PITSCAN: COMPUTER-ASSISTED FEATURE DETECTION. R. V. Wagner and M. S. Robinson. School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287-3603.

Introduction: The Lunar Reconnaissance Orbiter Camera (LROC) consists of a single Wide Angle Camera (WAC) and twin Narrow Angle Cameras (NACs) that provide multispectral and high-resolution imaging, respectively [**1**]. The NACs are capable of acquiring panchromatic images at 0.5 m/pixel from an altitude of 50 km. A typical NAC image consists of 5,064 samples and 52,224 lines, resulting in over 500 megapixels of image data in each observation pair. As of 1 November 2017, the NACs have collected over 700,000 image pairs of illuminated terrain (~350 *tera*-pixels of data) covering most of the Moon. This dataset is far too large to search by hand, so we developed a feature detection tool (*PitScan*) to enable the discovery of lunar pits by pre-processing images to extract potential pits for human analysis[**2**].

Finding Lunar Pits with *PitScan*: Lunar pits are deep, vertical-walled collapse features, generally <100 m in diameter, and usually have an inward-sloping rim (**Figures 1**, **2**). So far, we have located over 300 pits across the lunar surface. Thirteen of the known pits are in mare flood basalts, three are in highland terrain, and the remainder are in young crater impact melt ponds. Their small size and rarity make pits a prime candidate for automated searching, and in fact most of the known pits were found using *PitScan* (previously reported in [**2,4**]).

Theory. Since the majority of slopes on the Moon are below the angle of repose (~36°) [**3**], very few features cast shadows when the Sun is within ~54° of the zenith. Pits, boulders, and other features with vertical

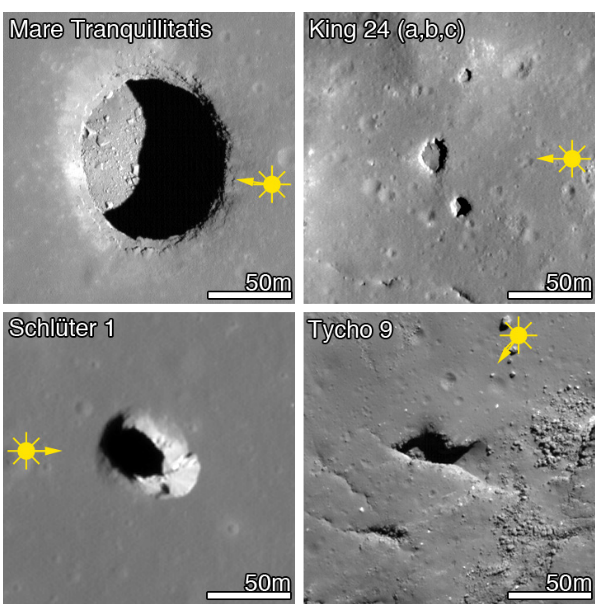

Figure 1: Examples of pits, demonstrating the range of sizes and morphologies that must be detected.

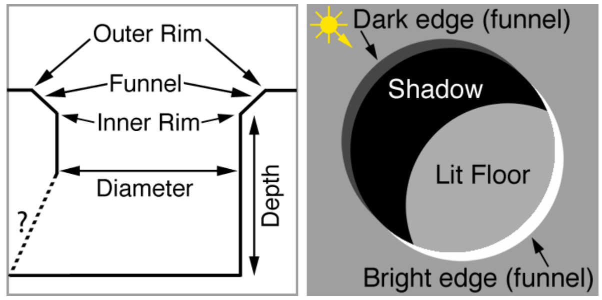

Figure 2: *Left:* Cross-sectional sketch of an idealized pit. Dashed line and question mark indicate possibility of overhang or cave entrance. *Right:* Overhead view of an idealized pit, showing how pit morphology produces distinctive features (compare to pits in **Figure 1**).

surfaces all cast shadows at even lower angles; thus, a catalog of shadows in a high-Sun image should contain any pits in the area. All that is needed is to filter out pit shadows from non-pit shadows.

Implementation. PitScan was developed to locate all shadows larger than 15 pixels across (approximately the smallest size at which a pit can be visually confirmed), and exclude those features that are most likely to be boulders. The remaining potential pits are saved as small image clippings for a human analyst to check manually. *PitScan* runs on 16-bit calibrated image files (CDRs), and can complete a search of a single 250 megapixel NAC image in thirty seconds.

To find shadows, *PitScan* uses an empirically derived equation to calculate a cutoff value for "shadowed" pixels. The formula for this cutoff value (given image mean value μ, cutoff value $T = \mu \times 0.113 + 20$ [**2**]) was determined by manual inspection of pits in several dozen calibrated images with various Sun elevations. A complicating factor in tuning this cutoff is that pit interiors often have strong secondary lighting from sunlight reflected off of an illuminated wall, and thus can be brighter than shadows cast by rocks.

Once all the continuous blobs of pixels with I/F values below the cutoff that are at least 15 pixels across have been located, *PitScan* extracts a profile across each blob parallel to the solar azimuth, extending approximately 30 pixels beyond the bounds of the shadow (**Figure 3**). If the average I/F value on the up-Sun side of the shadow is greater than 0.9× the average value on the down-Sun side (a factor chosen to include most known pits in the images available when the algorithm was written), then the feature is assumed to be a rock, and discarded. For the remaining cases, *PitScan* saves a 300 × 300 pixel clipping for human review, along with a plot of the pixel values in the profile (similar to the left and right columns in **Figure 3**).

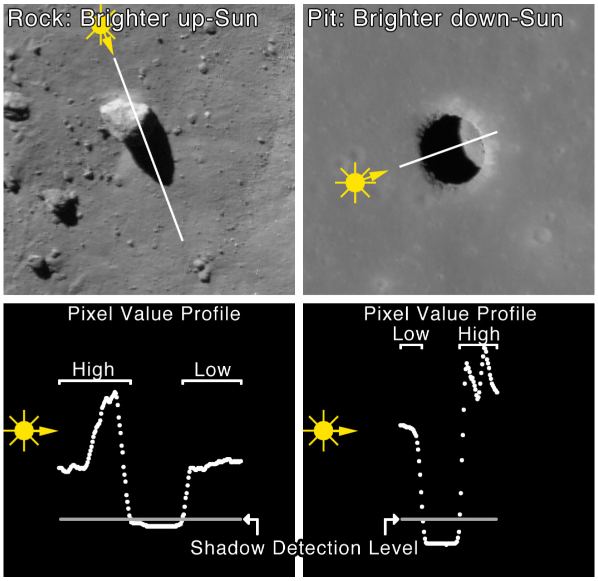

Figure 3: *Top*: Profile lines across detected shadows for rock (*left*) and pit (*right*). *Bottom*: Pixel values along the profile.

In cases where more than 50 potential pits are found in an image, *PitScan* instead saves a preview of the entire image with potential pit locations marked, so a human can check these feature-rich images for known patterns of false positives (such as outcrops on crater walls).

PitScan is normally used only on images with incidence angles (angle between Sun and zenith) less than 50°, as above this value shaded crater walls are frequently flagged as shadows, producing an excessive number of false positives.

Results. Excluding the feature-rich images, the algorithm historically has generated ~150 false positives for each successful pit identification. We consider this an acceptable level of false positives, as an experienced analyst can evaluate most image clippings in less than a second, and it only takes a few hours to check the results for six months of NAC images. The false negative rate can be greatly reduced by adjusting the ratio used to detect boulders: If the down-Sun side is at least 1.1x the up-Sun side, 40% of false negatives are excluded, and 85% of true positives are retained. To take advantage of this effect, the output clippings filenames start with this ratio, so the analyst can decide whether to start with the hundred or so clippings most likely to contain pits, or run through the thousands of false positives (and maybe one or two pits) at the other end of the list.

In a sample of all images from 2009-2016 of known pits with pixel scales such that the pit is at least 30 pixels across, and incidence angles < 50°, *PitScan* only detected 45% of the expected pits. Detection was better for non-impact-melt pits, with 86% of expected detections made, although there may be a sampling bias here, as 13 of the 16 known non-impact-melt pits were originally found using *PitScan*, while many impact melt pits were found by manual search near impact melt pits and related features identified by *PitScan*. Future work will focus on determining why pits are missed by the algorithm, and altering it to increase the detection rate.

Due to the limit on valid Sun elevations, *PitScan* can only search the region within ~50° latitude of the equator (77% of the Moon). To date, the NAC has acquired 307,824 images within the 50° incidence angle constraint, covering 76% of the searchable area.

Conclusion: *PitScan* allows for rapid searching of very large amounts of data to find small unusual features (pits). Currently we run *PitScan* 2-4 times per year (once or twice during each high-Sun imaging period) on all <50° incidence images acquired since the last run. The most recent run searched 17,907 images, using ~1,900 CPU-hours (not adjusted for CPU utilization- most of this time was likely spent on data transfer) on a 600-core processing cluster, and the output (~3,600 clippings) took about 1-2 hours of human analyst time to sort into pits, non-pits, and other interesting items (such as impact melt fractures and flow features, anomalously dark rocks, and a certain class of small, rocky craters with melt ponds). This run found eight images of pits, most of which were already known.

Pit discovery rates have fallen since 2012, mostly due to fewer new discoveries of pits in impact melt (mare pit discoveries have been relative constant, averaging ~1 per year). This drop-off is likely due to one of two factors: 1) The higher-altitude orbit LRO entered in late 2011 (leading to lower resolutions north of ~40° S, thus often placing the relatively smaller impact melt pits below *PitScan*'s size cutoff), or 2) most large young craters (the population most likely to have impact melt pits) having already been imaged early in the mission due to their scientific value.

Additional observations acquired during the LRO Cornerstone Mission and future extended missions will enable the LROC team to increase the spatial coverage of NAC images, and we will continue to use *PitScan* to find pits in this newly-imaged territory.

References: [**1**] Robinson, M.S. (2010), *Space Sci. Rev.* 129, 391-419. [**2**] Wagner, R. V. and Robinson, M. S. (2014), *Icarus*, 237C, 52–60. [**3**] Wagner, R.V. et al. (2013) 44th LPSC, #2924. [**4**] Wagner, R.V. et al. (2017) 3rd Planetary Data Workshop, #7074