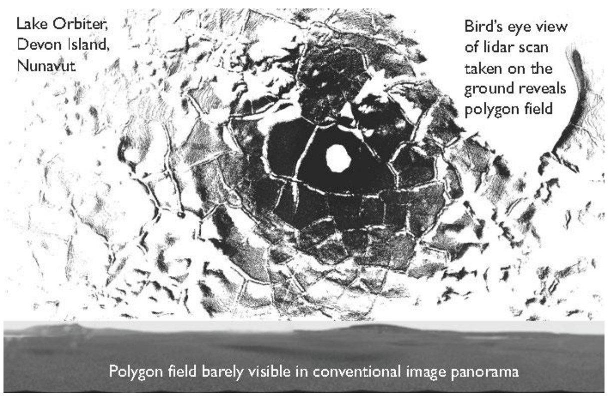


**Figure 2.** LiDAR scan and panoramic image (bottom) of polygons. The LiDAR scan often showed polygons and other low-relief topography that is difficult to discern with the naked eye or in photographs.

A particular strength of LiDAR is the independence from ambient lighting conditions. Many of the outcrops surveyed during the field tests had shadowed zones; with conventional camera systems little or no useful data could be obtained without supplementary active illumination, which was not the case with the LiDAR, and implicitly active system. This is particularly relevant for the Moon because many high-priority scientific targets lie within the permanently shadowed zones of lunar impact craters [12]. Thus, LiDAR is not just useful for rover navigation in such zones [2], but it may be the only method to obtain a visual record of outcrops in such zones.

The use of Differential Global Positioning System (DGPS) technologies is becoming widespread among field geologists to capture detailed physical and topographic information about areas of interest. However, this involves time-consuming traversing and point measurements and a substantial amount of data is required to generate accurate 3D maps; GPS is also unlikely in the near future for planetary missions. With one LiDAR scan, a geologist can obtain millions of point measurements and without the need for substantial post-processing and merging of data. This task is probably particularly suited for robotic scout and astronaut assistant platforms. The addition of mSM for rapid capture of close-up 3D imagery in a portable and low power system represents a powerful combination.

**FUTURE WORK:** In summary, these preliminary field tests suggest that LiDAR and mSM can have many scientific uses, in addition to pure exploration applications such as rover navigation and vision. Future work will address the specific scientific information that can be gleaned by LiDAR and mSM in a variety of lunar and Martian analogue environments.

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