On-orbit spatial resolution estimation of IRS: CARTOSAT-1 Cameras with images of artificial and man-made targets – Preliminary Results

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ABSTRACT

This paper investigates the estimation of modulation transfer function (MTF) and point spread function (PSF) using on-orbit data of the first dedicated cartographic mission of ISRO, namely, IRS-Cartosat-1. The Cartosat-1 was launched in May 2005 with a motivation to realize in-track stereo-pair imagery at a ground sampling distance of 2.5 m with one of its two cameras, AFT, kept to view a ground scene at -5° and the other, FORE, at +26° with respect to nadir. As with any high-resolution satellite imagery, several factors viz., stray light, optics aberrations, defocusing, satellite motion, atmospheric transmittance etc. can have a strong impact on the observed spatial quality of the Cartosat-1 imagery. These factors are cumulatively accounted by PSF or by the MTF in the spatial frequency domain. The MTF is, thus, of fundamental importance since it provides assessment of spatial response of the overall imaging performance of the system. In this paper, estimation of the PSF and MTF was carried out by capturing imagery over airport runway strip as well as artificial targets laid at two different locations within India. The method adapted here uses a sharp edge from two adjacent uniform dark and bright fields or targets. A super-resolved edge of sub-pixel resolution was constructed from the image edge slanted to satellite path to meet the basic requirement that the target width is much smaller than the spatial resolution width. From the preliminary results, the MTF for the FORE is found to be approximately lesser by about 2% with respect to AFT; this difference may be attributed to relatively a longer traverse of ground signal through the atmospheric column in the case of FORE camera.

Keywords: Modulation transfer function, Edge profile function, Line spread function, Signal-to-noise ratio.

1. INTRODUCTION

On-orbit estimation of parameters like signal-to-noise ratio (SNR), modulation transfer function (MTF) etc which characterize the spatial and radiometric properties of remote sensing systems is quite desirable. During the prelaunch laboratory, measurements when commissioning the imaging sensor, these parameters are evaluated under controlled experimental conditions. Onboard quantification is not a trivial task; since we have little, if any, knowledge or control over the imaging conditions. However, the quantification helps to compare what is achievable as well as to take necessary ground processing step to improve the sharpness of the imagery, especially in the case when images from multiple sensors are to be combined for a given task.

This research work was initiated to characterize the MTF of the first dedicated cartographic mission of ISRO, namely, IRS Cartosat-1[1]. The Cartosat-1 was launched in May 2005 with a motivation to realize in-track stereo-pair imagery at a ground sampling distance of 2.5 m with its two cameras kept to view a ground scene at -5 and +26 degrees with respect to nadir. As with any high-resolution satellite imagery, several factors viz., stray light, optics aberrations, defocusing, satellite motion, atmospheric transmittance etc. can have a strong impact on the observed spatial quality of the Cartosat-1 imagery. These factors are cumulatively accounted by the MTF in the spatial frequency domain. The MTF is, therefore, of fundamental importance since it provides assessment of spatial response in terms of a parameter known as the effective instantaneous field of view.

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Many methods have been proposed for determining the onboard MTF of the remote sensing instruments[2]. These methods can be brought under three broad categories: (1) Estimating the observed size of the points or line objects whose the physical dimensions are known *a priori*. Typical objects used are by laying artificially point targets (masks) on the uniform background or by analyzing the images of bridges over water, roads etc. whose physical dimensions are available. (2) Estimating by the use of edges of natural or man-made ground features. (3). Estimating the MTF by comparing the satellite image with a very high resolution imagery of for e.g., from airborne remote sensing system, with known MTF.

In this paper, we have adapted the edge-based method for estimating the PSF and MTF of Cartosat-1 cameras. This method uses a sharp edge from two adjacent uniform dark and bright fields or targets. The edge spread function was first computed which would denote the system response to a high contrast edge. The first order derivative of this function would result in line-spread function which could be viewed as the system response to a high contrast line. The normalized magnitude of the Fourier transform of the line spread function would yield a one-dimensional slice of the two-dimensional MTF of the system in a specific direction, either along-scan or across-scan.

This paper reports the preliminary results of the MTF of Cartosat-1 cameras on-orbit, by laying dedicated edge-like patterns on ground and also by acquiring images over airport-runway. The MTF was estimated from these edges kept along north-to-south orientations. These edges if slanted to satellite path would provide to create a super-resolved edge of sub-pixel resolution to meet the basic requirement that the target width is much smaller than the spatial resolution width. The methodology followed here is described in Sec. 2. Analysis and discussions are given in Sec. 3 and our conclusions are in Sec. 4.

2. METHOD AND MATERIALS

The basis of the algorithm used in the present study is the slanted or super-resolved MTF measurement technique. The procedure is much similar to the method given by Kohm[3]. The steps followed to derive the MTF are described below.

2.1. Algorithm

The first step in the proposed method consists of detecting the edges for analysis. The edges must meet contrast and noise requirements for selection. An edge detector operator followed by thresholding has been employed to identify the edge targets. Once such edges are located, they were to be trimmed out in order to ensure that no other nearby objects could play a role in edge processing by means of modulating the target uniformity. An initial estimate of the location and angle of the selected edges is determined by performing a least square fitting of the identified points along the edge.

In the second step of the algorithm, the edge profile function (EPF) is computed from the line profiles across the edge. As the output of the system is a sampled image, the fidelity of the EPF using a single line of image data is insufficient for the MTF analysis. In order to generate a high fidelity edge, a line is constructed perpendicular to the edge obtained from the first step. Each point in the given scan line is projected onto the perpendicular edge. This process is then repeated for each subsequent line of the image data along the edge. The difference in sub-pixel location of the edge with respect to sampling grid for different lines in the image results in differences in the location of the projected EPF data point onto the perpendicular.

In the third step, line spread function (LSF) is computed from the EPF. This is done by taking the numerical derivative of the equally spaced EPF samples. For best results, the data must be trimmed and resampled to a fixed interval after the individual EPF data points have been determined as above. The EPF data points were trimmed to reduce the noise present in the uniform areas on either side of the edge. The length and resolution of the LSF determines the Nyquist frequency. With more data points from the uniform areas however, noise effects would be enhanced; however, finer MTF resolution would be achieved. The data set must then be chosen for balance between the noise and MTF resolution.

In the last step, the MTF is obtained by performing a Fast Fourier transform on the LSF, and normalizing its magnitude to the zero spatial frequency value. Care must be taken to select the number of points calculated along the LSF with respect to the sampling rate in order to obtain the desired number of points in the resulting MTF. Appropriate scaling of the frequency axis of the MTF must also be performed to represent the calculated MTF in terms of the Nyquist frequency of the imaging system.

2.2. Satellite Imagery

2.2.1 Imaging Cameras:

The IRS: Cartosat-1 High resolution satellite sensor provides a stereoscopic pair of 2.5 m pixel size panchromatic imagery from an orbital altitude of 618 km. The instantaneous field of view values are typically 2.45 m by 2.78 m for the FORE camera with + 26° in across- and along-track directions, and 2.19 m by 2.23 m for corresponding directions for the AFT camera with -5° with respect to nadir. The geo-referenced (also referred to standard) data products were supplied resampled to 2.5 m pixel size. These two cameras are inclined with respect to nadir so that near-simultaneous stereo data can be realized with its Base to Height ratio of 0.62 for swath coverage of 26 km. The Cartosat-1 follows sun-synchronous orbit cycles with an inclination angle of 97.87 deg. The optics is a 3-mirror anastigmatic design with f-number of 4.5 covering a panchromatic spectral range from 500 nm to 850 nm. The CCD used is a linear array of 12,000 number of detectors each with a physical size of 7 μm by 7 μm in the across and along track directions. Even and odd detectors are offset in the along track direction by approximately 5 pixels or 35 μm. The offset pixels are aligned subsequently in the ground data processing system. Imagery is acquired at 10 bits per pixel (bpp) and is compressed onboard using JPEG-like algorithm to meet the satellite downlink capability of 105 Megabits per second per camera (approximately 3 bpp).

Even though the satellite nominally covers the same area of the earth in a specified interval of 126 days, the satellite is equipped with roll tilt capability permits to revisit the same point on the earth within a period of 5 days. The data handling system onboard is equipped with a solid state recorder of 120 GB memory capacity which permits to store about 9 minutes to cover the sensor data acquired globally.

2.2.2. Artificial Targets:

Edge targets that are constructed with specific layouts for the MTF estimation are generally preferred for the analysis. One such target has been constructed at the Shadnagar Earth Station which is about 80 km from the Hyderabad city. The site is bound by the geo-coordinates 17° 01' 15" to 17° 02' 30" N and 78° 10' 50" to 78°11' 50" E. The target was realized with the help of a black cloth of 50 m by 50 m and a white cloth of 25 m by 25 m. Photographs of these targets are shown in Figure 1. By laying the while cloth over the black one at one of its edges, a black-to-white edge of about 10 pixels is realized in both the directions of the satellite path. The target is of sufficient size to measure the MTF of imaging system with 2.5 m or less pixel size. The Cartosat-1 image of the MTF target is shown in Figure 2. The computed EPF in the across track direction edge is shown in Figure 3.

Figure 1 Photographs showing two views of the layout of black and white cloth targets.

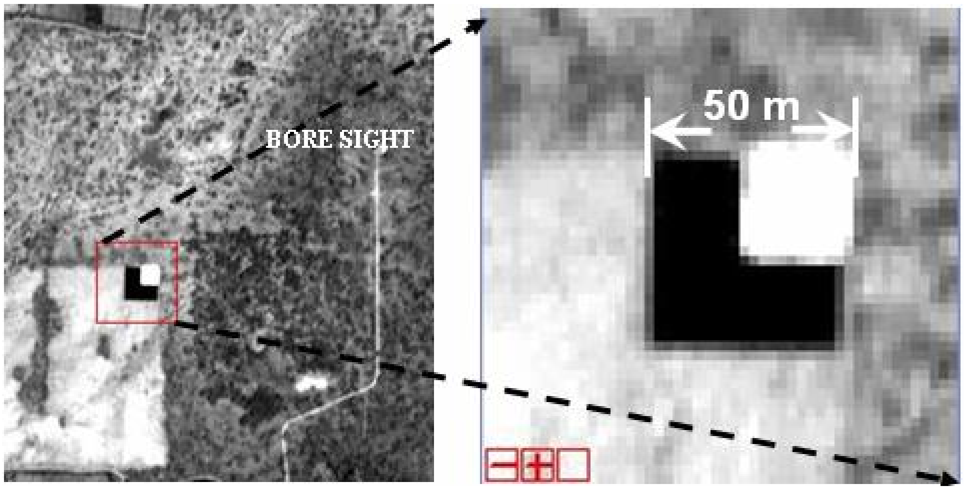


Figure 2 Edge targets laid at Shadnagar Earth Station, Hyderabad

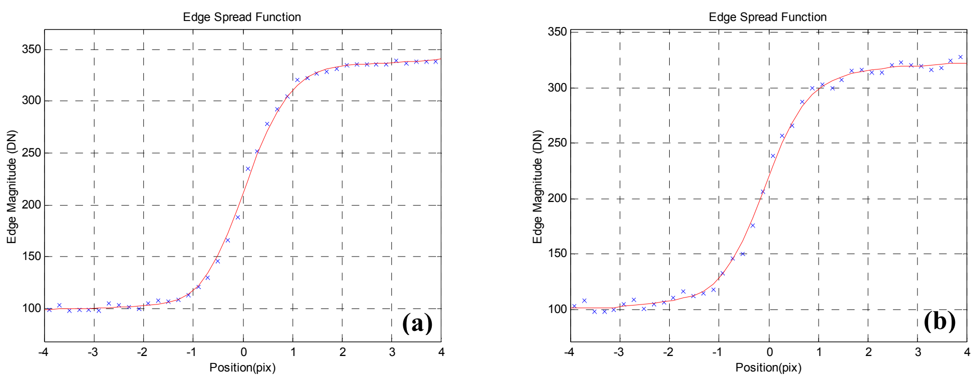


Figure 3 Edge spread functions of the (a) AFT and (b) FORE sensor data for the black-to-white edge target at Shadnagar.

Another calibration site with artificial targets for estimating sensor performance was laid at Chharodi (geographic location: 23° N, 72° 15'E) about 30 km. from the ISRO, Ahmedabad. This target has been used to evaluate spatial and radiometric characteristics of high resolution 5.8 m LISS-4 Multispectral sensor of IRS-Resourcesat-1 spacecraft[4]. The Cartosat-1 image of this target acquired on May 30, 2005 was shown in Figure 4. The white patch shown was due to white cloth of again size 50 m by 50 m in a black soil background of 300 m by 300 m. The edge spread function obtained at the black-to-white edge is shown in Figure 5.

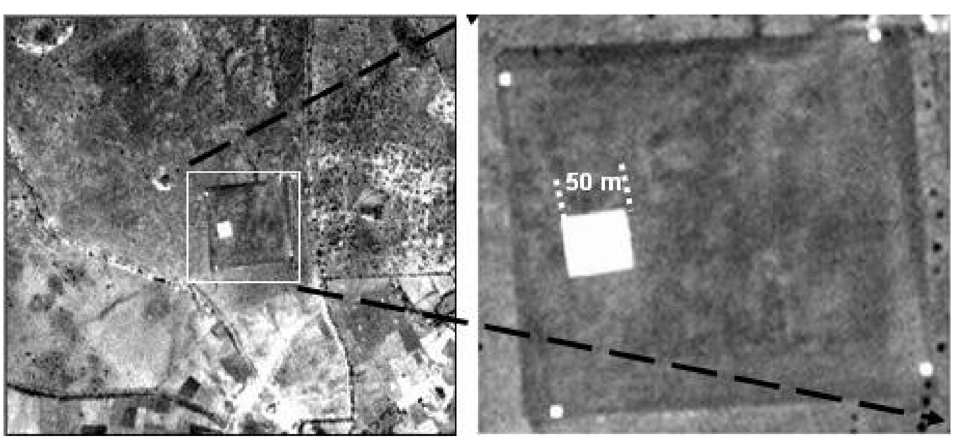


Figure 4 White cloth target lay on dark soil background at the Chharodi site, near Ahmedabad

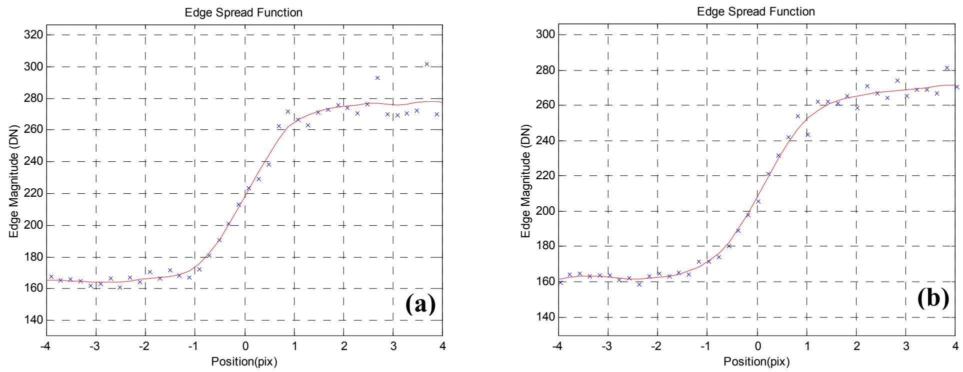
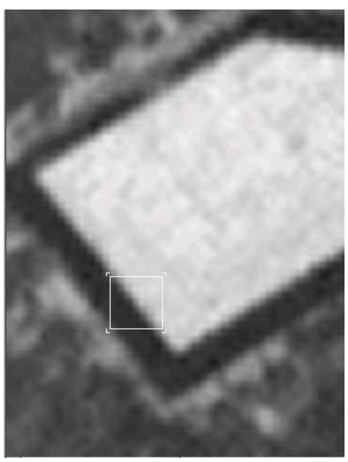


Figure 5 Edge spread functions of the (a) AFT and (b) FORE sensor data for the target at the Chharodi site.

2.2.3 Air-strip Runway Edges:

Opportunities for imaging specific or fixed targets like the above are quite limited, particularly as the near-nadir acquisitions are preferred to reduce the atmospheric effects. With careful search, suitable edges can be found in urban areas as well. This allows many more edge samples to be used in the analysis. Measurements from individual edges can be combined. In the present study, air-strip image of the airport runway was used for MTF measurement. The Cartosat-1 image of the air-strip for AFT camera is shown in Figure 6. The computed EPF in the across track direction is shown in Figure 7.



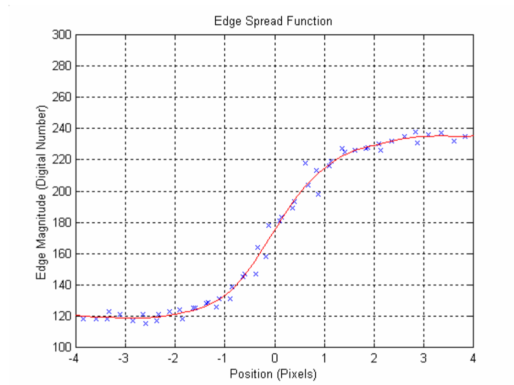


Figure 6 Runway strip of airport selected for MTF analysis.

Figure 7 Edge spread function from the airstrip edge.

3. RESULTS AND DISCUSSIONS

One dimensional MTF estimates were obtained for the two cameras of Cartosat-1. The MTF was computed on the radiometrically corrected (or Level-1) data products. At the level of data processing, the odd-even pixel shift is corrected upto the ancillary information estimated from spacecraft ephemeris data and 1-dimensional resampling the data with cubic convolution method. The MTF of imaging systems is in general specified by its value at the Nyquist frequency. For the Cartosat-1 AFT camera the overall Nyquist MTF (MTF_{Nq}) at the laboratory was better than 25%. The edge SNR is calculated as the ratio of the difference in mean digital number between the dark and bright portions of the edge and the mean of the standard deviation of the dark and bright portions of the image edge.

Estimated edge parameters to study the quality of the targets used for the MTF evaluation are given in Table 1. The step edge magnitude for the Shadnagar ES target was almost double the magnitude of either the airstrip runway or Chharodi site targets. Similarly, the variation across the black and white portions for the airstrip runway is also quite high, thus leading to the lowest edge SNR. For the Chharodi site, even though the variation in the black and white regions of the target is not very poor, but due to low magnitude of the edge, the edge SNR is low. The poor edge SNR brings the reliability of the PSF/MTF parameters with these targets. However, these targets were not excluded in this preliminary study. It should be mentioned that the Shadnagar ES site has scored over the other two targets due to considerable high step edge height and high edge SNR, and hence is well suited for reliable estimation of the PSF and MTF parameters.

Table 1: Estimated edge parameters for the two cameras of Cartosat-1 at selected targets.

SR. NO.	DATE OF PASS	TARGET	CAMERA	BRIGHT_SIDE		DARK_SIDE		STEP_EDGE		EDGE_ SNR
				Mean	Stdev.	Mean	Stdev	Mean	Stdev	
1	08-May-05	Airstrip Runway	AFT FORE	239.89 229.65	8.565 6.195	127.24 121.92	4.857 4.431	112.65 107.73	6.711 5.313	16.79 20.28
2	30-May-05	Chharodi site	AFT FORE	266.90 263.08	3.755 2.431	159.90 163.71	4.383 4.645	107.00 99.37	4.069 3.538	26.30 28.09
3	06-Dec-05	Shadnagar ES	AFT FORE	317.14 319.50	3.761 4.889	68.00 65.67	5.519 4.519	249.14 253.83	4.640 4.704	53.70 53.96
4	11-Apr-06	Shadnagar ES	AFT FORE	335.00 320.33	1.323 2.582	102.26 105.31	4.771 4.553	232.74 215.03	3.047 3.568	76.39 60.27

The estimated PSF and MTF values for the selected targets are given in Table 2. The first observation is that the FORE camera MTF, excepting the case of Chharodi site, was lower than the corresponding value for AFT camera. As mentioned above, the Chharodi site has a poor edge SNR, and the estimation can be erroneous. This relative difference may be attributed to relatively a longer traverse of the ground reflected signal through the atmospheric column in the case of FORE camera due to its viewing angle of 26 deg. Second observation is that the MTF values were reached maximum in the months of December when compared April – May period of the year. This can be attributed to clearer atmospheric conditions in India during the October – February period when compared to the summer months of April – June. Nevertheless, the results are to be considered as preliminary analysis, and further research efforts are needed to confirm the results obtained.

Table 2 Estimated PSF and MTF values for the Cartosat-1 cameras at different selected targets.

SR. NO.	DATE OF PASS	TARGET	PSF(PIXELS)		MTF_{NQ} (%)	
			AFT	FORE	AFT	FORE
1	08-May-05	Airstrip Runway	1.7	1.9	15.61	13.25
2	30-May-05	Chharodi site	2.5	2.2	14.15	17.17
3	06-Dec-05	Shadnagar ES	1.2	1.5	23.71	20.66
4	11-Apr-06	Shadnagar ES	1.6	1.8	17.99	17.13

4. CONCLUSIONS

The Modulation transfer function and the Point spread function of Cartosat-1 cameras were estimated based on slanted edge analysis from their imagery acquired over man-made and artificially laid targets. These parameters may help to assess the overall onboard image quality performance of the imaging sensors, and also provide inputs for image sharpening techniques to improve the poor contrast in case of a low modulation transfer function. From the preliminary results, the modulation transfer function for the FORE is found to be approximately lesser by about 2% with respect to AFT; this difference can be attributed to longer traverse of ground signal through the atmospheric column in the case of FORE camera. Improved imaging performance noted during the month of December compared to April may be attributed to higher atmospheric haze that is typical in summer months within the country. Nevertheless, the results obtained from this preliminary analysis are needed to be confirmed with subsequent many acquisitions over these and new targets.

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