FIELD TESTING ROBOTIC FOLLOW-UP FOR EXPLORATION FIELD WORK

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Overview: On July 16 2010 through August 5 2010, we conducted a field test and mission simulation of a *robotic follow-up* system with a robot at Haughton Crater, Nunavut, Canada, and a mission control cener at NASA Ames. During the test, K10 Black was used to conduct high priority field observations identified by human crews during simulated EVA's conducted at the same field site in 2009. The goal of the test was to improve our understanding of how robotic followup can help improve the overall productivity of human and robotic partnerships, and how robots might best be used to complement human crews.

Our test showed that robots can be useful by collecting lots of data that the human crew did not have time for, increasing the overall productivity and understanding of the human-robotic team.

In this abstract we summarize the objectives for the test, describe the test setup, and present results and some lessons learned.

Robotic Assitants for Human Exploration: In prior work[1–5] we identified significant differences between how robots have previously been used and what is needed for future human exploration. For example, past robot explorers (e.g., MER) were used as "primary science instruments", and not as tools to support human explorers.

If we wish to use robotic follow-up as part of a coordinated human-robot exploration campaign, we need to understand the benefits, requirements, limitations and risks associated. Key issues associated with robotic follow-up are: (1) robotic rover capabilities; (2) Earth-based ground control; and (3) coordination between humans and robots.

Concept of Operations: In our work, we assume that well in advance of a human mission, a science team will plan a traverse involving the use of a crew rover, such as the Lunar Electric Rover[10]. The science team will use any available a priori data of the traverse area, including orbital remote sensing. During the human mission, astronauts will execute the traverse. During and after the mission, crews, ground operators, and scientists will identify sites and tasks for robotic follow-up. After the human mission, the science team will use the mission data, the observations made, and the knowledge gained by the crew to develop a robotic mission. Finally, the robotic mission will be executed in order to perform the follow-up work. This overall flow is shown in Figure 1.

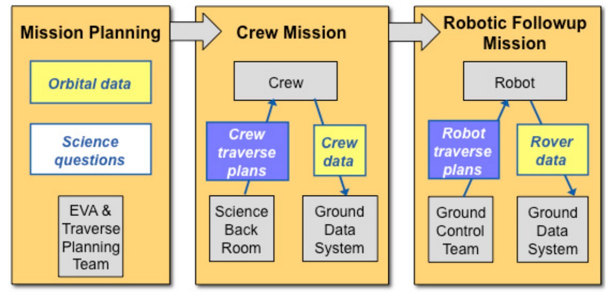

Figure 1. Crew mission results flow into robotic followup, allowing crew to identify high priority tasks.

Approach: The primary objectives of the test were to (1) evaluate the impact that robotic followup after crew EVA has on overall science productivity, and (2) test our ground control, rover systems, ops and assessment protocols.

To ground our research in appropriate scientific context, we have chosen to conduct field work at Haughton Crater, on Devon Island, Canada. This field work focuses on two themes: (1) geologic mapping of the major lithologic units; and (2) geophysical survey of the near-subsurface.

In July 2009, we conducted a simulated lunar crew mission. A geologist (M. Helper) and a geophysicist (E. Heggy) planned traverses using a HMMWV as a simulated pressurized crew rover. Each traverse was performed by a two-man crew and included short EVA's on foot with unpressurized concept space suits.

In 2010, K10 Black conducted robotic followup at the same field site, with the same geologists leading remote science operations at NASA Ames. K10 carried five instruments: a scanning 3D lidar, a color panoramic camera on a pan/tilt, a ground penetrating radar (GPR), an X-ray fluorescence spectrometer (XRF) and a high-resolution downward facing terrain imager.

The science team studied the results from the 2009 simulated mission and identified high priority science questions and specific targets for follow-up work. A ground control team remotely operated K10 to collect more detailed surface data. After robotic operations, the followup data was used to update the science team's knowledge and understanding of the two main science questions.

Figure 2 shows an example plan uplinked to the rover, and Figure 3 shows an example data product returned during execution.

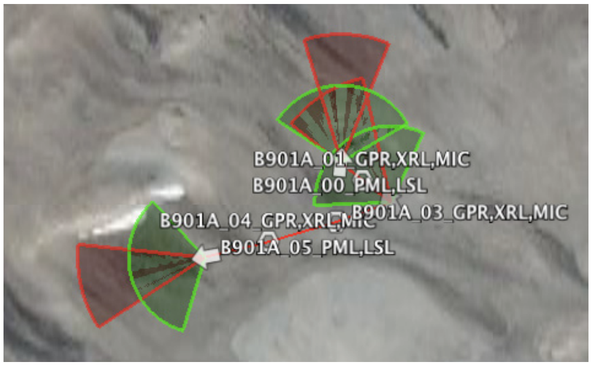

Fig 2. *Robotic followup traverse plan with commanded instrument FOV's.*

Fig 3. *Map of rover data products from plan in Fig 2.*

Ground Control: The ground control team (Figure 4) included a Flight Control Team (tactical operations), Science Team (strategic level planning and science data analysis), and Robot Team (diagnosis and repair). A Test Team was responsible for facilitating, and observing the mission simulation.

Results: Based on our field testing, we have confirmed several key differences between robotic exploration (e.g., as done by the Mars Exploration Rovers) and robotic follow-up. Most notably, whereas robot explorers serve as principal science tools, the primary function of robotic follow-up is to augment and complete human field work. This has significant implications for mission design and science operations.

From our 2010 robotic mission simulation, we learned that robotic follow-up can be useful for geological mapping. In particular, we found that K10 enabled us to further evaluate the structure of the inner wall of Haughton Crater, to map faults/fractures in rocks proximal to the crater rim, and to better understand the target sequence stratigraphy. For geophysical survey applications, we learned that robotic follow-up can provide precise metrics for quantifying the volumes, depths, concentration, and large-scale distributions of subsurface ice.

Figure 4. *K10 Science Operations at NASA Ames.*

Figure 5. *K10 Black at Haughton Crater.*

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