PRELIMINARY RESULTS OF HYDROGEN PROSPECTING WITH A PLANETARY ROVER.
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Introduction: High resolution hydrogen deposit mapping is central for a detailed understanding of lunar water ice deposits in permanently shadowed lunar craters. This becomes especially relevant in the context of potential in-situ resource utilization (ISRU). Although orbital remote sensing can provide much information, prospecting for subsurface resources can only be performed directly on the surface. The long acquisition time required as well as the extreme conditions within permanently shadowed craters require robotic execution of such a task.

The small HYDRA neutron spectrometer has been successfully integrated onto the K10 Black planetary rover operated by the IRG [1,2]. In September 2007, the system was used to assess hydrogen content in an initial set of field tests at NASA Ames (ARC). During these tests, we attempted to detect and map targets of various hydrogen contents and burial depths.

Test Objectives: The purpose of the rover test was to demonstrate the utility of HYDRA in a robotic prospecting task for near-surface hydrogenous deposits. Thus the objectives of the exercise were: (1) Acquire HYDRA data as the rover navigates a grid of GPS way-points chosen without prior knowledge of the target locations; (2) Detect and localize near-surface enhanced hydrogen deposits within the rover test area; (3) Validate the Haughton site-survey architecture and visualization tools in a small footprint sensor test with scientists in the loop.

Test Location and Setup: The K10/HYDRA rover tests were carried out at a relatively level, unvegetated pad of fill dirt, at ARC that served as a proxy for the lunar surface. The extent of the test area was approximately 50 meters in the north-south direction, and 20 meters in the east-west direction. Within this area holes were excavated. One set of targets consisted of 3x3 foot polyethylene slabs (each 0.5 in thick, stacked 8 deep for an overall thickness of ~10 cm), buried at depths of 0, 5, 15 and 30 cm. Another set of targets consisted of stacks of cut 0.5-inch thick drywall (gypsum, 21 wt% H_2O). Finally, some excavations were simply back-filled with the excavated material to act as decoys for the test. The locations of the targets were known only to three personnel involved in the exercise, in order to provide a single-blind test.

On the lunar surface, cosmic rays constantly impinge on the regolith, but for terrestrial testing, a Californium-252 neutron source (activity of ~2×10^6 neutrons/s) was used to interrogate the soil beneath the rover. The source was co-located with the HYDRA instrument, to provide a fixed geometry and to minimize the effects of variations in soil-to-source distance (approx. 15 cm). **Figure 1** shows HYDRA and the source mounted on the front of K10 Black. When the energetic neutrons from the source encounter hydrogenous materials, HYDRA measures an enhanced backscatter “albedo” flux of thermal and epithermal neutrons as the robot traverses the site.

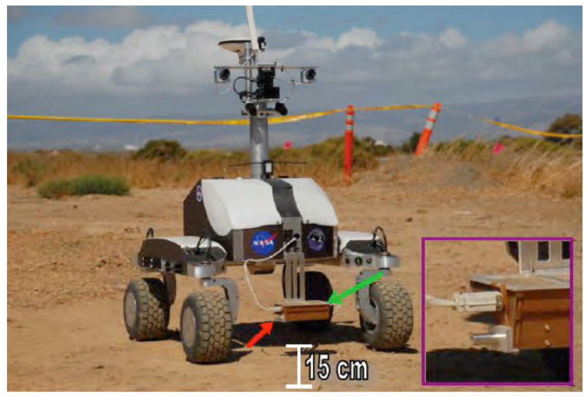

Fig. 1. Rover with HYDRA instrument. Green arrow points to the instrument, red arrow to the neutron source.

Test Execution:

(1) Phase 0, Calibration: K10/HYDRA was traversed across the known locations of three targets at different speeds. HYDRA data were reviewed to then establish the speeds for execution of the test phases.

(2) Phase I: K10/HYDRA was traversed across the test area by means of a series of predetermined GPS waypoints that were uploaded to the robot. This plan resulted in a series of parallel line transects, separated by approximately 1 m in the east-west direction, intended to provide coarse coverage of the test area.

(3) Phase II: Interesting features detected in the Phase I transect survey are revisited by K10, and a finer grid of spatial sampling is obtained by executing a series of square spirals from the center point.

Real Time Test Monitoring: Figure 2 shows a screenshot of the NASA Ames Viz 3D user interface, which allowed online-monitoring K10 test progress, and was used to identify targets of interest for Phase II testing. This view shows the results of a series of north-south transects carried out as part of Phase I.

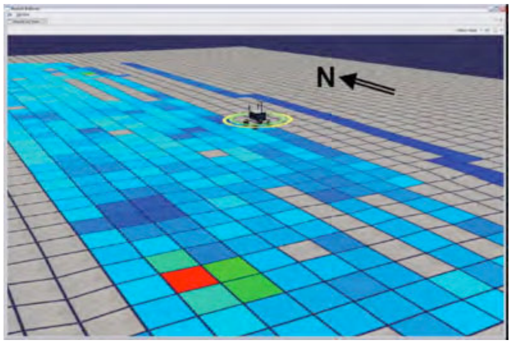

Fig. 2. Viz 3D rendering of K10/HYDRA transects, with count rates accumulated in 1x1 m bins. The red spot shows a high thermal neutron feature associated with "ice"-like polyethylene.

Viz monitors telemetry from the rover and generates data maps of the surveyed site in real time. The science data is displayed in the context of the robot's telemetry (pose estimates etc.) used e.g. to continually update a height field that represents the surface geometry. The rover's sensor data is binned to create 2D intensity maps that can be projected onto the terrain, as seen in **Figure 2**.

Test Results:

Phase 0 - Calibration: It was determined that the rover speed should be 10 cm/s for the Phase I transect survey. The 5 cm/s speed provided excellent resolution but required too much time to complete the survey; the 20 cm/s and 40 cm/s speeds did not satisfactorily resolve the extent of the smaller targets.

The calibration phase also revealed the surprisingly high hydrogen content (~10 wt% H_2O equivalent) of the supposedly dry soil of the test. This is roughly a factor of 100 higher than would be found in dry lunar regolith. The high soil hydrogen content masked the buried features beneath.

Phase I: A whole site survey was carried out by assembling a series of GPS waypoints that covered the test area with 1-meter separations between transects. The robot proceeded through the series of waypoints at 10 cm/s. Because of the way the rover executed turns and headed toward subsequent waypoints, the transect spacing was sometimes greater than 1 meter. The survey spanned more than 800m and took about 2.5 hours of continuous driving to execute.

Phase II: The last phase conducted a more detailed investigation of selected features identified in the transect survey. We chose to include the calibration features in this study as a way of testing K10's ability to perform high spatial resolution investigations of small features. Also included were some of the interesting features seen elsewhere in the test area. The rover was directed to move to the center of designated feature locations, and it then carried out a rectangular spiral search pattern around the target. In this way a higher sample density was obtained, permitting the delineation of the spatial extent of the feature. **Figure 3** shows the mapped results for all 3 phases.

Discussion: The test met all objectives, though the high hydrogen content of the soils made them a very poor analog for the Moon, but reasonable as an analog for some Martian materials containing phyllosilicates or evaporite sequences.

The Haughton Site-Survey architecture worked well for this sensor payload, especially the visualization tools that were used for Phase II planning. Nevertheless, the small sensor-footprint was a challenge for the rover's navigation system.

References: [1] Elphic R. C. et al. (2007) *LEAG Workshop on Enabling Exploration: The Lunar Outpost and Beyond,* abstract #3046. [2] Elphic R. C. et al. (2007) *Astrobiology, in press*.

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Fig. 3. Transect survey results displayed in Google Earth. The colored squares represent count rates detected by HYDRA's HeSn (thermal + epithermal) detector from low (dark blue) to high (red). The dark soil in the eastern (lower) part of the survey contains more iron, which is a thermal neutron absorber.