

Photogrammetric DEMs from Chang'E1 imagery

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Abstract

Initial work in creating a complete Lunar DEM and orthoimage from Level 3 Chang'E1 imagery is presented. The methodology for using commercial photogrammetric software, LPS, and integrating data from the Clementine mission of 1994 is presented. The DEM sections created are compared to those obtained from the Chang'E1 laser altimeter.

Key Words: Lunar; DEM; Chang'E1

1. Introduction

Scientific data from the Chinese Chang'E1 lunar mission was released to project partners in late 2008. Data from the laser altimeter (LAM) was received in early March and initial work will focus on computation of selenodetic models following that by Iz *et al.*(2009). Level 2C imagery from the CCD camera (CCD) was received at the end of March 2009 and will be used to photogrammetrically construct terrain models and orthoimages. A feature of the photogrammetry is the use of off-the-shelf digital photogrammetric software, Leica Photogrammetric System (LPS). The initial work reported here focuses on adapting the various sensor and object models to create the necessary data with a system not explicitly designed to work with extra-terrestrial three-line sensor imagery.

A significant issue in working in remote areas is that of object space control. When that area is essentially inaccessible, such as on the Moon, the problem is magnified. In absolute terms there are only 4 useable control points which are Lunar Laser Ranging retroreflectors and whose positions are defined in an absolute Mean Earth coordinate system (Williams *et al*, 1996). Other control networks such as ULCN2005 (Archinal *et al*, 2006) that are based on photogrammetric solutions based on the Clementine mission in 1994 and previously developed coordinate systems have been developed but they are not based on the previously mentioned absolute coordinate system (Iz *et al*, 2009). These networks though provide a plethora of pseudo control points that can be used for initial orientations of the photogrammetric models. A methodology for identifying these points will be presented.

Several experiments were carried out on data covering small areas of the lunar surface. The experiments investigated the appropriate use of sensor models and the use of various mapping systems – map projections and geographical coordinates. The quality of the photogrammetric data was assessed by point cloud registration between them and the LAM data.

2. Previous work

In order to prepare for using the Chang'E1 imagery a pilot project using Clementine imagery was undertaken. The purpose of the project was to become familiar with lunar imagery and to identify possible issues relating to the use of LPS. The main ones identified were:

- Image quality – harsh lighting of the lunar surface produces images with very bright highlights and very deep shadows. Such characteristics have a significant impact on the selection of control points and on image matching on the walls and floors of craters;
- Definition of coordinate systems;
- Identification of control.

The impact of the first issue could not be evaluated for the Chang'E1 imagery as no samples were available. For the second issue it was found that version 9.2 of LPS does not support ellipsoids with dimensions smaller than that of the Earth. Scaling the project was considered but rejected to the chance of forgetting some important factors. Projection coordinates were used instead but was a concern as

using various map projections is problematic when building a homogenous DEM. The third issue was resolved by developing a control point query system that makes use of the published ULCN2005 and Clementine data.

Work methodology

The methodology was divided into three stages, pre-processing, control for images and photogrammetric processing; each stage was further divided into several steps. The full workflow is shown in Figure 1.

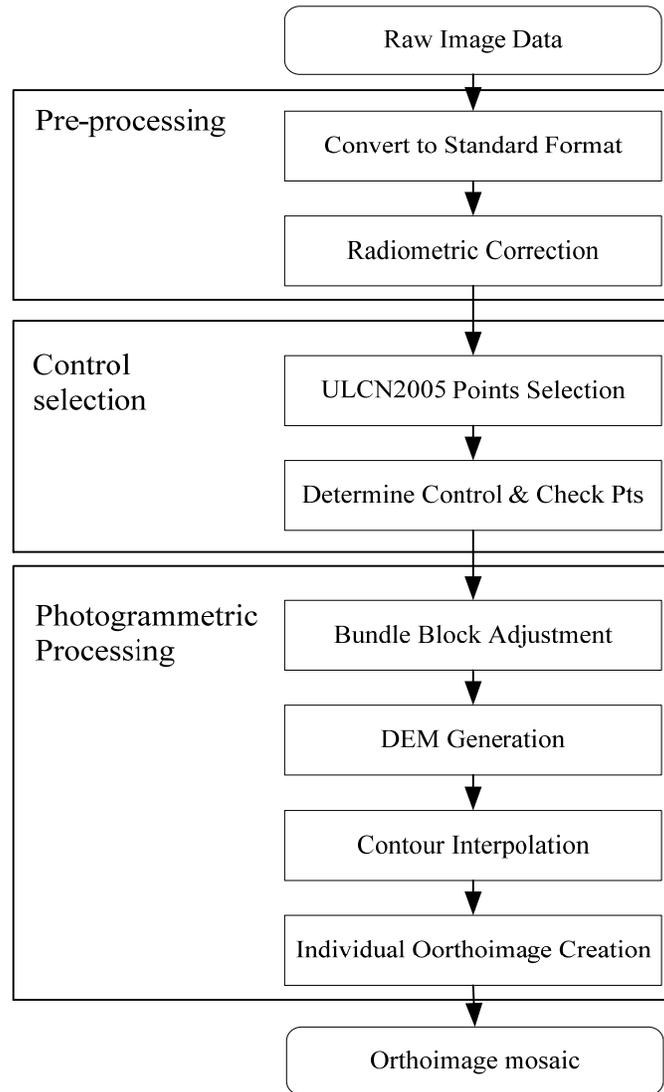


Figure 1. Workflow for pilot project.

Raw image data

Images from the Clementine UVVIS camera were selected. With over 2 million images in the Clementine archive, a database searching algorithm was developed. This algorithm made use of the database metadata of orbit, time, position and attitude, and combined it with histogram data from the candidate images to ensure all images were within the project area, of suitable exposure and not more than 20° off-nadir. In the high latitude regions, the cross-track overlap percentage of Clementine images can meet the requirement of stereo photogrammetry. A sector of the South Pole region (109.7°W to 163.4°W and 69.3°S to 84.2°S) was selected as the study area (Figure2). 60 UVVIS images, 6 images from 10 adjacent orbits. These images gave overlaps of at least 55%.

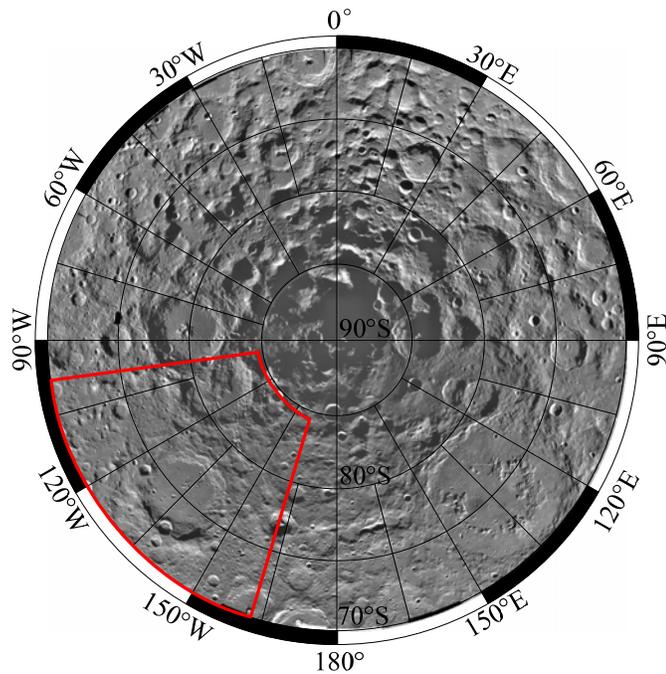


Figure 2. The lunar south-pole and the study area.

Pre-processing

Image files were converted from the compressed Clementine 8-bit format using the ISIS system (Torsen and Becker, 1997; USGS, 2008) to TIFF format and the image histograms were equalised in an effort to provide uniform image brightness that would assist in accurate automatic terrain extraction.

Control selection

ULCN2005 contains the 3-D positions of 272,931 points on the lunar surface. These are points generated by image matching during the photogrammetric processing of 43,866 Clementine images. 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. The interface is shown in Figure 3. Initially, a total of 408 points were chosen and were used as control points. Not all points appear on all images in a single overlap area in the ULCN2005 database and LPS was not able to use automatic point transfer to mark them on the unmarked images so the number was eventually reduced to 289 points that appeared on all overlapping images.

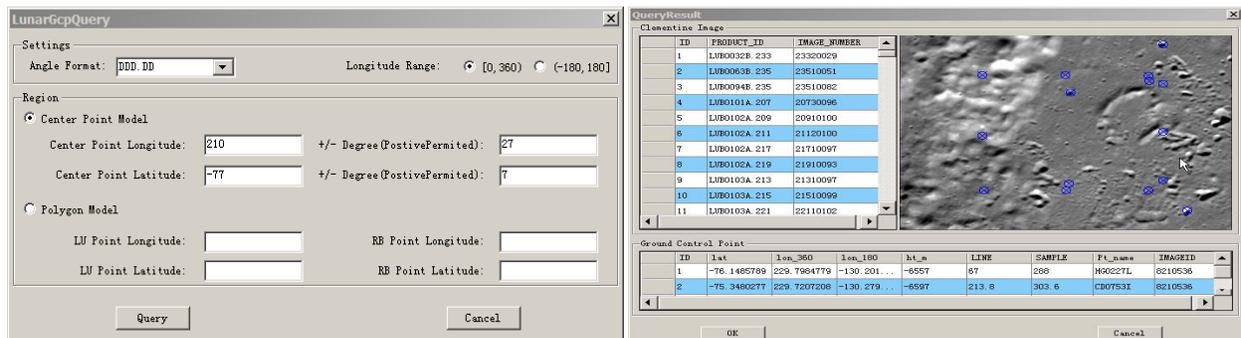


Figure 3. Control point query interface.

Photogrammetric processing

LPS was chosen as it is available in the Department and has an extensive range of processing options. Initial experiments made use of geographical coordinates and a lunar sized spheroid. Despite being able to select the spheroid it was found that default Earth-sized dimensions were used and the photogrammetric solution failed. To overcome this, 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 all points as control (see Figure 4) and 1337 tie points were automatically generated. After the bundle block adjustment the RMS residuals for the control points were approximately 90 metres for X and Y and 10 metres for Z. RMS image residuals were 0.2 pixel. The object space residuals are shown in Figure 5. A 4,000 metre DEM was extracted (Figure 6), the surface contoured (Figure 7), meshed (Figure 8) and 60 orthoimages were generated and mosaiced together covering the full 532.41km in length and 467.56km in width study area (Figure 9).

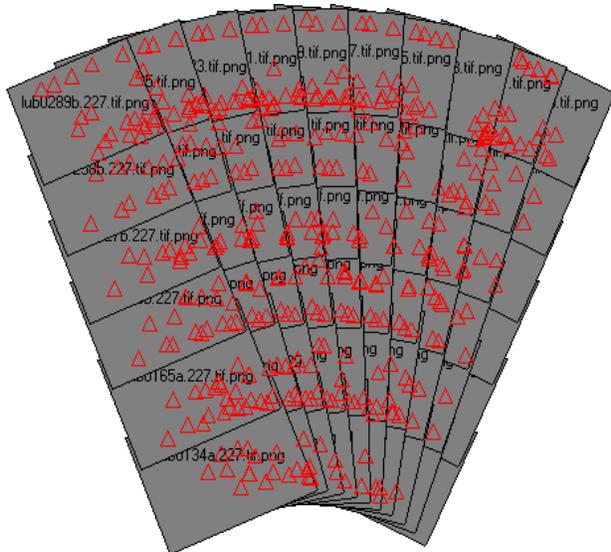


Figure 4. The photogrammetric block with initial 408 control points.

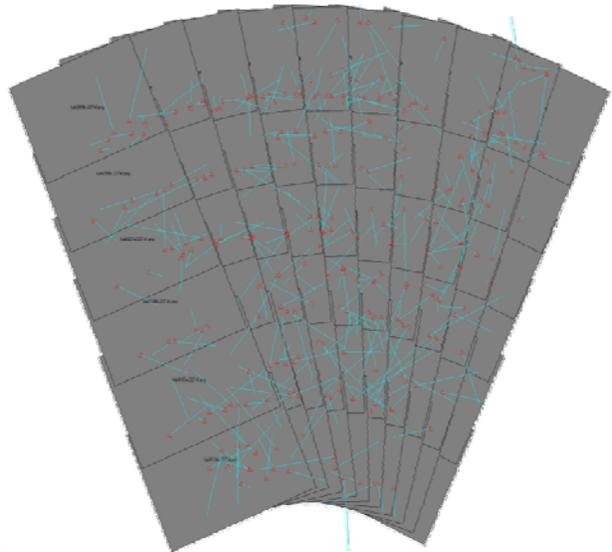


Figure 5. Object space residuals of final 298 control points.



Figure 6. The DEM.

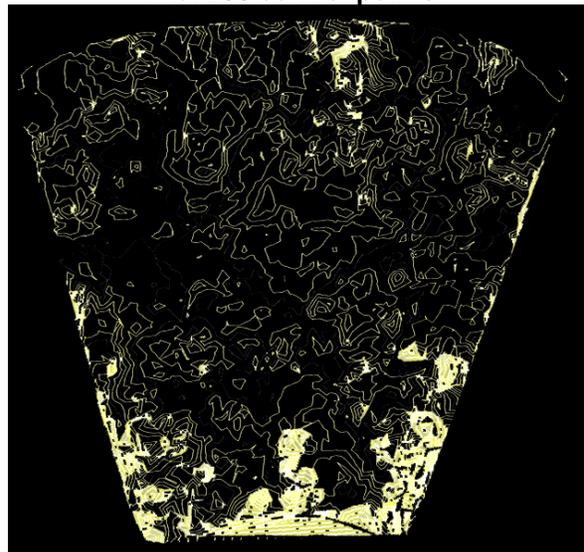


Figure 7. Contours.

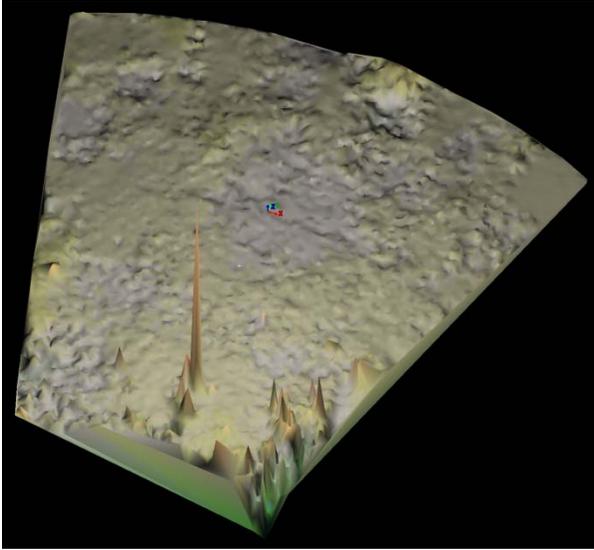


Figure 8. Meshed surface.

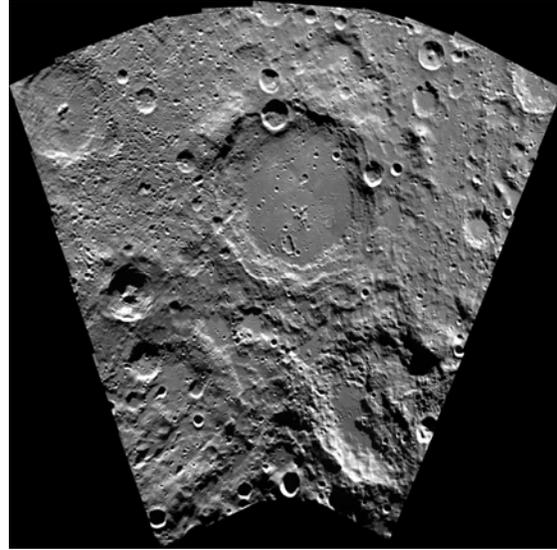


Figure 9. The mosaiced orthoimage.

Due to the relative low values of the RMS object space residuals the AT was re-run with minimal control. This block used 16 points distributed around the periphery for control and 273 points were used as check points. The RMS residuals for object and image spaces are given in Table 1 and the vectors are shown in Figure 10.

Table 1. RMS residuals for 16 control points.

	RMS X (metres)	RMS Y (metres)	RMS Z (metres)
Control	58	72	9
Check	158	198	1872
	RMS x (pix)	RMS y (pix)	
Control	0.24	0.18	
Check	0.14	0.14	

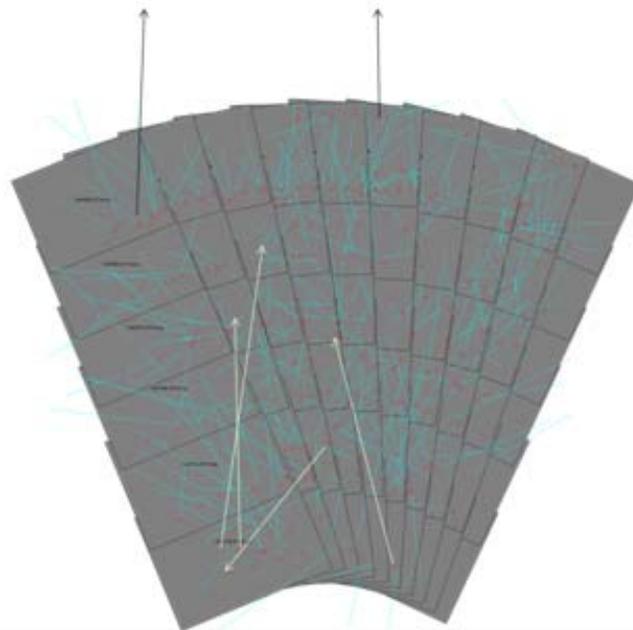


Figure 10. Object space residuals.

In comparison with the first block it can be seen that the control point residuals were only slightly smaller. Initial concern for an uncontrolled centre portion of the block don't appear to be founded as the residuals in that region do not show an overriding pattern. There are 5 check points that have significantly larger residuals. When compared to their residuals from the first block only the top left and the centre lower points showed any similarity; the other four points had different magnitudes and orientations. As this project was to understand some of the issues related to processing, no further investigations were made.

Results

The lessons learnt were:

- Image quality is critical for image point measurement and DEM construction. Simple histogram operators did little to improve DEM extraction.
- The ULCN2005 points as control provides unrealistically accurate results, using them as pass points shows their true accuracy. This is understandable given that the control points are actually terrain points generated by terrain extraction following the aerotriangulation of the Clementine project. How they will behave using Chang'E1 imagery will need to be carefully investigated.
- Version 9.2 of LPS could not make use of lunar sized spheroids. This problem was reportedly fixed in version 9.3.2 and will be tested during trials with Chang'E1 imagery.
- An automated methodology for identifying ULCN control will be necessary as manual identification on Chang'E1 will be very costly in operator time.
- As the Chang'E1 sensor design is that of a 3-line scanner and Clementine is a frame sensor, experiments with the LPS sensor options will be necessary.

3. Initial Chang'E1 study

Several experiments were done using LPS version 9.3.2 and one set of Chang'E1 imagery. 3,745 pixel long portions of forward, nadir and backward strips from orbit 161 (see Figure 11 and Table 2) were processed in three combinations:

1. Backward and nadir images
2. Nadir and forward images
3. Backward and forward images

Following the bundle adjustment each pair of images was used to create a DEM with 1200 metre (10 pixel) point spacing.

Several problem needed to be resolved:

- Sensor model
- "Flipped" images
- Control selection

Table 2. Geographical extents of the used portions of orbit image 161.

	Longitude (deg)	Latitude (deg)
Lower left	76.1	-69.3
Upper right	81.0	-54.3

Sensor model

The Chang'E1 CCD sensor is a frame sensor of 1024 x 1024 pixels but makes use of only three lines of 512 pixels wide for each line. No camera calibration information was released and the following sensor model was deduced from the mission's technical document produced by the Chinese Academy of Science (CAS 2008). There was conflicting information in the technical document so the statements regarding the pixel size and the sensor lines used for the backwards, nadir and forward images were adopted and the dimensions shown in Figure 11 computed. The stated principal distance is 23.33 millimetres. The location of the principal point was assumed to coincide with pixel (512,512) and lens distortions were assumed to be non-existent.

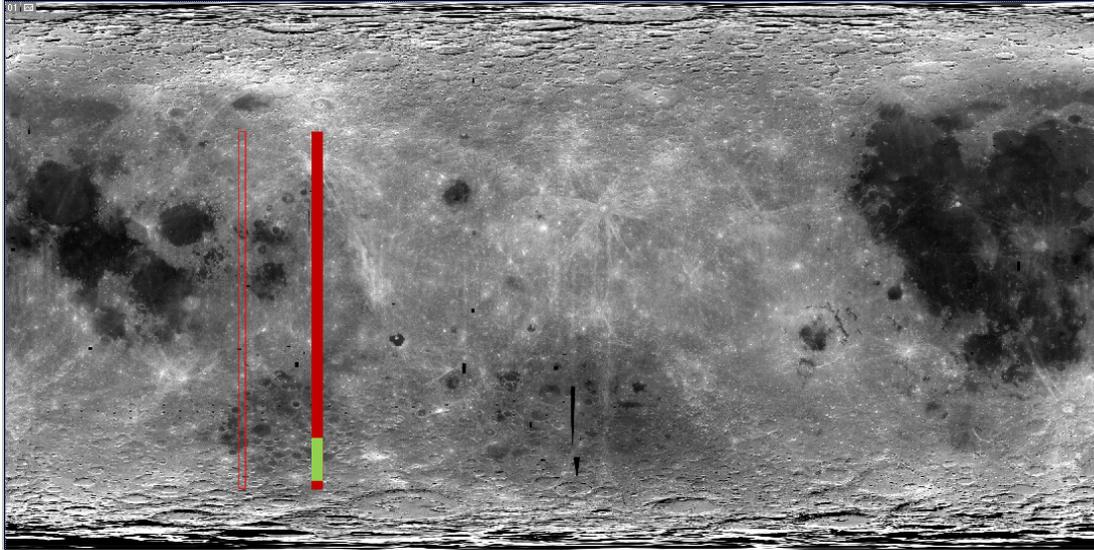


Figure 11. Location of orbit 161 (red) and the used portion (green) overlaid on Clementine 750 nm mosaic (ASU 2009). Zero degrees longitude is at the left edge of the image and increases to the right.

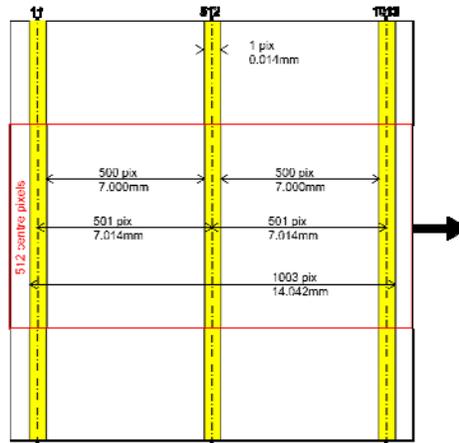


Figure 11. Chang'E1 CCD sensor geometry.

LPS provides a range of sensor models including platform-specific models and well as user-definable parametric models. The Chang'E1 CCD camera is similar in concept to that of the Leica ADS in that it has CCD lines fixed in the image plane. However this model, called Mixed Sensor in LPS, is not suitable as it requires GPS/INS orientation support. Other choices include Orbital, RPC and Polynomial categories. Orbital sensors require orbit ephemeris data and RPC sensors the numerical coefficients. The Polynomial type was chosen for these experiments and the effects of orders of the parametric models examined.

Another element that needs to be defined is the look angle of the sensor. For stereo-capable orbiting sensors this typically relates to off-nadir pointing of the sensor in the along-track or across track directions. In the case of Chang'E1 CCD the look angle corresponds to the angle subtended at the perspective centre between the nadir and forward and backward image lines. The angle was found to be 17.10 degrees.

Image flip

When transferring control points from the Clementine database to the Chang'E1 image it was found the Chang'E1 image was flipped about the vertical axis when compared to the Clementine imagery. Chang'E1 images are stored in PDS format (NASA, 2009) and were converted to TIFF format for use in LPS using an IDL script. The PDS data format combines ASCII and binary data and as Chang'E1 level 2C imagery is geo-referenced each image line begins with an ASCII segment that gives the longitude and latitude of the first and last pixel. It was found that the longitude of the first pixel of each line is larger (to the right when using conventional longitude) of the last pixel in each line. Thus, either the image readout is from right to left with respect to the direction of the satellite's orbit or longitude is defined as increasing to the left. It should be noted that the location of the Prime Lunar Meridian and direction of positive longitude has been defined in various ways over the history of man's reference to the Moon. A summary of these changes can be found in Walden *et al.*(2002). When the location of orbit 161 was plotted on Figure 10 it was obvious that the pixel recording order was the reason.

Control selection

Using LPS version 9.3.2 meant 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 as described earlier. For this small test it was deemed appropriate, but an alternative, automatic method has been proposed for larger scale studies. Based on the spacing of the ULCN2005 points, 18 points were found in two bands across the image strips of which 12 were used as control and 5 as check points. The same points were used in all three processings. Control point precision and convergence criteria were constant for each processing. The layout of control (triangles) check (circles) and tie (squares) points are shown in Figure 12.

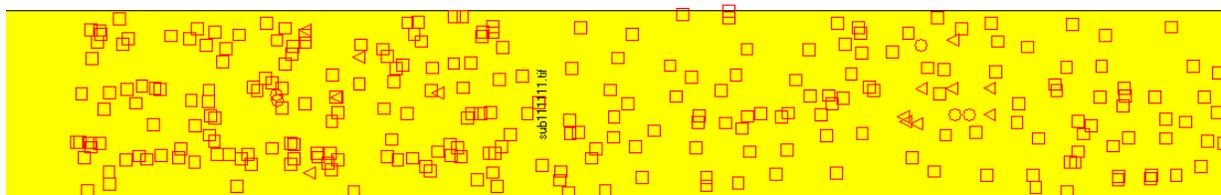


Figure 12. Locations of control, check and tie points.

Results

The statistical results of the block adjustment are shown in Table 3.

Table 3. Results of the block adjustments.

	Backward – Nadir	Nadir – Forward	Backward – Forward
RMSE image (pixels)	0.28	0.14	0.54
RMSE control X (deg)	0.06	0.18	0.05
RMSE control Y (deg)	0.01	0.03	0.00
RMSE control Z (m)	40.31	66.22	10.17
RMSE check X (deg)	0.03	0.11	0.22
RMSE check Y (deg)	0.02	0.04	0.05
RMSE check Z (m)	178.74	235.73	541.61

A key feature of these results is the large discrepancies between the RMS height errors between the check and control points. Testing several sensor polynomial combinations did not reveal any significant improvement in this regard so the issue is not sensor modelling. Instead it is the choice of control configuration. With two bands of control approximately 20% in from the ends of the strips, the polynomial fitted orbits will take the flatter shape of a straight line rather than the correctly curved shape of its true orbit. Selecting control points in the centre of the strip would have improved these results.

This flattening is obvious when comparing the DEMs with the point cloud of the Laser Altimeter (LA) data. Figure 13 shows the section of the point cloud with the DEM from the Backward – Nadir pair. The DEM is correctly located however the surface is significantly flatter than that indicated by the LA data. This is a result of the computed orbit being flattened by less than optimal control point selection. As selection of

control points is limited to those available from the ULCN2005 database longer strips are required to allow a third line of control to be used.

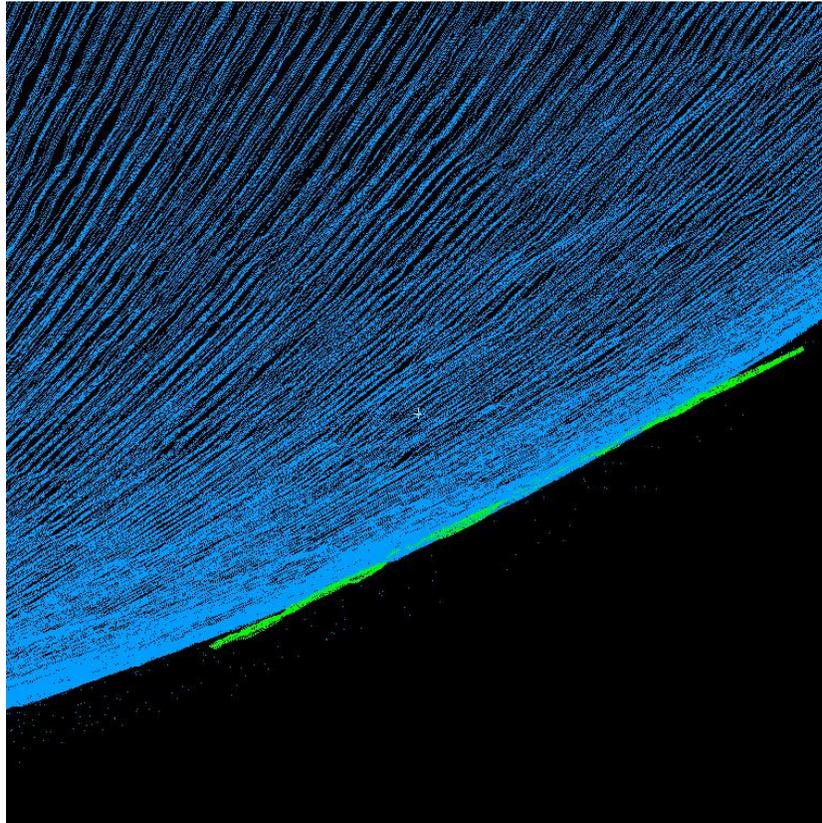


Figure 13. Profile view of the DEM from the Backward – Nadir pair (green) overlaid on the LA data (blue).

The three DEMs were overlaid and measurements taken between the surfaces at three sections along the surface as indicated in Figure 14. These locations corresponded approximately to the areas of the control points and mid-way between them. Differences in height ranged from a minimum of 0 metres to a maximum of 1150 metres.

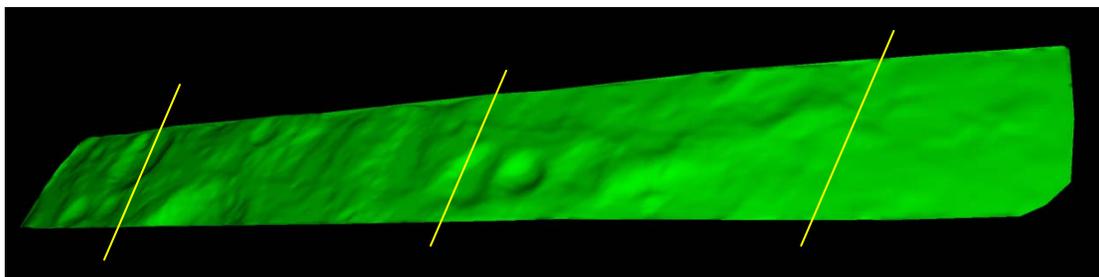


Figure 14. Locations of the test measurements shown on the Backward –Nadir DEM

4. Conclusions

This exercise reports what was a learning process in preparation for the creating of surface models of the Moon from Chang'E1 CCD imagery. A trial experiment using the 1994 Clementine images provided an insight into the capabilities of LPS as the processing environment and uncovered a significant limitation of

the software – the ability to use lunar-sized spheroids. A subsequent version of the software resolved this problem.

Processing of Chang'E1 imagery required the solution of several systematic problems and revealed further issues relating to the distribution of control points. Further studies will be done with longer strips and then expanding the processing of several strips. A methodology for automatically identifying and measuring a denser network is being developed.

Acknowledgments

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