# ERROR ANALYSIS FOR GOCI RADIOMETRIC CALIBRATION

Gmsil Kang, Heong-Sik Youn

Korea Aerospace Research Institute (KARI), 45 Eoeun-Dong, Yuseong-Gu, Daejeon, 305-333, Korea
kgs@kari.re.kr, youn@kari.re.kr

ABSTRACT

The Geostationary Ocean Color Imager (GOCI) is under development to provide a monitoring of ocean-color around the Korean Peninsula from geostationary platforms. It is planned to be loaded on Communication, Ocean, and Meteorological Satellite (COMS) of Korea. The GOCI has been designed to provide multi-spectral data to detect, monitor, quantify, and predict short term changes of coastal ocean environment for marine science research and application purpose. The target area of GOCI observation covers sea area around the Korean Peninsula. Based on the nonlinear radiometric model, the GOCI calibration method has been derived. The nonlinear radiometric model for GOCI will be validated through ground test. The GOCI radiometric calibration is based on on-board calibration devices; solar diffuser, DAMD (Diffuser Aging Monitoring Device). In this paper, the GOCI radiometric error propagation is analyzed. The radiometric model error due to the dark current nonlinearity is analyzed as a systematic error. Also the offset correction error due to gain/offset instability is considered. The radiometric accuracy depends mainly on the ground characterization accuracies of solar diffuser and DAMD.

**KEY WORDS: COMS, GOCI, Calibration, Error propagation**

## 1. INTRODUCTION

Space based observations of ocean color began with CZCS (Coastal Zone Color Scanner) which was launched in 1978. Since then many missions have been launched by various countries with increasing sophistication for ocean color monitoring: SeaWiFS (Sea Viewing Wide Field Sensor), OCTS (Ocean Color and Thermal Scanner), OCM (Ocean Color Monitor), MODIS (Moderate Resolution Imaging Spectro-Radiometer), MERIS (Medium Resolution Imaging Spectro-Radiometer). These ocean color sensors on low Earth orbiting satellites are capable of supplying highly accurate water-leaving spectral radiance with high spectral and spatial resolution at a global revisit period of approximately two to three days [1]. The relatively low frequency coverage of these sensors, further reduced in the presence of clouds, is inadequate to resolve processes operating at a shorter time scales. In addition, the current sun-synchronous polar orbiter observations along coasts are aliased with the tidal frequency. High frequency observations are required in order to remove the effects of tidal aliasing and to validate tidal mixing terms in coastal ecosystem models. Ocean color observation from geostationary platform is required to remedy the coverage constraints imposed by polar orbiting platforms. Unfortunately, no current geostationary platform possesses the ability to measure ocean color.

Korea Aerospace Research Institute (KARI) has a plan to launch COMS for consistent monitoring of the Korean Peninsula and studying processes which can vary rapidly in time on land, oceans, and atmospheres. Geostationary Ocean Color Imager (GOCI) is one of the main payloads of COMS which will provide a monitoring of ocean-colour around the Korean Peninsula from geostationary platforms. The COMS contract to develop the COMS satellite and to provide support for system activities has been award by KARI to ASTRIUM France.

The GOCI radiometric calibration is based on in-orbit solar calibration using on-board calibration devices; solar diffuser, DAMD (Diffuser Aging Monitoring Device). The GOCI is modelled as the nonlinear system due to the nonlinear characteristic of CMOS detector array. The GOCI radiometric model will be validated during ground test. In this paper, the GOCI radiometric error propagation is examined. The radiometric model error due to the dark current nonlinearity is analyzed as a systematic error. Also the offset correction error due to gain/offset instability is considered. The radiometric accuracy depends mainly on the ground characterization accuracies of solar diffuser and DAMD.

## 2. OVERVIEW OF THE GOCI SPECIFICATION

The GOCI has been designed to provide multi-spectral data to detect, monitor, quantify, and predict short term changes of coastal ocean environment for marine science research and application purpose. The target area for GOCI observation covers sea area around the Korean Peninsula. Table 1 shows the summary of the major requirement specification of the GOCI. The spatial resolution (GSD) shall be less than 500m in both E/W and S/N directions at the center of the target area defined. The GSD is varied over the target area because of the imaging geometry including the projection on Earth and the orbital position of the satellite. The GOCI has been designed to satisfy the dynamic range requirement that extends from the noise equivalent differential radiance (NEdR) to the maximum cloud radiance.

This characteristic has been achieved by applying different integration time for nominal target (ocean) and brightness target (cloud). The cloud radiance detection might be used to compensate its straylight impact on the ocean scene.

Table 1 GOCI requirement specifications

| Items | Technical requirements |
|---|---|
| Ground Sample Distance (GSD) | ≤ 500m × 500m at the center of the target area |
| Target area | ≥ 2500km × 2500km centered on 36N° latitude and 130 E° |
| Spectral coverage | 412 nm ~ 865 nm (8 channels) |
| Bandwidth | 10 nm ~ 40 nm |
| SNR | 750 ~ 1200 |
| Dynamic range | NEdR ~ Maximum cloud radiance |
| Radiometric calibration accuracy | 4 % |
| Radiometric stability | Short term stability (2 weeks): ±1%<br>Long term stability (life time): ±4% |
| Digitization | 12 bit |

The detector array for GOCI is a custom designed CMOS image sensor featuring rectangular pixel size to compensate for the Earth projection over Korea, and electron-optical characteristics matched to the specified instrument operations. The step and staring method using CMOS detector array and pointing mirror supported by a 2-axis scan mechanism is adapted in order to capture the target area. The 8 spectral channels are obtained by means of a filter wheel which includes dark plate in order to measure the system offset as well as 8 spectral filters. The single spectral channels will be acquired for two gain levels (integration time) corresponding to sea and cloud radiance revels. The shutter wheel carrying two on-board calibration devices is placed in front of optic entrance. One of the on-board calibration devices is the solar diffuser of transmission type which is used on short time period to perform solar calibration. The Diffuser Aging Monitoring Device (DAMD) is the other calibration device which is used on long time period in order to correct the degradation factor of solar diffuser.

## 3. GOCI RADIOMETRIC CALIBRATION

The GOCI radiometric calibration is based on in-orbit solar calibration using the on-board calibration devices. Thanks to the geostationary platform, the Sun can be used as a constant calibration reference covering the full GOCI detection chain (same optic for the Earth view) which provides the uniform radiance distribution.

The GOCI radiometric calibration consists of three parts; on-ground calibration, in-orbit calibration, and ground processing. The nonlinear radiometric model of the GOCI will be validated through on-ground calibration. Also characterization of on-board calibration devices will be major activity during on-ground calibration. The absolute gain (radiometric parameters of GOCI model) will be estimated periodically through the in-orbit solar calibration. The apparent radiance in front of the GOCI is calculated using the Sun angle and the diffusion factor of solar diffuser characterized through on-ground test. The change of radiometric response between pixels will be corrected through this in-orbit calibration. In-orbit calibration will be performed when the Sun is available in calibration field of view using solar diffuser. The DAMD will be used in order to correct the degradation factor of the solar diffuser.

### 3.1 Radiometric model

The radiometric model of the GOCI given by (1) defines the relationship between the output digital count and the input radiance for a pixel. In order to construct the GOCI radiometric model, the functional model based on GOCI design has been examined to consider non-linearity and temperature variation impact on equipments. The detector is identified as a major contributor to nonlinear characteristic. This nonlinearity is reflected in the GOCI radiometric model in order to achieve high calibration accuracy. For temperature variation of the detector, the dark current and the detector fixed offset will be changed resulting in the offset signal change. Although this variation on offset signal may cause the offset correction error corresponding temperature variation range between offset measurement and channel measurement, the temperature variation effect is not reflected in the GOCI radiometric model because it is expected that constant detector temperature will be kept during imaging period. The detector will be controlled to keep stable temperature by fine temperature control during mission life. The gain change and offset change due to the temperature variation shall be checked through the ground test.

$$S = G \times T_{\text{int}} \times L + b \times T_{\text{int}}^2 \times L^2 + T_{\text{int}} \times O + F \qquad (1)$$

where $S$: Output digital number of detector pixel

$L$: Spectral average radiance in the front of the GOCI
$G$, $b$: Linear gain and Nonlinear gain, respectively

$T_{int}$: Integration time (adjusted during the mission life)

$O$, $F$: Offset parameters

The radiometric model given by (1) includes the linear gain, the non-linear gain, and the offset parameters. The integration time is included as one of the calibration coefficient to take account the adjustment of integration time during mission life. The integration time for each spectral channel will be commanded by ground operation center in order to achieve the proper radiometric performance. It will be increased to compensate the degradation of the radiometric performance which is caused by the radiation environment.

## 4. RADIANCE ESTIMATION AND ERROR PROPAGATION

Using the GOCI radiometric model given by (1), the radiance at GOCI input is calculated by

$$\tilde{L} = \frac{1}{\tilde{T}_{\mathrm{int}}} \frac{2\bar{S}}{\tilde{G} + \sqrt{\tilde{G}^2 4\tilde{b}\bar{S}}} \tag{2}$$

where $\bar{S}$ : Output digital number after offset correction

$\tilde{G}$ : Estimated linear gain

$\tilde{b}$ : Estimated nonlinear gain

$\tilde{T}_{\mathrm{int}}$ : Estimated integration time

The GOCI input radiance is calculated from the output digital number using the radiometric parameters such as linear gain, nonlinear gain and integration time. The estimation error of each radiometric parameter will be propagated to the radiance estimation.

The first step to analyze the radiance estimation error propagation is to figure out all error contributors. Table 2 shows the identified contributors which are propagated to gain estimation and/or radiance estimation. The uncertainty due to the solar spectrum model and the Sun activity variation has not been considered for this analysis. For the radiance estimation errors, error contributors are divided into a systematic error and a random error; the offset correction errors due to radiometric model error and offset and gain stability are considered as systematic error. The radiometric parameter estimation errors due to ground characterization uncertainty are considered as random error. The radiometric model error is induced by the linear approximation of detector dark current offset for the simplicity of GOCI radiometric model.

Table 2 Error contributors

| Error contributors | Type |
|---|---|
| Radiometric model error | Systematic error |
| Characterization accuracy of solar diffuser | Random error |
| Characterization accuracy of DAMD | Random error |
| Degradation of DAMD over mission life | Random error |
| Reflectivity variation of pointing mirror | Systematic error |
| Integration time accuracy | Random error |
| Sun angle estimation | Random error |
| Short term offset variation(2 min) | Systematic error |
| Short term gain variation (2 min) | Systematic error |
| Long term gain variation (a day) | Systematic error |
| Noise (SNR) | Random error |

Even though the GOCI solar calibration using the solar diffuser covers the full optical and detection chain, any potential differences between the solar calibration and the Earth observation should be examined. There are two potential error contributors due to different operational condition; the system gain change between the Sun view and the Earth view due to the pointing mirror angle variation. The system gain variation (during a day) due to the temperature variation. Until the critical design review, these variations are not considered for radiometric correction since they are identified as a minor contributor.

The systematic error propagation of GOCI is expressed by

$$\frac{e_L}{L} = \frac{\partial L}{\partial G}\frac{G}{L}\frac{e_G}{G} + \frac{\partial L}{\partial b}\frac{b}{L}\frac{e_b}{b} + \frac{\partial L}{\partial \bar{S}}\frac{\bar{S}}{L}\frac{e_{\bar{S}}}{\bar{S}} \tag{3}$$

where $e_L$ : systematic error of radiance estimation

$e_G$ : systematic error of linear gain estimation

$e_b$ : systematic error of nonlinear gain estimation

$e_{\bar{S}}$ : offset correction error

The offset correction error $e_{\bar{S}}$ of the output digital number for the Earth observation is caused by the radiometric model error. Also the offset variation and gain variation during one slot imaging result in the offset correction error $e_{\bar{S}}$ .

The systematic gain errors $e_G$ and $e_b$ mean the error carried through the gain estimation process using the Sun image achieved through the solar diffuser. It should be noticed that the radiometric model error and the offset and gain stability (short term) has also appeared during the Sun image acquisition. This offset correction error for the Sun image acquisition results in the gain estimation error. Beside the offset correction error, the reflectivity variation of pointing mirror and the long term gain variation are the contributors for systematic gain error.

With assumption of uncorrelation between the radiometric parameter estimation errors, the random error propagation of GOCI is presented by

$$\frac{\sigma_L}{L} = \frac{1}{L}\sqrt{\left(\frac{\partial L}{\partial G}\right)^2 \sigma_G^2 + \left(\frac{\partial L}{\partial b}\right)^2 \sigma_b^2 + \left(\frac{\partial L}{\partial \bar{S}}\right)^2 \sigma_{\bar{S}}^2 + \left(\frac{\partial L}{\partial T_{\mathrm{int}}}\right)^2 \sigma_{T_{\mathrm{int}}}^2} \tag{4}$$

where $\sigma_L$ : random error of radiance estimation

$\sigma_G$ : random error of linear gain estimation

$\sigma_b$ : random error of nonlinear gain estimation

$\sigma_{\bar{S}}$ : random error (noise of output signal)

$\sigma_{T_{\mathrm{int}}}$ :random error of integration time

The gain estimation errors $\sigma_G$ and $\sigma_b$ are errors propagated from the ground characterization uncertainties (the solar diffuser and the DAMD), the sun angle estimation error, the output signal uncertainty, and the integration time error during the gain estimation using the Sun image. The uncertainties of output signal and integration time are appeared for radiance estimation again.

The impact of error contributors on the radiance estimation can be examined by using the error propagation coefficient. From the radiance calculation equation given by (2), the propagation coefficients for each parameter are given by

$$C_{GL} = \left( \frac{G}{L} \frac{\partial L}{\partial G} \right) = \frac{-G}{2bT_{\text{int}}L + G} \tag{5}$$

$$C_{bL} = \left( \frac{b}{L} \frac{\partial L}{\partial b} \right) = \left( \frac{-bT_{\text{int}}L}{2bT_{\text{int}}L + G} \right) \tag{6}$$

$$C_{\bar{S}L} = \left( \frac{\bar{S}}{L} \frac{\partial L}{\partial \bar{S}} \right) = \left( \frac{bT_{\text{int}}L + G}{2bT_{\text{int}}L + G} \right) \tag{7}$$

$$C_{TL} = \left( \frac{T_{\text{int}}}{L} \frac{\partial L}{\partial T_{\text{int}}} \right) = \left( -\frac{1}{L} \frac{O}{2bT_{\text{int}}L + G} - 1 \right) \tag{8}$$

It is expected that the error propagation depends on the input radiance level and the system gain parameter. In order to examine the propagation tendency of each contributor, the propagation coefficients are calculated by using the GOCI radiometric model implemented by Matlab Simulink. The propagation coefficients for each spectral filter at different input radiance level are given in Table 3 and Table 4. It is expected that the estimation errors of linear gain, output signal, and integration time are almost directly propagated to the retrieved radiance.

Table 3 Error propagation coefficients for ocean radiance level

| | $T_{\text{int}}$ (sec) | $C_{GL}$ | $C_{bL}$ | $C_{\bar{S}L}$ | $C_{TL}$ |
|---|---|---|---|---|---|
| B1 | 1,18E-01 | -1,05E+00 | 2,55E-02 | 1,03E+00 | -1,04E+00 |
| B2 | 6,92E-02 | -1,05E+00 | 2,45E-02 | 1,02E+00 | -1,02E+00 |
| B3 | 7,38E-02 | -1,05E+00 | 2,45E-02 | 1,02E+00 | -1,03E+00 |
| B4 | 6,61E-02 | -1,05E+00 | 2,51E-02 | 1,02E+00 | -1,02E+00 |
| B5 | 8,15E-02 | -1,04E+00 | 2,05E-02 | 1,02E+00 | -1,03E+00 |
| B6 | 1,95E-01 | -1,04E+00 | 2,15E-02 | 1,02E+00 | -1,08E+00 |
| B7 | 1,65E-01 | -1,04E+00 | 2,01E-02 | 1,02E+00 | -1,07E+00 |
| B8 | 2,08E-01 | -1,04E+00 | 1,84E-02 | 1,02E+00 | -1,10E+00 |

Table 4 Error propagation coefficients for ocean saturation radiance level

| | $T_{\text{int}}$ (sec) | $C_{GL}$ | $C_{bL}$ | $C_{\bar{S}L}$ | $C_{TL}$ |
|---|---|---|---|---|---|
| B1 | 1,18E-01 | -1,08E+00 | 3,98E-02 | 1,04E+00 | -1,03E+00 |
| B2 | 6,92E-02 | -1,08E+00 | 3,98E-02 | 1,04E+00 | -1,02E+00 |
| B3 | 7,38E-02 | -1,08E+00 | 4,05E-02 | 1,04E+00 | -1,02E+00 |
| B4 | 6,61E-02 | -1,08E+00 | 3,99E-02 | 1,04E+00 | -1,02E+00 |
| B5 | 8,15E-02 | -1,08E+00 | 3,86E-02 | 1,04E+00 | -1,02E+00 |
| B6 | 1,95E-01 | -1,08E+00 | 3,77E-02 | 1,04E+00 | -1,05E+00 |
| B7 | 1,65E-01 | -1,08E+00 | 3,88E-02 | 1,04E+00 | -1,04E+00 |
| B8 | 2,08E-01 | -1,08E+00 | 3,82E-02 | 1,04E+00 | -1,05E+00 |

The radiance estimation error coefficients are slightly increased with the input radiance level. Even though the error propagation sensitivity for the non-linear gain estimation is lower than the other contributors, it shall not be neglected since the estimation error of non-linear gain could be larger than the other contributors. The error propagation coefficient of nonlinear gain is proportionally increased to the input radiance since the system output is getting larger nonlinearity at high level input radiance. Therefore, the larger estimation error is expected at the saturation radiance than at the nominal radiance.

## 5. CONCLUSION

The GOCI which will be first instrument providing the ocean observation from geostationary platform. For the radiometric calibration, the nonlinear radiometric model is assumed. Based on this nonlinear model, the radiance calculation formula has been derived. The GOCI input radiance is computed from output digital number using the estimated gains. In this paper, the error propagation of estimated parameters such as linear gain, nonlinear gain, integration time and offset corrected digital output is analyzed. The error contributors for radiance estimation have been identified. The radiometric model error, offset variation and reflectivity variation of pointing mirror are considered as error contributor. The errors of linear gain, output signal, and integration will be directly propagated to estimated radiance. Based on their error budget, the linear gain estimation error will be major error contributor since the errors of output signal and integration time are expected to be small. The error propagation of nonlinear gain is lower than the other parameters.

**References**

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