SCIENTIFIC INSTRUMENTATION FOR A LUNAR SAMPLE RETURN ANALOGUE MISSION.

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Introduction: Four deployments of a lunar sample return analogue mission campaign were conducted at three sites during 2010-2011. The scenarios were: 1) a purely robotic mission; 2a) a robotic precursor mission; 2b) a human follow-on mission to 2a; and 3) a purely human mission [1]. Over the four deployments a suite of exploration tools were used by individuals simulating "astronauts" and/or by the rover, to gather data for Mission Control (MC) based at the University of Western Ontario, London, Ontario, Canada. In each case MC was made up of scientists who had not visited the field site and only had precursor and remote sensing data of the area. This simulated the lack of first hand information which accompanies a planetary mission. We outline here the instruments used, and their strengths and weaknesses from a field perspective. A MC perspective of vision systems is presented in [2].

2-D Visual Imagery: *Gigapan*: The Gigapan instrument is comprised of the Gigapan camera mount and a Canon Eos Rebel T3i digital SLR camera. It was attached to the rover or the lander (scenario dependent) and provided high-resolution panoramic images. Once the initial parameters (camera resolution, angular extent of view, etc.) are set, the instrument automatically captures the requested images leaving the field team free to accomplish other tasks. The instrument is light but bulky, requiring the use of a tripod, and the resolution and extent of images had to be carefully monitored to avoid exceeding the daily data budget. In the field it was found that the data quality could be maximized by: a) not using the instrument while the rover generator is running (causes vibrations); b) having the image resolution clearly specified by MC (close-up images at highest resolution, lower for wide angle panoramic images); and c) having a quantitative method for measuring horizontal orientation (this was visually estimated by the person setting up the scan).

Digital cameras: In scenarios involving astronauts, each astronaut carried a Ricoh 500SE ruggedized digital camera for obtaining visual 2-D images at their discretion. The highest resolution available on these is 8 MP, which in general provided enough resolution for MC to discern geological details; however, in the final deployment one astronaut also carried a higher resolution (15 MP) Canon Power Shot G10 digital camera for imaging significant areas of interest that required higher resolution. The combination of the two cameras proved successful as it allowed astronauts to balance data quality with quantity, respecting the data budget. Both camera models are also quite small, allowing for unencumbered use.

3-D Visual Imagery: A major drawback of 2-D images is that they do not convey 3-D relief [3]. We therefore included two instruments to fulfil this need.

C2SM: The Chemical, Biological, Radiological, and Nuclear Crime Scene Modeler (C2SM) is a rover-mounted instrument primarily used for taking a series of stereo image pairs which can be processed to create a 3-D model of an area. The system acquires images and data from interfaced cameras and sensors, and automatically registers it with the 3-D model. This enables intuitive and efficient access to data from this instrument [3, 4]. During the purely robotic missions the laser range finder on the C2SM was used for directing the placement of geochemical, mineralogical, and sampling instruments and measuring the distance to a given target. This was useful as it allowed MC to clearly specify a spot of interest for robotic operations. The large data products placed significant strain on the daily data budget. Recommendations include a) integrating the C2SM with lidar in a single user interface; b) expanding the articulation of the instrument to enable seeing the wheels and ground around the rover; and c) re-packaging the hardware to make it suitable (smaller/ lighter) for small rovers

mSM: The Mobile Scene Modeler (mSM) is a human (astronaut) carried instrument which can create local 3-D models by acquiring image sequences from a hand-held stereo camera, which are automatically augmented with higher resolution images [4]. While the instrument provides invaluable data the current model (which is already 5 years old) is quite bulky, making it cumbersome for the astronaut to carry any other tools and requiring the presence of two astronauts to efficiently set it up. A smaller, higher resolution model has been proposed for development.

Laser Surface Imager: Two different lidar (Light Detection And Ranging) units were used during operations to create 3-D point cloud images for use in determining scale of features, range to targets, and navigability of terrain.

Optech ILRIS-3-D lidar: Depending on the scenario the ILRIS (Intelligent Laser Ranging and Imaging System) was either mounted on the lander, providing only one 360° scan of the landing area, or on the rover, providing scans from various vantage points that were then stitched together into a semi-continuous mosaic. The lidar worked best when aboard the rover as it could take multiple scans of different areas, ultimately providing a 3-D map of the entire area of exploration [2]. The pan/tilt model of ILRIS is desirable as it saves time both in collecting and processing the scans.

Autonosys LVC-0702 video lidar: This unit was used mainly as an automated navigational sensor for the rover but could also be used by MC in a similar way to the ILRIS, although the range of view was more limited [2].

Subsurface Imagery: *Sensors and Software, 250 MHz Noggin GPR:* Rover-mounted ground penetrating radar (GPR) was useful for determining subsurface structures up to 5-10 m deep [5]. From a field perspective the instrument can be awkward to use over rugged terrain because it is bulky and needs to be dragged by a person. It has the benefit of low data consumption, as the files generated are quite small. Always including surface photos along the track greatly aids in data interpretation.

Geochemical and Mineralogical Analyzers: A *Bruker Tracer IV-GEO handheld X-ray Fluorescence spectrometer* (major and trace element geochemical analysis) and a portable *Delta Nu Rockhound Raman spectrometer* (mineralogical analysis) were included in all deployments. The instruments were either carried by an astronaut or operated as part of the rover depending on the scenario (see [6] for full details).

Sampling Devices: *Pomeroy EZ core drill:* The main sampling device on the rover was the Pomeroy EZ core water-cooled drill, which sampled specific spots in target rocks. Field difficulties arose from the requirement to carry water to the drill site. Regular drill maintenance was necessary to protect the drill bit. Cores would often become stuck in the holes, and it was, on occasion, time consuming to remove them. Data returned to mission control during operations was limited to two images to document and confirm that the core was successfully taken. The resultant drill cores and boreholes also provided scale and an excellent view several inches into the target, cutting through weathering and surface alteration.

Scoop: The rover and astronauts were equipped with a small trowel for sampling unconsolidated material. This proved extremely useful for collecting soils and loose gravel. Although not *in situ*, such samples did capture the diverse lithological materials within the area. The scoop was easy and quick to use and only required a single image to document the sample.

Digital Geological Mapping Tools: *Trimble Yuma and GeoXM PDAs:* Astronauts were equipped with ruggedized computers (Yumas) and personal digital assistants (Trimble GeoXM PDAs) for running ArcMap and ArcPad, respectively. As GPS was not being used, the astronauts used digital elevation models, visual satellite, and radar satellite data for localization and to relay coordinates back to MC [7]. Localization problems were exacerbated by poor resolution of raster data when exported to ArcPad and the simultaneous use of multiple data sets on the PDAs caused them to crash and resulted in lengthy delays while software was being reinitialized. Overall this localization method proved effective, but could definitely be improved by working out software bugs and increasing pre-deployment training.

Recommendations: No instrument should be allowed on deployment without both MC and the field team having been extensively trained on its use. Problems occurred when there was confusion about what the exact capabilities of each instrument were and how difficult/time consuming they were to use. This resulted in overly ambitious requests for data during early deployments and frequently not using the instruments to the best of their capabilities. Efficiency and scientific gain could be increased if all instruments were more integrated with each other and, in the case of rover-mounted instruments, with the rover itself. The requirement of running different programs off different computers resulted in increased bulk and weight for the astronauts on traverse, slowing traverse progress. Visual imagery proved useful in communicating between MC and astronauts [2]. Immediate information regarding geochemistry and mineralogy proved useful to informing the interpretations of astronauts while on traverse [6]. Down selecting samples was a necessary and educational step within the sample-return process, forcing MC and astronauts, when present, to decide which samples were most useful to fulfilling the overarching scientific goals of the mission. A full suite of scientific instruments increased scientific gain and aided decision making in the field and at MC.

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