Pre-flight FORMOSAT-5 Relative Radiometric Calibration

Kuo-Hsien Hsu*[1], Sunny Lee[2], Cynthia Liu[3]
[1]Associate Researcher, National Space Organization, 8F, 9, Prosperity 1st Road, Science-Based Industrial Park, Hsin-Chu, Taiwan; Tel: + 886-3-578-4208#1082;
Email: khhsu@nspo.narl.org.tw

[2]Engineering Assistant, National Space Organization, 8F, 9, Prosperity 1st Road, Science-Based Industrial Park, Hsin-Chu, Taiwan; Tel: + 886-3-5784208#1078
E-mail: sunnylee@nspo.narl.org.tw

[3]Principal Researcher, National Space Organization, 8F, 9, Prosperity 1st Road, Science-Based Industrial Park, Hsin-Chu, Taiwan; Tel: + 886-3-5784208#7379
E-mail: cynthia@nspo.narl.org.tw

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ABSTRACT: The primary payload of FORMOSAT-5 (FS-5) is an optical Remote Sensing Instrument (RSI), which will provide 2-meter high-spatial-resolution imagery with one panchromatic and four multi-spectral (blue, green, red, NIR) bands. Pre-flight activities of FORMOSAT-5 RSI calibration should be accomplished before launch. In this paper, we describe the relative radiometric calibration based on on-ground measurements of darkness and uniform light-source imageries with different electronic gain settings (*G1, G2, G4*). The purpose of pre-flight relative radiometric calibration is to derive a set of relative radiometric parameters, such as *relative response* and *offset*, as an important reference for in-flight calibration. In general, the calculation can be performed by firstly removing averaged offset, and then pixel-wise normalizing of individual gray-value with averaged gray-value which extracted from uniform-light source imagery. The preliminary test and calibration results show that laboratory raw imageries with specific testing conditions, gains of *G1, G2, G4*, and compression ratio of 3.75, can be successfully calibrated. Taking *G2* result for example, standard deviation of calibrated imageries can be dramatically decreased (PAN: 70.75 to 25.64, B1: 54.24 to 15.28, B2: 38.41 to 14.85, B3: 38.41 to 14.84, B4: 46.4 to 17.26). This achievement indicates that current calibration can qualitatively and quantitatively adjust the uneven response of sensor elements observed from raw imagery to obtain a high-quality calibrated imagery.

1. INTRODUCTION

Radiometric calibration is a processing technique to correct radiometric distortions caused by atmospheric conditions, solar illumination, sensor calibration, and view angles. Two levels of radiometric calibration including absolute and relative calibration have been developed and proposed in the literature [1-5]. Absolute radiometric calibration typically attempts to correct distortions caused by overall system behavior and atmospheric effects, whereas relative radiometric calibration attempts to correct distortions due to individual detector behavior. Generally speaking, both absolute and relative radiometric calibration can be performed before satellite launch. This paper addresses the part of relative radiometric calibration for FORMOSAT-5 (FS-5).

The primary payload of FORMOSAT-5 is an optical Remote Sensing Instrument (RSI), which will provide 2-meter ground sampling distance (GSD) in panchromatic band, 4-meter GSD in multi-spectral bands (blue, green, red, NIR) and 24-kilometer swath width in the nadir direction [6]. Pre-flight activities of FORMOSAT-5 RSI calibration should be accomplished before launch. Due to uneven response of sensor elements, remote sensing image acquired by a typical linear sensor array usually exhibits the vertical stripes in image raw data. To eliminate such defect, relative radiometric calibration is necessary to be performed. In this paper, based on the assumption of linear response for each sensor element, we perform this calibration by implementing proper relative radiometric coefficients such as *relative response* and *darkness offset* of each sensor element, which should be both stored in Calibration Parameter Files (CPF) of on-ground Image Processing System (IPS) for high-level image production generation.

The remainder of this paper is organized as follows. In Sec. 2, the RSI radiometric model is presented. Sec. 3 provides the methodology of on-ground radiometric calibration in detail. Sec. 4 demonstrates the preliminary results of calibration on experimental raw imageries with specific testing conditions. Finally, the conclusions of this paper research are given in Sec. 5.

2. RSI RADIOMETRIC MODEL

Before explaining the details of the radiometric calibration, the FORMOSAT-5 RSI radiometric model is described as follows [7]:

$$C\big(b,p,G(b,j),R(b)\big) = A\big(b,p,G(b,j)\big)\cdot R(b) + N\big(b,p,G(b,j),R(b)\big) + C\big(b,p,G(b,j),0\big), \quad (1)$$

where b = 0 for panchromatic band and b = 1, 2, 3, 4 for multispectral bands; p ranges from 1 to 12000 for panchromatic band and p ranges from 1 to 6000 for multispectral bands; $G(b,j)$ is the user-selectable gains for the spectral band b as

$$G(b,j) = j, \quad (2)$$

for j = 1, 2, 4; $R(b)$ is the mean radiance level of the scene in the spectral band b in the unit of $Wm^{-2}sr^{-1}\mu m^{-1}$; $C\big(b,p,G(b,j),R(b)\big)$ is the output signal in 12-bit binary scale; $A\big(b,p,G(b,j)\big)$ is the overall conversion factor from the input radiance to the output signal code; $N\big(b,p,G(b,j),R(b)\big)$ is the detected noise in 12-bit binary scale. $C(b,p,G(b,j),0)$ corresponds to the offset of the output code. It is obtained by averaging over a large number of lines (typically 512 consecutive lines) recorded in darkness ($R(b) = 0$) for each gain $G(b,j)$ without the noise term. $A\big(b,p,G(b,j)\big)$ can be expressed as

$$A\big(b,p,G(b,j)\big) = \rho(b,p)\cdot K(b)\cdot G(b,j), \quad (3)$$

where $K(b)$ is the mean conversion factor over the whole set of pixels of that band; $\rho(b,p)$ is the relative response of each pixel compared to $K(b)$. Substituting Eq.(3) into Eq.(1) and ignoring the detected noise $N\big(b,p,G(b,j),R(b)\big)$ that can be eliminated by taking averages over 512 consecutive lines within an uniform radiance scene, we are able to estimate the radiance from the following radiance conversion equation

$$R(b) = \frac{C\big(b,p,G(b,j),R(b)\big) - C\big(b,p,G(b,j),0\big)}{\rho(b,p)\cdot K(b)\cdot G(b,j)}. \quad (4)$$

3. ON-GROUND RADIOMETRIC CALIBRATION

The objective of on-ground calibration is to complete pre-flight RSI radiometric calibration and to derive the radiometric parameters for radiance conversion process. All required calibration parameters are determined by the following procedures [8]:

1. Calculate $C(b,p,G(b,j),0)$ by averaging over 512 consecutive lines recorded in darkness for each gain $G(b,j)$.
2. Calculate $\rho(b,p)$ by averaging over 512 consecutive lines within a uniform radiance scene to eliminate the noise. Note that $\bar{C}$ stands for the average value of the parameter C over the set of 512 consecutive lines. That is,
$$\rho(b,p) = \frac{\bar{C}\big(b,p,G(b,j),R(b)\big) - \bar{C}\big(b,p,G(b,j),0\big)}{\frac{1}{p(b)}\cdot\sum_{p=1}^{p(b)}\big[\bar{C}\big(b,p,G(b,j),R(b)\big) - \bar{C}\big(b,p,G(b,j),0\big)\big]}. \quad (5)$$
3. Calculate $K(b)$ by averaging 512 consecutive lines within a uniform radiance scene of known radiance level $R(b)$ to eliminate the noise. That is,
$$K(b) = \frac{\frac{1}{p(b)}\cdot\sum_{p=1}^{p(b)}\big[\bar{C}\big(b,p,G(b,j),R(b)\big) - \bar{C}\big(b,p,G(b,j),0\big)\big]}{G(b,j)\cdot R(b)}. \quad (6)$$

Taking *G2* result for example, relative response and offset of all bands with compression ratio (CR) of 3.75 are presented in Table 1 and Table 2, respectively. Basically, one CMOS sensor is composed with four smaller equal-sized sensor chips. Due to non-identical performance of sensor chips, some observations from Table 1 and Table 2 are found that significant edge effect between sensor chips, and very few hot-pixel elements. Additionally, performance of each chip is quiet different and independent of each other. Mathematically speaking of such condition, normalization equalization of relative radiometric calibration should be performed iteratively to achieve certain quality criteria.

Gain level	Relative response of PAN and MS bands (B side, CR = 3.75)

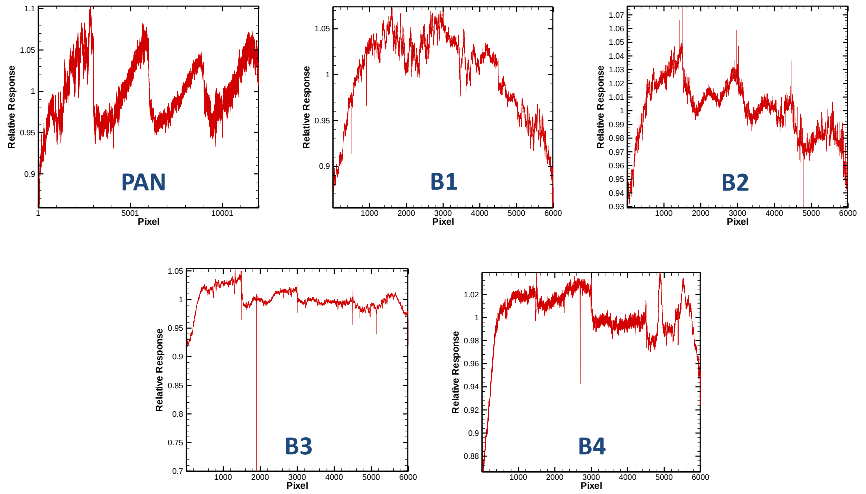
$G2 = G(b, 2)$	

Table 1. Distribution of relative response of panchromatic (PAN) and multi-spectral (MS) bands as function of pixel index for different gain levels with compression ratio (CR) of 3.75.

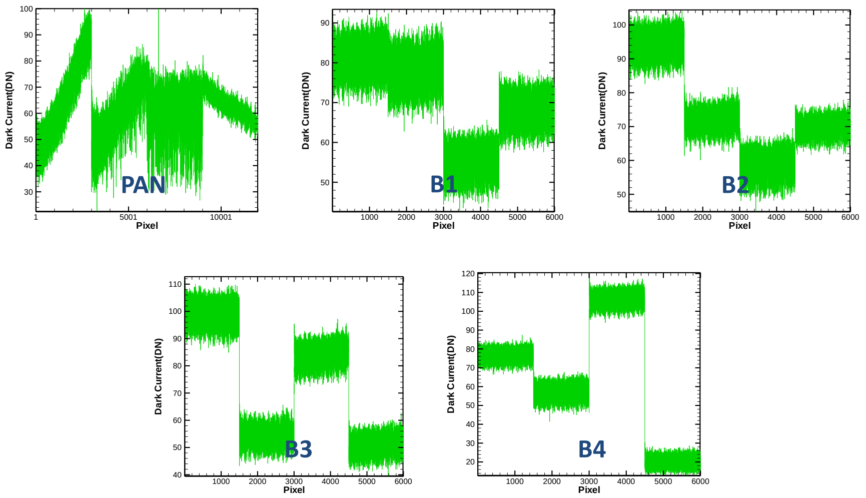
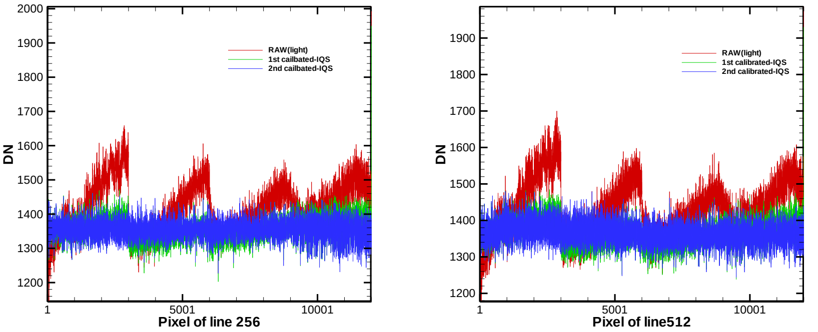
Gain settings	Offset of PAN and MS bands (B side, CR = 3.75)
$G2 = G(b, 2)$	

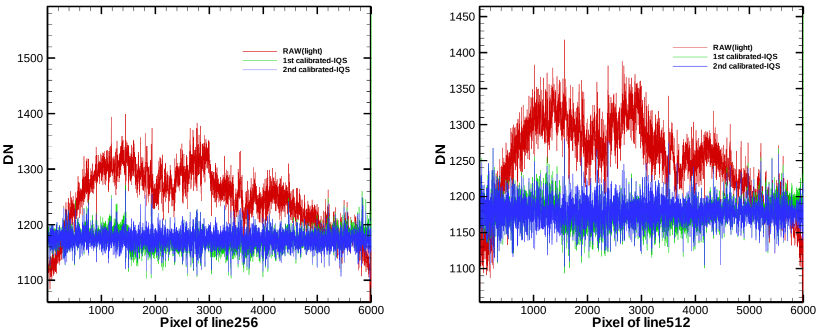
Table 2. Distribution of offset of panchromatic (PAN) and multi-spectral (MS) bands as function of pixel index for different gain levels with compression ratio (CR) of 3.75.

4. EXPERIMENTAL RESULTS

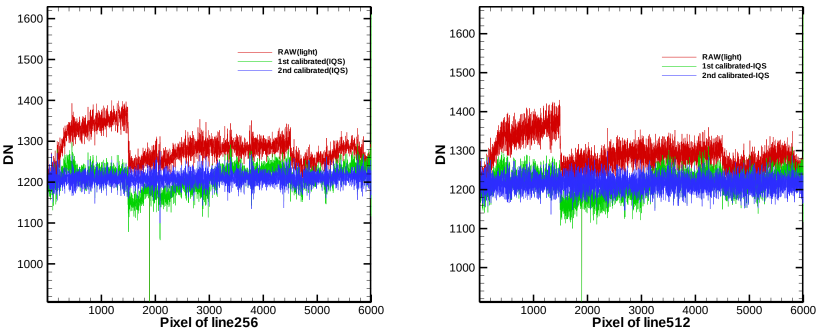
According to the radiometric parameters determined by the above methodology, the calculation can be performed by firstly removing averaged offset, and then pixel-wise normalizing of individual gray-value with averaged gray-value which extracted from uniform-light (radiance) source imagery. By selecting gray-value along line 256 and 512 within the experimental raw image, Fig. 1 demonstrates the calibrated results with specific gain level of *G2* and compression ratio of 3.75 for each band. Both for the selected line 256 and 512 of raw image, the variation of gray-value (DN) in terms of pixel can be dramatically decreased from manual inspection process. Such achievement also can be statistically evaluated by examining their standard deviation (STD) of raw and calibrated images in Table 3 to Table 5 for *G1*, *G2*, and *G4* settings, respectively. Overall speaking, the percentage of STD difference of raw and calibrated image ranges from 43% to 78%, which indicates the effectiveness of relative radiometric calibration.


RAW(light)
1st cailbated-IQS
2nd cailbated-IQS
DN
Pixel of line 256
RAW(light)
1st calibrated-IQS
2nd calibrated-IQS
DN
Pixel of line512

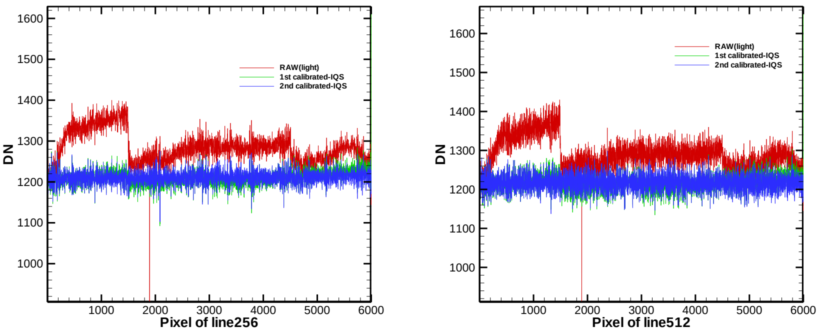
(a)


RAW(light)
1st calibrated-IQS
2nd calibrated-IQS
DN
Pixel of line256
RAW(light)
1st calibrated-IQS
2nd calibrated-IQS
DN
Pixel of line512

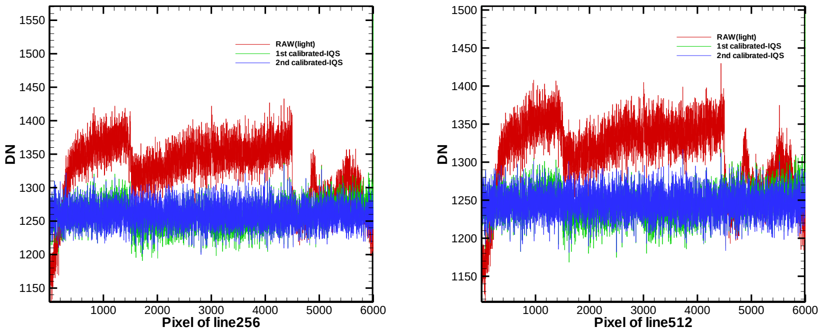
(b)


RAW(light)
1st calibrated(IQS)
2nd calibrated(IQS)
DN
Pixel of line256
RAW(light)
1st calibrated-IQS
2nd calibrated-IQS
DN
Pixel of line512

(c)


RAW(light)
1st calibrated-IQS
2nd calibrated-IQS
DN
Pixel of line256
RAW(light)
1st calibrated-IQS
2nd calibrated-IQS
DN
Pixel of line512

(d)



(e)

Fig. 1. Calibrated results with gain of *G2* and compression ratio of 3.75 for (a) PAN, (b) B1, (c) B2, (d) B3, and (e) B4, respectively.

Band	Line	STD (B side, uniform-light source, *G1*, CR = 3.75)		
		raw (A)	calibrated (B)	ratio ($\frac{A-B}{A}\cdot 100$)
PAN	Line 256	60.69	17.64	70.93
	Line 512	60.77	15.16	75.05
B2	Line 256	39.70	11.11	72.02
	Line 512	39.54	11.83	70.08
B3	Line 256	35.52	12.35	65.23
	Line 512	34.87	12.51	64.12
B4	Line 256	43.46	10.29	76.32
	Line 512	43.75	9.19	78.99

Table 3. STD examination corresponding to the calibrated results with gain level of *G1*.

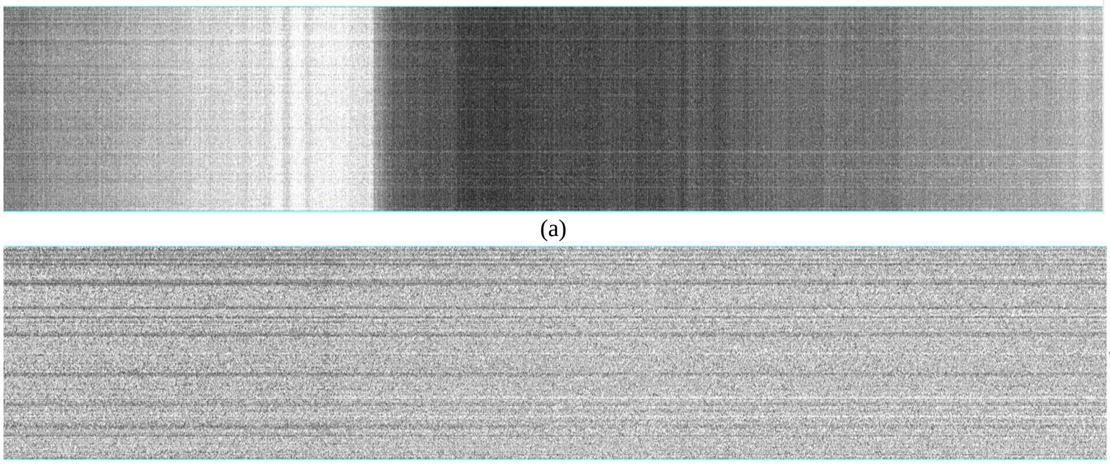
Band	Line	STD (B side, uniform-light source, *G2*, CR = 3.75)		
		raw (A)	calibrated (B)	ratio ($\frac{A-B}{A}\cdot 100$)
PAN	Line 256	70.75	25.64	63.76
	Line 512	74.30	28.60	61.51
B1	Line 256	54.24	15.28	71.83
	Line 512	54.64	17.39	68.17
B2	Line 256	38.41	14.85	61.34
	Line 512	41.83	19.64	53.05
B3	Line 256	38.41	14.84	61.36
	Line 512	41.83	19.64	53.05
B4	Line 256	46.40	17.26	62.80
	Line 512	46.14	17.60	61.86

Table 4. STD examination corresponding to the calibrated results with gain level of *G2*.

Band	Line	STD (B side, uniform-light source, *G4*, CR = 3.75)		
		raw (A)	calibrated (B)	ratio ($\frac{A-B}{A}\cdot 100$)
PAN	Line 256	109.49	52.55	52.00
	Line 512	109.54	61.98	43.42
B2	Line 256	59.25	26.21	55.76
	Line 512	57.36	24.10	57.98
B3	Line 256	58.02	25.95	55.27
	Line 512	59.88	27.58	53.94
B4	Line 256	53.51	22.40	58.14
	Line 512	59.17	31.48	46.80

Table 5. STD examination corresponding to the calibrated results with gain level of *G4*.

Practically, the relative response and darkness offset of all bands in terms of pixels do not always have the identical behavior which lead to generation of vertical stripes in raw image with uniform radiance (as shown in Fig. 2(a)). Validation is processed by successfully removing such vertical stripes by utilizing determined relative response and darkness offset. Fig. 2(b) shows the calibrated raw image without any vertical stripes. Additionally, significant edge effect between chips is also eliminated.



(a)

(b)

Fig. 2. Validation of relative radiometric calibration: (a) raw image; (b) radiometrically calibrated image.

5. CONCLUSIONS

The pre-flight FORMOSAT-5 relative radiometric calibration is an essential work before launch. In this paper, we introduced the RSI radiometric model of FORMOSAT-5 satellite firstly. Secondly, the method of on-ground radiometric calibration was presented. The relative radiometric parameters including relative response and offset are important references for in-flight calibration in the future. Thirdly, the experimental results were analyzed by standard deviation examination. The achievement indicated that current calibration can qualitatively and quantitatively adjust the uneven response of sensor elements observed from raw imagery to obtain a high-quality calibrated imagery.

6. REFERENCES

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