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Extraction of terrain parameters from IRS-1C PAN stereo data using photogrammetric techniques

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Digital Elevation Model (DEM) is used for extraction of terrain parameters such as elevation, slope, aspect, contour, drainage pattern, etc. These parameters are often required in preparation of development and conservation plan for natural resources, infrastructure development, town planning, etc. Indian Remote Sensing Satellites IRS-1C/1D carry on-board push broom Linear CCD PAN camera, providing high resolution (5.8 m) stereo imagery of the earth's surface. DEM has been derived from PAN stereo pair of IRS-1C/1D using suitable mathematical models. It has been used to generate contours and extract drainage patterns. DEM generated from stereo data has been validated using ground control points (GCPs) and also by the surface-to-surface comparison method. Evaluation of drainage pattern is carried out by morphometric analysis.

TERRAIN parameters such as elevation, slope, aspect, contour, drainage pattern, etc. are often required as input in a large number of applications such as landslide hazard

zonation, cellular phone network planning, watershed management, selecting sites for sewage treatment plants, solid waste disposal in urban areas, alignment of rail/road network, catchment area treatment, siting of rainwater harvesting structures, wetland conservation and management, etc. In addition, these are also needed in modelling of soil loss, run-off and site suitability analysis. Conventionally these parameters are obtained through field measurement/survey or from existing topographic maps depending on the purpose and level of information required. The above-mentioned terrain parameters can be extracted from DEM (Digital Elevation Model).

The DEM and ortho image can be generated from satellite stereo data using photogrammetric techniques. DEM extraction from SPOT stereo pair has been attempted by Giles and Franklin¹, Bolstad and Stowe², Rousan *et al.*³, Richard *et al.*⁴. Srivastava *et al.*⁵ discussed the use of IRS-1C panchromatic data for cartographic applications. They have given a theoretical assessment of cartographic potential of IRS-1C imagery and the early results from few stereo pairs.

Lawrence⁶ used DEMs to automatically map the stream channel and divide networks of a watershed. Jensen and Domingue⁷ developed algorithms to extract topographic structure and to delineate watersheds and overland flow paths from DEMs. Veregin⁸ discussed the effects of vertical errors in DEM on the determination of flow-path direction.

The Indian Remote Sensing Satellite IRS-1C/1D PAN camera has a spatial resolution of 5.8 m and it consists of 3 CCD arrays, each having 4096 sensor elements. The

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swath of PAN camera is approximately 70 km on ground. The PAN camera can be steered up to $\pm 26^\circ$ in the across-track direction. Thus by acquiring imagery over the same area from multiple orbits, a stereoscopic coverage can be obtained. The height resolution, i.e. the accuracy of DEM derived from the satellite stereo pair depends upon the horizontal resolution of the sensor (i.e. pixel size) and the B/H ratio used in acquiring the stereo pair. The relationship is: height resolution = pixel size/(B/H) ratio.

The accuracy of DEM and its derived products are of crucial importance. Errors in elevation, slope and aspect will cause errors in the cartographic model output. The generated DEM has to be therefore evaluated before utilizing it for various applications. Several methods have been adopted in literature for accurate assessment of DEM.

Rodriguez *et al.*⁹ evaluated the stereoscopic accuracy of the SPOT satellite using ground control points established using aerial photographs. Bolstad and Stowe² have evaluated the accuracy of the elevation, slope and aspect generated from SPOT-derived DEM, by comparing the elevation for control points obtained from DEM with the corresponding control points derived from a combination of conventional and GPS surveys. Giles and Franklin¹ evaluated the accuracy of elevation and its derived terrain parameters.

In the present study, DEM and ortho images are generated using IRS-1C stereo data. The ortho image is visually compared with the existing topographic map. DEM accuracy is evaluated using GCPs taken from 1 : 50000 topographic map. Evaluation of DEM has also been carried out by surface-to-surface comparison. In this, a reference DEM is generated from the contours and spot heights using the available map. Drainage pattern is extracted using DEM as input. Morphometric analysis has also been carried out. Perspective views are generated by draping IRS-1C LISS-III image over DEM.

The study area lies in the north of Alwar district of Rajasthan, located between $26^\circ 35' - 26^\circ 45' N$ latitude and $76^\circ 35' - 76^\circ 45' E$ longitude. The selected area is approximately 18 km by 18 km. It is characterized by plain-to-moderate relief with an elevation range of 200 to 600 m. The prominent cultural features include Shymak Reserved Forest (RF), Kalakhora RF, Bahadurpur city, etc.

IRS-1C PAN stereo digital data have been used in the present study. The first PAN image of the used stereo pair was acquired on 11 November 1996 with a view angle of $+19.12^\circ$, sun elevation of 42.37° and sun azimuth of 162.35° . The second image was acquired on 22 November 1996 with a view angle of -18.25° , the sun elevation and azimuth were 40.65° and 162.19° , respectively. The B/H ratio for the stereo pair was 0.67. IRS-1C LISS-III of 11 February 1999 was used to generate perspective views. LISS-III multi spectral data (green, red and near infrared bands) have a spatial resolution of 23 m.

The method used in the present study for the generation of DEM and ortho image, and the drainage pattern and morphometric analysis is described below.

DEM, one of the most important terrain parameters, is derived from stereo pair of IRS-1C/1D PAN data using suitable mathematical models. The software used in the present study for the generation of DEM and ortho image from stereo pair of IRS-1C/1D data has been developed at Space Applications Centre, Ahmedabad¹⁰. The software called DATDEM takes the input stereo pair of IRS-1C/1D data to generate DEM and ortho image as output. The model updates the orbital parameters by using a few ground control points (GCPs) and collinearity condition equation. Automatic identification of conjugate points is carried by using hierarchical matching technique. Three-dimensional ground coordinates are obtained by space intersection method, for all conjugate points. This gives an irregular DEM. Interpolation of irregular DEM generates a regular DEM at a specified interval. Ortho image is generated from regular DEM using object-to-image transformation and resampling techniques.

Drainage extraction from DEM requires three initial conditioning procedures, namely (i) filling depressions in DEM; (ii) calculation of flow direction; and (iii) calculation of flow accumulation data set. The technique is based on decision about individual grid cells based on the value of its eight surrounding neighbours and routes the flow into the cell that gives the direction of the steepest slope⁷. In the present case the size of the grid cell is 62.5 m.

Depressions occur in DEM, when a cell is surrounded by higher elevation cells. Depressions are filled by raising each cell's elevation to the elevation of its lowest neighbourhood cell. Flow direction was determined for every cell and by using this information, flow accumulation for each cell is calculated by the number of cells that flow to that particular cell. Drainage network is formed by highlighting cells which have flow accumulation value greater than the given threshold value. PCI EASI/PACE software module DWCON and DRAIN were used for conditioning procedure and to delineate drainage pattern.

Twenty metre contours were generated from DEM using CONTOUR program of PCI EASI/PACE software. The generated contours have been visually compared with existing 20 m contours of topographic map. It was observed that in plain areas, contours generated from DEM match well with those of the topographic map; slight mismatch was seen in contours of hilly areas. The reason may be because of DEM errors in the hilly area.

Perspective views were generated using EASI/PACE software module for draping LISS-III data with DEM. For this purpose, the ortho image was registered with LISS-III image with sub-pixel accuracy. The pre-enhanced LISS-III data were then used to generate different perspective views. These views are mainly useful for terrain visualization.

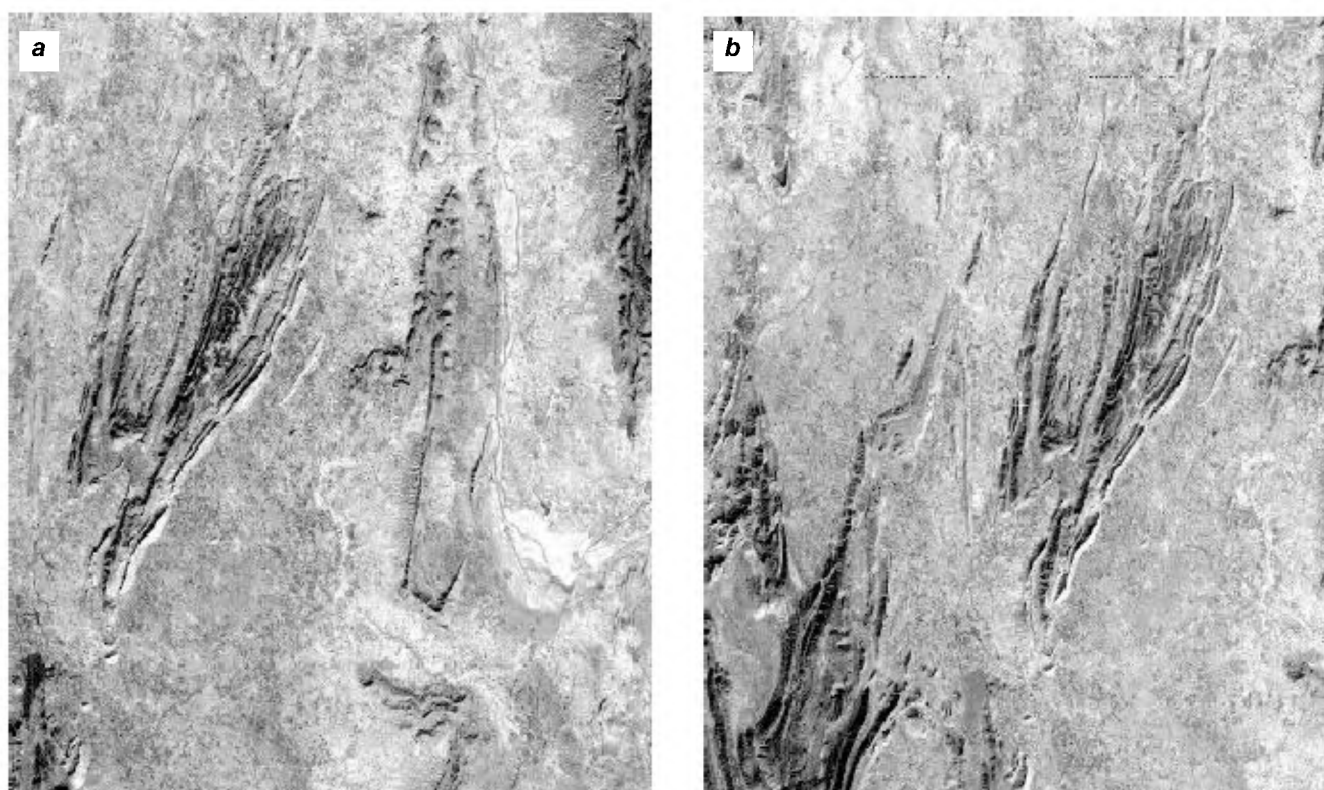


Figure 1. IRS-1C PAN *a*, left image; and *b*, right image.

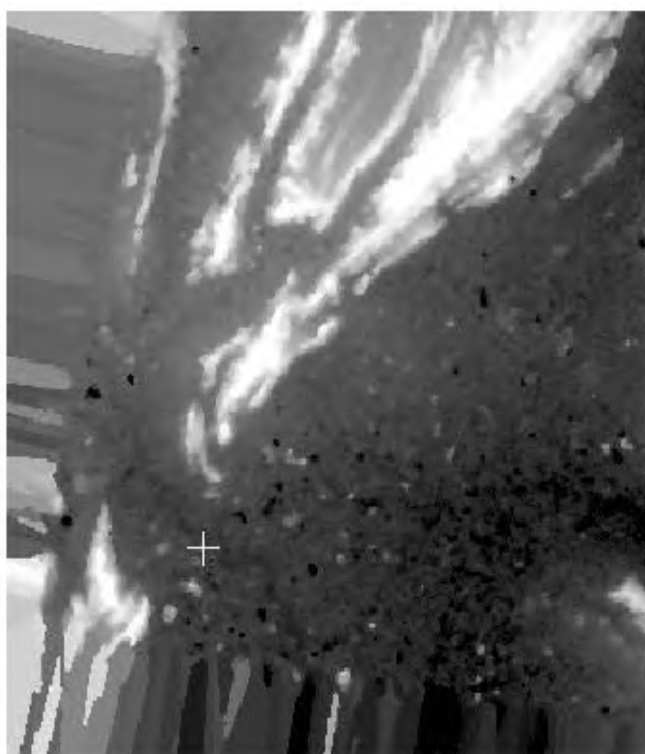


Figure 2. Digital elevation model.



Figure 3. Ortho image.

The evaluation of the DEM generated from IRS-1C stereo pair was carried out by the following two methods.

In point-to-point comparison, 44 check points were selected from 1 : 50000 topographic map. Height values as obtained from DEM were compared with the corresponding values obtained from the topographic map for these check points. Root-mean-square (RMS) error has been calculated. The check points were taken from both plain and hilly areas.

In surface-to-surface comparison, the reference DEM was generated through the contours and spot heights available on 1 : 50000 topographic map. DEM was generated by using TOPOGRID and GRIDIMAGE modules of ARC-INFO. DEM generated from stereo pair of IRS-1C data (SATDEM) was registered with reference DEM (ARCDDEM). Absolute difference of DEM (ARCDDEM-SATDEM) has been generated and studied.

Evaluation of ortho image and drainage patterns was done by registering them on the topographical maps. In case of ortho image, the registration errors were computed and compared with corresponding values obtained for geometrically corrected images (not corrected for relief distortion). The drainage patterns were evaluated by visual comparison with the information on 1 : 50000 topographical map and by morphometric analysis.

The IRS-1C PAN stereo pair of the study area is given in Figure 1 *a* and *b*. The corresponding DEM and ortho images are given in Figures 2 and 3. Comparison of the height values obtained from the DEM with the corresponding values from topographic map for 44 check points is presented in Table 1. The comparison shows that RMS error was 19.03 m. The absolute minimum elevation error was less than 5 m in plain areas; the absolute maximum elevation error was found to be as high as 56.8 m in highly undulating areas. The surface-to-surface comparison of DEM has been done by comparing SATDEM with ARCDDEM and the results are presented in Table 2. The residual errors were estimated. It has been found that for 15% of the points, the absolute height difference is less than 5 m, for 66% of the points it is less than 20 m for 28% of the points, the height difference is between 20 and 40 m, and for 6% of the points the residual difference is more than 60 m. The registration error between the two DEMs as well as the mismatch in the identification of conjugate points in the model might have contributed towards the inaccuracy. Qualitative comparison of SATDEM is carried out by draping LISS-III image on DEM (Figure 4). RMS error in the case of registration of ortho image with respect to the topographic map of 1 : 50000 scale is 3.75 m in Easting and 4.06 m in Northing, and in the case of geo-coded image, it is 5 m in Easting and 4.62 m in Northing.

Drainage pattern as extracted from the DEM is shown in Figure 5. Morphometric analysis of the drainage pattern has also been carried out and the results are given in Table 3. Comparison of the drainage delineated from

Table 1. Comparison of height values obtained from DEM with the corresponding values from topographic map

Sl. no.	Latitude	Longitude	Height (m)		Diff. Ht (m) Map – DEM (m)
			Map	DEM	
1	27d 37' 03.20"	76d 37' 03.20"	280	275.29	4.71
2	27d 43' 37.40"	76d 37' 40.00"	300	292.00	8.00
3	27d 41' 03.24"	76d 36' 12.72"	300	302.14	- 2.14
4	27d 40' 47.03"	76d 36' 21.83"	280	282.36	- 2.36
5	27d 43' 47.3"	76d 42' 47.4"	500	484.06	15.94
6	27d 41' 34.9"	76d 37' 43.7"	500	464.00	36.00
7	27d 42' 14.59"	76d 36' 09.51"	340	328.57	11.43
8	27d 38' 08.70"	76d 37' 00.90"	280	269.29	10.71
9	27d 42' 03.80"	76d 39' 32.6"	440	391.53	48.47
10	27d 42' 58.2"	76d 38' 24.6"	460	428.72	31.28
11	27d 42' 14.1"	76d 38' 34.9"	510	492.00	18.00
12	27d 39' 39.30"	76d 40' 58.80"	264	271.90	- 7.90
13	27d 40' 24.60"	76d 41' 58.00"	263	273.27	- 10.27
14	27d 40' 03.60"	76d 41' 02.40"	320	290.50	29.50
15	27d 41' 40.70"	76d 43' 37.20"	325	288.62	36.38
16	27d 41' 41.10"	76d 38' 26.50"	300	302.71	- 2.71
17	27d 38' 18.20"	76d 37' 30.70"	280	285.48	- 5.48
18	27d 41' 29.70"	76d 39' 50.70"	400	380.38	19.62
19	27d 42' 20.90"	76d 41' 41.70"	340	314.35	25.65
20	27d 42' 01.90"	76d 43' 44.60"	265	268.57	- 3.57
21	27d 42' 29.30"	76d 44' 35.40"	280	268.19	11.81
22	27d 42' 41.70"	76d 44' 29.00"	267	269.49	- 2.49
23	27d 42' 09.70"	76d 38' 34.10"	300	332.72	- 32.72
24	27d 41' 57.00"	76d 39' 08.40"	300	303.88	- 3.88
25	27d 37' 29.50"	76d 36' 50.80"	370	313.20	56.80
26	27d 42' 45.10"	76d 37' 18.50"	300	297.11	2.89
27	27d 44' 48.50"	76d 40' 13.10"	340	325.37	14.63
28	27d 41' 51.80"	76d 38' 54.80"	300	296.35	3.65
29	27d 43' 11.20"	76d 44' 37.90"	350	328.49	21.51
30	27d 43' 17.20"	76d 44' 17.70"	275	270.55	4.45
31	27d 38' 51.20"	76d 41' 57.80"	260	265.12	- 5.12
32	27d 42' 50.80"	76d 36' 47.70"	300	309.06	- 9.06
33	27d 41' 07.70"	76d 37' 13.10"	290	295.89	- 5.89
34	27d 42' 16.10"	76d 38' 53.50"	500	479.60	20.40
35	27d 39' 33.22"	76d 34' 36.18"	280	284.36	- 4.36
36	27d 38' 50.27"	76d 35' 21.82"	280	275.15	4.85
37	27d 37' 09.90"	76d 43' 39.50"	259	266.48	- 7.48
38	27d 36' 41.30"	76d 43' 13.80"	300	275.78	24.22
39	27d 38' 04.00"	76d 43' 27.90"	252	259.32	- 7.32
40	27d 37' 07.70"	76d 40' 33.90"	262	266.02	- 4.02
41	27d 37' 08.10"	76d 38' 54.30"	263	265.86	- 2.86
42	27d 42' 35.50"	76d 36' 33.90"	400	380.36	19.64
43	27d 40' 15.90"	76d 40' 00.50"	276	277.81	- 1.81
44	27d 39' 06.60"	76d 40' 38.30"	268	274.53	- 6.53

RMS error of elevation differences is: 19.03 m.

Table 2. Variation of absolute elevation values in difference DEM (SATDEM – ARCDDEM)

Absolute elevation difference value (m)	No. of pixels
< 5	8899
> 5 and < 20	30161
> 20 and < 40	12394
> 40 and < 60	4131
> 60	3435

Total number of pixels in the difference DEM image: 59020.

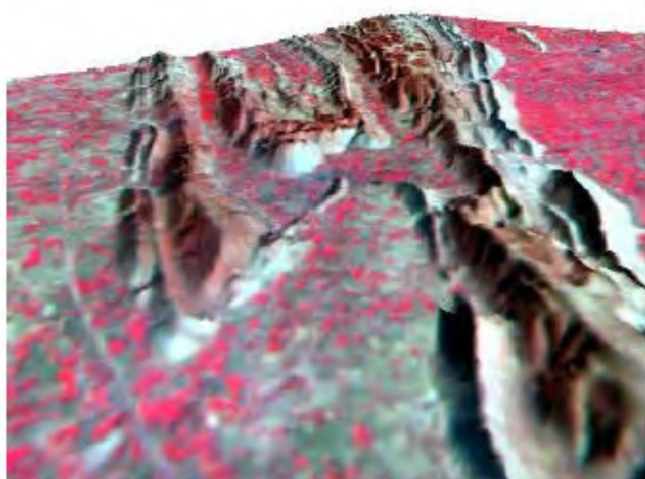


Figure 4. IRS-1C LISS III image draped on DEM.

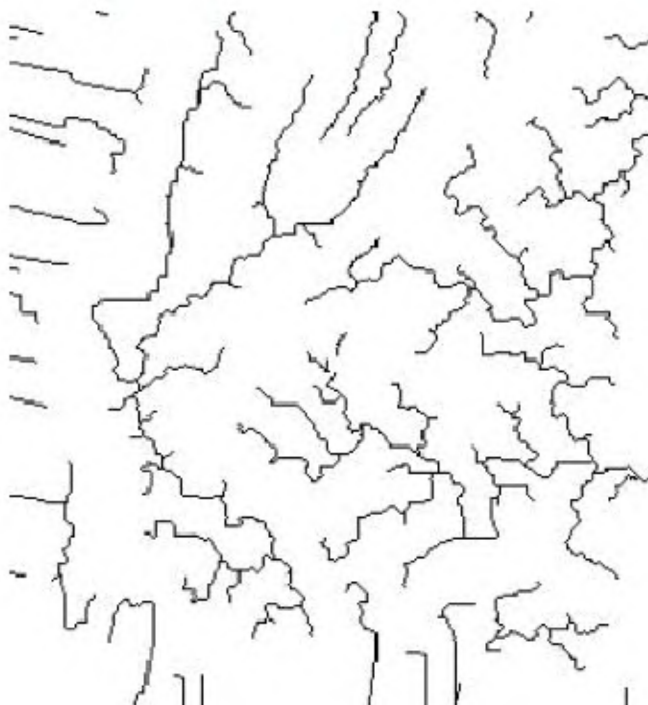


Figure 5. Drainage patterns extracted using DEM.

1 : 50000 topographic map and the automatic extracted drainage pattern from DEM is given in Table 3. It shows that out of 540 first-order drainage patterns delineated collectively from topographic map and DEM, 477 occur in topographic map and 157 in DEM, whereas 94 are common in both. Sixty-three additional first-order drainage patterns could be seen only in DEM-extracted drainage map, while 383 first-order drainage patterns seen in the topographic map could not be delineated using automatic extraction. Total number of second-order drainage patterns seen in the DEM is 38 as against 63 in the topographic

Table 3. Morphometric analysis

Description of stream	No. of streams as seen in	
	DEM	Topographic map (1 : 50000)
First-order stream	157	477
First-order stream only in DEM	63	—
First-order stream only in topographic map	—	383
Common first-order stream	94	94
Second order stream	38	63
Total length of stream (km)	192.5	200

map. Some of the channels depicted in the DEM-derived drainage pattern are missing in 1 : 50000 scale topographic maps, which strongly support the base flow and recharge conditions. Hanging valleys of lower order are seen on topographic maps, meeting stream flow path and further supporting a probable buried channel. This indicates that some of the buried channels can be picked up from the analysis of DEM.

IRS-1C/1D stereo data and DATDEM software have been used to generate DEM and ortho image. The DEM generated from IRS-1C stereo data has been validated by different methods. It is possible to retrieve useful terrain parameters/features from the satellite-derived DEM. Automatic method used for extraction of drainage pattern can also help in identifying buried channels. Further, validation of DEM needs to be carried out by measuring height values using differential GPS.

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