

SPATIAL AND RADIOMETRIC CHARACTERISTICS OF CARTOSAT-1

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ABSTRACT:

Post-launch performance analysis carried out to characterize spatial and radiometric aspects of IRS-CARTOSAT-1 is reported in this paper. The radiometric characteristics are estimated with scene dynamic range analysis, signal-to-noise ratio, impact of onboard data compression on image quality, and the spatial characteristics is by modulation transfer function (MTF). Histograms of about 42 scenes comprising of different land-cover features across the country were computed to estimate overall and most significant dynamic ranges of the sensor output. Similarly, the signal-to-noise ratios were estimated by visually selecting uniform target areas viz., water body, tar-road and snow to study the sensor radiometry at low, middle and high input signal levels. Also, the effect of JPEG data compression onboard (Compression Ratio = 1:3.2) on the data quality was studied by analyzing the satellite data over the same area with compression off- and on-modes of data acquisition. The MTF was estimated base on slant-edge algorithm, which allows to extract edge information at sub-pixel level for accurate estimation of the edge profile. The MTF was evaluated using the slant edge algorithm on an image edge over an airstrip target. It was found that the sensors onboard CARTOSAT-1 spacecraft has met all the mission set specifications, and would help to generate data products with adequate image sharpness, radiometric quality and insignificant image distortion due to onboard compression scheme to extract cartographic feature extraction and analysis.

1. INTRODUCTION

The IRS-Cartosat-1 (also known as IRS: P5) satellite was launched in May 2005 by ISRO with an intension to serve cartographic mapping of the country at a resolution of 2.5 m. The cartographic mapping is done by generating in-track stereo-pairs of two Panchromatic cameras – FORE (+26°) and AFT (-5°) with respect to nadir view in the along track direction. With the availability of star tracking sensors onboard, the spacecraft Attitude and Orbit Control System (AOCS) has been tuned to maintain a drift of less than 5.0×10^{-5} deg/sec, pointing and attitude determination accuracies of 0.05 deg, 0.01 deg respectively on all axes in order to maintain the specified swath, overlap and to provide the data within location accuracy limits. The FORE and AFT cameras are equipped with 12000 CCD element array with an optical pass-band filter window (500 - 850 nm) with radiance set to maximum of 55 mw/cm²-sr-μm at maximum allowable at 10 bits per pixel resolution and the signal-to-noise (SNR) of 345 at saturation radiance (Krishnaswamy, 2006). With line integration time of the sensors set to 0.336 ms, increased constraint on data downstream rate from the existing 105 Mbps has been met by onboard data compression to a maximum of 1: 3.2 with JPEG-like algorithm.

The data products of Cartosat-1 are supplied to user community after applying different levels of corrections to raw satellite data: (a) Level-1 or standard geo-referenced data products – correcting the data with available satellite ephemeris and knowledge of satellite and sensor orientations, (b) Level-2 or orthokit products with rational polynomial coefficients for further processing at

users' end with standard commercial software packages, and (c) Level-3 or ortho-rectified data products with the help of network of control points obtained from ground survey campaign (NRSA, 2006).

Post-launch performance analysis carried out on spatial and radiometric aspects of the Cartosat-1 imagery is presented in this study. The radiometric characteristics are estimated with scene dynamic range analysis, SNR at different signal levels, impact of onboard data compression on image quality, while the spatial characteristics is determined by estimating modulation transfer function (MTF).

The rest of the paper is organized as follows: In Section 2, data sets taken and methodology followed to evaluate the performance parameters are discussed. Section 3 deals with results and discussions. Concluding remarks are given in Section 4.

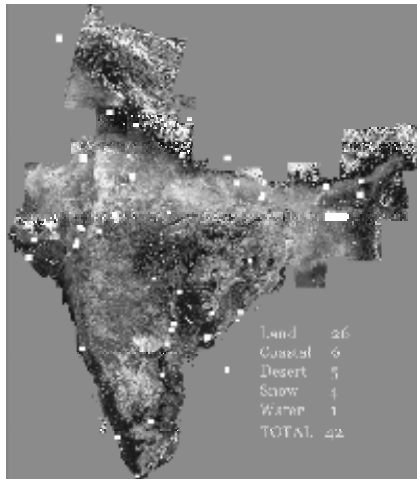
2. MATERIALS AND METHOD

Scene Dynamic range estimation: During the initial phase of Cartosat-1 operations, scenes covering several parts of India were collected and their histograms were computed to estimate image statistics, in terms of minimum, maximum, mean and data dynamic range limits of each scene. A total of 42 scenes within 5% cloud cover was selected comprising important land-cover features viz., urban, coastal, desert, snow and water body. Distribution of the scenes selected is shown in Figure 1. A histogram protocol software using IDL programming language was developed to extract the necessary details from the image file header and compute image statistical parameters such as mean,

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minimum, maximum, std. deviation etc. Overall and significant (within 1% cut-off at both ends of the histogram profile) dynamic ranges of gray level occupation was computed.

Figure 1 Selected scenes in and around the country's boundaries for scene dynamic range study.



Signal-to-Noise Ratio (SNR): Sub-images of some of the above scenes were extracted for estimating the SNR at different input signal levels. Visually identified uniform windows were extracted and their mean and std. deviations were computed. Three targets studied were water body, black tar road and fresh snow. The SNR was estimated as the ratio of mean DN value to std. deviation of the window region (Schowengerdt, 2001).

Impact of Onboard data compression: CARTOSAT-1 data, by default, is compressed by onboard hardware and transmitted. Data compression used is JPEG-like algorithm. It can be shown that the uncompressed data would have high data rates (340 Mbps), which needs to be compressed to meet existing transmission capability of 105 Mbps. The JPEG-like compression follows following sequence of operations: Discrete Cosine Transform (DCT), non-uniform quantization, zig-zag ordering, Huffman encoding and rate regulation. Prior to launch, the hardware was certified with a set of imagery over different land-cover features and a set of quantization and Huffman tables is kept onboard.

Table 1 Compression Bye-pass data sets covering different land-cover features

SL NO.	PATH / ROW	DATE OF PASS	SCENE CENTRE	PLACE / FEATURE
1	537 / 240	23.05.05	34.37 N 81.03 E	China / Snow
2	536 / 236	23.05.05	28.55 N 79.52 E	India / Agri. Fields
3	1403 / 221	08.06.05	38.54 N 110.32 W	USA / Desert
4	170 / 206	08.06.05	41.93 N 12.71 E	Italy / Urban

As a post-launch activity, it was planned to evaluate the adequacy

of these tables on the image quality. To do this, acquisition was programmed to transmit compressed data in real-time and record the real-time data before data compression step in On-Board Solid State Recorder (OBSSR). Table 1 shows the list of scenes collected for this study. This would then provide compressed and compression bye-passed data for evaluating the performance of data compression and further planning for switching the Huffman coding tables, if necessary. Four such bye-pass mode data sets of the AFT camera covering different land-cover features were selected and passed through data compression software for analysis.

MTF Estimation based on Image Edges: In-orbit evaluation of MTF is usually done by acquiring images over artificial targets laid over known locations with the knowledge of their physical dimensions on the ground. Fortunately, for high resolution imagery, some of the natural targets like bridges, buildings, air-strip patterns etc. can be used. In the present study, we have selected air-strip pattern for estimating the point spread function (PSF) and Modulation Transfer Function (MTF) of the Cartosat-1 cameras. These parameters are estimated from high fidelity edge realized following slant edge algorithm (Kohm, 2004). According to this algorithm, a good-contrast edge is identified in the image with aliasing due to the edge angle with respect to sampling grid. A line is constructed perpendicular to the edge. For each line across the edge, each point is projected onto the perpendicular edge line. Repeating this for all lines across the edge provides edge points at sub-pixel sampling. These points were then fitted with cubic spline interpolation. First-derivative of the edge function provides the point spread function in each direction. The Fourier transform of the PSF is computed to obtain the imaging system MTF. The MTF at the Nyquist frequency is computed and compared with mission specified value.

3. RESULTS AND DISCUSSIONS

Scene Dynamic Range Analysis: Histogram data with satellite ephemeris were collected from Data Processing Software to carry out the scene dynamic range analysis. Such image statistic parameters as mean, std. deviation, mode and median were computed to get overall scene dynamic range of the scene. The significant scene dynamic range was computed by setting a threshold of 1% on either side of the histogram. The average and std. deviations of the means of overall and significant dynamic ranges for selected land-cover features were computed. Results of this analysis are as shown in Table 2. It can be seen that the significant dynamic range over the land cover features of importance has been equivalent to 8 bit and could cover high reflecting features like snow within dynamic range where the significant range was extended to more than 8 bits.

Table 2. Scene dynamic ranges of many scenes covering different land-cover features

Target	Overall DN Range		Significant Range	
	Mean	S Dev	Mean	S Dev
Land	576.4	163.39	108.5	18.41
Coast	641.8	282.4	170.6	93.27
Desert	485.2	230.6	97.4	58.78
Snow*	891.0	-	645.0	-

* One scene was used in the analysis.

Image SNR: Image windows extracted for computing the image SNR are shown in Figure 2. Table 3 gives the estimated SNR at signal levels using the snow, tarmac and water body targets. Also shown are the expected SNR at saturation radiance of the cameras. It should be noted that the SNR mentioned in the introduction (>345) specified for the mission represents the variation of the signal along the columns, and is best estimated from the in-flight calibration by illuminating the CCD with internal lamp source under controlled environment. The image SNR represents the extent of radiometric normalization across the array, and is in general accepted to be better than 40% of the SNR of the along column. The image SNR at saturation was found by linear fit in least square sense of the three outputs obtained from the targets selected, and it was found that the image SNR was about 50 and 55% of the SNR along column. The SNR of the FORE is slightly lower than the AFT which can be attributed to longer atmospheric column that the light needs to travel for the FORE.

Figure 2 Sub-images covering features used for estimating the SNR from the image windows highlighted.

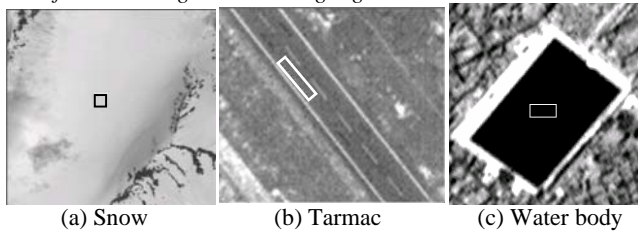


Table 3 Estimated SNR from the image features.

cover	Mean		Std Dev		L/Lmax		SNR	
	FO*	AFT	FO*	AFT	FO*	AFT	FO*	AFT
Water	89.3	91.3	2.15	2.36	0.09	0.09	42	39
Tar	121	131	2.28	2.56	0.12	0.13	54	51
Snow	848	844	5.74	5.2	0.83	0.83	148	162
At Saturation:					1.0	1.0	172	190

* FO denotes the FORE camera.

Data Compression: Here two exercises were carried out. One is about the impact of data compression on radiometric quality of the products. For this, compressed and compress-by-pass mode data sets were acquired for the same study area. Second was to evaluate the impact of Huffman compression tables on the radiometric quality in order to decide the choice of the table for different features.

Results of the first exercise were given in Table 4 for different land-cover features. As can be seen, the difference between the mean DN values was less than one count in almost all cases. The statistics were computed for barren land, river sand, vegetation and urban sprawls in both the regions. Figure 3 shows the difference histogram between the uncompressed and compressed images. As can be seen, the majority of the histogram falls within ± 2 counts.

To carry out second exercise, four bye-pass mode data sets of AFT camera over different scenes covering (urban, desert sand, agricultural fields and snow) were acquired separately, and data were passed through DCS compression software model,

functionally equivalent to hardware onboard with 8 compression tables provided. Results of application of these tables on Peak Signal to Noise Ratio (PSNR) for the four scenes were shown in Figure 4. Here Table 1 corresponds to desert, 2 to Hilly terrain, 3 to Snow-land, 4 to vegetation, 5 Snow, 6 to coastal, 7 to urban and 8 for mixture of above classes. Even though there are variations across the results, overall there is not much variation for most features. Keeping this mind, it was felt appropriate to use compression table meant for mixed classes.

Table 4 Image statistics of images generated with compression by-pass and compression-on.

Target	Bye Pass				Decompress			
	Min	Max	Mean	Sd	Min	Max	Mean	Sd
Barren	115	130	122.8	2.7	115	130	122.9	2.5
R.Sand	161	207	181.4	11	159	207	181.3	11
Veg	67	137	104.8	9.8	67	137	104.8	9.7
Urban	88	188	127.1	15	89	187	127.0	15

Figure 3 Difference image spatial profile.

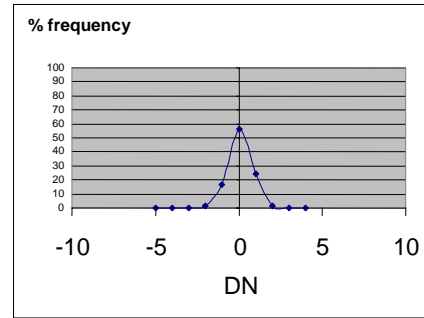
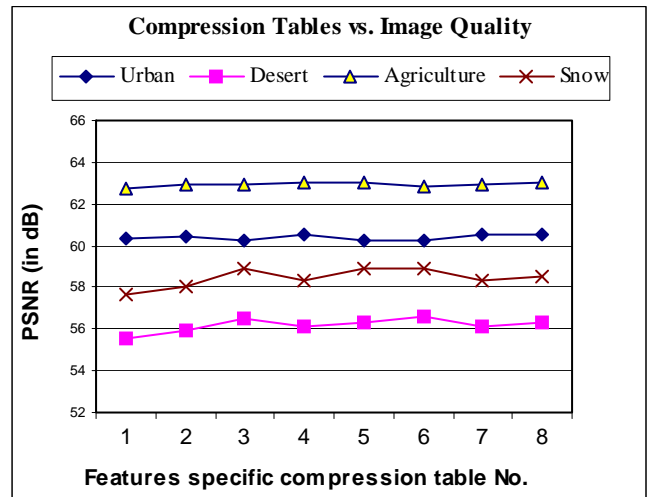


Figure 4 Impact of compression tables on image quality



Estimation of MTF: The Sobel edge detection operator was applied onto the sub-image containing the selected edge and the output was thresholded to minimize the false edge signals (shown in Figure 5). The transition points at each line across the edge

obtained from the edge image was then fitted with a straight line in least-square sense. Then pixel co-ordinate of each line was re-oriented with edge as the center, and the image points were projected onto the edge line. The edge-spread function thus obtained was shown in Figure 6. The smoothed function was then used to estimate the PSF and MTF of each camera. The magnitude of the Fourier transform at the Nyquist frequency was as given in Table 5. The MTF of the FORE was found to be slightly lower than the AFT camera. This can be attributed to long atmospheric column the light traverses from the ground to the sensor due to view angle of the FORE camera set to +26 deg.

Figure 5 Air-strip image showing the edge for MTF evaluation and the output from the Sobel edge operator.

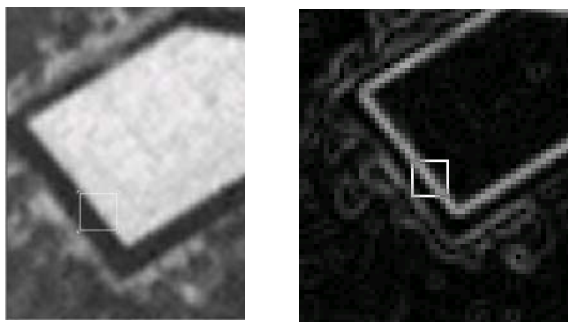


Figure 6 The spread function of the super-resolved edge derived from image of Figure 5.

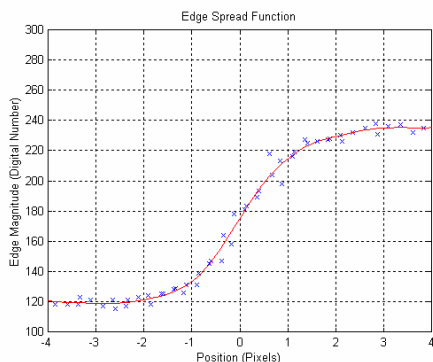


Table 5 Estimated PSF and MTF at Nyquist frequency for the two cameras of the CARTOSAT-1 spacecraft.

Camera	PSF	MTF (%)
FORE	1.87	13.25
AFT	1.71	15.61

5. CONCLUSIONS

Post-launch performance analysis was carried out on the two cameras of IRS-CARTOSAT-1 spacecraft. The radiometric performances were studied from the scene dynamics, signal-to-noise ratio at different signal levels and impact of onboard data compression and compression tables on the image quality. From the exercises carried out, there is no significant loss of radiometric

characteristics due to onboard compression, and there is no significant impact of choice of the compression tables on the image quality. For operations reasons, it has been recommended to use the mixture class table. The MTF of the AFT and FORE cameras is above 15%, though the FORE camera MTF is slightly lower than the AFT camera which can be attributed to longer optical path the light traverses due to view angle of the FORE camera when compared to the AFT.

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7. References

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