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Issues of geologically-focused situational awareness in robotic planetary missions: Lessons from an analogue mission at Mistastin Lake impact structure, Labrador, Canada

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Abstract

Remote robotic data provides different information than that obtained from immersion in the field. This significantly affects the geological situational awareness experienced by members of a mission control science team. In order to optimize science return from planetary robotic missions, these limitations must be understood and their effects mitigated to fully leverage the field experience of scientists at mission control.

Results from a 13-day analogue deployment at the Mistastin Lake impact structure in Labrador, Canada suggest that scale, relief, geological detail, and time are intertwined issues that impact the mission control science team's effectiveness in interpreting the geology of an area. These issues are evaluated and several mitigation options are suggested. Scale was found to be difficult to interpret without the reference of known objects, even when numerical scale data were available. For this reason, embedding intuitive scale-indicating features into image data is recommended. Since relief is not conveyed in 2D images, both 3D data and observations from multiple angles are required. Furthermore, the 3D data must be observed in animation or as anaglyphs, since without such assistance much of the relief information in 3D data is not communicated. Geological detail may also be missed due to the time required to collect, analyze, and request data.

We also suggest that these issues can be addressed, in part, by an improved understanding of the operational time costs and benefits of scientific data collection. Robotic activities operate on inherently slow time-scales. This fact needs to be embraced and accommodated. Instead of focusing too quickly on the details of a target of interest, thereby potentially minimizing science return, time should be allocated at first to more broad data collection at that target, including preliminary surveys, multiple observations from various vantage points, and progressively smaller scale of focus. This operational model more closely follows techniques employed by field geologists and is fundamental to the geologic interpretation of an area. Even so, an operational time cost/benefit analyses should be carefully considered in each situation, to determine when such comprehensive data collection would maximize the science return.

Finally, it should be recognized that analogue deployments cannot faithfully model the time scales of robotic planetary missions. Analogue missions are limited by the difficulty and expense of fieldwork. Thus, analogue deployments should focus on smaller aspects of robotic missions and test components in a modular way (e.g., dropping communications constraints, limiting mission scope, focusing on a specific problem, spreading the mission over several field seasons, etc.).

Keywords: Analogue mission; Science operations; Situational awareness; Geology; Robotic data

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1. Introduction

Historically, robotic missions have been the main method of exploring planetary surfaces – the Apollo program being the one exception – and this trend is expected to continue for the foreseeable future. There are ongoing discussions about the benefits and drawbacks to human exploration (e.g., Glass et al., 2003, and the references therein); however, it is clear that remote data relayed via a robot provides different information than the immersion that field geologists experience on site. As a result, personnel at mission control in a robotic mission have a significantly reduced level of situational awareness than what geologists in the field experience. This includes a limited understanding of their surroundings, distance to objects, lighting conditions, and so on. This prevents mission control scientists from employing their full range of experience and training and has been shown to affect mission control's ability to conduct comprehensive geological studies (e.g., Yingst et al., 2009, 2011a,b). It is, therefore, important to understand the differences and limitations of robot-collected data and to explore ways to mitigate, or compensate for, their adverse effects.

We observed geologically-focused issues of reduced situational awareness in an analogue robotic rover mission conducted in the summer of 2010. This mission was funded by the Canadian Space Agency and deployed at the Mistastin (Kamestastin) Lake impact structure (Fig. 1) in Labrador, Canada (Osinski et al., 2010a). The Mistastin Lake structure represents an ideal scientific lunar analogue site, as it includes both an anorthositic target, similar in composition to the dominant rock type of the lunar highlands (Grieve, 1975; Marion and Sylvester, 2010; Osinski et al., 2010a) and preserved ejecta deposits (Mader et al., 2011). It is a ~28 km diameter, 36 Ma complex impact structure that possesses a large range of impact melt rocks and breccias, which are predominantly generated from the anorthositic target rocks (Marion and Sylvester, 2010).

2. Methodology

The purpose of the deployment (the first of 3 conducted by this team), was to simulate a robotic precursor mission in advance of a 7-day human sortie mission conducted in the summer of 2011 (Osinski et al., 2010a). As such, the main goal of this first deployment was to provide reconnaissance of the area and to identify sampling target sites for the human follow-on mission. The intent was to develop a geological understanding of the study area at a variety of scales, including regional, outcrop, and hand sample scales. This understanding needed to be detailed enough to provide context for future sample collection and inform the selection of potential sampling sites.

Three main regions (Fig. 2) were selected as target areas during a 2-day site selection workshop (Shankar et al., 2011), where satellite data (8–200 m/pix resolution) and a geologic map (Currie, 1971) were used to represent the kind of data generally available for planetary missions. Suggested traverses were also determined during the workshop, however the resolution of available data was too low for detailed traverse planning to be robust at this stage.

For the deployment, the three target regions were visited over the course of 13 operational days, spanning a 3-week period, with 3–5 days spent on analogue activities at each of the indicated regions. During operations, a field team of 4 geologists simulated the robotic rover at Mistastin Lake. They conducted traverses and collected data, all under the direction of a remote mission control team. Instruments on the simulated rover included a GigaPan robotic camera mount and tripod, a digital SLR camera, a mobile Scene Modeler (mSM) stereo camera (Jasiobedzki et al., 2009; Osinski et al., 2010b), an Optech lidar instrument (approx. range of 1 km), a Bruker X-ray Fluorescence (XRF) instrument (Tracer IV-GEO), and a Noggin-plus ground penetrating radar (GPR) unit (Beauchamp et al., 2011). The field team, acting as robot components, would carry the required instruments to a target and collect any requested data. Typical robot constraints, such as limitations in mobility, reach heights, range of motion, etc. were significantly relaxed for the duration of this deployment, in order to focus on science operations. As a result, the field team flight rules allowed for travelling through dense vegetation, climbing on outcrops, and crossing water. GigaPan, camera, mSM and lidar measurements were acquired at a height of approximately 150 cm, with the instruments either mounted on a tripod or hand-held.

Communications between mission control and the field were limited to twice daily, in order to simulate a mission to the South-Pole Aitken basin on the far side of the Moon (with communications supported by a relay satellite in a polar lunar orbit). Instructions to the field team were uploaded prior to the start of each operational day and collected data was downloaded to mission control at the end of each operational day. Data download volume was limited to ~100 Mb per day, which although small by terrestrial standards, is a factor of 2–5 better than that achieved by the Mars Exploration Rovers (MER) (e.g., Mishkin et al., 2006) and comparable to or greater than the Phoenix Mars Scout mission (e.g., Bass and Talley, 2008).

Operations at mission control were conducted by a team of 10 trained geologists. At the start of the science operational shift, data was downloaded, processed, and analyzed by mission control members working in small teams. Each team selected potential targets (Shankar et al., 2011) for the field team's next steps, based on pre-determined objectives. These potential targets were then assessed and prioritized by the entire mission control team, and the final targets selected. The final task of the science operational shift was to provide the next day's operational instructions for the field team. The science operational process, from data download to instruction hand off occurred within a ~4–5 hour time frame. This is comparable to recent planetary missions (e.g., MER, Phoenix), where the time from data