

Research Article

Robust Crater Detection Algorithm Based on Maximum Entropy Threshold Segmentation

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For future lunar exploration and planetary missions, the digital elevation model (DEM) of the target object may not be well prepared before the mission, so developing a new robust crater detection algorithm (CDA) without prepared high-precision DEM is needed to meet the requirements of a high-reliability and high-precision detection and navigation system. In this paper, we presented a new robust lunar CDA method based on maximum entropy threshold segmentation. By calculating the entropy distribution of the ternary image, the threshold for retaining the maximum amount of image information is selected adaptively, a variety of evaluation indicators are proposed, and a multiple-indicator constraint matrix is constructed to realize the extraction and fitting of the craters. The proposed method has the following advantages: (1) it has strong robustness and is capable of extracting complete craters under multiple illumination conditions, which makes it suitable for the extraction of large-scale planetary and lunar images; (2) the extracted crater edges are clear and complete and do not merge with the surrounding environment edge; and (3) it avoids the problem of parameter sensitivity that is present in a traditional CDA algorithm. The proposed method was verified using an image taken by the Chang'e-2 lunar probe, and a comparison with the traditional method based on morphology and adaptive Canny edge detection shows that the number of craters detected increases by more than 35%, while the computational efficiency is improved by more than 40%.

1. Introduction

Planetary landing exploration is a key approach to study the formation and evolution of the solar system, the development and utilization of space resources, asteroid impact defense, and other major scientific issues. In the past decades, many countries have carried out a series of successful exploration missions for the Moon (Apollo [1, 2], Chang'e [3–7]), Mars (Tianwen-1 [8], Curiosity [9], and Opportunity [10]), asteroids (Rosetta [11]), and other celestial bodies. In general, terrain with high scientific value is more complex, and landing is more difficult; therefore, crater detection algorithms are important for lunar exploration and planetary missions. Chang'e-4 is the only exploration mission in a complex area that has successfully landed on the far side or back of the Moon [12, 13]. Compared with the traditional lunar sea area on the front of the Moon, the terrain on the back of the Moon is more complex and lacks high-precision terrain elevation data. Furthermore, tradi-

tional communication technology based on deep space networks presents greater risks for a mission due to communication delay problems [14], and therefore, algorithms need to be more robust.

To overcome the limitation of the traditional deep space network, it is necessary to develop a robust autonomous detection method for lunar craters under any illumination and construct autonomous hazard detection and avoidance (HDA) technology based on optical information for accurate navigation and autonomous landing-point selection for the lunar surface high-precision descent landing guidance, navigation, and control (GNC) system.

To detect craters, many crater detection algorithms (CDAs) have been studied by researchers all over the world. Some methods have focused on positive detection rates, while other methods pay more attention to speed or robustness. Studies by Stepinski et al., Delatte et al., Silburt et al., and Emami et al. [15–18] used machine learning and convolutional neural networks (CNNs) separately to process

