Digital Elevation Model Generation from Navigation Cameras of Chandrayaan-3 Rover for Rover mobility.

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Introduction: The Chandrayaan-3 mission consisted of Lander, Rover and a Propulsion Module. The Lander made a soft landing near to the south pole on the lunar surface on 23rd August 2023 at 12:34 UTC. After landing the Rover was rolled down from the Lander and made to traverse on the lunar terrain. In order to aid in the smooth and obstacle free navigation of the rover on the lunar surface a pair of Navigation Cameras (Navcams) had been mounted on the rover deck, in the front of the rover. The Navcams provide a pair stereo image of the lunar terrain in front of the rover. The Navcam stereo images were processed and the Digital Elevation Model (DEM) of the terrain was generated. The DEM was used to fetch the terrain parameters like slope, boulder height and distribution of boulders and craters. These parameters were used in the rover path planning for rover mobility. The specifications of the Navcams are given in Table-1

Table-1

Parameter	Value
Detector	STAR 1000 APS (Monochrome)
No: of pixels	1024x1024
Pixel dimension	15 µm x 15 µm
Spectrum	Visible
Frame Rate	3 fps
FOV	39º (H) x 39º (V)
Focal length	21 mm
Inter-camera distance	240mm
Height of Navcams	320mm
Tilt towards ground	11 deg

Requirements: The hazard constraints for the rover mobility were (1)The slope of the terrain should be less than 15 degrees (2)The obstacle height should be less than 50 mm. (3)The DEM to be generated at 1cm grid interval for a range of 10m in front of the rover. In order to meet these requirements, a process sequence as shown in Figure-1 was adopted for the generation of DEM. The details of processing are given in the next section.

Sequence of Processing: (1) Radiometric Correction: The raw navcam images were received at the ground station and the left and right images were extracted from the the Level-0 data format. These extracted images were normalized for detector non-uniformities using the Look-Up-Table (LUT) which was generated during radiometric calibration of the Left and Right Navcams in the clean room using Integrating spheres. Corrections for line losses and block losses were also part of this process. (2)Automatic Image Matching: This process automatically identifies dense conjugate points [3][4][5] between the left and right navcam images. A hierarchical image matching approach with a mean normalized cross-correlation technique was adopted with a slope-bias based disparity computation at the initial level. During pre-launch experimentations, it was observed that the slope of the plot of the line no. versus pixel disparity for the navcam images remained constant and was directly proportional to the inter-camera distance. It was also observed that the roll and pitch values of the rover deck affected the pixel disparities values in addition to local terrain variations, hence a rectangular search area windows adopted for getting dense match points. Few filtering approaches were also adopted to remove false match points in the process. (3) 3D Object Coordinates Computation: The 2D image coordinates in the left and right navcam images of the filtered conjugate points were used to compute their corresponding 3D object coordinates in the rover local coordinates system, as shown in Figure 2. The CAHV [1] vectors were used for computing the 3D coordinates. Since the navcams were rigidly mounted on the rover deck, an exclusive geometric calibration exercise for the navcam setup was carried out for a range of 10m in the Lab and the CAHV vectors were computed. These CAHV vectors

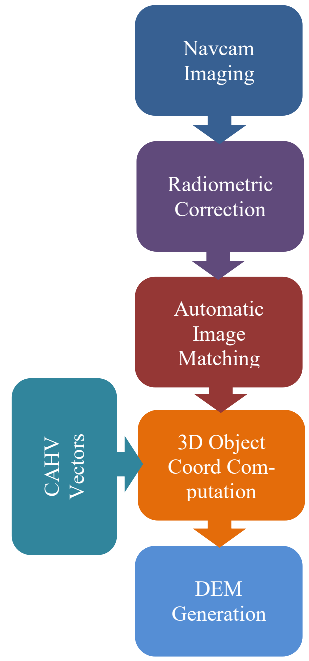

Figure 1: Process sequence for generation of DEM

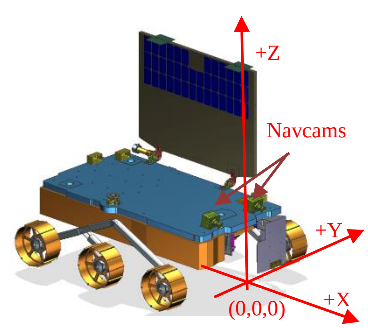

Figure 2: Rover Local Coordinate System

held good for the rest of the mission life. (4) DEM Interpolation: The computed 3D object points were filtered for the range of 10m and the residual few outliers were manually removed. The Inverse Distance Weighted (IDW)[6] technique was adopted to interpolate the filtered 3D object point cloud

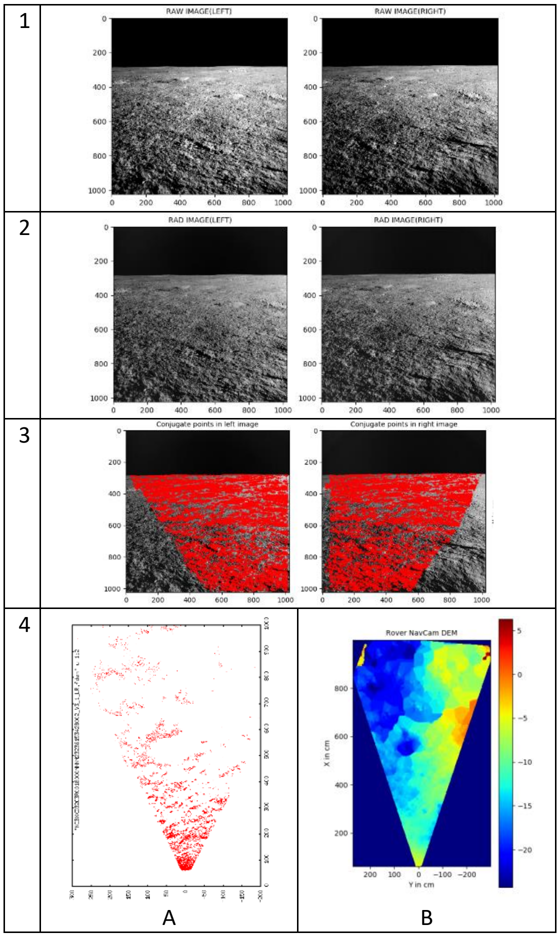

Figure 3: Processing of Navcam images

for generating a regular DEM at fixed grid interval of 1cm. The DEM, hence generated was used for rover path planning operations to find an optimal path for rover mobility free of any hazards

Results and Observations: Table-2 gives a summary report of the residual errors at the control points and the check points achieved during the geometric calibration exercise of the Navcams for computing the CAHV vectors. It can be observed that the errors are below 25mm.

Table-2

Error Type	Control Points (mm)			Check Points(mm)		
	X	Y	Z	X	Y	Z
Mean	0.005	-0.001	-0.001	-2.3	-1.5	-0.9
Std	0.162	0.013	0.401	13.4	3.4	1.8
Rms	0.162	0.013	0.401	13.6	3.7	2
Min	-0.203	-0.028	-0.615	-24.2	-10.5	-6.2
Max	0.304	0.015	0.566	24.7	3.2	1.5
Control points:**7**				Check points:**38**		

After landing, the Rover Navcam images were captured and received at the ground station where the images were processed and DEMs were generated. These DEMs were used for the rover path planning for rover traversal and the rover mobility commands were uploaded. In Figure-3, the 1st row shows one of the raw left and right navcam image captured on the lunar surface, the 2nd row shows the radiometrically corrected images, the 3rd row shows the plot of dense cloud of conjugate points in red colour on the images and in the 4th row, column A shows the spread of computed 3D object coordinates using the CAHV vectors in red colour and column B shows the color-coded regular DEM generated.

As a part of validation exercise of the CAHV vectors, measurement were made in one of the navcam images

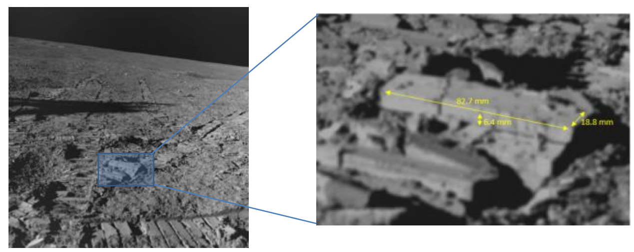

Figure 4: Navcam image with rover wheel impression

which had captured the undisturbed rover wheel impression. Figure-4 shows the navcam image and the zoomed portion of wheel impression. The observed wheel width was 82.7mm (with a small break) against 80mm. The observed distance between each wheel groove was 18.8mm against 19.8mm and groove depth of 6.4mm was observed against 5mm.

Conclusion: It can be concluded from the Table-2 that the residual errors at the check points are well within the specification and the 3D points produced through the model are of high accuracies. The same has been validated from the measurements of the rover wheel impression on the lunar regolith. The DEM generated for the lunar terrain had been extensively used for the Rover mobility on the Lunar terrain.

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