A METHODOLOGY FOR GENERATING SURFACE NORMALS OF A PLANETARY SURFACE USING IMAGE DATA OBTAINED FROM ORBITER. S. H. Moon[1] and H. L. Choi[2], [1]Department of Aerospace Engineering, Korea Advanced Institute of Science and Technology (KAIST), 291 Daehak-ro, Yuseong-gu, 34141, Daejeon, Republic of Korea (shmoon@lics.kaist.ac.kr), [2]Department of Aerospace Engineering, Korea Advanced Institute of Science and Technology (KAIST), 291 Daehak-ro, Yuseong-gu, 34141, Daejeon, Republic of Korea (hanlimc@lics.kaist.ac.kr).

Introduction: The construction of digital elevation model (DEM) is necessary to carry out space exploration missions, such as landing site selection for lander and planetary science research. In order to construct DEM, high-resolution stereo-image data on the surface of the planet or moon and altimeter data are required. A dataset of stereo-image and altimeter are acquired with LROC (WAC and NAC) and LOLA sensor of the lunar reconnaissance orbiter (LRO) sent to the Moon. In the case of Mars, data is obtained from CTX, HiRISE and MOLA of Mars reconnaissance orbiter (MRO). The altimeter based DEM has lower resolution than the stereo-image based DEM in the lateral direction, but it has high accuracy in the vertical direction perpendicular to the surface. So, it is used for truth based on performance verification of stereo-image based DEM. Using software packages like NASA Ames Stereo Pipeline (ASP), high-resolution DEM from stereo-image data can be built in nearly almost areas [1-3].

However, it is more difficult to construct a high-resolution DEM using stereo-image data in shaded regions. Generally, a DEM using a stereo-image compares the pixel information between the left camera image and the right camera image, and then generates altitude information. Therefore, it is difficult to construct a DEM by using a general stereo-based method in the shaded region because the pixel information is insufficient. Especially, the low altitude of the Sun and rough topography changes the shadow extremely near the North and South Pole. Even, there are the permanent shadowed regions and craters.

In this abstract, a procedure to solve this problem is outlined. The image processing technique called "photometric stereo" estimates the original shape of the object after collecting the information of the shaded area while varying the direction of the light source [4]. The position of the sun and the orientation of the satellite's camera determine the direction of the light source towards the surface. The surface normals of the region of interest are estimated in the image and light source direction.

Methodology: Photometric stereo is a type of the shape from shading (SfS) algorithm [5]. This type of algorithm uses light source information to estimate the surface normals of the image or shape. In general, SfS uses a single image to construct the surface normals, but photometric stereo uses multiple images, so it can collect more information than SfS. Therefore, photometric stereo technique is suitable for generating surface normals from shadowed image obtained with different light direction. To apply photometric stereo to the terrain image of a planet or moon, the following procedure is required; pre-processing of the sample images, ortho-image generation using orthrectification of sample images, and generation of surface normals.

Pre-processing. The Experimental Data Record (EDR) images are the decompressed spacecraft data from LRO or MRO. These fundamental images for pre-processing can be acquired from LROC WMS server (http://wms.lroc.asu.edu/lroc/) and HiRISE PDS server (https://hirise.lpl.arizona.edu/PDS/).

In order to process these image data in the software packages like ASP, it is needed to be converted from its original file name extension. These image data are converted from IMG file to ISIS cube format using the USGS Integrated Software for Imagers and Spectrometers 3 (ISIS3). Also, SPICE kernels are added to each images and photometric calibration is applied using ISIS3 functions.

Ortho-image Generation. Usually, the images from orbiters are not taken in nadir view (looking straight down); the terrains can be subtly distorted. To correct distortion, ortho-rectification process on the image is required. Existing DEM is used as a reference for ortho-recrifying the image. The global DEMs using altimeter sensors such as LOLA and MOLA can be accessed from the PDS LOLA RDR Query Tool (http://ode.rsl.wustl.edu/moon/indextools.aspx?displaypage=lolardr) and PDS MOLA PEDR Query Tool (http://oderest.rsl.wustl.edu/GDSWeb/GDSMOLAPEDR.html). The images are map-projected onto the given DEM and ortho-images are generated. If the position and direction error of the camera influence the result, the position and direction of the camera can be corrected by using bundle adjustment based on the existing DEM. Then, the ortho-images are cropped into the region of interest to be applied photometric stereo.

Surface Normals. The multiple shaded images obtained by changing the direction of the light source in topography can be represented by a matrix operation.

$$I = NL$$

I is a matrix of intensity of terrain pixel in image, N is a matrix of surface normal vectors of terrain pixel in image, and L is a matrix of direction vectors of light sources. Using sufficient datasets of intensity map of terrain and light source direction, this form of matrix calculation is an overdetermined problem. So, pseudo inverse matrix of L, L^+ is induced by matrix calculation.

$$L^+ = L^T(LL^T)^{-1}$$

Using this L^+, the surface normal vectors matrix N can be estimated.

$$N = IL^+$$

Finally, the surface normals are generated using ortho-images generated in the upper section and light direction.

Future Work: A workflow to construct the surface normals of shaded region using images acquired with different light sources is proposed in this abstract. This is the intermediate stage to generate a DEM using photometric stereo method. The next step is to merge surface normals with LOLA and verify this method using LOLA in the region where DEM cannot be constructed using stereo-image based DEM. Usage of other imaging sensors like mini-RF is also considered in permanently shadowed region near the lunar poles.

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