Topographic mapping and modeling of Chang’e-3 landing site using descent and ground images

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***Abstract*—Chang’e-3 mission is the first lander and rover of China following of Chang’e-1 and Chang’e-2 orbiters. High precision topographic mapping and modeling of Chang’e-3 landing site can provide detailed terrain information to ensure the safety of the rover as well as to support various scientific investigations. In this research, high resolution sequence images acquired by the lander’s descent camera and stereo ground images captured by the rover’s navigation cameras are combined used to generate high-precision DEMs and DOMs of the landing site. Furthermore, topographic modeling products are derived from the DEMs. Key technologies of the topographic mapping and modeling have been used to support the surface operations of Chang’e-3 mission.**

Keywords- Topographic mapping; descent image; ground image; DEM; DOM; terrain modeling

I. INTRODUCTION

Chang’e-3 (CE-3) mission is the lander ad rover mission of the second phase of China's lunar exploration program which includes three phases - orbiting, landing and returning to Earth. Following the successes of the Chang’e-1 and Chang’e-2 (CE-2) orbital missions, CE-3 was launched on 2 December 2013 and landed on Mare Imbrium (44.12°N, 19.51°W) on 14 December 2013. During the landing phase, the descent camera carried by the lander acquired thousands high and ultra-high resolution sequence images of the landing site. These descent images were used to monitor the landing process and pinpoint the locations of the lander. The rover Yutu was released to lunar surface and began its exploration soon after landing. Until 17 January 2014, Yutu rover has traveled 114.8 m on the lunar surface and performed a series of scientific investigations. Along the traverse, the rover stopped at the waypoints that are about 10 m apart and took stereo images using its navigation cameras (Navcam) to support teleoperation of the rover.

High precision mapping and modeling of the landing site is of fundamental importance both for safe rover navigation and for achievement of scientific and engineering goals. For example, rover path planning is mainly based on the high resolution DEM and slopes map generated from descent and ground images. During CE-3 mission, RADI team working together BACC teleoperation team, routinely producd topographic maps, and rover traverse maps to support surface operations of the rover. In this paper, we present high precision topographic mapping and modeling method using CE-3 descent images and Navcam images.

II. METHOD

The descending trajectory of CE-3 lander is recovered from descent sequence images by a self-calibration free network bundle adjustment; absolute orientation is achieved through several GCPs are selected from CE-2 topographic products. Based on a series of matching strategy (SIFT matching, RANSAC based outlier elimination, and dense matching), sufficient points are accurately matched among the descent images and their corresponding ground positions are calculated by space intersection. The whole process of Navcam image mapping includes automatic feature points extraction and matching based on epipolar-resampled stereo images, multi-threaded dense matching and 3D calculation. The DEM derived from Navcam images is then registered to the DEM derived from descent images by feature points and surface patches. Consequently, an integrated DEM is generated with all of the co-registered 3D points. Finally, terrain modelling products are derived from the integrated DEM.

III. DESCENT IMAGE AND NAVCAM IMAGE MAPPING

A. Landing site mapping with CE-3 descent images

CE-3 began to descent from the lunar orbit at an altitude of around 15 km, and when it was about 2 km above the lunar surface, the descent camera started to take images. During the phases of descending, hovering and obstacle avoidance and landing, the descent camera acquired totally 4,672 images with a resolution higher than 1 m within an area of 1*1 km and as high as 0.1 m within a range of 50 m from the landing point. Main technical parameters of the CE-3 descent camera are listed in table I. 180 equally spaced images are selected and incorporated in a self-calibration free network bundle adjustment, and the initial trajectory (including camera positions and attitudes) of the camera is recovered. Then, 26 GCPs are selected from the rectified CE-2 DEM and DOM for absolute orientation. The RMSEs (Root Mean Square Errors) of these GCPs are 0.724 m, 0.717 m and 0.602 m in three directions. The RMSEs of 18 check points are also less than 1 m. Figure 1 shows the DEM and DOM generated from 80 descent images with a resolution of 0.075 m. The dots in the

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maps represent the lander position. The maps cover an area of 97 m × 115 m. Using more descent images of higher altitudes, topographic products of larger coverage, e.g., 780 m × 1800 m with a resolution of 0.40 m, were also generated.

TABLE I. TECHNICAL PARAMETERS OF CE-3 DESCENT CAMERA

Image size	Actual imaging distance	Focal length	Pixel size
1024*1024 pixels	4 m~2000 m	8.3 mm	6.7 µm

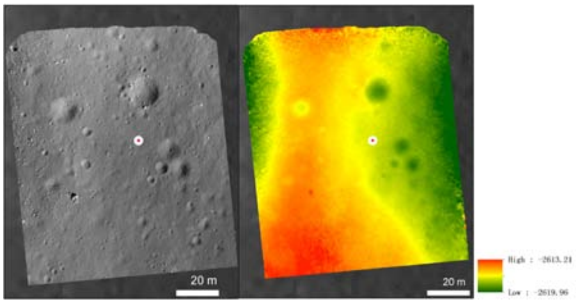

Figure 1. DEM (right) and DOM (left) generated from of descent images

TABLE II. PARAMETERS OF YUTU NAVCAM CAERAS

Stereo base	Focal length	Image size	Field of view
27cm	1189 pixels	1024*1024 pixels	46.4°*46.4°

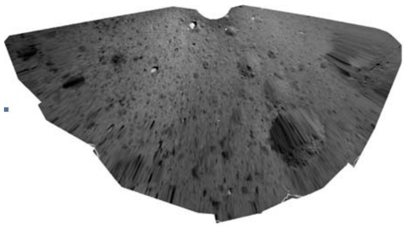

Figure 2. DOM of Navcam images at D site

B. *Mapping with Navcam images*

Topographic products (DEM and DOM) were generated quickly and routinely at 18 waypoints using Navcam images based on multi-threaded image processing. The geometric parameters of Navcam are listed in Table II. The expected measurement error of Navcam stereo images is less than 1m within 31 m from the rover. Figure 2 shows a typical DOM at waypoint D, it was automatically generated from the Navcam images taken by Yutu rover. In order to perform integrated topographic mapping with descent images, point clouds generated of the ground DEM is transformed into the lunar body-fixed coordinate system.

IV. INTEGRATION OF MAPPING PRODUCTS

Discrepancies exist between the topographic products from descent and ground images. Co-registration between the two DEMs were performed by matching feature points and surface patches. After the co-registration, the mean differences between the two data sets have been reduced from 0.142m, 0.096m, 0.765m to 0.003m, 0.004m, 0.221m in three directions, respectively. After the co-registration, integrated topographic mapping and modelling is acomplished by using all the 3D points to generate an integrated DEM, slope map, and obstacle map. Figure 3 shows the integrated DEM at waypoint D. Figure 4 shows the slope map. Figure 5 shows the obstacle map with the rover path superimposed; the red areas are obtacles, while the blue line is the rover path designed based on the terrain mapping and modeling products.

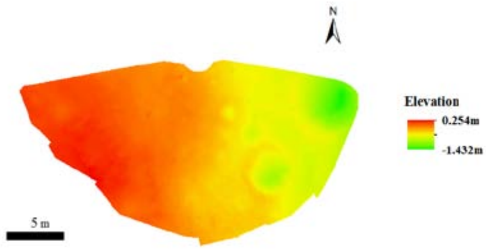

Figure 3. Integrated DEM

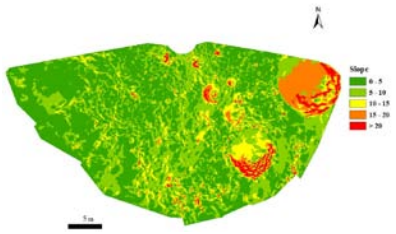

Figure 4. Slope map from integrated DEM

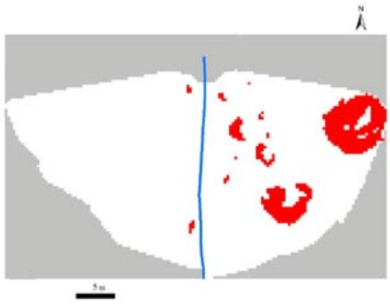

Figure 5. Obstacle map and rover path

V. CONCLUSIONS

In this paper, we presented a method for high precision topographic mapping and modelling at Chang'e-3 landing site using CE-3 descent images and Navcam images. The products satisfied the requirements for mission operation in terms of accuracy and timing. Key technologies of the topographic mapping and modeling have been used to support teleoperation of the rover on lunar surface.

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