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Coalescence and refinement of Moon Zoo crater annotations

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Abstract

The Moon Zoo citizen science project [1] allows members of the public to annotate lunar images, providing researchers with a wealth of location and size information regarding the population of small craters on the Moon. To date, approximately 4 million images have been inspected. Here, we show how data from multiple users can be combined to give a consensus as to the parameters of annotated craters. The process uses annotations and image data to provide Likelihood solutions, revealing the most probable crater parameters, from which crater Size-Frequency Distributions (SFDs) might be produced.

1. Introduction

The analysis of impact craters plays an important role in chronological studies of planetary bodies, yet annotating the location and size of impact craters is a time consuming and subjective activity [2]. To mitigate against this, the Moon Zoo project brings together large numbers of volunteers to identify lunar craters. Users are presented with images, via a web-based interface (www.moonzoo.org), and asked to place markers around visible craters. Each image is presented to multiple users, providing an opportunity for craters to be highlighted several times, giving more confidence in their identification. However, for SFDs to be produced, the raw crater annotation data requires considerable interpretation. The first stage in processing Moon Zoo data involves coalescing annotations from multiple users, allowing clusters of annotations to be associated with individual craters. To ensure efficient use of the data, an understanding of crater parameter errors is required, i.e. how variable centre and radii estimates are across multiple users. The second stage involves a corroborating check, where each annotation is compared against a template image to assess the strength of the pixel evidence for each crater's existence.

A combination of Monte-Carlo data and 40,000+ Moon Zoo annotations from around the Apollo 17 site (NASA's Lunar Reconnaissance Orbiter images M104311715LE and M104311715RE) are used to test the proposed processing stages.

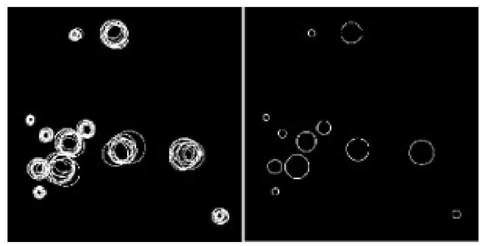

Figure 1: Annotations, before and after

2. Methodology

2.1 Coalescence

Multiple annotations, by different users, can be clustered into the most probable individual mark-ups by constructing a Likelihood description of the problem, then searching the Likelihood function for all local solutions. This begins by assuming Gaussian errors on x, y and radius parameters. Given a set of annotations, the probability that the source of an annotation falls within a particular range of parameters is proportional to the sum of Normal probability distributions, i.e. a logical 'or' where parameters can relate to one crater **or** another:

$$\mathcal{L} = \sum_i \left(\int_{r_{il}}^{r_{iu}} \int_{y_{il}}^{y_{iu}} \int_{x_{il}}^{x_{iu}} \mathcal{N}(x, y, r; x_i, y_i, r_i; \sigma_x, \sigma_y, \sigma_r) dx dy dr \right) \quad (1)$$

where x_i, y_i and r_i are parameters of annotation i, and sigma x, sigma y and sigma r are the errors on these respective parameters. The values of sigma can be estimated by sampling the residual distributions between spatially proximal annotations within different size bands. A brute-force approach is applied to finding all local solutions, with each solution taken as a probable crater. A quantised parameter space is constructed over *x*, *y*, *r*, then populated with Gaussian smoothed entries from each annotation. This process resembles a circular probabilistic Hough Transform [3]. Figure 1 clearly shows the purpose of this step.

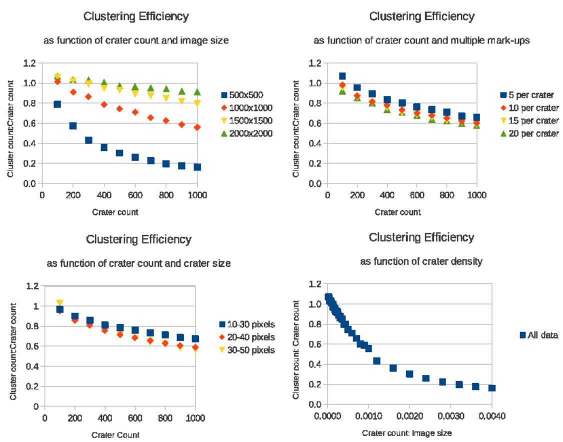

Figure 2: Efficiency of correct clustering

2.2 Refinement

Annotations can be fused with image data to refine parameters and check hypothesised craters against image evidence. Guided by solutions of **2.1**, a crater template is created by extracting examples, scaling to a common size, then computing a mean appearance. To mitigate against local illumination differences, derivative images are used which record local pixel differences, rather than absolute pixel values. The vicinity of the **2.1** solutions are then search for the best matches in image space using a dot-product style match score. The distribution of the resultant match scores provides information regarding the strength of signal within the image, with higher match scores more likely to be real craters. Contamination from false annotations might then be identified through their analysis (see associated abstract 'Quantification of false positives within Moon Zoo crater annotations').

3. Results

40,000+ annotations were used to determine the repeatability of mark-ups, i.e. to estimate the sigmas as described in **2.1**. Parameters (*x*, *y*, *r*) were all found to consistently have a 20% proportional error in relation to the size of the crater. Coalescence results, using Monte-Carlo generated annotations, show very high efficiency when used in sparsely cratered regions. Figure 2 shows this efficiency as a function of crater density. The refinement step of **2.2** was tested on Moon Zoo images, with the distribution of match scores manually separated into true craters and false positive annotations. These distributions are shown in Figure 3.

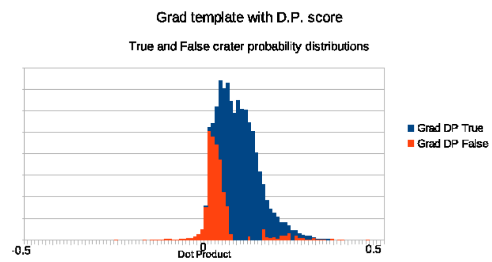

Figure 3: True and false annotation distributions

4. Summary and Conclusions

Key results: 1) The 20% **proportional** errors (relative to crater radii) on *x*, *y* and *r* annotation parameters show that citizen scientists have scale-invariant behaviour. 2) The high efficiency achieved during coalescence (99%) at low crater densities conveniently coincides with typical crater densities found in Moon Zoo data. 3) Refinement match-score distributions are clearly different for true verse false annotations. **Further work**: The match-score distributions must be used to quantify contamination from erroneous annotation before valid SFDs can be produced.

Acknowledgements

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References

[1] K Joy et al., Moon Zoo: Citizen science in lunar exploration; Astro & Geophy v 52 i 2; 2011 [2] S.J. Robbins et al., The Variability of Crater Identification Among Expert and Community Crater Analysts. Planetary Crater Consortium, 4, 2013 [3] H. Kalviainen et al. Probabilistic and non-probabilistic Hough transforms: overview and comparisons, Image and Vision Computing, Volume 13, Issue 4, 1995