Thesis for the Degree of Master of Engineering

Radiometric Calibration and Validation of KOMPSAT-2 Images Using Relative Method

by

Cheong Gil Jin

Department of Satellite Information Science

The Graduate School

Pukyong National University

February 2012

Radiometric Calibration and Validation of KOMPSAT-2 Images Using Relative Method (KOMPSAT-2 고해상도 위성영상의 상대복사보정 및 검증)

Advisor: Prof. Chul Uong Choi

by

Cheong Gil Jin

A thesis submitted in partial fulfillment of the requirements
for the degree of

Master of Engineering

in Department of Satellite Information Science, The Graduate School,
Pukyong National University

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by
Cheong Gil Jin

Approved by:

(Chairman) Kyung Soo Han

(Member) Yang Won Lee

(Member) Chul Uong Choi

February 24, 2012

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Cheong Gil Jin

Department of Satellite Information Science, The Graduate School,
Pukyong National University

Abstract

Korea possesses Korea Multi-Purpose SATellite(KOMPSAT)-2 which can acquire high resolution image of 1 meter. Those researches utilizing these high resolution image can draw reliable result only when validation and calibration of standard images are preceded, thus considerable effort to maintain quality of satellite image data. Especially, reliability of theme image that are prepared with technique using reflection of ground surface and solar radiation is depend on the validation and calibration at atmospheric radiation level.

The purpose of this study is to validate and supplement radiometric calibration coefficient of KOMPSAT-2 image with relative radiometric calibration method. For the purpose, satellites which KOMPSAT-2 can refer were selected and the images taken from same target at the same day were compared. First of all, IKONOS and QuickBird Satellites whose resources and spectral bands were similar as KOMPSAT-2 were chosen and similarity of spectral response was figured out to obtain more accurate results. The comparison result of spectral response showed that area and range of lower part of graphs from each satellite were different that made matching rate low each other to some extent. In spite of this result, since more than 90% of matching rate could be obtained and radiation energy sensed by satellite sensor and lower area of spectral response graph were in proportion, it was thus judged that research with images from two reference satellites can be carried out. After that, the data for image comparison was sampled as DN average value using square polygon size 8m x 8m from arbitrary target. And then only those data whose deviation were within 2.5% were used by calculating standard deviation of overlapping pixels with lattice. This effort was made to

improve accuracy of data by reducing geometric error of satellite and by removing effect caused by scattering that was existed in sampled pixels. The coefficient which has been used on reference image from reference satellites during relative radiometric calibration of KOMPSAT-2 with preset data was radiometric calibration coefficient which is provided during satellite image procurement. The coefficients that were used in images from reference satellites were validated through sufficient research, but these again went through validation process by absolute radiometric calibration. The absolute radiometric calibration result was quoted from field campaign data performed by Korea Aerospace Research Institute(KARI). Radiometric calibration coefficient of KOMPSAT-2 obtained by relative radiometric calibration technique were finally calculated as 0.0114294 at Blue Band, 0.0139369 at Green Band, 0.0148859 at Red Band, and 0.0151555 at Near Infra-Red Band.

These results are expected to ensure reliability of various theme information generated by KOMPSAT-2 satellite through relative radiometric calibration and to attribute in reliability improvement with absolute radiometric calibration by applying them on KOMPSAT-3 which is due launch in future.

1. Introduction

1.1. Background and necessity of research

Earth Observation Satellite(EOS) is an satellite which acquires information of visual, near infrared, thermal infrared, and microwave regions to observe condition of ground like earth resources or environment. Various remote sensing data acquired through EOS provide very useful theme information in public work in government and public institutions etc.(Lee, 2006).

Korea also had made a good effort to secure earth observation satellite of visual and near infrared region as a national level mid- and long term space development plan. The outcome result was successful launching EOS, Korea Multi-Purpose SATellite-2(KOMPSAT-2) on 28th July 2006 from Russia.

Multi-Purpose SATellite-2(hereinafter referred as "KOMPSAT-2") Project has objectives of securing technology of precision satellite development and high resolution camera loading in advance and effective management of our territory through ground as well as oceanographical observation. Therefore, MSC(Multi-Spectral Camera) was loaded on KOMPSAT-2 satellite and it is providing remote sensing and geometrical information system data about our land.

By year 2000, existing images from satellites were utilized mainly for national project purpose like map preparation, measurement, military purpose, and intelligence. However, ever since commercial sales of satellite images of IKONOS that was launched in the year 1999 started, usage of high resolution satellite image became all the way high(Lim, 2010). Reflecting the changing market trends, commercial services rendered by KOMPSAT-2 also started from June 2007. Therefore, it has to satisfy various requirements at customer ends for the expansion of KOMPSAT-2 satellite image market and quality improvement and research about stabilized and standardized usage became important. These researches made continuous image data supply by KOMPSAT-2 possible and has got important meaning in assuring independent technology for forthcoming KOMPSAT-3 and KOMPSAT-3A.

In this study, radiometric calibration of MSC sensor which is base in quality improvement and standardized usage of KOMPSAT-2 image was performed with relative method. Unlike absolute radiometric calibration during which actually measured data are utilized, this relative method is radiometric calibration method which is performed by comparing data acquired from other satellites of similar properties. Relative radiometric calibration technique is expected to attribute radiometric calibration of image from KOMPSAT-2 since it can countervail errors caused by atmospheric effect with the fact that the atmospheric condition of images taken at the same day are similar.

1.2. Scope and purpose of research

For satellite image, to assure its image quality, validation and calibration works are must. Validation and calibration works are broadly categorized into Geometric Calibration/Validation related with spatial location expressed in image and Radiometric Cal./Val. related with solar radiation energy which is sensed by satellite sensor. Sensors of satellite go through pre-launch calibration at ground before satellite launch, and it is continuously controlled by on-board calibration during performing satellite's duty, and degradation of sensor are prevented by post-launch calibration using ground target after launching(Dinguirard et al., 1999). Generally, consistent validation · calibration for the launched satellite is performed by post-launch calibration process. This radiometric validation · calibration is further divided into absolute radiometric calibration and relative radiometric calibration.

Absolute Radiometric Calibration is a method to trace relation by comparing DN(Digital Number) of image recorded by satellite sensor by measuring solar radiation energy reflected from ground with Spectroradiometer. For absolute radiometric calibration, accurate sensor spectral profile at the time of field campaign and atmospheric property profile are required(Du et al., 2002). Forecast value of accurate radiometric conversion coefficient from satellite image can be provided if we can use all these information. However, information about atmospheric property is difficult to collect even if it is pre-planned. The method to supplement atmospheric calibration algorithm which is being used in absolute radiometric calibration is Relative radiometric calibration. Relative radiometric calibration is being used either in normalization of strength between bands in single remote sensed image or in normalization of strength of multiple period remote sensing data by matching with standard image(Jensen, 2004).

The objective of this study is to calculate and validate radiometric calibration coefficient of KOMPSAT-2 image with relative radiometric calibration method. Therefore, images taken from the same target on the same date were collected to select reference satellite of KOMPSAT-2 and to minimize effect caused by atmosphere. Also, sampling of size 8m × 8m to reduce geometrical error and scattering effect of satellite was done and standard deviations were calculated for sampled data and then average DN was used for the data with standard deviation within 2.5%. After that, for the reference satellite image, radiometric conversion was performed and relative radiometric calibration coefficient was calculated using average DN and liner regression of KOMPSAT-2. Finally, these values were compared with calculated coefficient by absolute radiometric calibration and relative radiometric calibration coefficient was validated.

1.3. Research trends

Calibration/Validation of optical satellite is directly related to reliability of research result on which satellite image is used. Therefore, persistent research for the improvement of reliability of satellite image are being pursued. Among these, Relative Calibration method suiting to KOMPSAT-2 on which Visible/NIR(Near Infra-Red) are loaded through investigating researches is sought.

Relative Calibration is analysis technique which is widely being used to assume the data which can be expressed in the form of function and has got linear relations or to figure out relationship using linear regression. With this process, Cross-Sensor Calibration is performed for the sensors which have got correlation in various fields.

During early 1990s, mainly cross calibration of Landsat TM and SPOT HRV image was performed, and Hill et al.(1990) has executed research of comparison between Landsat TM image which has been acquired in the year 1984, year 1988 and SPOT HRV image during year 1986 based on TOA(Top Of Atmosphere) Reflectance. Results of the above comparison study yielded correlation between two images of higher than 0.996 in visible region and RMSE(Root Mean Square Error) also very low with value less than 0.16. Besides, it showed that in case of images taken at the same time line at space orbit provided that atmospheric condition is sufficiently stable, atmospheric effect can be countervailed.

During year 2000, various satellites such as Landsat-7 ETM+, IKONOS, ASTER, and QuickBird were launched. With this trends, number of those satellites that can perform Cross Calibration was increased. Here, Teillet et al.(2001) has performed Cross Calibration for Landsat-7 ETM+ and Landsat-5 TM whose platform between sensors are similar and could obtain relatively accurate result with difference below 2% in Band 1, 2, 3, and 4 those are equivalent to Visible/NIR. There has been a Cross Calibration between Multi-platforms that Chuanmin et al.(2001) proposed the use of Rayleigh and Aerosol data of SeaWiFS/MODIS for atmospheric calibration of LANDSAT-7 ETM+. Also, Goward et al.(2003) carried out research for the calibration of IKONOS image with reference Landsat-7 ETM+ image and they did sampling from 30m, 60m, 90m, and 120m by referring resolution of Landsat-7 ETM+ image and used average value to overcome difference in resolution. They also performed validation using actually measured values with Site images for EOS validation.

Though researches about image calibration as per the geometrical target and sensor property are actively proceeded, the same about Radiometric Calibration related with atmospheric calibration was somewhat lacked. Kim et al. (2002) proceeded research comparing optical capability of EOC sensor by analyzing basic statistical values, statistical values per different ground coverings, and separability of panchromatic image of SPOT and IRS which have got similar characteristics with KOMPSAT-EOC(Electro-Optical Camera) Sensor. Ji et al.(2008) carried out absolute radiometric calibration for KOMPSAT-2 and proceeded research in validation of absolute radiometric calibration coefficient using image from ASTER.

The researches so far reviewed have performed Relative Calibration for various satellites and most of them are researches based on Reflectance. These research target are to consider spectral property and Sun Zenith Angle. Besides, with research result of countervailing atmospheric effect under stable atmospheric condition, they attempted to acquire satellite images whose photographing times were closely adjacent. Considering those research objectives and methodologies, this study was intended to pursue relative calibration by linear regression method keeping spectral characteristics based on reflectance in mind.

2. Methods

This research was performed as per flow chart as in Figure 1. Research procedure was largely divided into Relative Radiometric Calibration and Absolute Radiometric Calibration part and radiometric calibration coefficient during performing each calibration process was calculated and then validation was followed. Same absolute radiometric calibration was performed for the image from QuickBird to confirm accuracy of model which has been used for atmospheric calibration.

For relative radiometric calibration, spectral bands were compared and pre-treatment was given on collected images taken from same target and same date by designating suitable satellite. DN of IKONOS image which has been selected from the above process was sampled, its radiance was converted and then again it was converted to reflectance. These converted IKONOS reflectance is similar as that of KOMPSAT-2, therefore reflectance conversion formula was reversely applied to assume radiance of KOMPSAT-2. Linear regression analysis was performed for assumed radiance with DN of original image from KOMPSAT-2 and final relative radiance calibration coefficient was calculated.

Absolute radiance calibration was also carried out to validate relative radiance calibration coefficient. On the basis of field campaign data conducted at Gimje, Korea on 23rd Nov. 2010, TOA radiance was calculated using MODTRAN for linear regression analysis with DN of KOMPSAT-2 to calculate absolute radiance calibration coefficient. During this process, it was judged that sufficient data were not collected for the atmospheric variables that could be otherwise input, therefore for the image from QuickBird taken from same site on the same date, absolute radiance calibration was performed and the difference from actual coefficient which was provided as imd file was analyzed to remove uncertainty of atmospheric model.

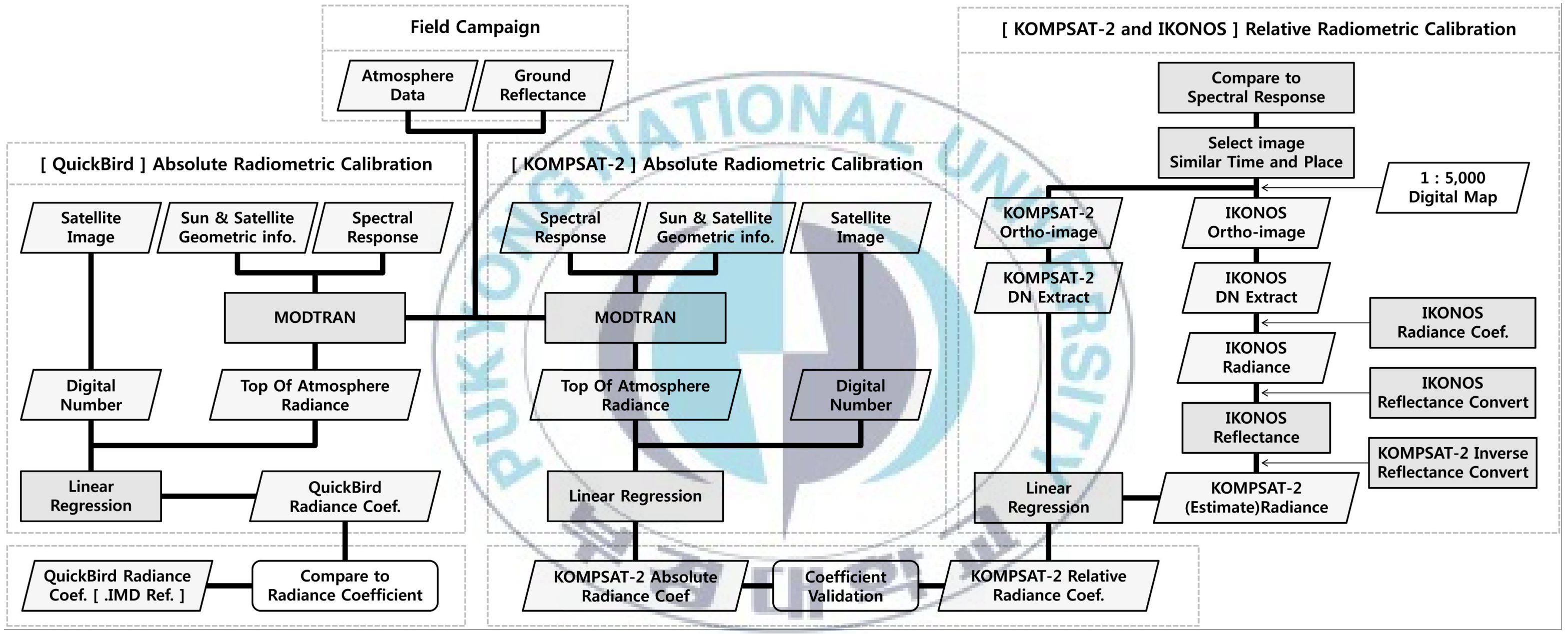

Figure 1. Flow Chart

2.1. Comparison of Satellite Resources and Spectral Band

For the relative radiometric calibration of KOMPSAT-2, similarities in resources and spectral band were figured out. In this study, by considering spatial resolution of Multi-Band, IKONOS and QuickBird were chosen as reference satellites for spectral band comparison.

2.1.1. Resources comparison between satellites

The resources of KOMPSAT-2, IKONOS, and QuickBird are shown in below Table 1.

Table 1. Resources comparison between satellites.

Satellite type	QuickBird		IKONOS		KOMPSAT-2	
Launch date	28 July 2006		24 Sept. 1999		19 Oct. 2001	
Altitude Flight	450㎞		681		690	
Orbital inclination	98°		98.1°		98.1°	
Orbital characteristics	Sun-synchronous		Sun-synchronous		Sun-synchronous	
Weight	953㎏		726㎏		765㎏	
Plan Lifetime	7year		7year		3year	
Par value cycle	1~3.5 day		1~3.5 day		3 day	
swath width	22㎞		11㎞		15㎞	
Tues-compliant products	22㎞ X 22㎞		11㎞ X 11㎞		15㎞ X 15㎞	
Resolution	Pan	Multi	Pan	Multi	Pan	Multi
	0.6m	2.4m	1m	4m	1m	4m
wavelength(㎛)	0.455 -0.900	0.45-0.52	0.450 -0.900	0.44-0.52	0.450 -0.900	0.45-0.52
		0.52-0.60		0.51-0.60		0.52-0.60
		0.63-0.69		0.63-0.70		0.63-0.69
		0.76-0.90		0.76-0.85		0.79-0.90
Data format	11bit		11bit		10bit	

All 3 satellites are similar in characteristics of sun synchronous type, inclination of satellite orbit is 98°, revisit rate for 3 days, especially in IKONOS, path altitude, weight, swatch width, and resolution are much similar as those of KOMPSAT-2. In QuickBird, path altitude is 450km and resolution within Multi zone is best as 2.4 meter, but its weight is heaviest 953kg.

2.1.2. Comparison of spectral bands between satellites

Relative spectral response per different band was expressed as graph as in Figure 2 and the area matching with those from KOMPSAT-2 is presented in Table 2.

Table 2. Relative spectral response graph area of the bottom agreement.

KOMPSAT-2 Ref. Matching Rate (%)		Band			
		(A) Blue	(B) Green	(C) Red	(D) NIR
Satellite	QuickBird	76.687	91.831	87.530	82.549
	IKONOS	83.501	92.666	96.823	66.865

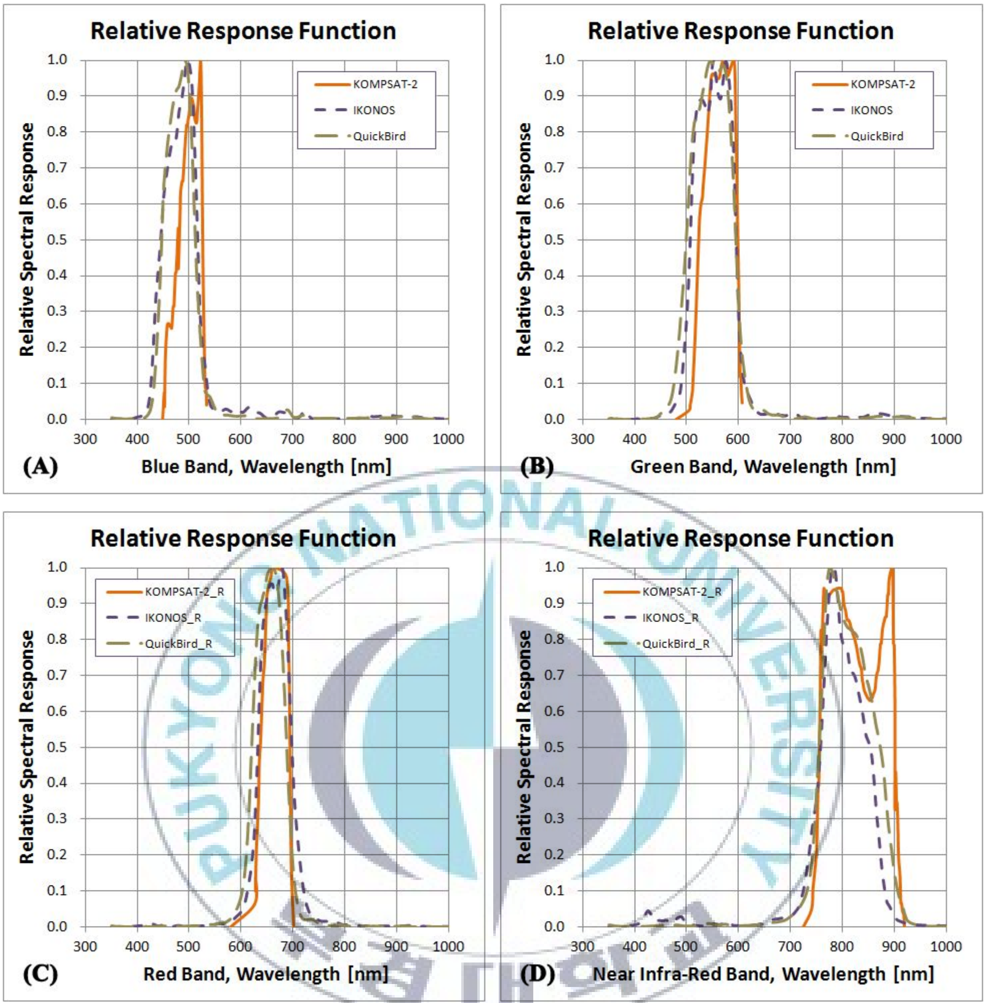

Figure 2. RSR(Relative Spectral Response) graph

Response and matching rate comparison at Blue Band per each satellites yielded result that in case of KOMPSAT-2, it has got relatively small area at lower side of graph, it seems to be difficult to analyze by comparing with graphs of other satellites. Still, with KOMPSAT-2 as reference, matching rate up to 76.666% in QuickBird, and up to 83.501% from IKONOS, it is needed to judge by practical application result. At Green band, unlike of those of at Blue Band, minimum matching rate of 91.831% led assumption that both spectral characteristics are very much similar, whereas matching rate at Red Band 87.530% with QuickBird, matching rate of 96.832% with IKONOS were obtained, therefore Red band of IKONOS would be very much similar as that of KOMPSAT-2. However, matching rate at NIR band with IKONOS was found 66.865% and that of QuickBird was 82.549%. This result was judged that NIR Band of KOMPSAT-2 shows unique response rate and it need to examine carefully by comparing actual DN and Radiance.

We judged that IKONOS image was suitable for relative radiometric calibration because analysis result of graph for spectral response rate for the above 3 satellites revealed relatively high matching rate in visual range. Meanwhile, image from QuickBird was only used in supplementation of atmospheric radiative transfer code since its image showed low matching rate than those of IKONOS in all the band regions except NIR.

2.2. Pre-treatment on satellite image

When correlation is compared by selecting small number of DN that present in image, though accuracy may be increased, statistical significance can be impaired. Keeping this fact in mind, orthoimage was prepared and then pre-treatment of data extraction from orthoimage was performed. Geometric error occurred during this process was corrected by obtaining DN for uniform pixels using sampling and standard deviation.

2.2.1. Image collection and shooting targets

Images that did not have cloud were collected by searching service site provide by commercial satellite imagery vendors. Those searched images were listed up and images from overlapped site were selected. Finally selected images are shown in Figure 3. Images of IKONOS and KOMPSAT-2 were taken from Iksan area, Jeolalbuk-do, Korea, while images of QuickBird and KOMPSAT-2 were taken from nearby Gimje region located in the same province. The shooting information of each image are as in Table 3.

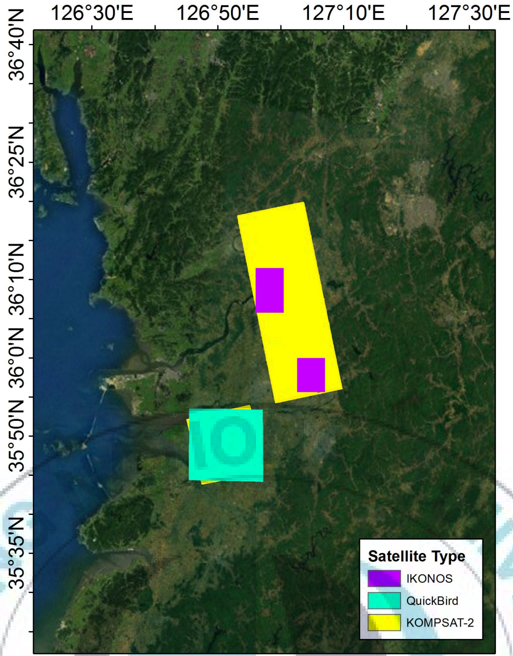

Figure 3. Study Area

Table 3. Image metadata

Date	Local Time	Satellite Type	Astro Unit	Sun Elevation
2008-05-01	11:12:00 AM	IKONOS	1.00784	63.19
	10:56:21 AM	KOMPSAT-2		59.23
2010-11-23	11:08:45 AM	QuickBird	0.98760	31.70
	10:00:14 AM	KOMPSAT-2		24.79

2.2.2. Geometric calibration

Geometric calibration was performed using Digital Map of scale 1:5,000 provided by National Geographic Information Institute to prepare Digital Elevation Model and Ground Control Point was preoccupied. Since scale 1:5,000 Digital Map provided accuracy of 1 meter, it was judged that it would be sufficient because resolution of Multi Sensor was 4 meter and geometric calibration yielded accuracy within 2 meter with average Root Mean Square Error less than 0.5.

2.2.3. Data Extraction

For the comparison of radiometric characteristics, there is need to make spatial resolution of images from each satellite same. However, in general, in the image taken from other satellite, coordinates of pixel starting point are not matching even if same resolution, same ellipsoidal, and projection are used. Also, one should consider errors that occurred during image processing and according to accuracy below decimal point in program. To resolve this problem, generally adopted method is that all the values which are overlapped at nth pixel are sampled and average would be taken to make this average as nth pixel value(Bian, 1997). By adopting this method in this study, arbitrary image with spatial resolution 8 meter was prepared and then it was converted into Polygon Shape file which has got same location and same size with pixel. Using this polygon shape file, average value and standard deviation of pixels in high resolution images that were overlapped in polygon were calculated. Comparison data were thus established by selecting data within 2.5% of standard deviation.

2.3. Radiometric Calibration

The satellite on which manual sensor was loaded senses incident TOA radiance and records it as DN. However, sun irradiance would pass atmosphere in the course of incidence and reflection to/from ground, it is affected by various atmospheric effects like absorption and scattering, consequently creates difference between sensor radiance and ground radiance. This effect is expressed as equation as in Equation 1.

$$at\ Sensor\,Radiance\ =\ Ground\,Radiance\ +Atmospheric\ Effect\,Radiance$$

Equation 1

From this equation, if Atmospheric Radiance is eliminated, this equation becomes relation between Ground Radiance, at Sensor Radiance, TOA Radiance, and Digital Number. On the basis of this theory, deciding and applying the relation function or coefficient to convert DN into TOA Radiance is known as radiometric calibration.

2.3.1. Atmospheric correction

Since atmosphere is present in earth, the observed data via sensor loaded on satellite have many distortions generated by various atmospheric effect as in Figure 4. and it shows large difference from actual radiation energy measured from ground surface.

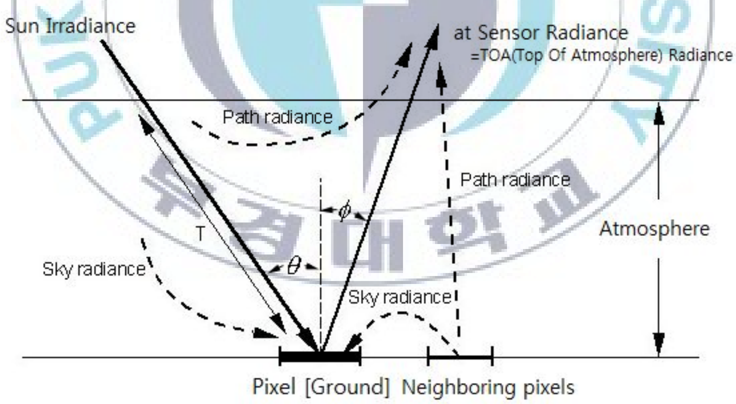

Figure 4. Atmospheric Effect

When Sun Irradiance in Exo-atmosphere of ideal condition without atmosphere is let and Sun Zenith is let , Ground irradiance can be expressed as . Thus, if average spectral irradiance of sensor wave band() is let and reflection rate of ground is let , if reflected energy is radiated as hemisphere shape, Radiance measurement value becomes as in below

Equation 2.

$$L = E_{\Delta\lambda}\cos\theta \bullet \lambda R/\pi \qquad \text{Equation 2}$$

If this Equation 2 is expressed in the form of DN recorded by satellite sensor, it would become Equation 3.

$$L = Ck + L_{\min}$$
$$k = (L_{\max} - L_{\min})/C_{\max} \qquad \text{Equation 3}$$

When atmosphere is considered, atmospheric transmission coefficient(T) through the atmospheric transmission route, Sky Radiance(E_D) which affects on reflection spot by scattered from atmosphere and adjourning areas, and Path Radiance(L_P) which affects on sensor by being scattered at atmosphere and adjourning area have to be considered, thereby radiance received by ground(E_G) is sane as Equation 4.

$$E_G = E_{\Delta\lambda}\, T_\theta \cos\theta\, \Delta\lambda + E_D \qquad \text{Equation 4}$$

The radiance that reaches to sensor with all the effects as expressed in Equation 2, Equation 3, and Equation 4 will be same as in Equation 5 and it can explain the relation between DN and radiance.

$$L = \frac{RT_\phi}{\pi}(E_\Delta\, \lambda\, T_\theta \cos\theta\, \Delta\lambda + E_D) + L_P \qquad \text{Equation 5}$$

These equations are basic method to calculate Sensor Radiance considering atmospheric effects. However, those calculation with these equations are much cumbersome job and it is difficult to consider various atmospheric variables, hence Radiative Transfer Model is much being used. Radiative Transfer Model is widely being used in atmospheric correction of image in remote sensing field and it has got merit of considering all the physical parameters of atmosphere(Kim, 2002). The most frequently used radiative transfer models are MODTRAN(Moderate Resolution Transmittance) developed by US Air Force Research Laboratory/Space Vehicles Directorate and 6S(Second Simulation of the Satellite Signal in the Solar Spectrum) developed in France.

2.3.2. Conversion of radiation energy of IKONOS image

IKONOS has a fame of first high resolution of 1 meter level commercial satellite and considerable amount of research for validation · calibration to maintain IKONOS image quality were carried out. In this study, DN was converted into radiation energy using methods(Equation 6, Equation 7) and coefficient(Table 4) officially provided by GeoEye and proposed by Taylor et al.(2005).

$$L_{i,j,k} = DN_{i,j,k} \times [CalCoef_k]^{-1} \qquad \text{Equation 6}$$

i, j, k : pixel of ith line, jth column, and k band

$L_{i,j,k}$: intensity of radiation at each band (mW/㎠×ster)

$CalCoef_k$: Calibration constant of radiation intensity per band (mW/㎠×ster-DN)

$DN_{i,j,k}$: Brightness of image

$$CalCoef_k = G_k^{-1} A_{opt} \Omega_k \int L(\lambda) R_k(\lambda) L_k^{-1} d\lambda \qquad \text{Equation 7}$$

G_k : Gain constant of IKONOS k band (e-/DN)

A_{opt} : Diaphragm area of IKONOS lens telescope(㎠)

Ω : View angle of IKONOS k band(ster)

L_k : Radiation intensity of solar incidence at diaphragm of IKONOS k band (mW/㎠-ster)

$L(\lambda)$: Solar irradiance at sensor diaphragm per each spectral band (mW/㎠-㎛)

$R_k(\lambda)$: Response of IKONOS k band per spectral band(e-/mW)

Table 4. $CalCoef_k$ at each band of IKONOS

	Blue	Green	Red	NIR
$CalCoef_k$	728	727	949	843

2.3.3. Conversion of radiation energy of QuickBird image

QuickBird is a commercial satellite with the most excellent resolution as of now and the conversion method of DN into irradiance is provided as in Equation 8(Keith Krause, 2005).

$$L_{i,j,k} = DN_{i,j,k} \times abs\,CalCoef_k \qquad \text{Equation 8}$$

Generally QuickBird data is provided as 16bit but in some case, data is provided as 8bit and is different accordingly. Also there is need to review imd file which is provided along with image during irradiance calibration since which is implemented from 6th June 2003 onward is different from earlier version. As per review result of imd file of image used in this study, conversion coefficient of 16bit is as in Table 5.

Table 5. .IMD file referenced in QuickBird radiance conversion constant.

	Blue	Green	Red	NIR
$absCalCoef_k$	0.0160412	0.0143847	0.0126735	0.0154242

2.4. Reflectance Convert and Estimate Radiance

Those images which were taken by other satellites or during multi period have different correlation between DN and Radiance thus makes comparison difficult. Normalization is required for this problem and the standard used during this normalization is Reflectance. Reflectance is characteristics unique in specific material and incident Sun irradiance with Zenith Angle Reflectance has got different reflectance according to type of materials composed of horizontal plane.

The atmospheric reflectance of ground surface and earth are calculated as in Equation 9.

$$\rho_P = \frac{\pi \cdot L_\lambda \cdot d^2}{ESUN_\lambda \cdot \cos\theta} \qquad \text{Equation 9}$$

ρ_P : TOA Reflectance

λ : band width

L_λ : at Sensor Radiance(Each band)

d : Earth-Sun Distance (Unit : Astronomical Units)

$ESUN_\lambda$: Mean Sun Irradiance(Each band)

θ_S : Sun Zenith Angle (Unit : degree)

When DN or Radiance are converted to Reflectance, two merits with elements included in equation can be utilized. First, solar elevation difference caused by time interval in acquired data can be eliminated by COS, and second, since spectral bands are different with different satellite, generated Radiance difference which is sensed can be countervailed.

Under the assumption that Reflectance is unique characteristics of materials and analysis based on reflectance is normalized data, in a reverse way, equation by which radiance can be assumed from reflectance calculation equation. Equation 10 is another arrangement from Equation 9 focusing Radiance.

$$L_\lambda = \frac{\rho_P \cdot ESUN_\lambda \cdot \cos\theta_s}{\pi \cdot d^2} \qquad \text{Equation 10}$$

Reflectance was calculated from IKONOS image using Equation 10 in this study and this reflectance was assumed as Radiance of KOMPSAT-2, it was analyzed as liner regression with DN of actual KOMPSAT-2 image to perform Relative Radiometric Calibration.

2.5. Field Campaign Data

Figure 5. Field Campaign Area (Left : KOMPSAT-2, Right : QuickBird)

For the validation of relative radiometric calibration, absolute radiometric calibration coefficient was calculated with field campaign data performed by Korea Aerospace Research Institute on 23rd Nov. 2010 along with images taken by KOMPSAT-2 and QuickBird on the same date. By reflecting latest data, difference caused by degradation of sensor can be looked into and the effect by atmosphere since QuickBird image taken at 1 hour and 8 minute difference could be minimized. The target of field campaign was Gimje Public Stadium Region(35.8°N, 126.9°E), Jeollabuk-do, Korea and the reflectance of ground surface observed by Spectroradiometer is as in Figure 6.

Table 6-1. Result of spectrometer observations

	point	Target	Time	Sun Angle		Blue (M2)	Green (M1)	Red (M4)	NIR (M3)
				Zenith	Azimuth				
1th	1	Tarp 23%	09:20	70.22	135.5	0.288	0.274	0.261	0.234
	3	Tarp 35%	09:22	69.94	135.9	0.406	0.389	0.374	0.349
	4	Tarp 53%	09:24	69.66	136.3	0.665	0.661	0.657	0.639
	5	Water	09:58	65.22	143.5	0.031	0.054	0.035	0.008
	6	Grass(Yellow)	09:49	66.33	141.5	0.046	0.080	0.059	0.088
	7	Grass(Green)	09:50	66.21	141.7	0.034	0.057	0.034	0.137
	10	Artificial Turf	09:27	69.24	136.9	0.090	0.158	0.143	0.224
	11	Footsal Ground	09:53	65.83	142.4	0.080	0.123	0.282	0.323
	12	Asphalt	09:40	67.49	139.6	0.168	0.176	0.181	0.189
	13	Track	09:30	68.83	137.5	0.055	0.090	0.219	0.245
	14	Track next to asphalt	09:33	68.42	138.1	0.173	0.183	0.192	0.198
2th	15	Tarp 23%	10:35	61.23	152.1	0.280	0.270	0.259	0.237
	17	Tarp 35%	10:33	61.42	151.6	0.384	0.374	0.366	0.337
	18	Tarp 53%	10:31	61.61	151.1	0.603	0.591	0.577	0.548
	19	Water	10:04	64.51	144.8	0.033	0.056	0.036	0.009
	20	Grass(Yellow)	10:12	63.6	146.7	0.049	0.083	0.063	0.092
	21	Grass(Green)	10:13	63.49	146.9	0.026	0.047	0.025	0.123
	24	Artificial Turf	10:29	61.81	150.7	0.090	0.153	0.139	0.209
	25	Footsal Ground	10:10	63.82	146.2	0.076	0.118	0.268	0.308
	26	Asphalt	10:18	62.94	148	0.150	0.158	0.164	0.174
	27	Track	10:26	62.11	149.9	0.054	0.088	0.217	0.252
	28	Track next to asphalt	10:47	60.15	155.1	0.153	0.164	0.173	0.182

Table 6-2. Result of spectrometer observations

	point	Target	Time	Sun Angle		Blue	Green	Red	NIR
				Zenith	Azimuth	(M2)	(M1)	(M4)	(M3)
3th	29	Tarp 23%	11:22	57.68	164.2	0.254	0.265	0.276	0.235
	31	Tarp 35%	11:23	57.63	164.5	0.352	0.360	0.369	0.334
	32	Tarp 53%	11:25	57.52	165	0.591	0.600	0.611	0.570
	33	Water	11:51	56.49	172.2	0.033	0.050	0.027	0.008
	34	Grass(Yellow)	11:40	56.85	169.2	0.054	0.075	0.044	0.079
	35	Grass(Green)	11:41	56.81	169.4	0.026	0.047	0.027	0.116
	38	Artificial Turf	11:26	57.47	165.3	0.140	0.155	0.091	0.206
	39	Footsal Ground	11:43	56.74	170	0.247	0.105	0.068	0.285
	40	Asphalt	11:35	57.05	167.8	0.184	0.179	0.170	0.191
	41	Track	11:28	57.37	165.9	0.212	0.084	0.052	0.240
	42	Track next to asphalt	11:30	57.27	166.4	0.179	0.169	0.158	0.187

Observed reflectance was utilized in MODTRAN® 5.2.0.0 to apply atmospheric radiance transfer code during absolute radiometric calibration process. In MODTRAN, basic atmospheric model is made as database and has got merit of providing standard data about aerosol, by this MODTRAN atmospheric data which was not measured during this round field campaign could be supplemented. In atmospheric model of MODTRAN, using database 1976 US Standard, basic values were utilized and considering observation data obtained from Korea Meteorological Administration and characteristics of Gimje region, Urban-VIS of city center type was set as 23 km and then TOA radiation against reflectance was calculated.

3. Calculation and validation of radiometric calibration coefficient

3.1. Calculation of relative radiometric calibration coefficient.

3.1.1. Calculation of relative radiometric calibration coefficient using IKONOS image

To assume Radiance of KOMPSAT-2 that is for linear regression analysis with DN of KOMPSAT-2, DN of IKONOS was converted to reflectance. After that, reflectance calculation equation was re-arranged focusing Radiance and then Reflectance value from IKONOS image was used for assumption of Radiance of KOMPSAT-2. Relative radiometric calibration coefficient was calculated through linear regression analysis with DN of actual KOMPSAT-2 image showed trends as in Figure 6 and the calculated coefficient is tabulated as in Table 7.

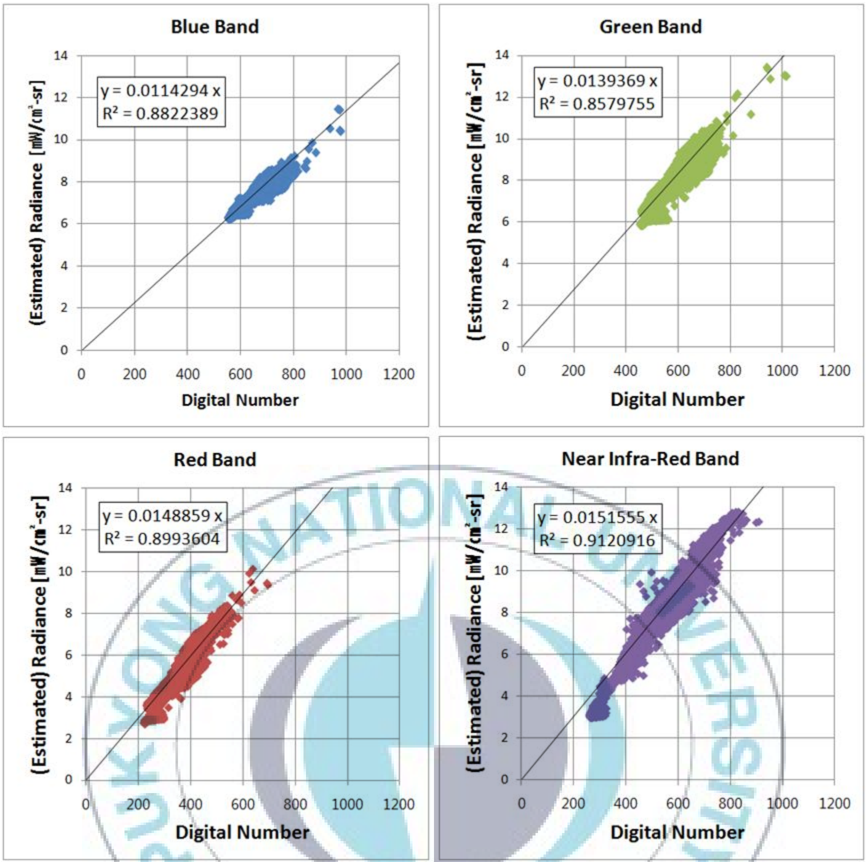

Figure 6. IKONOS images using the calibration results of the estimated relative radiometric calibration.

Table 7. IKONOS images using the estimated coefficients

Band	Relative Coefficient	R^2
Blue	0.0114294	0.8822
Green	0.0139369	0.8580
Red	0.0148859	0.8993
NIR	0.0151555	0.9120

1st linear regression is expressed as Gain and Offset. However, the regression which is being used in radiometric calibration limits Offset value as 0. This is because theoretically, actual World Radiance value can not be a negative one. By setting Offset value 0, calculated coefficients were 0.0114294 at Blue Band, 0.0139369 at Green Band, 0.0148859 at Red Band, and 0.0151555 at Near Infra-Red Band as shown in Table 7. Further, R^2 values appeared more than 0.85 throughout all the bands which advocates that there is high correlation between actual DN and assumed Radiance value and it is self explanatory about DN with assumed Radiance value.

3.2. Calculation of absolute radiometric calibration coefficient

Generally absolute calibration method yields the most accurate value since this work is performed at the time of image taking. Nevertheless, various atmospheric effect and observation error can be generated so that these would again go through continuous absolute calibration process or relative radiometric calibration using satellite images which has been validated through sufficient research to select most accurate data. By this reason, using absolute radiometric calibration result of QuickBird taken from same target at the same time with KOMPSAT-2, atmospheric radiation transfer code was supplemented and absolute radiometric calibration coefficient of KOMPSAT-2 was calculated.

3.2.1. Supplementation of atmospheric transfer code

Absolute radiometric calibration was carried out based on reflectance for the QuickBird image taken from same target with KOMPSAT-2 with time difference of 1 hour and 8 minute and difference in Gain according to availability of Offset value in linear regression was compared. Figure 7 showed graph where Offset value was allowed, whereas Figure 8 shows graph by limiting Offset value as 0.

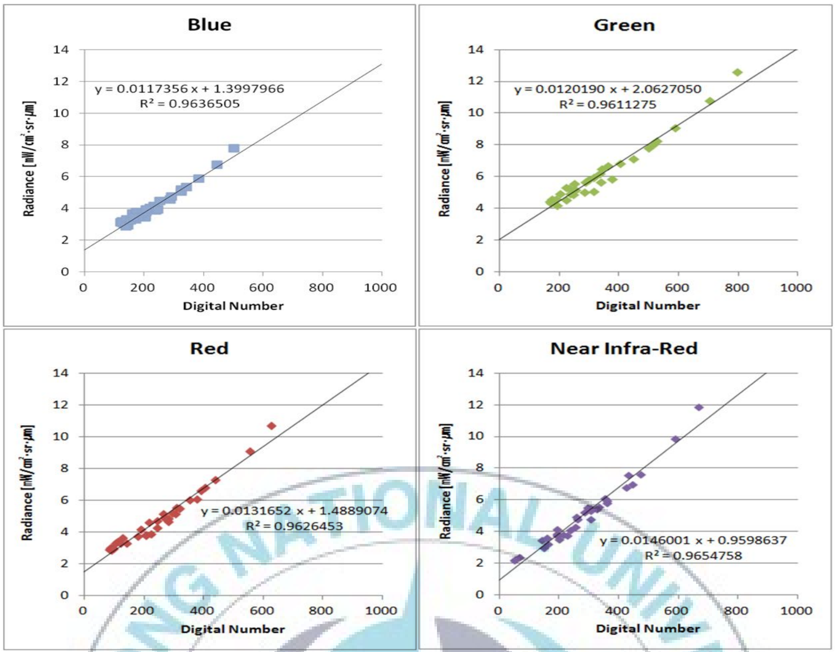

Figure 7. Results of absolute calibration of QuickBird (Offset Allow)

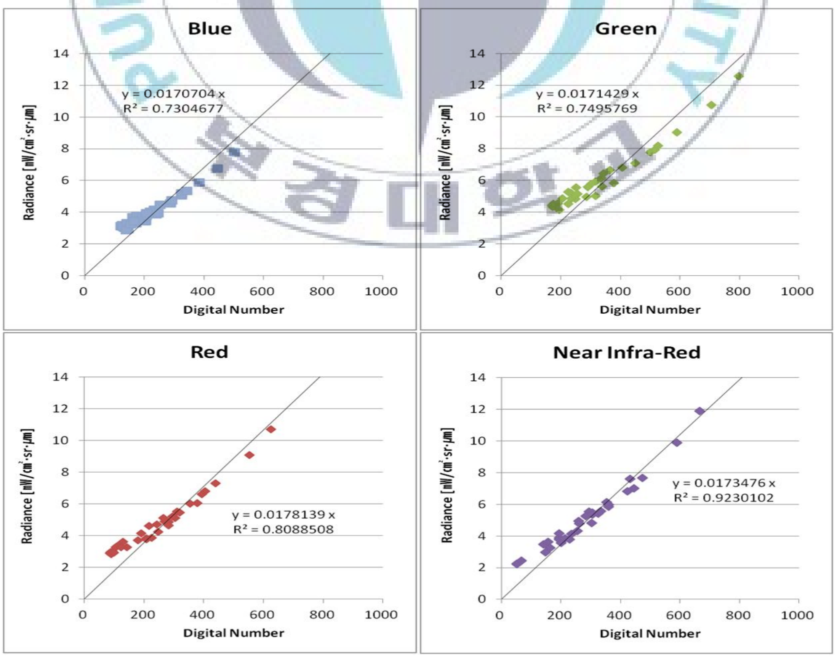

Figure 8. Results of absolute calibration of QuickBird (Offset Deny)

Table 8. Coefficient and R^2 result with availability of Offset.

Band	[Non Offset] Coefficient	R^2	[Apply Offset] Coefficient	Offset	R^2
Blue	0.0170704	0.730	0.0117356	1.3997966	0.963
Green	0.0174290	0.749	0.0120190	2.0627050	0.961
Red	0.0178139	0.808	0.0131652	1.4889074	0.962
NIR	0.0173476	0.923	0.0146001	0.0146001	0.965

Table 9. Convert Coefficient which is provided as IMD file.

Band	(A) Coefficient [.IMD]	(B) Coefficient [Non Offset]	(A)-(B)	(C) Coefficient [Apply Offset]	(A)-(C)
Blue	0.0160412	0.0170704	-0.0010	0.0117356	+0.0043
Green	0.0143847	0.0174290	-0.0030	0.0120190	+0.0024
Red	0.0126735	0.0178139	-0.0051	0.0131652	-0.0005
NIR	0.0154242	0.0173476	-0.0019	0.0146001	+0.0008

In conventional absolute radiometric calibration, since radiance can not have negative value, Offset was limited as 0 during linear regression analysis and Gain value is used instead. However, R^2 and calibration coefficient as per Offset availability were compared to judge compatibility of used atmospheric radiation transfer code. The result indicated large difference in R^2 value with Offset value as in Table 2 and with Off set value, this R^2 values were similar in all the band except at Blue Band when compared with confirmed value in this study. This difference might be caused by error generated from atmospheric observation data which were not collected at the time of field campaign and it could be eliminated by using Offset value.

3.2.2. Calculation of Absolute radiometric calibration coefficient of KOMPSAT-2

During absolute radiometric calibration of QuickBird image, we judged that improved result could be obtained by supplementing atmospheric transfer code, same atmospheric transfer code was used and absolute radiometric calibration was performed with Offset value.

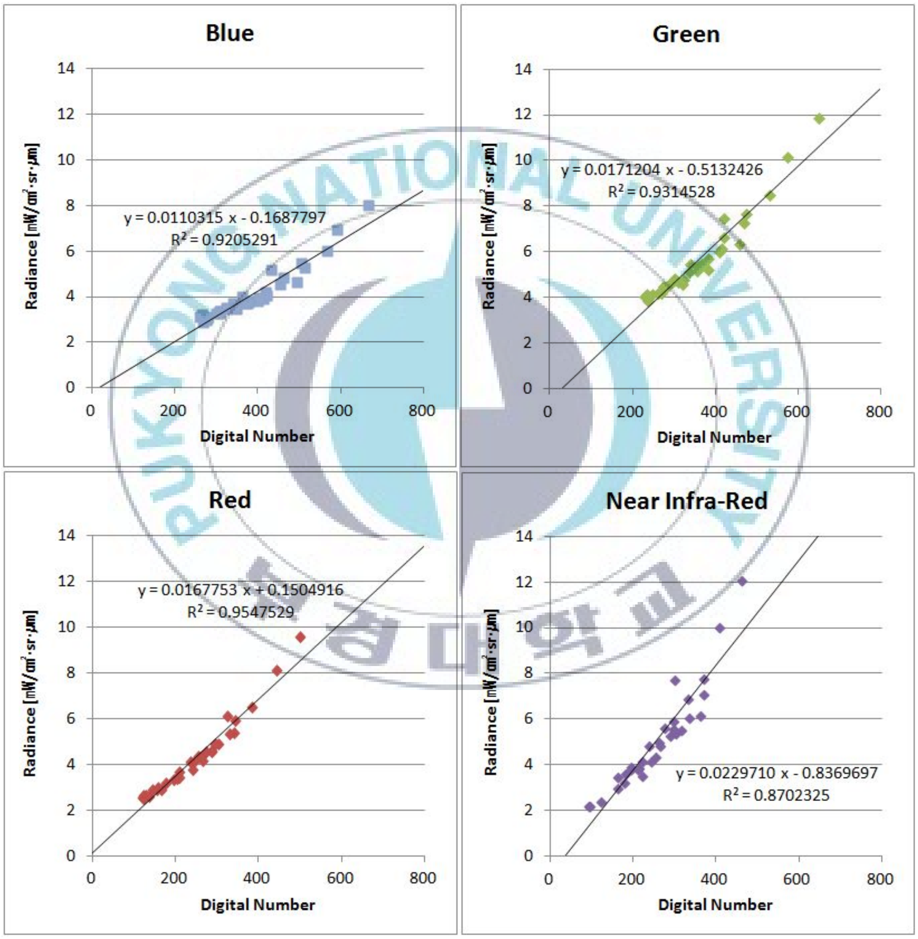

Figure 9. Absolute calibration graph of KOMPSAT-2 image

Table 10. KOMPSAT-2 image of the absolute calibration Coefficient and Offset, R^2

Band	Coefficient	Offset	R^2
Blue	0.0110315	-0.1687797	0.9205
Green	0.0171204	-0.5132426	0.9315
Red	0.0167753	+0.1504916	0.9547
NIR	0.0229710	-0.8369697	0.8702

The absolute radiometric calibration result for KOMPSAT-2 was, as shown in Table 4, 0.0110315 at Blue Band, 0.0171204 at Green Band, 0.0167753 at Red Band, and 0.0229710 at Near Infra-Red Band. Lower R^2 level as compared with that of QuickBird as in some regression graph is shown in Figure 9. Also, some part shows 2nd linear regression equation which can be regarded that though COS calibration was performed, with low solar angle and measurement error caused by diffusion might have interfered accurate result. In spite of this assumed error, higher R^2 level except at NIR Band could be judged as the results reliable.

3.3. Validation of radiometric calibration coefficient

For the validation of calculated relative radiometric calibration coefficient, it was compared with absolute radiometric calibration coefficient as in Table 5.

Table 11. Difference in radiometric calibration coefficient by absolute and relative radiometric calibration methods

Band	(A) Relative Coefficient	R^2	(B) Absolute Coefficient	R^2	|(A)-(B)|
Blue	0.0114294	0.8822	0.0110315	0.9205	0.0004
Green	0.0139369	0.8580	0.0171204	0.9315	0.0032
Red	0.0148859	0.8993	0.0167753	0.9547	0.0019
NIR	0.0151555	0.9120	0.0229710	0.8702	0.0078

Difference in coefficient level between relative radiometric calibration and absolute radiometric calibration were found as 0.0004 at Blue Band, 0.0032 at Green Band, 0.0019 at Red Band, and 0.0078 at Near Infra-Red. If these values are converted into ratio of coefficient values, there exists difference around 3% at Blue Band and around 50% at Near Infra-Red Band. Yet, considering image of KOMPSAT-2 is 10bit, the values below 4 decimal point can affect calculated radiance somewhere in between minimum 2% and maximum 7%, thereby it could make only minute problem in Radiance result at Near Infra-Red region, all in all, it would be significant coefficient.

4. Conclusion and Discussion

This study has objective of carrying out relative radiometric calibration and calculating radiometric calibration coefficient of KOMPSAT-2 through linear regression analysis with two images taken at the almost similar time line. The radiometric calibration coefficients therefore obtained were 0.0114294 at Blue Band, 0.0139369 at Green Band, 0.0148859 at Red Band, and 0.0151555 at Near Infra-Red Band. The conclusion by obtained results is as follows.

Table 12. KOMPSAT-2 coefficient by relative radiometric calibration.

	Blue Band	Green Band	Red Band	NIR Band
Relative Coefficient	0.0114294	0.0139369	0.0148859	0.0151555

First, it is possible to perform relative radiometric calibration of image taken by other satellite utilizing satellite image whose radiometric calibration was well maintained provided that images are taken with very short time interval from two satellites whose spectral characteristics are similar. This resulted fact proved merit of omitting execution of atmospheric transfer code if images were taken with very narrow time gap enough to ignore atmospheric condition. Also, theoretically Offset is not being used in absolute radiometric calibration, whereas Offset use status can be judged to supplement atmospheric transfer code in relative radiometric calibration method.

Second, radiometric calibration was performed with image taken from city not from a validation/calibration site and ultimately stable result could be acquired by using this image. Though there exists drawback of lower accuracy in the calculation result of radiometric with general images than that with validation/calibration site, it can be judged that it would be an outstanding merit to figure out trends at long term maintenance view point of satellite sensor. If more accurate radiometric calibration coefficient can be calculated with general images, Bidirectional Reflectance Distribution Function also can be considered by utilizing image taken from plain area.

Third, it was judged that error is generated by many variables during radiometric calibration. IKONOS image was taken in the month of May 2008 while image from QuickBird was taken in Nov. 2010 which creates difference in two images due to different solar angles, soil covering changes, and sensor degradation. Besides, for the occasion of automation, DN of pixels whose DN of adjourning area were similar were used for calculation introducing standard deviation in this study. Slight error was generated accordingly, but it could be resolved by directly preoccupying Pseudo Invariant Feature.

Radiometric calibration coefficient was obtained by using images from different three satellites and two methodologies. Calculated coefficient was compared with that of absolute radiometric coefficient during validation stage and difference in radiance value by applying coefficient was just maximum 7% between relative/absolute calibration techniques that result can be comfortably judged as significant. It means more efficient and accurate radiometric calibration coefficient can be calculated while using images from satellite with various method as has been performed in this study that Radiance was assumed using IKONOS image during relative radiometric calibration and atmospheric transfer code was supplemented using QuickBird image during absolute radiometric calibration process. Therefore, to improve accuracy of radiometric calibration coefficient, additional study with image taken by KOMPSAT-2 at different date needs to be pursued and the issues mentioned in this conclusion also need to be resolved. Further, long term and periodical validation·calibration should be conducted for the development of validation·calibration technique for the maintenance·correction of KOMPSAT-2 image as well as forthcoming satellites.

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