THAICHOTE Level 1A Production using SIPRO Procedure

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Abstract— **The objective of this research is to study the level 1A image correction processes of THAICHOTE satellite which was originally developed by the satellite manufacturer. The information extracted from the study will be used as guidance in developing SIPRO procedure (Self developed image processing procedure) that enables the generation of radiometric corrected images. The aim of this development is to use SIPRO as a backup and replacement for THAICHOTE image processing system. The result from the study demonstrates that the level 1A images from actual image processing system and SIPRO procedure possess very similar characteristics. This research will focus on radiometric parameters aiming to further improve the quality and efficiency of the algorithms.**

Keywords—Level 1A image processing, radiometric correction, THAICHOTE imagery, SIPRO

I. INTRODUCTION

The image processing unit (IPU) is the critical part of any successful earth resource satellite imagery systems. The Geo-Informatics and Space Technology Development Agency (GISTDA), the owner of the THAICHOTE satellite --also known as THEOS, understood the importance and employed the state of the IPU from the satellite manufacturer in 2008. However, in the last 7 years, there are rapid changes in technological advancement while the current IPU has become more and more obsolete both in term of hardware and software. The fallout in processing power has become more significant and can affect the operation performance which is to promptly service dedicate satellite imagery and GIS data to relevant collaborators . As a result, this research aims to study and develop an alternative computing procedure to process the Level 0 or GERALD (Generic Exchange for Raw Archive Level Data) to Level 1A imagery of which the radiometric parameters and systematic band-to-band registration have been carried out. Various dedicate procedures referred to as the SIPRO procedure (Self develop image processing procedure) is applied to both image correction and systematic pixel positioning processes. Consequently, this prototype can generate the Level 1A output that possesses, if not better, equivalent level of radiometric accuracy to the previous IPU developed by the satellite manufacturer. SIPRO improves the operation performance both in terms of speed and accuracy by incorporate the modern technological advancement with the SIPRO procedure. Moreover, SIPRO enables GISTDA to establish sustainable development of ground receiving station for EO satellite which is a part of primary missions of Thailand to develop capacity in space technology domain.

II. FUNDAMENTAL

A. THAICHOTE Satellite

THAICHOTE satellite possesses 2 optical instruments consisted of panchromatic camera which can record high resolution grayscale image and multispectral camera which consisted of wide swath width red, green, blue and near infrared sensor. Panchromatic camera contains 1 single line with 12,000 points sensor while the MS camera has 4 single line with 6,000 points each. THAICHOTE satellite has the Pushbroom imaging mechanism which allows the image to be recorded in synchronize with the trajectory of the satellite. There are 2 main types of standard output that the current image processing system can offer which are level 1A corrected product (radiometric correction) and level 2A corrected product (both radiometric and geometric correction).

B. Radiometric correction

Radiometric correction aims to minimize the errors during the image recording caused by light condition and relevant factors such as diffraction of light in atmospheric or sensor malfunction which can result in low quality data compression or lost lines of data. The important processes that are employed in SIPRO procedure are defective detector processing, lost lines and bad blocks processing, MS registration and image restoration.

C. Geometry

Level 1A correction for Multispectral products involves some of the geometry calculation aiming to determine the 5 important coordinates which are 4 corners of the image as well as the center coordination of the image. Due to a certain offset between R, G, B and N-IR detector, the GERALD for each band usually misalign. We need to identify the corner pixels in band 1, 2 and 4 that are correspond to the pixel in reference band. Moreover, the 5 major points are recorded in the metadata file of the corresponding image as well.

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III. METHODOLOGY

A. Defective detector processing

In order to have the right condition and environment before performing radiometric correction, it is essential to check the condition of each pixel on the sensor. Defective detector processing shows the status of each pixel on the sensor its operating condition which are classified numerically in threes value of 0, 1 and 2. The meaning behind the number is the following; 0 stands for damaged or broken pixel, 1 stands for operating pixel and 2 stands for underperformed pixel. These numbers are the resulted from Calibration Parameter File (CPF). In case of lost data due to incapacitated pixel, the SIPRO procedure will fill the empty or lost value by averaging out nearby pixels.

B. Lost line and bad block processing

Lost lines and bad blocks processing are performed on the level 0 data which are compressed and saved in form of GERALD. Multispectral data which is consisted of 4 bands possesses 4 GERALD file; one GERALD corresponding to one band. In the same manner, panchromatic data possesses only one GERALD file. Missing data in level 0 file occurred from bad synchronization during data acquisition, these data must be recalculated because they are not up to quality.

Defective detector processing and lost lines and bad blocks processing employ linear interpolation in order to estimate the closest value. However, if numbers of consecutive columns of missing data exceed the acceptable limit, the SIPRO procedure shall not compute the new estimation. Instead those big losses are replace by 0.

$$If\ N > N_{max}: \quad Y(k) = 0, Y(k+1) = 0, \ldots, Y(k+N) = 0 \quad (1)$$

$$else: \quad Y(j) = X(k) + \frac{j+k}{N+1}\big(X(k+N+1) - X(k)\big) \quad (2)$$

N : Number of lost data
N_{max} : Maximum consecutive loss of data admitted
k : The most recent column with valid data
$k+N+1$: The first column with valid data after losses
$Y(j)$: New data at column j
$X(k)$: Old data at column k

C. Detector equalization Equations

Detector equalization is performed due to internal and external interferences at sensor level. This correction aims to normalize the numerical dataset. The non-uniformity of the detector can be caused by the deterioration due to the life cycle of the equipment resulting in different value in the same region where the light condition is the same at those pixel. This issue is very critical for satellite imaging mission. There are 2 level of correction for this process. The correction aiming to normalize the responsiveness of the detector which can be calculate by the following equation;

$$Y_n(p,b,g) = \frac{X(p,b,g) - X_0(p,b,g)}{\rho(p,b)} \quad (3)$$

And the process or equation that is employed to determine the radiance value at sensor level;

$$Y_r(p,b) = \frac{X(p,b,g) - X_0(p,b,g)}{\sigma(b)\times\rho(p,b)\times G(g)} \quad (4)$$

p : Primary sensor position
b : Band index
g : Gain index used in each row
$\sigma(b)$: Absolute sensitivity coefficient of band b at Gain 1
$\rho(p,b)$: Detector Relatives Gain of column p band b
$G(g)$: gain which is proportion to g (gain index) at $G(g) = 2^{\frac{g-1}{2}}$
$X(p,b,g)$: Read value from sensor at column p band b and gain g; the value read on the level 0 image
$X_0(p,b,g)$: Dark current at column p band b and gain g

Performing correction at sensor level needs absolute gain, absolute offset, detector relative gain and dark current information which can be found in the CPF.

D. MS Registration

MS registration process is performed to minimize the inter-bands shift which is caused by satellite altitude and attitude. There are 3 important information that are required in this process which are GER, CPF and CUF. For calculation, Band 3 is set as the reference band for this image correction process aiming to realign band 1, 2 and 4 on band 3. 50 x 50 grid points are created as a layer on the reference band with the distance of 120 x 120 pixels between each grid point. (Figure 1.). Once every point is determined, it has to be recalculated as in WGS84 system. Using the 2nd degree polynomial equation we can determine the closest point from band 1, 2 and 4 compared to the reference point on band 3. Band 1, 2 and 4 data are resampled using the bi-cubic interpolation method onto band 3.

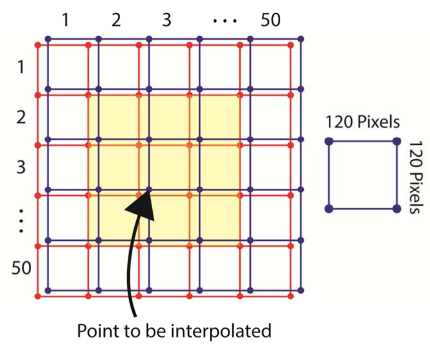

Fig. 1. MS Registration process using band 3 as reference band.

There are many method to interpolate data. In this study we find Bicubic Interpolation which is an extension of cubic interpolation of 2 data points on a two dimensional regular grid to be the most suitable method. The number of grid points to be employed to compute the interpolation function is16 or 4x4 pixels, two grid points on either side of the point under consideration for both horizontal and perpendicular direction. The bicubic convolution interpolation kernel is

$$W(x) = \begin{cases} (a+2)|x|^3 - (a+3)|x|^2 + 1 & for\ |x| \le 1 \\ a|x|^3 - 5a|x|^2 + 8a|x| - 4a & for\ 1 < |x| < 2 \\ 0 & orthewise \end{cases} \quad (5)$$

where x is the distance between the point to be interpolated and the grid point being considered and a is usually set to -0.5 or -0.75. The two-dimension cubic convolution interpolation kernel versus distance is show in the following Figure 2

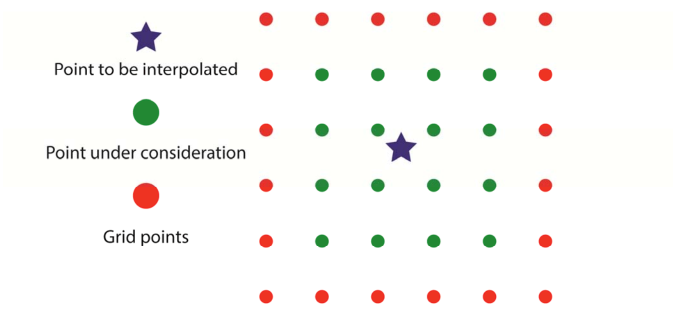

Fig. 2. The interpolated value (blue star) is a weighted sum of the 4x4 nearest pixels or 16 grid points (green dots).

If we use the matrix notation for the common case a = -0.5, we can define as

$$I(k, m+r) = \frac{1}{2}\begin{bmatrix} 1 & r & r^2 & r^3 \end{bmatrix} \begin{bmatrix} 0 & 2 & 0 & 0 \\ -1 & 0 & 1 & 0 \\ 2 & -5 & 4 & -1 \\ -1 & 3 & -3 & 1 \end{bmatrix} \begin{bmatrix} I(k, m-1) \\ I(k, m) \\ I(k, m+1) \\ I(k, m+2) \end{bmatrix} \quad (6)$$

And

$$I(k+q, m+r) = \frac{1}{2}\begin{bmatrix} 1 & q & q^2 & q^3 \end{bmatrix} \begin{bmatrix} 0 & 2 & 0 & 0 \\ -1 & 0 & 1 & 0 \\ 2 & -5 & 4 & -1 \\ -1 & 3 & -3 & 1 \end{bmatrix} \begin{bmatrix} I(k-1, m+r) \\ I(k, m+r) \\ I(k+1, m+r) \\ I(k+2, m+r) \end{bmatrix} \quad (7)$$

$I(k, m)$ is the color intensity at point (k, m)

E. Image restoration

Image restoration process helps the final product to have better sharpness by increase the image frequency and deduct noises. The advance parameter file (APF) contains filters which are applied in the image deconvolution process. There are nine 5 x 5 filters available to choose for the deconvolution process. By study the end products from the old image processing system, we have found that the filter number 1 and 2 are the same as filter number 3. Filter number 7 is identic to filter number 8. As a matter of fact, there are 6 filter to choose from. After a number of test we come to the conclusion that it is the filter number 9 that give the best image quality and is the closest to the product from old image processing system.

IV. COMPARISON WITH DPF SYSTEM

By generating products from 4 different sources (revolutions) PAN and MS, we compare the root mean square error of the DN values. The tests are performed on each band separately (4 bands of MS and 1 band of PAN). The result shows that the products from both system possess very close characteristics.

To reduce sampling bias, this research chose 4 different sources (revolutions) PAN and MS which they have disperate in term of time and topographic. Then, we compare the root mean square error of the DN values. The tests are performed on each band separately (4 bands of MS and 1 band of PAN). The result shows that the products from PAN have 0.12879 standard deviation. Moreover, The result shows that the products from MS have 1.58247, 1.74510, 1.38372, and 0.72997 standard deviations for MS band 1, 2, 3, 4, respectively. Hence, the results of both system have very close characteristics (Table 1 and Table 2).

Table 1: Average RMSE value from multiple samplings for MS products

Revolution Number	**RMSE**			
	Band 1	***Band 2***	***Band 3***	***Band 4***
12627	4.66425	5.35264	3.26788	5.15965
27231	1.45734	3.66165	1.06058	3.84976
32823	4.48187	5.35045	0.0	5.17880
32837	2.36590	1.68292	0.94561	3.96543
Mean	3.24234	4.01192	1.31852	4.53841
SD	1.58247	1.74510	1.38372	0.72997

Table 2: Average RMSE value from multiple sampling for PAN products

Revolution Number	**Band 1 RMSE**
12627	0.91872
27231	0.80022
32823	0.85993
32837	1.09833
Mean	0.09193
SD	0.12879

We then compare the difference between coordinates of the products from the old image processing system and the new version. We calculate the means error in latitude and longitude which are value at 0.0000758 and 0.000403 respectively.

The standard deviation that we have for the same samplings are 0.0000603 for latitude and 0.000201 for longitude. The error in term of real distance on earth is also calculate and we have reached 46.535 meters in average with the standard deviation of 21.198 meters.

For panchromatic, we have the average error in latitude and longitude at 0.000171 and 0.000537 respectively. In term of standard deviation, we have 0.000183 for latitude and 0.000256 for longitude. The average error in real distance on earth is calculated and it is about 65.42493 meters with the standard deviation of 29.3226. (Table 2)

Table 3 Comparison of coordinates between old system and new system from Revolution number 32823 (MS)

	Lat/Long DPF System	Lat/Long SIPRO	Geolocation error in meter
Topleft	20.357816/ 98.871671	20.357789/ 98.871490	20.34301
Topright	20.199106/ 99.844988	20.199176/ 99.845335	39.37292
Bottomleft	19.598229/ 98.677559	19.598148/ 98.677521	9.92582
Bottomright	19.440729/ 99.645737	19.440643/ 99.645350	44.12208
Centre	19.901258/ 99.250666	19.901196/ 99.251107	14.18357

Table 4 Comparison of coordinates between old system and new system from Revolution number 32823 (PAN)

	Lat/Long DPF System	Lat/Long SIPRO	Geolocation error in meter
Topleft	20.453495/ 99.274989	20.453463/ 99.275130	16.07719
Topright	20.415668/ 99.505508	20.415657/ 99.505823	35.04775
Bottomleft	20.236466/ 99.217563	20.326185/ 99.361238	85.79242
Bottomright	20.198963/ 99.449570	20.236333/ 99.216803	17.58146
Centre	20.326280/ 99.361742	20.198957/ 99.449728	57.02912

The comparison of angle of satellite attitude between the old system and the new one is calculated and the study shows the average error of measured angle at 0.1152 degrees with the standard deviation of 0.1498

Table 5 Comparison of computed satellite angle and attitude between the old system and the new system (SIPRO) from Revolution number 32823 (MS)

Angle	DPF System	SIPRO	Difference
Scene orientation	9.665563	9.668817	0.003254
Viewing Along track	-6.047008	-6.081476	0.034468
Viewing Across track	15.541520	15.529952	0.011568
Satellite Incidence	18.810843	18.803359	0.007484
Satellite Azimuth	262.881353	262.697349	0.184004
Sun Elevation	149.274039	148.7628	0.511284
Sun Azimuth	40.286067	40.5988	0.312735

Table 6 Comparison of computed satellite angle and attitude between the old system and the new system (SIPRO) from Revolution number 32823 (PAN)

Angle	DPF System	SIPRO	Difference
Scene orientation	9.826018	9.665562	0.160455
Viewing Along track	-6.052885	-6.047008	0.005877
Viewing Across track	15.538369	15.54152	0.003151
Satellite Incidence	18.801209	18.810843	0.009634
Satellite Azimuth	262.835942	262.881353	0.045411
Sun Elevation	149.032079	149.274039	0.24196
Sun Azimuth	40.273702	40.286067	0.012365

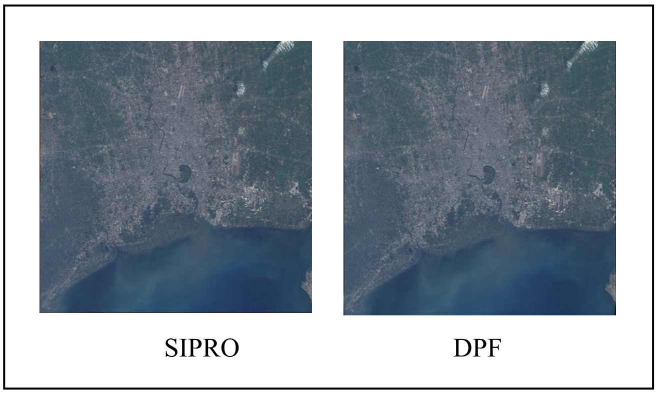

Fig. 3 Level 1A MS products from both image processing system

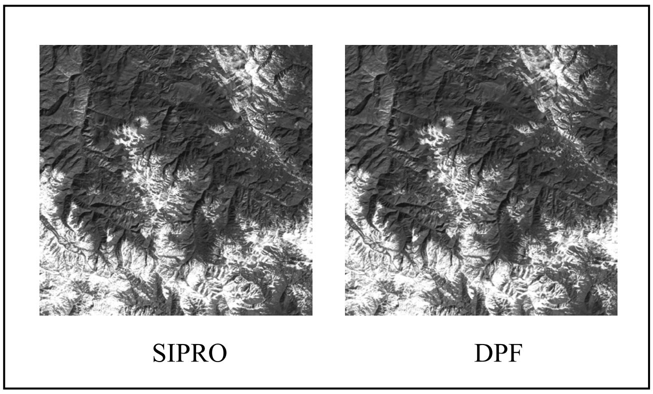

Fig. 4. Level 1A PAN products from both image processing system

The results shown in this paper are selected randomly from numerous tests that were conducted during the study. The researchers generated the level 1A images using SIPRO procedure. The sample source images or GERALDs are chosen from different location around the world to verify the compatibility issue in geometry aspects such as northern half that has positive latitude value and southern half the has negative value or even the image that fall in the intersection of 2 UTM grids.

V. Conclusion

From the comparison of root mean square value of color intensity of two sampling, the result shows no significant difference in term of radiometric correction, georeferencing and angular calculation. However, the researcher noticed that there are more differences in value for the MS samplings when compare it to the PAN samplings. This is because the MS registration process which involve resampling processes for band 1, 2 and 4. We conclude in this matter that SIPRO procedure employs different method of correction for the inter-band registration. Looking at the PAN samplings which involve no resampling process, the result of the comparison is much better. The revolution 12627, which was taken in the year 2009, has the highest RMSE value, we strongly believe that it was due to the changes in software of the old image processing system over time (2008 - present).

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