

# POTENTIAL OF HIGH-RESOLUTION INDIAN REMOTE SENSING SATELLITE IMAGERY FOR LARGE SCALE MAPPING

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## ABSTRACT:

This paper gives an assessment of the mapping potential of high-resolution Indian remote sensing satellites Cartosat-1 and Cartosat-2. The satellites are equipped with in-track stereo mapping capability; Cartosat-1 has two fixed panchromatic cameras and Cartosat-2 has a single panchromatic camera and body steering capability for along-track stereo acquisition. At ADRIN, we have developed a methodology for correction of images with a rigorous sensor model and minimum GCPs which is used for georeferencing of a wide class of linear CCD array sensors. The model is based on the photogrammetric collinearity equations. Variations in the sensor model with respect to the viewing geometries of Cartosat-1 and Cartosat-2 are explained in the paper. Aspects of photogrammetric processing of the imagery are discussed. The geometric accuracy achieved from Cartosat-1 and Cartosat-2 images over the same set of check points are analysed. Cartosat-1 DEM, geometric accuracy and capability for topographic feature capture are good enough for making 1:10000 scale maps. Geometric accuracy and feature detectability of Cartosat-2 indicate that it is capable of making 1:7000 scale maps. Cartosat-1 satellite is more stable because it is not continuously changing the view while imaging. . Based on the error estimation and analysis, it is concluded that if the strict photogrammetric processing model and ground control points are employed, high-resolution satellite imagery can be used for the generation and update of topographic maps of scale 1:10,000 and larger.

## 1. INTRODUCTION

The new very high space resolution satellite images, with a ground pixel size of better than 1m, open new possibilities for cartographic applications. For the full exploitation of the potential of this data, the “classical” satellite image processing methods must be extended in order to describe the imaging geometry. In general, the processing of these kinds of images provides a challenge for algorithmic redesign and this opens the possibility to reconsider and improve many photogrammetric processing components, such as image enhancement, image orientation (georeferencing), orthophoto and DTM/DSM generation and object extraction. Many different geometric models of varying complexity, rigour and accuracy have been developed for rectification of satellite images. In recent years, a large amount of research has been devoted to efficiently utilize these high spatial resolution imagery data. Examples can be found in sensor modeling and image orientation (Baltsavias et al., 2001; Jacobsen, 2003; Grodecki and Dial, 2003; Fraser et al., 2002; Radhadevi et al., 2008a, b), automatic DTM/DSM generation (Jacobsen, 2004; Toutin, 2004; Poli et al., 2004). Indian space programme witnessed several major accomplishments and scaled newer heights in mastering space technology during the last few years. Cartosat series of satellites with stereo mapping capabilities have become main stay towards large scale mapping for urban and rural applications. A method for

processing the Cartosat-1 data is explained in Srivastava et.al, 2007.

In our work, the used geometric model is based on the viewing geometry of the satellite, combining the principles of photogrammetric collinearity equations, originally developed for SPOT-1 [Radhadevi et al., 1994], and further adapted and tested for different sensor geometries. The sensor position is derived from the given supplementary data, while the attitude variations are modeled by a simple polynomial model. For self-calibration, two additional parameters are added to the model: the focal length (camera constant) and the principle point correction. The exterior orientation and the additional parameters of the sensor model are determined in a general formulation of the least-squares adjustment.

### 1.1 Features of Cartosat-1 and Cartosat-2

Cartosat-1 (IRS-P5) is the first satellite of ISRO designed to provide high resolution along-track stereo imagery for mapping applications. The platform contains two panchromatic camera payloads with +26° and -5° tilted with respect to nadir. The base to height ratio is about 0.62. Data is quantized with 10 bits. Integration time is 0.336ms. Nominal GSD is 2.5 m. Each CCD has 12000 pixels, separated in to 6000 each of odd and even pixels. These odd and even pixel rows are separated by 35µm (equal to 5 pixels). India's highest resolution imaging satellite Cartosat-2 was launched from Satish Dhawan Space Centre (SDSC) on January 10, 2007. Cartosat-2 is an advanced

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remote sensing satellite capable of providing scene-specific spot imagery. With the panchromatic camera (PAN) on board, the satellite can provide imagery with a spatial resolution of better than one meter and a swath of 9.6km. On each overpass, the satellite captures a swath of imagery that is 9.6km wide. Therefore if a programmed area of interest is wider than 9.6km, more than one swathe is required to capture the imagery. However, as the Cartosat-2 sensor can swing in any direction, it can capture up to 4 swaths (covering an area of up to 38km wide) in one overpass or on one day. Because of the agility of the satellite, multi view imagery is commonly captured for production of digital elevation models (DEMs). Three views; nadir, fore and aft are captured with which stereo triplets can be formed. By processing multi-view images of Cartosat-2, high resolution DEMs can be produced. The satellite can be steered up to 45 deg along as well as across the track. There are two CCD arrays in the payload; main array and redundant array both having 12000 pixels arranged as it is for Cartosat-1. Several new technology elements like high performance star sensor, improved Inertial Reference Unit, dual-gimballed antenna, high-bit telemetry and data handling systems, light weight and compact spacecraft structure etc. have been introduced in to the design of Cartosat-2. The precise ephemeris and attitude data allows for reducing the number of ground control points. Furthermore, this information enables direct georeferencing of the imagery without geometric reconstruction of the imaging process and ground control. The data from the satellite is used for detailed mapping and other cartographic applications at cadastral level, urban and rural infrastructure development and management as well as applications in Land Information System and geographical Information System. More details about Cartosat-1 and Cartosat-2 payload systems are available in Krishnaswami (2002).

## 2. MAPPING FROM SATELLITE IMAGERY

The major thrust of the current and future technologies are on generation of spatial information on large scale. With the higher spatial resolution satellite images available on these days, it is possible to prepare accurate base maps larger than 1:10,000 scale. Cartosat series of satellites with stereo mapping capabilities have become main stay towards large scale mapping for urban and rural applications.

Important criteria or considerations while going for large scale mapping from satellite images are

- (1) Information content and
- (2) Geometric fidelity

Information contents or the feature deliameibility will be increased as and when the spatial and spectral resolution of the satellite improves. But achievable geometric accuracy depends upon many factors including the stability of the satellite, method of imaging (synchronized, asynchronous, TDI, Step and Stare, look angle etc.), used control points and the model used to rectify the imagery. Capability for mapping from satellite imagery depends upon the following factors.

### 2.1 Resolution of the image

Spatial as well as spectral resolution of the image is important. The ground sampling distance (GSD) – the distance of the pixel centres on the ground – may not be the same as the size of the physical pixels projected to the ground. We do have

the influence of the optics, the actual situation of the atmosphere and a numerical over or under sampling. In addition, the image quality, especially the contrast, is depending upon the grey value range which goes from 6 bit or 64 different grey values to 12 bit or 4096 different grey values. Object identification is easier in multi-spectral images compared to panchromatic images.

### 2.2 Viewing geometry/agility of the satellite

High resolution images can be acquired by different methods like step and stare technology, TDI, asynchronous imaging, synchronous imaging etc. Stability of the platform is very important in deciding the final achievable accuracy. Along-track stereo images taken by fixed camera system with a good base –to- height ratio is preferred for mapping compared to images taken by agile satellites using a single camera. To acquire stereo along the pass with a single camera system, the satellite body has to be tilted with high oblique angles. There is a strong influence of the sun elevation and azimuth to the object identification.

### 2.3 On-orbit Calibration of the sensor

Precise On-orbit calibration of sensors during the commissioning phase of the satellite becomes very important with high resolution agile satellites especially when we talk about direct georeferencing. The primary challenge in alignment calibration is the need to estimate the underlying alignment trend for each sensor from a series of precision correction solutions, which measure a combination of orbit, attitude and alignment errors. Correlation between the physical parameters of the camera and the bore sight misalignment parameters between the payload and body is very significant.

### 2.4 Sensor model used for ground to image and image to ground transformation

The sensor model used is very crucial in deciding the final geometric accuracy of the product. Each image acquisition system produces unique geometric distortions in its raw images, which vary considerably with different factors, mainly the platform, its orbit, and the sensor. The geometric correction methodology has to take care of all these aspects. Different mathematical models used for establishing the relation between ground coordinates and image coordinates are polynomial model, rational function model and rigorous sensor model. Rational function model can be used as a replacement model if ephemeris and sensor parameters are not provided to the user. Rigorous sensor model based on the collinearity equation will reconstruct the imaging process. We have developed a methodology to rectify the satellite imagery with a rigorous sensor model and minimum GCPs. This model is used for mapping from Cartosat-1 and Cartosat-2/2A.

### 2.5 Ground control points

When the spatial resolution of the camera increases, the capability of topographic data capture also increases. But geometric fidelity may not increase in the same proportion especially due to the difficulty in transferring GCPs into high resolution images. For making ortho-adjustment of high resolution data, it is most important to assure a high precision

GCPs identification, interpretation and measurement in terrain and on the image. Variability of viewing angles within an image, if not respected properly, affect the accuracy potential and become very sensitive to the number and distribution of control points.

### 3. RIGOROUS SENSOR MODEL (RSM)

A sensor model reconstructs the imaging geometry. Reconstruction of the viewing geometry includes the exterior and interior orientations of the sensor. The model relates 3-D object point position to their corresponding 2-D image positions by describing the geometric relationship between the image space and object space. The algorithm for orbit attitude model, which combines the principles of viewing geometry of the satellite with photogrammetric collinearity equations, was originally developed for SPOT-1 and IRS-1C/D. This model has been adapted to suit the camera characteristics of Cartosat-1 and Cartosat-2. The information about of the satellite ephemeris, attitude, sidereal angle, time etc. are extracted from the ADIF. The orbit 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  $(\omega)$ , pitch  $(\phi)$ , and yaw  $(\kappa)$ . Satellite position and orientation are given at every 125 msec. Attitude data in terms of quaternion are converted into Euler angles. Fitting of the given telemetry values are done for predicting at required time interval i.e. to make it continuous from discrete values given. The initial values of all the parameters are derived by least squares adjustment to the ephemeris data using a generalized polynomial model.

Collinearity equations express the fundamental relationship that the perspective centre, image point and object point lies on a straight line i.e.

$$\begin{pmatrix} f \\ -x_s \\ -y_s \end{pmatrix} = d \cdot M \begin{pmatrix} X - X_p \\ Y - Y_p \\ Z - Z_p \end{pmatrix} \quad (1)$$

where  $(f, -x_s, -y_s)$  are the image coordinates,  $(X, Y, Z)$  are the coordinates of the object point and  $(X_p, Y_p, Z_p)$  are the co-ordinates of the perspective centre,  $d$  is the scale factor and  $M$  is the orthogonal rotation matrix to transform the geocentric to sensor co-ordinate system. The rotation matrix  $M = Q_{GI} * Q_{IO} * Q_{OB} * Q_{BP} * Q_{PC}$ , where

- $Q_{PC}$  = CCD to payload transformation matrix
- $Q_{BP}$  = Payload to body transformation matrix
- $Q_{OB}$  = Body to Orbit matrix
- $Q_{IO}$  = Orbit to Inertial matrix
- $Q_{GI}$  = ECI to ECEF matrix

CCD to payload transformation matrix is included into the rotation matrix. Thus, a pixel in any band of a camera can be projected onto ground co-ordinates through a series of transformations.

#### 3.1 Combined camera adjustment for Cartosat-1

We have refined our physical sensor model to simultaneously correct the images from both the cameras through a tied-

camera approach. In such an approach, in-flight calibration of the cameras is a very important pre-requisite. The objective of in-flight calibration is to compute the individual and relative alignment offsets of the cameras and include them in the sensor model. Remaining errors at the system level are due to small uncertainties in the body attitude, which are shared by both the cameras. This can be corrected with few conjugate points. Each conjugate point serves as two GCPs separated in the time line by 52sec. A generic polynomial model is developed so that by selecting the order of polynomial, it can be adapted for different types of sensors. This option allows the modelling of the sensor position and attitude with 3<sup>rd</sup>, 2<sup>nd</sup> or 1<sup>st</sup> order polynomials. Corrections up to constant and 1<sup>st</sup> order coefficients are done for Cartosat-1. Over a long pass, the variation in the attitude angles will not be a bias and therefore, time-dependent coefficients are also updated with GCPs. If fore and aft images are independently corrected with GCPs, correction of the constant terms (3 parameters) is enough because the length of the orbital arc will be small (for each camera image) and can be piecewise corrected.

#### 3.2 Sensor model updation for Cartosat-2

Cartosat-2 is an agile satellite. Figure1 shows the attitude variations over the entire strip. Self-calibration approach with correction to the constant term as well as first order and second order time-dependent terms is used for Cartosat-2.

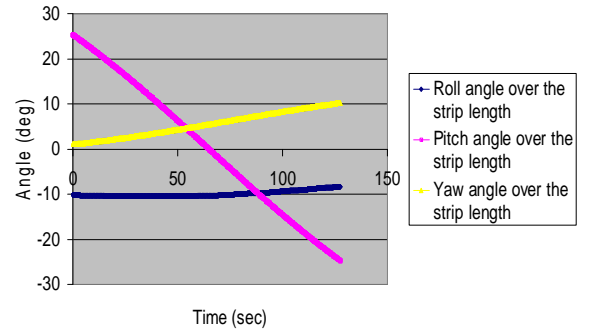


Figure 1 Attitude variations over the strip of Cartosat-2

### 4. MAPPING FROM CARTOSAT-1 AND CARTOSAT-2 DATA

Cartosat-1 is a very stable satellite meant for mapping applications. ADRIN is routinely generating DEM and Orthoimage from Cartosat-1 data using in-house developed sensor model and DEM generation methodology. To check the achievable accuracies from Cartosat-1, we have used the base maps, which are of 70cm accurate, as reference data. Accuracy evaluation is done over 6 data sets. Only a single GCP is used in all the cases. Area covered in each data is 30kmX30km. Distributed Check points are identified. Errors obtained for different datasets are shown below. GCP requirement is minimized by using the ephemeris and attitude data and precise payload geometry in to the rigorous sensor model.

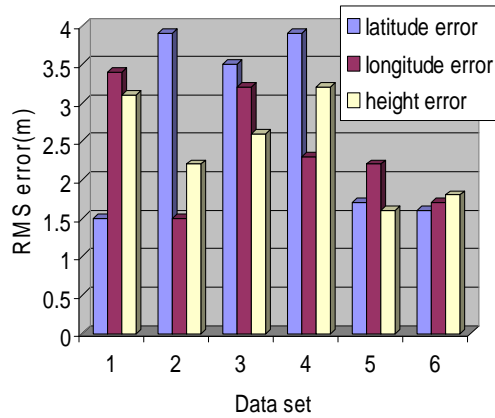


Figure 2 Achievable accuracies from Cartosat-1(1GCP is used)

It is clear from this figure that Cartosat-1 data is capable of giving 3-4m accuracy just with 1 GCP. DEM and ortho images are generated from these datasets.

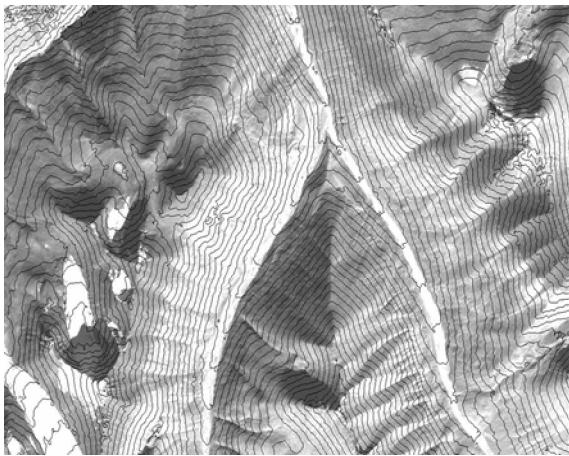


Figure 3 Contours shown on the orthoimage draped over DEM

Figure 3 shows the contours generated from the DEM over an area where height range is about 4000-6000m. The kinks in the contours are exactly falling over the ridges.

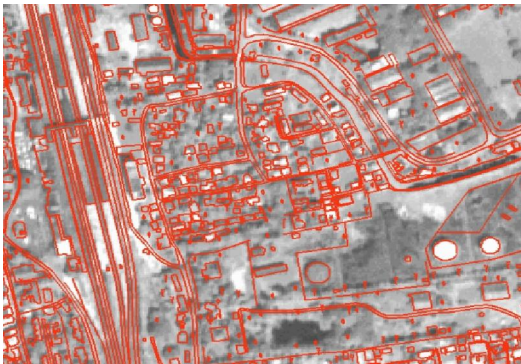


Figure 4 Vector layer from reference data overlaid on spatially accurate Cartosat-1 imagery

Figure 4 shows vector layer from the reference data overlaid on to the orthoimage .All road networks and other features are exactly sitting over the image.

Mapping potential of Cartosat-2 imagery was evaluated with multi view images and strip images over the areas where Cartosat-1 accuracy evaluation was done. Following Figure shows RMS errors achieved.

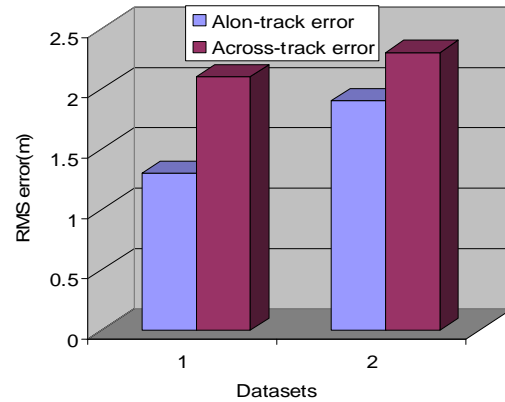


Figure 5 Achievable accuracies from Cartosat-2 (2GCPs used)

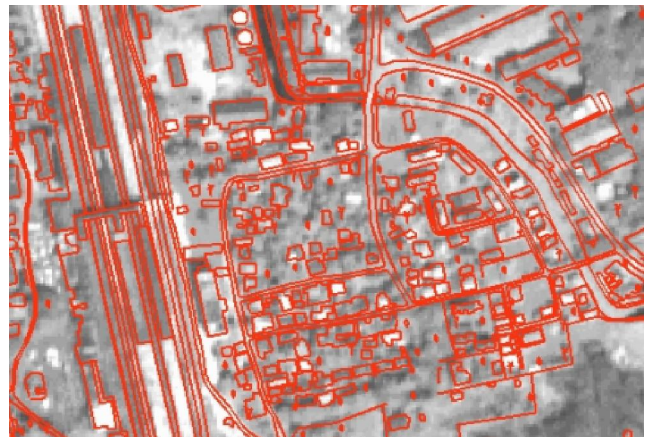


Figure 6 Vector layer from reference data overlaid on spatially accurate Cartosat-2 imagery (same area of fig. 4)

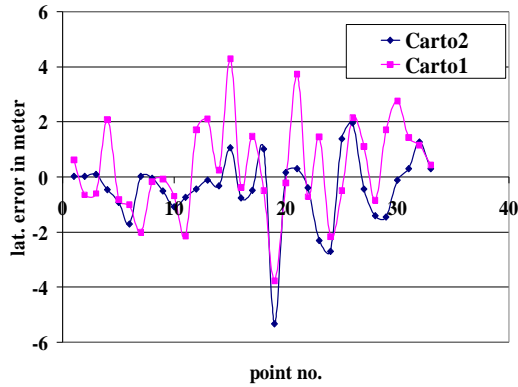


Figure 7 Comparison of along-track error over same check points with same GCPs used for both Cartosat-1 and Cartosat-2 (RMS error: Cartosat-1=1.7m; Cartosat-2= 1.3m)

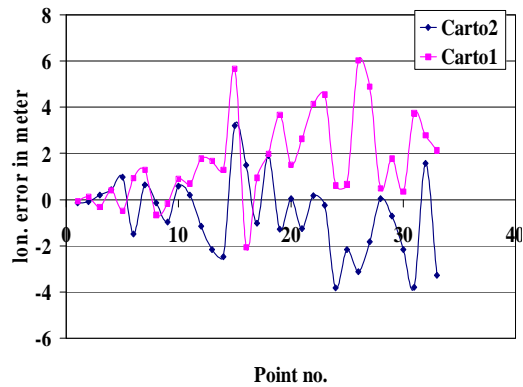


Figure 8 Comparison of across-track error over same check points with same GCPs used for both Cartosat-1 and Cartosat-2 (RMS error: Cartosat-1=2.4 m; Cartosat-2= 1.7m)

The above figures (figures 7 & 8) give a comparison of geometric accuracy achieved from Cartosat-1 and Cartosat-2 images over the same set of check points. Two GCPs are used for Cartosat-1 and Cartosat-2 images for correction. It is obvious from Figures 7 and 8 that achievable accuracy will not linearly improve in the same proportion as resolution increases. Both satellites, Cartosat-1 and Cartosat-2 shows almost same range of accuracies with same set of check points.

#### 4. CAPTURING TOPOGRAPHIC VECTOR DATA FROM THE IMAGERY

The orthorectified imagery was analysed with the capture of spatial information. Sub-areas of the image were analysed to ensure that different types of topography were investigated, viz. urban, semi-urban and rural. In each of these areas we attempted to capture all the features present in the specifications of the various mapping scales. The features collected in this study included roads, railways, tracks and paths, buildings, vegetation limits, water features and field boundaries. Many of the feature types that are required for 1:10,000 scale mapping could be satisfactorily identified and captured in Cartosat-1 and Cartosat-2 satellite images. In some

cases, features required for larger than 1:10,000 scale mapping (e.g. roads and woodland boundaries at 1:2500 scale) could also be captured in the images. Major exceptions to this are transmission lines, walls, fences and hedges, which are generally impossible to distinguish even in imagery with 0.4m resolution. Figures 9 and 10 show the feature delineability from Cartosat-1 and 2 at different scales. The national mapping accuracy standards in Great Britain indicate RMSE of 1.1m for 1:2500 scale data and 3.4m for 1:10,000 scale data.



Figure 9 Feature delineability at 1:5000 scale (a) Cartosat-2 (b) Cartosat-1

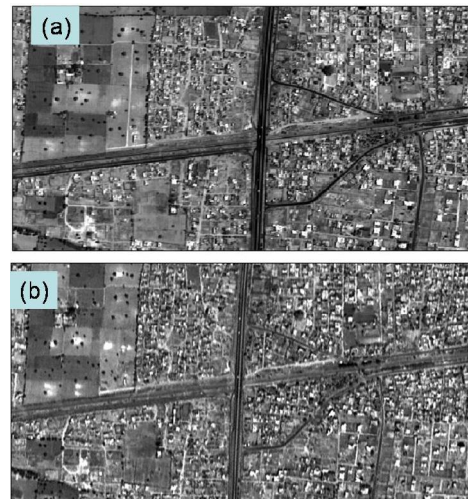


Figure 10 Feature delineability at 1:10,000 scale (a) Cartosat-2 (b) Cartosat-1

Over a built-up area of 2\*3 km, base map was generated at 10,000 scale from Carto-1 and Carto-2, and are shown in figure 11.

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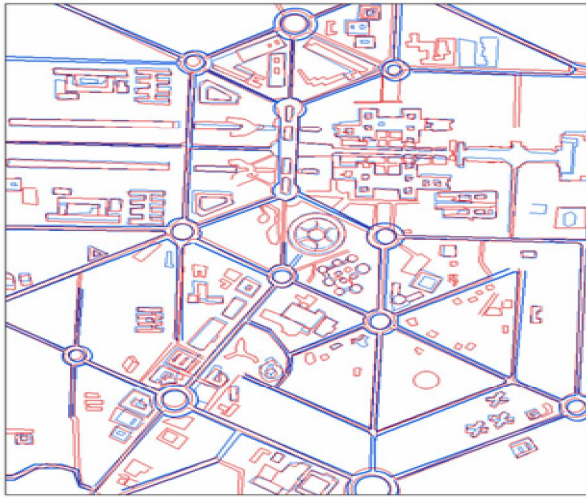


Figure 11 Portion of map generated from Cartosat-1 (blue) and Cartosat-2 (red) orthoimages overlaid (Scale: 1:10,000)

Major road networks and buildings could be captured from both satellite images. The level of features in Carto-1 and Carto-2 are comparable at 10,000 scale. Thus, generated base map clearly demonstrate the mapping potential of Cartosat imageries

## 5. CONCLUSIONS

In this study, we have evaluated the potential of Cartosat-1 and Cartosat-2 satellites for large scale mapping. Following are the major conclusions.

- Cartosat-1 DEM, geometric accuracy and capability for topographic feature capture are good enough for making 1:10000 scale maps.
- Geometric accuracy and feature detectability of Cartosat-2 indicate that it is capable of making 1:7000 scale maps.
- Cartosat-1 satellite is more stable compared to Cartosat-2 because it is not continuously changing the view while imaging. This ensures that no scale variation will be there at different parts of the imagery and will give uniform accuracy over a single image as well as images taken from different orbits. It is better to use stable satellites than agile for mapping applications.
- Number of GCP requirement is less for Cartosat-1. One conjugate point from Fore and Aft images over a scene gives an accuracy of about 3-4m. Minimum two GCPs are required for correction of Cartosat-2 to take care of the agility of the satellite.
- The majority of features seen in Cartosat-2 Images are delineable in rural and mixed areas in Cartosat-1 images with the desired accuracy.

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