

Evaluation of cartosat-1 satellite triangulation & DSMs in varied terrain conditions

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Abstract: Digital surface models (DSMs) and Digital elevation models (DEMs) has become inevitable input for many applications including various types of modeling problems besides photogrammetric product generation such as orthoimages and visualization. Automatically generated DSMs using image matching techniques are an efficient means to extract bare earth DEMs or DTMs for various applications including modeling. This paper highlights and evaluates the accuracy of satellite triangulation, and DEM generated from Cartosat-1 data by using Rational Polynomial Coefficient's (RPC's) provided with the Cartosat-1 data along with ground control points (GCPs) collected through differential Global Positioning System (DGPS) surveys. Three study sites were taken for evaluation of DSMs in different topographic conditions, namely, a) Dehradun, Uttarakhand characterized by relatively high undulating terrain comprising of shivalik hills in the south and higher Himalayas on the north, b) Jaipur, Rajasthan having more of urban and plain agriculture area with Aravalli ranges, and c) Kendrapara, Orissa which is having a plain terrain conditions with agriculture fields, river, and sparsely populated area. DGPS surveys were conducted at the three sites to collect ground control points (GCPs) for satellite triangulation & subsequent analysis. The satellite triangulation resulted in RMSE of better than a pixel for all the three sites. The RMSE for DEM is varying from within a pixel for plain area to about four pixels for highly undulating terrain. The paper describes the positional and vertical accuracies achieved for cartosat-1 stereo data through photogrammetric process of satellite triangulation and Digital surface model generation in the three study sites having different topographic conditions.

Keywords: Satellite Triangulation, Digital Surface Model, Digital Elevation Model, Differential GPS survey, Ground Control Points, Rational Polynomial Coefficient's

1. Introduction

The scientific developments in the area of ground as well as space instrumentation such as GPS/GNSS, gyroscopes, star sensors, and INS/IMU are increasing the chances of better and better RPC based triangulation or even onboard triangulation on aerial as well as satellite platforms. Terrestrial photogrammetry and close range photogrammetry (CRP) are also fast developing with the new Structure from Motion (SfM) approach and fast computers [1]. Low height platforms like UAVs (unmanned aerial vehicles), ROVs (remotely operated vehicles) [2] are getting more attention and prominence for research work in photogrammetry and feature extraction as compared to earlier days. The collinearity equations forms the basis of all kind of photogrammetric applications whether aerial, satellite or terrestrial. Digital Surface Models (DSMs) offer the possibility

of extracting the elevations of surface features to leave the ground surface DEM. Inherent limitation in accuracy assessment has been the use of limited GCPs, a DEM with higher resolution and quality can provide a better evaluation. However, such high resolutions DEMs are usually unavailable or do not have open access [3].

Cartosat-1 is the eleventh satellite, built in the Indian Remote Sensing (IRS) series and was launched on May 5, 2005. This sun synchronous satellite carries two panchromatic (fore/aft) cameras that capture along-track stereoscopic images over a 30 km swath at 2.5m ground resolution with 10 bit radiometric resolution enabling the creation of accurate 3D maps [4]. The large number of studies world over on cartosat-1 emphasises on its success, both as a technology giving high geometric accuracy with its base-to-height (b/h) ratio of 0.62 and economics as it is priced very optimally for maximum usage for the benefit of humankind. In terms of technology and as a successor of

ASTER and SPOT-5 (HRS), Cartosat-1 has proved its potential for photogrammetric applications particularly topographic mapping and visualization [5]. It has been followed now by ALOS PRISM having three cameras and Pleiades-1A/1B satellite sensors. More new generation satellites are also going to be launched soon like the sentinel series of satellites and cartosat series of satellites. Most of these satellites will be based on the concept of rational polynomial coefficients (RPCs). The concept of RPC's has been introduced by IKONOS [6]. Many studies have carried out IKONOS stereo data analysis using Rational Function Model (RFM) for evaluating geometric accuracy [7], bundle adjustment [8], stereo feature extraction [9] and mapping [10]. The study of Cartosat-1 stereo data products reveals DEM accuracy of about 4m [11,12] and its use in natural hazard applications [13,14]. Studies by Jacobsen have shown subpixel accuracy for Cartosat-1 stereo scenes. ISPRS-ISRO Cartosat-1 Scientific Assessment Programme (C-SAP) Technical report describes results over test areas [15]. YVN Krishna Murthy *et al.* (2008) from their analysis have stated that the cartosat-1 imagery are capable of producing topographic maps at 1:25000, thematic maps at 1:10000 and contour map with contour interval of 10m [16]. Nelson and Wilson separately describe various DEM production methods and sources in details [17,18]. Willneff *et al.* (2008) has compared the geopositioning accuracy achievable with Cartosat-1 imagery via the 3D affine, bias-corrected RPC and generic pushbroom sensor models [19]. Singh *et al.* (2008) has shown results of 5 datasets from Cartosat-1 using RPCs and concluded that RPCs can be provided to the users for photogrammetric processing at their end without compromise on the accuracy [20]. Gorokhovich *et al.* has shown in their results that absolute average vertical errors from CGIAR dataset can range from 7.58 ± 0.60 m to 4.07 ± 0.47 m (mean \pm S.E.M.). This is significantly better than a standard SRTM accuracy value (i.e. 16 m) [21]. Studies have shown that the vertical accuracy of an ASTER DEM approaches 25 m, but this can improve to 9–11 m in areas with less vegetation cover [22]. The overall vertical accuracy of open source DEMs such as ASTER and SRTM DEMs has RMS error of 12.62 m and 17.76 m respectively, for Dehradun area when compared with Cartosat-1 DEM [23, 24]. The geometric quality of an ortho-imagery depends on the accuracy of the orientation during Epipolar generation, accuracy of ground control points and on the geometric quality and resolution of the used DEM. The accuracy of the primary and secondary DEM derivatives depends on the accuracy of the DEM used to generate or extract these parameters. The determination of exterior orientation parameters is a key element for any kind of imagery from terrestrial, airborne or satellite based sensors. This orientation task traditionally is solved in analytical/analog/digital photogrammetry by aerial triangulation with GPS or Kinematic GPS data [25]. RPC's relate object space to image space and vice versa. Even though no GCP's are available, ground co-ordinates can be derived from image co-ordinates using RPC's. The accuracy of the coordinates depends on the

source of RPC's. If GCP's are available one can refine the RPC's using polynomial functions.

2. Objectives

The objective of present study is to evaluate the satellite triangulation and the digital surface models (DSMs) generated from Cartosat-1 for varied terrain conditions.

3. Study Area

The three sites selected for the study were selected in three different kinds of topography and terrain conditions. A brief description of sites is given below.

3.1. Dehradun, Uttarakhand Site

The study area includes the Dehradun city and its surroundings. The general elevation of the area ranges from 450m to 2000m above mean sea level. Dehradun is the provisional capital city of the Uttarakhand state, India. It is located in the Doon valley, 260 km north of India's capital New Delhi. The study area is surrounded by the Himalayas in the north, Shivalik Hills in the south, the river Ganga in the east, and the river Yamuna in the west. The water divide of Ganga and Yamuna passes through the city. The study area is characterized by hills and valleys as shown in Figure 1.

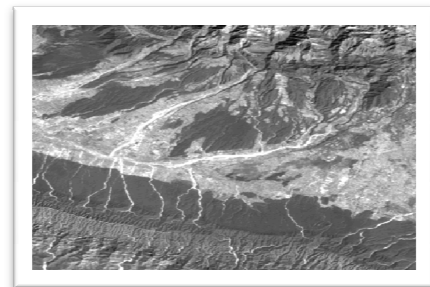


Figure 1. Dehradun & surroundings (2006, Cartosat-1 aft image)

3.2. Jaipur, Rajasthan Site

Jaipur is the capital city of the Rajasthan state, India. Figure 2, shows the location map of Jaipur. The stereopair comprises of terrain ranging from plain area, agriculture fields, urban area, waterbody and Aravalli hill range. The data was acquired over Jaipur, on 18 May 2005.

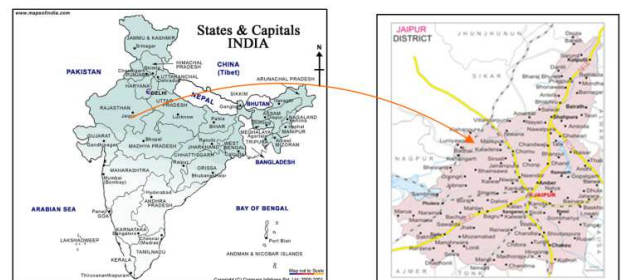


Figure 2. Location map of Jaipur, Rajasthan

3.3. Kendrapara, Orissa Site

Kendrapara District lies in 20° 20' N To 20° 37' N Latitude and 86° 14' E To 87° 01' E Longitude and situated in central coastal plain zone as per the Agro-Climatic Classification of the Orissa. Four other districts surround Kendrapara District. The District is situated in the north of the Jagatsingpur district, west of the Cuttack District, southwest of the Jajpur District and south of the Bhadrak District. The scene was taken for study under the plain and agriculture area. The area is highly flood prone with extreme hazardous conditions.

4. Methodology

The methodology adopted for this study is shown in figure 3. A differential GPS survey was conducted at all the three sites using single frequency Leica GPS 500 System. Planning has been done for uniform distribution of GCPs at all sites. Clearly identifiable sharp points on both the AFT and FORE images were selected as ground control points and observed for measurements using base stations and rovers. The GPS data was post-processed using Leica software to achieve high accuracy. The Cartosat-1 scenes were processed for satellite triangulation using the ground control points for all the three test sites. These three sites being spread over different UTM zones with varied topography were used to infer the relationship between the topography type and accuracy. A set of points were used as GCPs for satellite triangulation and another set is used as check points. Subsequent to satellite triangulation, DSMs were generated through automatic process in LPS software and analyzed for accuracy in different terrain conditions.

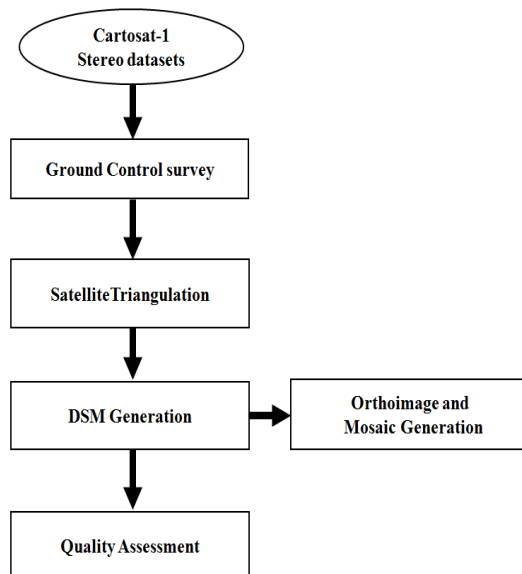


Figure 3. The flowchart of Methodology

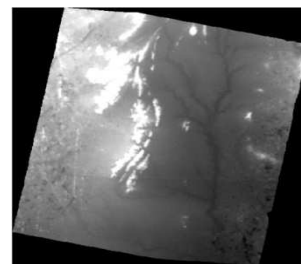
5. Results and Analysis

5.1. Satellite Triangulation

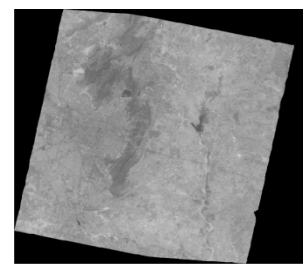
The overall RMSEs (Table 1) for satellite triangulation for the three test sites: Kendrapara, Jaipur, Dehradun has come to 0.501 pixel, 0.753 pixel, and 0.72, respectively. The digital surface models and orthoimages were generated and are shown below in figure 4. Horizontal accuracies are within a pixel for X and Y direction. The vertical accuracy of is within 2-4 pixels depending on the terrain roughness.

Table 1. Summary RMSE for ground control points and check points

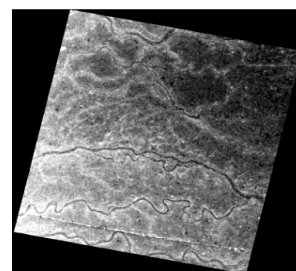
S.No.	Study area	Data Used (Path/Row)	No. of control points	No. of check points	RMSE
1.	Kendrapara, Orissa	528/302	11	6	0.501
2.	Jaipur, Rajasthan	273/520	12	6	0.753
3.	Dehradun, Uttarakhand	526/258; 527/258	20	4	0.70



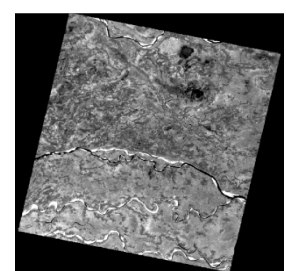
a) DEM (Jaipur site)



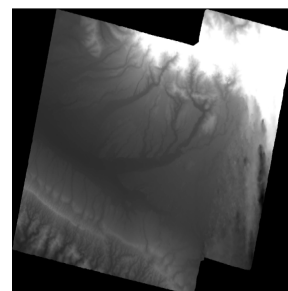
b) Orthoimage (Jaipur site)



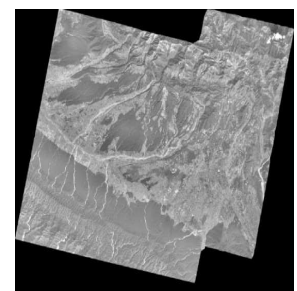
c) DEM (Kendrapara site)



d) Orthoimage (Kendrapara site)



e) DEM (Dehradun site)



f) Orthoimage (Dehradun site)

Figure 4. DEMs and orthoimages for the three sites

5.2. Accuracy assessment of Digital Surface Model

To validate the accuracies of DSMs generated through Cartosat-1 data the check points measured by DGPS surveying techniques were used. Tables (2, 3, and 4) give the observations on control points. Accuracy assessment was done by using the check points at all the three sites. Figure 5, shows RMSEs (equation 1) for different terrain types (sites). It reveals that for a plain terrain the RMSE is better than a pixel, for a urban and relatively plain area it is within two pixels. In a highly hilly area like Dehradun, RMSE is above three pixels and less than four pixels. $Z_{(DSM)}$ and $Z_{(DGPS)}$ are the elevation values using the DSM and differential GPS survey respectively.

$$RMSE = \left[n^{-1} \sum_{i=1}^n (Z_{(DGPS)} - Z_{(DSM)})^2 \right]^{1/2} \dots \text{equation 1}$$

Where n is the number of observation.

Table 2. Shows difference in DSM and DGPS elevation (Dehradun)

Point ID	$Z_{(DGPS)}$	$Z_{(DSM)}$	$Z_{(DGPS)} - Z_{(DSM)}$
1	550.0822	551.3629	-1.280669
2	464.9568	459.9175	5.039273
3	479.3538	481.7321	-2.378269
4	440.3713	439.1867	1.184533
5	427.7813	429.0768	-1.295568
6	475.4596	474.5103	0.949369
7	730.8304	734.6276	-3.797187
8	592.8734	591.6462	1.227202
9	527.1464	527.1631	-0.016794
10	513.9255	516.3663	-2.440793
11	734.5752	730.4836	4.091531
12	621.2138	620.5668	0.646959
13	576.9679	574.1219	2.845987
14	610.5417	610.0467	0.495043
15	543.0078	541.1225	1.885312
16	517.3277	518.0052	-0.677519
17	504.6624	504.5548	0.107609
18	497.3283	498.4792	-1.150905
19	487.6069	485.1017	2.505221
20	491.2866	490.2747	1.011910

Table 3. Shows difference in DSM and DGPS elevation (Jaipur site)

Point ID	$Z_{(DGPS)}$	$Z_{(DSM)}$	$Z_{(DGPS)} - Z_{(DSM)}$
1	358.19	366.21	-8.02
2	324.16	327.58	-3.42
3	423.65	420.18	3.47
4	357.39	366.54	-9.14
5	311.87	313.73	-1.85
6	290.72	285.52	5.20
7	301.99	298.84	3.14
8	342.02	343.84	-1.81
9	332.62	325.62	7.00
10	316.97	310.50	6.47
11	302.97	297.66	5.31
12	316.06	320.24	-4.18
13	375.08	374.45	0.62
14	300.17	300.22	-0.04
15	327.29	327.63	-0.33
16	353.28	351.35	1.93
17	326.92	321.56	5.36
18	286.53	278.92	7.61

Table 4. Shows difference in DSM and DGPS elevation (Kendrapara site)

Point ID	$Z_{(DGPS)}$	$Z_{(DSM)}$	$Z_{(DGPS)} - Z_{(DSM)}$
1	-55.49	-59.13	3.64
2	-54.98	-55.96	0.98
3	-55.58	-56.94	1.36
4	-53.46	-52.83	-0.63
5	-51.29	-54.43	3.14
6	-49.37	-52.7	3.33
7	-46.74	-50.81	4.07
8	-52.15	-53.48	1.33
9	-49	-51.94	2.94
10	-46.93	-49.95	3.02
11	-44.76	-45.56	0.8
12	-45.42	-41.44	-3.98
13	-49.64	-47.17	-2.47
14	-51.14	-53.26	2.12
15	-54.11	-53.04	-1.07
16	-51.48	-51.18	-0.3
17	-52.44	-49.46	-2.98
18	-52.4	-50.78	-1.62
19	-53.4	-51.72	-1.68
20	-51.83	-54	2.17

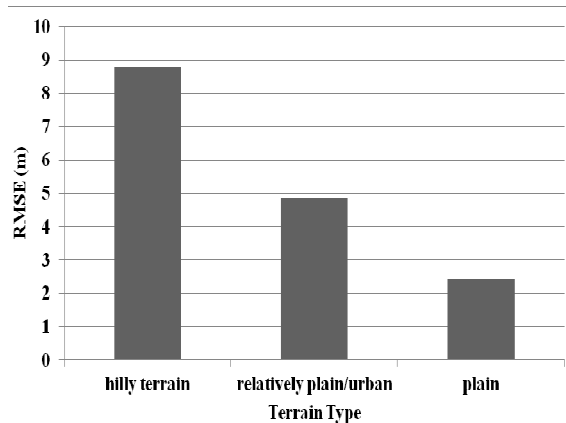


Figure 5. shows RMSE for DSMs generated

The two sites i.e., Jaipur and Dehradun are above the WGS84 datum and thus have positive elevation values. The third site i.e. Kendrapara, Orissa is below the WGS 84 datum and thus have negative elevation values. The EGM values were calculated for third site (Orissa) using equation 2.

$$H=h-N \quad \text{equation 2}$$

Where, H is the orthometric height, h is ellipsoidal height from GPS and N is the Geoid height. The orthometric heights were calculated for GCPs at Kendrapara site and analysed using EGM2008 geoid model [26]. The geoid height is averaging to about 62 m at the control points and is found consistent at kendrapara study area.

6. Conclusion

The digital surface models generated from Cartosat –1 stereo data by inclusion of ground control points are highly accurate to 1-2 pixels in planimetry and 1-4 pixels in vertical for plain to rough terrain. The influence of topography is clear from the results of satellite triangulation. The RMSE of satellite triangulation is better than a pixel or nearly a pixel, in all the three sites. Kendrapara, Orissa being the least undulating area among the three sites, has the minimum differences in the DSMs and DGPS elevation values. In all the three studies the observation is that, the accuracy of DSMs generated from Cartosat-1 Stereo data improves highly by use of well distributed GCP's. The geometric accuracy of cartosat-1 data is well suited for topographic mapping for regional planning to local planning.

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