RADIOMETRIC CALIBRATION OF MULTI-SPECTRAL FILTER SENSOR

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ABSTRACT: In order to get 4 different spectral images for an ocean imager currently developed by ITRC and NTOU, architecture of multi-filter is designed on CMOS image sensor to acquire images with specific spectrum. Four filters are glued on an area CMOS sensor. The spectral ranges of 4 filters are 420-460 nm, 470-510 nm, 530-570 nm and 830-910 nm respectively. Since filters with different spectrum on a sensor affect responses of the ocean imager, the purpose of the research is to retrieve the correct response of this imager and then to perform the radiometric calibration on multi-spectral images. An integrating sphere with light source A (color temperature of 2854K) is applied for deriving calibration parameters. Since there're different spectral responses for 4 spectral ranges on a CMOS sensor, the measurement process for radiometric calibration is divided into four parts to have strong enough signals. As a result, the calibration parameters for image radiometry can be derived correctly based on results of image calibration using images of integrating sphere. And image calibration using aerial images with 4 spectral bands near NTOU is also performed for demonstration based on the calibration parameters.

INTRODUCTION

Ocean color is affected by penetrative solar radiation and different suspended particulates included phytoplankton and inorganic particles in the ocean. Particulates are associated with the absorption and reflection of solar radiation, thus affecting the purity and color of the ocean. Especially phytoplankton contains the chlorophyll, which absorbs red and blue lights and reflects green ones. According to ocean color data, we could evaluate depth of solar radiation (Zhang etc., 2011) and contents of ocean biology. To measure ocean color data, an airborne Marine Environmental Imager (MEI) with multi-bands CMOS sensor for pre-test satellite based imager has developed. The CMOS module has 512 x 256 pixels, the pixel size is 50 x 50 µm and the dynamic range is 12 bits. Three bands of visible wavelength and one Near-infrared band are chosen for mapping and detecting vegetation purposes. Before applying the imager, radiometric calibration parameters of each band should be derived. Radiometric calibration in laboratory could recover correct responses of images introduced by the imager itself. The ocean color data would be more accurate after performing radiometric calibration.

FILTER SPESIFICATION

The important components of Ocean Color Imager are CMOS sensor module and 4 filters glued on sensor. According to the requirement analysis for ocean color data and MEI system, specifications of MEI are listed in table 1. The designed spectral ranges of filters are 440±20 nm, 490±20 nm, 550±20 nm and 870±40 nm for blue, green, red and near infrared bands respectively. We use calibrated spectrometer to measure the spectrum range of each filter. The results of measurement are illustrated as Figure 1 and 2, and show the spectrum of each band is qualified.

Table 1. Specifications of MEI

Items	Specifications of MEI
Wavelength range of each band	B1: 440 ± 20 nm B2: 490 ± 20 nm B3: 550 ± 20 nm B4: 870 ± 40 nm
iFOV / FOV	0.5882 mrad / ± 4.31°
CMOS (pixel number)	512 x 256 ; 128 x 256 (each band)
Pixel size	50 x 50 μm
Focal length	85 mm
Swath	229 m
Frame rate	1.31 frame/sec

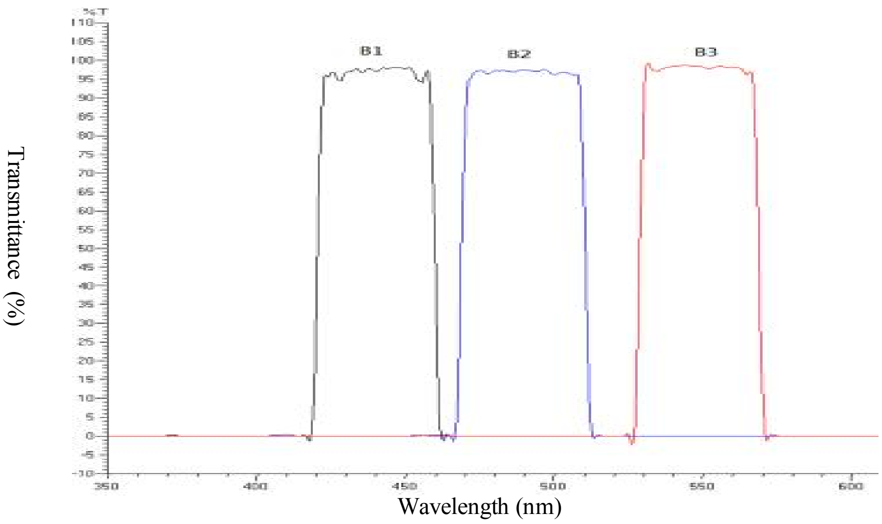

Figure 1. Spectral range of B1 to B3

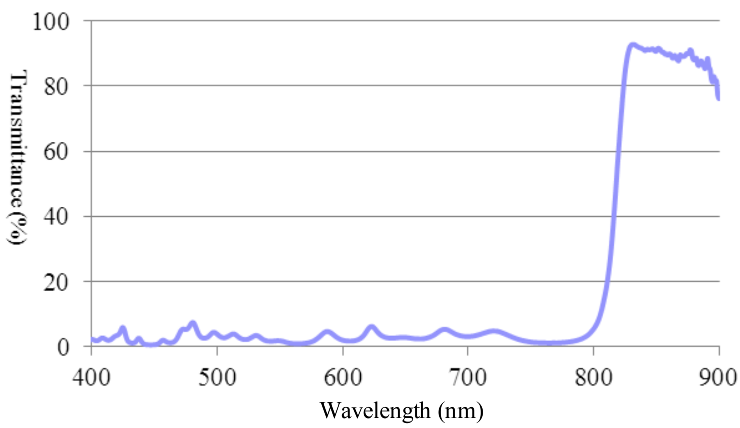

Figure 2. Spectral range of B4

RADIOMETRIC CALIBRATION

It's inevitable that images in the middle of field are brighter than that in the corners by using optical lens. When taking an image of the flat field, we get a disk image instead of a uniform image and this phenomenon is called fall-off effect (Figure 3(a)). To avoiding the situation that incorrect readouts affect the relation between radiance and pixel values, radiometric calibration is necessary for images in various applications.

(a) (b)

Figure 3. (a) Original flat field image; (b) Radiometric calibrated flat field image

In order to get the correct pixel response, we have to establish the calibration model between radiance and digital number. As different intensity of radiance and images acquired at the same time, the relationship between radiances and digital numbers can be found. Linear function to fit the relationship, shown as formula (1), has been adopted. L is the calibrated digital number; l_i is the scale factor comparing to the standard spectrum radiance and i represent the pixel number; X_i is the digital number; m_i is the offset of dark signal. We use least-square method to solve l_i and m_i.

$$L = l_i X_i + m_i \quad (1)$$

After performing radiometric calibration, the flat filed image is recovered as Figure 3 (b). The filters of MEI are glued on the same CMOS sensor, and spectral ranges of each band are discrete. So the readouts are much different especially for B1 and B4 as shown in Figure 4. Hence the parameters of radiometric calibration can't be derived correctly in only one calibration measurement because of the measuring scale error. In order to get the correct parameters by fitting the linear equation of formula (1), the calibration measurement has to be conducted repeatedly for each band.

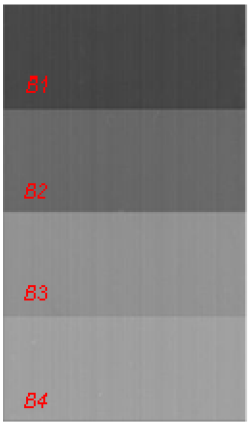

Figure 4. Images for different bands under same input radiance

EXPERIMENTS

The structure of calibration measurement and data processing for spectral calibration is shown as Figure 5. Table 2 shows the specifications of used spectral radiometer. It can measure the radiance of spectrum range from 350 nm to 2500 nm. MEI takes images for various radiances with different radiation intensity provided by integrating sphere via switching lamps on/off one by one. The function of integrating sphere is to provide a uniform intensity of light. Taking the image of it allows us to calibrate the CMOS sensor pixel by pixel; by controlling the light intensity, the spectral response of each pixel can be calibrated.

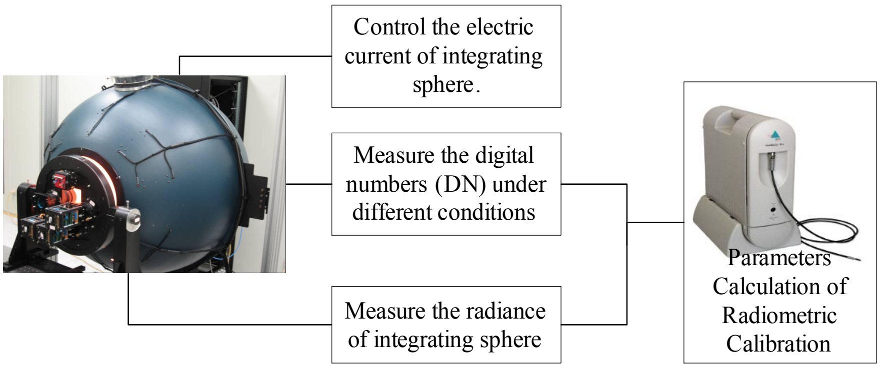

Figure 5. Structure of calibration measurement

Table 2. Specifications of spectral radiometer

Spectral range	Resolution	Spectral band number	Wavelength accuracy
350 nm～2500 nm	3 @ 700 nm 10 @1400 nm/2100 nm	2150	± 1 nm

Tungsten halogen bulbs with color temperature of 2300 ~ 2800K are adopted within the integrating sphere. The characteristics of tungsten halogen spectrum is smooth and continuous (Mahajan & Jung, 2008), but the spectral radiance of blue band is weaker and the one of NIR band is stronger than others (as green curve in Figure 6). The spectral ranges of 4 bands for MEI are represented as color bars shown in Figure 6, and the radiance from B1 to B4 diverge greatly.

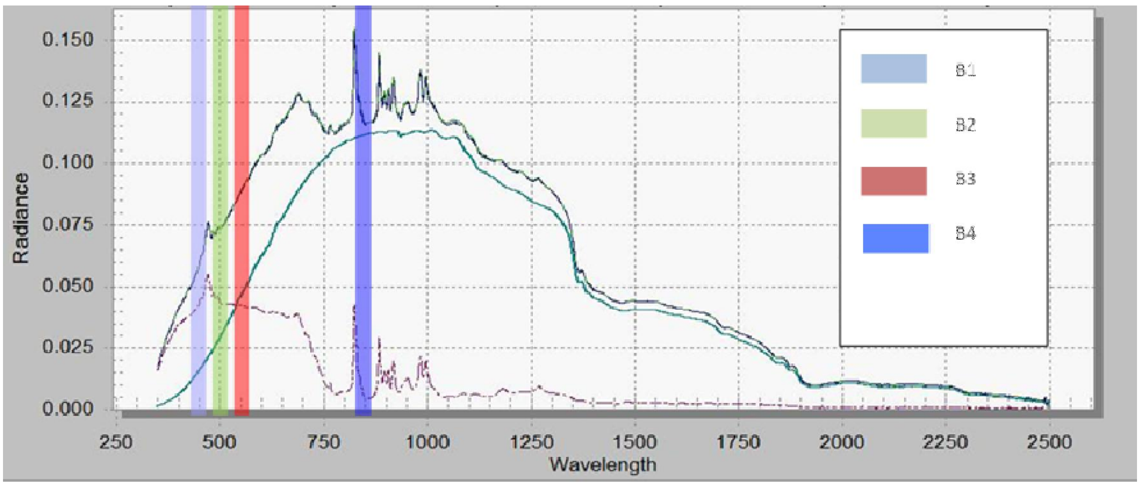

Figure 6. The relative spectrums for light sources of tungsten halogen and xenon

Figure 6 shows that image readouts and spectral radiance of tungsten halogen lamp for each band have positive correlation. Considering the relationship between radiance and image readouts, the calibration measurement is separated into 4 parts for each band to avoid the saturation of CMOS sensor and increase the dynamic range of pixels, and to reduce the scale errors. Electric current of the integrating sphere can be adjusted as experimental condition (as Table 3), and the lower current the lower intensity of radiance.

Table 3. Specifications of spectral radiometer

Experiments	B1	B2	B3	B4
Electric current (ampere)	6.25 A	5.60 A	5.30A	4.21 A

RADIOMETRIC CALIBRATION

After performing calibration measurement for each band, parameters of radiometric calibration for every pixel are calculated. We can recover the radiance of images by using these calibration parameters as follows:
We use MEI to capture ground images and splice these images as panorama images. Figure 7 shows splice images for 4 spectral bands before and after performing radiometric calibration. The lateral and vertical axes represent time and spatial distance respectively. After conducting the radiometric calibration, tones of images are more uniform and background noises are reduced, and the details in images are revealed more clearly.

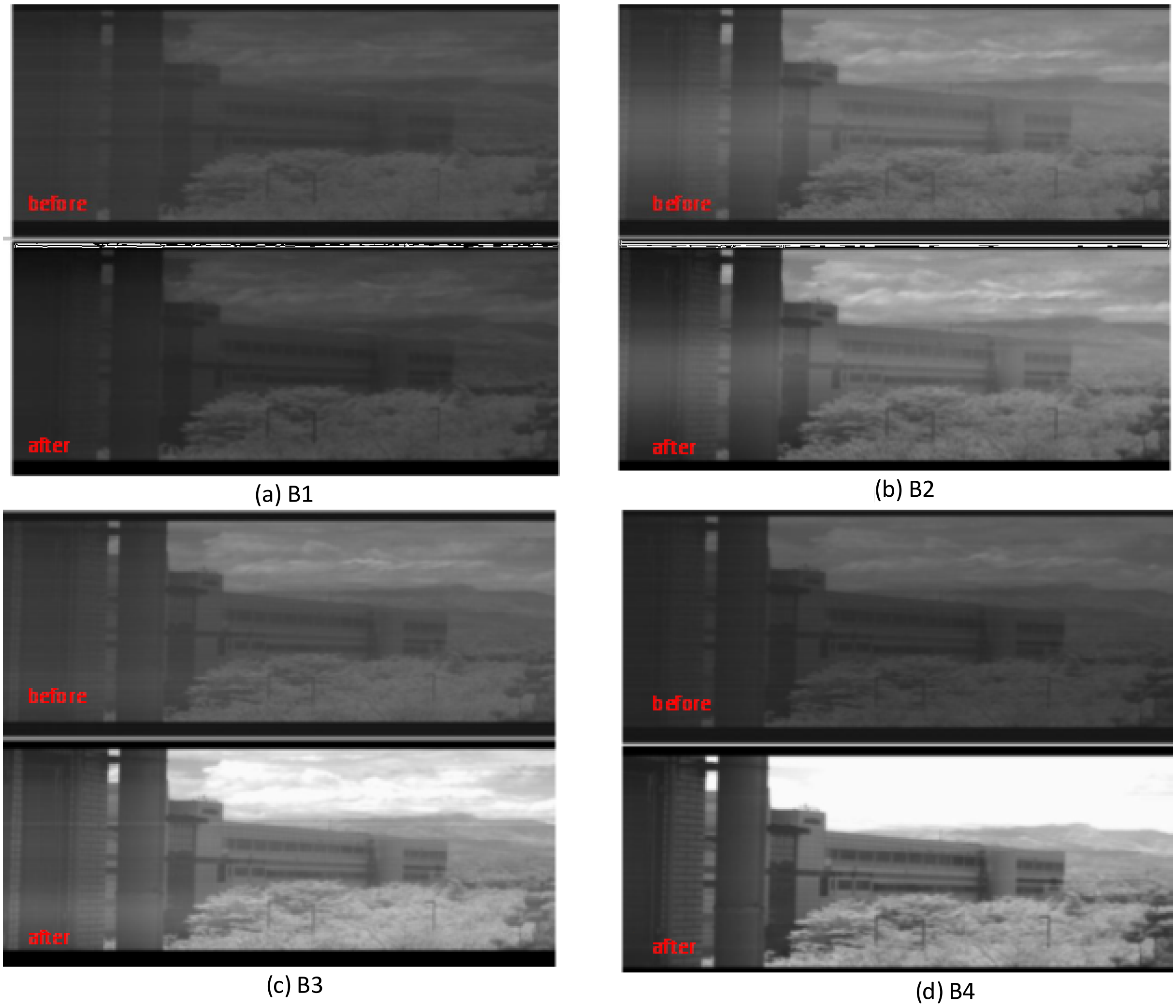

Figure 7. Panorama images of 4 bands before and after radiometric calibration

The aerial images for experiments were also taken near National Taiwan Ocean University (NTOU) in July 2012. The testing field contains the area of ground and ocean. The images are calibrated and spliced as shown in Figure 8. The false color image is fused as well by using images of B4, B3 and B2 for feature identification as Figure 9. Therefore, we can easily discriminate the regions of water from vegetation. For example, the top-left area in Figure 9 is the water region and the center-bottom area is the vegetation.

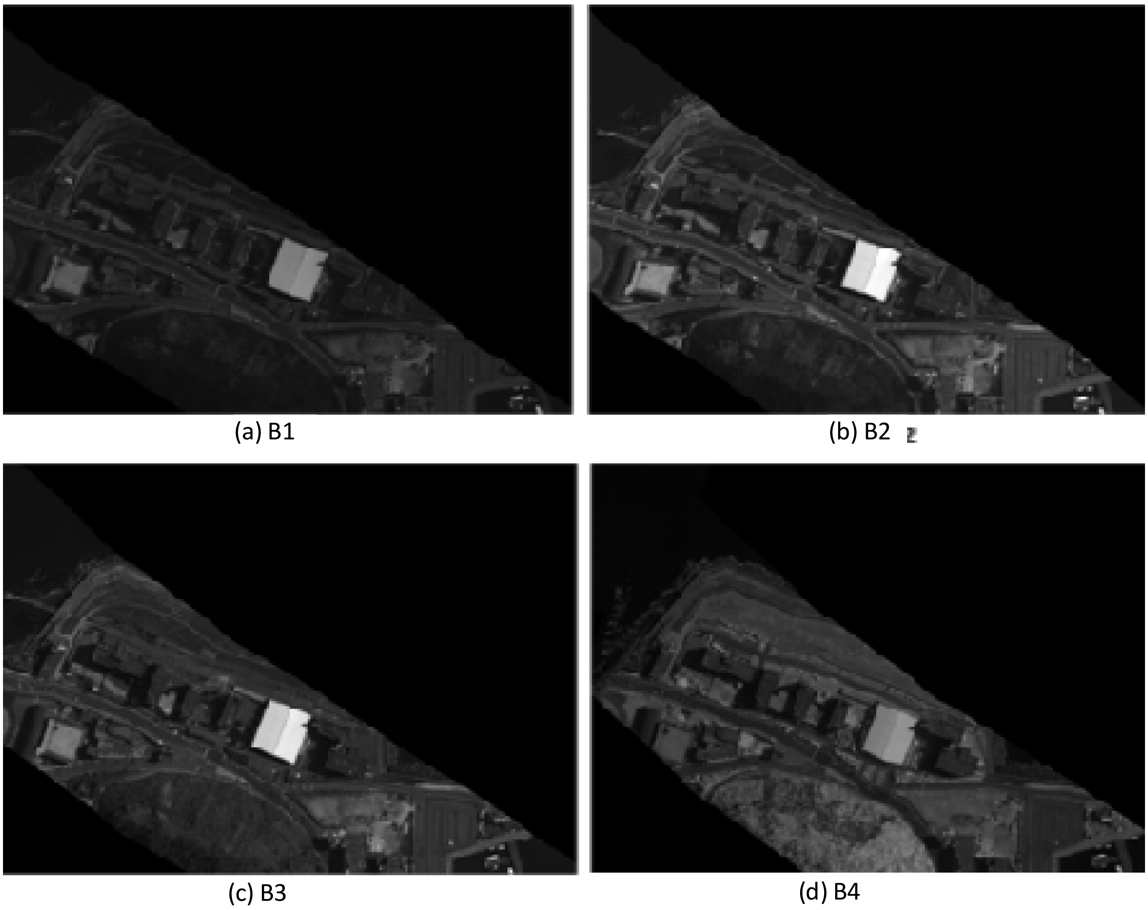

Figure 8. Spliced aerial images of 4 bands after radiometric calibration

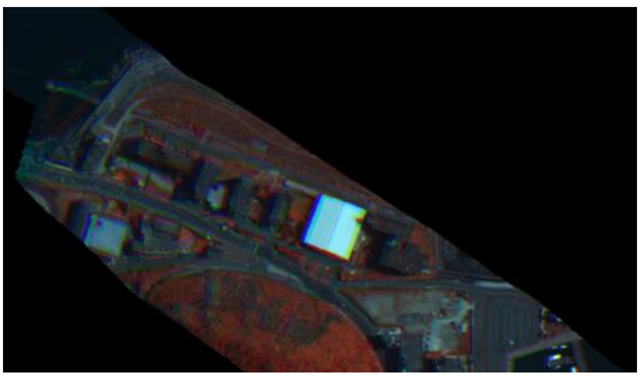

Figure 9. False-color image

CONCLUSION

After performing above processes of calibration measurement and data processing, we can derive the parameters of radiometric calibration for 4 spectral bands correctly based on results of image calibration using integrating sphere.

And the radiance of ground features also can be retrieved successfully according to aerial images near NTOU. But radiometric calibration excludes the atmospheric radiometry in laboratory.

REFERENCE

1. Paulson, C. A., and J. J. Simpson, 1977: Irradiance measurements in the upper ocean. J. Phys. Oceanogr., 7, 952–956.
2. Zhang, R. H., Chen, D. and Wang, G., 2011, "Using Satellite Ocean Color Data to Derive an Empirical Model for the Penetration Depth of Solar Radiation (Hp) in the Tropical Pacific Ocean", Journal of Atmospheric and Oceanic Technology, vol.28, 944-965.
3. Mahajan, V. and Jung, D.J., 2008. Design and Characterization of Uniform Spectral Radiance Source for Test and Calibration of Radiometers Used for KOPMSAT-3, SPIE Proceeding, Vol. 6958.
4. Lai, J.Y., Chen, M.F., Lee, L.J. and Huang, T.M., 2011," Measurement and parameters derivation of radiometric calibration for hyperspectral imager"