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Precision Registration of LRO Altimeter Tracks and Stereo Terrain Models – Implications for Surface Slopes and Roughness

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Abstract

Lunar Orbiter Laser Altimeter (LOLA) tracks and Lunar Reconnaissance Orbiter Camera (LROC) terrain models are co-registered using rigorous least-squares techniques. The precisely matched data allows us to determine the alignment of the two instruments, to identify offsets and erroneous trends between the two topographic data sets, and ultimately to study surface slopes and roughness in two dimensions.

1. Introduction

The Lunar Reconnaissance Orbiter is collecting precise topographic data, inevitable for understanding surface processes of the Moon as well as supporting future exploration. Topographic information is obtained by the onboard laser altimeter LOLA (Lunar Orbiter Laser Altimeter) as well as by models computed from stereo images taken by the LROC (LRO Camera), in particular, the NAC (Narrow Angle Camera). While LOLA is collecting precise altimetric measurements along individual profiles, the NAC models provide contiguous coverage and context information. LOLA and LROC data may suffer from combinations of time tag-, orbit-, and pointing data uncertainties. Errors in pointing data may include offsets, trends, or jitter. Hence, the precise registration of the two data sets (in particular, if obtained in different orbits) is often not obvious. In order to bring these two DTMs together, a surface matching routine has been developed and is presented here.

2. Data Set

2.1. LOLA

LOLA generates single laser pulses transmitted through a diffractive optical element (DOE) which splits up the laser pulse into five beams. For each beam the time of flight (range), pulse spreading (surface roughness) and the ratio of transmitted/returned energy (surface reflectance) is measured. From the pattern of five laser spots, along- and across-track surface slopes can be determined. The pulse rate of 28 Hz creates a 50 m wide swath at an orbit altitude of 50 km. LOLA spot sizes are 5 m in diameter, along-track spacing is 10 m between two successive points. LOLA has a ranging precision of 10 cm [1].

2.2. LROC NAC

The two Narrow Angle Cameras onboard LRO, NAC-L and NAC-R, are line scanners (5,000 pix/line), operated in the pushbroom mode. From the nominal orbit height of 50 km, the two NAC cameras cover a field of view of 5 km over a swath of 25 km at an image scale of 0.5 m/pix. For the production of DTMs, multiple observations from different orbits and appropriate convergence angles are required. Typically, one nadir-looking image is combined with an off-nadir image taken from an adjacent orbit with the spacecraft being tilted by up to 20°. For this analysis NAC-L images (1.6 m/pix image resolution) from subsequent orbits 598 and 599 of the commissioning phase are used. Both stereo pairs, NAC-L/L and NAC-R/R are almost completely overlapping, forming a convergence angle of 9°. The solar incidence angle is 59° for both images (Δt $\approx$ 2 h). The DTM is computed at a grid size of 5 m to match the LOLA spot size. The processing was carried out by means of the adapted DLR photogrammetric processing system, which has been used for DTM generation from Mars Express HRSC [2][3] and other stereo imagery.

3. Method

The height differences of subsequent lola points are calculated for the desired area

$$\Delta h_{lola_i} = h_{lola_i} - h_{lola_{i-1}} \tag{1}$$

Height differences for subsequent points in the NAC DTM are calculated for the nominal position of the LOLA track ($l = s = 0$) and for shifted tracks by line l and sample s.

$$\Delta h_{nac_i,l,s} = h_{nac_{i,l,s}} - h_{nac_{i-1,l,s}} \tag{2}$$

The best match between the data sets is found at the minimum of the differences eq. 2 and 1 meaning that the gradient of the two profiles are most similar.

$$\sigma_{h_{l,s}} = \sqrt{\frac{\sum_{s=0}^{s}\sum_{l=0}^{l}\sum_{i=0}^{i}(\Delta h_{nac_i,l,s} - \Delta h_{lola_i})^2}{\sum_{i=0}^{i} i}} \tag{3}$$

4. Results

The DTM of the selected area features a small crater inside a volcanic dome (Mons Gruithuisen Gamma) in the Gruithuisen region of the Moon at 36.5°N and 319.4°E. The LOLA orbit track 1619 is displayed at its nominal position, cross-cutting the crater (Fig. 1). For the example shown, we find that the LOLA track and NAC DTM must be shifted relative to each other by 10 lines, 15 samples and 3 m in height to match. This is in rough agreement with visual inspection of the data. Standard deviation of the matching is 2 m and remaining residuals are of the order of +/-10 m and do not show any gross outliers (Fig. 3, top profile) and are expected to be mostly caused by jitter due to the sinusoidal form. In the example shown, the LOLA track intersects a small crater, approximately 2.6 km in size, 400 m depth and with a crater rim rising 100 m above average terrain (Fig. 3). Precision matching of the LOLA track to the DTM indicates that the track intersects the crater about 360 m off from its center. The LOLA spot-to-spot slopes are measured to reach 20° (Fig. 2). From knowledge of the location of the track within the crater, we estimate much higher slopes.

5. Summary

Using the described algorithm, we obtain data on lateral and vertical offsets between the LOLA and LROC topographic data sets at the level of the LOLA spot size. More data from different orbits will provide crucial information on the precise alignment angles of NAC and LOLA, as well as data on pointing data offsets, trends, and jitter. The procedure also allows us to merge NAC and LOLA data for studies of surface morphology, in particular, surface slopes and roughness within larger context.

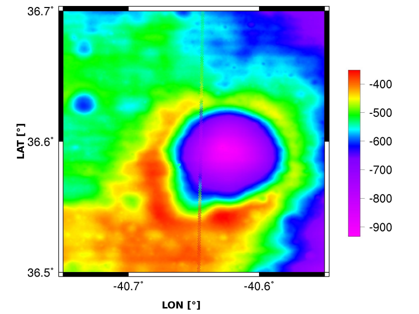

Figure 1: The nominal LOLA track (before fitting) over the color coded NAC DTM. Heights are given in meters with respect to the sphere 1737.4 km.

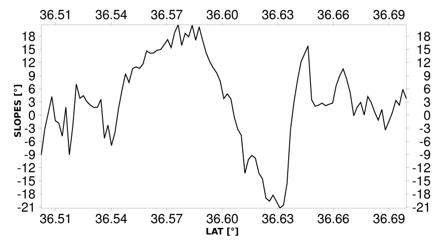

Figure 2: Slopes along the LOLA track. The length of the track is 6.06 km.

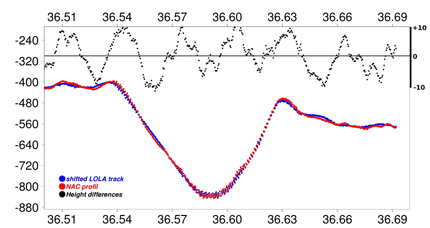

Figure 3: LOLA profile (red), NAC DTM profile along the track (blue), and differences (black) after fitting.

References

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