HIGH RESOLUTION SENSOR SPECIFIC PARAMETER EVALUATION USING CARTOSAT-1 IMAGERY

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ABSTRACT:

The launch of Cartosat-1 is the beginning of yet another series of satellite mission after IRS satellites for earth observation and natural resource management applications. The first in its series of satellite for Cartographic applications, Cartosat-1 was launched on 5th May 2005. The along-track stereo viewing capability was realized by employing two cameras viz. FORE with mounting pitch angle of 26deg and AFT with that of –5deg with respect to nadir. The camera-mounting angle combined with the agility of camera in Roll, Pitch and Yaw direction to achieve better revisit created blend of viewing geometries.
The Chharodi test site with its known dimension and artificial targets with controlled time-invariant radiometric properties were used to evaluate sensor specific parameters under these viewing geometries. Modulation Transfer Function, Square Wave Response, Point Spread Function and adjacency effect parameters were evaluated for FORE and AFT cameras. Along and across track spatial resolution were evaluated using Ground measured length, width and orientation of each side of test site using GPS in DGPS mode

1.0 INTRODUCTION

After successful development of high spatial resolution satellites like TES and IRS-P6, the plausible next step was a mission with stereo viewing capability. The stereo imaging can be accomplished in more ways than one: a) in across track direction by imaging same area in different orbits by tilting camera in across track direction, b) using two camera with different fixed mounting angle in along track direction c) Along track tilting of single camera to view the same region from two different angles. The accuracy of height information derived from stereo imaging using former method can be adversely affected as these images are acquired on different days during which the atmospheric condition may not remain constant.

The objective of this analysis is to validate high-resolution sensor parameters using calibrated ground targets.

The continuous improvement in GSD, mission to mission, requires close monitoring of parameters like spatial resolution and radiometry, important for mapping satellites [1].

During this study following radiometric and geometric parameters were analyzed.

a) Ground measured length, width and orientation of each side of test site using GPS in DGPS mode.
b) Computation of frame length, swath width and orientation of each side of test site as Along & Across track distance using Stereo pair and Geo-referenced image data.
c) Derivation of Along and Across track spatial resolution using aforesaid parameters.
d) At sensor target mean count, standard deviation, radiance and Apparent Reflectance
e) Point Spread function from specially designed PSF targets
f) Square wave response for various frequencies, (Along and Across scan).
g) Edge-based Modulation Transfer function
h) Adjacency Effect

2.0 CARTOSAT-1 CONFIGURATION

Cartosat-1 satellite, the first dedicated stereo imaging mission [2] by ISRO, was launched on 5th May 2005. The payload performance specification for CARTOSAT-1 mission is listed in Table 1.

Sr. No.	Parameter	Specification
1	Spatial Resolution (m) at Nadir	2.5m
2	Swath (km) Fore Aft Swath steering Range	 30Km 27.5Km 131Km(+/-12deg)
3	Spectral Bands (μ)	.50 - .75
4	Camera SWR at Nyquist Freq.	>.20
5	F Number Height Resolution	f/4.5 4.0 Meters
6	Quantization	10 Bits
7	SNR (at sr.)	>64
8	Saturation Radiance	53.46 $mw/cm^2/sr/\mu$
9	Integration Time	365.71 μs
10	No of output Ports	8
11	Data Rate (mbps)	2 x 52.5

Table: 1 Payload Performance Parameters

The satellite with along track stereo imaging capability and dedicated to cartographic applications, CARTOSAT-1, uses two Panchromatic camera operating in spectral band 0.5-0.85μm with spatial resolution of 2.5m each, mounted with +26deg pitch angle (named FORE) and another mounted in –5.0deg pitch angle (named AFT) to generate along track stereo images. The swath coverage is 30km. The two identical PAN cameras cover dynamic range of 100% albedo with 10bit radiometric quantization, suitable for cartographic applications. The CCDs of size 7μm x 7μm forms an array of 12k CCDs with odd/even pixels separated into two rows to avoid electronic cross-talk effect on adjacent pixels [2]. This arrangement is to improve Modulation Transfer Function at detector level. Over and above the mounting angles of FORE and AFT camera, which introduces time lag in data acquisition by both cameras, the platform yaw tilt compensates the earth rotation. Roll bias of up to ±25^o can be given to achieve revisit capability of 5 days. The capability of platform to rotate in three-axis for fulfilling mission objectives creates great challenge in characterizing image formation.

3.0 TEST SITE DESCRIPTION

Chharodi Calibration Site at Sanand, situated about 30Km West of Ahmedabad has been used for Calibration/Validation of optical sensor with high spatial resolution [3,4]. Gujarat Agriculture University (GAU) owned the North Cot cattle farm, in which the site is located. After the division of GAU into separate universities, the North Cot cattle farm now belongs to Anand Agricultural University (AAU). Fresh MoU with AAU authorities has been signed when this paper is being written. The 300m x 300m-square site with corner-markers in the form of lime- painted RCC platforms facilitate in characterizing the orientation of site in the image taken by different viewing angles. The availability of modular artificial targets with ground reflectance properties covering dynamic range of the sensor allows radiometric characterization. The land within the site is maintained free from any natural or man-made obstruction throughout the year. The targets made of Black and White Cloth stripes are laid prior to satellite pass as per pre-designed parameter-specific design.

The ground radiance and reflectance of these artificial targets as well as Bare soil is measured using ASD SpectroRadiometer[5], synchronous to satellite pass.

4.0 PARAMETER SPECIFIC TARGET DESIGN AND DATA AVAILABILITY

The analysis was carried out using two data sets of summer and one from winter season. The specific dates and viewing geometry on corresponding days is given in Table 2.

Date Of Pass	Sun Elevation angle	Sun Azimuth angle	ROLL	PITCH	YAW
			Aft & Fore		
10Jun 05	72.60	85.64	7.58891	0.00857	3.67867
15Jun 05	70.04	84.69	-11.82407	-0.00804	3.24775
4Jan 06	40.06	155.14	-0.14104	.06398	3.33179

Table: 2 Data Availability and Viewing Geometry

Description of a typical design deployed over Chharodi Calibration Site, along with the parameter, is listed in Table: 3. The target design deployed in June 2005 and that on 4th Jan 2006 were different owing to the fact that post-monsoon, the asbestos targets were removed from the site due to heavy breakage making them unusable. After the condemnation of asbestos, various materials were studied for use to make targets. The stripes of Black and White Cloth material was selected for making modular targets [6], which can be deployed before satellite pass.

Indentation of parameter specific design of targets was carried out before each pass day.

Sr No	Parameter	Target Size	Average Reflectance
1	Adjacency Effect	7.5m x 7.5m Black at center of 50m x 50m White Target	Black Target with 4% reflectance White Target
		7.5m x 7.5m White at Center of 50m x 50m Black Target	
2	Uniform Target for	50m x 50m Black Target	4.7%
		50m x 50m Bare Soil	17%
		50m x 50m White Target	80%
3	Along / Across Track Square Wave Targets at μc/4	10m x 25m x 5 bars	4.0% reflectance for Black 80.0% reflectance for White
4	Point Spread Function	5x5 Matrix of 2.5m x 2.5m size with Quarter pixel shift between pixels	17.0% for Bare Soil 80.0% for White Target
5	Ground Sample Distance	300m x 300m Test site identifiable by RCC structure.	17.0% Reflectance of Bare Soil

Table-3 Typical Parameter Specific Artificial Target Design

These targets as imaged by Cartosat-1 FORE and AFT camera on 4th Jan 2006 are shown in Fig: 1

Fig: 1 Image showing Site with Targets on 4th Jan 06

5.0 IMPORTANT PARAMETERS FOR MAPPING MISSIONS

The spatial resolution is one of the most important parameter for missions like Cartosat-1 aimed at cartographic and mapping applications. The various parameters, which influence the spatial resolution and computed during this study, are discussed in subsequent sections. The basic image sensor parameters are as follows:

5.1) Geometric Characterization: The CARTOSAT-1, with along-scan stereo viewing capability and three-axis attitude maneuverability to achieve 5-days revisit, poses greater challenge in geometric characterization of imaged features. The Chharodi site with four marked corners aids in earmarking the shape and size of square site. Stereo pair and Geo-referenced data was ingested and it was interesting to observe and study the images acquired by AFT and FORE camera (with different viewing geometry) on Chharodi Test site. The preliminary observations were that shape, size and orientation were different on all dates for both cameras.

5.2) Radiometric Characterization: Radiance at sensor level is a sensor response function, which is a combined effect of weighted integrated effect of spectral & spatial response. A linear relationship between sampled & quantized Digital number and at sensor radiance exists. The inversion technique to obtain band radiance values from image DN is known as "Sensor Calibration". This sensor calibration is further evaluated by removing atmospheric effect, which converts radiance to reflectance as a "Scene Calibration".

5.3) Point Spread Function: For a diffraction-limited system, the point source is imaged as a airy disc with diameter d related to the system f/no f and average wavelength λ by the equation [7]:

$$d = 2.44 * f * \lambda$$

For Cartosat-1, with average wavelength of 675nm and f/no value of 4.5, the diameter of airy disc will be 6.58μm. As the size of detector is 7 μm x 7 μm, the resolution is determined by detector size rather than the optics [2]. The scene-sample phase for a point target will also result in it's blurring. Sample-Scene-Phase characterizes the uncertainty in the location of the scene with respect to known sampling grid of the system. The two extreme sample-scene phases result in a spatial signal that has either maximum contrast or no contrast, which is a measure of target blurring effect. Two-dimensional array of (5x5) matrix was arranged from 1square pixel target with 0.25 pixel shift in along /across track direction to balance sample-scene-phase effect. Point spread function is reconstructed using (5x5) matrix data.

5.4) Square Wave Response: The sensor's spectral/spatial response is measured in laboratory from series of equally spaced bright-dark bars at various frequencies. With 7μm size of detector, the nyquist frequency is 70lp/mm. The width of bar is an integral multiple of GIFOV of the sensor. The spectral response of the sensor is an average constant over an effective spectral band and spatial response is an average constant over an effective GIFOV. The total system Square wave response characterizes radiance-recording capability for given target contrast & size.

5.5) Modulation Transfer Function: The widely used and accepted parameter to qualify the imaging quality of a sensor is Modulation Transfer function (MTF). MTF of imaging system is obtained as the modulus of the discrete Fourier Transform of the PSF. Edge-based method for computing MTF has been used during this study. The edge function is derived from uniform High/Low contrast target by successive pixel Grey count difference or derivative of edge function gives Line Spread Function (LSF). The normalized amplitude of Fourier transform of LSF gives MTF of imaging system.

6.0 ANALYSIS AND DISCUSSION OF RESULTS

This section describes the procedure of computing and analyzing results of various parameters listed in preceding section. The ground measured reflectance and radiance values for different target features during summer and winter are shown in Table 4.

Parameter/Target	Black Cloth	Bare Soil	White Cloth
Radiance ($mW/cm^2/sr/\mu m$)	0.53 (0.85)	2.4 (6.0)	14.4 (24.0)
Reflectance (%)	3.01 (3.1)	11.3 (20.2)	80.4 (80.2)
Irradiance (W/m2)	0.705 (1.076)		

Table: 4 Ground Measured parameters for various targets (Values in summer are shown in bracket)

6.1 Geometric Characterization: The ground measurement of site size and orientation wrt North direction was carried out using GPS in DGPS mode. The measurements are given in Table 5.

Sr. No.	Side Id	Size in meters	Orientation w.r.t North
1	North	299.3	094.54 deg
2	West	299.8	184.40 deg
3	South	299.8	274.56 deg
4	East	300.9	004.38 deg

Table: 5 The Ground Measured Distance and Angle subtended by Site wrt North

These measurements are pictorially depicted in Fig 2.

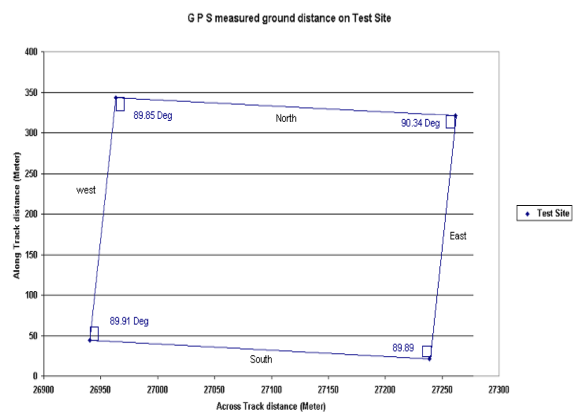

Fig: 2 GPS Measured Ground distance and Site orientation

The targets as imaged by Cartosat-1 FORE and AFT camera on 10th and 15th Jun 2005 are shown in Fig3a, b. The orientation of site shows large variability depending on the attitude parameters on the day (Ref: Table 3)

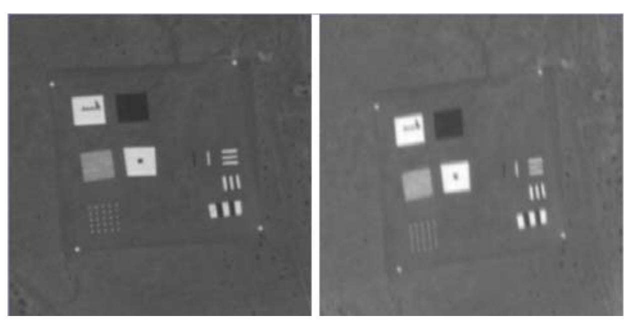

Fig3a: Site and Targets as imaged on 10 Jun 2005

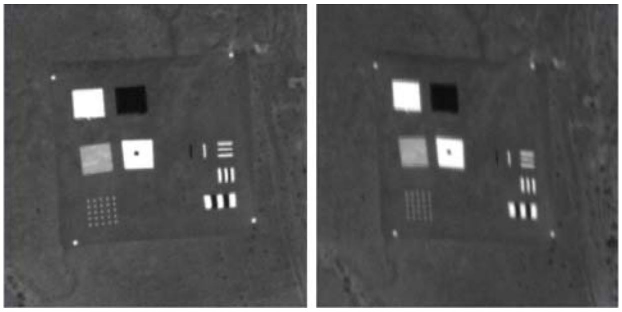

Fig3b: Site and Targets as imaged on 15 Jun 2005

The geometric characterization of site in terms of pixel distance is shown in Table: 6. The geo-referenced dimension shows the reclaimed size of site and hence, improved resolution.

Date	Side Id	RAD		Geo-Reference	
		Fore	Aft	Fore	Aft
10 Jun 05	North	116.5	129.00	119.27	119.42
	West	116.11	117.10	120.27	120.34
	South	117.28	130.75	119.27	119.42
	East	117.24	119.36	120.27	120.34
15 Jun 05	North	110.00	110.00	120.34	119.51
	West	120.81	120.70	120.42	120.42
	South	112.00	112.00	121.41	121.50
	East	121.06	120.93	121.33	120.27
4 Jan 2006	North	119.41	133.43	120.32	119.84
	West	120.78	119.71	122.62	121.62
	South	119.10	132.23	120.61	120.34
	East	120.96	119.54	123.34	121.58

Table: 6 Geometric Distance Characterization of Site (All numbers in pixels)

The product corner co-ordinates of stereo pair data of 10 Jun 05 has been plotted as shown in Fig 4. The graphical plots for visualization, shows geodetic coverage variation for acquired images. These variations are quantified and computed product size in four directions show that product swath in pixel direction for each camera is different due to camera viewing geometry and increases with Roll tilt magnitude. Also that product frame length is constant in scan direction but scanning orientation is varying. After geo-referencing, product orientation for both cameras is identical.

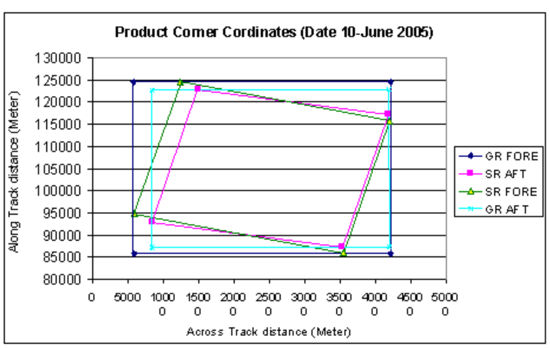

Fig: 4 Product Corner Coordinates on 10 Jun 05

The derived spatial resolution corresponding to acquired images is given in Table 7.

Date	Roll Tilt	Direction	Fore	Aft
10 Jun 2005	7.58891	Along Scan	2.575	2.54
		Across Scan	2.565	2.31
15 Jun 2005	-11.82407	Along Scan	2.485	2.485
		Across Scan	2.70	2.70
4 Jan 2006	-0.14104	Along Scan	2.48	2.50
		Across Scan	2.52	2.24

Table: 7 Derived pixel resolution in meters

6.2 Radiometric Characterization:

The at-sensor radiance is shown in Table 8. Ground measured radiance for all targets has diminished as compared to summer readings. The Radiance (Lt) on ground, solar irradiance (Eg) and target ground reflectance (ρ) are related by the general equation

$$Lt = \rho \, Eg/\pi$$

For targets with time-invariant reflectance property, the radiance is proportional to the solar irradiance. Thus, when weighted against the ground-measured reflectance, the bare-soil reflectance has reduced whereas reflectance for other artificial targets has practically remained invariant. The decrease in radiance is due to lower solar elevation angle and hence the lower solar irradiance during winter. This also signifies the importance of artificial targets as against the natural features, which has temporally varying radiometric property.

Date of Pass	Camera	At-Sensor Radiance for		
		White Cloth	Bare Soil	Black Cloth
10 Jun 05	Fore	20.13	8.43	5.42
	Aft	21.07	8.43	5.22
15 Jun 05	Fore	22.14	8.32	4.94
	Aft	23.49	8.74	5.05
04 Jan 06	Fore	13.75	4.47	3.85
	Aft	12.65	4.69	3.55

Table: 8 Multi-temporal Target Parameters

6.3 Point Spread Function

The sample-scene phase introduces uncertainty in the acquisition of single pixel target by detector. A 5x5-pixel matrix of 1 pixel size target with quarter pixel displacement was made to accommodate the sample-scene phase.

The Point targets imaged by CARTOSAT-1 AFT and FORE camera on 10jun05 is shown in Fig 5. The re-orientation in Geo-referenced (GR) image for both dates can also be seen.

Reconstructed Point Spread Function is shown in Fig6a, b.

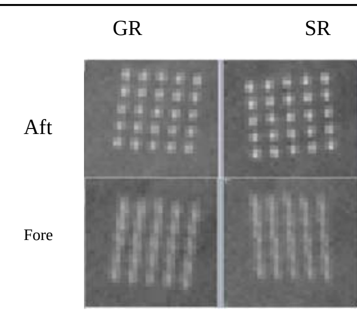

Fig5: Image showing Point Targets
Date: 10-Jun 2005

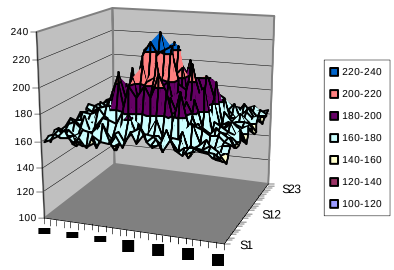

Fig: 6a Reconstructed AFT Point Spread Function of 10 Jun 05

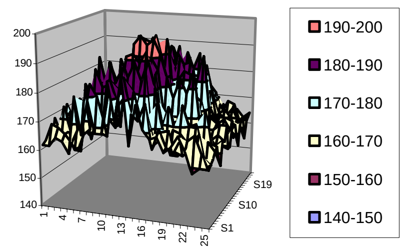

Fig: 6b Reconstructed FORE Point Spread Function of 10 Jun 05

The spread in AFT is less as compared to that in FORE and hence better PSF. The Point spread function targets were also aligned to North on 4th Jan 2006. The reconstructed PSF for 10th Jun is shown in Fig8a, b below. Whereas no PSF could be computed for SR product on 15th Jun data for FORE camera, the PSF on 4th Jan is 6. This number improved to 4.75, in FORE camera of GR product. The Across Scan PSF for AFT camera improved to 2.25 from 2.75. These observations demonstrate that PSF varies with viewing geometry for same fixed targets. This will also reflect in subsequent parameters like SWR and MTF; ultimately, spatial resolution.

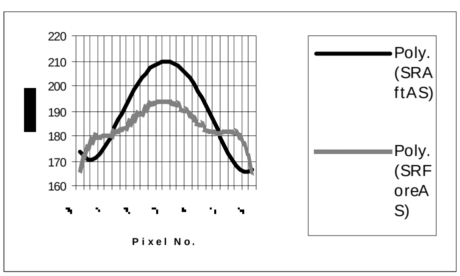

Fig: 7a Along Scan PSF on 10 Jun 05

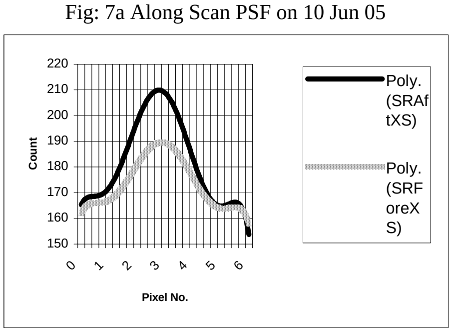

Fig: 7b Across Scan PSF on 10 Jun 05

6.4 Square Wave Response: The along and across scan SWR targets were deployed on three days. The Fig 8 shows sensor response to the SWR pattern. The SWR was computed using the following equation:

$SWR = (DN_{max} - DN_{min}) / (DN_{max} + DN_{min})$

The selection of pixels corresponding to DN_{max} and DN_{min} was carried out appropriately as per the designed target frequency.

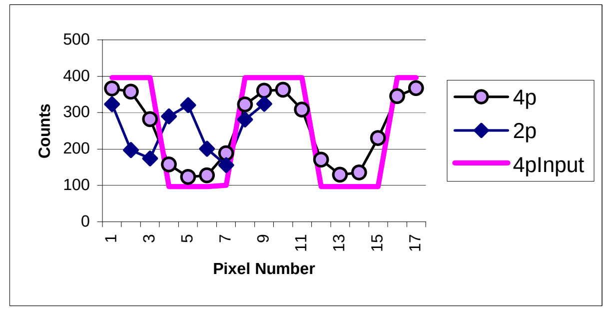

Fig 8: Sensor Response to Across Scan µc/4 Input SWR Targets
Date: 10 Jun 2005 Camera: Fore

The computed Square Wave response on three days for µc/4 spatial frequency in along and across track direction is given in Table: 9. It shows that, but for along track SWR of FORE camera, all other values meet the specifications laid down for this frequency.

Date	Fore		Aft	
	Along Scan	Across Scan	Along Scan	Across Scan
10-Jun-05	TND	0.55	TND	0.50
15-Jun-05		0.59		0.54
04-Jan-06	0.39	0.51	0.54	0.50
Note: TND= Target Not Deployed				

Table: 9 Multi-temporal Square Wave Response at µc/4

6.5 Modulation Transfer Function: The edge, shown in Fig 9, of White target against bare soil background was used for calculating Modulation Transfer Function in along and across track direction. The normalized FFT of the first derivative of the edge function gave the MTF at different frequencies. Table 10 shows the MTF (in %) at nyquist frequency, derived using Edge-based method.

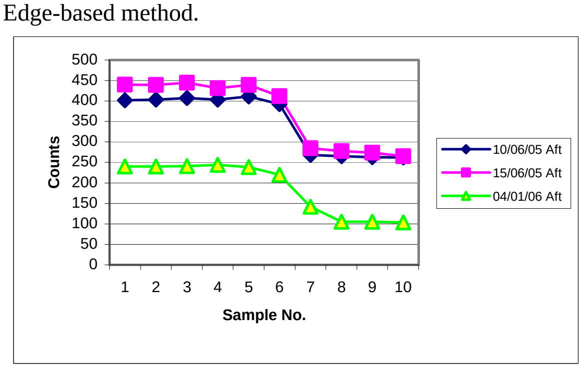

Fig 9: Edge for MTF computation for AFT camera

Direction/Camera	**15-Jun -05**		**4-Jan-06**	
	Aft	**Fore**	**Aft**	**Fore**
Along Scan	25	17	18.2	12.3
Across Scan	26	20	17.6	17.4

Table: 10 Modulation Transfer Function

The seasonal analysis for MTF parameter has given an average sensor MTF of >20% for AFT and >15% for FORE camera.

6.6 Adjacency Effect: The study of adjacency effect signifies sensor's ability for target recognition from surrounding background. Three-pixel by three-pixel black target with 4% reflectance was placed in the center of a large White target of size 50m x 50m with 80% reflectance. Another three-pixel by three-pixel White target was also placed in the Black Uniform background with 4% reflectance on 4th Jan 06.

Black-in-White					Pure Black				
352	308	295	335	366	101	101	103	101	102
328	256	244	296	359	102	106	100	99	102
326	243	**216**	269	358	104	104	**97**	103	105
345	280	231	279	358	104	101	100	101	105
370	331	286	320	366	103	103	105	103	103

Table: 11 Dump showing effect of White background On Black Target for 10 Jun 05

Date	PAN-A			PAN-F		
	Pure Black	Black In White	Adj_ Eff	Pure Black	Black In White	Adj_ Eff
10Jun05	100	154	54	97	216	119
15Jun05	96	168	72	93	249	156
04Jan06	69	101	32	72	152	80
	Pure White	White In Black	Adj _Eff	Pure White	White In Black	Adj_ Eff
04Jan06	245	229	-16	266	194	-72

Table: 12 Multi temporal adjacency effect results

The three- pixel by three-pixel size was selected to ensure that, theoretically, at least one pixel corresponds to one detector fully covered by the center target image. Considering that one detector was fully covered by center target, contribution from the neighboring background was computed. The dump of the image for Black-in-White target is given in Table 11.

The larger absolute values of adjacency effect in Table 12 imply greater contamination from surrounding background. From Table: 12 it is clearly seen that pixels in FORE camera are infected by greater adjacency effect.

CONCLUSION

The exhaustive analysis of all parameters on stereo pair data & geo reference mono product for two seasons, summer and winter, has demonstrated that,

1) The groundwork of re-orientation of target on ground for 4 Jan 06 based on June exercise produced desired effect with target edges perfectly aligned in Geo-referenced product
2) Product swath in pixel direction for each camera is different due to camera viewing geometry and increases with Roll tilt magnitude. Also that product frame length is constant in scan direction but scanning orientation is varying. After geo-referencing, product orientation for both cameras is identical.
3) The reduction in counts and hence the radiance, even for time-invariant ground reflectance of artificial targets, on 4th Jan data is due to lower solar elevation angle
4) The μc/4 SWR values match the laboratory measured values and meet specifications
5) The spread of point reconstructed point targets is larger for FORE camera which is reflected MTF parameter
6) The adjacency effect in FORE camera is very high for SR as well as GR product for all data and the ratio of pure-count to count-difference has gone higher on 4th Jan 2006
7) This study has helped to understand the effect of viewing geometry on parameters important for mapping missions like CARTOSAT-1
8) Quantification of sensor specific parameters for high resolution can be incorporated to improve image quality.

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