A Large-scale Path Planning Method for the Lunar Surface Coupled with Multi-level Map Models

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Abstract: With the planning and implementation of lunar exploration missions such as manned lunar exploration and lunar scientific research stations, the driving distance of lunar rover units in the future will span kilometers, tens of kilometers. Even hundreds and thousands of kilometers, and the long-range path planning of lunar rovers has become an urgent need for lunar patrol exploration. In order to solve the problem of lack of travel cost data for lunar rovers, such as a high-resolution digital elevation model, this paper proposes a multilevel map model path planning method that combines existing high-resolution image data with mid-low resolution remote sensing data such as DEM and rock abundance. This method uses an extensive range of driving costs and obstacle maps constructed with medium- and low-resolution remote sensing data for rough planning. Local obstacles on the lunar surface are extracted by combining deep learning algorithms on high-resolution images, and path precision planning is carried out on local grid layers. Local high-resolution elevation models verify the reliability of the method. In this paper, long-distance reachability analysis and path planning experiments are carried out in regions with scientific value, including Golden Nails. The results show that the proposed method can meet the requirements of long-distance reachability analysis and path planning of lunar rovers under the limited high-resolution digital elevation model. It provides theoretical reference and technical support for the design, mission demonstration, and subsequent engineering implementation of the new lunar rover in China.

Keywords: Manned lunar exploration, lunar research stations, long-distance driving, multi-level mapping, path planning.

1. Manuscript

1.1 Introduction

The American Opportunity Rover has the longest driving distance (45.16 km in 14 years). The path planning technology involved is mainly local path planning, such as China's Yutu 1 and Yutu 2 lunar rovers (Bai and Oh, 2020; Wang et al., 2020), the American Spirit Rover, Opportunity and other rovers (Lin et al., 2024; Zeng et al., 2023). While the early rovers were generally operated by remote control or manned, the Yutu rover was the first to realize China's autonomous inspection and exploration on the lunar surface (Zhong et al., 2023). However, the inspection distance was limited (Tompkins et al., 2006). China, the United States, ESA, and Japan have all proposed research plans for rovers with a wide range of autonomous mobility capabilities. Most of the research on path planning and autonomous navigation-related technologies has focused on local planning technologies, and some plans have carried out detailed pre-planning of moving routes (Ding et al., 2024; Hong et al., 2023). However, more research is needed on global planning technologies.

1.2 Method

Path planning is based on the travel cost and obstacle map to calculate the minimum cost path. Firstly, the starting and end points are determined, and the nearest neighbor cost between adjacent pixels is specified. The minimum cost path between the starting and endpoint points is determined by finding the minimum cost path between the starting and endpoint points and the backtracking link matrix, which is the optimal path when the lunar surface moves. On this basis, Lunar Reconnaissance Orbiter Camera Narrow Angle Cameras (LROC NACs) high-resolution images and other high-precision environmental sensing data are used to update the path of the local grid layer. The overall technical route is shown in Figure 1, which is divided into two parts: data processing and path planning.

1.3 Experiments

The long-distance reachability analysis and path planning experiments are carried out by integrating the scientific value of the lunar golden nail and other areas as a large-scale experimental area, and the local high-resolution elevation model verifies the planning results. The travel cost map is established based on the gradient map of fusion CE-2 DEM. The detection starting, path stopping, and detection termination points are shown in Table 1. Based on high-precision mapping of the lunar surface, the driving cost constraints were carried out with the following conditions: the slope of the path position of the lunar rover should be less than 8°; for a few harsh terrains, the area with small rock abundance and no more than 20° when working in obstacle crossing mode should be regarded as the mobility limitations of the lunar mobile vehicle. The experimental results are shown in Figure 2.

1.4 Results

This paper uses a large-scale path-planning method for the lunar surface and a multi-level map model. This method can meet the requirements of long-distance reachability analysis and path planning of lunar rovers. The experimental results of path planning in the golden nail region of the lunar surface show that the proposed method can ensure the reliability of the path planning of the lunar rover under the limited condition of the high-resolution digital elevation model and thus provide critical technical support for the design, mission demonstration and subsequent engineering implementation of the new lunar rover in China.

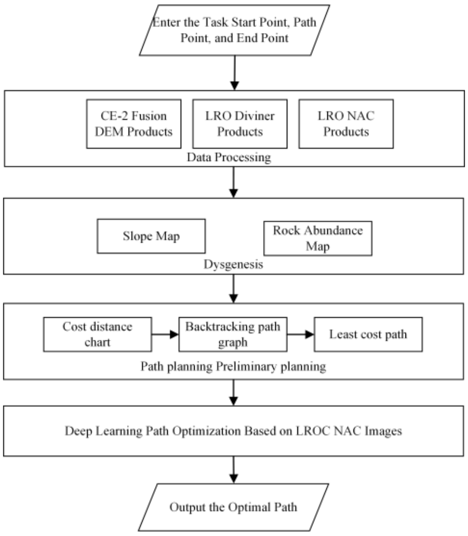

Figure 1. A large-scale path planning method for the lunar surface coupled with multi-level maps.

Table 1. The lunar golden nail area route passes through the point.

Point ID	Longitude	Latitude
1	3.454°E	12.233°N
2	5.022°W	14.727°N
3	5.330°W	13.905°N
4	6.588°W	15.175°N
5	8.339°W	15.069°N
6	11.896°W	13.372°N
7	17.547°W	12.726°N
8	21.019°W	11.191°N
9	18.167°W	6.958°N
10	15.212°W	5.890°N

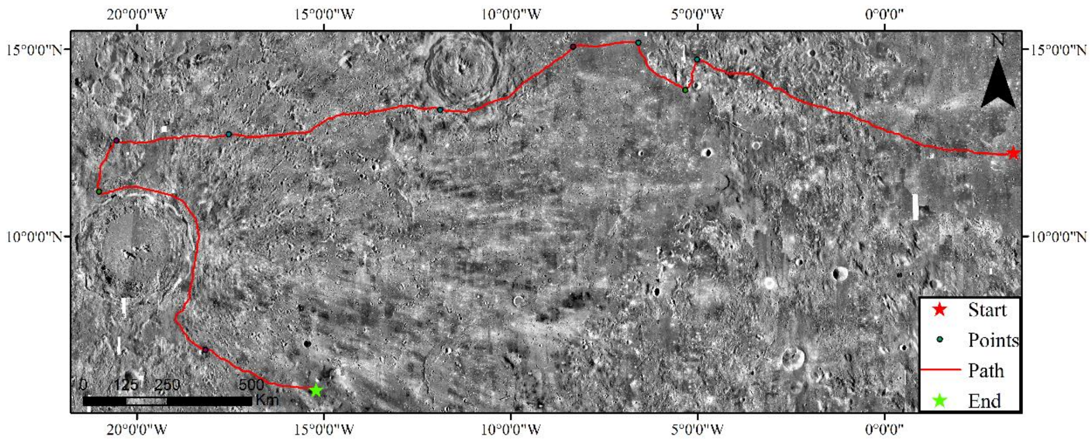

Figure 2. Route planning results of the Golden Nail area on the lunar surface. (Base map LRO NAC)

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