VICARIOUS CALIBRATION OF THAICHOTE OVER THAILAND

Teerayoot SAWANGSRI, Chaichat MUSANA and Panatda KIETLEADSEREE
Calibration and Validation Division, Thaichote Ground Control Station,
Geo-Informatics and Space Technology Development Agency (Public organization),
88 Moo 9, Si Racha, Chon Buri 20110, Thailand;
Tel: +66(0) -2141-4470; Fax. +66(0) -2143-9586
Email: (thirayuth,chaichat, panatda)@eoc.gistda.or.th

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ABSTRACT This paper describes the radiometric calibration based on vicarious test site for Thaichote Satellite which was executed for the first time in Thailand on March 23rd, 2013 in order to verify the absolute gain coefficient of Thaichote multispectral sensor for converting digital numbers to at-sensor spectral radiance**.** First**,** the selection of test site in Thailand is based on two conditions which are the homogeneity and the site accessibility, the harvested sugarcane farm at Phukeaw in Chaiyaphum province, Northeast Thailand was a choice. The ground-based measurement data, that are ground reflectance of selected test site and atmospheric condition, was collected by a portable Spectroradiometer and a sunphotometer, along with Thaichote's image acquired simultaneously. The measurement data were used for estimating the actual at-sensor radiance and the absolute gain coefficients of each spectral band. Finally, the result from this calibration was compared with the gain ratio values (instrument and predicted) of the other ways of calibrations that were carried out in the past.

INTRODUCTION

Thaichote is the first earth observation satellite with both a high-spatial-resolution sensor of 2 meters for panchromatic and multispectral-resolution sensors of 15 meters with four spectral bands. It has been operated and owned by the Geo-Informatics and Space Technology Development Agency (GISTDA), Thailand since 1st October, 2008. The Calibration and Validation Division has performed the process of quantitative defining the system responses to known, controlled signal inputs, and the process of assessing the quality of the satellite image data derived from the Thaichote since it was launched. In order to execute more quantitative application, we need to accurately assess the sensor performance and regularly conduct absolute radiometric gain calibration. To do that, there are two major methods: pseudo-invariant calibration and vicarious calibration. The pseudo-invariant calibrations were conducted for Thaichote by collaboration with South Dakota State University (SDSU) over Libya4 from 2008 to 2012. Besides, the vicarious calibrations were conducted for Thaichote during the summer of 2012 over the test site located in Brookings, SD, United States. In order to frequently access to the test site of vicarious calibration that regularly is required field campaigns; therefore, we propose to conduct this calibration in Thailand.

This paper describes the result of the absolute radiometric gain calibration of the Thaithote multispectral sensor, based on the ground campaign collected at the harvested sugarcane farm in the Northeast Thailand on March 23rd, 2013. Firstly**,** the radiometric model and on-orbit gain coefficient calibration are explained in details. Secondly, the absolute radiometric gain calibration over the selected test site had been conducted during field campaign. Thirdly, the method and predicted gain coefficient are explained in this section. Fourthly, the gain ratios are obtained from this calibration. Lastly, in order to validate the results of vicarious calibration, we compared them with both the result of the cross calibration analysis which was presented at the ACRS 2012 conference and the vicarious calibrations which were conducted by SDSU.

The purpose of this work is to study the effectiveness of vicarious calibration over Thailand of Thaichote images. The paper also provides the effort we have recently made to develop such processes to uncover hidden opportunity and barrier of development.

THAICHOTE

Radiometric Model of Thaichote

The radiometric model of Thaichote, that is used to convert the analog signal to digital number, is the following simple equation.

$$\text{DN} = \text{At-sensor Radiance}_{\lambda} * \text{Gain} + \text{DN}_0 \quad (1)$$

DN is the output digital number in an 8 bit data; At-sensor Radiance$_\lambda$ is radiance that reach a sensor in the $\boldsymbol{\lambda}$ spectral band in the unit of $W.m^{-2}.sr^{-1}.\mu m$; Gain is the conversion factor of each Thaichote spectral bands from the input radiance to the output digital number; and DN_0 is the dark signal that is the permanent radiometric offset that can be measured when there is no radiative input, or the offset of the digital number without signal input which is measured using images over Pacific or Atlantic Ocean during the moonless night; and it can be removed by production system of Thaichote.

On-orbit Gain Coefficient Calibration

Thaichote sensor was calibrated before launching by satellite manufacturer, Atrium, yet it becomes important for satellite owner to regularly calibrate and validate image data during on-orbit life-span in order to monitor the trend of the stability of the sensor and compare the results with the pre-orbit calibration data based on the procedure of Atrium. Moreover, the cross calibrations with other satellite were conducted for absolute radiometric gain calibration by collaboration with South Dakota State University at desert site: Libya 4. This site and the Landsat 5 TM satellite were selected for the inter-comparison with Thaichote. Mainly, it was concluded that there has been no significant drift in all 4 bands for the passed 4 years in orbit. The gain ratio (instrument and predicted) calculated value were 1.043, 1.025, 1.004 and 0.952 for the blue, green, red and near-infrared bands, respectively. Furthermore, the vicarious calibrations were conducted for Thaichote by collaboration with South Dakota State University (SDSU) during the summer of 2012 over the SDSU test site located in Brookings, SD. The gain ratio values (instrument and predicted), by ignoring the outlier data, were 1.085, 1.045, 1.033 and 0.999 for the blue, green, red and near-infrared bands, respectively. These data are used as the criteria to validate the result of this vicarious calibration in Thailand.

VICARIOUS CALIBRATION

Method

Vicarious calibration is a part of the radiometric calibration method. In this paper, it relies on in situation data, and the reflectance-based technique, which relies on ground surface reflectance measurement, is used.

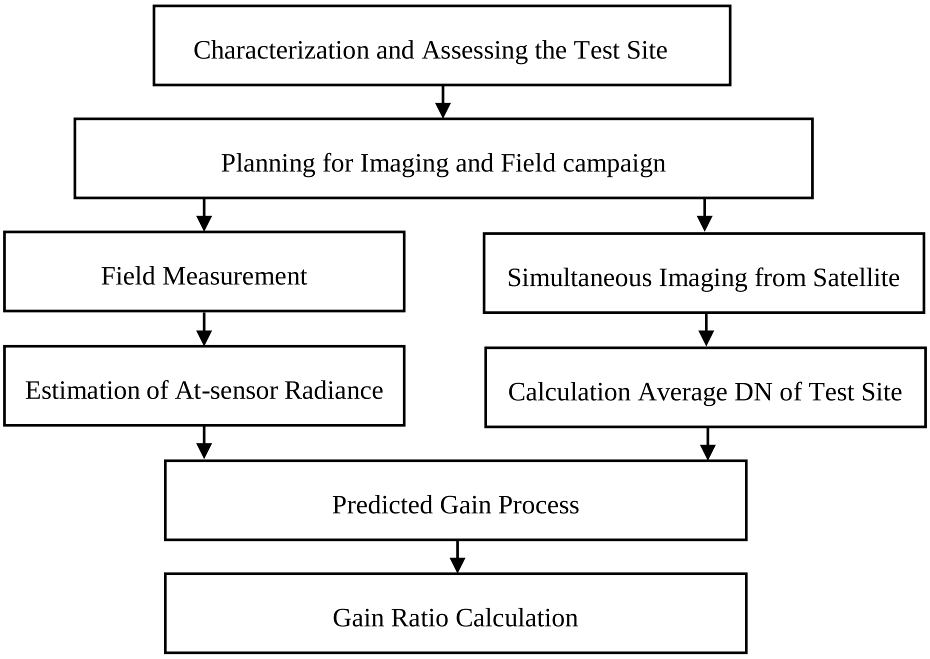


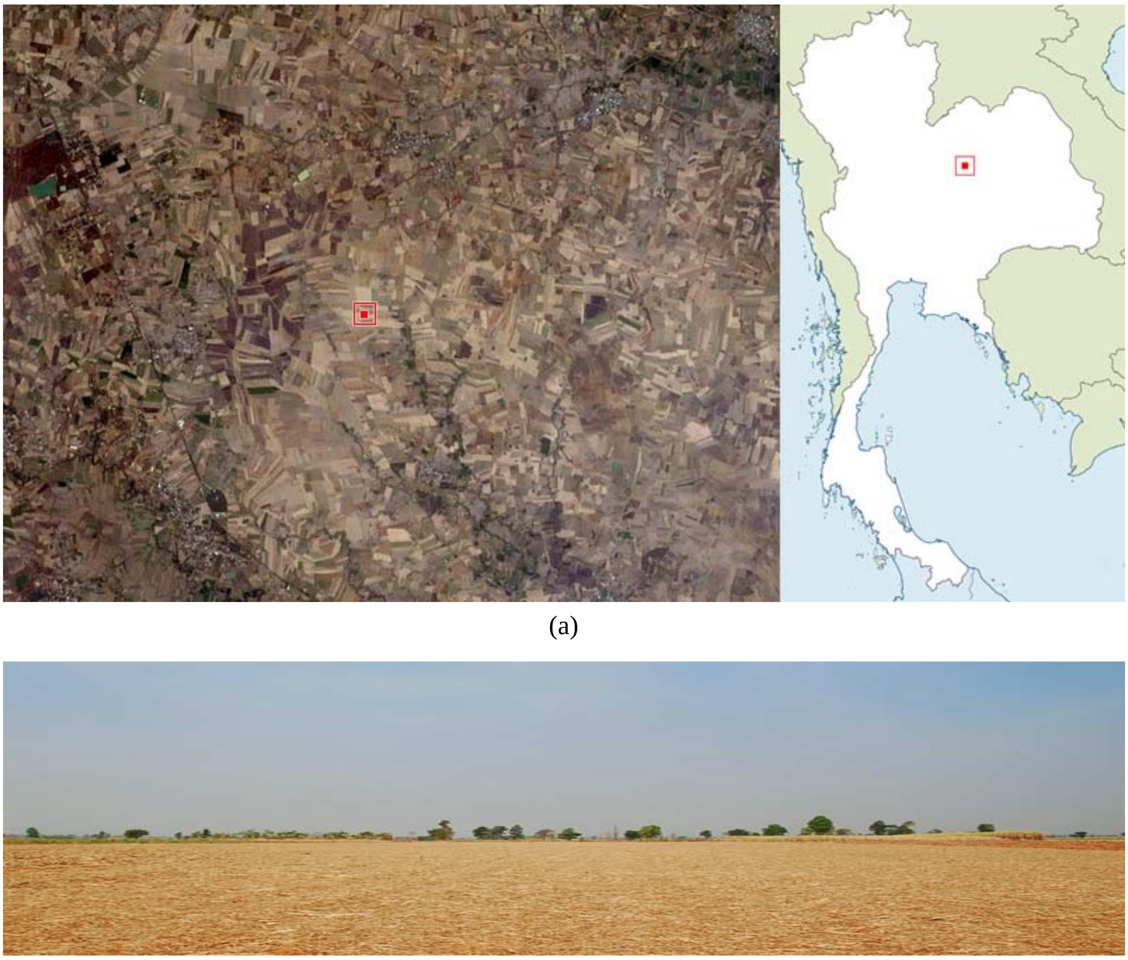
Figure 1. The flow chart of proposed vicarious calibration over Thailand

According to the Figure 1, first**,** the selection of test site in Thailand is based on two conditions which are the homogeneity and the site accessibility, the harvested sugarcane farm at Phukeaw in Chaiyaphum province, northeast of Thailand was a choice. Next**,** the ground-based measurement data had been collected by a portable

Spectroradiometer and a sunphotometer, along with Thaichote's image acquired simultaneously from the site. The ground surface reflectance and the measured atmospheric parameter are input into a radiative transfer code which results in the at-sensor radiance. After that, the average digital numbers from an area of interest on image acquired at the time of the satellite overpass is calculated. With both this average and instrument gain, the predicted gain is calculated as equation (2). Finally, the gain ratio (instrument gain and predicted gain) on each spectral band, are compared with the gain ratio values of the calibration that were carried out in the past to validate this calibration. The flow chart of this method is shown in Figure 1.

Field Campaign

The vicarious calibrations were conducted at the selected test site, where is a harvested sugarcane farm at Phukeaw, Chaiyaphum Province, in the Northeast of Thailand (latitude 16.456° N, longitude 101.991 °E, and Elevation 241 meters) (Figure 2). The size of test site is 80 x 200 meters (about 4 x 13 pixels on image). Due to limited site accessibility, time constraints and resources, the field campaign was decided to be conducted on 23rd and 24th March 2013.



(a)

(b)

Figure 2. The test site for vicarious calibration for Thaichote a) satellite's view b) user's view

Predicted Gain Coefficient

Thaichote images were used to determine the digital number (DN) within the Test site area. With the averaged DN and predicted at-sensor radiance, the predicted gain of the vicarious calibration was calculated as

$$\text{Gain}_{\text{Predicted}} = \text{DN} \,/\, \text{At-sensor Radiance}_{\text{Predicted}} \quad (2)$$

At-sensor $\text{Radiance}_{\text{Predicted}}$ is simulated from the field data and ingested into radiative transfer code; $\text{Gain}_{\text{Predicted}}$ is calculated based on the models radiance predictions.

RESULTS AND DISCUSSION

Field Measurements and Data Processing

In order to estimate the at-sensor radiance for all bands of Thaichote, we used radiative transfer code in simulation. There are two input parameters, namely, imaging condition and atmospheric parameters. The imaging conditions were in metadata of image, including the viewing-zenith, viewing-azimuth, sun-zenith, sun-azimuth angle as in Table 1. The atmospheric parameters, the aerosol optical thickness, ozone, and temperature were retrieved from the sunphotometer during the satellite overpass time as shown in Table 2. For ground measurement, we used the Spectroradiometer to measure the spectral surface reflectance of the test site as it is shown in Figure 3. The simulated results, that are the transmittance at-sensor radiance, are shown in Figure 4.

Table 1. Imaging conditions of the metadata of Image

Parameter / Date	Solar Zenith	Solar Azimuth	Satellite Zenith	Satellite Azimuth
23rd March 2013	32.23	57.77	9.82	279.23
24th March 2013	36.13	53.87	28.14	109.21

Table 2. Atmospheric parameters of the field measurement

Parameter / Date	Temperature ($^{\circ}$K)	Aerosol Optical Thickness (550 nm)	Column Ozone (atm-cm)
23rd March 2013	313.3	0.651	0.268
24th March 2013	312.7	0.451	0.268

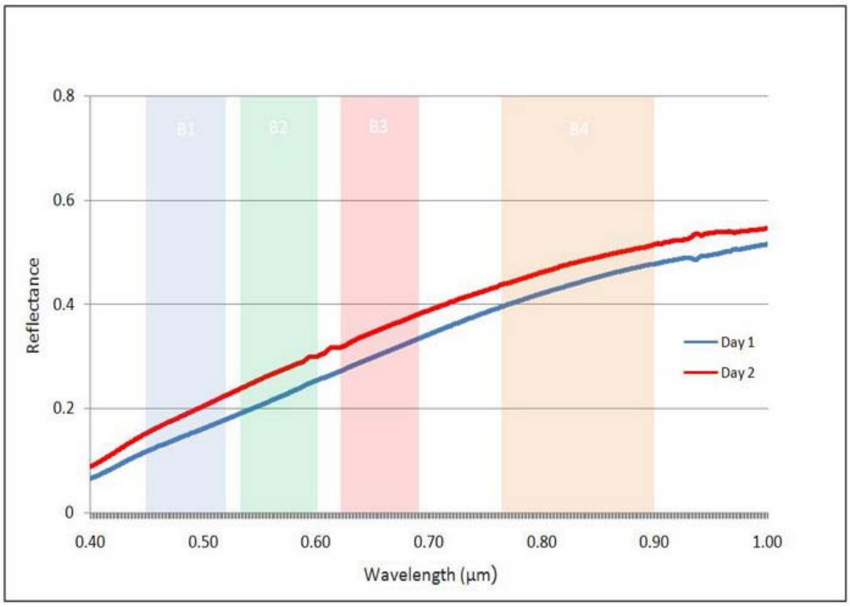
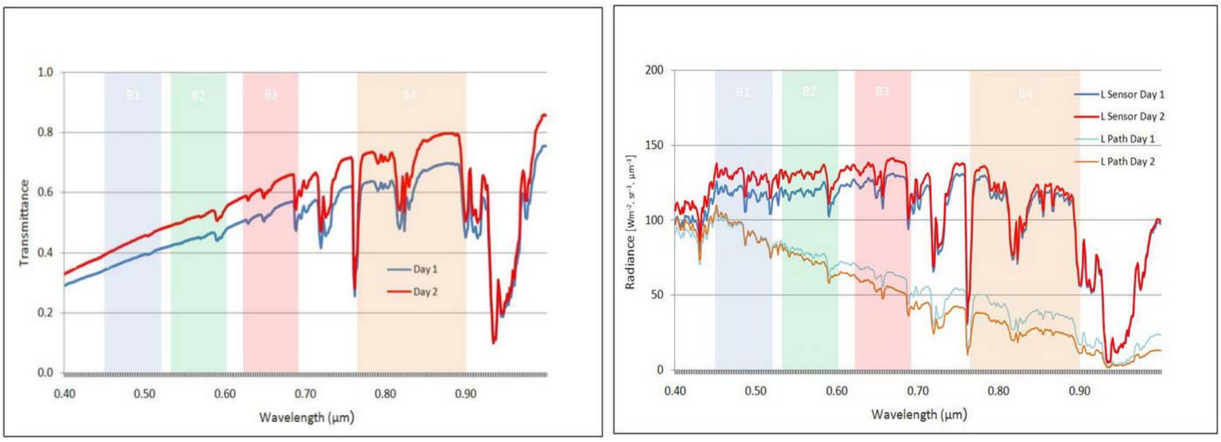


Figure 3. The average of test site ground reflectance.



(a) (b)

Figure 4. Simulated results a) Atmospheric Transmittance b) Path radiance and At-sensor radiance on 23rd and 24th March 2013.

Results of vicarious calibration

We analyzed the results where the satellite data were extracted from the imagery during measurement over the selected test site. The standard deviation for the digital number represents the uniformity of the field. The instrument gain values were retrieved from the included Metadata, consequently, we could calculate the radiance at-sensor. With the field data, we used the radiative transfer code to simulate the predicted radiance. Thereafter, based on the equation (2), we could calculate the predicted gain. The gain ratio instrument gain and predicted gain were calculated and shown in Table 3 and 4.

Table 3. Results of 23rd March 2013 vicarious calibration over Thailand test site

23/03/2013	Average DN	Stdev	Instrument gain	Sensor Radiance	Predicted Radiance	Predicted Gain	Gain Ratio
Band 1(Blue)	106.95	0.83	1.46853	72.83	117.233	0.91227	1.610
Band 2(Green)	113.64	1.53	1.50071	75.72	117.720	0.96535	1.555
Band 3(Red)	139.26	2.07	1.71019	81.43	122.058	1.14090	1.499
Band 4(NIR)	138.92	2.70	1.67119	83.13	104.772	1.32595	1.260

Table 4. Results of 24th March 2013 vicarious calibration over Thailand test site

24/03/2013	Average DN	Stdev	Instrument gain	Sensor Radiance	Predicted Radiance	Predicted Gain	Gain Ratio
Band 1(Blue)	122.79	1.03	1.46853	83.62	128.642	0.95455	1.538
Band 2(Green)	133.28	1.83	1.50071	88.81	129.092	1.03246	1.454
Band 3(Red)	169.18	2.75	1.71019	98.92	131.353	1.28798	1.328
Band 4(NIR)	173.18	2.61	1.67119	103.63	109.172	1.58630	1.054

Comparison with Cross and Vicarious Calibration

In order to validate the results of vicarious calibration over Thailand, we compared them with both the result of cross calibration analysis, and the result of vicarious calibration, which were performed by South Dakota State University (SDSU). The comparison of gain ratios are shown in Table 5. According to Table 5, the deviations of the values of gain ratio in Band 1-3 of this calibration are greater than both cross calibration and vicarious in 2012. In contrast, the values of gain ratio in Band 4 are quite close to each other by ignoring that date on 23rd March 2013.

Table 5. Summary of Gain ratio (Instrument gain and Predicted gain)

Gain ratio / Band Number	Cross Calibration 2012	SDSU Vicarious Calibration 27/06/2012	23rd March 2013	24rd March 2013
Band 1(Blue)	1.043	1.085	1.610	1.538
Band 2(Green)	1.025	1.045	1.555	1.454
Band 3(Red)	1.004	1.033	1.499	1.328
Band 4(NIR)	0.952	0.999	1.260	1.054

According to the calculated path radiance by radiative transfer code on both days, it was shown that there were high value in Band 1, 2 and 3. Therefore, we can assume that there was the atmospheric effect on this calibration. Moreover, according to the parameter value of optical thickness (550nm) on both days in Table 2, show high value of this measurement during field campaign such as 0.651 and 0.451 on first day and second day, respectively. Whereas the average value of optical thickness (550nm) of the best known site, is Railroad Valley, was 0.07(Cheng-Chien Liu, 2010). As a result of atmospheric reflection such as aerosol and water vapor, and nearby area of test site, Figure 4 illustrates high values of path radiance in Band 1-3. On the contrary, these values are normal in Band 4 as they normally are not affected from the aerosol. Furthermore, the effect of unstable white reference during field measurement is also note. Besides, there were the variations of transmittance as the deviation between tests date are shown in Figure 4.

CONCLUSIONS AND RECOMMENDATIONS

Vicarious calibration for Thaichote sensor assessment and calibrations were conducted with normal process as same as other satellites. According to the results, there were some signs of non-conformation of calibration; whereas, the result of vicarious calibration in 2012, and cross calibration with Landsat5 TM from June 2009 to August 2012, showed that there was no significant drift in all 4 bands over its 4 years in orbit. As a result, we suspect that spurious data might occur by location of this test site where atmospheric non uniformity is higher than other locations of calibrations that were carried out in the past. Consequently, it is obviously that further investigation should be continuously conducted to verify this issue to order to improve this process for using the test site of vicarious calibration in Thailand, and GISTDA can have own methodology, technology as well as skills to work in this area. More importantly, the effort we have recently made to develop such process, showed the hidden opportunity and obstacles to development.

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