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3 authors, including:

Nur Diyana Kamarudin
National Defence University of Malaysia

Siti Noormiza Makhtar
National Defence University of Malaysia

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Craters Detection on Lunar

Nur Diyana Kamarudin, Siti Noormiza Makhtar, Hizrin Dayana M.Hidzir

Department of Electrical and Electronic Engineering, Faculty of Engineering, Universiti Pertahanan Nasional Malaysia, 57000 Kem Sg. Besi, Sg.Besi, Kuala Lumpur

east.diyana@gmail.com, noormiza@upnm.edu.my, hizrin@upnm.edu.my

Abstract **— This project focuses on identification of craters in terms of its characteristics and detection of these visual features of the moon to determine a safe landing site for a lunar Lander. Cheng et al. proposed using craters as landmarks for navigation purposes because this geometric model grants a robust detection under different lighting conditions. Moreover, craters appear in enough density on most planetary system bodies of interest and also known as a fairly stable in appearance or shapes over time or under different conditions and environments. These special features make them an appropriate type of landmark to observe. Currently, there are a lot of ongoing researches mainly on craters detection and optical navigation systems for the moon but still using a complex and similar approach such as detection using the Hough transform method. To part from this limitation, the author decides to build a simple algorithm for detecting craters on a moon surface which will detect the craters based on two important measurements that are the distance and angle measurements. The advantages of using this approach are (1) its uncomplicatedness (2) fast detection (3) can be used further in ellipse reconstruction algorithm to determine the position and orientation of the crater. This paper will discuss the method of employing MATLAB and image processing tool on an optical image as well as the morphological image detection fundamentals. In addition, some geometrical projection analysis in reconstructing an ellipse as a disc will be evaluated in order to obtain the orientation of the disc (crater) for autonomous optical navigation system.**

Keywords-morphological image detection, light and dark patches, distance and angle measurement, ellipse reconstruction algorithm.

I. INTRODUCTION

Crater plays a vital feature to estimate the age of the moon surface when sample specimen is not available [2, 3]. An autonomous craters detection algorithm will help space research scientists by reducing their laboratory works of manually identifying those craters. Previously, several automatic and semi-automatic crater detection algorithms were proposed [4], but their accuracy was not enough for craters chronology and yet they're all not being tested fully for practical use (example: spacecraft navigation). Craters chronology means the history or the sequent of events that formed the craters on the lunar surface and the variety of its features. Optical Landmark Navigation using craters on the planetary surface was first used operationally by the Near Earth Asteroid Rendezvous (NEAR) mission [6, 7]. This mission is to determine the spacecraft orbits about the body for close flybys condition and low attitude orbiting [5].

Many planetary missions such as SELENE (Selenological and Engineering Explorer) and Clementine takes moon surface images for ongoing research. This contemplation to the moon exploratory particularly will help us divulge the unimagined information and characteristics of planetary science on a moon surface mainly. In 2006, a Japanese Lunar Orbiting Spacecraft were launched and is expected to bring a large amount of useful data for ongoing planetary research. However, it is known that the images taken under the low sun elevation, such as those from 'Lunar Orbiter' and 'Apollo' are suitable for crater detection to differentiate the 'light and dark patches' for sooner analysis.

Current descent and landing technology for planetary operations, such as those to lunar, is performed by a landing error ellipse greater than 30x100 kilometers without terrain recognition or hazard avoidance capability. Most of the earlier research on lunar pin point landing specifically, has a limitation such that requires *a priori* reference map describing the past and future lunar imaging and digital elevation map data sets in order to detect the landmarks on a particular planetary surface. Due to this limitation, the author proposes a landmark-based detection algorithm named craters detection algorithm to detect main hazards on the moon surface independently from those references in order to produce a reliable and repeated detection system. This intelligent imagery-based algorithm will detect craters based on their pointing direction relative to the sun and classification to differentiate between the light and dark patches.

II. CRATERS DETECTION ALGORITHM

This reliable topography-based Craters Detection Algorithm that we have proposed here mainly based on real image (optical image) analysis and morphological image analysis. There are sequence stages of the codes in order to get a satisfaction result by assuming that the sun elevation angle to be known. The algorithm flowchart can be comprised as figure (1) below. To reduce the complex analysis on image detection, the author analyzed a 2-D optical image. The threshold for the image is set using intelligent approach from Sawabe, Natsunaga and Rokugawa in classification of images as can be shown in equations (1) below.

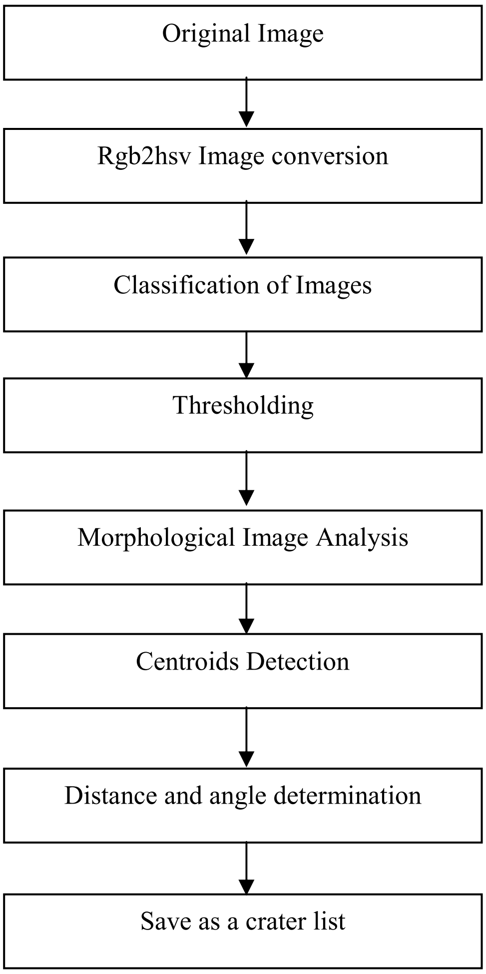


Figure (1): Flowchart of the proposed Craters Detection Algorithm.

By using this approach, images were classified into two components that are light and dark patches or obviously known as 'sunny and shady patches' with a regard of known sun direction or sun vector. Ideally, these two groups of patches are easily recognizable if image was taken under low sun elevation. These patterns of light and dark patches were detected when all these equations are satisfied [5]:

$$\begin{gathered} R_{min} < R_m - \sigma \\ R_{max} > R_m + \sigma \\ P_{min} < P_{max} \end{gathered} \tag{1}$$

where R_{min} indicates the minimum pixel value, R_{max} indicates the maximum pixel value, R_m indicates the average pixel value and σ indicates the standard deviation in the small area including the target patches. P_{min} and P_{max} indicate the positions at the minimum and maximum value pixels from the direction of the sun radiation or sun vector [5].

To classify and consider it as a crater, two ways of detection are proposed which is minimum distance measurement and angle detection based on known sun vector. In distance measurement, the minimum distance between each of the centroids calculated previously is determined using this formula:

$$|\mathbf{Distance}| = \sqrt{[(\mathbf{x}^2-\mathbf{x}^1)^2 + (\mathbf{y}^2-\mathbf{y}^1)^2]} = |\mathbf{r}| \tag{2}$$

Where |**Distance**| is the measurement of the distance between two pairing patches (light and dark), $\mathbf{x}^2,\mathbf{x}^1$ are the x-component of the centroids and $\mathbf{y}^2,\mathbf{y}^1$ are the centroid's component of the y-axis respectively. In angle determination, there will be an input for sun vector which is known by looking at the sunrays effect at those craters (the position of the light and dark patches). This algorithm will then compute each of the angles of every pairing patch with their minimum distances using scalar product or dot product in vector analysis which is:

$$\mathbf{r} \cdot \mathbf{s} = |\mathbf{r}|\,|\mathbf{s}| \cos\theta \tag{3}$$

where
- $\mathbf{r}$ = vector of each pairing blobs
- $\mathbf{s}$ = sun vector
- $|\mathbf{r}|$ = distance/length of each pairing blobs
- $|\mathbf{s}|$ = distance of sun vector = unit vector = 1
- θ = angle between sun vector and vector of each pairing blobs.

Each of pairing patches angle is calculated using above equation and those who has minimum angle with regards to the sun vector and has a minimum distance calculated previously will be considered and stored in a crater list. Oppositely, those who are against the direction and have the maximum angles with regards to the sun vector will be scrapped and considered as noise.

III. ELLIPSE RECONSTRUCTION ALGORITHM

A. Bounding Ellipse Algorithm

The geometrical part is generally based on mathematical analysis on vector calculus, the rotation matrix, ellipse equations and also the mathematical applications to presently determine the orientation of a crater. From the previous codes, one of the best craters in a crater list was chosen to run a bounding ellipse algorithm around the target crater. The bounding ellipse algorithm input the P matrix which is composed from the target crater itself and the tolerance. The tolerance is set to obtain more precise result. The bounding ellipse equations are denoted by:

$$\frac{((x-xo)\cos\omega+(y-yo)\sin\omega)^2}{a^2} + \frac{((-x+xo)\sin\omega+(y-yo)\cos\omega)^2}{b^2} = 1 \tag{4}$$

$$(\tilde{x}-\tilde{c})^T A(\tilde{x}-\tilde{c}) = (x-xo)^2 A_{11} + ((x-xo)(y-yo))$$
$$(A_{21}+A_{12}) + (y-yo)^2 A_{22} = 1 \quad (5)$$

The output will be the **A** matrix and **c**, the centre of the ellipse. **A** matrix is in the form of

$$\mathbf{A} = \begin{pmatrix} A_{11}\, A_{12} \\ A_{21}\, A_{22} \end{pmatrix} \quad (6)$$

All the ellipse parameters that are embedded in this A matrix can be extracted by using those two bounding ellipse equations above yields

$$a = \left(\frac{2\sin 2\omega}{(A_{11}+A_{22})\sin 2\omega + 2A_{12}}\right)^{1/2} \quad (7)$$

$$b = \left(\frac{2\sin 2\omega}{(A_{11}+A_{22})\sin 2\omega - 2A_{12}}\right)^{1/2} \quad (8)$$

$$\omega = \tan^{-1}\left(\frac{-2A_{12}}{A_{22}-A_{11}}\right)/2 \quad (9)$$

The next step is to draw the ellipse using another algorithm using all those parameters above and also the centre of the ellipse that can be determined straight away from the bounding ellipse algorithm. The bounding ellipse algorithm gave the same value in semi-major axis ***a*** and semi-minor axis ***b*** which means that we have a circle. This output tells us that our space camera is actually pointing straight around 90 degrees vertically to the target crater on the moon surface. If we have an ellipse instead of a circle, that means that the camera is not pointing straight 90 degrees downward and pointing quite away from it (crater).

B. Reconstruction of Ellipse in an Image Plane

This reconstruction vision is to model the craters or projected ellipse as a disc. Mathematically, the concepts are adapted by taking the focal point as an origin of a camera frame and the x-axis is aligned with the focal axis of the camera and x>0 is what the camera looking for [8]. Furthermore, the image plane is always assumed in front of the focal point rather than those in practice. Taking this objective into account, the half length of the semi major axis ***a*** is taken to 0 because it is a disc. In comparison, the half length of the semi-minor axis ***b*** is actually the radius of the crater or a disc. This reconstruction or projection ellipse algorithm is based on Stephen's proposed complex method on reconstruction spheroid [8].

There are two vital equations of reconstruction a disc that will be used in this reconstruction algorithm to determine the position and orientation of the spacecraft which are described as below [8]:

$$\tilde{q} = \frac{B}{\sin\alpha}\left\{\cos\beta\tilde{R}_1 \pm_1 \cos\alpha\sin\beta\sqrt{\tan^2\alpha - \tan^2\beta}\tilde{R}_2\right\} \quad (10)$$

$$\tilde{p} = \pm_2 \cot\alpha\left\{\frac{\sin\beta}{\cos\alpha}\tilde{R}_1 \pm_1 \cos\beta\sqrt{\tan^2\alpha - \tan^2\beta}\tilde{R}_2\right\} \quad (11)$$

where:

$\tilde{q}$ = is the position of the reconstructed ellipse
$\tilde{p}$ = is the orientation of the reconstructed ellipse
B = is the radius of a disc (craters that we model as a disc)
α= is the arc length of the semi-major axis
β= is the arc length of the semi-minor axis
$\tilde{R}_1$= Rotation matrix of the column vector
$\tilde{R}_2$=Rotation matrix of the column vector

The two equations above where as we can see the equation $\tilde{p}$, the orientation of a disc, is independent of parameters B (the radius) which means, we can determine it straight away using our reconstruction algorithm to determine the orientation of the spacecraft relative to the moon surface. There is the ambiguity case in equation $\tilde{p}$ which is the negative and positive case of $\pm_2$ sign. In this facts, the $\tilde{p}$ equations always takes a positive value instead of negative value as the crater's orientation is just pointing upward towards a camera or in other words a disc will only be seen if its outward face points towards the camera rather than away [8]. This is discerning case; when one considers how human calculates an object's position, its exact size is needless in finding the direction of neither its centre nor its orientation. In contrast, the equation $\tilde{q}$ anyway is dependent to the radius of a disc, B, which we don't know the radius of the craters and how far we are away from the moon surface. This will be a recommendation for a future work to determine the position of the crater for a safe landing site for Lunar Lander.

IV. RESULTS AND DISCUSSION

A. Crater Detection Algorithm

The user can choose how many craters to be detected by the system based on the original image taken. As for the first case in figure 2(b) below, it will select the eight best craters that satisfy the minimum distance and angle conditions by assuming the sun direction to be known. An image of the landing site on the moon surface has to be captured first and the amount of craters need to be detected are calculated manually. With reference to the original image, assumption on the sun direction was made based on the shady and sunny pattern locations that formed the craters itself. If the image has less than eight craters, then the system will choose the maximum number of craters on the image.

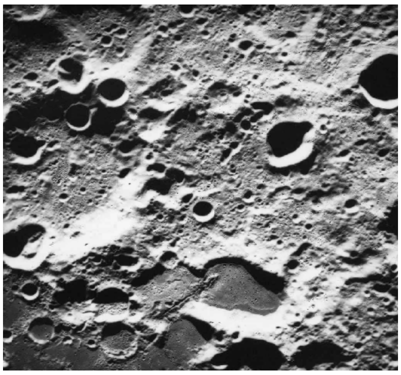
Although sometimes the system will detect the craters with wrong pairing patches (light patch connected to the wrong dark patch and vice versa) but still the Lander should understand that one of them might still be one of the hazards that has to be avoided during landing application. The radial distance is calculated for each of the pairs detected in green lines as in figure 2(b) and 2(c) below using the equation (2) and the shortest distance between adjacent pairs (light and dark patch) is chosen as a preliminary results for further angle calculations. After the light patches were connected to the dark patches with minimum distance between them, then the system will calculate the minimum angle by inputting the direction of the sun (assume that we know the sun angle) and later compare it with the pairing patches angle using the dot product (equation 3) as can be described fully on methodology section. By taking into account of both techniques (minimum distance and angle), we can determine the best craters that we desire on an image. The final craters detected will be denoted in yellow lines such in figure 2(b) and 2(c) below.

Ideally, this algorithm will work on any images that have a clear pattern of light and dark patches and we don't even have to know the important parameters such as radius, gradient and etc of the craters. Unfortunately, this algorithm will work effectively on the image that has a clear pattern of these light and dark patches.

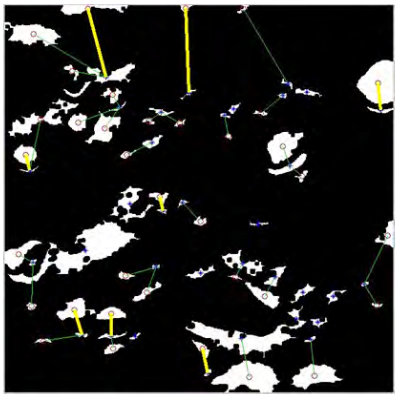
This craters detection algorithm has been tested into two different optical images with different sun angles which are ≈10 degrees and > 10 degrees. These evaluations below are to measure the accuracy of the algorithm based on the two images proposed and how robustness the algorithm is. By comparison of figure 2(b) and 2(c), the accuracy of the algorithm based on these two images with different type of craters, sun elevation angles and lighting conditions can be calculated as:

(80% +73%)/2 = **77% accuracy** (12)

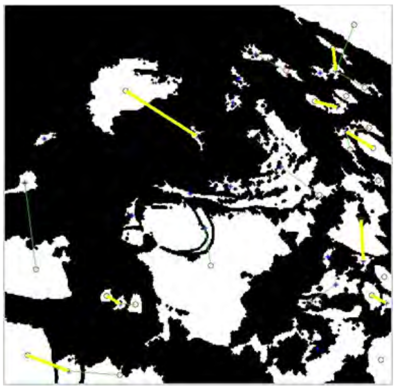
From calculation above, this can be conclude that the tested craters detection algorithm has a detection rate of 77%.The accuracy of the algorithm can be improve if we know exactly the sun elevation angle as here we just assumed it to be known and the value is not really accurate. In a real application, this sun angle can be measured separately using the satellite, altimeter or radar prior to this detection process and the value will be more accurate. Moreover, this algorithm will detect the craters that are above 0.0265 meters in image size (100 pixels). This can be vouched by using the '*bwareaopen'* function where it will remove the entire blob pixels which is less than 100 pixels.



(a)



(b)



(c)

Figure (2):(a)Original image (b) Craters detected in yellow lines with sun angle ≈10 degrees. (c) Craters detected in yellow lines with sun angle >10 degrees.

B. Bounding Ellipse Algorithm

In geometrical analysis section, commencing with bounding ellipse algorithm using the information from the previous proposed craters detection algorithm to bound the target blob as shown in figure (3) below. The blob is selected randomly from the true craters detected by the detection algorithm by labeling the target output using '*bwlabel*'. This function numbers all the objects in a binary image. By using this information, the user can select the true matching pair that wish to be selected for further research (to determine its orientation) by using the function 'find' in Matlab and this step can be repeated for all of the true matching pairs detected by the algorithm. This is the first step before we can reconstruct the crater selected as a disc using ellipse reconstruction algorithm. This reconstruction is beneficial to later determine the orientation of a crater relative to the space craft using the equation $\widetilde{p}$ proposed before during Entry, Descent and Landing of the spacecraft. There are some mathematical fundamentals and equations need to be understood before one can apply the bounding ellipse algorithm to a certain target object. They are fundamentals of the ellipse itself and also the rotation matrix fundamentals. This knowledge is used to extract the embedded entities from the output of bounding ellipse algorithm in terms of basic ellipse parameters such as ***a***, ***b***, **Xc**, **Yc** and **ω** that is further use to draw an ellipse around the target object (target patch). Generally, we want to express all those ellipse parameters in terms of **A** matrix which is the output of bounding ellipse algorithm. This **A** matrix takes a form of **A**= $\begin{pmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{pmatrix}$. Finally, we want to express the ellipse parameters in terms of $A_{11}, A_{21}, A_{12}, A_{22}$ to draw the bounding ellipse and further to reconstruct it as a disc. The selected blob is bounded in a green circle using the bounding ellipse algorithm as shown in figure (3) below.

Figure (3): Detection blobs in green circle using Bounding Ellipse Algorithm.

C. Ellipse Reconstruction Algorithm

This algorithm is about to model a crater as a disc and reconstruct an ellipse to a circle in 2 dimension (2-D) plane in order to determine the orientation of a crater relative to the spacecraft. As mentioned before, after we perform the bounding algorithm and draw the bounding ellipse on a particular target crater, we have an image of a circle that bounded a target crater rather than an ellipse and therefore we have an assumption that the camera on the spacecraft is pointing vertically, almost 90 degrees from above in angle if measured from a flat lunar surface. From bounding ellipse algorithm, we have determined the image plane ellipse parameters and results showing that the semi-major axis, ***a*** is similar to the semi minor axis, ***b***. Taking advantage of this idea, a circle will only have one solution in order to determine the position of a crater and the ambiguity case (2 solutions, as an ellipse have) can be eliminated.

An ellipse will be detected on the image plane for each disc that is visible on the camera's view. For each ellipse detected, there will be two discs reconstructed in 3-D space in terms of its orientation and position as well, one is pointing away from the plane which is a true direction while the other will be pointing in the wrong direction. The orientation of the disc can be described as a unit vector giving the direction of the centre of the disc. It is a positive value since the crater can be seen orientated upwards rather than downwards (negative side). Once we ran the reconstruction algorithm, we have the crater's orientations of (1.0000,-0.0000,0.0000) and (1.0000,-0.0049,-0.0007). This ambiguity case can be removes away by taking consideration that from camera perspective, a disc will only be seen if they're orientated upwards (positive values) rather than downwards (negative values). So, using the information above, it is clear that the image plane is one unit away (P (1, 0, 0)) from the origin (of a camera at the spacecraft) which is the orientation of the spacecraft itself regards to the image plane. The reader should also notice that in this case, the orientation vector is the unit vector giving the direction of the centre of the crater. Hence, this orientation vector is also considered as the normal vector of the crater that pointing upward.

V. CONCLUSIONS

This paper focuses primarily on identification and detection of craters on a lunar surface. To realize these goals, an algorithm to detect craters which are the main hazardous features on lunar is proposed. The evaluation of this algorithm has been divided into a flowchart as per discussed in the previous sections. First, using the original image of craters on a moon surface, the author converts the RGB image plane to HSV image plane and analyzes only the Value parameter of a HSV plane. Further, the thresholding is applied to the image for classification using this Value and thresholding approaches by Sawabe et al [5]. After these classifications of images to light and dark patches, they were labeled and the centre of each patch was determined using '*regionprops*' function. This stage is then followed by a vital stage in determination the best craters of all using two proposed methods: minimum distance determination and angle measurement. This is a new and simple method that has been proposed in detecting craters as main hazardous features on a moon surface.

For precise moon landing, the geometrical analysis that has been proposed consisted of projection or reconstruction of the ellipse to a 2-D circle on an image plane. At this stage, the bounding ellipse algorithm has been applied as a first step in modeling a crater as a disc. All the ellipse parameters then were calculated using the information embedded in the output of bounding ellipse algorithm then drew the bounding ellipse around the target patch. This output will then be used in ellipse reconstruction algorithm to get the orientation, $\widetilde{p}$ of the disc (crater) from the camera projection. This is very useful information for the Lunar Lander as a first step before one can measure the position of the crater using the same algorithm.

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