ROBUST AUTOMATED IDENTIFICATION OF MARTIAN IMPACT CRATERS. T. F. Stepinski, *Lunar and Planetary Institute, Houston TX 77058-1113, USA, (tom@lpi.usra.edu)*, M. P. Mendenhall, *Dept. of Physics, Caltech, Pasadena CA 91125, USA. (mpm@caltech.edu)*, B. D. Bue, *JPL, Pasadena CA 91109, USA, (Brian.D.Bue@jpl.nasa.gov)*.

Abstract. Impact craters on Mars are identified and characterized by a new, automated system based on a fusion of rules-based and machine-learning algorithms applied to topographic data. Applying this system to six large and diverse Martian sites reveals that, in general, it outperforms existing manual counts. Machine-derived crater sizes and depths are comparable to those measured manually. Sample application for rapid comparison of depth-diameter diagrams characterizing different regions on Mars is given. The system is robust enough to be used, in near future, for cataloging craters over the entire surface of Mars.

Introduction. Detailed analysis of the number and morphology of impact craters on Mars provides the worth of information about the geologic history of its surface. Global catalogs of Martian craters have been compiled (for example, the Barlow catalog [1]) but they are not comprehensive, especially for smaller craters. Existing methods for machine detection of craters from images suffer from low efficiency and are not practical for global surveys. We have developed a robust two-stage system for an automated cataloging of craters over the entire Martian surface using topography data as given by the MOLA Mission Experiment Gridded Data Record (MEGDR) [2] with the resolution of 1/128 degree.

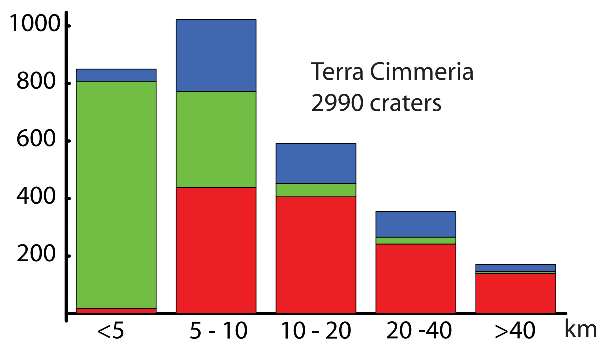
The first stage is a rules-based algorithm that performs an innovative "crater-finding" transform on topographic data to create a series of artificial landscapes, each one optimized for identification of craters with different size. Using these landscapes the rules-based algorithm produces a preliminary catalog of potential craters by identifying all round depressions and calculating their extents, depths, and other characteristics. We made the rules-based algorithm available at cratermatic.sourceforge.net. The second-stage is a machine-learning-based algorithm that eliminates the false positives from the preliminary catalog. A machine-learning algorithm uses a training set of expert-labeled depressions to construct a decision (crater / no crater) function that is then applied to all depressions (their vectors of characteristics) in the preliminary catalog in order to separate craters from other depressions. The result is a final catalog that lists craters' depths in addition to their positions, sizes, and measures of shape. The machine-learning stage is implemented in WEKA (www.cs.waikato.ac.nz/ml/weka/).

Application to the test sites. To test the performance of our crater identification system we have applied it to six large test sites on Mars. The parameters of our identification system are fixed, they are not tuned to account for specificity of each site. The "crater finding" transform is set to identify depressions with radii of about 5 pixels and larger. Thus, the system is set to identify craters with diameters of about 5 km or larger, although, in practice, smaller craters are also identified.

Four of these test sites are located in the Terra Cimmeria between 117.4^{o}E and 145.4^{o}E. The sites are located progressively southward starting from 7.6^{o}S, each site has $\sim$10^o latitudal extent and an area of $\sim 10^6$ km^2. All four Terra Cimmeria sites are dominated by heavily cratered Noachian terrain. Our system has identified 2444 craters in all four sites in comparison to 1987 craters listed in the Barlow catalog for the same areas. Fig.1 (left) gives a detailed comparison between our results and the Barlow catalog. We have divided all craters into five (arbitrarily defined) size bins and compare the quality of the two catalogs in each bin separately. In general our system outperforms Barlow catalog for smaller craters, but fails to identify some large, degraded craters. The remaining two test sites are located at Hesperia Planum (107.1^{o}E, 118.5^{o}E, 17.0^{o}S, 29.6^{o}S) and Sinai Planum (261.5^{o}E, 278.6^{o}E, 10.3^{o}S, 29.7^{o}S), respectively. They are dominated by more sparsely cratered Hesperian terrain. Our system has identified 773 craters in these two sites in comparison to 260 craters listed in the Barlow catalog for the same areas. Fig.1 (right) gives a detailed comparison between our results and the Barlow catalog. Our system clearly outperforms the manual catalog on these sites.

For 1370 craters identified by our system in all six sites, that are also present in the Barlow catalog, we have compared our automatic estimate of crater's diameter to what has been manually measured. Our algorithmically derived diameter is systematically about 15% larger than a diameter manually measured from an image. This difference is due to a specific value of a parameter that controls size estimation. This parameter is set to favor over-estimation of crater size. The ability to estimate crater depths significantly increases the scientific utility of a catalog generated using our system. For 144 craters identified by our system in Hesperia Planum and Sinai Planum the depths has been previously manually derived [3]. The comparison between our algorithmic depth estimates and manual depth estimates reveals a systematic 30% difference. However, most of this difference is likely to be attributed to different definitions of "crater depth." We estimate the depth as difference between the elevation of the highest point on the rim and the elevation of the crater floor, but in the manual calculations the depth was defined as the difference between an average elevation on the rim and the elevation of the crater floor.

Our system allows for fast generation of depth-diameter diagrams for different regions on Mars. Such diagrams, constructed for the four Terra Cimmeria sites, show a qualitative difference between the three northmost sites, where craters naturally cluster into "deep" or "shallow" populations, and the southmost site, with "deep" crater population severely depleted. Fig.2 summarizes this result by showing a depth/diameter ratio as function of a latitude for craters in all Terra Cimmeria sites. Northward of $\sim 38^o$S the two populations of craters coexist, with "deep" population constituting a majority, but southward of $\sim 38^o$S only "shallow" craters are observed.



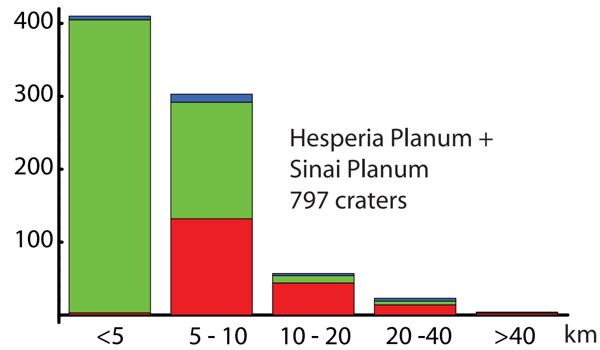


Figure 1: Comparison of crater counts between our automatic system and manual Barlow catalog for craters of different sizes. Red - craters present in the Barlow catalog and identified by our system, green - craters identified by our system but absent from the Barlow catalog, blue - craters present in the Barlow catalog but not identified by our system. (Left) Four Noachian sites in the Terra Cimmeria. (Right) Two Hsperian sites, Hesperia Planum and Sinai Planum.

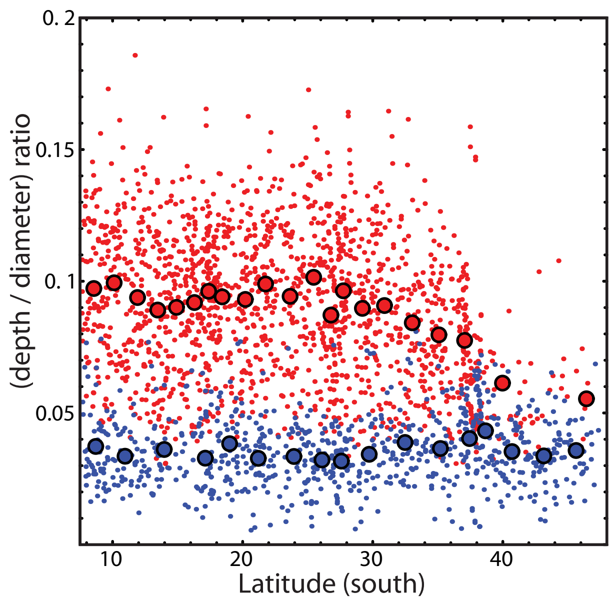


Figure 2: Depth/diameter ratio as function of latitude for 2444 craters identified in the four Terra Cimmeria sites. The red dots indicate craters labeled as "deep" and the blue dots indicate craters labeled as "shallow". The labels are assigned on the basis of clustering observed on the depth-diameter diagram (not shown here). Larger circles indicate mean values of depth/diameter ratio calculated from equally spaced bins in latitude for "deep" craters (red), and separately for "shallow" craters (blue). They indicate the overall trend of depth/diameter ratio dependence on latitude. Somehow similar result was obtained previously by means of tedius manual measurements for Hesperia Planum [4] and Noachian regions in the southern high latitudes [5].

Discussion. The extensive testing reveals that our system is robust enough to be used for cataloging craters over the entire surface of Mars. We expect to compile such a catalog by the end of 2007. Based on the results from the test sites we expect that it will list more craters than the Barlow catalog. It will list estimates of crater depths allowing extensive examination of spatial distribution of craters depth/diameter ratio. We are also planning on cross-referencing our catalog with the Barlow catalog that contains numerous morphological descriptors. In addition to our own effort to catalog craters on Mars, we have made our code (and its documentation) freely available to the community. Our system is scale-independent and is expected to work without significant modification on higher resolution DEMs (for example, on DEMs derived from Mars Express HRSC images) to identify smaller craters. It also can be applied to future topography data from other planets. For example, it may be utilized to catalog craters on Mercury and the Moon using altimetry data to be gathered by Messenger and LRO spacecrafts.

References

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