Common Region Detection Algorithm for Adjacent Lunar Surface Images using Crater Matching. M. G. Seo[1], M. H. Cho[2] and M. J. Tahk[3], [1]KAIST (Korea Advanced Institute of Science and Technology 291, Daehak-ro, Yuseong-gu, Daejeon, 34141, Korea, mgseo@fdcl.kaist.ac.kr), [2]KAIST (Korea Advanced Institute of Science and Technology 291, Daehak-ro, Yuseong-gu, Daejeon, 34141, Korea, mhcho@fdcl.kaist.ac.kr) , [3]KAIST (Korea Advanced Institute of Science and Technology 291, Daehak-ro, Yuseong-gu, Daejeon, 34141, Korea, mjtahk@fdcl.kaist.ac.kr).

Introduction: The digital elevation model (DEM) of the lunar lunar surface is vital information for lunar exploration missions. The algorithms to construct DEM of the certain region using a camera image has been developed in previous studies. In order to construct the high-resolution DEM of a broad area, a single high-resolution image over that region is required. Since the resolving power of a camera is limited, a high resolution image of a large area is difficult to acquire.

Another method is to construct DEMs from the partial images of the designated area and combine them into a single DEM. This method needs the information of the relative position and attitude angle between images. Especially for images of adjacent areas, the overlapping regions of two images are defined from this information. This indicates that the relative position and attitude angle between those two images should be exactly known to make the overlapping regions to contain only the duplicately taken area.

This paper deals with the algorithm to figure out the common region of the given two neighboring lunar surface images using crater matching. Craters are approximated as circles using the algorithms addressed in the previous studies.[1,2] The proposed algorithm calculates the relative position and attitude angle of two images, which minimize the newly defined cost function. This cost function is defined as the average of the distances between the centers of two circles with the similar radius on the overlapping region of each image.

Crater Detection Algorithm: The algorithms to detect and approximate craters as simple geometric figures has been studied in various articles.[1,3,4] The craters are approximated as circles for simple crater matching algorithm in this paper. The algorithms proposed in [1] are applied for crater edge detection and pairing. The paired edges are approximated as circles with the method introduced in [2]. This method calculates suitable circle on each crater based on least square fitting and uses finite number of points on edges.

Crater Matching Algorithm: The craters on the two images are approximated as circles and their positions and radii are given from the algorithms introduced in the previous section.

The altitude and the relative attitude of the camera against the image normal vector are assumed to be identical for two images. Under this assumption, the difference between radiuses of the circles, derived from same crater on each image, are considered to be small. One of the image is defined as Image A and the other is called Image B in this paper.

An orthogonal coordinate system is defined with its origin at the center of Image A. Its x-axis is defined to be parallel to the horizontal sides of the image. The position of the center of Image B, (x_B, y_B), is defined in this coordinate system. The attitude angle of Image B with respect to Image A, θ_B, is defined as the angle between x-axis and the horizontal side of Image B. Those definitions are addressed in Fig. 1.

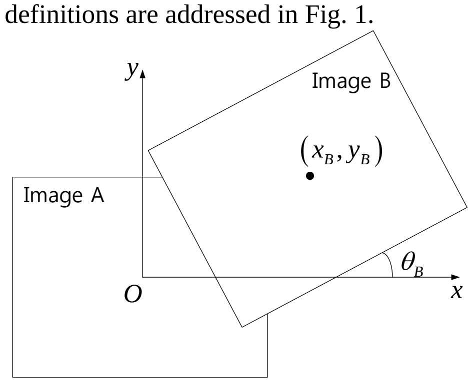

Fig. 1 Coordinate System and Parameters

It is obvious as shown in Fig. 1, the overlapping region of two images are given from (x_B, y_B) and θ_B. The crater matcing algorithm is proposed to find the proper (x_B, y_B) and θ_B which makes the overlapping region to be the actual common area. This is accomplished by figure out (x_B, y_B) and θ_B which minimizes the objective function $J(x_B, y_B, \theta_B)$.

$$\min_{x_B, y_B, \theta_B} J(x_B, y_B, \theta_B) \tag{1}$$

$J(x_B, y_B, \theta_B)$ is defined as the average of the distances between the centers of two circles approximated from the same crater. The process to calculate $J(x_B, y_B, \theta_B)$ is given as follows.

a. Figure out the circles whose centers are on the overlapping region of each image. Let the number of them on Image A as n, and that of Image B as m.

b. Sort the circles on each image in descending order of their radiuses. The i -th circle of Image A is symbolized as $C_{A,i}$, and the j -th circle of Image B is defined as $C_{B,j}$.

c. In $n<m$ cases, from $i=1$ to $i=n$, search the nearest $C_{B,j}$ whose radius and that of $C_{A,i}$ differs by a small threshold value designed by the user, and pair those two circles. $C_{B,j}$ s, those paired with $C_{A,k}$ s of $k=1,\cdots,i-1$, are excluded from the search process for $C_{A,i}$. In $n>m$ cases, the same searching and pairing processes are conducted for $C_{B,j}$ from $j=1$ to $j=m$.

d. When the number of pairs obtained from c. is l ($l \le n$ for $n<m$ case, $l \le m$ for $n>m$ case), $J\left(x_B, y_B, \theta_B\right)$ is calculated as below. $d_k\left(x_B, y_B, \theta_B\right)$ is defined as the distance between two circles of k -th pair $(k=1,\cdots,l)$.

$$J\left(x_B, y_B, \theta_B\right)=\frac{1}{l}\sum_{k=1}^{l} d_k\left(x_B, y_B, \theta_B\right) \qquad (2)$$

In the case where the only one crator exists on the overlapping regions, θ_B is not able to be uniquely defined with the proposed detection algorithm. In order to prevent this drawback, $J\left(x_B, y_B, \theta_B\right)$ is defined to be a extremely huge number for $n \le 1$ or $m \le 1$ cases.

Image Merging: The image merging test is conducted with two neighboring lunar surface images to show the performance of the proposed algorithm. The following lunar surface image is obtained from [5].

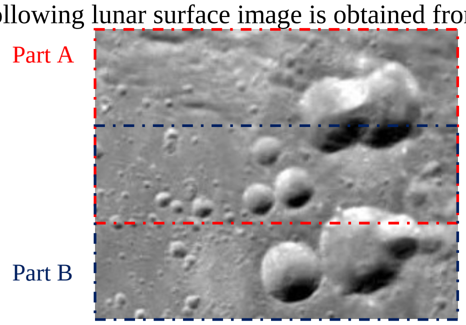

Fig. 2 Lunar Surface Image

Image A is defined as Part A of Fig.2. Image B is obtained by rotating Part B by 180° clockwise. The crater detection results with those two images are presented.

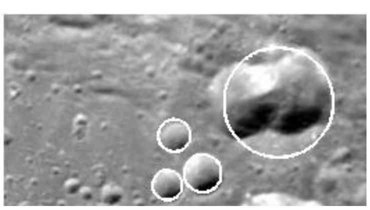

Fig. 3 Crater Detection with Image A

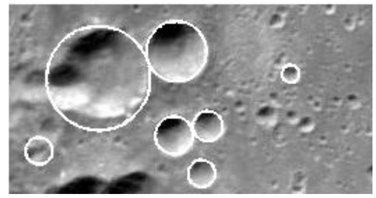

Fig. 4 Crater Detection with Image B

The relative position and attitude of Image B with respect to Image A is given from the crater matching algorithm. The optimal solution is obtained with the optimization tool of MATLAB, called 'fminsearch'.

$$\begin{aligned} &\left(x_B, y_B\right)=\left(2.2154, -72.7507\right) \quad \theta_B=176.7808^\circ \\ &J\left(x_B, y_B, \theta_B\right)=0.8913 \end{aligned} \qquad (3)$$

The image merging is conducted by applying the relative position and attitude angle condition in (3) to Image A and Image B. The merged image is obtained by defining the grayscale values of pixels on the overlapping region as the average values of two images.

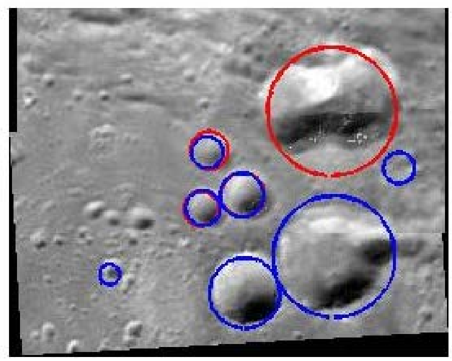

Fig. 5 Merged Image using Crater Matching

Conclusion: The algorithm to figure out the common area of two partially overlapping lunar surface images is proposed in this paper. The performance of this algorithm is demonstrated by the image merging test.

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References: [1] Jeon. B. J. et al. (2013) Asia-Pacific International Symposium on Aerospace Technology [2] Pratt. V. (1987), ACM SIGGRAPH Computer Graphics., Vol. 21, No. 4 [3] Jiang. H. et al. (2010) Intelligent Control and Information Processing, 2010 International Conference on [4] Junhua. F. et al. (2010) Systems and Control in Astronautics, 2010 3rd International Symposium on [5] NASA Planetary Data System (Planetary Image Locator Tool, http://pilot.wr.usgos.gov, (Searching Date : 07.23.16)