

PATH RADIANCE ESTIMATION USING REFLECTANCE MEASUREMENTS IN RADIOMETRIC CONTROL AREAS

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ABSTRACT:

A new algorithm of path radiance estimation based on measurements of surface reflectance at radiometric control areas (RCA) has been developed. Path radiance estimates of the proposed RCA-based method were compared against estimates of other methods including the dark object subtraction method, multi-band regression technique, and the covariance matrix method. The RCA-based method is superior to other methods based on three assessment criteria. Paved surface which could be easily identified in most images was also found to be a good choice for radiometric control areas. The dark object subtraction method and the covariance matrix method tend to overestimate path radiance. Although in our study the multi-band regression technique seems to perform as well as the RCA-based method, its estimates may be less reliable.

1. INTRODUCTION

In light of the synoptic spatial coverage and routine availability of satellite images, remote sensing images have been widely applied for monitoring of earth surface processes. For such Earth surface monitoring applications, radiances received at satellite sensor have been interfered and altered by the atmosphere, and are not the same as the radiances leaving the Earth surface. The dynamic earth surface processes cannot be truly monitored unless the temporally varying atmospheric effect has been removed.

One major source of the atmospheric interference is the upwelled radiance, also known as the *path radiance*. Many methods of path radiance estimation have been documented in the literature (Slater 1980, Kaufman and Sendra 1988, Richter 1996, Schott 1997, Rees 2005, Hadjimitsis, et al. 2009). The *dark object subtraction* (DOS) method is perhaps the most widely applied method (Schott 1997, Cheng and Lei 2001). The basic concept of DOS is to identify very dark features (or features with near-zero reflectance) within the scene and the minimum radiance from the selected dark objects represents the path radiance. The *multi-band regression* (MBR) *technique* was developed utilizing correlation between radiances of different spectral bands (Chavez 1975, Porter 1984, Kaufman 1997, Schott 1997). Switzer et al. (1981) developed a *covariance matrix method* (CMM) which utilizes the correlation between multispectral bands of data simultaneously. The CMM method does not require auxiliary data, but operate solely upon the digital numbers of satellite images.

The above mentioned techniques yield estimates of path radiance without measuring properties of the atmosphere or ground surface, and are referred to as *in-scene* estimation. However, when facilities are available for *in-situ* measurement of atmospheric or surface properties, it is desirable to take these *in-situ* measurements into account in determining path radiance. In this paper, we present a path radiance estimation algorithm which estimates band-specific path radiances using ground measurements of surface reflectance at certain *radiometric*

control areas (RCAs). We also compare the results of path radiance estimation by different estimation methods.

2. AT-SENSOR RADIANCE MODELING

For a target of Lambertian surface, the at-sensor solar radiance ($L_{s\lambda}$) can be expressed by

$$L_{s\lambda}(\theta_r, \phi_r) = L_{p\lambda} + \frac{r_{d\lambda}}{\pi} [E_{0\lambda} \cos \sigma \tau_1(\lambda) + FE_{d\lambda}] \tau_2(\lambda) \quad (1)$$

where

θ_r, ϕ_r = the zenith and azimuth angles of the target-sun direction, respectively,

$E_{0\lambda}$ = exoatmospheric solar irradiance with respect to spectral wavelength λ ,

σ = incident angle of the solar irradiance at the target,

τ_1, τ_2 = transmittance along the sun-target and target-sensor directions, respectively,

F = shape factor due to obstruction of terrain slope or adjacent objects,

$E_{d\lambda}$ = downwelled irradiance

$r_{d\lambda}$ = diffuse reflectance of the Lambertian surface,

$L_{p\lambda}$ = path radiance.

For cases which do not cover extensively wide study areas, the downwelled irradiance, path radiance, and atmospheric transmittances can all be assumed spatially homogeneous. Thus, the at-sensor radiance in equation (1) reduces to

$$L_{s\lambda}(\theta_r, \phi_r) = K_0(\lambda) + [K_1(\lambda) \cos \sigma + FK_2(\lambda)] r_{d\lambda} \quad (2)$$

where

$$K_0(\lambda) = L_{p\lambda} \quad (3)$$

$$K_1(\lambda) = E_{0\lambda} \tau_1(\lambda) \tau_2(\lambda) / \pi \quad (4)$$

$$K_2(\lambda) = E_{d\lambda} \tau_2(\lambda) / \pi \quad (5)$$

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3. RCA-BASED PATH RADIANCE ESTIMATION

For local remote sensing applications, spatial variation of the at-sensor radiance in equation (2) is due to $\cos\sigma$ and F which represent the topographic characteristics of individual ground samples. Dependence of K_0 of equation (2) on the wavelength λ , which can be considered as the central wavelength of a spectral band, indicates that path radiance is band-specific. If only ground samples of horizontal and unobstructed surface are considered, $\cos\sigma$ and shape factor ($F=1$) are constant and at-sensor radiance associated with such ground samples can be expressed as

$$L_{s\lambda} = K_0(\lambda) + r_{d\lambda} K^*(\lambda) \quad (6)$$

The path radiance $K_0(\lambda)$ can thus be estimated by choosing a few radiometric control areas of the same landcover types within the scene and adopting a path radiance estimation method described as follows.

Suppose that two radiometric control areas (RCA-1 and RCA-2) of the same landcover types within the study area are chosen. A radiometric control area is an area with spatially homogeneous and temporally stationary land surface condition. Surface reflectance of ground samples in radiometric control areas can be obtained by taking *in situ* measurements using a spectroradiometer. Measurements of surface reflectance should then be integrated over the wavelength ranges of individual spectral bands of spaceborne or airborne sensors.

Let $r_{d\lambda}^{(1)}$ and $r_{d\lambda}^{(2)}$ respectively represent surface reflectance of ground samples in RCA-1 and RCA-2. Similarly, at-sensor radiance associated to ground samples in RCA-1 and RCA-2 are represented by $L_{s\lambda}^{(1)}$ and $L_{s\lambda}^{(2)}$, respectively. Band-specific path radiance can then be determined by establishing a regression relationship for $L_{s\lambda}$ and $r_{d\lambda}$ using at-sensor radiance and reflectance of all individual pixels in RCA-1 and RCA-2, as illustrated in figure 1. The intercept of the regression line represents the path radiance.

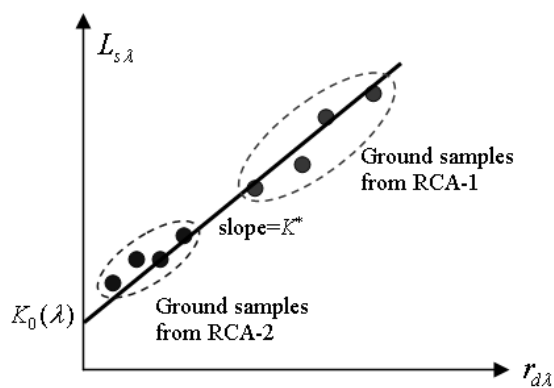


Figure 1. Determining path radiance from $L_{s\lambda} \sim r_{d\lambda}$ regression relationship.

4. STUDY AREA AND MEASUREMENT OF SURFACE REFLECTANCE

An area surrounding the Shihmen Reservoir in northern Taiwan was chosen as the study area (Figure 2). It encompasses approximately 90 km² and is mostly covered by dense forest. A set of Formosat-II multispectral images of the study area acquired on December 11 2008 was collected. Four spectral bands (blue 0.45 – 0.52 μm , green 0.52 – 0.60 μm , red 0.63 –

0.69 μm , and near infrared 0.76 – 0.90 μm) are available, with a spatial resolution of 8 m and dynamic range of 8 bits.

Three radiometric control areas were chosen for in-situ measurement of surface reflectance. All the three RCAs situate on horizontal and unobstructed surface, and have the same landcover type of paved surface.

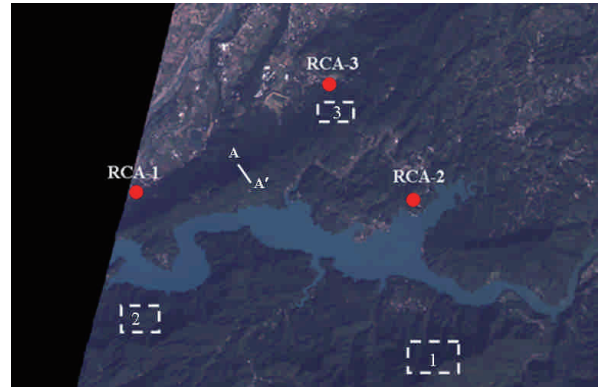


Figure 2. Formosat-II image of the study area. Radiometric control areas are marked by red dots.

A multispectral radiometer (MSR) was used to measure the surface reflectance of ground control areas. Aided by a pre-calibrated standard reference disk, the MSR is capable of measuring average surface reflectance within a spectral window of varying size (from 1.5 to 2 nm) continuously from 350 nm to 1050 nm. The MSR was moved around within each RCA, achieving a few reflectance measurements within individual Formosat-II ground samples. From each spectral reflectance curve, average reflectance over the wavelength range of each Formosat-II band was calculated. Then band-specific ground-sample-average reflectance (hereafter referred to as the *pixel-reflectance*) was calculated using band-average reflectances from measurement locations that fall within the spatial coverage of individual ground samples.

5. DISCUSSION ON RESULTS OF PATH RADIANCE ESTIMATION

Both the multi-band regression technique and the covariance matrix method require knowing the path radiance of one spectral band a priori. In this study, path radiance of the near infrared band was assumed zero, and path radiances of the blue, green, and red bands were estimated using different methods. Results of path radiance estimation are listed in table 1.

For the DOS method, minimum radiance of the blue, green and red bands were calculated by converting minimum digital numbers to minimum radiances using the gain values of individual bands. These minimum radiances are considered as the path radiance of the corresponding bands. All these pixels of minimum radiance are located in shadowed mountainous areas with dense forest cover. Thus, path radiances are likely to be overestimated by the DOS method.

Since no real measurements of path radiance were made, we resorted to a few indirect criteria for assessment of path radiance estimates by different methods. The first criterion is based on the effect of atmospheric scattering with respect to wavelength of the incoming solar radiation. Since path radiance is the upwelled radiance due to atmospheric scattering and the effect of atmospheric scattering reduces with increasing wavelength of solar radiation, we can expect the path radiance also reduces with increasing wavelength. Table 1 demonstrates

that band-specific path radiances estimated by different methods all comply with this phenomenon.

	Band-specific path radiance (in $W/m^2/sr$)		
	Blue	Green	Red
DOS method	1.662 (69)	1.026 (36)	0.398 (26)
Multi-band regression	1.802 (75)	0.761 (27)	0.246 (16)
Covariance matrix method	1.781 (74)	1.063 (36)	0.401 (26)
RCA-based method	0.943 (39)	0.810 (28)	0.246 (16)

Table 1. Results of path radiance estimation using different methods. Number in parenthesis represents the corresponding digital number.

Another assessment criterion is based on the ratio of radiances of different spectral bands, after path radiance was removed. The traverse line A-A' in figure 2 consists of 80 pixels of very homogeneous forest cover. It traverses across the mountain ridge, with half of the pixels facing northwest and others facing southeast. The ratio of adjusted radiances (i.e., $L_{s\lambda} - L_{p\lambda}$) of the green band and red band (G/R) was calculated for all pixels along the traverse line using path radiance estimated by each of the four methods. Figure 3 shows values of G/R band-ratio across the traverse line. The curve of raw band-ratio represents the ratio of at-sensor radiances (i.e. path radiance was not removed). Other curves were constructed using adjusted radiances. Raw band-ratio values of the northwest-facing and southeast-facing pixels are significantly different due to the effect of opposite slope aspect. If the path radiance is properly removed, one can expect similar values of band-ratio across the traverse line because the effect of slope aspect is subdued.

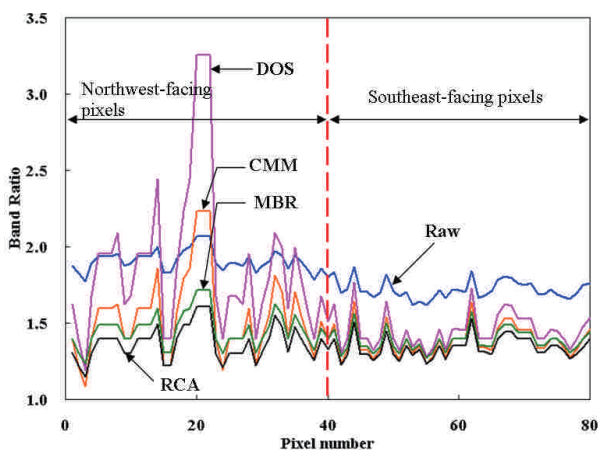


Figure 3. Band ratio (G/R) values across traverse A-A'. Raw: band ratio without correction of path radiance.

The RCA-based method has the lowest and very small standard deviation of band-ratios, indicating the slope aspect effect has largely diminished. Among the four methods of path radiance estimation, the RCA-based method is apparently most superior, while the DOS method is least effective. It can also be observed that the DOS method may result in abnormally high values of G/R band-ratio due to overestimation of path radiance. Similar observation has also been reported by Switzer et al. (1981).

6. CONCLUSIONS

In this study we present a new RCA-based path radiance estimation algorithm using surface reflectance measured at radiometric control areas. The method is superior to other path radiance estimation methods such as the DOS method, multi-band regression technique, and the covariance matrix method. A few concluding remarks are drawn as follows:

(1) Application of the proposed RCA-based method requires surface reflectance calibration at a few radiometric control areas with homogeneous land surface condition. All RCAs should also have similar topographic conditions, for example, horizontal and unobstructed. Paved surface areas which often can be easily identified are good candidates for radiometric control areas.

(2) Among the four methods of path radiance estimation, the RCA-based method is most superior, while the DOS method is least effective.

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