RIGOROUS PHOTOGRAMMETRIC PROCESSING OF CHANDRAYAAN-1 TERRAIN MAPPING CAMERA (TMC) IMAGES FOR LUNAR TOPOGRAPHIC MAPPING. P.V.Radhadevi, V.Nagasubramanian, S.S.Solanki, T.Krishna Sumanth, J.Saibaba and Geeta Varadan , Advanced Data Processing Research Institute, Department of Space, Manovikasnagar P.O., Secunderabad 500 009, India ,e-mail:drpvr@adrin.res.in

Introduction: The Terrain Mapping Camera (TMC) on India's first satellite for lunar exploration, Chandrayaan-1 has opened up possibilities for Lunar topographic mapping with unprecedented precision and information. The camera has three CCD arrays acquiring stereo triplet of the target scene in the Fore (F), Nadir (N) and Aft (A) views with a resolution of 5m. Specifications of TMC are given in [1].For the full exploitation of the potential of this data, the "classical" satellite data processing methods are extended in order to describe the imaging geometry. The processing scheme described in this paper is an integral part of the operational software package called as Lunar Mapping System (LMS) for generation of data products.

Methods: This paper describes the process of generating Digital Elevation Models (DEM) and ortho-images from Chandrayaan-1 TMC stereo triplets involving various operations such as modeling camera trajectory, sensor modeling, automatic tie point/check point/Lunar Control Point (LCP) identification, block adjustment, image matching and stereo intersection. The geometric model is based on the viewing geometry of the satellite, combining the principles of photogrammetric collinearity equations, originally developed for SPOT-1 and further adapted and tested for different sensor geometries from IRS-1C/1D to Cartosat-2 (see [2], [3]). Figure 1 shows the flow chart of the photogrammetric processing scheme for TMC stereo triplet. Individual strip adjustment, combined strip adjustment and block adjustment are performed and compared.

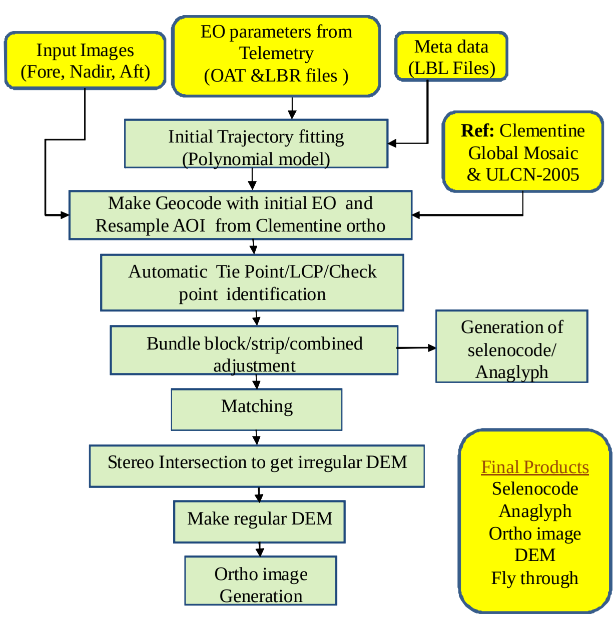

Figure 1. Flow chart of the processing scheme.

The orbital parameters in the collinearity equations are position (X_p, Y_p, Z_p), velocity (V_x, V_y, V_z) and attitude parameters are roll (ω), pitch (ϕ), and yaw (κ).

The initial values of all these parameters are derived by least squares adjustment to the given ephemeris and attitude data. Full strip data with approximately 3,00,000 lines are processed. 3rd order polynomial and 9th order polynomial are used for fitting orbital and attitude parameters respectively. Exterior Orientation (EO) parameters can be computed by refining the polynomial coefficients. Refinement is done for the constant and first order tems (time-dependent) of attitude parameters.

Initial trajectory fitted is same for all the three strips. LCPs from each strip are used and refinement is done for the attitude parameters so that three separate sets of EO parameters are computed in the individual strip adjustment. The challenge of developing a combined camera model for TMC is to find common exterior orientation parameters for all the three strips. The benefit is that the number of unknown parameters is reduced.Bundle adjustment aims at removing the inconsistencies between TMC triplet images by adjusting their EO parameters through the tie points.A subset of LCPs used for combined adjustment is used for block adjustment and remaining are used as tie points. EO parameters are separately computed for each strip after the block adjustrment.

Area based image matching using cross correlation is developed and adopted for the automated DEM generation from stereo pairs. Hierarchical approach for matching is perfomed at different levels from coarse-to-fine images. For each level, the mismatches are removed using a spike removal algorithm and automatic quality control algorithms are also incorporated. Least square matching methods is implemented to achieve sub-pixel accuracy at the final level pyramid. As the results of image matching between Fore and Aft combination is poor, matching is done between Nadir-Aft and Nadir-Fore combinations for DEM generation.

Results and Discussion: An analysis is done to evaluate the initial trajectory fitting accuracies. High-frequency jitter of the spacecraft canbe filtered out by subtracting the best-fitting polynomial from the original telemetry and attitude data.Figure 2 shows the extracted jitter on ω, φ, κ with the horizontal axis being the time and the vertical axis being the jitter magnitude in degrees.

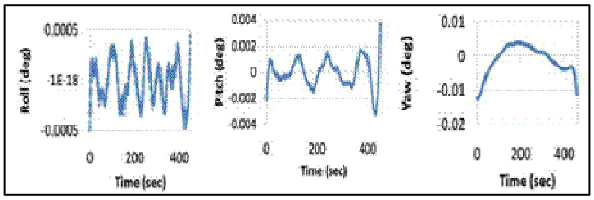

Figure 2 Residuals after subtracting best fitting polynomial from telemetry data

To evaluate the topographic effect of orbital/attitude jitter, a single CCD pixel was projected onto the lunar surface using telemetry EO data and the point of intersection with the lunar sphere was computed. The projected footprint was compared with another projected footprint using EO parameters adopted using polynomial fitting.A maximum difference of 22 meters was detected from the comparison over the full pass of 1600 kilometer.

3D modeling accuracy was tested on independent checkpoints. A set of conjugate points are identified automatically in all the three images, so that same set of LCPs/Tie points are used in all the three adjustments. Table 1 gives comparison results from different adjustments. Results from 4 orbits are presented. It is obvious from Table 1 that the RMS residuals are of the same order as of input LCP/data errors, being a combination of image pointing error and planimetric error in addition to the propagation of Z-error depending on the viewing angles.

Orbit	Date	Stereo pair	RMS Errors w.r.t. Clementine Ortho & UNCL 2005 (m)								
			Individual camera Adjustment			Combined camera Adjustment			Block Adjustment		
			Y	X	Z	Y	X	Z	Y	X	Z
519	02-01-2008	F&N	574	136	1278	293	175	800	329	133	927
		F&A	400	184	1597	236	153	611	397	175	1120
		N&A	582	143	1984	295	100	1111	331	120	1117
2488	02-06-2009	F&N	752	358	1094	588	351	1529	759	380	1403
		F&A	654	398	1461	570	474	1342	818	420	1296
		N&A	917	313	1826	625	434	1227	710	368	1302
3266	01-08-2009	F&N	327	419	789	352	468	676	357	434	668
		F&A	375	438	958	303	471	696	335	428	656
		N&A	349	420	1316	430	526	1216	400	408	687
2011	02-04-2009	F&N	362	110	1165	510	149	1725	453	141	947
		F&A	209	142	891	169	149	932	479	211	914
		N&A	380	163	825	592	124	1436	500	255	932

Table 1 Comparison of 3D Model Accuracies

Block adjustment shows better consistency between different stereo combinations compared to independent and combined camera adjustments. Out of all the three methods, combined camera adjustment shows most inconsistent results. The reason is that a relative and absolute in-flight calibration of the indivual cameras is not done and this results in comparatively inexact handling of systematic image errors while computing a single set of EO parameters. The in-flight calibration will ensure that errors at the system level are due to small uncertainties in the body attitude, which are shared by all the cameras.

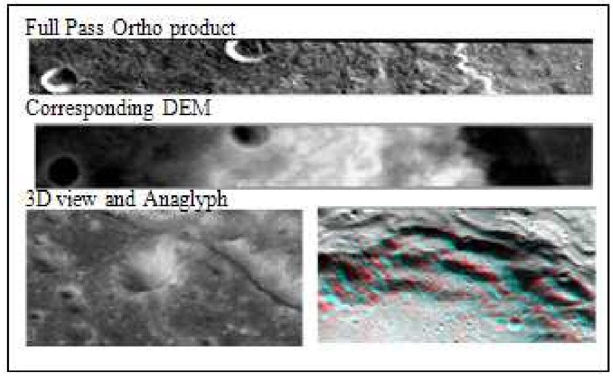

Figure 3 Final Products after the photogrammetric processing of TMC images

Conclusions: In this paper, a methodology based on photogrammetric processing of TMC images of Chandrayaan-1 is presented. Topographic effect of orbital /attitude jitter of the spacecraft is evaluated and found that a maximum of 22 meters error can occur over the full pass image of 1600 kilometers. Results are compared between individual camera adjustment, combined adjustment of all the cameras and a block adjustment. Block adjustment shows better consistency between different stereo combinations. It is concluded that in a combined camera approach, in-flight calibration of the cameras is a very important pre-requisite. The results are representative of the stability of the platform and the potential of TMC for accurate lunar referencing.

References: [1] Kiran Kumar,A.S. et.al. (2009), *Current Science*, *Vol.96, NO.4,25*,492-495. [2] Radhadevi P. V. et.al (1994), *Photogrammetric Record, 14(84)*, 973-982.[3] Radhadevi,P.V et.al (2010) , *Photogrammetric Engineering & Remote Sensing, Vol. 76, No. 9*, 1031–1040. [4]LPSC40th ,Abstract1694.

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