2015 CANMARS MSR ANALOGUE MISSION: THE KEY ROLE OF LIDAR IN ROVER NAVIGATION AND POTENTIAL FOR FUTURE MISSIONS. W. Zylberman[1,2], D. Hickson[4], T. Haid[3] and G. R. Osinski[2,3], [1]CEREGE, Aix-Marseille Université, Aix-en-Provence, 13090, France (zylberman@cerege.fr), [2]Centre for Planetary Science and Exploration / Dept. Earth Sciences, University of Western Ontario, London, ON, N6A 5B7, Canada (haid@uwo.ca), [3]Dept. Physics and Astronomy, University of Western Ontario, London, ON, N6A 5B7, Canada (gosinski@uwo.ca), [4]Centre for Research in Earth and Space Science, York University, Toronto, ON, M3J 1P3, Canada (hicksodc@yorku.ca).

Introduction: Rover navigation on planetary surfaces can be extremely hazardous, which is why high resolution topographic data is required to ensure rover safety and mission success. For this reason, and to test its potential as an onboard rover instrument, LiDAR was a key component to the 2015 CanMars MSR Analogue Mission [1]. This was a Mars Sample Return Analogue Mission carried out in partnership between the Canadian Space Agency, MacDonald, Dettwiler and Associates Ltd., and the Centre for Planetary Science and Exploration (CPSX) at the University of Western Ontario, as part of the NSERC CREATE project “Technologies and Techniques for Earth and Space Exploration” (create.uwo.ca). The Mars Exploration Science Rover (MESR) is equipped with a LiDAR instrument from SICK AG mounted to its Pan-Tilt Unit (PTU). It can provide 360^{o} scanning of the rover surroundings and has an effective maximum range of 25 m.

Identified by the CSA and NASA as a key-technology for space exploration, LiDAR is a distance ranging instrument especially used for safe landing and rover displacement. LiDAR uses the time-of-flight principle and angle of emission to measure ranges (via laser pulses in the near-infrared between 500 nm and 1550 nm) to objects with extremely high accuracy (within centimeters). The receiver can collect thousands of points per second, with each point containing specific x, y, and z coordinates that can be attributed to a precise point on the object or surface that is being scanned [2,3].

LiDAR has been utilized in many fields as a remote sensing and surface classification tool, including forestry [4], archaeology [5], glaciology [6,7], volcanology [8], and hydrology [9]. LiDAR has also been utilized off Earth, both as a docking aid on the International Space Station [10], and for atmospheric measurements on the Phoenix rover on Mars [11]. More recently, an advanced LiDAR system (OLA) will be incorporated as one of the science instruments on OSIRIS-REx, which is set to launch in September 2016 [12]. The uses of LiDAR for future space and planetary exploration are vast [13, 14], and the benefits of incorporating LiDAR onto a future Mars rover for precise navigation and simultaneous surface mapping are investigated here.

Distance estimates: The scans allowed detection of topographic features such as boulders (Figs.1 and 2), outcrops (Fig. 3) or even short vegetation on the ground. However, the principal use of the LiDAR was for MESR safe navigation (i.e., displacement on flat ground), calculation of distances to potential targets for contact science, or estimation of distances to targets for remote science (7 m maximum range). The point cloud raw data is visualized with the freeware program FugroViewer (©Fugro Geospatial). This software allows 2D and 3D visualizations of the point cloud, as well as close-up profile views in which height of objects can be displayed. Distances between two points can be estimated through a “ruler” tool (yellow lines on Fig.1) in the 2D view. This information, although simple, was vital for deciding between targets during the science team discussions.

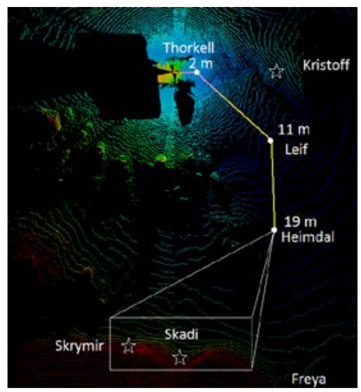

Fig. 1. 2D-visualization of LiDAR scan acquired on Sol6 annotated with a 19 m navigation pathway planned for Sol7 and targets of interest.

Figure 1 is a typical example of navigation plan where MESR had to avoid obstacles (here boulders) in order to reach targets for remote science. This pathway comprises three steps: (1) MESR should move 2 m forward in order to reach the location named Thorkell and be able to perform remote science operations (i.e., XRF, RAMAN) on the target Kristoff, (2) change direction and move 9 m to reach the Leif location, and (3) change direction and reach Heimdal after an additional 8 m displacement. Once at Heimdal, MESR acquired a panorama on the Skadi and Skrymir outcrops (white rectangle on Fig.1). This plan was successfully realized during the Sol7 operations.

3D-visualization of the point cloud allowed observation of details in features of interest (FOI) such as rocks and outcrops. In Figure 2, MESR is facing a 1.2

m high boulder during Sol4. This LiDAR scan was necessary for instrument placement during contact science operations. TEMMI (yellow cube on Fig. 2), solar panels and wheels of MESR can also be detected on the scans.

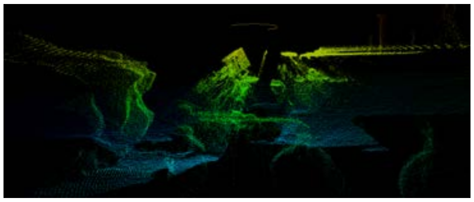

Fig. 2. An example of 3D visualization of LiDAR point cloud acquired during Sol4 contact science operations.

Slope estimations: Another fundamental use of LiDAR is providing accurate estimates of topographic slope. High slope areas cannot be safely traversed by MESR and can limit contact science objectives such as acquiring TEMMI scans and core sample drilling. This information is used in planning the navigation of MESR on a daily basis as well as constraining what kind of science can be achieved at particular locations. As one of the mission priorities was sampling sedimentary material there was a particular focus on sampling outcropping sedimentary structures in which slope information was crucial. A program was written in MATLAB that allowed 3D surface modelling of the LiDAR point cloud data as well as calculating the gradient in elevation values for each x-y coordinate (Fig.3a).

Figure 3b shows a 2D elevation contour map of the outcrop highlighted in Fig.3a with arrows indicating the magnitude (length of arrow) and direction of the gradient from a particular x-y coordinate. This information provided a coarse estimation of high/low slope areas for further analysis. Slope calculations were realized in FugroViewer by analyzing designated profiles within the LiDAR scans. Simply measuring the horizontal and vertical distances associated with a rise in the topographic profile provided slope measurements (Fig 4).

Conclusion: Our work shows that LiDAR has a key-role in rover navigation: additionally to be easy-to-use and therefore adapted to fast-making decisions during mission control operations, the data allows cm-precise estimations of distances, heights and slopes, which are critical for safe rover displacement as well as remote and contact science operations. It also allows extremely detailed surface mapping of objects and therefore has implications for our knowledge of planetary surfaces.

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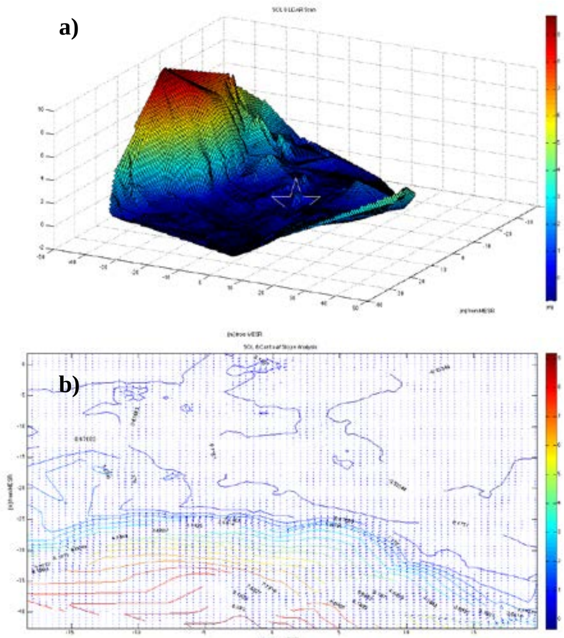

Fig. 3. a) MATLAB rendering of 3D surface of Sol6 LiDAR point cloud data. The star indicates the MESR location. b) Elevation contours and gradient visualization of the 3D surface.

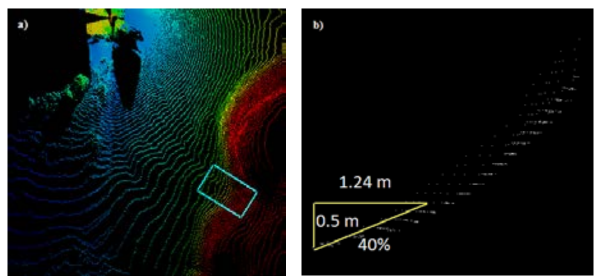

Fig. 4. Left: Sol7 LiDAR point cloud 2D visualization with FugroViewer and location of the topographic profile (blue rectangle). Right: Topographic profile with slope estimation (%).

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Acknowledgments: This work was funded by the Natural Sciences and Engineering Research Council of Canada's CREATE program and the Canadian Space Agency.