

THE LUNAR DEM GENERATION PROCESS BASED ON CLEMENTINE AND CHANG'E-1 IMAGES

B. King^a, J. Guo^{a,b,*}, Y. Q. Chen^a, J. X. Zhang^b, Y. H. Zhang^b, X. G. Ning^b

^a Department of Land Surveying and Geo-Informatics, Hong Kong Polytechnic University, Hung Hom, Hong Kong, P.R. China
(lsbaking, lsarrow, lsyqchen)@inet.polyu.edu.hk

^b Chinese Academy of Surveying and Mapping, Beijing, 100039, P.R. China
arrow_guojian@126.com, (zhangjx, yhzhang, ningxg)@casm.ac.cn

KEY WORDS: Lunar Mapping; DEM; Clementine; Chang'e-1, ULCN 2005; LPS

ABSTRACT:

A photogrammetric method and process to generate a portion of the lunar DEM based on the Clementine images and 93 Unified Lunar Control Network 2005 (ULCN2005) control points in Leica Photogrammetric System (LPS) 9.2 were presented. A test using 12 Clementine images from 4 orbits was performed and the results were introduced. This work provides the foundation for the processing of Chang'e-1 images. Three tests using a subset of Chang'e-1 backward, nadir and forward image combination from orbit 161 were made via LPS version 9.3.2. Following the triangulation each pair of images was used to create a DEM with 1200 meters (10 pixels) resolution. Finally, the results of the tests and conclusions relating to improvements in processing methodology were described.

1. INTRODUCTION

Understanding the topography of the Moon is an important issue for further lunar exploration. It is a key factor for choosing land sites, setting up lunar observation stations and developing exploration activities in the future.

In the 1960s and 1970s, the Moon was explored using numerous unmanned and manned missions of the United States and the Soviet Union. Remote sensing data, in-situ experiment data, and returned sample data provided by the missions were analysed in great detail. The 1990s brought a new era with new views that had been improved from previous ones, with global material mapping experiments by Galileo, Clementine, and Lunar Prospector and so on. In 1994 the Clementine mission provided a comprehensive survey of altitude, albedo (intrinsic brightness), and multispectral data in 1994 (Byrne, 2007).

On 24th October 2007 China launched its first lunar exploration satellite, Chang'e-1, from the Xichang Satellite Launch Center in Sichuan province. It was placed into a peripolar orbit at an altitude of about 200km. The satellite contained an array of sensors including a three-line optical scanner for the acquisition of imagery to be used for the generation of a high-precision lunar DEM.

2. PREVIOUS WORK

2.1 Clementine Data and Selection

Clementine imagery was superior in topographic resolution and uniformity of coverage than that produced by other earlier lunar imagers, such as Lunar Orbiter, Apollo and Surveyor. Although the Clementine imagery covered the entire Moon, its primary purpose was to provide multispectral imagery with minimal shadowing. Consequently, there is little information about the shape of the surface except near the poles, where the Sun angle is more favourable to show the topography (USGS,

1998). Imageries from the south polar region were chosen in this study. Control was provided by the ULCN2005 control network (Archinal et al, 2006).

The Clementine satellite also had various sensors and images from the UVVIS (ultraviolet and visible range) camera were selected. The image size is 288*384 pixels with a GSD of 102 metres. 12 images from 4 orbits were selected using the Lunar Query Software (LQS) which was developed for this project. LQS allows an area to be defined and will search the Clementine image catalogue and ULCN2005 database to provide compatible image and control data. The test site covered the area bounded by 120°W to 150°W and 70°S to 80°S and is shown in Figure 1. Processing was done using LPS version 9.2.

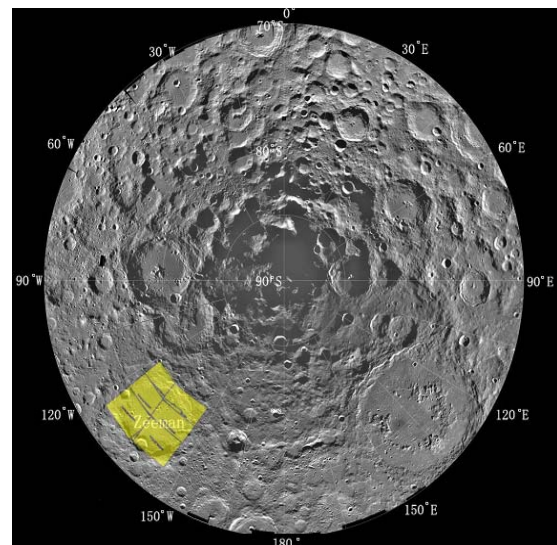


Figure 1. The location of the Clementine study area

2.2 Chang'e-1 Sensor Model and Data Selection

* Corresponding author. arrow_guojian@126.com

Although the Chang'e-1 CCD sensor is a frame sensor of 1024 x 1024 pixels it is operated as a three line pushbroom sensor with 512 pixel wide backward, nadir and forward looking lines and a GSD of 120 metres (CAS, 2008). Level 2C imagery was used and processing was done with LPS version 9.3.2 using imagery from orbit 161. The test covered an area from 76.1°E to 81.0°E and from 54.3°S to 69.3°S. Figure 2 shows orbit 161 in red and the segment used in green.

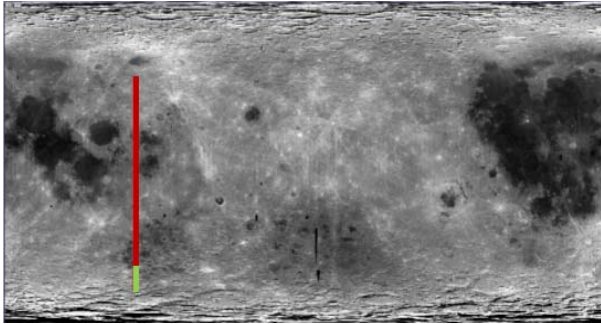


Figure 2. The location of orbit 161 and study area

2.3 Data Pre-processing

Clementine and Chang'e-1 imagery are stored in PDS format (NASA, 2009) and must be converted for use in the LPS software. The Clementine imagery was changed into TIFF format using ISIS (USGS, 2008). Similarly, Chang'e-1 images were converted to TIFF format using and IDL scripts.

3. METHODOLOGY

3.1 Clementine

3.1.1 Overview: The processing of Clementine images was divided into two main stages, control selection and photogrammetric processing; each stage was further divided into several steps. The full workflow is given in Figure 3.

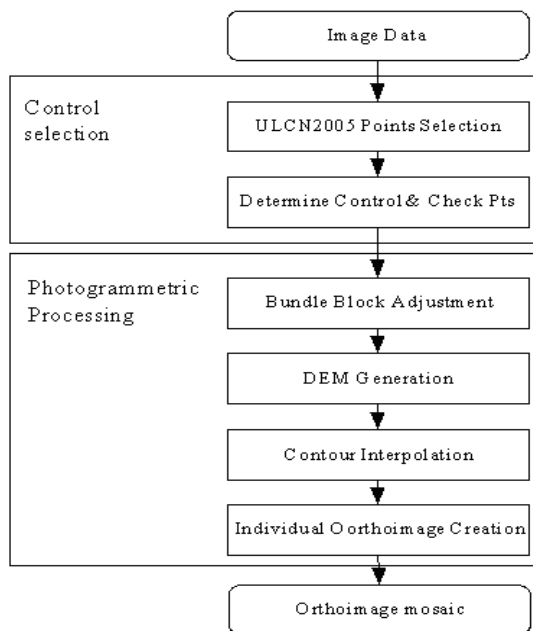


Figure 3. Workflow for pilot project.

3.1.2 Control selection: ULCN2005 is based on a combination of Clementine images and a previous network derived from Earth based and Apollo photographs, and Mariner 10 and Galileo images, and constitutes the largest planetary control network ever completed. It includes the determination of the 3-D positions of 272,931 points on the lunar surface and the correction of the camera angles for 43,866 Clementine images, using 546,126 tie point measurements (Archinal, 2006).

The Clementine database contains lists of photos, point names, object space coordinates (latitude, longitude and height) and image coordinates for all points. A query system was written to interrogate the Clementine database, select the images in the project area, list the available control points and indicate them on the Clementine images. Finally, 93 ULCN 2005 control points were chosen, which were divided into 80 control points and 13 check points manually.

3.1.3 Photogrammetric Processing: Due to a limitation with version 9.2 of the LPS software a Transverse Mercator projection and a sphere of radius 1,737,400 metres were chosen with an origin at the centre of the project area. The geographical coordinates of the control and check points were exported from the query system and transformed using Matlab functions and imported into LPS. The image coordinates of the points were exported from the query system as formatted text files and imported into LPS. Initial processing was done with 80 points as control and 13 points as check (see Figure 4). 12 orthoimages were generated and mosaiced together (Figure 5). DEM was interpolated by nearest neighbour method, whose resolution is 4500 meters, besides, coloured DEM was shown in Figure 6. Figure 7 showed the DEM and the corresponding contour map.

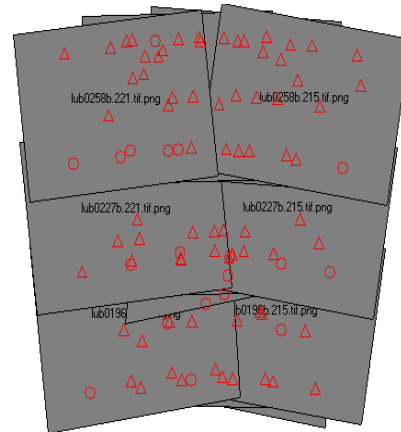


Figure 4. The photogrammetric block with points

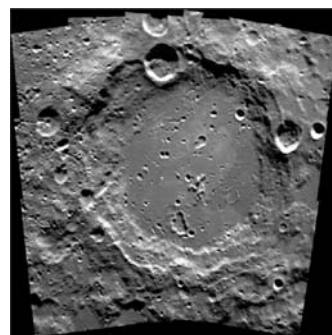


Figure 5. The mosaiced orthoimages

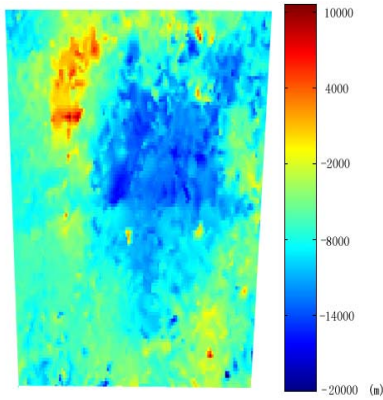


Figure 6. Coloured DEM

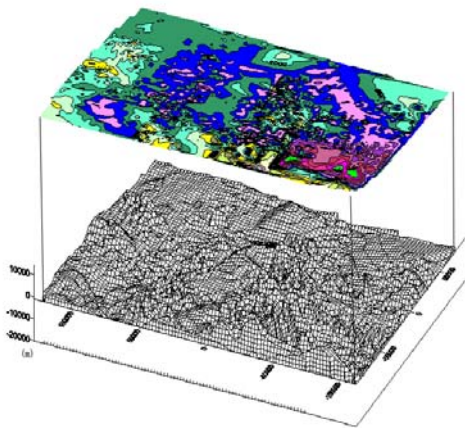


Figure 7. DEM and corresponding Contour map

3.2 Chang'e-1

LPS version 9.3.2 was used in this test, with the advantage that the original geographical coordinates of the ULCN2005 database could be used along with the Lunar spheroid. Control points were manually transferred from the Clementine database to the Chang'e-1 images. For this small test it was deemed appropriate, but an automatic method has been developed for larger scale studies. Finally, 18 points were found in two bands across the image strips of which 12 were used as control and 5 as check points. The imagery was processed in three combinations: backward-nadir, nadir-forward and backward-forward. The same points were used in all three processing. Control point precision and convergence criteria were constant for each processing. The layout of control (triangles) check (circles) and tie (squares) points were shown in Figure 8. Finally, the DEM with 1200 meters resolution of this small area was presented in Figure 9.

4. RESULTS

4.1 DEM generation

A summary of the DEM generation statistics was given in Table 1.

Table 1. DEM generation statistics

	Clementine	Chang'e-1
Point quality (%)		
Excellent	79.4	88.8
Good	1.1	9.0
Suspicious	19.5	2.2
Vertical accuracy (m)		
Minimum error	-5203	-4703
Maximum error	6095	2633
Mean error	28	71
RMS error	1539	507

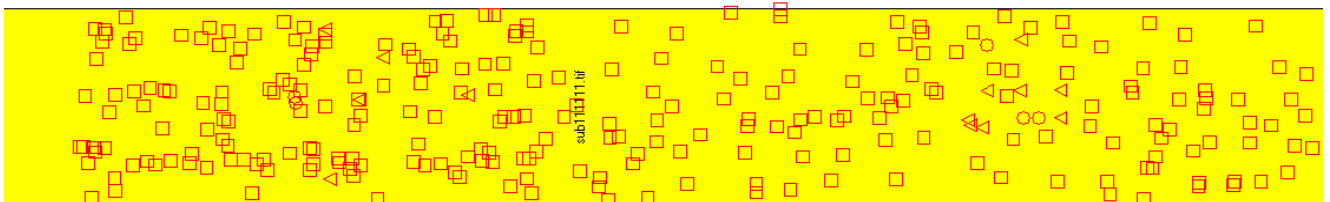


Figure 8. The location of points

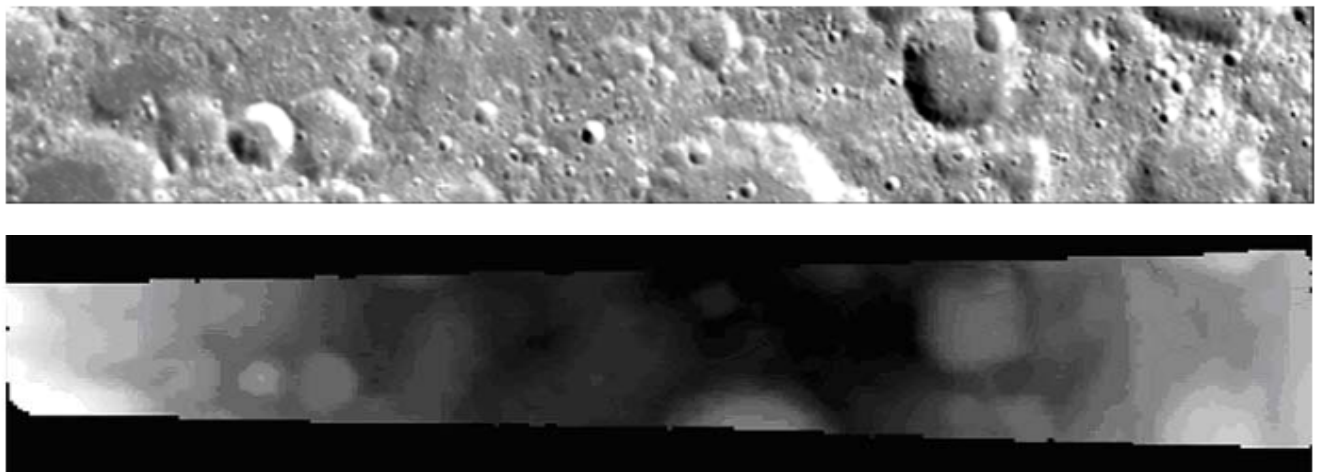


Figure 9. The portion of the Chang'e-1 161 orbit imagery (above) and corresponding DEM (below)

The difference in image quality produced by the Clementine and Chang'e-1 sensors was reflected in the point quality data. In general, DEM extraction with the Chang'e-1 was more reliable with a total of 98% of points having either excellent or good correlations compared to only 80% for the Clementine imagery. With severe lighting conditions experienced on the Moon, radiometric performance of the sensor is critical for the generation of high quality DEMs.

The sensors' radiometric performance was echoed by the geometric performance in DEM creation. With minimum, maximum and RMS errors all smaller for the Chang'e-1 imagery than for the Clementine imagery. The difference is not only due to the performance of image matching, but also to the sensor geometry. With significantly larger fields of view, Chang'e-1 is geometrically more suited to creating DEM data than was Clementine.

4.2 Block adjustments

The statistical results of the one Clementine and three Chang'e-1 block adjustments were shown in Table 2.

Table 2. Results of the block adjustments

	Clementine	Chang'e-1		
		Backward – Nadir	Nadir – Forward	Backward – Forward
RMSE image (pixel)	0.39	0.28	0.14	0.54
RMSE control X (m, deg)	229.74	0.06	0.18	0.05
RMSE control Y (m, deg)	188.83	0.01	0.03	0.00
RMSE control Z (m)	187.37	40.31	66.22	10.17
RMSE check X (m, deg)	384.92	0.03	0.11	0.22
RMSE check Y (m, deg)	230.75	0.02	0.04	0.05
RMSE check Z (m)	1215.38	178.74	235.73	541.61

Due to the inability of LPS version 9.2 to make use of a Lunar sized spheroid, the closes we could come to a plane coordinate system over such a large area was to adopt topocentric TM coordinates. This resulted in the significantly large RMS errors. In comparison, the Chang'e-1 test was done with LPS version 9.3.2 which allows the use of a Lunar sized spheroid and so geographical coordinates could be directly used resulting in significantly smaller residuals.

From the results of the three Chang'e-1 tests, we could see that, in terms of the RMSE of the check points, the backward-nadir combination is marginally more accurate than the other two. However, the common key feature during the three tests results is the large discrepancies between the RMS height errors between the check and control points. As the selection of

control points was limited to those available from the ULCN2005 database it was found that the polynomial modelling of the path of the camera's perspective centre was not accurate. This could be resolved by using a longer strip of imagery that would allow a third line of control to be used and a more accurate orbit to be modelled.

5. CONCLUSIONS

- (1) The Chang'e-1 sensor design is that of a 3-line scanner and provides significantly larger overlap and field of view compared to Clementine's frame sensor. Chang'e-1 imagery should provide better photogrammetric performance.
- (2) Version 9.2 of LPS could not make use of lunar sized spheroids. This problem was fixed in version 9.3.2 and allowed easier use of the Chang'e-1 imagery.
- (3) There was little difference in the aerotriangulation results between the different Chang'e-1 image pairs. It was seen that the backward-nadir combination was more accurate than the other two, but this is not a conclusive result.
- (4) Further studies with the Chang'e-1 data will be done with longer strips and then expanding the processing to several strips. A methodology for automatically identifying and measuring a denser network of control points is being developed.

ACKNOWLEDGEMENT

The work described in this paper was substantially supported by a grant from the Hong Kong Polytechnic University (Project No. 1-BB83).

REFERENCES

- Archinal, B.A, M.R. Rosiek, R.L. Kirk, B.L. Redding, 2006. *The Unified Lunar Control Network 2005* (Open-File Report 2006-1367-Version1.0). USGS, pp.1-3. Available online at <http://pubs.usgs.gov/of/2006/1367/>.
- Byrne, C.J., 2007. *The far side of the Moon: A photographic Guide*. Springer, pp.1-3.
- CAS, 2008. *Working References for the Lunar Explorer Project Scientific Application User*. Chinese Academy of Sciences, Lunar Exploration Project, General Design Section, pp.4-6.
- NASA, 2009. *PDS: The Planetary Data System*. National Aeronautical and Space Administration. <http://pds.nasa.gov/>. (Accessed on 19 June 2009).
- USGS, 2008. *ISIS Software Manual*. United States Geological Survey. <http://isis.astrogeology.usgs.gov/Application/presentation/Tabbed/clem2isis/clem2isis.html>. (Accessed on 28 June 2008).
- USGS, 1998. *Clementine – USGS images*. <http://astrogeology.usgs.gov/Projects/Clementine/> (Accessed on 30 April 1998)