LOCATION IDENTIFICATION USING HORIZON MATCHING. E. E. Palmer[1*], R. W. Gaskell[1], L. D. Vance[2], M. V. Sykes[1], B. K. McComas[2], W. C. Jouse[2], [1]Planetary Science Institute (1700 E. Ft. Lowell, Suite 106, Tucson, AZ 28519, *epalmer@psi.edu), [2]Raytheon Missile Systems (1151 E. Herman's Rd. Tucson, AZ 85756).

Introduction: Navigation on Earth has become trivial with the advent of GPS. However, position identification and navigation remains difficult on other solar system objects, usually relying on time-intensive triangulation of control points [1,2] or using an Inertial Measurement Unit (IMU) and wheel odometry from a known location [3]. Occasionally, the location of rovers has been verified by spacecraft imagery [4].

We have begun work to determine the position of a rover using an automated horizon matching algorithm that can identify the location of a rover using a panoramic surface image and a digital elevation model (DEM) of the surrounding terrain similar to [2].

Method: To do horizon matching, two pieces are needed; the first piece is a series of images taken from a rover that can be mosaiced into a "ground truth" panorama. The second piece is a DEM that we use to generate "synthetic" panoramas for comparison.

For our initial tests, we simulated the "ground truth" rover data by using images derived from a DEM of Tsiolkovsky crater, Fig. 1. [4]. The DEM was generated using stereophotoclinometry [5]. The base map is 10 x 25 km with a resolution of 5 meters per pixel, and we expect to derive a resolution on the order of 1.5 meters per pixel with continued processing.

We selected 20 locations for the rover, using locations on hilltops, valleys, flat plains and craters, Fig. 1. Then, we generated 360-degree panoramic images with a resolution of 10 pixels per degree, Fig 2.

The second piece of the project was generating "synthetic" panoramic images that represents our virtual world. For the initial testing, we used the same DEM as the rover images, but we decreased the resolution to 10 meters per pixel. We used this down sampled map to generate the synthetic panoramas. We calculated the horizon line for each synthetic panorama, building a database of the horizon profiles for the entire region with a sampling of every 100 meters.

We calculated the horizon line for the simulated "ground truth" image (the rover's panoramic image) and ran a brute force test to determine the best fit by testing it against every synthetic panorama. For error measurement, we used the sum of the absolute values of the differences between a synthetic horizon profile and the simulated horizon profile from the rover. The results were scaled so that a perfect match would be 1.00 and a poor fit would be 0. A full test consisted of testing all 25,000 synthetic profiles.

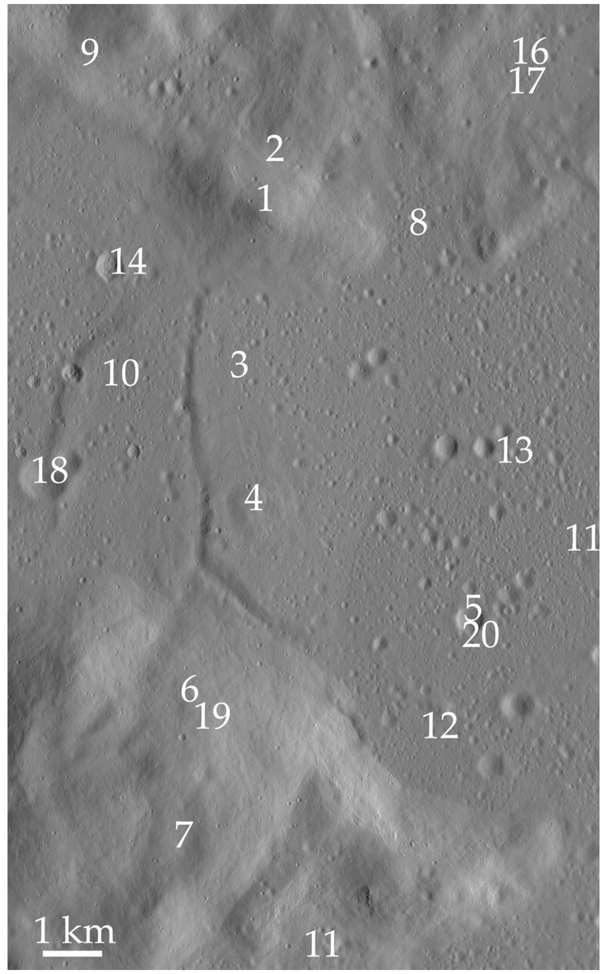

Figure 1. A shaded relief DEM of the testing region and the locations that were tested.

We added realism to the simulated rover images to more closely match actual mission data. We modeled a camera with a 1024x1024 CCD and a 100mm lens. Additionally, we introduced noise to the modeled images to include a point spread function, hot pixels, dark current and cosmic rays. We generated 24 images that is then combined in a panoramic mosaic, Fig 3.

We expect that there will be error between the real terrain and the DEM. In order to test how the algorithm would handle error, we used a down sampled DEM and selected rover locations that were between the synthetic terrain locations, causing an offset of 10s of meters. Work is ongoing to generate an updated DEM that has higher resolution (1.5 meters per pixel) and error will be added to it.

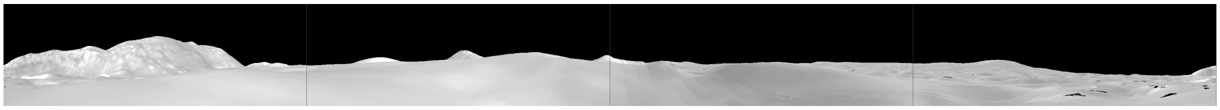

Figure 2. A 360 degree panoramic image calculated from the DEM. Each "ground truth" horizon profile was tested against each synthetic panorama evaluating for the smallest deviation between the two horizon profiles.

Results: We conducted evaluations for 20 sample locations. Initial results showed that the horizon matching program worked well. Two of the selected locations had horizon profiles that went above or below the field of view of the camera, and thus, were unusable, locations 6 and 7. All but two of the test cases resulted in the lowest error location matching the correct answer. The two failed cases were ones where the rover was within a crater, locations 5 and 20, and it is likely that with higher resolution DEM, it would be able to identify not only the crater it was in, but where it is within that crater. Figure 4 shows an example of the quality of match with the DEM test region.

Discussion: While the initial results are promising, additional work is needed, both to improve the resolution and the realism of the system.

During the testing, some problems were noted. One problem is that the camera tilt may need to be raised or lowered in order to keep the horizon line in the field of view. Another problem is that cosmic rays that strike the CCD almost vertically can trick our horizon tracing algorithm.

Due to the realistic artifacts that we added to our images, some data sets were no longer useable -- typically a broken horizon line. To account for this, we added a flag that would indicate that the dataset was of poor quality, and it would not generate a location on this bad data.

Future work includes two real-world implementations of this algorithm which will provide "ground truth" validation. First, we will embark on a full production cycle of this technology on Earth providing actual data. It will use the Army's RMAX unmanned areal vehicle to get the overhead images that will be used to generate the DEM using stereophotoclinometry, as well as the low altitude images comparable to a rover's point of view. This will test all aspects of a horizon matching algorithm by providing ground truth.

The second follow-on project is to use the DEMs of the Apollo landing sites and see if we can uniquely identify the location of each of the Apollo panoramas.

These tests will provide a robust validation of the algorithm's ability to identify a rover's location with minimal human interaction.

References: [1] Li R. et al (2002) *JGR*, 107, E11. [2] Olson C. F. and Matthies L. H. (1998) *Intern. Conf. on Robotics & Automation* [3] Li R. et al. (2004) *Photogramm. Eng. Remote Sens.*, 70(1), 77-90. [4] Li R. et al. (2011) *JGR, 116*, E00F16. [4] Gaskell R. W. (2008) *LPS XXXIX*, Abstract #1152. [5] Gaskell R. W. et al. (2008) *MAPS, 43*, 1049-1061.

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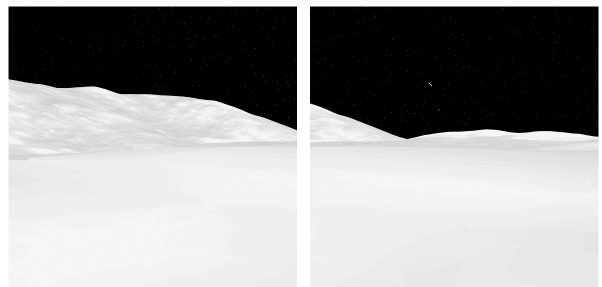

Figure 3. Two images generated from the DEM to simulate the "ground truth" rover images. 24 images are used to form a 360 degree "ground truth" panoramic image.

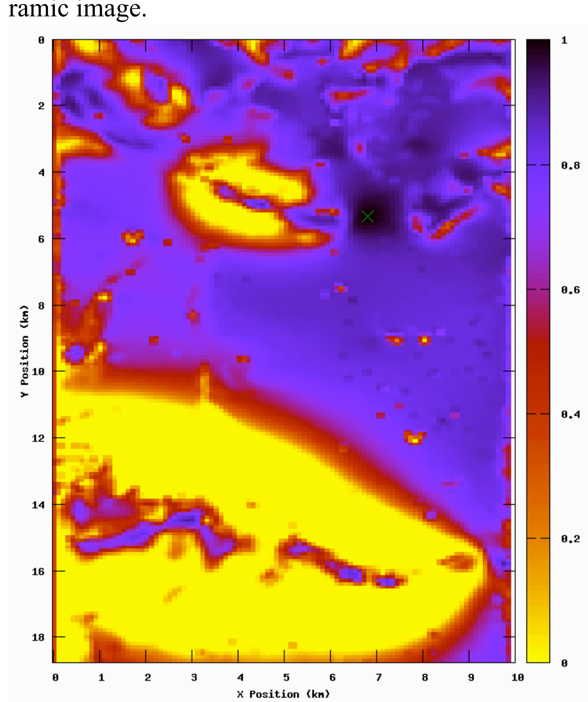

Figure 4. Plot showing the quality of matching between simulated rover images and the synthetic panoramas from location 8. In this example, there is a large region where the fit becomes good, with the absolute minimum matching where the rover is located.