Finding Secondary Crater Clusters Using Automated Crater Detection Across Chang'e 5 Landing Site.

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Introduction: The Moon's cratered surface and lack of significant geological activity makes it suitable record for the solar systems chaotic past. The craters scattered across the lunar surface can be mapped and measured giving a relative chronology [1]. Furthermore, the spatial densities of those craters, when linked with radiometric measurements from collected samples, provide absolute model ages [1]. The various sample sites from the Apollo and Luna missions have greatly increased our understanding of the Moon's and Earth's geological evolution [2]. Looking onward to the most recent sample return mission, Chang'e 5 (2022) which brought back 1,731g of material from north-eastern Oceanus Procellarum, the in-situ lunar samples host a range of radiometric ages [3,4]. This momentous mission was the first sample return in 44 years, which returned samples from the youngest Mare region on the Moon dated to 1963±57 Ma [3]. Many of the Lunar samples, including those from CE-5, contain clasts that suggest that they have been transported by impacts [4]. This raises questions about where the lunar material originates from, and what can we determine about those areas from the collected sample material. During an impact, a significant amount of material is ejected, and without of atmosphere or strong gravity, this material can travel great distances [5]. This material falls back down to the surface forming a network of secondary craters and debris. Looking at secondary crater clusters around the sample sites, which are typically small (<1km) and number in the several millions [5,6], researchers can determine potential trajectory and distance lunar material has traveled. Specifically for the CE-5 material, probable source locations have been identified through crater mapping and numerical modeling [4]. To aid the time-consuming process of mapping secondary craters we propose using a machine learning algorithm to automatically detect small lunar craters across high-resolution image datasets [7,8,9]. Identifying secondary craters at ultimate resolutions can provide the source of the exogenic material contained in CE-5 samples, and more generally for other lunar samples.

Image Datasets: Our team have utilized two high-resolution lunar image datasets for this project. The first was the Lunar Reconnaissance orbiter – Narrow Angle Camera (LRO-NAC), offering a resolution of 0.5-2 m/px [10]; and the second was the Kaguya Terrain Camera (TC), offering a resolution of ~10m/px [11]. This allows us to compile automatic crater detections over across multiple geographical scales.

Crater Counting Algorithm: The Crater Detection Algorithm (CDA) is a machine learning image-based Convolutional Neural Network (CNN) that has been specialized to detect craters over high-resolution satellite imagery [7,8,9]. Our CNN uses 'You Only Look Once version 5' (YOLOv5) as the network's architecture. We have two crater detection models, each focusing on a different image dataset (NAC and Kaguya). The NAC model has been trained and validated across 247 square image tiles (416 pixels in length/width) with a detection accuracy of ~92% [9]. The Kaguya model was trained and validated on ~420 tiles and has a detection accuracy of ~94%. All the training image tiles have afternoon/morning lighting conditions, to facilitate impact crater recognition. Before running the detection model across the dataset, they are processed and converted into GeoTiffs through USGS ISIS3 and GDAL, respectively. The CDA is then run across the image datasets, detecting millions of craters at the 10m to 100m scale, magnitudes faster than manual methods.

Chang'e 5 Secondary Clusters: The preliminary results over the Chang'e 5 landing site and surrounding areas show multiple secondary clusters (>10) cross cutting the region. At the Kaguya-scale (10m/px), we analyzed a ~800km by ~800km region and found considerable secondary clusters that crosscut the landing region from Aristarchus crater. At the NAC-scale (2m/px), we analyzed a ~450km by ~275km area and located a significant secondary cluster less that 10km from the landing site, originating from Rümke E crater. We also mapped a series of north-west and east-west trending clusters.

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