Type of the Paper (Article, Review, Communication, etc.)

**Identification of lunar crater in the Chang'e 5 region based on Kaguya TC morning**

Yanshuang Liu 1, Jialong Lai 2,\* , Minggang xie 3, Yiqing Qian 3, Jiahao Deng 3

|  |
| --- |
| **Citation:** To be added by editorial staff during production.  Academic Editor: Firstname Lastname  Received: date  Revised: date  Accepted: date  Published: date    **Copyright:** © 2023 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/). |

1 Affiliation 1; e-mail@e-mail.com

2 Affiliation 2; e-mail@e-mail.com

**\*** Correspondence: e-mail@e-mail.com; Tel.: (optional; include country code; Only one author should be designated as corresponding author)

**Abstract:** Impact craters are among the most typical and widespread geological features and structures on the lunar surface. The recognition algorithm for the crater detection algorithm (CDA) is progressively transitioning from conventional machine learning methods towards the domain of deep learning. Presently, automated identification of impact craters relies predominantly on Digital Elevation Model (DEM) to detect larger craters. However, utilizing DEMs to discern impact craters with diameters smaller than 1 km poses considerable limitations. Therefore, this paper proposes using an improved Faster R-CNN algorithm and the Kaguya Terrain Camera (TC) morning map to identify small impact craters in the Chang'e-5 landing area. By employing model fusion, the accuracy of identifying small impact craters is significantly enhanced. The results indicate a recall rate of 96.33% and a precision of 90.19% for identifying craters with a diameter above 200m. The total number of identified impact craters in the CE-5 region is 187,101. The spatial distribution density of impact craters in the CE-5 region with diameters ranging from 100m to 200m is approximately 2.5706/pixel. For impact craters with diameters ranging from 200m to 1000m, the average spatial distribution density is approximately 0.9016/pixel. Additionally, a chronological analysis of the Im2 and Em4 geological units in the CE-5 region was conducted, revealing ages of 3.781 Ga for Im2 and 1.964 Ga for Em4. The experimental results demonstrate that automated impact crater identification based on the Kaguya TC morning map achieves satisfactory performance.

**Keywords:** Chang’e-5 landing site; CNN; Kaguya TC morning; impact crater detection;

1. Introduction

Impact craters are among the most typical and widespread geological features and structures on the lunar surface. In the exploration of lunar science, impact craters represent one of the extensively studied geological landscape features [1–3]. Research on impact craters contributes to investigations into various aspects of lunar science, including the absolute age of Mare Units on the Moon [4], rock abundance [5], regolith thickness [6,7], and dielectric constants [8].

The lunar surface is abundant with numerous impact craters of varying sizes. Research related to impact craters relies on their identification and recording. Early identification of impact craters primarily relied on manual labeling [9–11], morphological feature extraction algorithms [12–15], and machine learning-based identification [2,16,17]. With the advancement of computer vision and artificial intelligence, the identification of impact craters has gradually shifted towards deep learning. Continuously evolving deep learning algorithms have made crater detection more accurate and efficient. In 2019, Silburt et al. [18] processed lunar Digital Elevation Model (DEM) using Convolutional Neural Networks (CNN) to identify craters. By comparing with a manually generated crater catalog, they achieved a recall rate of 92%. In 2020, Yang et al. [19] used transfer learning with neural networks to identify craters, detecting 109,956 newly identified craters, including 18,996 craters larger than 8 km. In 2022, Tewari et al. [20] employed unsupervised and semi-supervised learning for crater identification, extracting crater morphology using a morphological approach. In addition to CNN, semantic segmentation networks have also been successfully used for crater identification, yielding promising results [21–25].

The current focus of automated impact crater identification predominantly centers on medium to large-sized craters using DEM [23,25–28]. However, research regarding the automated recognition of small-sized impact craters is constrained by the paucity of datasets and pertinent references. Nevertheless, delving into the automated identification of small impact craters holds significant importance. Fu et al. [29] conducted a study on the subsurface structure and stratigraphy of the Chang'e-4 mission's landing site by analyzing small impact craters (diameter <1 kilometer) at the bottom of the Von Kármán crater. Fassett et al. [30] delved into the study of terrain degradation utilizing small impact craters. Additionally, small impact craters find frequent application in secondary crater analysis [31,32] and the determination of equilibrium diameter for specific regions [6,33,34]. The currently documented lunar impact crater database contains upwards of a million craters with diameters exceeding 1 km [11,28]. For small craters with a radius greater than r, the equilibrium cumulative size-frequency distribution (SFD) per unit area is proportional to [35]. This infers that impact craters larger than 100 m might exceed a billion in number, rendering manual identification of small impact craters nearly infeasible. While significant progress has been made in the field of crater recognition, identifying small craters remains a challenging problem.

However, there are notable limitations in identifying small impact craters using DEM data. This is primarily due to the typical image resolution of DEM being 59m/pixel or higher [36]. Automated detection necessitates a minimum of 10 pixels to reliably identify impact craters [37]. Consequently, accurate identification is possible only for impact craters with a diameter of at least 590m. In 2022, Fairweather and colleagues [38] performed registration on Lunar Reconnaissance Orbiter (LRO) Narrow-Angle Camera (NAC) images of the Moon. They manually annotated samples and utilized the YOLOv3 network for training and recognizing craters in the registered images. In 2023, La Grassa et al. [39] utilized a deep learning model based on YOLOLens for impact crater identification. They employed Robbins' impact crater catalog [11] and LRO Wide-Angle Camera (WAC) images for crater detection. However, since Robbins' impact crater catalog only includes craters with diameters larger than 1 kilometer, there are inherent limitations in identifying craters with diameters smaller than 1 km. Hence, automated identification of small impact craters remains a challenging problem.

Chang’e-5(CE-5) landing site is located in the Rümker region, with coordinates ranging from 49°W to 69W° and 41°N to 45°N. The area is predominantly populated by small impact craters, and the CE-5 mission successfully obtained 1731 g of lunar samples [40–43]. Therefore, an improved Faster R-CNN algorithm [44] and Kaguya Terrain Camera (TC) morning map [45] were utilized to identify small impact craters in the CE-5 landing area, enhancing the accuracy of crater identification through model fusion [46]. The TC morning map boasts a remarkable resolution of 7.403 meters per pixel, which is significantly superior to the 59 meters per pixel resolution typically found in DEM imagery. This higher resolution enables more precise detection of smaller craters. Furthermore, unlike LRO NAC images, the TC morning map eliminates the need for image registration, thereby reducing errors in latitude and longitude that may arise during the registration process. The improved Faster RCNN model and TC morning map were employed to predict the lunar impact crater catalog for the CE-5 region. Following crater catalog retrieval, region density and dating analyses were conducted, comparing them with the radiometric dating results of samples collected in the CE-5 area. This comparison can provide reference data for lunar dating, aiding in a deeper understanding of the moon's geological history.