Calibration Slope Adjustment for De-Striping KOMPSAT-1 EOC Images

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Abstract: KOMPSAT-1 (KOrea Multi-Purpose SATellite – 1) EOC (Electro Optic Camera) raw images are radiometrically corrected on ground based on the characteristics of EOC. They consist of each CCD (Charge–Coupled Device) pixel's calibration slope which was measured on ground, electrical gains which are applied to amplify for increasing output pixel counts. Currently, radio-metrically corrected EOC images with calibration slope have still shown defective features by residual stripes. So, it should be compensated by adjusting the calibration slope. In this paper, the adjustment of current calibration slope for de-striping EOC images is addressed and test results are shown.

Keywords: KOMPSAT-1, EOC, Radiometric Correction, Calibration Slope Adjustment

1. Introduction

Generally, each transfer function for each CCD pixel is not identical. As a result, images produced in this fashion show undesirable, regular striping. Stripes can be removed with several methods. The de-striping algorithms using mean and standard deviation was suggested by Horn and Woodham [1]. This method assumes that the image sensors are LTI (Linear and Time Invariant) system. Also, de-striping method using histograms in the raw image was suggested [1]. Weinreb has shown that the method using histograms has been successfully applied to de-striping GOES (Geostationary Operational Environmental Satellite) images [2]. This algorithm assumes that each histogram of detectors have the same probability distribution. Meanwhile, non-linear de-striping algorithm of satellite images by Choi [3].

Above methods deal with relative de-striping. So, these de-striping methods are applied only on the basis of statistical characteristics of image itself. When the pre-defined mathematical relationship between input radiance and output DN (Digital Number) are applied to de-striped EOC images acquired from these methods, they can not generally be used in retrieving absolute input radiance close to in-situ values. So, calibration slope should be adjusted to remove stripes and to get more accurate absolute input radiance from EOC raw images. In this paper, calibration slope adjustment using EOC test scene and result are addressed.

2. EOC Characteristics

Table 1. EOC Electronic Gains

Gain Setting	Nominal Gain Value	Measured Electronic Gain	Relative Electronic Gain	Maximum Radiance
0	4	1.1475366	3.66781082	226.458
1	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A
3	N/A	N/A	N/A	N/A
4	2	0.5965550	1.90673734	435.616
5	N/A	N/A	N/A	N/A
6	1	0.3128669	1.00000	830.605
7	1/2	0.1600441	0.51154053	1623.732

1) Electronic Gains and Offsets

KOMPSAT-1 EOC is a single-channel panchromatic push-broom imager. EOC CCD simultaneously receives earth's radiance from 2,592 pixels in the cross-track direction. EOC electronics assembly provides separate gain controls for each odd and even set of pixels with 8 possible gain settings as table 1 [4]. Also, EOC electronics assembly provides separate offset controls for each odd and even set of pixels, with 16 possible offsets as table 1 and Eq. (1).

$$Electronic\ Offset = 40 - 5 \cdot offset \quad (1)$$

2) Calibration Slope

EOC Calibration slope has been measured on ground before the launch of KOMPSAT-1. Calibration slope is defined as the amount of input radiance per CCD output DN count [4]. Fig. 1 shows EOC calibration slope, which measured on ground.

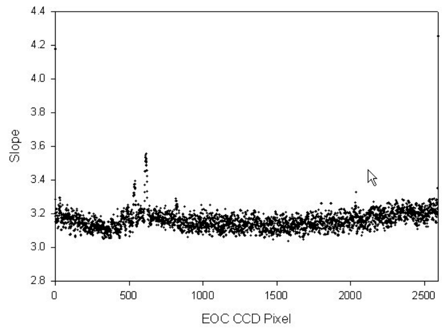

Fig. 1 EOC Calibration slope

3) EOC Radiometric Correction Model

Eq. (2) describes the radiometric correction model to be used for the EOC sensor.

$$Radiance = \frac{Calibration\ Slope}{Electronic\ Gain} \cdot \{C - DC\} \qquad (2)$$

Where C is the pixel count of EOC raw image in units of counts for each pixel and DC is the dark current in units for each pixel. In the model, degradations, which are dependent on time and temperature, were neglected.

4) EOC 1R Image Generation

After the generation of EOC radiance image, it is scaled to 8-bit pixels to generate EOC 1R image according to Eq. (3) [4].

$$EOC\ 1R\ image = 255 \cdot \frac{Radiance}{Maximum\ Radiance} \qquad (3)$$

Where maximum radiance is the maximum CCD output radiance allowed for gain setting and is referred to Table 1.

3. Calibration Slope Adjustment

For the calibration slope adjustment, it is assumed that EOC sensor is LTI (Linear and Time Invariant) system. And electronic gains and maximum radiance are identically applied to both pre-amplifiers. On these assumptions, the calibration slope generation algorithm is suggested as below:

1) Selection of EOC raw image

An EOC raw image (or EOC 1A image) of Fig. 2 was selected at first. It is the ocean image near Oman, Arabia. This EOC raw image was acquired when relative electronic gain is 4 and electronic offset is –30. Fig. 3 shows the image of which brightness is stretched. Generally, ocean images have more homogeneous features and small variations in radiance compared to those of land. In the selected ocean image, pixel values run from 20 to 32 and standard deviation is about 1.276. Although there are small variations in pixel distributions of the image, it is assumed that the selected image area would be homogeneous in overall areas.

2) EOC 1R Image Generation with Original Slope

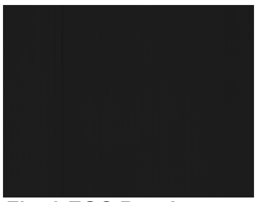

Fig. 2 EOC Raw Image

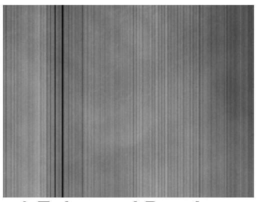

Fig.3 Enhanced Raw Image

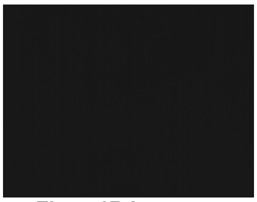

Fig. 4 1R Image

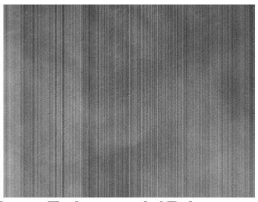

Fig. 5 Enhanced 1R Image

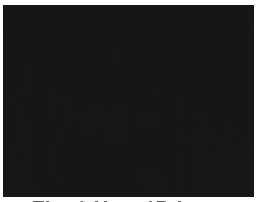

Fig. 6 New 1R Image

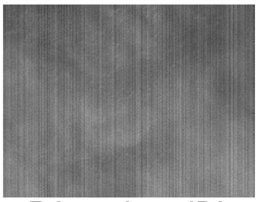

Fig. 7 Enhanced new 1R Image

After the step 1, an EOC 1R image was generated using its dark current information, original calibration slope, electronic gain and maximum radiance. In an ideal case, EOC 1R image would show de-striped features in overall areas. But actually, EOC 1R image showed residual stripes after radiometric correction. Fig. 4 is the EOC 1R images. Fig. 5 is the enhanced image for better viewing.

3) Mean, Standard Deviation Matching

It seems reasonable that we assume that EOC raw ocean image would be homogeneous. If this assumption were applied, each column of the EOC 1R image would have same mean and standard deviation in an ideal case. On this assumption, we have matched mean and standard deviation of each column of EOC 1R image to those of reference column, which is 1,000th CCD pixel. Fig. 6 & Fig. 7 shows results after mean and standard deviation matching. Mean and standard deviation matching is executed on an EOC radiance image and an EOC 1R image results from an EOC radiance image. After 8-bit scaling, mean and standard deviation of each column of an EOC 1R image has small difference due to quantization error compared to those of reference.

4) Calibration Slope Adjustment

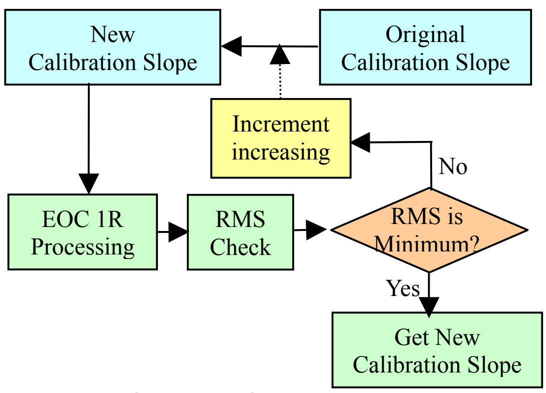

Fig. 9 Calibration Slope Adjustment Process

After applying mean and standard deviation matching, it is assumed that result image is rightly corrected EOC 1R image. So, it is reasonable that we think that newly generated EOC 1R images should have features closest to those of rightly corrected EOC 1R image after newly generated calibration slope is applied to EOC 1R process. Considering this assumption, new calibration slope was generated according to the block diagram of Fig. 9.

At first, specific range in which new calibration slope of each pixel can be was set. It means that new calibration slope should exist within specific range. After that, the increment of calibration slope was set and a new temporary calibration slope where increment was applied was calculated iteratively. Each column of new EOC 1R image was generated for each pixel and compared to the reference column using RMS (Root Mean Square) check with the increasing increment until minimum RMS would be found. After minimum RMS error has been found, new calibration slope for each CCD pixel was determined. Fig. 10 shows newly generated EOC calibration slope.

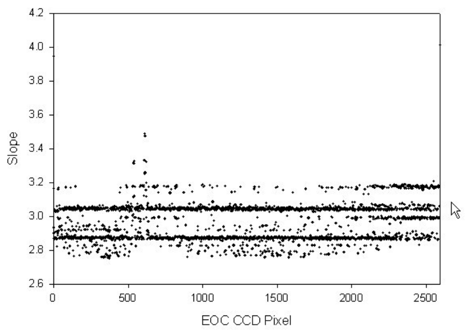

Fig. 10 Newly Generated EOC Calibration slope

4. Test & Result

After generating new calibration slope for EOC radiometric correction, validation test was held selecting another EOC raw image where the same gain and offset was applied. Fig. 11 shows zoomed test image. This image is radiometrically corrected EOC 1R image where original calibration slope was applied. Fig. 12 shows zoomed test EOC 1R image where newly generated calibration slope was applied. As a result, it seems that newly generated calibration slope removes many stripes which exist in EOC 1R image where original calibration slope was applied. So, EOC 1R image with fewer stripes can be generated using newly generated calibration slope with less radiometric loss.

5. Conclusion

In this paper, new algorithm for calibration slope adjustment are suggested and tested. After generating new calibration slope, a test image has been selected and tested for its validation. As a result, an EOC 1R test image, which is produced using new calibration slope, has less striping features. Many stripes in EOC 1R image with original calibration slope are removed with the replacement of calibration slope to new one. So, it seems that this algorithm is properly applied to EOC 1R process.

But, even when newly generated calibration slope is applied to EOC 1R image generation, a few stripes still remain. It is guessed that they mainly result from the selection of reference image for the generation of new calibration slope. In this paper, the ocean image of Oman is adopted as the reference image for new calibration slope generation and assumed that it has homogeneous features in overall areas. But, this is not real situation. Although they are very small, there exist some inhomogeneities in the ocean image, which came from the ocean's local radiometric features. It is guessed that these small but existing inhomegeneities were neglected in applying mean and standard deviation matching and this plays an important role in remaining residual stripes. In addition, quantization errors due to the conversion from radiance image to 8-bit image and the mean of dark current may contribute to stripes. As a result, more homogeneous EOC raw images can make more accurate calibration slope.

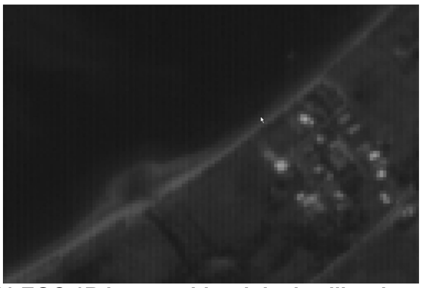

Fig. 11 EOC 1R image with original calibration slope

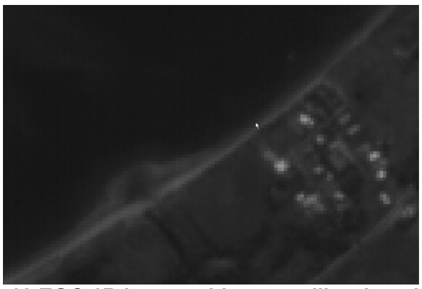

Fig. 12 EOC 1R image with new calibration slope

References

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