Radiometric Calibration Method of the GOCI (Geostationary Ocean Color Imager)

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Abstract: 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. In this paper radiometric calibration concept of the GOCI is introduced. The GOCI radiometric response is modeled as a nonlinear system in order to reflect a nonlinear characteristic of detector. In this paper estimation approaches for radiometric parameters of GOCI model are discussed. For the GOCI, the offset signal depends on each spectral channel because dark current offset signal is a function of integration time which is different from channel to channel. The offset parameter can be estimated by using offset signal measurements for two integration time setting is described.

Keywords: COMS, GOCI, nonlinear radiometric model, radiometric calibration, solar diffuser, offset correction

1. Introduction

Ocean color sensors such as MODIS, SeaWiFS, and MERIS have been developed to obtain the multi-spectral visible and near infra-red images of oceans. 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 [1]. High frequency observations are required in order to remove the effects of tidal aliasing and to validate tidal mixing terms in coastal ecosystem models.
Geostationary Ocean Color Imager (GOCI) is under developing to provide a monitoring of ocean-color at the Korean Peninsula from geostationary platforms. It is planned to be loaded on Communication, Ocean, and Meteorological Satellite (COMS) of Korea. The mission of GOCI and the corresponding requirement specification have been defined according to the requirement from the oceanography user community. The COMS contract to develop the COMS satellite and to provide support for system activities has been award by KARI to ASTRIUM France.

In this paper major technical requirements of the GOCI are summarized. Also characteristic of the GOCI radiometric model and the estimation method of radiometric parameters are introduced in section 3. The offset parameter estimation method using offset signal measurements for two integration time setting is described in section 3.

2. Overview of the GOCI Requirement Specification

The GOCI is 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. Target area for the GOCI observation covers sea area around the Korean Peninsula.

Table 1. Summary of GOCI requirement specification

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% Long term stability (life time): ±4%
Digitization	12 bit

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. It is known that the stray light contamination to be roughly proportional to the brightness of the adjacent cloud [3]. The GOCI shall be designed to operate over a dynamic range that extends from the noise equivalent differential radiance (NEdR) to the maximum cloud radiance.

The detector array for GOCI is a custom 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. Radiometric Calibration Concept

The radiometric calibration of the GOCI will be performed for all pixels of array detector at ground segment by using the on-ground and in-orbit calibration data. The GOCI radiometric calibration consists of three parts; on-ground calibration, in-orbit calibration, and ground processing. The radiometric response of the GOCI will be characterized through on-ground calibration. The radiometric gain parameters also can be estimated through in-orbit calibration. The change of radiometric response will be corrected periodically through in-orbit calibration using the on-board calibration devices. The GOCI operation concept will provide possibility of everyday in-orbit calibration. In-orbit calibration will be performed when the Sun is available in calibration field of view using solar diffuser. The on-board calibration device, solar diffuser, will provide a constant radiance in the whole filed of view of the GOCI. 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 DAMD will be used in order to correct the degradation factor of the solar diffuser.

The GOCI radiometric calibration method has been derived from radiometric characteristics defined by the radiometric model. The GOCI radiometric model and the parameter estimation methods of radiometric model are described in this section.

1) GOCI radiometric model

The preliminary radiometric model of the GOCI given by (1) defines the relationship between the output digital count and the input radiance for every 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.

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.

$$\begin{aligned} S(B,i,j) &= G(B,i,j)\times T_{\text{int}}(B)\times L(B,i,j) \\ &+ b(B,i,j)\times T_{\text{int}}^2(B)\times L^2(B,i,j)+T_{\text{int}}(B)\times O(i,j)+F(i,j) \end{aligned} \tag{1}$$

where $S(B,i,j)$: Output digital number of each detector pixels for each spectral band.

$T_{\text{int}}(B)$: Integration time $T_{\text{int}}(B)$ of each spectral band which will be adjusted during the mission life.

$L(B,i,j)$: Spectral average radiance in the front of the GOCI instrument defined by

$$L(B,i,j)=\frac{\int L_\lambda R_\lambda(B,i,j)d\lambda}{\int R_\lambda(B,i,j)d\lambda} \tag{2}$$

where $R_\lambda(B,i,j)$ and L_λ mean the spectral response of the GOCI instrument and incident spectral radiance in front of the GOCI instrument, respectively.

$O(i,j)$: Dark current offset parameter

$F(i,j)$: Fixed offset parameter which is independent of the integration time

$G(B,i,j)$: Linear gain term means "absolute radiometric gain" in [counts/radiance/integration time] unit for each spectral band. The $G(B,i,j)$ is the overall gain including the optic transmission, detector, amplifiers, A/D converter responses, and pseudo averaging. This gain will be periodically updated to take account in-orbit variation during mission life time.

$b(B,i,j)$: Non-linear pixel gain $b(B,i,j)$ means the overall non-linearity which will be mainly caused by the non-linear response of detector. Even though the non-linearity of the detector is constant during the mission life time, this non-linear term will be changed due to the variation of the linear gain terms of the optic gain.

The incident radiance at the GOCI can be calculated from (1) by using estimated radiometric parameters of radiometric model, as follows;

$$L(B,i,j) = \frac{1}{T_{\text{int}}(B)2\bar{b}(B,i,j)} \times \left(-\bar{G}(B,i,j) + \sqrt{\bar{G}^2(B,i,j) + 4\bar{b}(B,i,j)\bar{S}(B,i,j)}\right) \quad (3)$$

where $\bar{S}(B,i,j)$ means the output digital count after offset correction. The gain parameters $\bar{G}(B,i,j)$, $\bar{b}(B,i,j)$ mean the estimated values.

2) *Estimation of offset parameters*

For the GOCI, offset signal depends on each spectral band because the integration time is different from channel to channel. There are two components of offset signals in the GOCI radiometric model; offset signal depending on integration time and fixed offset. The offset signal is not measured for every spectral channel. According to the GOCI operation concept, the offset signal will be measured for two integration time setting; long integration time and short integration time. Before measurement of first spectral band, the offset signal will be measured with high gain(long integration time) setting. After the measurement of the last spectral channel, the offset signals will be measured with low gain (short integration time) setting. For offset signal measurement (dark plate), the GOCI radiometric model given by (1) is expressed by

$$S_{dark}(i,j) = T_{\text{int\_}dark} \times O(i,j) + F(i,j) \quad (4)$$

The offset parameters $O(i,j)$ and $F(i,j)$ can be estimated using offset signal acquisitions for two integration time setting as follows;

$$O(i,j) = \frac{S^H_{dark} - S^L_{dark}}{T^H_{\text{int\_}dark} - T^L_{\text{int\_}dark}} \quad (5)$$

$$F(i,j) = \frac{T^L_{\text{int\_}dark} S^H_{dark} - T^H_{\text{int\_}dark} S^L_{dark}}{T^L_{\text{int\_}dark} - T^H_{\text{int\_}dark}} \quad (6)$$

where $S^H_{dark}(i,j)$: Output digital count for offset signal(dark plate) measurement with high gain setting (long integration time)

$S^L_{dark}(i,j)$: Output digital count for offset signal(dark plate) measurement with low gain setting (short integration time)

($T^H_{\text{int\_}dark}$, $T^L_{\text{int\_}dark}$): Long and short integration time

Using these offset parameters, the offset signal for each spectral band can be calculated and corrected by using the integration time defined for each spectral band.

3) *Estimation of gain parameters*

The linear gain and the non-linear parameter for each spectral band will be changed during mission life time because of aging effect due to exposure to in-orbit radiation environment. The gain variation is mainly caused by the degradation of optic transmission, the electro-optical performance of detector, and the video signal chain. The radiometric gain parameters can be expressed in terms of initial gain and gain change term relative to initial gain, as follows;

$$G(B,i,j,t) = G_0(B,i,j) \times \Delta G(B,i,j,t) \quad (7)$$

$$b(B,i,j,t) = b_0(B,i,j) \times \Delta b(B,i,j,t) \quad (8)$$

where $G_0(B,i,j)$ and $b_0(B,i,j)$ mean initial gain which shall be estimated at the beginning of mission operation. The time dependent parameters $\Delta G(B,i,j,t)$ and $\Delta b(B,i,j,t)$ mean the gain change amount accumulated from the beginning of mission operation. It will be set to unity at the beginning of the mission operation.

The initial gain parameter $G_0(B,i,j)$ and $b_0(B,i,j)$ can be estimated through the on-ground calibration using calibrated radiance source. In order to use the initial gain parameter $G_0(B,i,j)$ and $b_0(B,i,j)$ estimated through on-ground calibration, it should be guaranteed that these parameters are kept until the beginning of the mission operation after launch. Also when a reflectance reference (solar diffuser) and a solar irradiance model are available, the initial radiometric gain $G_0(B,i,j)$ and $b_0(B,i,j)$ can be estimated through in-orbit calibration at the beginning of the mission. In this paper, the in-orbit absolute calibration method is only treated. The gain change terms $\Delta G(B,i,j,t)$ and $\Delta b(B,i,j,t)$ shall be continuously updated using on-board calibration devices during mission life time.

The diffusion factor of solar diffuser is represented by

$$\rho_{SD}(\theta, T_0 + n\Delta T) = \rho_{SD0}(\theta) \times \Delta\rho_{SD}(\theta, T_0 + n\Delta T) \quad (9)$$

where $\rho_{SD0}(\theta)$ means the initial diffusion factor which shall be characterized through the on-ground calibration and $\Delta\rho_{SD}(\theta, T_0 + n\Delta T)$ means the degradation factor at $t = T_0 + n\Delta T$ accumulated from the beginning of the mission T_0.

It is assumed that diffusion factor of DAMD is constant during mission life time. For short term calibration period Δt, the $\Delta G(t)$ and the $\Delta b(t)$ can be estimated through the sun acquisition operation using solar diffuser. The DAMD will be used to estimate the degradation of solar diffuser with long time duration ΔT. The long term calibration period shall be defined to meet the radiometric accuracy requirement through analysis of radiation impact on DAMD. The GOCI has no function to monitor the degradation of DAMD. The radiometric accuracy will be limited by DAMD degradation which will be proportional to its exposure time to radiation environment. For in-orbit calibration, the combination of solar irradiance and solar diffuser is considered as a uniform radiance reference source which is characterized by diffusion factor and incidence angle. The GOCI radiometric model for the sun acquisition through solar diffuser is given by

$$\begin{aligned} S_{SD}(t) &= G(t) \times T_{SD} \times \frac{\rho_{SD}(\theta) E_s \cos\theta}{\pi} \\ &+ b(t) \times T_{SD}^2 \times \left[\frac{\rho_{SD}(\theta) E_s \cos\theta}{\pi} \right]^2 + O \times T_{SD} + F \end{aligned} \quad (10)$$

where T_{SD} means integration time for the Sun acquisition. $\rho_{SD}(\theta)$ and E_s means the diffusion factor of solar diffuser corresponding the solar angle and solar irradiance spectrum which is function of distance between spacecraft and the sun, respectively.

After offset correction, there are two unknown parameters $G(t)$ and $b(t)$ in the radiometric model for the sun acquisition given by (10). Therefore gain parameters $G(T_0 + m\Delta t)$ and $b(T_0 + m\Delta t)$ can be estimated using two points calibration data, as follows;

$$\begin{aligned} G &= \frac{\pi}{E_s} \times \frac{1}{T_{SD}^A \rho_{SD0}(\theta^A) \cos\theta^A T_{SD}^B \rho_{SD0}(\theta^B) \cos\theta^B} \\ &\times \frac{1}{(T_{SD}^B \rho_{SD0}(\theta^B) \cos\theta^B) - (T_{SD}^A \rho_{SD0}(\theta^A) \cos\theta^A)} \\ &\times \{(T_{SD}^B \rho_{SD0}(\theta^B) \cos\theta^B)^2 \bar{S}_{SD}^A (T_0 + m\Delta t) \\ &- (T_{SD}^A \rho_{SD0}(\theta^A) \cos\theta^A)^2 \bar{S}_{SD}^B (T_0 + m\Delta t)\} \end{aligned} \quad (11)$$

$$\begin{aligned} b &= \frac{\pi}{E_s} \times \frac{1}{T_{SD}^A \rho_{SD0}(\theta^A) \cos\theta^A T_{SD}^B \rho_{SD0}(\theta^B) \cos\theta^B} \\ &\times \frac{1}{(T_{SD}^B \rho_{SD0}(\theta^B) \cos\theta^B) - (T_{SD}^A \rho_{SD0}(\theta^A) \cos\theta^A)} \\ &\times \{(T_{SD}^B \rho_{SD0}(\theta^B) \cos\theta^B) \bar{S}_{SD}^A (T_0 + m\Delta t) \\ &- (T_{SD}^A \rho_{SD0}(\theta^A) \cos\theta^A) \bar{S}_{SD}^B (T_0 + m\Delta t)\} \end{aligned} \quad (12)$$

where $\rho_{SD}(\theta^A)$, $\rho_{SD}(\theta^B)$: diffusion factors

T_{SD}^A, T_{SD}^B : integration time for two point calibration

$\bar{S}_{SD}^A(T_0 + m\Delta t)$, $\bar{S}_{SD}^B(T_0 + m\Delta t)$: output digital counts

4. Conclusions

In this paper the nonlinear radiometric model of GOCI is introduced. The nonlinearity of the GOCI is mainly induced by nonlinear response of detector. The offset signal depends on each spectral channel because dark current offset signal is a function of integration time which is different from channel to channel. The offset parameter estimation method using offset signal measurements for two integration time setting is described. It is expected that the estimation uncertainty of offset parameter will depends on the integration time setting for offset signal measurements. This will be examined in near future.

References

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