LONG STRIP MODELLING FOR CARTOSAT-1 WITH MINIMUM CONTROL

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ABSTRACT:

Cartosat-1 satellite, launched on 5th May 2005, is designed to deliver high-resolution spatial data of better than 2.5m in stereo with ~27 km swath. The twin panchromatic cameras (Fore & Aft), with a fixed base-to-height ratio 0.62, image the terrain through along-track stereo almost simultaneously. The primary mission goal of this Indian satellite is to generate Digital Elevation Model (DEM) of a geographic region of interest (e. g. country) to facilitate the user communities of remote sensing and cartography. Space Applications Centre, ISRO, India has developed & demonstrated a technology to extract DEM from Cartosat-1's high resolution stereo data based on geometric modelling of long stereo strips using a few Ground Control Points (GCPs). This geometric modelling technique has been termed as Stereo Strip Triangulation (SST) for which dual camera space resection software is the core. It utilizes GCP observations from Fore & Aft cameras and rigorous photogrammetric imaging geometry model in order to update spacecraft attitude parameters to the geometric accuracies of < 15m in planimetry. The SST technique is advantageous due to robustness of modelling and reduction in GCP requirements. The reason is that, the same GCP is visible in both Fore & Aft images; thereby a single GCP contributes to two observations in the modelling process simultaneously. In addition to the updated satellite orientations, DEM over a strip as well as Triangulated Control Points (TCPs) are the outputs of SST software.This paper presents the outcome of the exercises aimed at demonstrating the SST performance for (i) modelling long stereo strips and (ii) extension feasibility of the model over those imaged areas which are devoid of GCPs.

1. INTRODUCTION

Digital Elevation Model (DEM) derived from stereo images, is an important component of geo-spatial data, feeding to the applications in the area of urban planning, agriculture and civil engineering etc.

With the launch of Cartosat-1, ISRO's first satellite with along track stereo capability in May 2005 by PSLV-C6 vehicle, a new era began for user communities of remote sensing and cartography. The high-resolution stereo data beamed from twin cameras onboard Cartosat-1 mission facilitates topographic mapping upto 1:25,000 scale. The primary goal and advantage of Cartosat-1 mission is generation of Digital Elevation Model (DEM) of a given geographic region of interest (e. g. country) for extracting drainage patterns, contour line generation, orthoimage production and 3D terrain visualization on a global basis. The stereo imagery pair from Cartosat-1 can also be used to derive secondary ground control points (i.e. Triangulated Control Points) towards generating high accuracy satellite data products.

Space Applications Centre, ISRO, India has developed & demonstrated a technology to extract DEM from Cartosat-1's high resolution stereo data based on geometric modelling of long stereo strips using a few Ground Control Points (GCPs). This geometric modelling technique has been termed as Stereo Strip Triangulation (SST) for which dual camera space resection software is the core. It utilizes GCP observations from Fore & Aft cameras and rigorous photogrammetric Imaging Geometry model in order to update spacecraft attitude parameters for achieving geometric accuracies of < 15m in planimetry. In addition to the updated satellite orientations, DEM as well as TCPs over a strip are the outputs of SST software.

This paper presents the outcome of the exercises aimed at demonstrating the SST performance for (i) modelling long stereo strips and (ii) extension feasibility of the model over those imaged areas which are devoid of GCPs.

2. CARTOSAT-1 MISSION

Cartosat-1 is the first operational remote sensing satellite capable of providing in-orbit stereo images with 2.5m nadir resolution and 27km swath. The two cartographic camera payloads viz. Fore and Aft are designed with state-of-the-art technologies in order to provide images of high quality [Nandakumar et. al 2005]. They are mounted in along track direction with a tilt of +26 deg (Fore) and –5 deg (Aft) to provide along track stereo with 2.5m resolutions each approximately. Major specifications of Cartosat-1 mission are given in **Table 1.0**

Being an along-track stereo mission, Cartosat-1 has certain advantages viz.

- The first is the systematic coverage that means the stereo pairs are acquired for the given region within same day at almost same time, giving operational stereo capability.
- Above condition also helps in preserving the radiometry between both the images thus helping better image matching for common features.

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- Fixed B/H ratio ensures constant height resolution for a fixed point identification error
- Single orbit with two cameras gives nearly the same attitude and orbital parameters and hence lesser number of unknown parameters are to be determined leading to lesser number of Ground Control Points (GCPs) requirement.

S. No	Parameter	Specification
1	Nominal Altitude (km)	618
2	Swath (km)	30 Fore, 27 Aft
3	Local time for equatorial crossing	10:30 AM
4	Spectral Bands a) No. Of bands b) Bandwidth (μmicrons)	 1 Panchromatic 0.5 – 0.85
5	Quantisation bits	10
6	No. of detectors	12000 per camera
7	Compression	JPEG Like, 3.2:1
8	B/H Ratio	0.62

Table-1.0: Major specifications of Cartosat-1 Satellite

3. STEREO STRIP TRIANGULATION (SST) APPROACH FOR CARTOSAT-1

As mentioned earlier, SST is the technique for modelling long stereo strip imagery from Cartosat-1. SST software assumes a primary GCP library database to be available for all passes over the geographic region of interest (with GCPs' ground coordinates better than 1 m; both in planimetry and height). These GCPs are identified manually using GCPId Graphical User Interface (GUI) provided by SST software on Fore & Aft images.

Identified image coordinates along with the ground coordinates of GCPs are utilized by SST software to update attitude parameters [Srinivasan T. P. et al, 2006] to the geometric accuracies < 15 m in planimetry. The SST technique is advantageous due to robustness of modelling and reduction in GCP requirements. The reason is that, the same GCP is visible in both Fore & Aft images; thereby a single GCP contributes two observations in the modelling process simultaneously.

The underlying algorithms are described briefly in the following sub-sections.

3.1 Rigorous Imaging Model

The crux of SST is modelling the Cartosat-1 imaging sensor geometry. Here, the model is based on photogrammetric collinearity condition, which states that the perspective centre, image point and object point lie in straight line at the time of imaging. The model is rigorous in the sense that emphasis is on use of all the available information about the satellite position, orientation and payload geometry in an effective way to describe the physical behaviour of the spacecraft as closely as possible.

As the model resorts mainly to the measurements of various parameters pertinent to satellite motion and behaviour, the number of undetermined parameters is less compared to the models, which do not utilize system information fully. Extension of model for longer strips with a very few GCPs makes it an attractive option for operational use. System knowledge over 52 seconds gap between two cameras in sighting a common GCP is well utilised by this model.

3.1.1 Coordinate Systems

Several co-ordinate systems are needed to apply photogrammetric formulations in the context of orbital and geodetic conditions. They are used to provide rigorous link between the photogrammetric model, orbit and the reference ellipsoid as needed in the implementation of solution. Various coordinate systems required by this model are:

- Earth Centred Inertial (ECI) True of Date (TOD) system;
- Earth Centred Earth Fixed System (ECEF in WGS84);
- Local Orbital co-ordinate system;
- Spacecraft body co-ordinate system;
- focal plane coordinate system and
- Image coordinate system.

Several standard definitions and conventions are adopted for all coordinate systems.

3.1.2 Ground to Image

The imaging model defines the relationship between a point in object space to the same point in image space. Conversion of object space point to image space involves a series of transformations among different coordinate systems as given above. For a given ground or object point in terms of latitude (ϕ,), longitude (λ) & height (h) above ellipsoid, a unique point in image co-ordinate system i.e. scan line(s) and pixel (p**)** is estimated**.** This transformation is an iterative process and time is an unknown parameter to be determined, though it is sacrosanct to know the satellite position and orientation.

3.1.3 Space Resection

The spatial position and orientation of Cartosat-1 image is determined based on image coordinates of the GCPs appearing on the image. In space resection, the exterior orientation of the image is largely modelled by the time varying attitude parameters with the help of GCPs. Here, it is assumed that the knowledge of spacecraft position is sufficiently accurate while error in attitude is modelled linearly for estimating attitude biases and attitude rate biases. Onboard star sensors' measurements for attitude and GPS based state vector information for orbit are used.

The dual camera space resection software [Srinivasan T.P. et al. 2006] is the heart of the SST approach. It utilizes GCPs observations from Fore & Aft cameras and rigorous photogrammetric collinearity model in order to update spacecraft attitude parameters by superimposing a linear correction model on the measured attitude values in the following manner:-

Updated_roll = initial_roll + (delta_roll_bias + delta_roll_rate * time) (1)
Updated_pitch = initial_pitch+ (delta_pitch_bias + delta_pitch_rate * time) (2)
Updated_yaw= initial_yaw+ (delta_yaw_bias + delta_yaw_rate * time) (3)

These "delta" coefficients of the linear correction model are derived based on simultaneous adjustment of multiple GCP observations in a least-square sense [Slama 1980]. This method is executed over multiple iterations until these coefficients become 'negligible' (or a pre-set number of iterations are completed).

4. EXPERIMENTS WITH SST FOR LONG STRIP MODELLING

SST software is operational in India for processing Cartosat-1 stereo data regularly. Strip wise DEM (at 100m posting interval) & TCPs (approx. one per square km) with geometric accuracies < 15m in planimetry have been generated & archived covering almost 70% of Indian geography for use by data products generation. Since launch, many dates have been processed and ortho-image products have been generated using SST' TCPs & DEM. These ortho-image products have been evaluated to assess the performance both at model level and at product level. Some of the initial observations on SST System performance are described in [Srinivasan T. P. et al. 2006].

Currently, individual stereo strip segments up to ~500 km length are processed at SST system. Based on the encouraging observations on the SST model performance and Cartosat-1 platform stability, it was felt worth to carry out experiments to study the SST performance for modelling longer strip lengths (> 1000 km) including the assessment on the feasibility of interpolating/extrapolating SST model for those strip areas that are devoid of GCPs.

In essence, the following three types of exercises have been conducted using various data sets of different 'dates of imaging'/ 'Paths':-

1. Modelling of Longer Stereo Strips (i. e. > 1000 km) using well-distributed GCPs.
2. Simulation of GCP gaps between 'Top' and 'Bottom' of the longer strip, thus enabling assessment of "Interpolation" feasibility of the SST model. This has been achieved by treating inner GCPs as 'Check' points for evaluating Interpolation accuracies and using Top & Bottom GCPs for modelling.
3. Simulation of GCP gaps at Top/Bottom of the longer strip, thus enabling assessment of "Extrapolation" feasibility of the SST model. This has been achieved by treating a number of GCPs at Top and/or Bottom as 'Check' points for evaluating Extrapolation accuracies and using remaining GCPs for modelling

4.1 Results and discussion

SST' data (i.e. GCP-Identification information & measured Spacecraft Orbit-Attitude information) corresponding to two dates of imaging have been used for carrying out the above-mentioned exercises (**Table 2.0**).

	Date of Pass	Path	No of GCPs
Case 1	04 November 2005	523	123
Case 2	28 December 2005	541	41

Table-2.0: Datasets used for experiments

The data set corresponding to case 1 consists of three segments of varying lengths. GCP observations corresponding to these segments were merged to form data set of longer strip length (~1150 km) and the planned experiments were conducted. In this case, extrapolation corresponding to additional strip length of 670 km is achievable with accuracies better than 10 meters by modelling a strip length of 340 km using 8 GCPs. Interpolation accuracies of better than 10 meters over strip length of ~1000 km are achievable using 2 GCPs (**Table 3.0**).

The data set corresponding to case 2 consists of four segments of varying lengths. GCP Observations corresponding to these segments were merged to form data set of longer strip length (~1500 km) and the planned experiments were conducted. In this case, extrapolation corresponding to additional strip length of 605km is achievable with accuracies better than 10meters by modelling a strip length of 475km using 11 GCPs. Interpolation accuracies of better than 10 meters over strip length of ~1500 km are achievable using 2 GCPs (**Table 4.0**).

Results from the exercises have been analyzed and the following points have been inferred:

1. Larger stereo strip lengths (e. g. ~1500 km) can be modelled with acceptable accuracies and interpolation over the similar strip length is possible.
2. Feasibility of Extrapolation exists. However, acceptable extrapolation duration largely depends on 'Modelling duration' and 'Accurate positioning of GCPs'. In general, Modelling Duration > 52 seconds should be ensured in order to take adequate advantage of 'Dual camera Resection Model' (i.e. balanced adjustment/refinement of attitude parameters). For instance, modelling corresponding to ~500 km strip length may enable updation of 'Attitude' for an extrapolated duration corresponding to additional strip length of ~600 km.

It may please be noted that accuracies were evaluated using ground to image transformation at GCP locations and Root-Mean-Square-Error (RMSE) was computed for both cameras in scanline and pixel directions.

Long Strip Modeling Statistics		
Modelling Duration		169.942625 Seconds
Modeled Strip Length		1161.71 km
No. of Model Points		123
Direction	**Fore-RMSE (Pixels)**	**Aft-RMSE (Pixels)**
Scanline	1.26	1.13
Pixel	1.45	1.16
Interpolation Statistics		
Modelling Duration		169.942625 Seconds
Modeled Strip Length		1161.71 km
No. of Model Points		2
Interpolation Duration		151.035574 Seconds
Strip Length		1032.471012 km
No. of Check Points		121
Direction	**Fore-RMSE (Pixels)**	**Aft-RMSE (Pixels)**
Scanline	1.91	1.55
Pixel	2.47	2.33
Extrapolation Statistics		
Modelling Duration		49.829402 Seconds
Modeled Strip Length		340.63 km
No. of Model Points		8
Extrapolation Duration		98.0592 Seconds
Strip Length		670.32 km
No. of Check Points		110
Direction	**Fore-RMSE (Pixels)**	**Aft-RMSE (Pixels)**
Scanline	1.47	1.39
Pixel	2.53	2.6

Table-3.0: Results for case1

Long Strip Modeling Statistics		
Modelling Duration		224.378626Seconds
Modeled Strip Length		1533.84 km
No. of Model Points		41
Direction	**Fore-RMSE (Pixels)**	**Aft-RMSE (Pixels)**
Scanline	3.19	2.59
Pixel	2.35	2.34
Interpolation Statistics		
Modelling Duration		224.378626 Seconds
Modeled Strip Length		1533.84 km
No. of Model Points		2
Interpolation Duration		217.502466 Seconds
Strip Length		1486.83 km
No. of Check Points		39
Direction	**Fore-RMSE (Pixels)**	**Aft-RMSE (Pixels)**
Scanline	3.88	2.45
Pixel	2.81	2.57
Extrapolation Statistics		
Modelling Duration		69.423666 Seconds
Modeled Strip Length		474.57 km
No. of Model Points		11
Extrapolation Duration		88.405866 Seconds
Strip Length		604.33 km
No. of Check Points		14
Direction	**Fore-RMSE (Pixels)**	**Aft-RMSE (Pixels)**
Scanline	2.94	2.98
Pixel	2.25	3.35

Table-4.0: Results for case2

As mentioned above, long strip modeling has resulted in updation of roll, pitch and yaw components for extrapolation duration in addition to modelling duration. The **Figures 1a, 1b** & **1c** depict updated attitude in comparison with initial attitude for Case-1. The similar comparison for Case-2 is depicted in **Figures 2a, 2b** & **2c.**

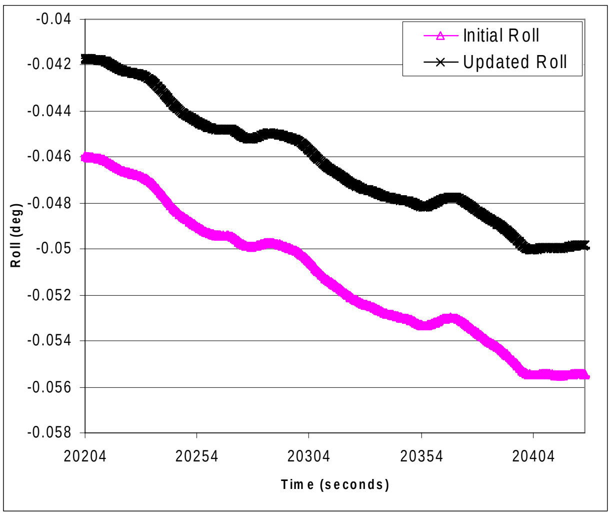

Figure-1.a: Comparison plot for Initial and Updated Roll for case1

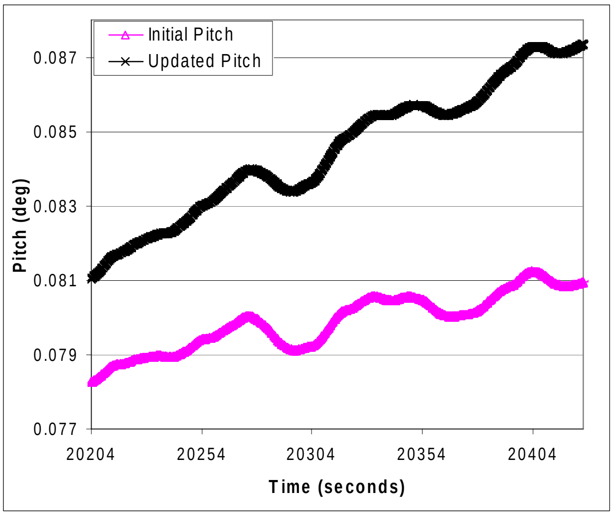

Figure-1.b: Comparison plot for Initial and Updated Pitch for case1

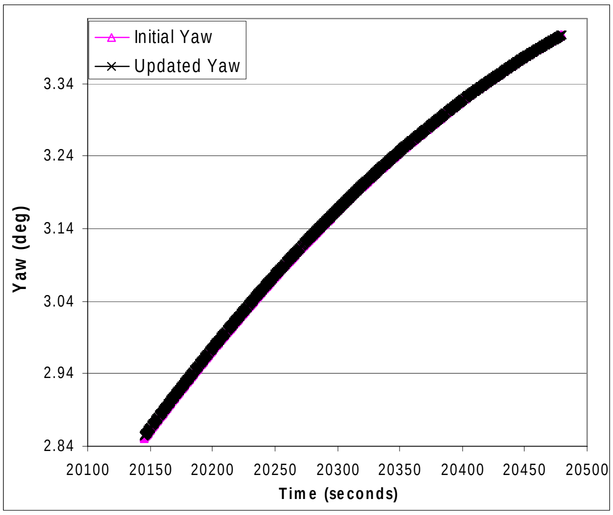

Figure-1.c: Comparison plot for Initial and Updated Yaw for case1

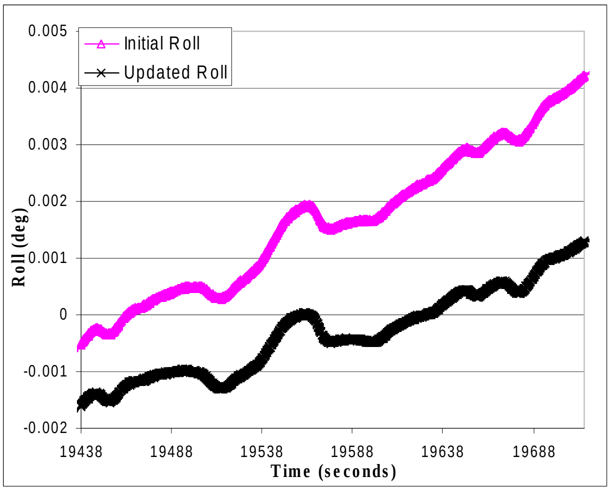

Figure-2.a: Comparison plot for Initial and Updated Roll for case2

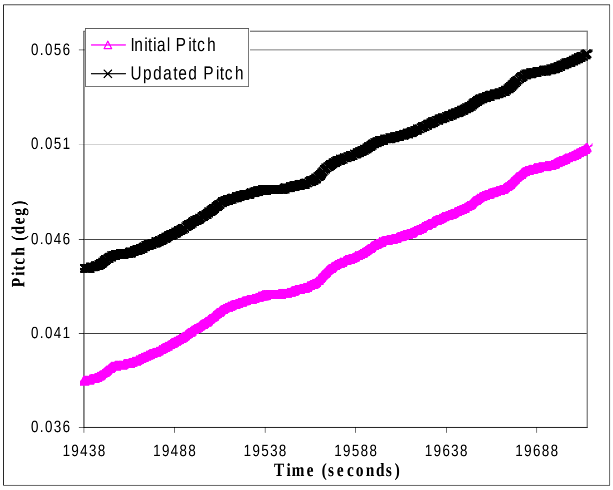

Figure-2.b: Comparison plot for Initial and Updated Pitch for case2

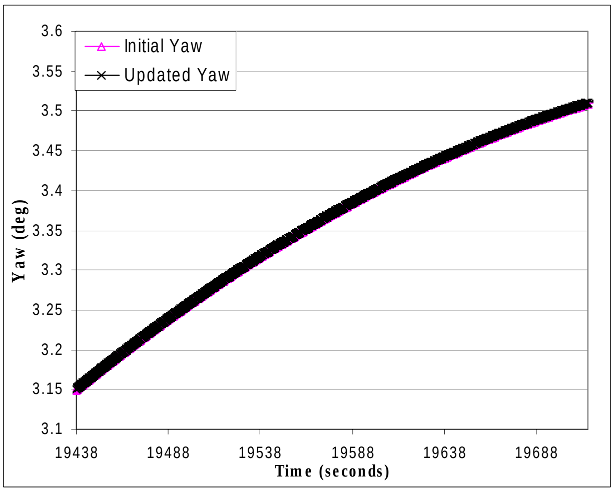

Figure-2.c: Comparison plot for Initial and Updated Yaw for case2

5. CONCLUSIONS

Cartosat-1 is among the first dedicated satellite mission for acquiring high-resolution stereo imagery with a capability of global coverage. SST software is one of the softwares identified for operational generation of DEM and TCPs for Indian region. Based on the results of exercises for various stereo data sets, it has been deduced that SST technique can be fruitfully employed for modelling long stereo strips (e.g. 1000-1500 km length) from Cartosat-1 using optimum number of GCPs (e. g. 6-8) realizing specified geometric accuracies for DEM (< 15m planimetric error). It has also been demonstrated that feasibility of SST model extension exists e. g. modelling duration corresponding to ~500 km strip length enables updation of 'Attitude' for an extrapolated duration corresponding to additional strip length ~600 km. The long strip modelling approach is also useful in generation of a large number of TCPs (can be stored in a library form) over the strip length, which is a resource useful for generation of precision correction of the data sets of similar resolutions in an automated mode.

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