RADIOMETRIC CALIBRATION OF HIGH RESOLUTION OPTICAL SENSOR USING ARTIFICIAL TARGETS

Shweta Sharma*, R.P. Prajapati and A.K. Mathur
Space Applications Centre, ISRO, Ahmedabad, Gujarat, India-380058
*corresponding author e-mail: shweta@sac.isro.gov.in

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ABSTRACT: In-flight radiometric calibration of satellite optical sensors require a large number of field measured data (sub-satellite ground based measurements of atmospheric parameters and surface reflectance data) synchronous to satellite pass. This requires more number of field campaigns, resulting in much greater human efforts which in turn makes it a tedious and time consuming process. Also, traditional approach for post-launch radiometric calibration requires the use of radiative transfer code, the accuracy of which in turn affects the accuracy of the calibration of the satellite sensors. This study estimates the calibration coefficients with only one date data by utilizing the artificial targets for high resolution optical sensors. Two independent approaches were used for the estimation. One being the vicarious calibration and using radiative transfer code 6S, which is popularly used world-wide and other being physics based simple analytical approach eliminating the need of radiative transfer code. Both the vicarious and analytical approach show almost the similar results with difference less than 5% in the estimated mean value of multiplicative factors. The insignificant difference between the results estimated from the two methodologies shows the potential of analytical approach with one date data and artificial targets for the estimation of the calibration coefficient without using radiative transfer model. This exercise will help in the radiometric calibration of upcoming high resolution optical sensors using one date ground measurements only.

1. INTRODUCTION

Various applications require accurate, well calibrated and characterized measurements. Numerical weather prediction and climate change detection studies critically depend on accurate, reliable and consistent satellite radiance data. In order to extract accurate and reliable quantitative information from digitally remotely sensed data, it is necessary and essential to properly calibrate the sensor and validate the associated data products. Calibration is the process of quantitatively defining the satellite instrument response to known controlled signal inputs. The inputs can range from a well-defined, lambertian source like a uniform integrating sphere in the laboratory and on-orbit satellite as well as field measurements over a large (relative to pixel size) homogeneous land/water area. A sensor calibration coefficient relates a digital number (DN) observed in an image pixel to its radiance, which is a physical quantity characterizing the radiative property of an Earth surface feature represented by the pixel. The methods and protocols involved in prelaunch, laboratory measurements of calibration coefficients have been comprehensively reviewed in a CEOS report (Datla et al, 2011). However, the satellite data available to the users is in the form of quantized DN values which can be converted to radiance using the general calibration relation:

$$L = a*DN + b \tag{1}$$

where, L is radiance in units of W/m2/sr/μm, DN is the quantization value expressed as an integer in a satellite image, and ‘a’ and ‘b’ are coefficients. The coefficients ‘a’ and ‘b’ (also called gain and offset, respectively) are different for each wavelength for different satellite sensors and are usually supplied in the satellite header file.

In order to estimate the calibration coefficients (‘a’ and ‘b’ in equation 1) for in-flight radiometric calibration of satellite optical sensors, a large number of field measured data (sub-satellite ground based measurements of atmospheric parameters and surface reflectance data) synchronous to satellite pass are required. This requires more number of field campaigns, resulting in much greater human efforts which in turn makes it a tedious and time consuming process. Therefore, there is a need to evolve a methodology which will help in reducing the time and effort and produce similar results. Katsev et al. in 2013, have proposed a new method to calibrate the satellite sensors of high spatial resolution which requires the registration of signals from two (or more) closely located test pixels. With this proposed calibration procedure, the knowledge of the vertical structure of the atmosphere and use of radiative transfer model are not required.

In the present study, the method proposed by Katsev et al. has been slightly modified and a simple mathematical equation has been formulated based on the literature. This modified analytical approach was then applied to three different ground based targets including artificial targets (soil, black cloth and white cloth) and calibration coefficients were estimated. Use of different artificial targets eliminated the need for large number of field campaigns for the estimation of calibration constants. Using only one date data, multiplicative and additive factors were estimated for high resolution optical sensor without using full scale multi-layered radiative transfer model. For comparison purpose, calibration coefficients were also estimated using vicarious calibration approach with 6S radiative transfer model.

2. OBJECTIVES

The detailed objectives of the study are to estimate the calibration coefficients of high resolution optical sensor with one date field measurements utilizing the artificial targets (black and white cloth).

3. STUDY AREA AND DATA USED

3.1 Study area

SAC-Bopal Cal Val site in Ahmedabad was used as a study site for the study. This site has been developed for vicarious calibration of high resolution optical as well as SAR sensors. It has been artificially created by Space Applications Centre (SAC, Ahmedabad) adjacent to Bopal campus. The site consists of a very uniform levelled bare land (yellow in colour) of 115m x 115m with very clear brick boundary constructed on all four sides and 4m x 4m concrete white squares on the four corners of the site. Figure 1 shows the location of the study area in false colour composite (FCC) image of Resourcesat-2 LISS-4 sensor having green, red and NIR bands.

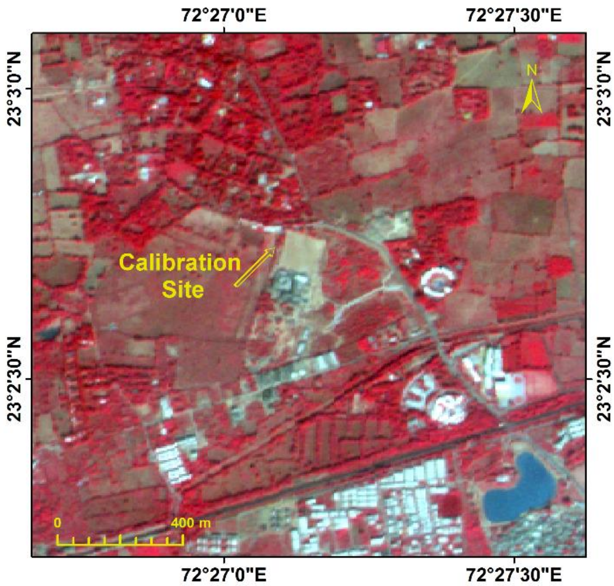

Figure 1: Calibration site near SAC, Bopal Campus shown in FCC image of Resourcesat-2 LISS-4 sensor

3.2 Data and material used

High resolution Cartosat-2 data (1m spatial resolution) of 3rd May 2016 was used for the study. For artificial targets, we used black cloth of 5 m × 5 m and white cloth of 6 m × 6 m (Figure 2).

Figure 2: Artificial targets deployed at SAC-Bopal calibration site

3.3 Sampling strategy

A sampling grid plan of 3m * 3m pixels was adopted for all the three targets (black cloth, soil and white cloth) at Bopal site for characterizing surface reflectance and associated atmospheric measurements. This choice is dictated partly by practical constraints, viz., the measurements have to be completed preferably within ±30 minutes of satellite pass and to avoid boundary pixels. Measurements were confined to 3×3 pixels which corresponds to approximately 3 m × 3 m area on the ground (Figure 3) for satellites under consideration here i.e. for Cartosat-2, in order to avoid path adjacency effect for all the three targets (high reflectivity, low reflectivity and soil target).

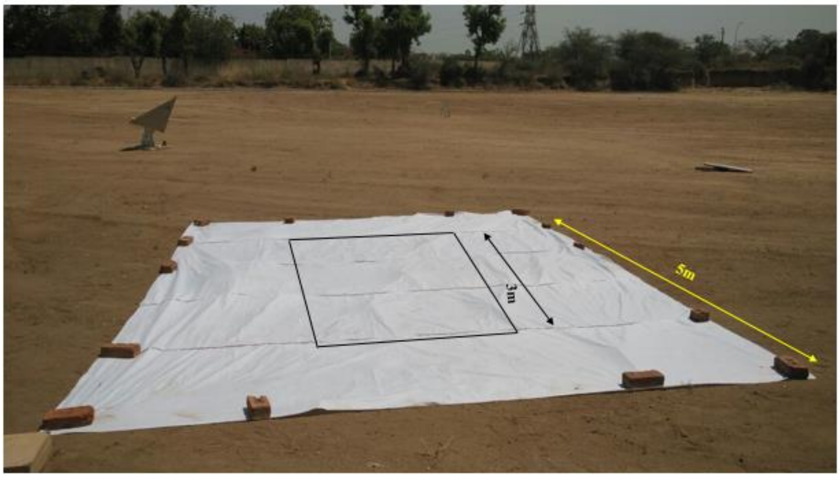

Figure 3: Sampling plan for the measurements
(measurements were confined to inner 3m × 3m)

4. METHODOLOGY

The estimation of calibration constants was done using two approaches: (i) by using vicarious calibration approach and radiative transfer model 6S and (ii) by using simple analytical approach. Both the approaches are described as follows:

4.1 Estimation of calibration constant using Vicarious calibration approach

Vicarious calibration is, in principle, a comparison of estimated TOA radiance with satellite measured radiance over the same ground area at the same time. The details of the steps adopted are as follows:
Step 1: Field-measured spectral reflectance (350–2500 nm) from the site was first exported to Excel format using ViewSpecpro software for all the three targets.
Step 2: Reflectance data (averaged over 3×3 pixels for each target at 1 nm interval) relevant to Cartosat-2 panchromatic band was extracted over the bandwidth corresponding to 5% cut-off of sensor's RSR. In this study, the surface reflected flux recorded by the sensor over 5% cut-off bandwidth is used to compute TOA radiance.
Step 3: Both the SRF (spectral response function) and reflectance data were re-sampled to 2.5 nm intervals using a spline interpolation method using MATLAB code. This was done since the 6S code requires that both SRF and surface reflectance data are input at 2.5 nm intervals.
Step 4: The 6S code was used to compute TOA radiance. The inputs are sun-sensor geometry (sun and view zenith and azimuth angles), atmosphere model, aerosol model, AOD, levels of ozone and water vapour, and ground reflectance.
Step 5: Using the TOA radiance estimated for all the three targets and corresponding average DN value observed from Cartosat-2 image data, calibration coefficients (gain and offset) was estimated for panchromatic band.

Surface reflectance of the three targets (black cloth, white cloth and soil) was measured using ASD spectro-radiometer synchronous to Cartosat-2 pass and atmospheric measurements were done using Microtops-II sunphotometer and ozonometer. In the 6S code, when ground measured values of water vapour and ozone are given as input, the code assumes the US 62 standard atmosphere profile for computations (Vermote et al. 2006). The US 62 atmosphere profile gives pressure, temperature, water vapour, and ozone concentrations as a function of height (up to 100 km), at discrete intervals of 34 layers. The continental aerosol model consists of a mixture of dust-like, water-soluble, and soot components in fixed proportions. For a given aerosol model, the code computes the extinction coefficient, single scattering albedo, asymmetry parameter, and phase function using Mie theory. In

forward mode, the 6S code computes TOA reflectance and radiance for given surface reflectance, while in the inverse mode the code computes atmosphere-corrected surface reflectance for the same atmospheric parameters as in the forward model, for a given TOA at-satellite radiance input. The 6S code is a point based code (and not an image based code), i.e. the inputs are given for a single pixel.
Since the 6S code estimates atmospherically corrected surface reflectance in the inverse mode, the same dataset can also be used for its validation. This is done by studying the correlation between measured and estimated surface reflectance.

4.1.1 Uncertainty analysis

For uncertainty analysis, the approach used by V.N. Sridhar et al. (2013) was used in this study. The effect of surface reflectance anisotropy is not included in this study as the only product available was MODIS BRDF product at 500 m spatial resolution. The available MODIS product was generated based on the assumption that the surface is homogeneous in a pixel of 500 m, which is not the case here as we are dealing with the artificial target of few meters' size. The uncertainty due to Bidirectional Reflectance Factor is planned to be included in the future work by using the ground measured values of the targets using Goniometer.

4.2 Estimation of calibration constant using simple analytical approach

The reflectances of the two artificial targets: one bright (white cloth) and another dark (black cloth) can be measured using ASD FieldSpec®3 Spectro-radiometer, which is a compact, field portable precision instrument with a spectral range of 350-2500 nm having rapid data collection time of 0.1 second per spectrum. The SWIR component of the ASD spectrometer is a scanning spectrometer, while the VNIR component is an array spectrometer. If the bright and dark targets' reflectance's are ρ_1 and $\rho_{2,}$ respectively. Using equation 1 we have,

$$L_1(TOA)=a\times DN_1+b \quad (2)$$

$$L_2(TOA)=a\times DN_2+b \quad (3)$$

where $L_1(TOA)$ and $L_2(TOA)$ are the radiance at the top of the atmosphere and DN_1 and DN_2 are the DN values in the image corresponding to bright and dark target respectively.
From equations (2) and (3), is easy to get,

$$a = \frac{L_1\,(TOA) - L_2\,(TOA)}{DN_1 - DN_2} \quad (4.1)$$

$$b= L_1(TOA)- ((L_1(TOA)-L_2(TOA)) / (DN_1-DN_2)) \times DN_1 \quad (4.2)$$

It is obvious from equation 4.1 that DN_1 should be much greater than DN_2, that is, their difference should be large. Otherwise, 'a' will blow up. Since it is difficult to get white sand and water (for example) near to each other in real life, we need artificial targets for the same.
In order to simulate the TOA radiance, following equation is used:

$$L(TOA) = \frac{E_{sun} \times \cos(\theta) \times \rho^*}{\pi \times d^2} \quad (5)$$

where, d is the sun-earth distance in the Astronomical Units (AU), Esun is the bandpass exo-atmospheric solar irradiance for a particular spectral channel of a sensor and 'θ' is solar zenith angle, ρ^* is apparent reflectance at the sensor level which can be calculated as:

$$\rho^* = \rho_a + \frac{\rho_t \times T_{\theta_v} \times T_{\theta_s}}{1-\rho_t \times s} \quad (6)$$

where, ρ_a is the path radiance in terms of reflectance, 's' is spherical albedo of the atmosphere, $T_{(\theta v)}$ & $T_{(\theta s)}$ is the transmissivity of the atmosphere in the downward and upward direction respectively and ρ_t is the surface reflectance of the target.
Calibration constant is estimated using top-of-the-atmosphere radiance L(TOA) for each target (which in turn is estimated using equations 2 and 3) and corresponding DN values of the target from the satellite image.

The main assumption that has been taken in the proposed methodology for the estimation of calibration constant with one date data and artificial targets is that for the high resolution optical sensor, in this case, Cartosat-2, the pixels are so close that the vertical structure of the atmosphere can be assumed to remain same for both the targets and hence the contribution of radiation due to scattering in the atmosphere without interaction with the surface is same for signal registered at sensor in the given band for both the pixels (bright and dark). The path radiance term ρ_a is assumed to be constant for both the targets because of the above said assumption and hence it is cancelled out while estimating the calibration constant.

5. Results and discussions

The mean coefficient of variation corresponding to different targets for Cartosat-2 panchromatic band (500-850 nm) used in the study was found to be less than 3% (Figure 4). The maximum variability was found for black target and minimum corresponding to soil target. The reflectance of the targets was measured using ASD spectro-radiometer and its spectral variation over Cartosat-2 band is shown in Figure 5.

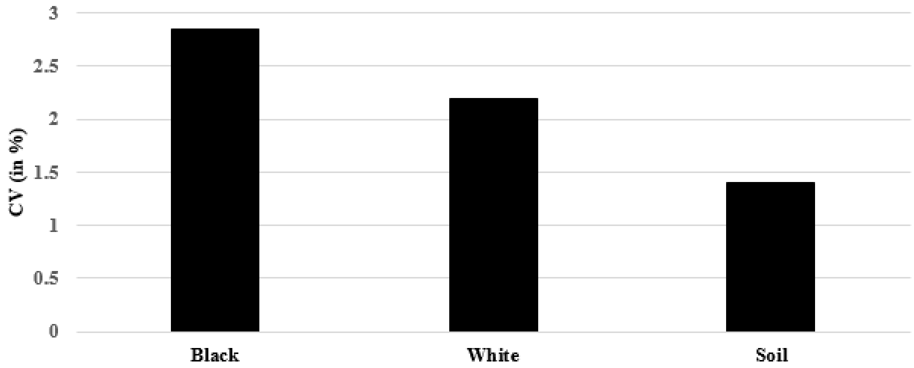

Figure 4: Mean Coefficient of variation (CV) corresponding to different targets

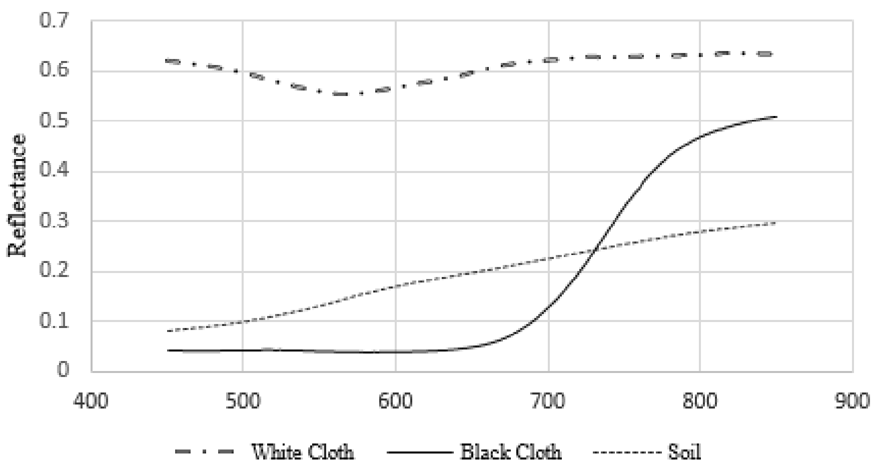

Figure 5: Variation of ASD spectro-radiometer measured reflectance of different targets for 450-850 nm range

It can be seen from Figure 5 that the reflectance of white cloth is more or less constant with wavelength and its mean value being 0.6 (approximately), whereas, the variation of black cloth's reflectance is not constant over the entire bandwidth. Until around 675 nm, it remains constant with its value being (0.04) and after that it shoots up to 0.5. The variation in the reflectance of black cloth with wavelength indicates that this material is spectrally different than the white cloth material.

Artificial targets response on the Cartosat-2 image is shown in Figure 6. White cloth is captured well by the sensor as compared to the black cloth as can be seen from the image. This is due to the difference in the size of both the clothes. White cloth was bigger in size and thicker than the black cloth and the effect of which is evident in the response.

Figure 6: Response of artificial targets on Cartosat-2 image

5.1 Results using vicarious calibration approach

Top-of-the-atmosphere radiances (L_{TOA}) were estimated using the approach mentioned in the methodology section. The uncertainty in the mean value of TOA radiance value was calculated by perturbing each of the four independent variables (surface reflectance, Aerosol optical depth, ozone and water vapour) by ±1σ from their mean values. The total error is shown in Table 1. Calibration coefficient calculated using mean value of TOA radiance estimated using vicarious calibration approach is shown in Figure 7. Multiplicative factor was found to be 0.475±0.013 with additive factor being -46±2.4.

Table-1: Uncertainty in mean value of TOA radiance estimated using vicarious approach

Target	Total Uncertainty -	Total uncertainty +
Black cloth	0.833	0.832
White cloth	4.656	4.649
Soil	0.777	0.778

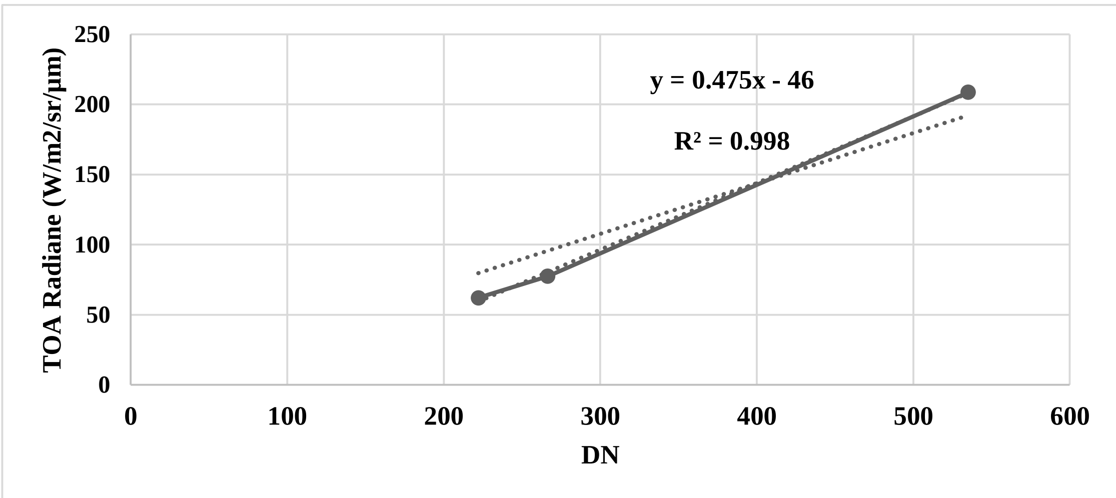

Figure 7: Estimated calibration coefficients using vicarious calibration approach

In order to do the validation, estimated TOA radiance using vicarious approach was given as an input to 6S code and simulated surface reflectance was compared with the ground measured surface reflectance value. Results thus obtained are shown in table 2 and show that the surface reflectance estimated was found to be closer to the ground measured surface reflectance value (except for the black target) when TOA radiance estimated using vicarious calibration approach was used than the surface reflectance obtained using the Cartosat-2 sensor measured TOA radiance.

Table 2: Comparison of estimated surface reflectance with ground measured value

Target	Estimated surface reflectance		Ground measured surface reflectance (c)	Difference (in %)	
	Using Cartosat-2 sensor observed TOA radiance (a)	Using TOA radiance estimated using vicarious approach (b)		{(c-a)/c} × 100	{(c-b)/c} × 100
Black	0.1318	0.1504	0.1852	28.83	**18.79**
White	0.3828	0.6022	0.6009	36.29	**0.22**
Soil	0.1683	0.2007	0.2044	17.66	**1.81**

5.2 Results using simple analytical approach

Top-of-the-atmosphere radiances (L_{TOA}) were estimated using equations 5 and 6 and the mean value of the digital number corresponding to the target pixels were noted down from the satellite image. The estimated TOA radiances for all the three targets are tabulated in Table 3. The estimated TOA radiance for soil (Table 3) is found to lie in between the range specified by the black and white targets, which is as per the expectation. The gain and offset i.e. multiplicative and additive factors were estimated using the correlation between DN values and TOA radiance. Figure 8 shows the obtained relation between DN and TOA radiance.

Table 3: Estimated/Observed values of the parameters

Parameters	Estimated/Observed Value
L_{TOA} Black cloth	78.214 (W/m^2/sr/µm)
L_{TOA} Soil	86.48 (W/m^2/sr/µm)
L_{TOA} White cloth	267.12 (W/m^2/sr/µm)
DN Black cloth	218
DN Soil	257
DN White Cloth	608

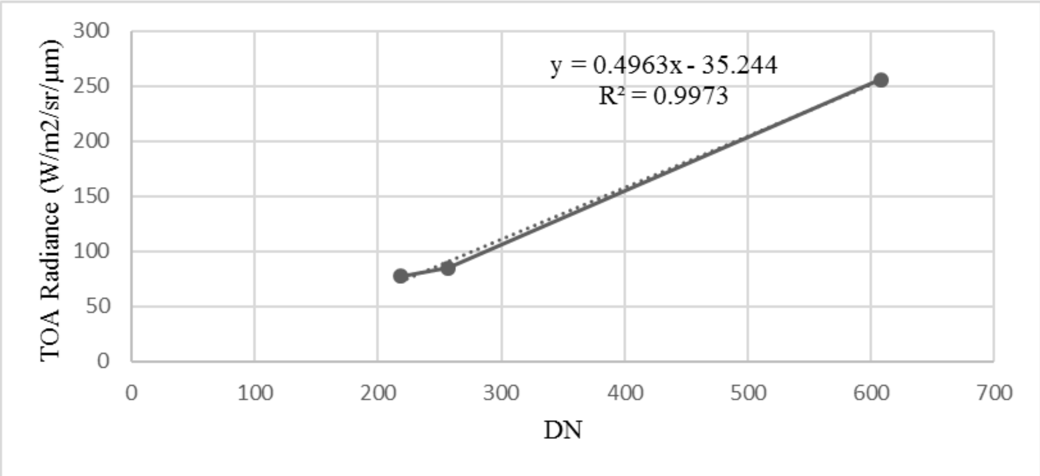

Figure 8: Estimated calibration coefficients using simple analytical approach

The comparison of the calibration constants estimated using vicarious approach and using simple analytic approach is shown in Table 4. It can be seen from the table that multiplicative and additive factor estimated using simple analytical approach is closer to the constants estimated using vicarious approach.

Table-4: Estimated calibration constants

Approach used	Estimated Multiplicative factor	Estimated Additive factor
Vicarious calibration approach	0.475±0.013	-46±2.4
Simple analytical approach	0.496±0.013	-35.24±1.62

6. Conclusions

In this study, the calibration constants for Cartosat-2 sensor were estimated using the image of 3rd May 2016 and artificial targets (black cloth and white cloth). Two independent approaches were used for the estimation. One being the vicarious calibration, which is popularly used world-wide and other being physics based simple analytical approach which eliminates the use of radiative transfer model. The multiplicative factor and additive factors were estimated using one date data only. Both the vicarious and analytical approach show almost the similar results with the difference of 4.4% in the estimated mean value of multiplicative factors by vicarious and analytical approach. Although, more number of data is required for the refinement of the analytical model. The analytical approach will help in estimating the calibration factors for high resolution optical sensors using one date ground measurements only synchronous to satellite pass.

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REFERENCES

1. Datla R.U., J. P. Rice, K.Lykke and B. C. Johnson. 2011. Best Practice Guidelines for Pre-Launch Characterization and Calibration of Instruments for Passive Optical Remote Sensing, NISTIR 7637 (Gregory, 2011, l. ARM handbook, DOE/SC-ARM/TR-056).
2. Katsev I.L., A.S. Prikhach and E.P. Zege. 2013. New method for radiation calibration of satellite sensors with high spatial resolution. AIP Conference Proceedings 1531, 328 (2013); doi:10.1063/1.4804773.
3. Vermote, E., D. Tanre, J. L. Deuze, M. Herman, J. J. Morcrette, and S. Y. Kotchenova. 2006. Second Simulation of Satellite Signal in the Satellite Spectrum (6S). 6S User Guide Version 3, University of Maryland.
4. V.N. Sridhar , Kaushal B. Mehta , R.P. Prajapati , K.N. Babu , N.M. Suthar & A.K.Shukla. 2013. Absolute vicarious calibration of OCM2 and AWiFS sensors using a reflectance-based method over land sites in the Rann of Kutch, Gujarat, International Journal of Remote Sensing, 34 (16), pp. 5690-5708.