Crater Detection Algorithm (CDA) – A Tool to Explore the Planetary bodies

Impacts and cratering on solar system objects is a fundamental and continuing process. Recognizing and distinguishing impact craters is a difficult task even for expert observers, because of their varied sizes and vast presence. Identifying and analyzing impact craters individually is a time consuming and extremely difficult job, though, interestingly they are the dominant feature on the surface of planetary bodies (Mars, Mercury), satellites (Moon, Phobos) and even asteroids (Eros, Vesta). This dominating nature acts as a gateway, through which the planetary body can be explored. What can be inferred from craters? They can tell us a lot about what’s going on a planetary surface.

Need for the CDA:
The importance of crater detection on planetary bodies relay on their detailed morphological analysis that the algorithm can bring forth. The deployed crater detection algorithm should be capable of retrieving relevant information from each crater along with their detection. If so, the need for such automatic algorithm is fulfilled. Initially, the CDA was only developed to detect the crater, but the advancement in computing technology and algorithm development, allow the extraction of relevant information from each crater. But, the complexity in planetary surface posses a great challenge to such algorithms because of their heterogeneous nature in the surface as seen in Fig.1.

The information obtained from previous CDA are like number of craters automatically detected (Bue and Stepnski 2007, Salamuniccar et al 2011) and their relative count for age estimation (Sawabe et al 2006). The absolute ages derived from the radiometric dating of Apollo samples are used as a base source to estimate the age from crater counting. Crater chronology depicts that the surface that has certain number of craters of certain size will inform about the surface age. In general, it is defined as, older the surface it holds more number of craters and younger surface holds relatively less number of craters. This condition is handled carefully, because the presence of secondary craters will have a great influence in the estimation of surface age. Thus, one of the main tasks of CDA’s is to generate catalogues of craters for age dating.

But this is not the only task for which the CDA was deployed. Besides this, the current algorithms are more focused to extract crater characteristics and their contextual information. The former one includes the crater diameter, depth, type, etc., whereas the later one depicts about the presence/absence of ejecta, their aerial extent, etc. These will explain about the crater process and depicts about the surface on which they are formed. Moreover, the current CDA’s are proceeding towards utilizing the hyperspectral images in addition to the detected crater to spectrally classify them.

Due to the voluminous data available on planetary bodies, the need for the automatic algorithm is inevitable. Salamuniccar et al (2011) lists the currently available ~83 crater detection algorithms and few of those CDA’s are listed in Table 1. Most of the developed algorithms are DTM-based, and are predominantly available for Martian surface. From the data source point of view, two types of algorithm were available, they are image-based (most often panchromatic) and elevation-based (DEM/DTM).
However, some of the algorithm utilizes both dataset to detect craters. The detection process will differ for panchromatic and DEM/DTM based images. In this article, the image- and DTM-based approaches are discussed using the planetary images. In addition, extensions of such algorithms to asteroids are also discussed.

**Image-based algorithm:**

In panchromatic images, the craters are easily distinguishable by their occurrence of shadow-bright pair. The first step in panchromatic image based CDA is to identify and discriminate the bright and shadow parts of the crater. The threshold technique is the widely used approach to discriminate crater parts in most of the detection algorithms. In accordance, the image-based approach uses techniques like gradient and texture analysis, Haar transform, pattern recognition, etc for further processing. The CDA detection process includes an edge detection filter, binarization and circular pattern detection using hough transform.

Fig. 2 shows the CDA applied to the lunar and Mars images. In the Lunar images, along with the crater detection the CDA is also capable to detect the overlying craters. Earlier crater detection works were carried out for larger diameter craters, but advancements in planetary imagery resolutions leads to detect even sub kilometer craters. Urbach and Stepinski (2009) CDA capable to detect Mars sub-km crater based on the pairing crescent like highlight and shadow regions. The scale and rotation-invariant shape filters were used to identify the pair along with the use of power and area filters. Mathematical morphological principle (minimum distance technique) is used to match the pair and form the crater candidate.

### Table 1. Some of the existing CDA

<table>
<thead>
<tr>
<th>Satellite instrument/ Image (Pan/DTM)</th>
<th>Planetary body</th>
<th>Technique</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apollo and Clementine/ Pan</td>
<td>Moon</td>
<td>Multiple approaches</td>
<td>Sawabe et al (2006)</td>
</tr>
<tr>
<td>MOC/ Pan</td>
<td>Mars</td>
<td>Template matching technique</td>
<td>Bandeira et al (2007)</td>
</tr>
<tr>
<td>MOLA/ DTM</td>
<td>Mars</td>
<td>Unsupervised learning</td>
<td>Bue and Stepinski (2007)</td>
</tr>
<tr>
<td>HRSA/ Pan</td>
<td>Mars</td>
<td>Shape and Texture based</td>
<td>Bandeira et al (2012)</td>
</tr>
<tr>
<td>LOLA, MOLA/ DTM</td>
<td>Moon/Mars</td>
<td>Crater shape based learning</td>
<td>Salamuniccar et al (2012)</td>
</tr>
</tbody>
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Figure 2: Panchromatic image based CDA (Top) Moon, taken from Sawabe et al. (2006) and (Bottom) Mars, taken from Martins et al (2009). The detected craters are bounded by a circle/box.
Subsequently, supervised machine learning and decision tree algorithm were used to distinguish the crater regions. The algorithm achieved a detection rate of ~70% and this was intently made to detect only sub kilometer craters because of their larger presence. The image based crater detection algorithm is widely dependent on the illumination and view angle. The low illumination angle will create a large shadow and have a severe effect on the crater under study. But, current algorithms are invariant to scale and rotation, thereby they are capable to detect craters irrespective of Sun angle, until otherwise it is not a low angle image.

DTM-based algorithm:
In general, the simplest way to distinguish and detect craters from the DTM images is by their depression. The crater depression will create a darker tone in the DTM image, whereas the elevated rim represents a brighter tone. The DTM-based approach utilizes crater depression, fill sink techniques, etc to detect the craters. But, not all the depressions are craters. This make the detection process complex, these non-crater depression are caused by 1) undulating topography, 2) rilles, etc. Due to the rugged topography and bombardments from small impacts the planetary surface is predominant with small depressions. The DTM-based CDA carry out a smoothing process during the crater detection process to remove the small depression. Using the flooding algorithm, all the depressions are filled up and these filled regions are easily demarcated using thresholding to produce binary images. With the use of morphological closing and thinning operation, the crater candidature can be narrowed down. Finally, each crater was extracted by applying the hough transform. Fig. 3 shows the Mars topography data obtained from MOLA. The figure on the left shows the detected depression on the topography data, whereas the figure on the right shows the delineated craters. This clearly depicts that all the depressions are not craters. The local depression is one of the major hindrances in the automation process. Delineating such local depression will greatly improve the detection process and also helps to estimate a better surface age.

Though the crater detection was carried out automatically, the extension of detection to the planetary surface age estimation is still under anvil. The age estimation is widely carried out manually by counting the craters. Now-a-days the detection process was checked not only for their efficiency but also for their reliability in detecting craters. The Receiver Operator characteristics (ROC) curves are used to statistically quantify the detected craters for their authentication. Such statistical measure greatly improves the reliability on detected craters. And this has made way to directly estimate the age from the detected craters.

Crater detection on Satellites and Asteroid:
The crater detection algorithm is not only developed to analyze the planetary images, rather it is also developed for asteroid and other small bodies to carry out the landing mission. A visual positioning system by Leroy et al (2001) used to explore asteroids, with autonomous spacecraft landing. The detection of surface feature or crater in the asteroid will be utilized to precisely position the spacecraft with regard to the asteroid, and chooses a landing site. Fig. 4 shows the crater detection carried out on the Eros asteroid, similarly for the Mars moon Phobos.

![Figure 3: (Left) Depression detected on the topographic image, (Right) distinguished craters are separated from local depressions. (Source: Stepinski et al., 2012)](image-url)
also. Though the current crater detection algorithm was extended to these small bodies successfully, some solar system objects have created difficulty in the detection process because of their complex shape. These preliminary CDA analyses on such small bodies are carried out in view of future safe landing on such bodies. Similarly, there is a current initiative to investigate Vesta’s surface history through craters. The extent of CDA to other small bodies in the solar system is to understand the distribution and formation of craters on such bodies. Essentially, the asteroid belt is a very different place in the solar system, which is dominated by number of features of all sizes and shapes. One among the largest body on the asteroid belt is Vesta. CDA was carried out to understand their distribution pattern. Moreover, Vesta also has pit chains on its surface that look very similar to crater chains on Moon. Study on crater distribution may reveal a different cratering history for Vesta when compared to other planetary bodies.

Open source CDA:
The first global Martian crater database was created by Barlow for craters >5 km. The recently developed crater detection algorithm for the Martian surface can be found at [http://craters.sjrdesign.net/](http://craters.sjrdesign.net/). This CDA developed by Robbins, S.J, is capable to detect craters from 1 to 512 km, and one of the simplest uses of it is to age-date the features. This CDA has completed the first global Mars crater data base by detecting ~384,343 craters. For the detection purpose the THEMIS Daytime IR mosaics at 232 m/pix and 100 m/pix scales are used. In addition to this, it also uses the MOLA gridded data at 463 m/pix to extract the elevation details. This algorithm is an open source, the users can query their interested location and crater size, and in return the CDA gives approximately 90 different columns of possible information for each crater. Similarly, there are many algorithms as listed in Table 1, which have their own technique to detect the craters. These kinds of algorithms reduce the manual involvements and fetch the required information from the planetary images in an efficient manner.

Along with this CDA the other open source automatic/manual crater detection tools available for scientific exploration are, 1) ImageJ used to extract features from images, it can be customized to detect craters ([http://rsbweb.nih.gov/ij/index.html](http://rsbweb.nih.gov/ij/index.html)), 2) Program for plotting crater counts and to estimate the surface age ([http://hrscview.fu-berlin.de/software.html](http://hrscview.fu-berlin.de/software.html)), 3) Crater tools ([http://webgis.wr.usgs.gov/pigwad/tutorials/scripts/](http://webgis.wr.usgs.gov/pigwad/tutorials/scripts/))

Most of the crater detection algorithms are developed for regional or global studies. The CDA developed for regional studies utilizes high resolution images and capable to detect even meter-scale craters. On the other hand, the CDA developed for global studies uses coarse resolution images and are capable to detect larger craters.

Further Reading:

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