

A TWO-STEPS RADIOMETRIC CORRECTION OF SPOT-4 MULTISPECTRAL AND MULTITEMPORAL FOR SEAMLESS MOSAIC IN CENTRAL KALIMANTAN

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Abstract. This research analyzed the radiometric correction method using SPOT-4 imageries to produce the same reflectance for the same land cover. Top of Atmosphere (TOA) method was applied in previous radiometric correction approach, this TOA approach was upgraded with the reflectance effect from difference satellite viewing angle. The 250 scene of Central Kalimantan SPOT-4 imageries from 2006 until 2012 with varies viewing angle was used. This research applied two-step approaches, the first step is TOA correction, and the second step is normalization using a linear function of reflectance and satellite viewing angle. Gain and offset coefficient of this linear function was calculated using an iterative approach to producing the same reflectance in the forest area. The target of iterative processed is to minimize the standard deviation of a digital number from a forest area in the selected region. The result shows that the standard deviation of a digital number from a forest area in the two steps approach are 8.6, 16.5, and 16.8 for band 1, band 3 and band 4. These values are smaller compared with the standard deviation of digital number result from TOA approach are 15.0, 28,3 and 34.7 for band 1, band 3 and band 4. Decreasing the standard deviation shows the homogeneity of forest reflectance that could be seen in the seamless result. This algorithm can be applied for making seamless SPOT-4 mosaic whole of Indonesia.

Keywords: *Radiometric correction, Reflectance, Viewing angle*

1 INTRODUCTION

For several decades, remote sensing has been used to support many aspects of human life such as predicting agricultural areas and harvesting phase, climate and weather forecasting, natural disaster mitigation, health monitoring in a spatially, forest monitoring, oceanography, urban planning, military etc. This because reliability of remote sensing data which records and provide information of earth surface by detecting objects based on

radiation of electromagnetic energy (EME) that differs depend on the material that composed in the objects, and the ability to image regionally and continuously (Lillesand *et al.*, 2007). However, applications of remote sensing data require geometric and radiometric correction due to attenuation of radiation in the atmosphere, earth curvature, and satellite position including acquired on a different date. This particularly occurred in passive remote sensing where depend on sun illumination. Therefore,

this research will focus on the radiometric correction, specifically in the use of SPOT-4 satellite imagery.

Schott (2007) defines radiometric correction as a method to measure EME radiation in a certain wavelength ranging from ultraviolet, visible, infrared to microwave for detecting sun-irradiance which applied in each band in order to increase information accuracy such as predicting the difference of vegetation biophysics characteristic like the greenness level of chlorophyll (Main *et al.*, 2011). Moreover, radiometric correction is important for analysis using multitemporal and multisensor data that can be used for environmental monitoring.

SPOT-4 satellite images has specification of 20meter spatial resolution for 4 multispectral bands with wavelength range at Green (500-590 nm), Red (610-680 nm), NIR (780-890 nm), and 10meter spatial resolution for panchromatic band with wavelength at 500-730 nm. The satellite revisits the same location for 4 – 11 times during 26-day period cycles (CNES, 2013). SPOT-4 images were acquired from LAPAN's ground station at Parepare, South Sulawesi from 2006 – 2012. Thus abundance availability of SPOT-4 data can be used as a complementary to Landsat data in order to support regional mapping such as forest monitoring. However, the application of this data requires geometric and radiometric correction where the image was acquired with viewing angle from nadir to off nadir (-30° to 30°) which can effect a non-seamless mosaic.

Trisakti *et al.* (2012) apply SPOT-4 images processed using Top of Atmosphere (TOA) radiometric correction as the complementary to Landsat for 1990, 2000 and 2002 for monitoring Total Suspended Material (TSM) at the Limboto lake during 1990-2010. Some research in seamless

mosaic using remotely sensed imagery have been done. Hansen *et al.* (2008) used the MODIS data to normalize or to correct the radiometric value of Landsat-5/7 images. Roy *et al.* (2010) developed the composited mosaics to provide consistent Landsat data that can be used to derive land cover and geo-physical and biophysical products for detailed regional assessments of land-cover dynamics and to study Earth system functioning. The data layers in the composited mosaics are defined at 30 meter and include TOA reflectance. Guindon (1997) created the large area image mosaics from moderate and high resolution (less than 100 meter) satellite data presents special challenges particularly in the achievement of radiometric continuity (i.e. seamlessness). Typically, scenes must be employed which have been acquired over a broad time window and which therefore exhibit a diversity of atmospheric and seasonal conditions. Radiometric normalization has been achieved using a variety of empirical techniques, the success of which has been assessed solely through visual inspection.

This study aims to develop a better radiometric corrections of SPOT-4 especially in forest area, so the reflectance of forest is the same in spatial and temporal domain. The consistency of reflectance from certain object is the target of this study, so it can be used in any digital classification for any applications. The method used in this study was considering the viewing angle parameter to correct the reflectance. This parameter is related to gain or coefficient factor for each band in the multispectral composite, the eight coefficient was chosen and analysed to get the best coefficient. It is hoped that, this algorithm can be used to make the Indonesia's SPOT-4 mosaic to be used as

data complement with the Landsat-5/7 data to provide a better cloud free images.

2 MATERIALS AND METHODS

2.1 Data

The study was using 250 scene of SPOT-4 multispectral with 2A geo-reference level, focus at Central Kalimantan region

from 2006 to 2012. As shown in Figure 2-1, some of area were composed of 5 different images date (red) while others were composed of 1-2 (blue) with standard of cloud free at scene selection was 90%. The images were in various viewing angle ranging from -30° to 30° .

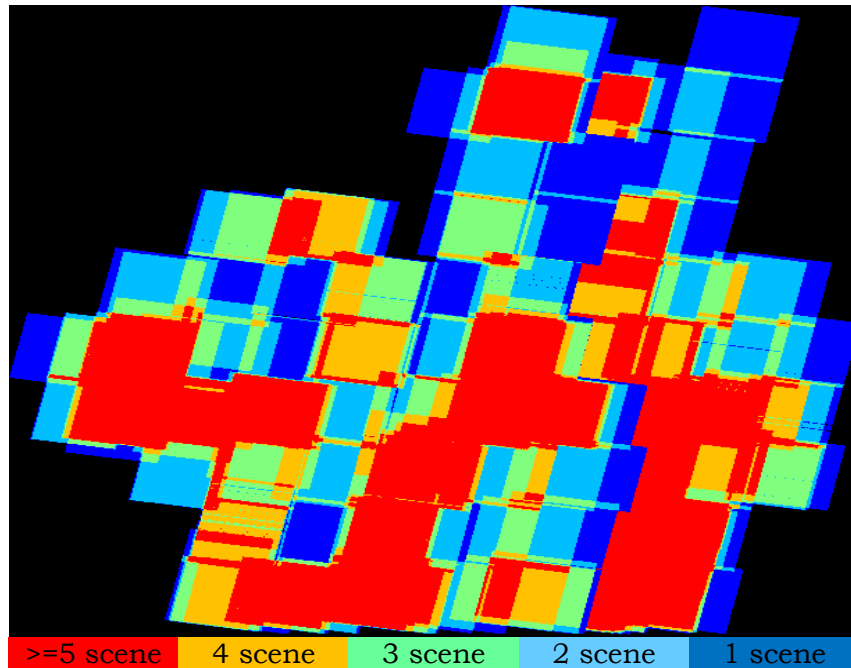


Figure 2-1: SPOT-4 at Central Kalimantan that composed of multiple image date acquired from LAPAN-Parepare ground station in 2006 – 2012

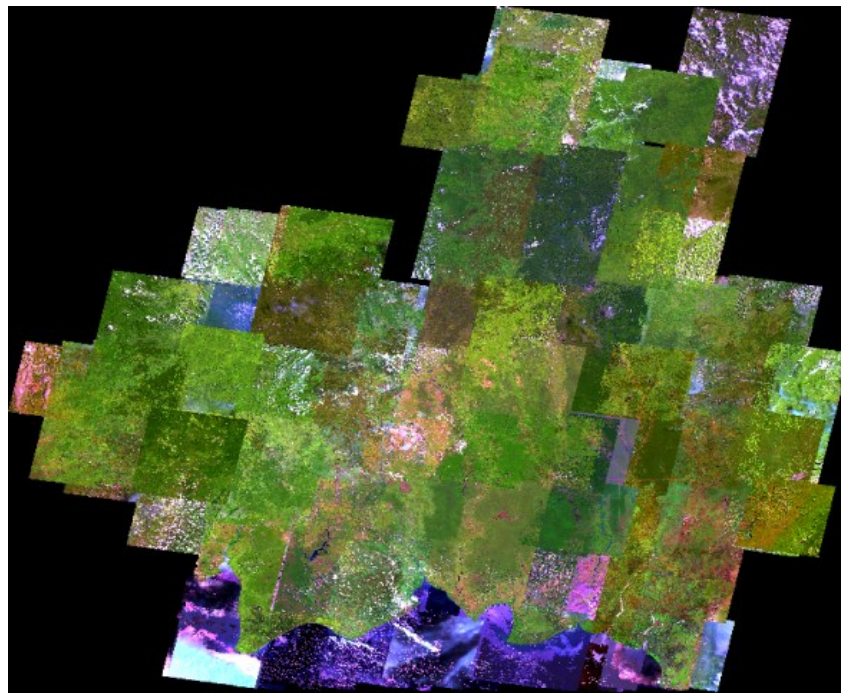


Figure 2-2: SPOT-4 coverage at Central Kalimantan from 2006 - 2012

2.2 Radiometric Correction

Most of the satellite images are delivered to the user in raw digital number (DN) that require a radiometric correction which process by measuring the radiance and converting to the reflectance value. This process to improve the radiometric accuracy due to different viewing angle, earth-sun distance, weather that interfere the radiation in the atmosphere and many other factors. The types of radiometric correction are as follows;

- a. Systematic correction for rectifying internal sensor error. This can be found in the moderate optical sensor with the spatial resolution more than 20 meter. However, this correction yet suitable with the real condition of the object because the EME radiation recorded in the sensor was attenuated twice in the atmosphere. First when the sun illumination hit the object and the second when its reflectance recorded in the sensor where the radiation was absorbed and diffused. This can cause haziness effect that reduce image contrast and adjacency effect where the radiance value interferes and determine by the total of radiance that diffused by the neighboring pixel.
- b. Reflectance correction for rectifying external error factor. This to rectify the external error such as sun distance position, topography, viewing angle including to rectify atmospheric effect such as haze. The methods are composed of TOA, Bidirectional Reflectance Difference Function (BRDF) and Slope Correction.
- c. Atmospheric correction aims to eliminate atmospheric and illumination effects in order to retrieve physical parameters of the earth's surface, such as surface

spectral reflectance, emissivity and temperature.

2.2.1 Top of Atmosphere (TOA)

TOA radiometric consists of two steps, first is to convert the raw DN to radiance spectral value and second is to convert to the reflectance spectral value.

A. Convert raw DN to radiance

At this stage, information of gain and bias from each band is measured to transform the radiance which may processed systematically based on the DN calibration curve. The calibration is set before the sensor launched, while the accuracy of the calibration decrease as the sensitivity of sensor changed over time, which require re-calibration of the sensor. The method to convert the raw DN to spectral radiance value (L_λ) are;

$$L_\lambda = \text{Bias} + (\text{Gain} \times \text{DN}) \quad (2-1)$$

Where the algorithm to measure gain and bias depend on the information processed in the image. Gain and bias for each band λ is measured based on minimum value of the data ($L_{\min\lambda}$) and maximum value ($L_{\max\lambda}$) counted from radiance value after the sensor calibrated. The information of the L_{\max} and L_{\min} can be found in header file.

$$\text{Gain} = \frac{L_{\max\lambda}}{254} - \frac{L_{\min\lambda}}{255}; \text{Bias} = L_{\min\lambda} \quad (2-2)$$

B. Convert spectral radiance to spectral reflectance

The following stage is to normalize irradiance by transforming spectral radiance measured using cosine value that differ due to different sun elevation and different exoatmospheric irradiance in each band. Therefore, the exoatmospheric reflectance is the combination of earth

surface curvature and reflectance from atmospheric effect. The algorithm is as follows;

$$\rho_p = \frac{\pi \cdot L_\lambda \cdot d^2}{ESUN_\lambda \cdot \cos\theta_s} \quad (2-3)$$

Where:

- ρ_p : Reflectance
- L_λ : Radiance
- d^2 : Earth – sun distance in astronomical unit
- $ESUN_\lambda$: Irradiance value
- θ_s : Sun zenith angle in degree

In the study, the irradiance value for SPOT-4 can be seen in Table 2-1.

Table 2-1: POT-4 Solar Exoatmospheric Irradiance (ESUN λ)

Band	Satellite SPOT-4
Band-1	1858
Band-2	1573
Band-3	1043
Band-4	236

Where the value of d^2 , sun zenith (sz) and sun elevation (se), can be seen as follows; $d^2 = 1 - 0.0168 \cdot \cos(((\text{julday}/365) \cdot 360) / 180 \cdot \pi)$ (2-4)

$$sz = (90.0 - se) / 180 \cdot \pi \quad (2-5)$$

2.2.2 Radiometric correction using viewing angle satellite

This method is processed after the TOA correction which tend to normalize the TOA correction using satellite viewing angle in the SPOT-4 multispectral or can be called a two-steps method of radiometric correction. The next step is to calibrate the reflectance using the multiply factor resulted from the measurement of viewing angle satellite. In the study, the sample to

obtain the multiply factor were taken in the forest area, either primary or secondary forest.

Thus the hypothesis in the study assume that the increasing of the viewing angle will decrease the reflectance value, as the consequence the TOA reflectance should be multiply with factor larger than 1. On the other hand, to balance the result, in the lower satellite viewing angle caused the TOA reflectance will be multiply with multiply factor less than 1. While multiply factor of 1 is use for satellite with viewing angle taken in nadir. The coefficient reflectance for each band of SPOT-4, is as follows;

$$FK_i = 1 + ((sdt/30) \cdot CK_i) \quad (2-6)$$

Where,

- Fk_i : the multiply factor for reflectance of i -th band ($i:1,2,3,4$)
- CK_i : the coefficient reflectance of i -th band ($i:1,2,3,4$)
- sdt : satellite viewing angle in degree

The value of 30 is the maximum and minimum of viewing angle in the study $\pm 30^\circ$. For example, for coefficient of 0.16 will produce multiply factor between 0.84 ($1 - 0.16$) to 1.16 ($1 + 0.16$) which can be seen in Figure 2-3.

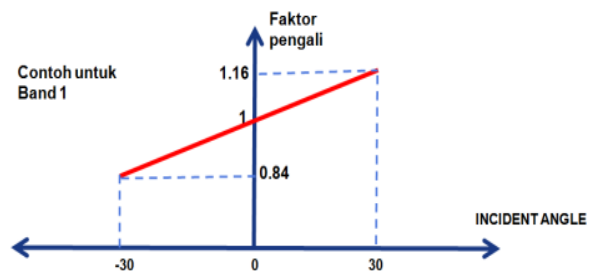


Figure 2-3: Multiply factor with coefficient 0.16

Thus the new reflectance determined by the linear function of TOA reflectance using the multiply factor for each band.

$$RF_i = FK_i \times RF_i \text{ TOA} \quad (2-7)$$

Where, RF_i : new reflectance for i -th band ($i:1,3,4$), FK_i : the multiply factor for reflectance of i -th band ($i:1,3,4$), $RF_i \text{ TOA}$: reflectance from TOA correction of i -th band ($i:1,2,3,4$)

3 PROBLEM STATEMENT

To produce a seamless mosaic which have small deviation of reflectance value for SPOT-4 mosaic in Central Kalimantan using the two steps method of radiometric correction requires the multiply factor (FK_i) and coefficient (CK) for each band in the multispectral composite. The eight coefficient were derived by experimental based on the calculation of the parameter in each different viewing angle ranging from -30° to 30° . The eight coefficient were 0.10,0.12,0.14,....., until 0.24. The result assessed by visual assessment using the true color composite of band 431. Another

method to measure the quality of the mosaic image resulted from the two-steps radiometric correction method is by the comparison of statistic information of the new reflectance, such as in the forest area.

4 RESULTS AND DISCUSSION

4.1 Results

Based on the comparison of the radiometric correction between the image that rectified with TOA reflectance and the two-steps method of TOA reflectance with normalization, the result can be assessed visually that shown in Figure 4-1.

While based on the statistical assessment resulted from the comparison of minimum, maximum, mean, median, and standard deviation applied on the sample location of forest area (primary forest and secondary forest) can be seen in Table 4-1.



(a) Mosaic SPOT4 using TOA reflectance



(b) Mosaic SPOT4 using TOA reflectance+ normalization

Figure 4-1: The comparison result between the TOA reflectance correction of SPOT-4 in Central Kalimantan

Table 4-1: Statistical comparison between TOA correction and two-steps TOA correction on several sample in primary forest

	TOA			TOA+Normalization		
	B1	B3	B4	B1	B3	B4
Min	45.0	37.0	17.0	48.0	36.0	16.0
Max	255.0	236.0	255.0	255.0	210.0	255.0
Mean	79.5	123.8	119.0	75.4	117.4	108.0
Median	75.0	114.0	105.0	75.0	116.0	108.0
Stddev	15.0	28.3	34.7	8.6	16.5	16.8

Table 4-2: Statistical comparison between the TOA correction and the two-steps TOA correction on several sample in secondary forest

	TOA			TOA+Normalization		
	B1	B3	B4	B1	B3	B4
Min	54.0	77.0	70.0	52.0	82.0	87.0
Max	159.0	240.0	255.0	255.0	251.0	255.0
Mean	84.5	153.7	160.1	81.9	149.1	151.0
Median	81.0	150.0	154.0	80.0	149.0	150.0
Stddev	16.0	28.0	37.1	11.5	17.5	20.9

Table 4-1 and 4-2 show that the standard deviation of a two-steps radiometric correction where TOA correction combined with the normalization decreased nearly two times. In Table 4-1 where the sample located in the primary forest, the standard deviation decreased from 15 to 8.6 for band 1, 28.3 to 16.5 for band 3 and 34.7 to 16.8 for band 4. While in Table 3 where the sample located in the secondary forest, the standard deviation decreased from 16 to 11.5 for band 1, 28 to 17.5 for band 3 and 37.1 to 20.9 for band 4.

4.2 Discussion

Based on visual assessment of the three mosaic images which are from mosaicked of original SPOT-4, the mosaicked images with ordinary TOA correction and the two-steps method where the TOA correction is normalized with the variation of viewing angles satellite, shows that the two-steps method

provides more seamless mosaic compare to the others.

Quantitative assessment, particularly in the forest area, shows that the standard deviation in each band of the two-steps method decreased compare with to the ordinary TOA correction. This can also be seen qualitatively in the mosaic images where the contiguous area of forest and non-forest area show homogeneous and no border-line detected in each scene in the mosaic.

The coefficient of 0.16 for visible band and 0.22 for NIR band obtained in the two-steps method were selected as the optimum coefficient, where in the NIR band shows more sensitive to the variation of the incidence angle of satellite.

In general, the two-steps method successfully produces more seamless mosaic where the result can be applied for other area in Indonesia in order to support digital classification.

5 CONCLUSION

SPOT-4 offers an oblique viewing capability with the viewing angle ranging from $\pm 30^\circ$ relative to the vertical. This various of viewing angle may produce misradiometric value, and caused non-seamless mosaic. Therefore, kind of error need to be corrected. This study offers a two-steps method in the radiometric correction process where the TOA reflectance correction was combined with the normalization affected by the varying of viewing angle.

The study found the coefficient for the normalization obtained from multiple experiment in several sample such as in the primary forest and secondary forest. The coefficients are 0.16 for band 1, 2 and 3, coefficient 0.22 for band 4, and it caused the decreasing of standard deviation in the sample location of primary forest and secondary forest and produce a seamless image mosaic in the Central Kalimantan. The result from this method was better compare with the previous algorithm which used TOA corrections.

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