

Pre-Flight Radiometric Model of Linear Imager on LAPAN-IPB Satellite

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Abstract. LAPAN-IPB Satellite is Microsatellite class with mission of remote sensing experiment. This satellite carrying Multispectral Line Imager for captured of radiometric reflectance value from earth to space. Radiometric quality of image is important factor to classification object on remote sensing process. Before satellite launch in orbit or pre-flight, Line Imager have been tested by Monochromator and integrating sphere to get spectral and every pixel radiometric response characteristic. Pre-flight test data with variety setting of line imager instrument used to see correlation radiance input and digital number of images output. Output input correlation is described by the radiance conversion model with imager setting and radiometric characteristics. Modelling process from hardware level until normalize radiance formula are presented and discussed in this paper.

1. Introduction

Multispectral Imager is one main payload of LAPAN-IPB Satellite. This Imager Consist of 4 Channel are Blue, Green, Red, and Near Infrared. Multispectral imager on satellite show in figure 1. Imager like standard Camera can produce image with Digital Number (DN) representation of light Intensity of object in some spectral Response. Radiometric model is formula to predict radiance input value on entered in imager surface. This Model will convert each DN to radiance unit. Normally Imager have setting to enhanced of DN images for suitable image looking with high dynamic range. With Limited mechanical and electronic of Lens and CCD sensor cause different response each pixel. Need Radiometric Model to convert DN to Radiance with specific imager setting and Algorithm correction to create DN images which uniform radiance representation. Process Photon energy to DN is depends of Hardware level on CCD Sensor and Analog Digital Converter (ADC).

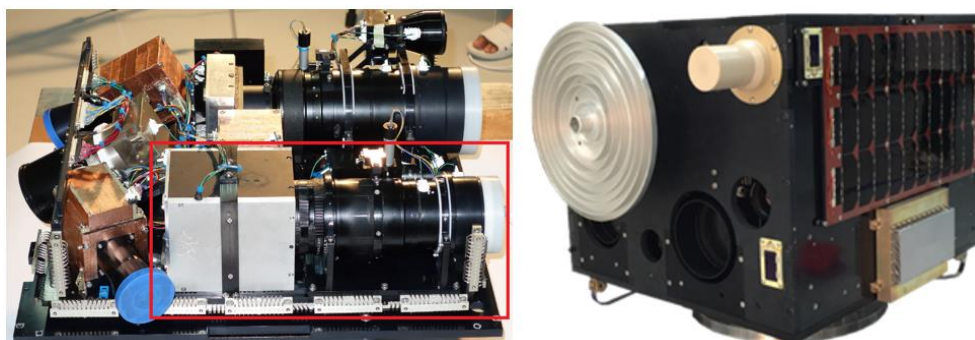


Figure 1. Multispectral imager on LAPAN-IPB Satellite.



Satellite images have own calibration and have correlation with calibration in ground or pre-flight. Possible different factor is vacuum and temperature which can't simulation in ground. The pre-flight data can be references for orbit calibration and estimation error caused and study for next calibration project. The accuracy of the pre-launch calibration is estimated to approximately 8 percent [1].

One important for radiometric quality is uniformity each pixel which describes reflectance from earth surface. First to correction is uniformity each pixel from light coming in lens surface or call path radiance before error cause external factor like atmospheric, sun angle, and terrain or variation of topography. Image after correction generally representation of dynamic range of uniform responsivity pixel of object after remove two noise parameter. Radiometric characterization of the sensor (actually whole camera) are linearity, DSNU (Dark Signal Uniformity) and PRNU (Photo Response Non Uniformity) [2].

Each imager have own structure mechanical, electronic, and methods for capture of images. Imager design decision have limitation for device used, budget, material, assembly, integration, and test for this component. The knowledge of models of these errors allows for developing some methods of reducing some of the noise and for removing some artefacts from the images [3]. Radiometric Correction algorithm is representation of hardware flow and imager setting when images captured.

2. Methodology

Hardware level is represent each parameter setting which effect DN value from ADC digitation. Model define by conversion of hardware flow to mathematic representation. Methods for radiometric calibration typically involve up to four steps [4].

1. The camera response is corrected to be linear.
2. The camera's black response is subtracted.
3. Corrections are applied for spatial variations in the effective aperture of the lens and the sensor sensitivity. This correction yields a relative radiometric calibration.
4. Converts the relative calibration to absolute calibration by applying an appropriate scaling factor.

All each parameter have Constanta based on measurement statistic. To define Parameter characteristic use two measurement, first is spectral measurement by Monochromator and second is radiometric measurement by integrating sphere with some variation setting. In the present study a monochromator is used for precise measurement of the spectral sensitivity of the camera [5]. Spectral measurement show in figure 2. Monochromator will be set to 5-10 nm from 400nm – 1100 and parallel record on four Band.



Figure 2. Test with monochromator.

First measurement for Full width at half maximum (FWHM) of four channel of camera. This useful to calculate to define part of spectral power base on FWHM of integrating sphere which already known. Second measurement to get correlation between power input and DN of images with Setting Parameter. These methods included the prelaunch calibration using spherical integrating sources [6]. Test with integrating sphere with output 14 inch describes in figure 3. Nine lamp on integrating sphere can switch on-off and one can smooth tuning with aperture control.



Figure 3. Test with integrating sphere.

3. Result and discussion

3.1. Hardware level

Hardware level of multispectral imager show in figure 4. Photon light energy will be charge photodiode array and store to CCD Cells during exposure time and conversion analogue voltage. This signal will transmit to ADC with clock transfer video signal with correlation double sampling. Signal will be add voltage from offset Digital to Analog Converter (DAC) and multiple by Power Gain Amplifier (PGA) and quantification 16 Bit ADC with range input 0-4 volt. Offset and Gain decided to control signal not saturation or Cut off.

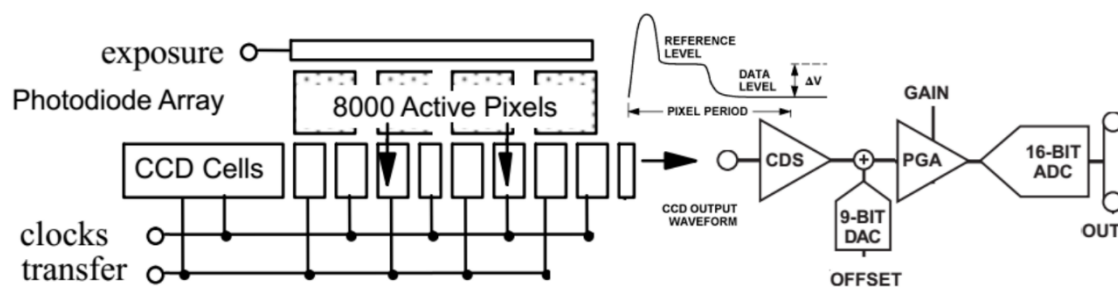


Figure 4. Hardware level diagram of multispectral imager.

On this diagram have four setting parameter will cause increase or decrease of DN value with same input. Another control like repetition line rate is not have directly effect to converting from DN to radiance. Repetition rate cause percentage of overlap each line to make image size geometry between along track in two dimensional XY. Setting value will adjust after images operate in orbit, it possible have a lot combination to get better images. For this reason all value will convert to output CCD voltage before convert to DN which uniform radiance representative. This methods to remove of signal conditioning setting.

3.2. Spectral and radiometric

On figure 5 FWHM spectral define and imager input from integrating sphere calculated beside on this FWHM. Output intensity integrating sphere not same in Multispectral channel because lamp halogen spectral characteristic. FWHM and bandwidth value describes in table 1 column number 2 and 3. Every pixel has illuminated 99.2% uniform in surface lens imager with fix power depend of lamp sphere on.

In figure 6 describes voltage to radiance. Constanta DN to radiance conversion get from DN of images after subtract by dark image and input power sphere comparison. Average voltage to radiance value conversion describes in table 1 in last column. Constanta DN to Radiance is correlation with responsivity pixel in line imager. In edge DN have more radiance representation than centre pixel because vignette effect. It is typically caused by sensor components (e.g. barrel) occluding light from the detector plane at wide angles [7].

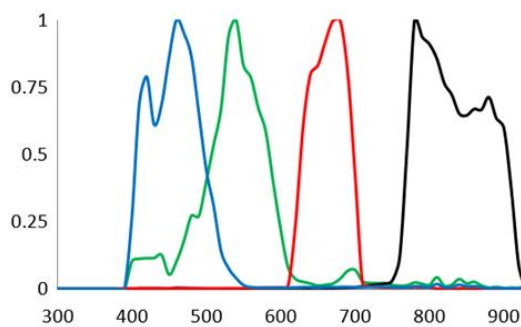


Figure 5. Normalize spectral value multispectral imager.

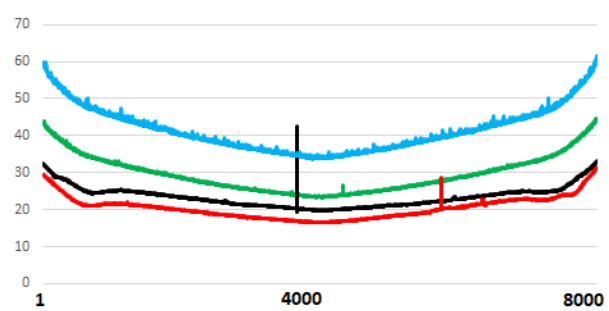


Figure 6. Voltage to radiance value Detector Index each band.

Table 1. FWHM and average radiance voltage to radiance Constanta.

Band	FWHM	Bandwidth	Radiance (mW/cm ² -sr-um)
Blue	0.410 - 0.490	0.080	41.76
Green	0.510 - 0.580	0.070	29.69
Red	0.630 - 0.700	0.070	20.45
NIR	0.770 - 0.900	0.130	23.43

3.3. Setting characteristic

Model created use voltage CCD output prediction this means precise value between nominal setting and real value is important. Exposure can set with precision 10 Nano Second. Gain have 64 setting with decibel gain, and offset will increase plus or minus 1.18 millivolt. Dark current have increase versus long time of imager ON. The setting characteristic describes in figure 7. On this result generally is same with datasheet but have small response different in high setting value.

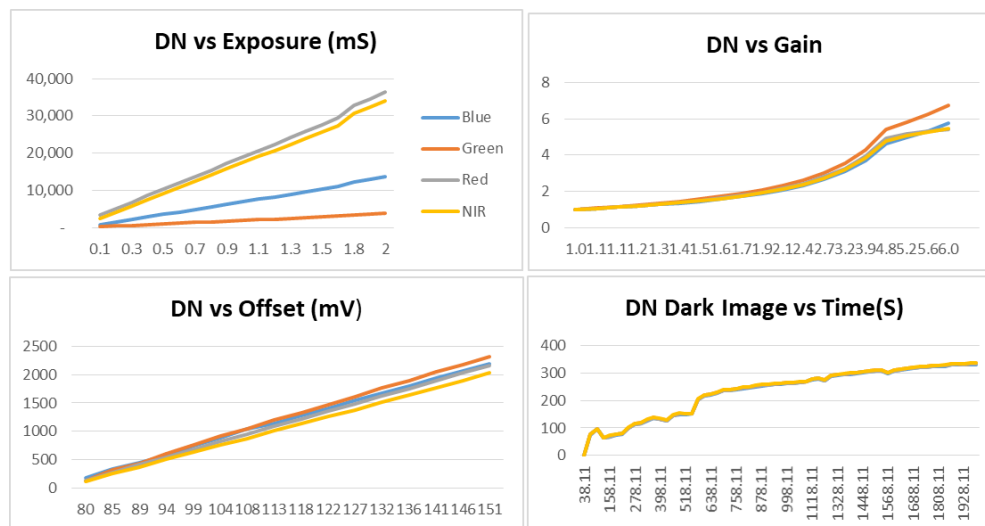


Figure 7. Setting Characteristic of average DN each channel with variety exposure, variety gain, and variety offset. Also response dark current vs time.

Table 2 describes 10 measurement procedure with variety setting and two combination value of input integrating sphere. Input each band in one procedure is different because spectral output have unique every wavelength. Value PRNU is high every procedure measurement and consistent around less than

30%. Nominal response dark DN and flat test describes in figure 8 and 9. Dark test use close lens with dark object and flat test use integrating sphere.

Table 2. Result of PRNU and DSNU calculation before correction. Measurement with input different radiance (mW/cm²-sr-μm) from integrating sphere and different setting from multispectral imager.

	1	2	3	4	5	6	7	8	9	10
Eksp (mS)	1.0	1.0	1.0	1.0	1.5	1.5	1.5	1.0	1.0	1.5
Gain	1.6	1.6	2.9	2.9	1.6	2.9	2.9	1.6	1.6	1.6
Offset(mV)	75.2	150.5	75.2	150.5	75.2	75.2	150.5	75.2	150.5	75.2
B Inp (rad)	2.8	2.8	2.8	2.8	2.8	2.8	2.8	5.6	5.6	5.6
B DSNU (%)	1.6	0.8	1.6	0.8	1.9	1.9	1.0	1.9	0.9	2.3
B PRNU (%)	27.7	27.5	28.1	27.8	27.7	27.2	27.7	27.4	27.3	27.3
G Inp (rad)	7.3	7.3	7.3	7.3	7.3	7.3	7.3	14.5	14.5	14.5
G DSNU (%)	0.6	0.4	0.7	0.5	0.8	0.9	0.6	0.8	0.6	0.9
G PRNU (%)	29.6	29.6	30.0	29.8	29.7	29.5	29.6	29.6	29.5	29.3
R Inp(rad)	12.8	12.8	12.8	12.8	12.8	12.8	12.8	25.2	25.2	25.2
R DSNU (%)	2.9	1.5	3.1	1.5	3.2	3.3	1.6	3.3	1.6	3.5
R PRNU %	29.2	29.3	29.3	29.2	29.2	29.2	29.2	29.2	29.2	28.9
N Inp (rad)	16.0	16.0	16.0	16.0	16.0	16.0	16.0	31.6	31.6	31.6
N DSNU (%)	1.5	0.6	1.4	0.6	1.8	1.5	0.6	1.68	0.6	1.9
N PRNU (%)	26.8	26.8	26.9	26.8	26.6	26.6	26.6	26.94	26.9	25.5

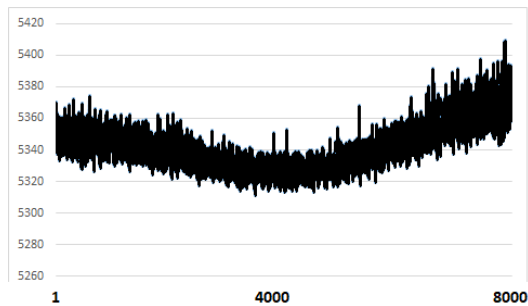


Figure 8. Uncorrected green DN vs detector index in dark test.

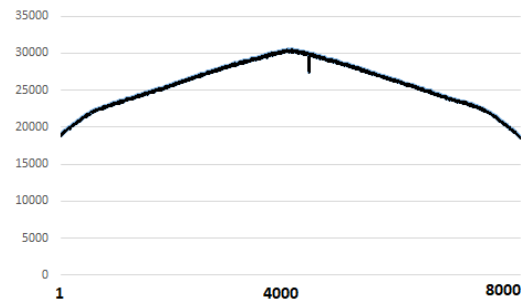


Figure 9. Uncorrected green DN vs detector index in flat test.

3.4. Radiometric model

Radiometric model formulated by mathematic model of hardware level of multispectral imager and convert from DN to voltage after subtract dark DN. Multiple voltage to radiance each detector index based on figure 6 and resampling use average gain on table 3 last column. Detail formula describes in formula 1. Example DN subtract from image 9 and 8 show in figure 10. DN after correction describes in figure 11. Correction result from table 2 show in table 3. In this table PRNU can reduce significant.

$$DN_{new_i} = \text{Int} \left(\frac{E \cdot R_i \cdot ((DN_i - DN_{dark_i}) \cdot 4/2^{16}/G) - Offset}{Radiance} \right) \quad (1)$$

DN_{new_i} : DN with Uniform radiance representation

Int : Float to Integer

E : Exposure Time
 i : number of pixel sensor in Line imager
 R_i : Responsivity each pixel i
 DN_i : Digital number of raw images
 DN_{dark_i} : Dark Digital Number
 G : Gain PGA of ADC
 $Offset$: Offset of ADC
 Radiance : Average DN to Radiance value

DN images will convert to CCD voltage output depend of imager setting and multiple by imager responsivity each pixel to find radiance pixel value. New DN is find by radiance image divide with common radiance value. These noise levels are converted from DN to radiance units using the band averaged absolute gains [8].

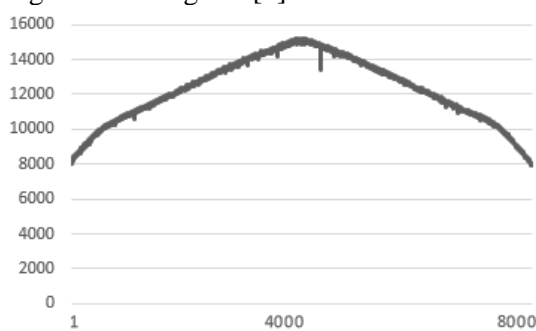


Figure 10. Green DN vs Detector Index after subtract with DN dark.

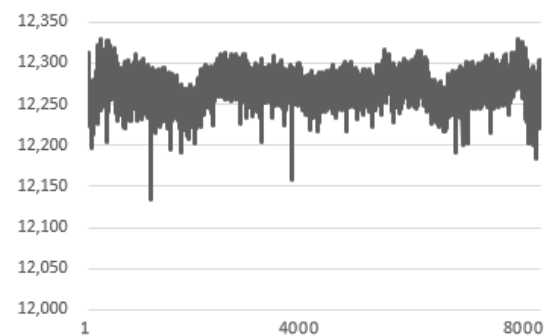


Figure 11. Green DN Corrected vs Detector Index.

Based on figure 10 relative radiometric correction can be done by normalize each pixel like figure 11 with error smaller than raw data. Relative radiometric correction is necessary to account for the detector-to-detector non-uniformity seen in raw imagery [9]. Image Before and after correction show in figure 12. On this image have little different between before and after except uniformity of sky.

However, the standard for designating the reference image needed for these methods is not unified [10]. For comparison with another image in different time need unified factor for time series analysis purpose. Two levels of radiometric correction, absolute and relative, have been developed for remote sense imagery [11]. Table 3 show DN to Radiance value get from input integrating sphere compare with DN value and parameter setting of camera and FWHM each channel. In absolute radiometric correction, atmospheric radiative-transfer codes are used to obtain the reflectance at the Earth's surface from the measured spectral radiances [12].



Figure 12. Before and after correction.

Table 3. Result of PRNU calculation after correction and gain DN to radiance ($\text{mW}/\text{cm}^2\text{-sr-}\mu\text{m}$) with offset 0 radiance.

PRNU (%)	1	2	3	4	5	6	7	8	9	10	DN to Rad
Blue	1.82	1.98	1.77	1.91	1.02	0.99	1.00	1.60	1.47	2.32	0.001505
Green	0.79	0.77	0.88	0.73	0.46	0.40	0.40	0.68	0.60	0.89	0.000599
Red	0.51	0.52	0.50	0.49	0.31	0.35	0.32	0.40	0.38	0.81	0.000738
NIR	0.47	0.47	0.39	0.42	0.55	0.57	0.57	0.47	0.44	1.21	0.000851

4. Conclusion

Radiometric model can be formulation by hardware level process to radiance conversion and normalization. With this simple model can reduce response non uniformity less 30% to less than 2%. With statistic data experiment this formula more accurate prediction. This model can be implement to radiometric correction for multispectral imager in LAPAN-IPB Satellite on Orbit.

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References

- [1] Leroy M, Henry P, Guenther B and McLean J 1990 Comparison of CNES spherical and NASA hemisphere large aperture integration sources *Remote Sens. Environ.* **31** 97-104
- [2] Misgaiski-Hass M. and Hieronymus J 2014 Radiometric Calibration of dual Sensor Camera System, a Comparison of classical and low cost Calibration *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.* **XL-5** 421-424, <https://doi.org/10.5194/isprsarchives-XL-5-421-2014>

- [3] Mansouri A, Marzani F and Gouton P 2005 Development of a protocol for CCD calibration: application to a multispectral imaging system *International Journal of Robotics and Automation* **20**(2) 94–100
- [4] Hamey L 2008 Radiometric Camera Calibration *Wiley Encyclopedia of Computer Science and Engineering* 2329-2338 DOI: 10.1002/9780470050118.ecse590
- [5] Shoji T 1999 Spectral imaging by a multichannel camera *Journal of Electronic Imaging* **8**(4) <http://dx.doi.org/10.1117/1.482702>
- [6] Thorne K, Markham B, Barker I, Slater P, and Biggar S 1997 Radiometric Calibration of Landsat *Photogrammetric Engineering & Remote Sensing* **63**(7) 853-858
- [7] Goldman D B 2010 Vignette and exposure calibration and compensation *IEEE transactions on pattern analysis and machine intelligence* **32**(12) 2276–88
- [8] Morfitt R, Barsi J, Levy R, Markham B, Micijevic E, Ong L, Scaramuzza P, Vanderwerff K 2015 Landsat-8 Operational Land Imager (OLI) Radiometric Performance On-Orbit *Remote Sens.* **7** 2208-2237
- [9] Bradley G, Henderson, Keith S, Krause 2004 Relative radiometric correction of QuickBird imagery using the side-slither technique on orbit *Proc. SPIE* **5542** Earth Observing Systems IX ; doi: 10.1117/12.559910
- [10] Yong X, Jie H, Xingfa G, Qiyue L 2017 On-Orbit Radiometric Calibration for a Space-Borne Multi-Camera Mosaic Imaging Sensor *Remote Sensing* **9** 1248 ISSN 2072-4292
- [11] Hu Y, Liu L, Liu L, Jiao Q 2011 Comparison of absolute and relative radiometric normalization use Landsat time series images *Proceedings of SPIE - The International Society for Optical Engineering* 8006. 41-. 10.1117/12.902076
- [12] Júnior DC, Osmar & Guimarães R, Silva N, Alan RG, Roberto G, Cristiano S, Carvalho PVD 2013 Radiometric Normalization of Temporal Images Combining Automatic Detection of Pseudo-Invariant Features from the Distance and Similarity Spectral Measures, Density Scatterplot Analysis, and Robust Regression *Remote Sensing* **5** 2763-2794. 10.3390/rs5062763