LANDING SITE ANALYSIS AND PATH PLANNING FOR
JAXA'S FUTURE LUNAR POLAR EXPLORATION MISSION

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Introduction: Recently, remote-sensing observations have suggested that valuable resources (e.g., volatiles captured in the cold trap) are likely to exist in the lunar polar region. Also, due to the long-duration of preferable illumination, the polar region has gained much attention as one of the most attractive exploration places for many countries.

JAXA is studying a Moon polar surface exploration mission. The objective of the mission is to investigate the usability of water ice in the lunar polar region; that is, JAXA aims to obtain data regarding water quantity and quality to determine whether water can be employed as a resource.

In such a landing mission, we must select a landing site while considering various conditions such as illumination, communication with the Earth, slope, and terrain hazards. Since landing-site selection is critical for the mission accomplishment and safety of the spacecraft, a great deal of previous work has analyzed various conditions using remote-sensing data in the Moon polar region [1, 2, and 3].

At the same time, landing-site selection cannot be decoupled from path planning after the landing; that is, the optimal landing site is not necessarily favorable for the path planning. Hence, the landing site must be chosen along with path planning.

In this paper, we present the result of landing site selection and path planning for a surface exploration mission in the lunar polar region. We first present landing site analysis results for both north and south polar regions obtained by simulating the sunshine, communication with the Earth, and slope conditions. In this analysis, we used Digital Elevation Models (DEMs) created from the observation data of the Lunar Orbiter Laser Altimeter (LOLA) of LRO. We also present an optimal path planning method in time-variant environments based on the A* algorithm [4]. The effectiveness of our proposed path-planning method is demonstrated by the simulation using real observation data from LOLA and NAC.
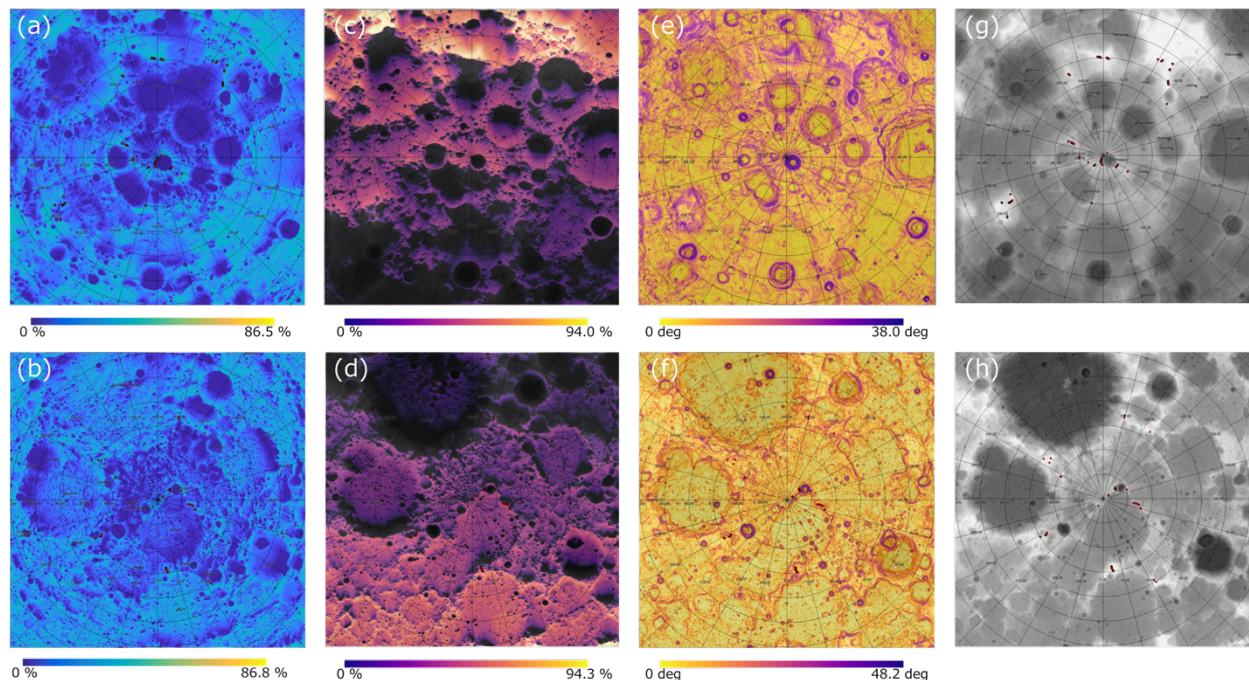

Figure 1. Landing site analysis results. (a) and (b) are illumination ratios of the north and south polar region above 84 degrees. (c) and (d) are communication ratios of the north and south polar region. (e) and (f) are slope angles. In (g) and (h), red points are candidates of the north and south region above 84 degrees. The simulation term is all two years from Apr. 1, 2023 to Mar. 31, 2025.

Landing Site Analysis: To select the landing sites for the mission, we simulated the conditions mentioned above using the LOLA DEM with a grid resolution of 40 meters and the orbit of the Sun/Earth relative to the Moon. Figure 1 shows the analysis result of three conditions (i.e., illumination, communication, and slope) and the candidates of landing sites that we chose. The resulting candidates satisfy the following three restrictions: 1) The number of sunshine days exceeds 100 in two years. Here, the threshold is defined as 50% of the sun disks (For the definition of the sun disk, see [5]). 2) The ratio in which Earth-Moon communication can be conducted exceeds 25%. The sunshine and communication simulations' duration is two years, from April 1, 2023 to May 31, 2025. 3) The slope angle is less than 10 degrees.

Optimal Path Planning: After landing site candidates are chosen, operation analysis is necessary for each candidate. Our proposed method is a variety of the A* algorithm [4] in which the minimum cost path is obtained in a time-variant environment. By extending the exploring space to three dimensions, we model the time-variant cost function (though the cost function of each edge in the graph is time-invariant).

First, we detected hazards such as craters and boulders using the orthorectified NAC image around the landing site (see Figure 2 (a)). We then classify the exploration region as in Table 2 according to the existence of the hazard, illumination, and communication. Finally, on the classification map, we search the path between waypoints by an extended A* algorithm. An example of the optimal path around a landing site candidate is shown in Figures 2 (b) to (e). You can see that the path chose the safe region on the time-variant environments.

Conclusions: This paper presents the analysis results for landing site selection using previous remote-sensing data such as LOLA and NAC. After the landing site candidates are determined, we obtain the optimal path by using the extended A* algorithm. In the future, we will add geological analysis and temperature simulation for the landing site selection.

References: [1] Heldmann, Jennifer L., et al. (2016) *Acta Astronautica*, 127, 308-320. [2] Ivanov, M. A., et al. (2015) *Planetary and Space Science,* 117, 45-63. [3] De Rosa, Diego, et al. (2012) *Planetary and Space Science,* 74.1, 224-246. [4] P. E. Hart, et al. (1968) IEEE transactions on Systems Science and Cybernetics, vol. 4, no. 2, pp. 100–107. [5] Mazarico, E., et al. (2011) *Icarus,* 211.2, 1066-1081.

Table 1. Classification of the terrain type from white to black. White region is the safest, and black region is the most dangerous. In our proposed method, the weighted cost function is defined for each terrain type.

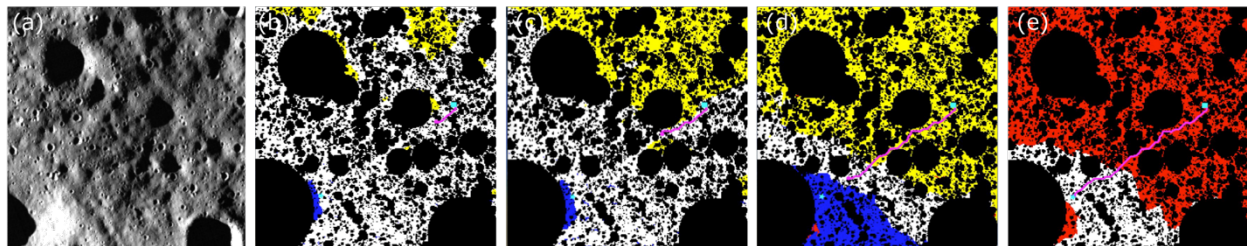| Terrain type	Hazard	Illumination	Communication
White	None	Good	Good
Blue	None	Good	Bad
Yellow	None	Bad	Good
Red	None	Bad	Bad
Black	Exist	-	-

Figure 2. (a) The orthorectified NAC image around a landing site candidate. (b) to (e) are examples of the optimal path. Cyan square (upper right) is the start, and cyan star (lower left) is the goal. Magenta line is the optimal path. The background terrain environment changes from hour to hour. The terrain type is explained as Table 1 (white, blue, yellow, red and black).