CCD Pixel Correction Table Generation for MSC

Young Sun Kim*, Jong-Pil Kong, Haeng-Pal Heo, Jong-Euk Park
and Hong-Yul Paik

Korea Aerospace Research Institute, Eun-Dong 45, Yusung-Gu, Daejon, Korea

*yskim1203@kari.re.kr

kjp123@kari.re.kr

hpyoung@kari.re.kr

pje@kari.re.kr

phy@kari.re.kr

Abstract: Not all CCD pixels generate uniform value for the uniform radiance due to the different process of manufacture and each pixel characteristics. And the image data compression is essential in the real time image transmission because of the high line rate and the limited RF bandwidth. This pixel's non-uniformity and the loss compression make CCD pixel correction necessary in on-orbit condition. In the MSC system, the NUC unit, which is a part of MSC PMU, is charge of the correction for CCD each pixel. The correction is performed with the gain and the offset table for the each pixel and the each TDI mode. These correction tables are generated and programmed in the PMU Flash memory through the various image data tests at the ground test. Besides, they can be uploaded from ground station after on-orbit calibration. This paper describes the principle of the table generation and the test way of the non-uniformity after NUC

Keywords: NUC, MSC, Gain, Offset CCD

1. Introduction

The MSC(Multi-Spectral Camera) shall be integrated into the KOMPSAT 2, which is a LEO spacecraft and will be used to generate observation imagery data in two main cameras: a PAN(panchromatic) camera and a MS(Multi-Spectral) camera with 4 different spectral bands. EOS(Electro-Optical Subsystem) in the MSC is to obtain data for high-resolution images by converting incoming light into digital stream of pixel data. This data converting is accomplished by CCD(Charge Coupled Device) detector.

The ideal CCD has to give uniform signal level for the uniform radiance. But, practically, not all CCD pixels generate uniform value for the uniform radiance due to the different process of manufacture and each pixel characteristics. That is to say, it is necessary to overcome the non-uniformity of the CCD's photo-response. This non-uniformity can be measured and calculated through the special tests. This characteristic can usually be compensated in the ground station after receiving image data from satellite. But, unfortunately, the image data compression in the MSC is essential in the real time image transmission because of the high data transmission rate and the limited RF bandwidth. This loss compression make CCD pixel correction necessary in on-orbit condition, which is done by NUC(Non-Uniformity Correction Unit) using the correction tables.

This table consists of the gain and the offset tables. In this paper, the specific method to generate the CCD correction table will be shown. The generation methods will be described for the PAN camera and the MS camera separately considering the NUC unit's function and the limitation. Specially, the correction algorithm for the PAN camera will consider not only the CCD characteristics but also whole optics system.

2. NUC Unit's Role and its limitation

The NUC unit in the MSC system is a high speed high throughput image processing unit and performs all pixels' correction with the gain and the offset tables for all the TDI(Time Delay Integration) modes. Additionally, the NUC unit rearranges the MS camera's pixel stream, combines video data with uploaded headers and receives and adds ancillary data to imagery header. In these functions, the CCD correction function is the most important function for image quality point of view because the compression unit after NUC correction will discard the CCD non-uniformity characteristics. This compression process is necessary in the real time image transmission due to the high transmission rate and the limited RF bandwidth. So, this correction cannot be in the ground station and should be done in on-orbit condition to make more accurate image.

The non-uniformity correction is common to all video channels and all TDI modes. The NUC unit stores correction tables in the SRAM. Simply, the NUC block operates on input data as in

$$Px_{out} = Px_{in} \times (1 + Gain/1024) + Offset \qquad (1)$$

Eq. (1) shows the basic correction method using the gain and offset table. However, due to the memory size limitation of the NUC unit, each gain value and offset value has 8 bits' size. Due to these reasons, the maximum gain value is fixed as 1.25 and the maximum offset 255 respectively. This NUC unit's limitation makes the new correction table generation method for the PAN camera comparing to the MS camera.

3. Correction Table Generation Algorithm

In the MSC, the PAN camera and the MS camera have different image shapes due to the different optics and the different DFPA(Detection Focal Plane Assembly).

1) Basic Algorithm

The basic generation algorithm for correction table is simple as in

$$P_{ideal} = Gain(i)P(i) + Offset(i) \qquad (2)$$

where *P_ideal* is desired pixel value for all pixels, *Gain(i)* is *i*th pixel's gain, *Offset(i)* is *i*th pixel's offset and *P(i)* is the each pixel's measurement value.

In Eq. (2), there is two unknown numbers, which are the gain and the offset. In order to achieve two unknown numbers, we need two equations at least. It makes more accurate solutions to get two equations from high signal and low signal. So, we can make two equations as in

$$\begin{aligned} P_{hA} &= Gain(i)P_h(i) + Offset(i) \\ P_{lA} &= Gain(i)P_l(i) + Offset(i) \end{aligned} \qquad (3)$$

where subscript *A* means average value of all pixels for the same radiance and *h* and *l* means high radiance and low radiance respectively as inputs.

2) Correction Algorithm for PAN Camera

The PAN camera is based on 3 detectors each having three linear arrays of pixels. Each band has 5,000 pixels, and has selectable 5 TDI levels. The requirement for the PAN camera is to deliver 15,000 active pixels per line. Three detectors are butted together to form a line of 15,000 active pixels. The incorporation covers all swath width. This butted DFPA structure, a number of pixel number and optics characteristics makes big gain value and offset value at the both sides and the butting zone. As well, due to the NUC board's limitation, the basic correction algorithm cannot be applied. Fig. 1 shows the PAN camera output characteristics for the uniform radiance. From this figure, we can know that the PAN camera has low frequency factor as well as CCD's high frequency non-uniformity.

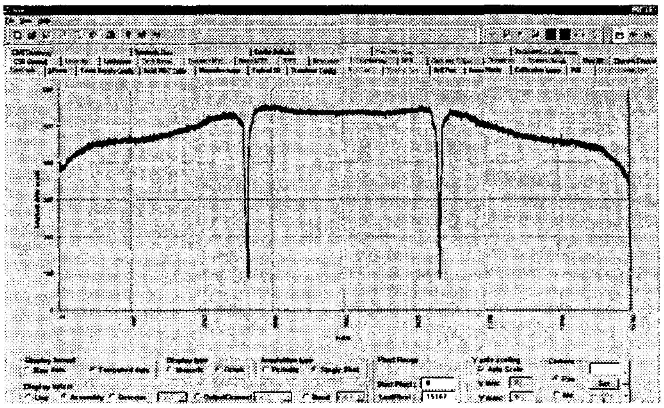

Fig. 1. PAN Camera Signal for the uniform radiance

In the case of the PAN camera, the low frequency part and the high frequency part should be separated because of PAN camera characteristics and NUC board's limitation. The high frequency correction will be done by NUC unit and low frequency correction will be done by ground station. Even if compression module in the MSC performs loss compression, the low frequency part remains as it is, and only the high frequency part will be discarded. That is to say, the low frequency part can be corrected by ground station during image procession.

In order to obtain the PAN CCD correction table, there are a few steps. Fig. 2 describes these steps. For the first step, the raw signal will have high frequency noise and low frequency noise as shown in Fig. 1. Using this raw data, low frequency vector can be achieved as Eq. (4)

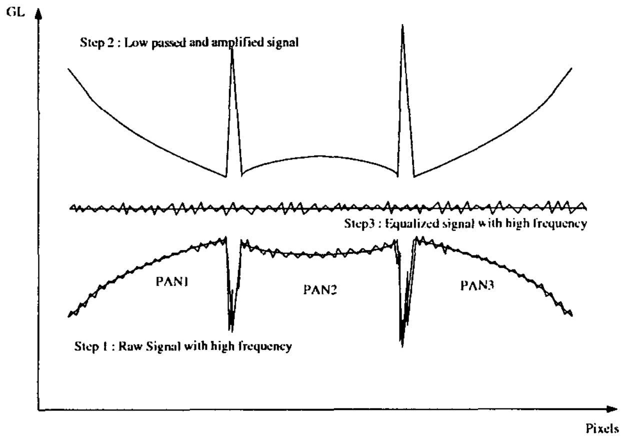

Fig. 2. CCD Correction table generation method for PAN camera

$$\begin{aligned} LF_h(i) &= \frac{Sig_{max}}{Sig_{h\_LPF}(i)} \\ LF_l(i) &= \frac{Sig_{max}}{Sig_{l\_LPF}(i)} \\ LF(i) &= Opt(LF_h, LF_l) \end{aligned} \qquad (4)$$

If multiplying the low frequency vector to image data, the image data will be placed on the equalized position. Now, by Eq. (3), high frequency gain and offset can be calculated using this equalized signal.

However, mentioned above, due to the NUC board's limitation, the no gain should be less than 1.0 and offset should not be negative as well. So it needs the normalization. This normalization will be done by Eq. (5)

$$Gain_i = \frac{Gain_i}{Gain_{\min}}$$
$$Offset_i = Offset_i - Offset_{\min} \qquad (5)$$

These calculated gain and offset will be used in the NUC unit and will be corrected using Eq. (6)

$$P_{hf}(i) = P_i(i) \cdot Gain(i) + Offset(i) \qquad (6)$$

For the more, it is needed to calculate 2nd low frequency vector using the corrected signal, which is by corrected calculated gain and offset, in order to get more accurate image data. After obtaining 2nd low frequency vector for the high signal and the low signal, the final 2nd low frequency vector can be optimized as in

$$LF_{cor}(i) = Opt(LF_{h\_cor}, LF_{l\_cor}) \qquad (7)$$

The low frequency correction with high frequency corrected data, which is final step, will be done by Eq. (8). This step will be done in ground station after receiving image data.

$$P_{hf\&lf}(i) = P_{hf}(i) \cdot LF_{cor}(i) \qquad (8)$$

3) Correction Algorithm for MS

The correction algorithm for the MS camera is simple because the MS camera does not have low frequency term. So, Eq. (2) is directly applied to get high frequency gain and offset and can be normalized by Eq. (5). In addition, due to this reason, the ground station does not need to do low frequency correction.

3. Algorithm Verification

To verify this algorithm, the special test software is implemented. This software makes the simulated camera signal assuming the uniform radiance. This simulated data for the PAN camera has low frequency term and high frequency term and for the MS camera only has the high frequency term. In this simulation, the high frequency term, that is the gain and the offset, is generated by random number generator.

1) Verification of PAN CCD Correction Algorithm

The gain and the offset is verified by comparing the simulated value, which is generated by random number generator, and calculated value which is calculated by NUC table generation algorithm mentioned before. In this simulation, butting zone simulation is omitted because this algorithm verification is not necessary. In this step, to determine the gain and the offset, the nominal high signal level and the low signal level is used as 800GL and 300 GL respectively. Fig. 3 and Fig. 4 show these test results and this algorithm can track properly.

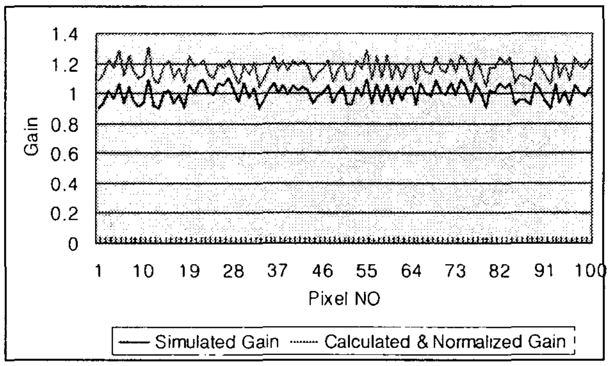

Fig. 3. The Gain Tracking for PAN Camera

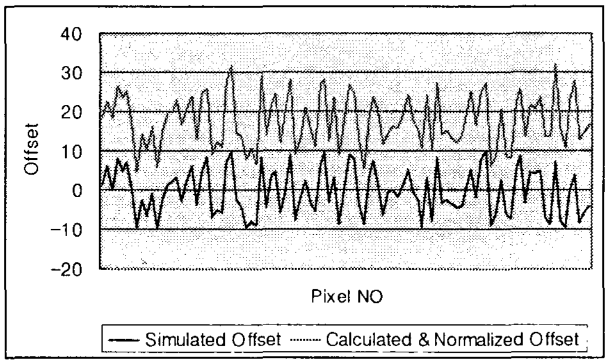

Fig. 4. The Offset Tracking for PAN Camera

To verify if it can be applied to all the illumination level the 600 GL level is used as sample. Fig. 6 shows the high frequency correction result for the sample. This figure describes the corrected data does not have high frequency term.

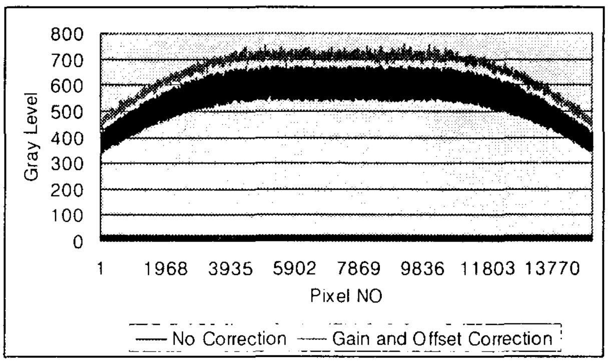

Fig. 5. High Frequency Correction for PAN Camera

Fig. 6 shows the correction results for both the high frequency and low frequency terms. As shown in figure, when the 1st low frequency vector is used, some disturbance at both sides is shown. This is due to the normalization for the gain and the offset. If the 2nd low frequency vector is used to reconstruct, there is not this kind phenomenon. This result shows that it is better to obtain the final corrected data using 2nd low frequency vector. This final process may be done by ground station.

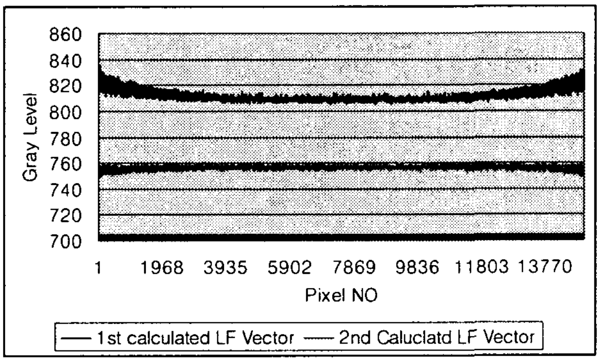

Fig. 6. Correction using 2nd LF Vector

2) Verification of MS CCD Correction Algorithm

In the case of MS camera, the gain and the offset can be got much easily. For the MS camera, we don't need to get low frequency vector because this camera does not have any low frequency term.

Fig. 7 and Fig. 8 show the gain and the offset tracking results and good tracking results.

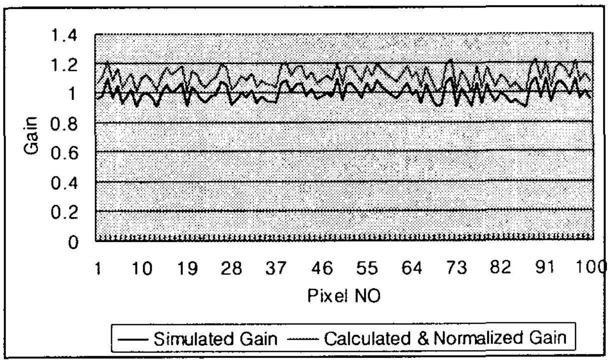

Fig. 7. The Gain Tracking for MS Camera

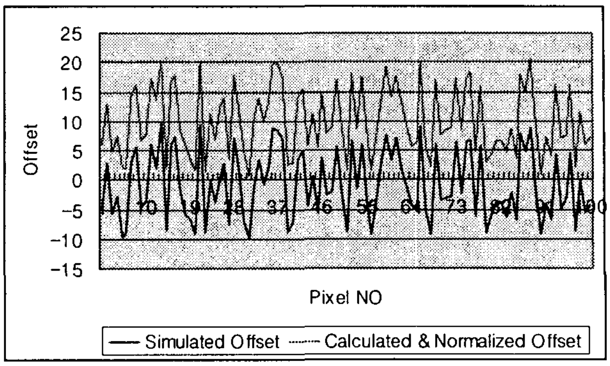

Fig. 8. The Offset Tracking for MS Camera

For the MS camera as well, to verify if it can be applied to all the illumination level, the 600 GL level is used. Fig. 9 shows this high frequency correction result for the sample. This figure describes that this correction algorithm deletes CCD pixel's non-uniformity properly.

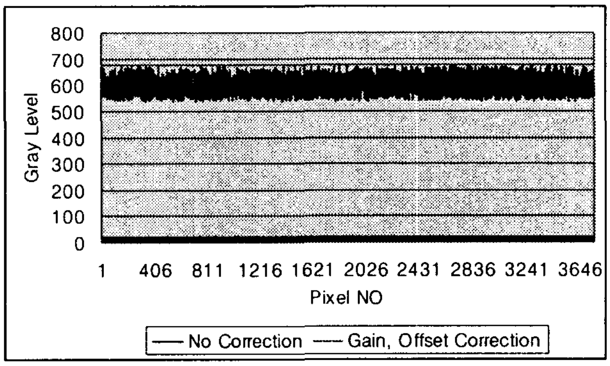

Fig. 9. High Frequency Correction for MS Camera

4. Conclusions

Not all CCD pixels generate uniform value for the uniform radiance due to the different process of manufacture and material characteristics. In the MSC system, the NUC unit is charge of the correction for CCD pixel using the correction tables. This paper describes the principle of the table generation for the PAN camera and the MS camera respectively. Specially, the generation algorithm for the PAN camera considered not only the CCD characteristics but also whole optics system because this camera has the high frequency term and the low frequency term simultaneously for the uniform radiance. This paper also shows this algorithm verification results through various simulations.

References

[1] MIL-STD-454 Standard General Requirements for Electronic Equipment.

[2] A. P. Malvino, 1995, Electronic Principles, Los Angeles: McGraw-Hill.

[3] NUC Hardware Assembly Specification.

[4] EOS EGSE Software Requirement Specification.