An Improved Approach for Digital Elevation Model Generation using Chandrayaan-2 Terrain Mapping Camera-2 (TMC-2) and Quality Assessment

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Introduction: DEM plays an vital role and are valuable tool for scientific analysis of lunar surface geology and large scale geomorphology. Generation of DEM with best possible accuracy in-terms of planimetry and height accuracy is an important requirement to be achieved. DEMs generated using triplet camera of TMC is continuously assessed for further improvement and also explored new approaches of generating DEMs. The objective of this paper is to (i) describe the new methodology of DEM generation and (ii) to illustrate the DEM accuracy achieved in comparison with LRO LOLA DEM.

Improved Methodology: During Chandrayaan-1 and early Chandrayaan-2 phase, satellite attitudes(roll, pitch and yaw) are modelled using control points identified on reference image and triplet images for DEM generation. Due to illumination differences between TMC images and reference images, control points are identified in some part of the ~2000km image strip. This introduces a uncertainty in modelling the entire strip of image using attitude based modelling. As TMC has triplet camera, each camera is modelled individually, which will produce updated attitude parameters for each camera geometry, that will be used for height estimation. Due to uncertainty in control points accuracy and distribution of control points, the three camera geometry based model lead to height error of the order of more than 200m at some points and difference between TMC estimated height and reference LOLA height is in bi-directional or gradually in the increasing order. Because of this, height errors couldn't be adjusted with simple biases. Upon detailed analysis of root cause of these problems, it was found that three camera geometry model with sparse distribution of control point is creating the issue and attitude values appeared to be more accurate than orbital parameters. Based on these analysis, it was decided to perform updating orbital parameters using single camera geometry model. The improved methodology flow chart is shown in figure-1. Orbital parameters are refined using control points identified between nadir image and reference image using nadir camera geometry model. A single refined orbital model parameters are used by fore, aft and nadir camera with their respective camera geometry to determine height values on triplet match points. The computed 3D coordinates are generated in point cloud format as irregular 3D coordinates to generate surface generation at 10m grid interval. The minimum no. of points required for interpolation in surface generation is set as 12 and if it is not satisfied, that point is marked as undefined height with the value of -32768m.

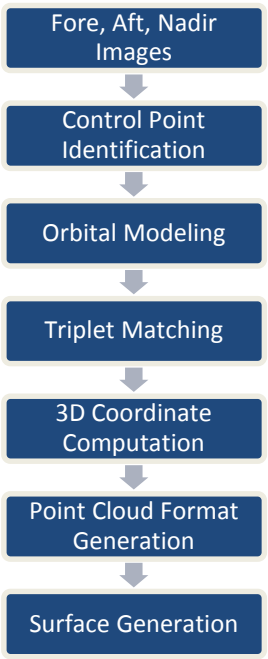

Figure-1: Improved DEM Generation Methodology

Datasets Used: For carrying out DEM generation using improved methodology, eight orbits of datasets featuring different surface characteristics have been chosen as shown in table-1.Selene Ortho-images are used as planimetry reference and LOLA DEM are used as height reference in LCPS. In case of non-availability of LCPs from Selene, LRO-WAC / Clementine will be considered for the LCP identification [2] and [3]. Previous version of DEM generation approach and its quality assessment are described in [1].

Quality Analysis: A detailed analysis on DEM generation using single camera attitude and orbital model was carried-out and the observations are shown in following figure-2. In figure-2, plot 1,2,3 and 4 illustrates the across track profile from different test datasets. In figure-2, height profile extracted in across track from attitude model based DEM, orbital model based DEM and LOLA DEM is plotted. The attitude model based DEM (red plot) with respect to reference (green plot) is deviating as we go across track, whereas orbital model based DEM (blue plot) is having only bias with respect to reference. This observation is common in all of the attitude model based DEM and by registering 3D point cloud of

orbital model based DEM with reference point cloud removes the observed biases as shown in following figure-3.

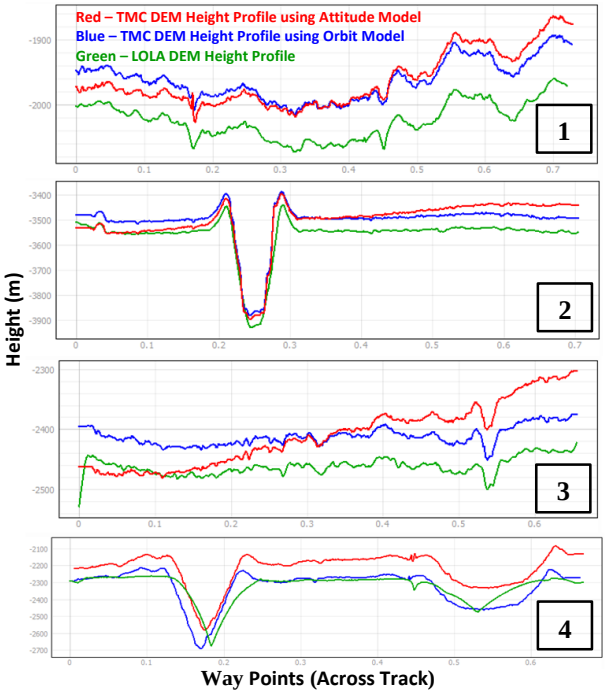

Figure-2: Attitude and Orbit Model DEM Comparison

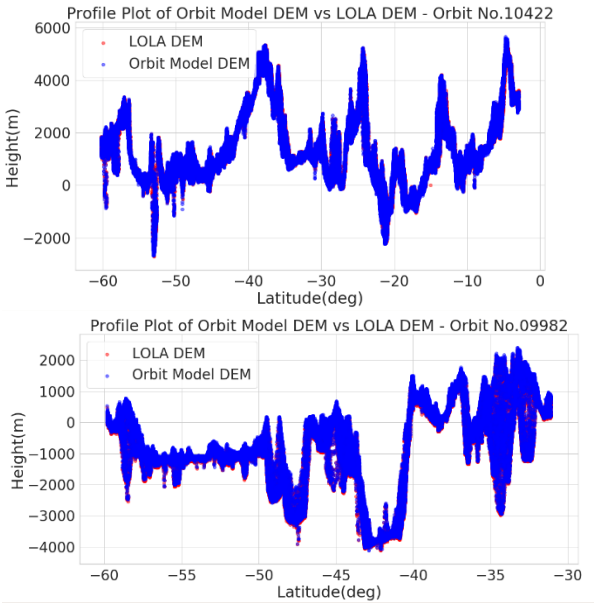

Figure-3: Bias Corrected Orbital Model DEM

The TMC DEM are used to generate ortho images at 5m grid spacing and automatic control point identification between TMC ortho image and Selene ortho image is performed for evaluation of positional and height accuracies. The following figure-4 shows the computed height error variation in an orbit using automatic evaluation and they are well within the range of 100m.

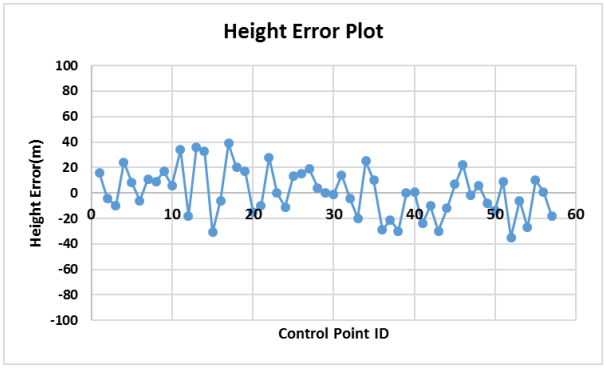

Figure-4: Height Error Plot

The following table-1 shows the RMSE height error in comparison with LOLA DEM on 08 test datasets. The height errors are <100m for varying terrain types and strip lengths.

Table-1: RMSE Height Error

S. No.	Orbit No.	Strip Length (km)	Min. Height (m)	Max. Height (m)	RMSE Height Error (m)
1.	1136	871	-327	7483	34
2.	1261	881	-5052	1350	42
3.	1336	881	-4183	1148	34
4.	1439	884	-2849	4151	14
5.	9982	969	-4166	2437	66
6.	5617	1770	-4101	2198	56
7.	10522	1778	-3170	4336	57
8.	10422	1791	-2727	5672	63

The following figure-5 shows the color coded DEM (orbit no. 10522) of TMC and LOLA at 30m grid spacing.

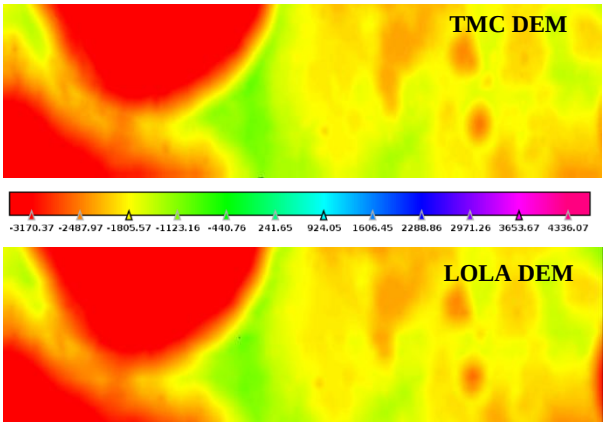

Figure-5: Color Coded DEM of TMC and LOLA

Conclusion: DEM height accuracy with ≤50m is achievable by modelling orbital parameters alone as orbital parameters are poorer than attitudes. It is planned to fuse LOLA DEM with TMC DEM for those undefined height areas to have continuous surface elevation values. **References:** 1. Triplet Camera Based DEM generation of Lunar Surface from Chandrayaan-2 Terrain Mapping Camera-2Imagery-Quality Improvements and Results, Abstract # 1397, LPSC2021;2.https://www.lroc.asu.edu;3.http://www.kaguya.jaxa.jp