APPROACH FOR GENERATION OF DIGITAL ELEVATION MODELS (DEM) AND ORTHOIMAGES FROM IRS-1C STEREO DATA

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ABSTRACT

Methodology adopted for generating DEM and Orthoimages using IRS-1C stereo data is discussed in detail. A workstation based user friendly system developement is followed for easy orthoimage product generation. The package is tested with several IRS-1C stereo data sets, over different terrains with varying tilt angles, in generating DEM and Orthoimages. Accuracies achieved are commensurate with the reference data (ground control) used for product generation. DEM accuracies for all the test data sets and orthoimage accuracies for few cases are given at the end.

1. INTRODUCTION

The application potential of the satellite imagery is broadly limited by two factors, namely the resolution of the sensor and the geometric quality of the data products. Major causes of geometric inaccuracies are errors in knowledge of satellite orientation and the terrain undulations. The random ground height variation poses major difficulties in remote sensing data processing for cartographic applications. Error in satellite orientation can be modelled and estimated precisely by using Ground Control Points (GCPs) and the errors due to terrain undulation can be corrected using DEM. The DEM can be derived either by digitising a map or from a stereo pair acquired by a satellite with a high resolution sensor onboard. A product which is map aligned and corrected for all geometric distortions including height distortions and camera tilt is called orthoimage.

The Indian Remote Sensing satellite IRS-1C carries onboard push-broom linear CCD scanner camera in panchromatic mode, capable of providing high resolution (5.8m) imagery of Earth's surface. This camera can be steered up to $\pm$ 26 deg in the across track, thus by acquiring imagery over the same ground area from multiple orbits, a stereoscopic coverage can be obtained. Using this tilting mechanism of the camera, suitable stereo pairs can be acquired on the required area. By applying suitable models, a terrain height profile can be derived using these stereo pairs. The IRS-1C missions thus provide both planimetric and elevation information. The methodology used for deriving DEM and orthoimage generation is extensively given in [Stereo Products Design Team, 1993; Rebanta Mitra et al, 1994a; Rebanta Mitra et al, 1994b; Gopala Krishna et al, 1996]. The capability of this data in updating topographic maps, including some results is given in [Srivastava et al, 1997a; Srivastava et al 1996]. Orthoimage is one of the value added products planned for IRS-1C due to the oblique viewing capability of PAN payload.

This paper gives a detailed approach of DEM generation using IRS-1C stereo pair and explains the orthoimage generation process using the DEM. More emphasis is given towards a system development and implementation on softcopy photogrammetric workstation. Basically the inputs to the orthoimage generation process are (i) Basic stereo pair, (ii) GCPs/Map and (iii) Satellite ephemeris. The generation of orthoimage necessarily requires three steps viz., (i) DEM generation using the stereo pair and GCPs (ii) Geometric correction grid generation in a given map projection using ground to image mapping and (iii) resampling to generate a grey level image in a required output resolution (map resolution).

In section 2.0, a brief methodology with various important steps for generating DEM from IRS-1C stereo pairs are discussed. Section 3.0 gives the details of generation of orthoimage using the derived DEM, model and one of the stereo pair images. Details of utility package is given in section 4.0. Evaluation procedures of orthoimages are discussed in section 5.0. Detailed results on several IRS-1C stereo data sets are given in section 6.0 and finally conclusions are given in section 7.0.

2.0 DEM GENERATION APPROACH

DEM generation contains four important steps, (i) geometric modelling using photogrammetric collinearity conditions (ii) automatic conjugate point identification using hierarchical matching technique (iii) three dimensional ground co-ordinate determination of identified conjugate points and (iv) height interpolation & DEM editing. Using these concepts a software package is developed and well tested using IRS-1C data sets.

The DEM/Orthoimage generation software, which is developed at Space Applications Centre for IRS-1C stereo data is purely in digital mode, using the softcopy photogrammetric workstation based on R-10000 Silicon Graphics workstation. This system has a capability of generating stereo pairs (more than one, if mapsheet falls between two successive strips of same 70 km PAN scene) for a given 1: 25000 scale Survey of India (SOI) map sheet. Generation of stereo pair products, are done through a scheduler and DEM and orthoimage generation are done using a separate package. At the end mosaicing of orthoimages can be performed if the map sheet lies between two successive strips of same 70 km PAN scene. This package uses a semi-automatic mode of operation for deriving DEM. Various functionalities involved in DEM generation are as follows:

(a) Input Workorder Entry
(b) Scene Selection
(c) Data Downloading and Pre-processing
(d) GCP collection
(e) Model Setup
(f) Conjugate Point Identification
(g) Determination of 3D Ground co-ordinates
(h) DEM interpolation
(i) DEM editing

(a) Input Workorder Entry: To start the DEM generation process, a Workorder is to be made, which contains the basic inputs for the stereo pair viz., path, row, date of pass, sub scene-id for both the scenes and a mapsheet ID (corresponding to an SOI 1:25000 scale). All the above information is supplied through a data sheet using a dialogue box.

(b) Scene Selection: The required scenes for a mapsheet ID are generated through this process, using the satellite auxiliary data base (contains basically scene information in terms of path/row/date of pass, corner co-ordinates and attitude orbit information etc.). One or two stereo pairs are selected depending on the mapsheet coverage between the three strips of a single PAN scene.

(c) Data Downloading and Pre-processing: In this task, image data will be downloaded from the HDDT to the disk for the required number of stereo pairs. Then radiometric correction (detector to detector response normalisation and line loss correction) followed by extraction of ephimeris and header information (for the scenes from IMS database) are performed.

(d) GCP Collection: At this stage when the data is available (image as well as auxiliary) some Ground Control Points (GCP) are required for modelling the satellite orientation, which normally has some uncertainty. In the present system, the GCPs are digitised from a scanned map. The map is rectified first with respect to its tickmarks, then using a projective transformation of the grid points, the ground co-ordinate of any other point (a GCP) on the map can be calculated. The elevation of the point is taken from the map contours.

(e) Model Setup: Several different models are available for orienting linear images. The orientation model adopted here for IRS-1C is essentially similar to that developed in [Srivastava et al, 1989] using orbital elements. In this, initial orientation (six orbital elements (a) eccentricity, (b) inclination, (c) longitude of ascending node, (d) argument of perigee, (e) semi-major axis and (f) true anomaly) is computed using the initial satellite ephemeris. Space resection refines these six parameters, with the help of few GCPs and collinearity conditions which state that perspective centre, image point and the corresponding ground point lie in a straight line at the time of imaging [Srivastava et al, 1989; Stereo Products Design Team, 1993]. After model setup updated orientation is created, which can be used in the ground-to-image-to-ground relation derived from collinearity equations [Stereo Products Design Team, 1993], the collinearity condition equations use the inflight calibration angles of the sensors [Srivastava et al, 1997b].

(f) Conjugate Point Identification: This is an important step in DEM generation from satellite stereo pairs. The automatic conjugate point identification developed in this work uses hierarchical matching technique. This has four major elements viz., (a) creation of pyramid, (b) interest point finding, (c) local mapping and (d) digital correlation.

In the pyramid creation five levels of hierarchy is created by condensing data by 16, 8, 4, 2 and 1, by just pixel skipping method. The conjugate point identification starts from level-5, which is condensed by 16. An interest operator [Lu Yan, 1988; Forstner, 1986] is applied on the reference data first to get the candidate features for matching. The exact position of these features are found out by blind correlation at this stage. The match points found in this level are taken as seed points for the next level, i.e. level-8. At this level once again interest operator is applied on reference image. For all the interest points, their approximate locations are found out on the other image by applying a local mapping between the conjugate points of the previous level. Local mapping is basically a polynomial fit on 8 neighbourhood points. This is followed by a digital correlation to find out the exact match point and hence the conjugate point. These steps are repeated till the pyramid reaches the last level, i.e. level-1.

(g) Determination of 3D Ground co-ordinates: Once the conjugate points are obtained , the next task is to find the DEM at these points. The co-ordinates of the points of interest can be computed in the object space using inverse collinearity equations [Stereo Products Design Team, 1993]. Each image point in the overlapping images define a ray from each image intersecting at an object point. Intersection of these rays coming from conjugate points determine the position of the point in object space.

(h) DEM interpolation and Editing: Space intersection generates an irregular grid of DEM at conjugate points determined by automatic matching process. In order to compute heights at regularly spaced grid points of specified interval, a height interpolation is to be performed. There are several techniques available for height interpolation. Two interpolation algorithms are provided in this system viz., (a) weighted average technique [ISRO-GIS Design Team, 1993], in which weights are calculated for each neighbourhood points of the unknown depending upon the Euclidean distance (b) Kriging method [ISRO-GIS Design Team, 1993], uses variogram of the distances within a neighbourhood. After getting a regular grid of DEM, a median filter is applied to remove the spurious peaks of heights. The median threshold can be set externally depending on the height variations of the area under consideration.

3. ORTHOIMAGE GENERATION

Once the DEM, updated orientation parameters and image are available, the important steps in orthoimage generation process are as follows:

(a) Grid Generation: The geometric correction grid in a given map projection is prepared at regular intervals using ground to image mapping generated with the collinearity condition equations [Stereo Products Design Team, 1993; Rebanta Mitra et al, 1994b]. This transformation relates the input co-ordinates in one of the stereo images corresponding to the geodetic output co-ordinate on the basis of satellite orientation parameters.

(b) Resampling: Once the correction grid is generated, using a cubic convolution image resampling on the input image, output corrected grey level image is generated. Freedman resampling algorithm is implemented in this case. The co-ordinates within the grid are approximated using a bilinear transformation.

(c) Tickmark and Product Generation: Tickmarks are generated for every 2' interval of the 7.5' x 7.5' area (corresponds to 1:25000 scale map) and are appended along with other relevant product information.

4. UTILITIES

In addition to generating the orthoimages the package has the following additional utilities.

(a) Display : To display mono and stereo images
(b) Mosaicing : To mosaic orthoimages interactively
(c) Point Probing: To get 3D ground co-ordinate of any point on the orthoimage, taking the DEM in background.
(d) Product Evaluation: To evaluate the product, using the GCP image chips created in the GCP identification phase. With respect to the tickmarks the product can be evaluated using this utility.
(e) Modify Parameters: Parameters required for DEM generation, automatic matching process, orthoimage generation can be modified through this utility.

A schematic diagram of DEM and orthoimage generation involving all the above steps in detail is given in figure 1.

5. EVALUATION TECHNIQUES

One of the most critical part after orthoimage generation is to evaluate the DEM and orthoimage product. This includes qualitative as well as quantitative aspects. DEM evaluation includes checking of conjugate points visually, checking of heights of known points and checking of models using some check points. The first two procedures are qualitative in nature, whereas last one is quantitative [Rebanta Mitra et al, 1994a; Rebanta Mitra et al, 1994b]. Errors in height calculation of GCPs which are not included in model calculation can give a very good estimate of model accuracy. The evaluation of DEM and orthoimage include the following steps:

(i) DEM image generation and overlay on to the map and evaluating heights at various height contours of map and at bench mark points.

(ii) Overlaying orthoimage onto the DEM and finding the heights at various height points and comparing them with respect to the map.

(iii) Overlaying map on to the orthoimage and finding the deviations at various points to evaluate internal distortion and RMS error with respect to the tickmarks.

(iv) Through a visual simulation module, by draping orthoimage over DEM, a qualitative check can be made.

(v) A stereo view of orthoimage and geocoded product of the same image, can give some qualitative feel of accuracy

The capability of IRS-1C data in the mapping and its cartographic potential are discussed in detail in references [Gopala Krishna et al, 1996; Srivastava et al, 1997a; Srivastava, 1996].

6. TEST RESULTS

The software is tested on several test data sets of IRS-1C stereo pairs. Table-1 gives the test data sets used for generating DEM and Orthoimages. The test data sets contain different terrain types viz., flat regions, medium undulations and highly hilly terrains. Also the date of passes show the different kind of data sets (seasons) used for matching. Data sets also include different tilt angles, resulting B/H ratios ranging from 0.3 to 0.75. Table-2 gives the DEM accuracies of the test data sets on check points and Table-3 gives orthoimage accuracies for some cases. As can be seen from the test results, the accuracies of the DEM and orthoimages are dependent on the source of GCPs. Better accuracies (in planimetry and height) are achieved when GCPs are collected from 1:25000 scale map. In some cases (7, 8 and 12) the DEM accuracies are not very good. This is because of the older maps used for GCP identification and the feature availabily problems. In some cases height of the GCPs are obtained by interpolation of 40m interval height contours of map. The orthoimage accuracies are better than 30 m with respect to tickmarks, when controls used are from 1:50000 scale map (Table-3).

7. CONCLUSIONS

Orthoimage can be generated as a regular product using scanned map, stereo pairs. The stereo data processing system has been tested with data pertaining to different types of terrains. Accuracies achieved are commensurate with the reference data used for product generation. Generation of product depends upon opportunities due to sensor and orbital characteristics. Chances are better for 7.5' x 7.5' products than map sheet based products.

The DEM and orthoimage accuracies are dependent on the source of GCPs used for modelling. Height accuracies of better than 15 m are achieved using 1: 25000 scale SOI map GCPs and better than 30 m using 1: 50000 scale SOI. Planimetric accuracies upto 20 m and 35 m (most of the cases) are achieved respectively when 1: 25000 and 1: 50000 scale maps are used for GCP collection. Apart from GCP accuracy (position and co-ordinates), other factors like GCP distribution, map quality, scanner quality and the models also affect the final DEM accuracies.. The accuracies can be further improved by using the GCPs obtained from field control. These exercises are being carried out to prove the system capability in generating better products.

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Table-1: Input Data Used

Set No.	Path/Row	Sub-Scene	Date Of Pass	Tilt Angle (deg)	Undulation (m)
1.	097/058 097/058	D7 C8	15011996 19011996	-14.5 +12.8	460-560
2.	097/058 097/058	D4 C5	15011996 19011996	-14.5 +12.8	460-630
3.	097/050 097/050	B9 B7	07021996 13021996	+18.88 -18.03	600-2200
4.	096/050 096/050	A1 A1	09041996 17021996	23.33 -2.32	270-350
5.	096/051 096/051	C7 C7	09041996 17021996	23.33 -2.32	230-310
6.	107/056 107/056	B1 B1	06051996 12091996	+2.24 +20.29	30-70
7.	096/049 096/049	C7 C7	09041996 17021996	23.33 -2.32	300-1800
8.	096/062 096/062	C3 B7	08011997 09011997	11.28 -18.56	0-300
9.	096/049 096/049	A1 A1	07111996 11111996	-2.32 21.6	200-700
10.	096/049 095/049 096/049	C7 D4 C8	11021997 17111996 11021997	-2.0 -14.8 -2.0	600-1800
11.	096/051 095/051 096/051	A8 B8 A9	11021997 17111996 11021997	-2.0 -14.8 -2.0	200-300
12.	092/047 091/047	A9 B5	10121996 13041997	-10.6 16.9	600-1700
13.	092/047 091/047	A6 B2	10121996 13041997	-10.6 16.9	900-2300
14.	096/052 096/052	A6 B4	11111996 22111996	21.0 -20.0	300-700
15.	095/051 096/051	C8 C9	17111996 11021997	-14.8 -2.0	150-300

Table-2: DEM Accuracy at Check Points (RMSE)

Set No.	Number of Points		Error at Check points		
	GCPs	Check points (CP)	Easting (m)	Northing (m)	Height (m)
1.*	5	16	20.3	11.5	8.9
2.**	4	6	23.9	25.1	31.2
3.**	5	14	35.1	25.2	26.4
4.**	4	4	31.0	7.7	28.5
5.*	4	14	23.7	20.4	13.9
6.**	4	7	38.0	33.4	16.8
7.**	4	10	36.1	40.9	39.9
8.**	4	4	46.6	65.7	12.2
9.**	4	1	11.1	9.9	6.9
10.**	4	2	4.2	25.6	14.8
11.*	4	4	18.4	18.2	11.7
12.**	4	3	49.8	25.2	28.0
13.**	4	2	8.0	5.8	9.0
14.**	4	5	25.9	29.6	13.5
15.*	4	17	17.6	20.7	15.1

* GCPs and CPs are taken from 1:25000 scale SOI maps

** GCPs and CPs are taken from 1:50000 scale SOI maps, heights are interpolated from height contours of 20m & 40m (highly hilly regions) interval.

Table-3: Evaluation Results of Orthoimages (RMSE)

Set No.	Map No.	Easting (m)	Northing (m)	Number of points used for evaluation
1.	47M/13/SE	15	16	6
2.	56/A0/NW	30	24	4
3.	53K/13/SW	26	15	4
5.	53D/12/NW	14	14	9
6.	73M/12/NE	17	20	5
7.	53F/06/SW	24	25	6

Note: The magnitude of RMS error in Easting and Northing of Orthoimage is observed to be less than that of DEM accuracy. This is because of the combined contribution from GCPs and checkpoints together. However at individual point level orthoimage error has a close agreement with that of the DEM accuracy.

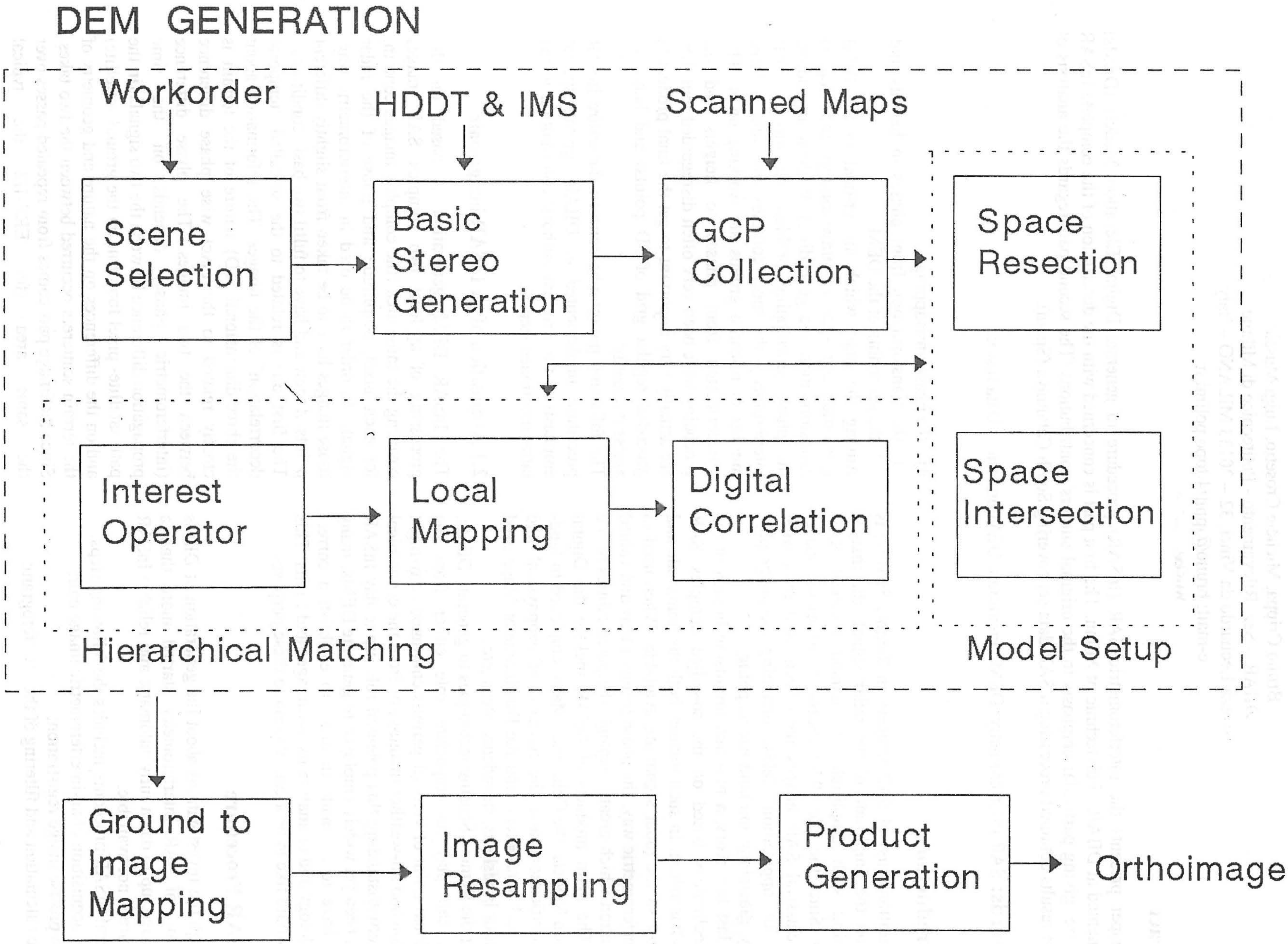

Figure-1 : Schematic Diagram of Orthoimage Generation