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Informed lunar exploration with probabilistic viewsheds

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Abstract

Future lunar exploration (robotic and human) can be efficiently planned from existing images and elevation data acquired by previous and current lunar missions. The aspects of communication and data acquisition on the lunar surface is of vital importance for exploration and is predominantly dependant on line-of-sight methods. Uncertainty in the elevation affects the line-of-sight computation and can lead to erroneous inferences, the magnitude of which varies from place to place. Viewsheds from multiple observer positions on a region on the rim of lunar South Pole Aitken (SPA) basin are analyzed in this work to evaluate and analyze Type I and Type II uncertainty errors.

1. Introduction

Line-of-sight data acquisition and transmission techniques still remains the most potent form of communication between assets on the lunar surface and are of vital importance for robotic and human extravehicular activity [1,2]. In this work we show how the terrain information can be judiciously utilized towards pre-mission analysis [3] and planning. An observer (robotic or human) on the lunar terrain can only see (or acquire data) up to the limits imposed by topography (visible area is called a viewshed). In order to understand the restrictions, a model of the topography is sufficient. Whether a line-of-sight exists between two points on the lunar surface is a logical decision computed based on an available Digital Elevation Model (DEM). Hence, an inherent probability dependent on the accuracy and resolution of the DEM is associated with the line-of-sight (and viewshed) information. In this work we study lunar viewshed generation from a probabilistic standpoint using high resolution DEMs available from Lunar Reconnaissance Orbiter Narrow Angle Camera (LROC NAC) stereo images.

2. Methods

For this work we select a region on the rim of lunar South Pole Aitken (SPA) basin (Figure 1). A total of 16 observers are chosen at different points on the DEM and viewsheds corresponding to these observers are analyzed.

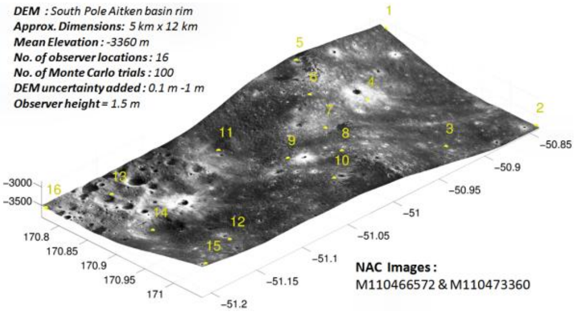

Figure 1: SPA rim DEM used for analysis and position of observers

Line-of-sight indicates the mutual visibility between two points on an elevation map. Variations from the true elevation (all Z values) can change the validity of the above inequality. Such variations can be caused due to inaccuracies in the DEM information and this inaccuracy is simulated via a Monte-Carlo procedure (Figure 2) and the errors are analyzed.

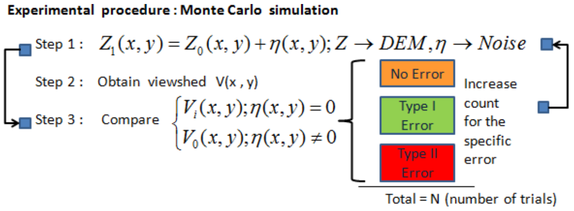

Figure 2 : Monte-Carlo method for uncertainty analysis

Probability of a hypothesis is evaluated via the Monte Carlo method. Hypothesis H_0 indicates obscured target and H_1 a visible target. Hence $P(H_0 \mid H_1)$ indicates a miss (predicting not visible when target was actually (ground truth) visible) and $P(H_1 \mid H_0)$ indicates a false alarm (to predict visible when it was actually not visible). The error due to $P(H_1 \mid H_0)$ is Type I error and due to $P(H_0 \mid H_1)$ is Type II error. These probabilities can be computed since we know the ground truth and results from the Monte Carlo simulations can be stacked together and probabilities at each spatial location can be computed to generate a viewshed with probabilities (probabilistic viewshed). A total of 100 runs are performed for each observer location.

3. Results

The viewsheds obtained for observer locations 6 and 9 (Figure 3 top and bottom respectively) show the uncertainty variation via the colours (deeper blue is lower uncertainty, greener or yellow indicates higher uncertainty). The colour represents total uncertainty which is the weighted effect of all the DEM errors (at various uncertainty levels). Observer location 6, which is at a higher altitude than location 9 has lesser visible area. This is an important counter-intuitive observation (as higher altitude does not necessarily mean larger viewshed) . Also note that the craters are easily identified via the viewshed diagrams.

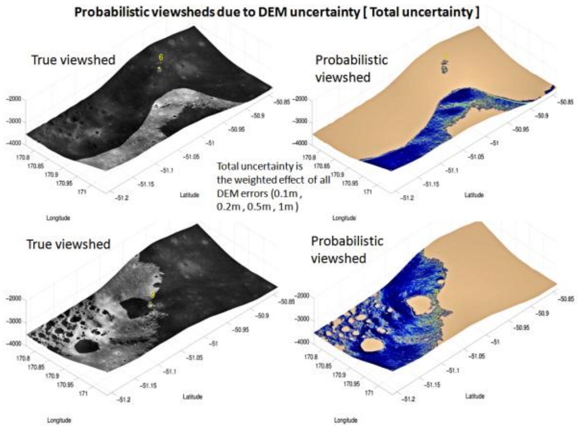

Figure 3: True and Probabilistic viewsheds

Plots of false alarm probability and miss probability (Figure 4) are obtained from using the information from all the observer positions.

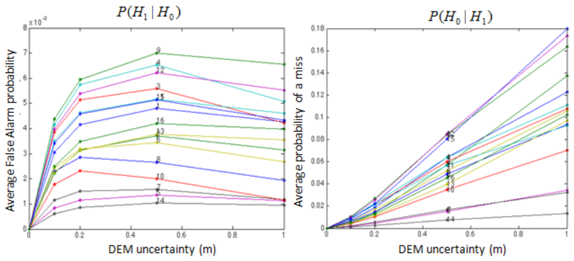

Figure 4: Variation of Type I and Type II errors with DEM elevation uncertainty

It may be noted that height of observer is another variable that can be changed for the analysis (here it was kept constant at 1.5 m)

4. Conclusions

Computation of viewsheds is an important step for lunar exploration planning. The LROC NAC DEMs are providing the high resolution terrain information required for assessment of viewsheds. By analyzing the effect on elevation uncertainty, the preparedness for an exploration can be improved further. From the results obtained by computing probabilistic viewsheds in this work we find that local terrain affects the degree of uncertainty propagation from source DEM to viewshed, so even with equal levels of uncertainty added, two points may behave different statistically for line-of-sight computation. For a given viewshed, true viewshed boundaries are the most affected due to DEM uncertainty. Type I & Type II errors increase with DEM uncertainty, Type I error appears to saturate. It was also observed that Type I error has a lower magnitude than Type II error, so contributes less to total error. Lastly, as DEM uncertainty increases, viewshed area decreases.

References

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[2] T. Hanson, et al. (1993) in GLOBECOM'93., IEEE.

[3] P. Mahanti, et al. (2012) LPI Contributions 1685:3006.