New In-Orbit Pixel Correction Method

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ABSTRACT:

All CCD pixels do not react uniformly even if the light of same radiance enters into the camera. This comes from the different camera optical characteristics, the read-out characteristics, the pixel own characteristics and so on. Usually, the image data of satellite camera can be corrected by the various image-processing methods in the ground. However, sometimes, the in-orbit correction is needed to get the higher quality image. Especially high frequency pixel correction in the middle of in-orbit mission is needed because the in-orbit data compression with the high frequency loss is essential to transmit many data in real time due to the limited RF bandwidth. In this case, this high frequency correction can prevent have to have any unnecessary high frequency loss. This in-orbit correction can be done by the specific correction table, which consists of the gain and the offset correction value for each pixel. So, it is very important to get more accurate correction table for good correction results. This paper shows the new algorithm to get accurate pixel correction table. This algorithm shall be verified theoretically and also verified with the various simulation and the test results.

KEY WORDS: Non-uniformity, CCD, High Frequency, Low Frequency, Limitation of On-board Calibration

1. Introduction

The ideal CCD has to give uniform signal level for the uniform radiance. However, practically, not all CCD pixels generate uniform value for the uniform radiance. This non-uniformity comes from the different optical characteristics, the read-out characteristics, the pixel own characteristics and so on. 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 corrected through the special calibration. Usually, the image data of satellite camera can be corrected by the various image processing methods in the ground. However, it is needed the high frequency non-uniformity correction in the middle of in-orbit mission because the in-orbit data compression with the high frequency loss is essential to transmit many data in real time due to the limited RF bandwidth.

The typical camera system has the low frequency and the high frequency non-uniformity together. The low frequency mostly comes from the optical characteristics, and the high frequency is mainly from the CCD own characteristics. If the uniformity correction is totally performed in the ground, it is not necessary to separate the low frequency term and the high frequency term. However, unfortunately, it is needed since the in-orbit correction has some limitations.

This paper shows the specific method for correction of the high frequency and the low frequency non-uniformity using the non-uniformity correction table. This table may consist of the gain and the offset value. In addition, the idea to generate the more accurate table shall be shown with various simulations.

2. Algorithm for Non-uniformity Correction Table Generation

The non-uniformity correction is mandatory because the in-orbit compression unit will discard the high frequency data as the low pass filter does. This compression process is necessary in the real time image transmission due to the high transmission rate and the limited RF bandwidth. Thus, the high frequency non-uniformity should be performed in in-orbit condition before data compression.

2.1 Limitation of On-board Correction

If the non-uniformity correction is performed on board, we have to consider several limitations. First, the maximum value to correct the non-uniformity is limited due to the confliction of the memory limitation and the required accuracy. This makes the high frequency and the low frequency separate. Second, the high speed is needed since the non-uniformity correction is performed in the image data stream with the high speed. This requires the hardware implementation of the correction algorithm instead of the software. Since it is hard to implement the floating or the signed operation by the hardware, the normalization of the gain and the offset value is needed.

2.2 Basic Algorithm

The basic algorithm for correction table is simple as in

$$P_{ideal} = Gain(i) \cdot P(i) + Offset(i) \qquad (1)$$

where P_{ideal} is desired pixel value for all pixels, $Gain(i)$ is ith pixel's gain, $Offset(i)$ is ith pixel's offset and $P(i)$ is the each pixel's measurement value.

In Eq. (1), 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 the high signal and the low signal. So, we can make two equations as in

$$\begin{aligned} P_{h\_ideal} &= Gain(i)P_h(i) + Offset(i) \\ P_{l\_ideal} &= Gain(i)P_l(i) + Offset(i) \end{aligned} \qquad (2)$$

where subscript h and l represent the high radiance and the low radiance respectively as inputs.

2.3 Correction Algorithm of Practical System

Since the typical optical system is focused on the center of whole detector, the small radiance arrived relatively in the both sides. This kind of optical characteristics makes the low frequency term. On the other hand, the high frequency term is from the CCD own characteristics as explained.

Figure 1 shows the example of the output characteristics of typical electro-optical system for the uniform radiance. From this figure, we can know that the system has the low frequency factor as well as the high frequency non-uniformity.

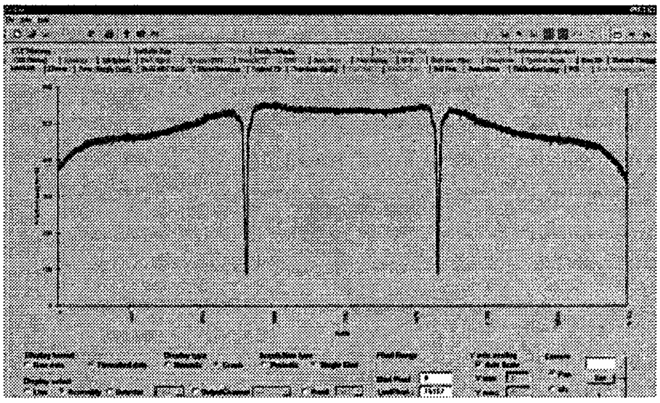

Figure 1. Example of typical electro-optical system

If the on-board calibration has no limitation, the high frequency and the low frequency correction can be performed at the same time. But, practically, the low frequency part and the high frequency part should be separated because the on-board's limitation exists. The high frequency correction will be performed on on-board unit and the low frequency non-uniformity can be recovered by image processing in ground station. Even if the compression module in in-orbit performs lossy compression, the low frequency part remains as it is, and only the high frequency part will be removed.

In order to generate the correction table, there are a few steps. Figure 2 describes these steps. The correction table can be acquired through step 1 to step 3 as shown in the figure. The raw signal, which is acquired in the step 1, may have the high frequency and the low frequency noise together. In the next section, the step 2 and the step 3 shall be described in detail.

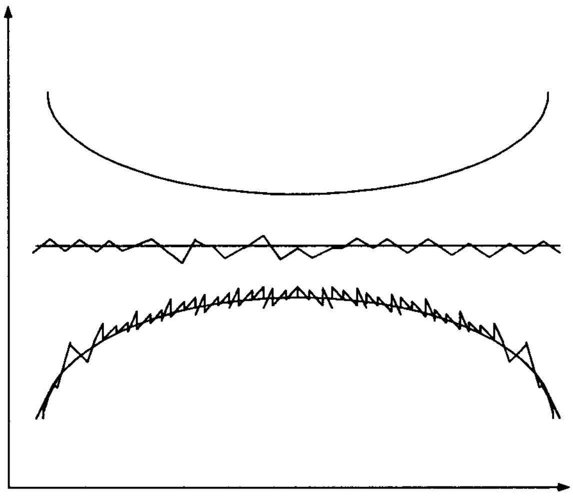

Figure 2. CCD correction table generation method for typical electro-optical camera

2.3.1 Generation of Low Frequency Gain table

This low frequency non-uniformity mainly comes from the optical characteristics. To calculate the low frequency gain, we can use a smoothing filter N around a given pixel. For the calculation, we will also use the values obtained at the high illumination $V_H[i]$ and the low illumination $V_L[i]$. The filter will slide along the pixels in the vector $V_H[i]$ and $V_L[i]$ beginning at the Nth pixel from each end after. The filter will provide a simple average of the included pixel values. The resulting vector $W_H[i]$ and $W_L[i]$ will contain the smoothed values. The value V_{mean_H} and V_{mean_L} will be assigned the maximum value found in vector $W_H[i]$ and $W_L[i]$ respectively.

The low frequency gain can be explained as the V_{mean} value relative to the smoothed vector values for each pixel as follows:

$$\begin{aligned} G_{LF\_H}[i] &= \frac{V_{mean\_H}}{W_H[i]} \\ G_{LF\_L}[i] &= \frac{V_{mean\_L}}{W_L[i]} \end{aligned} \qquad (3)$$

Where $G_{LF\_H}[i]$ is the low frequency gain of the ith pixel for high illumination, $V_{mean\_H}[i]$ is the maximum value found in vector $W_H[i]$, and $W_H[i]$ is the smoothed value for the *i*th pixel.

From the low frequency gain calculated by above two equations, the low frequency gain to apply to all the illumination can be optimized as follows:

$$G_{LF}[i] = Opt(G_{LF\_H}[i], G_{LF\_L}[i]) \quad (4)$$

2.3.2 Generation of High Frequency Gain and Offset table

The high frequency table contains the gain and the offset values. For the gain table, at first, we shall multiply all the values in the measured pixel value vectors by the appropriate low frequency gain values as in

$$U_H[i] = H[i] \cdot G_{LF\_H}[i]$$
$$U_L[i] = L[i] \cdot G_{LF\_L}[i] \quad (5)$$

We can calculate the difference between the two resulting vectors for each pixel as in

$$D[i] = U_H[i] - U_L[i] \quad (6)$$

Finally, the high frequency gain is calculated as the D_{max} value relative to the calculated pixel differences as in

$$G_{HF}[i] = \frac{D_{\max}}{D[i]} \quad (7)$$

where D_{max} is the maximum pixel values in *D[i]*, *$G_{HF}[i]$* is the high frequency gain for the *i*th pixel and *D[i]* is the the pixel value difference for the *i*th pixel. All *$G_{HF}[i]$* are greater or equal to 1.0 for all *i* values.

The high frequency offset can be calculated using the calculated high frequency gain. For the offset calculation, the acquired data from low illumination can be used as in

$$T_L[i] = U_L[i] \cdot G_{HF}[i] \quad (8)$$

where *$G_{HF}[i]$* is the high frequency gain for the *i*th pixel and *$U_L[i]$* is calculated from Eq. (5). Finally the high frequency offset is calculated using Eq. (9).

$$Off[i] = T_{\max} - T_L[i] \quad (9)$$

where *Off[i]* is the offset for the *i*th pixel, T_{max} is the maximum value in *$T_L[i]$*. All *Off[i]* are not negative for all *i* values.

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

$$LF_{cor}(i) = Opt(LF_{h\_cor}, LF_{l\_cor}) \quad (10)$$

2.3.2 Correction

In order to correct the sampled pixel values using the correction table, we can apply the following finally:

$$Y[i] = (V[i] \cdot G_{HF}[i]1 + Off[i]) \cdot G_{LF}[i] \quad (11)$$

Where *Y[i]* is the corrected *i*th pixel value, *V[i]* is the sampled *i*th pixels value, sampled at any illumination level, *$G_{LF}[i]$* is the low frequency gain for *i*th pixel, *$G_{HF}[i]$* is the high frequency gain for the *i*th pixel and *Off[i]* is the offset for the *i*th pixel. This final process may be done in ground station.

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 has the low frequency term and the high frequency term. In this simulation, the high frequency term that consists of the gain and the offset is generated by random number generator.

The gain and the offset are verified by comparing the simulated values, which are generated by random number generator, and calculated values which are calculated by table generation algorithm mentioned in section 2. The nominal high signal level and the low signal level is used as 800GL and 300 GL respectively to verify the suggested algorithm. Figure 3 and Figure 4 show these simulation results and this algorithm can track correctly.

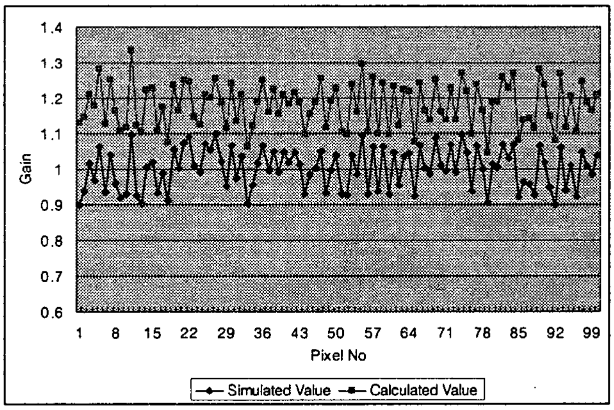

Figure 3. Gain tracking test result

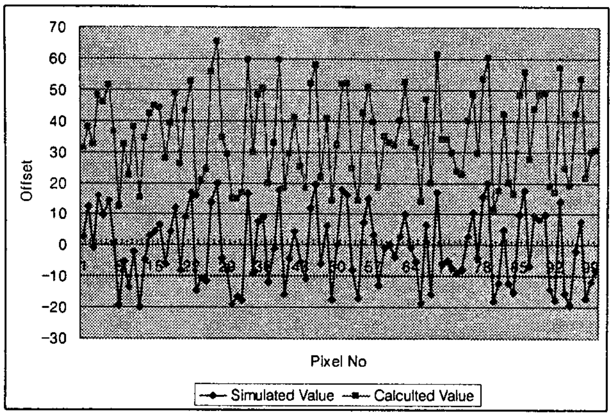

Figure 4. Offset tracking result

In order to verify whether it can be applied to all the illumination level, the 600 GL level is used as test imag data. Figure 5 shows the correction results for both the high frequency and the low frequency terms. As shown in figure, when the 1st low frequency gain, which means that Eq. (10) is not performed yet, is used, some disturbance at both sides is shown. This is due to the normalization effects of the gain and the offset. If the 2nd low frequency gain, which is acquired through Eq. (10), is used to reconstruct, there is not this kind of phenomenon any more. This result shows that it is better to obtain the final corrected data using 2nd low frequency gain.

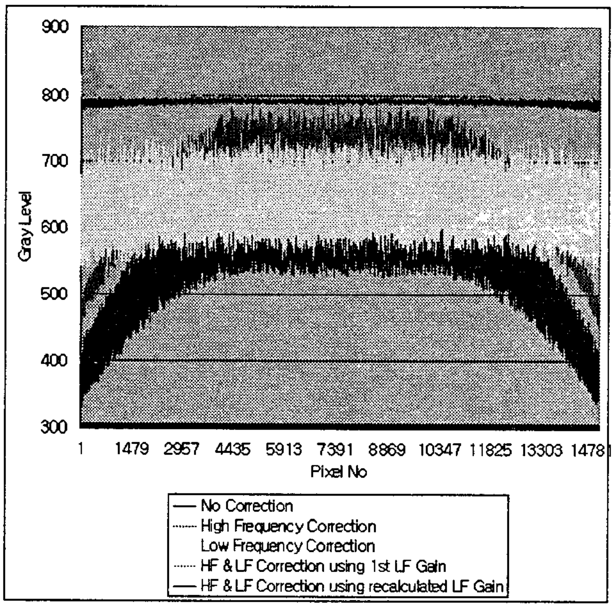

Figure 5. Verification of test image

The Residual Photo Response Non-Uniformity(RNU) is a numerical value for the non-uniformity. The equation to get the RNU value is as follows:

$$RNU_{\max} = \frac{Q_{\max} - Q_{mean}}{Q_{mean}} \cdot 100(\%)$$

$$RNU_{\min} = \frac{Q_{\min} - Q_{mean}}{Q_{mean}} \cdot 100(\%)$$

$$RNU = Max(|RNU_{\max}|, |RNU_{\min}|) \qquad (12)$$

Where Q is the signal value and subscript *min*, *max*, *mean* represent the minimum, maximum and average value respectively. RNU_{max} and RNU_{min} are the deviations of the maximum and the minimum value from the average in percent respectively.

Table 1 shows the numerical simulation results. We can know from the table that the suggested algorithm makes the RNU results get better so much and the recalculated LF gain makes more accurate result.

Table 1. RNU simulation results

Correction	RNU Results(%)
No correction	40 %
Only high frequency correction	36 %
Only low frequency correction	19 %
HF & LF correction using 1st LF gain	5.3 %
HF & LF correction using 2st LF gain	1.6 %

4. Conclusions

All CCD pixels do not react uniformly even if the light with same radiance enters into the camera. This non-uniformity mainly comes from the different optical characteristics, and the pixel own characteristics. The typical camera system has the low frequency and the high frequency non-uniformity together. If the uniformity correction is totally performed in the ground, it is not necessary to separate the low frequency term and the high frequency term. But, it is needed in the practical satellite camera due to the limitations of on-board correction.

This paper shows the method to correct the high frequency and the low frequency non-uniformity simultaneously using the correction table. This table consists of the gain and the offset value. And the idea to generate the more accurate table is shown with various simulations. Besides, the numerical analysis results show the how much the RNU results get better by the suggested correction algorithm.

References

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