AUTOMATED CRATER DETECTION AND ABSOLUTE MODEL AGE ESTIMATION FOR CRATERS IN THE SOUTH POLE-AITKEN BASIN OF THE MOON. X. Cui¹², M. Ding¹² and G. Wang³ ¹State Key Laboratory of Lunar and Planetary Sciences, Macau University of Science and Technology, Macau, China (miding@must.edu.mo), ²CNSA Macau Center for Space Exploration and Science, Macau, China, ³Data Science and Information Technology Research Center, Tsinghua-UC Berkeley Shenzhen Institute, Shenzhen, China.

Introduction: Impact cratering is the dominant geologic process on the Moon, where the wide-spread craters provide key clues for the evolution of this planet and even the solar system. The absolute model age determination of geological units is also based on crater identification and counting.

As the ever-growing high-resolution satellite images and elevation data can hardly be processed manually, a reliable automated crater identification algorithm is now demanding, especially for small-sized craters. Crater identification has been automated using classic classification and pattern recognition techniques [e.g., 1,2]. Recent years have seen the application of Convolutional Neural Networks (CNN) in crater identification [3-5], which permits complex morphologic features to be automatically incorporated.

As the more ancient geological unit (including mid-sized impact craters) is able to accumulate more superimposed impact craters (with smaller size) since its formation, the relative and absolute ages of a geological unit can be determined by counting the superimposed craters in the geological unit, and comparing the observed crater size-frequency distribution (CSFD) with theoretical distributions.

In this study, we first use a convolutional neural network (CNN) to detect small craters in the South Pole-Aitken (SPA) basin, and then estimate model ages of four regional mid-sized craters with rim diameters of ~100 km using automatically detected small craters. Different from previous applications of CNN to globally detect lunar impact craters, here we are focused on one specific terrane (SPA) on the Moon in order to improve the performance of our detection algorithm.

Data Preparation: Our input data is the SELINE-LRO merged digital elevation model SLDEM2015 [6] with a spatial resolution of 60 m that ranges from -60° to 60° in latitude. This global data is then cropped to square images of 1°×1°, corresponding to 512×512 pixels. Adjacent images have 50% overlap to ensure the existence and identifiability of marginal craters. These images are expected to be suitable for detecting small craters with rim diameters of 600 m to 15 km. The crater database used to train the CNN is 2–15 km diameter craters from the Robbins’ database [7]. For the SPA basin, we then randomly select 80% of the associated images (with crater labels) to train CNN and the rest to test the model.

Convolutional Neural Networks: We use You Only Look Once version 5 (YOLOv5, Fig. 1), which is one of the most effective state-of-the-art target detection algorithm, as the crater detect system. YOLOv5 uses spatial pyramid pooling (SPP) to convert feature maps into fixed size, allowing input images with varied aspect ratio and size. And the path aggregation network (PANet) is used to aggregate features with different sizes by generating feature pyramids, which helps enhance the detection of objects on varied spatial scales.

After training, the performance of our network is measured by F1-score, which is the harmonic mean between precision $P$ and recall $R$: $F1 = 2PR/(P+R)$, where $P = TP/(TP+FP)$, $R = TP/(TP+FN)$, and $TP$, $FP$, and $FN$ are numbers of true positive, false positive, and false negatives (Fig. 2). In our study, “true” or “false” represent whether our detected crater is the same with in the Robbins’ database [7], and “positive” or “negative” represent whether the target is in the ground-truth database [7]. A true positive is defined here as an identified crater with an overlapped area larger than 50% with the corresponding crater in the ground-truth database.

Age Determination: As an application of our automatically detected crater database, we then date four mid-sized craters in the SPA basin, including Bose, Koch, Langmuir, Fizeau craters. We choose the crater floor for crater counting and dating [9], which are plausibly not re-surfaced by post-impact processes. Therefore, the absolute model ages of these mid-sized craters can be estimated by comparing CSFDs derived.
from the automated detection results with theoretical CSFDs of Neukum’s chronology system [10].

**Results:** We use our trained CNN to detect craters in the SPA basin and compare with the ground-truth Robbins’ database [7], reaching a high recall, precision, and F-1 score of larger than 95%. We then estimate the absolute model ages of four mid-sized regional craters.

**Crater Detection Results.** We detect 32,800 craters in the SPA basin with a diameter range of 2-15 km [11] (Fig. 2). Our overall recall is 96% and precision is 95%, yielding an F1-score of 95% that is (marginally) better than the previous global CNN crater detection results [3]. Among the detected craters, ~ 450 are new craters (i.e., false positives), more than half of which are confirmed to be real craters based on visual inspection (with the aid of DEM and wide angle camera images, ref. 12).

**Estimated Model Ages.** Our estimated absolute model ages of the four mid-sized craters in the SPA basin are $\mu_3.81^{+0.02}_{-0.03}$ Ga for the Bose crater (Fig. 3A), $\mu_4.02^{+0.02}_{-0.02}$ Ga for the Koch crater (Fig. 3B), $\mu_3.79^{+0.04}_{-0.05}$ Ga for the Langmuir crater (Fig. 3C), and $\mu_3.84^{+0.02}_{-0.02}$ Ga for the Fizeau crater (Fig. 3D). Our model age estimates are consistent with those based on manually picked craters [13, 14].

**Future Work:** We are now applying this automated crater detection method to other terranes and smaller craters on the Moon. It is likely that using smaller craters, we will be able to improve the statistics of the CSFDs and the corresponding crater model age estimations. We are also working on algorithms to automatically exclude secondary craters and date the mid-sized and large craters on the Moon.

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**References:**