Field Testing of a Mission Concept to Sample Ground Ice in Martian Polygonal Terrain.

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INTRODUCTION: During the summer of 2008, we investigated a novel mission concept to sample ground ice in polygonal terrain. We found that a lander-mounted lidar and a rover-borne stereo camera / ground-penetrating radar (GPR) suite (see Figure 1) are two important scientific tools that may be used to help pin-point ground ice in polygon troughs. We field tested this mission concept on a previously-unstudied polygon site on Devon Island in the Canadian High Arctic and showed its viability. This unique collaboration between the technological and scientific communities has led to a deeper understanding of how such a science-driven mission could actually be implemented robotically.

SCIENCE OBJECTIVE: Polygonal terrain (a network of interconnected trough-like depressions in the ground) is a landform commonly found throughout the polar regions of both Earth (Lachenbruch, 1962) and Mars (Kuzmin and Zabalueva, 2003). In terrestrial environments, these features are formed by the response of an ice-bonded substrate to thermal forcing mechanisms induced by winter freezing and subsequent spring/summer warming, and are often indicative of subsurface ice bodies termed ice wedges. On Mars, the recent Phoenix mission appears to have confirmed the presence of an ice-bonded substrate, but evidence of massive ice wedges has not yet been identified; that Phoenix's digging arm is incapable of delving more than a few centimeters into the Martian permafrost has precluded the possibility of such a discovery. However, previous studies of Mars polygonal terrain have suggested that such ice bodies may indeed exist beneath the Martian surface (e.g. Mangold et al. (2004)). We propose a followon mission concept to pinpoint and sample ground ice found in Martian polygonal terrain using a suite of robotic tools.

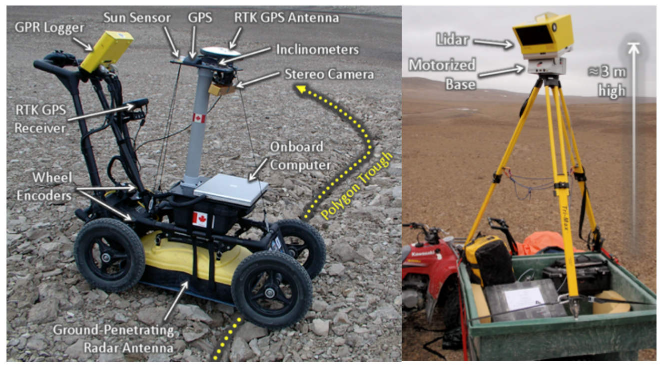

Figure 1: (left) Rover mockup with stereo camera and GPR; (right) lander mockup with lidar.

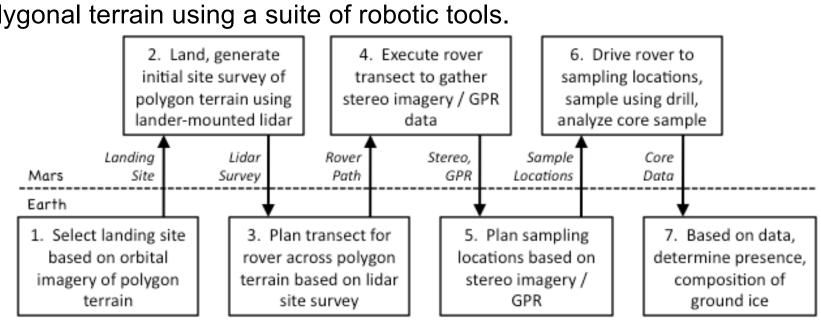

Figure 2: Operational steps of mission concept.

MISSION CONCEPT: Figure 2 depicts the main steps in our concept. We select a landing site based on orbital imagery (which can reveal the presence of polygonal terrain). We land and build a large-scale 3D model of the surrounding terrain using a lidar on the lander (the lidar could also be on the rover). We use this lidar scan to (i) select candidate polygon troughs for closer examination using stereo cameras and GPR and (ii) plan a rover path to deliver these instruments to these troughs. The rover drives this planned path and (using a forward-looking stereo camera and GPR) builds a coupled surface/subsurface model (Furgale et al., 2008). This is enabled by a robotics technique called 'visual odometry'. At select trough crossings, a second stereo camera is used to build a 360-degree local 3D photorealistic model, exploiting the flexibility of a mast- or robotic-arm-mounted stereo camera. The surface/subsurface model, as well as the 360-degree local 3D models at each trough, are used by the science team to select troughs for subsurface sampling. The rover returns to these sites, samples ground ice, analyzes the samples' composition, and returns the data to Earth.

FIELD TEST: The experiments described in this paper were conducted on a previously-unstudied region of polygonal terrain on Devon Island in the Canadian High Arctic, as part of the CSA's Canadian Arctic Research Network (CARN). See Figure 1 for photographs of the apparatus. The rover was simulated using a pushcart equipped with a stereo camera (Point Gray Research Bumblebee XB3), a ground-penetrating radar, an on-board computer, and a Real-Time Kinematic GPS unit used for ground-truth positioning. The GPR (and cart) was a Sensors&Software Noggin 250 MHz system. The stereo camera used to generate 360-degree local 3D models was an MDA mSM handheld system (not shown). The lidar was an Optech ILRIS3D-ER with an integrated pan-tilt unit, mounted on a 3-m-high tripod.

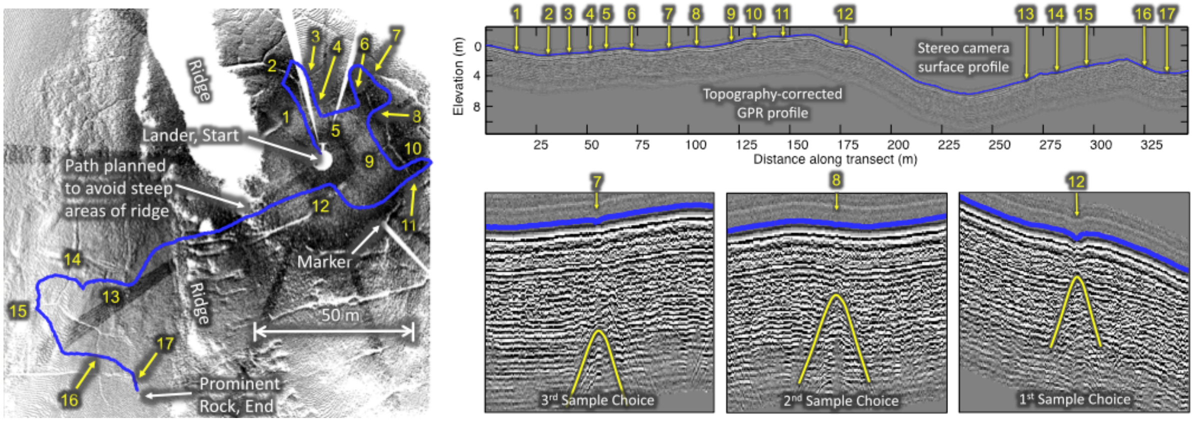

Figure 3: (left) Lidar scan with rover path planned to cross 17 polygon troughs; (right) coupled surface/subsurface model with science team's top three ice-wedge candidates shown (troughs 12, 8, 7).

We implemented key aspects of our mission concept at this site, being careful to only allow the science team access to the data products that would be available on Earth during a real mission (i.e., they were not allowed to view the test site in person). Figure 3 (left) shows the initial lidar scan conducted at the 'landing site'. Both primary and secondary polygon troughs are easily detected out to a range of over 100 m. This fine level of detail was not available in the 60 cm/pixel orbital photograph used to select the landing site. The science team planned a 350 m path to cross 17 troughs and the 'rover' was pushed along this path to gather the datasets described above. Figure 3 (right) shows an example of one type of model built from the stereo/GPR data. Based on all the gathered datasets, three troughs were selected for subsurface sampling by the science team, however, at the time of selection, the team indicated there was a chance that none of the 17 troughs actually contained ice. Ultimately, these troughs were cored manually with an auger and did not reveal ice down to a depth of 1.2 m; there could have been ice at greater depths, but this was the limit of the manual auger. These findings do not invalidate the mission concept, but rather emphasize the need for such a methodical approach to pinpointing ice deposits prior to drilling.

CONCLUSION AND FUTURE WORK: We have proposed a mission concept driven by the top-level scientific objective of pinpointing and sampling ground ice in Martian polygonal terrain. This led to the initial operational concept discussed above. We have shown that our concept is viable on real polygonal terrain at a Martian analog site. From a technological point of view, we have shown that (i) existing lidar technology can easily map out polygon troughs to 100 m from a lander, and (ii) a subsurface model based on GPR data (as well as a coupled surface model based on stereo vision) can be automatically created from a rover platform. Outstanding technical challenges include: GPR/rover integration, automatically driving the rover along the planned path, automatically returning the rover to the subsurface sampling sites, and automatically extracting and analyzing the subsurface samples.

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