Identification and Analysis of Risk Factors in Lunar Path Planning using High Resolution Digital Elevation Model. J. Bai[1], M. Cho[2], H. Choi[2], and M. Tahk[2], [1]Korea Advanced Institute of Science and Technology (tdabjohn@kaist.ac.kr), [2]Korea Advanced Institute of Science and Technology.

Introduction: A reconnaissance mission on the moon is limited by various factors: mission time, solar illumination, thermal inertia, etc. Thus, in the early stages of mission planning, it is important to understand and identify which areas can be explored without violating any constraints. Thus, each factors must be addressed and analyzed beforehand.

Before, digital elevation models(DEM) did not have high resolution, limiting humans to understand the lunar surface more thoroughly. However, with the advance of technology, high resolution digital elevation models(HRDEM) are obtainable - using some techniques, such as shape-from shading - from the primary data that NASA's LRO provides. With the use of high resolutionized DEM, this abstract will identify and analyze two main risk factors in lunar path planning missions: slope and roughness.

HRDEM: Risk factors are mostly obtained using DEM. Thus high resolution DEM is desirable. The HRDEM is obtained using shape from shading in the NASA ASP, obtained from stereo DEM. The shape from shading is implemented on the low resolution DEM by minimizing the below cost function.

$$\iint \sum_k [I_k(\phi)(x,y) - T_k A(x,y) R_k(\phi)(x,y)]^2 \, dxdy + \iint \mu \left\| \nabla^2 \phi(x,y) \right\|^2 dxdy + \iint \lambda [\phi(x,y) - \phi_0(x,y)]^2 dxdy \quad (1)$$

Here, $I_k(\phi)(x,y)$ is the k-th camera image interpolated at pixels obtained by projecting into the camera 3D points from the terrain $\phi(x,y)$, T_k is the k-th image exposure, $A(x,y)$ is the pixel per albedo, $R_k(\phi)(x,y)$ is the reflectance computed from the terrain for k-th image, $\left\| \nabla^2 \phi(x,y) \right\|^2$ is the sum of squares of all second order partial derivatives of ϕ, $\mu > 0$, is a smoothing term, and $\lambda > 0$ determines how close we should stay to the input terrain ϕ_0 [1]. The first term in (1) signifies that the image brightness must be the same with the reflected brightness of the calculated terrain. The second term signifies that the surface must be smooth, and the third term signifies that the HRDEM must not differ geometrically from the input DEM(ex.LOLA DEM).

Slope: Slope is one of the crucial elements in lunar path planning. Since rover's speed determines how large of an area the mission can cover, maintaining maximum speed is desirable. However, speed of the rover is inversely proportional to slope [2], thus high slope will decrease rover's speed. To achieve optimal path planning route, slope must be included as a penalty. Rover also has maximum climable slope, limited by its power output. This should also be considered as a hard constraint. In this abstract, maximum climable slope is assumed to be 45 degrees.

Since maximum slope of a pixel is the only interest for robotic path planning missions, maximum elevation difference between the center pixel and four adjacent pixels is considered. This method is widely used; NASA's GDAL software provides this method.

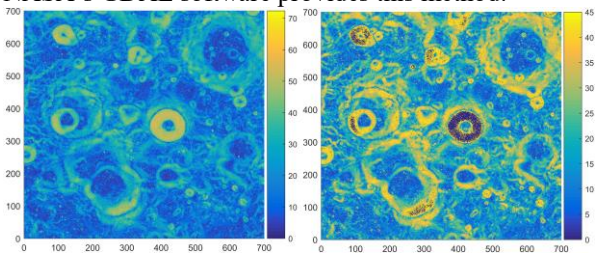

Figure 1. Slope map(left), Deleted slope map(right)

The figures are slope maps-slope represented in degrees-, generated using HRDEM. The right figure is the processed version, in which hard constraint violating region are depicted as 0 (dark region).

Roughness: Similar to slope, roughness must be considered for safe passage of the rover. There are many definitions of roughness, but this abstract will use the concept defined by Wilson et al [3].

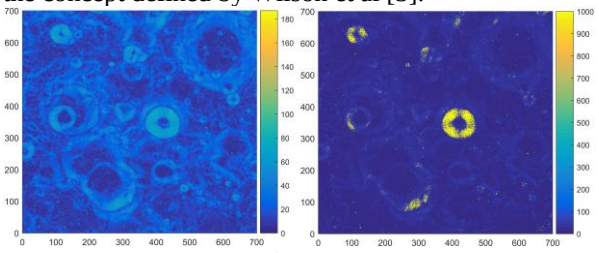

Figure 2 Roughness map(left), Deleted roughness map(right)

Assuming that a rover cannot pass through roughness over 60, those locations are depicted as pixel value of 1000 (yellow). High roughness region coincides with high slope regions in Figure 1.

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