

AUTOMATIC CRATER DETECTION ON LUNAR SURFACE

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Abstract: This paper focuses on automatic identification of lunar craters in the context of safe landing site identification. Craters appear on the lunar surface in high density and are the most interesting features of any planetary surface. In this paper, the technique presented is for crater detection and fitting an ellipse after determining the position and orientation of the craters. Image smoothing is optional as it is done to extract crater features greater than a specified size from the image. Morphology gradient technique is used in this approach to extract edges belonging to craters only. Ellipse is fitted on the edge map using least square error and square completion method. This algorithm is tested on different datasets of Chandrayaan-1 TMC and LRO (NAC) and results are compared with manually detected craters.

Keywords: Craters, least square error, square completion, morphology gradient.

I. INTRODUCTION

Technologies for planetary landing have been studied and developed since the late fifties during the Moon race, which culminated in 1969 with the first human landing on the Moon. Nowadays, instead of humans, small probes/landers are sent to distant planetary bodies. These landings are often performed by a pre-programmed time sequence of events that bring the lander to a full stop in a desired area at the planet surface [1]. There are many surface hazards in the form of craters, rocks, faults, ridges, ravines, boulders, slopes and channels existing over the entire surface of solar system bodies. Landing a spacecraft of probe safely on a body surface autonomously requires the ability to detect and avoid hazards on the surface. In order to achieve precise and safe landing, future planetary landers should have the ability of hazard detection and avoidance.

Now-a-days many missions are launched to unknown planets to know about the life on the planetary surface. Craters are studied more because craters are vital feature to estimate the age of the planetary surface. Craters are concave terrain generated by meteorite impacts or volcanic activity. The moon has no atmosphere so craters are important for studying the morphology of the lunar surface, the structure of lunar rock and origin of the moon [2]. Craters of varied size are ubiquitous on planetary surfaces.

To detect craters manually is difficult and time consuming task. As there is a large volume of data from different satellites and extracting efficient information from every image is a difficult task. There are various automatic and semiautomatic techniques to overcome this problem [3-7].

In [8], the authors proposed a method for crater detection. The algorithm is divided in six steps: Edge Detection, Crater anchor point detection, Rim edge grouping, Ellipse fitting, Ellipse refinement and Crater confidence evaluation. Experimental studies show that this algorithm has achieved sub-pixel accuracy in position, its detection rate is better than 90% and false rate is lesser than 5%.

Region segmentation method proposed by Kun Li et al [9] used non local means algorithm for image filtering before edge detection. Different morphological operations are applied for regional segmentation. Template matching approach is used to detect and identify the craters for approximately circular regions, and for other irregular craters candidate regions are used for statistical analysis.

The method in this paper, obtains the edge map using image smoothing and morphology gradient. The method is dependent on feature extraction. Once the edge map is obtained, the ellipse is fitted on the connected component of edge map using least square error and square completion method.

This paper is organized as follows. Section II describes how the edge map is generated automatically. After edge detection, ellipse fitting using a least square error and square completion method are given in Section III. Section IV

presents experimental results showing results on Chandrayaan-1 Terrain Mapping Camera (TMC) and Lunar Reconnaissance Orbiter Narrow Angle Camera [11] images. Finally, Section V presents conclusion and future scope of work.

II. CRATER DETECTION

A typical crater in an image has a circular rim surrounding a bright-to-dark shading pattern dictated by the lighting angle and the crater's topography. These distinguishing characteristics are used extensively in crater detection. The structure of the crater detection algorithm is shown in Figure 1. The proposed crater detection algorithm employs image smoothing followed by gradient image and thresholding. Image smoothing is applied on the gray scale image.

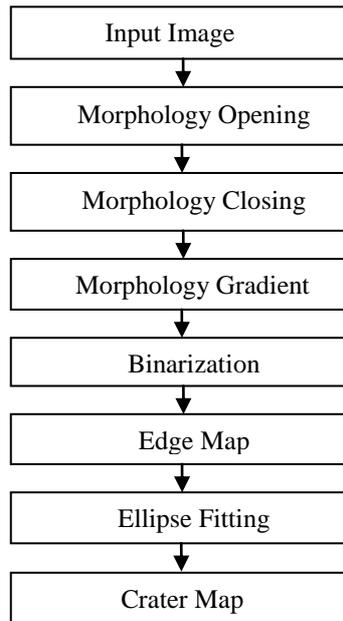


Fig.1 Structure of Algorithm

As this is a feature based method, morphological image smoothing is done. Morphology smoothing is a combination of opening and closing, as opening suppresses the bright part and closing suppresses the dark part. The advantage of morphological smoothing compared to other smoothing algorithm is that it will discard the features less than the structuring element size. So to detect craters greater than specified size, morphology smoothing is very useful approach.

$$\text{Opening} = f \circ b = (f \ominus b) \oplus b$$

$$\text{Closing} = f \bullet b = (f \oplus b) \ominus b$$

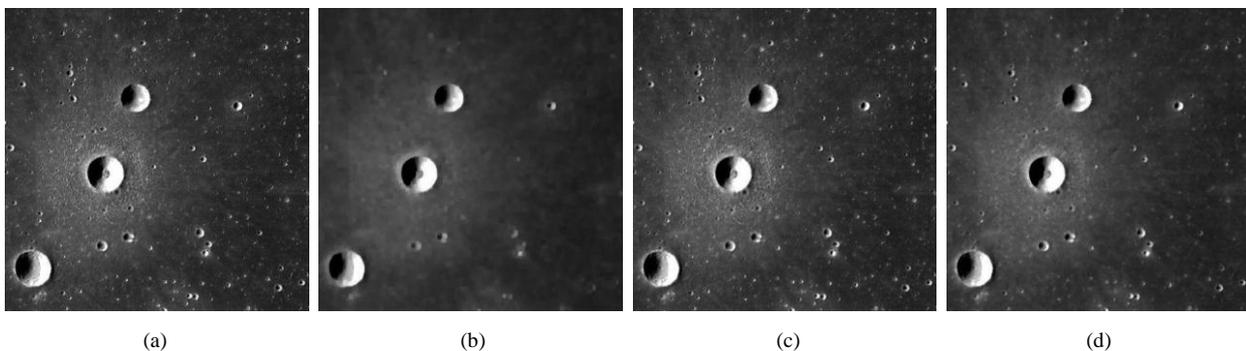


Fig.2 Image Smoothing (a) Input Image[11] (b) Image smoothing using morphology operation (size of structuring element is 2)(c) Image smoothing using Gaussian (d) Image smoothing using size of structuring element 1.

Figure 2 shows the output of image smoothing on the input image. Figure 2 (a) is the input image. Figure 2 (b) & (d) are the outputs of image smoothing with different size of structuring element. Figure 2 (c) is the output of Gaussian image smoothing applied on the input image. It can be clearly seen; morphology smoothing not only removes the noise but also extracts desired crater features.

Usually craters are of circular so to detect only circular edges morphology gradient operation is applied on the image. Circular edges can be extracted by specifying the shape of structuring element as disk. Morphology gradient is a combination of dilation and erosion. Dilation thickens the regions in an image and erosion shrinks them. Their difference emphasizes boundaries in a region. The benefit of calculating gradient using morphology over other edge detection technique is that it will detect edges only of circular shape. Edges of irregular shape will be discarded.

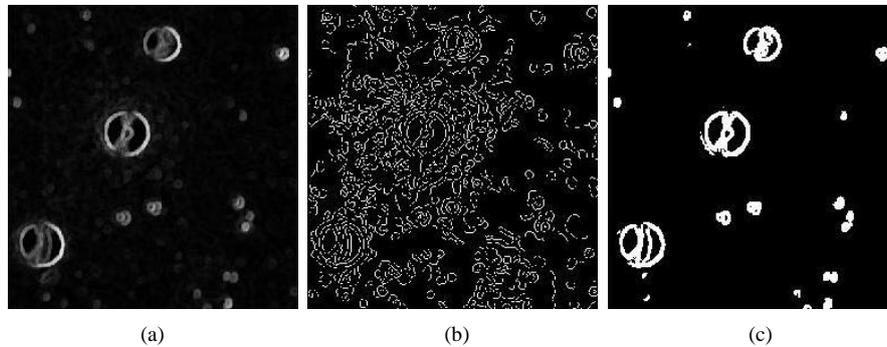


Fig.3 Edge Detection (a) Edge detection using morphology (b) Edge detection using canny algorithm (c) Edge Map.

Figure 3 (a) shows the output of edge detection using morphology and (b) shows the output using canny algorithm. Figure 3 (c) shows the edge map generated by applying global threshold on the gradient image. It can be concluded that canny algorithm produced many extra edges that does not belong to the craters. Thus to extract edges that belong to craters a threshold is to be selected. Selecting an optimal threshold value is a tricky task because single threshold value cannot work for all images.

$$\text{Morphology Gradient} = (f \oplus b) - (f \ominus b)$$

A thresholding operation is performed on Gradient operation to separate out edge pixels from background. Global thresholding technique is used to produce the binary image.

III. ELLIPSE FITTING

Once an edge map is obtained, next step is to fit an ellipse to the regions of craters extracted from the edge map. Regions are extracted using connected components in the edge map. Boundaries of the regions are extracted to fit an ellipse on that region.

Ellipse fitting is done using least square error method. This method is more efficient and accurate than many other alternative approaches for ellipse fitting like Hough transformation, fuzzy and c-shell clustering. Least square method is used to fit an ellipse using boundary points with minimum error [10]. Least square method takes less time and is less complex than other techniques mention above. Hough transformation requires a large memory space and its calculations are too complex. In fuzzy, some template or raining data sets are needed. C-shell clustering algorithm will need some threshold value for clustering the data points belonging to one crater. Parameters of ellipse are calculated using square completion method.

Ellipse fitting using least square error method is done using following equations. Parametric equation of an ellipse is

$$Ax^2 + Bxy + Cy^2 + Dx + Ey + F = 0$$

Candidate pixels from edge map are substituted in parametric equation and parameters of ellipse parametric equation are calculated.

Orientation is calculated using

$$\theta = \frac{1}{2} \tan^{-1} \frac{B}{(C - A)}$$

Plot ellipse using below equation

$$\begin{aligned} X &= X_0 + a \cos \theta \\ Y &= Y_0 + b \sin \theta \end{aligned}$$

To obtain coordinates of points on the tilted ellipse multiply points with rotation matrix to rotate the axis with respect to θ .

$$R = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}$$

Co-ordinates of ellipse = R * [X; Y]

Figure 4 shows the output of crater detection with ellipse fitted on the detected craters.

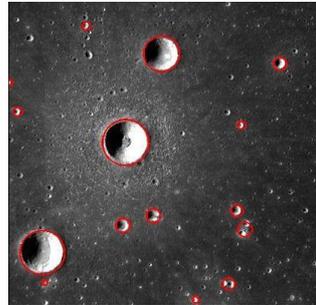


Fig.4 Detected Craters with Ellipse fitting

IV. EXPERIMENTAL RESULTS

Proposed algorithm is implemented and tested on CHANDRAYAAN-1 (TMC) and LRO (NAC) images [11]. Different types of images are taken for validation of the crater detection method, proposed in this document. Results tested on LRO satellite images are shown below. The result of the proposed algorithm is compared with manually detected craters.

In figure 5 (a) craters are detected manually so that the output of the proposed algorithm can be compared with the desired output. Figure 5 (b) shows the result of the proposed algorithm.

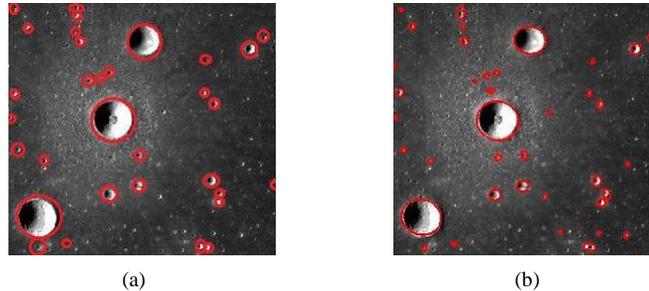


Fig.6 (a) Crater Detected Manually (b) Crater detected using proposed algorithm

From the above result it can be concluded that the proposed algorithm is able to detect almost all craters properly and parameters of the ellipse are getting calculated accurately using least square method. Proposed algorithm works on the connected components so the twin craters in figure 5 (b) are detected as one crater by the proposed algorithm. The purpose of the algorithm is to detect hazardous places, so this is not going to affect our objective. Individual craters are detected with proper accuracy. The proposed algorithm is able to detect craters of different sizes.

Results tested on CHANDRAYAAN – 1 satellite images are shown below. Images are captured using TMC with 5 meter by 5 meter per pixel resolution.

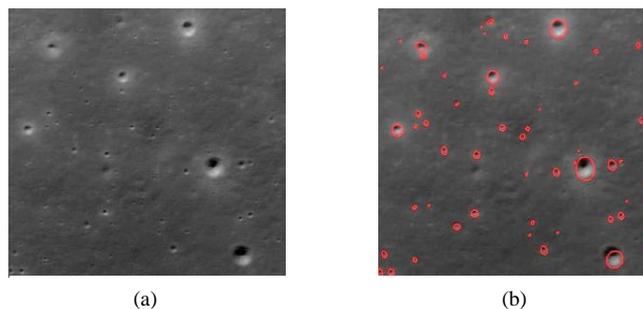


Fig.6 (a) Input image (b) Crater detected using proposed algorithm

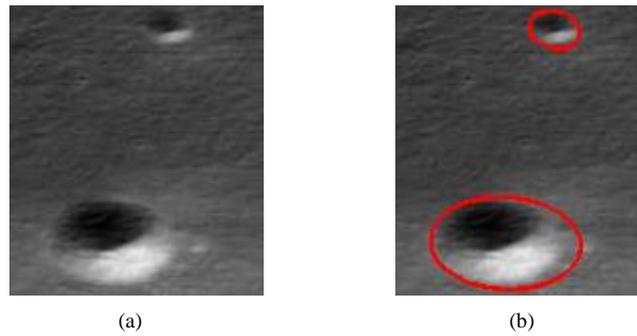


Fig.7 (a) Input image (b) Crater detected using proposed algorithm

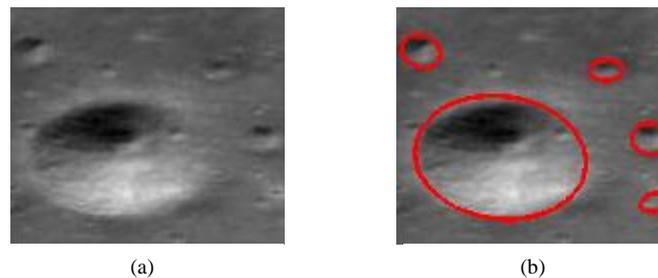


Fig.8 (a) Input image (b) Crater detected using proposed algorithm

In figures 6 (a), 7 (a) and 8 (a) are input images of TMC Nadir. Figures 6 (b), 7 (b) and 8 (b) shows the result of the proposed algorithm.

V. CONCLUSIONS

This paper focuses on detection of craters on lunar surface. The structure of algorithm has been shown in flowchart. Firstly, the input image of lunar surface containing craters is smoothed so that noise is removed and unwanted features get suppressed. Further gradient map is formed so that edges of circular shape are extracted only, other edges are discarded. Then thresholding is applied to generate an edge map on the gradient map so that only prominent edges from the gray image can be extracted and others can be discarded. For precise landing of a lander on the lunar surface ellipses are fitted using connected components of the edge map. Parameters of ellipse are calculated using square completion method and ellipse is fitted using least square method. The algorithm is dependent on the edge strength of the image so, if edge strengths are weak, algorithm will not be able to detect edges properly. Proposed algorithm does not work properly for low contrast images. Some pre-processing is required to convert the image to high contrast. Ellipse is fitted using common connected components of the edge map. So, twin craters are not detected individually because twin craters have common connected components. Proposed algorithm is very useful to detect craters greater than a specified size.

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