MEASUREMENT AND PARAMETERS DERIVATION OF RADIOMETRIC CALIBRATION FOR HOPE HYPERSPECTRAL IMAGER

Jyun-Yi Lai [1], Ming-Fu Chen[2], Long-Jeng Lee [3], Ting-Ming Huang [4]

[1]Assistant Researcher, Instrument Technology Research Center, NARL,

20, R&D Rd. VI, Hsinchu, Science Park, 300, Taiwan; Tel:+886-3-5779911#656;

E-mail: laijy@itrc.narl.org.tw

[2] Associate Researcher, Instrument Technology Research Center, NARL,

20, R&D Rd. VI, Hsinchu, Science Park, 300, Taiwan; Tel:+886-3-5779911#657;

E-mail: mfchen@itrc.narl.org.tw

[3] Researcher, Instrument Technology Research Center, NARL,

20, R&D Rd. VI, Hsinchu, Science Park, 300, Taiwan; Tel:+886-3-5779911#210;

E-mail: ljlee@itrc.narl.org.tw

[4] Researcher, Instrument Technology Research Center, NARL,

20, R&D Rd. VI, Hsinchu, Science Park, 300, Taiwan; Tel:+886-3-5779911#229;

E-mail: tmw@itrc.narl.org.tw

KEY WORDS: Hyperspectral Images, Radiometric Calibration

ABSTRACT:

HOPE (Hyperspectral Observer of Plants and Environment) imager developed by ITRC is an airborne pushbroom hyperspectral imager. It's composed of a PGP dispersing device and lens with wide FOV of 72°. HOPE can acquire an image line with spectral range of 400~1000nm, covering blue to Near-Infrared bands on a single focal plane. Because of high spectral and spatial resolution, there're many applications in agriculture, forest and ecological environment using hyperspectral images.

It is essential to perform the radiometric calibration before applying HOPE imager. An integration sphere with light source A with color temperature of 2854K was applied during the calibration process. However, due to the lower responsive characteristics of CCD detector, the readout of the imager in the range of blue band was less than the others based on the calibration light source A. As a result, the parameters of HOPE radiometric calibration presented a larger uncertainty of image radiometry. In this article, an improved mixed light source has been proposed. It is adopted by adding Xenon light into the integrated sphere to enhance the color temperature of light source. The combination of light source A and Xenon light with different number of bulbs is conducted as well for comparison and investigation. A calibrated spectral-radiometer has been used to be the transferred standard for radiometric calibration. Thus, we can derive precise calibration parameters for image radiometry by adding required light sources according to spectral responses. The calibrated results will be compared between those with only light source A and mixed light source. Discrepancies of experiments and their possible reasons are also discussed for radiometric calibration. After completing proposed process, the radiance of ground features captured by HOPE imager could be correctly recovered based on the refined radiometric calibration parameters.

1. Introduction

The HOPE (Hyperspectral Observer of Plants and Environment) imager developed by ITRC is an airborne pushbroom hyperspectral imager. It's composed of the component with an entrance slit and a PGP dispersing device, electronic devices and wide-angle optical lens, etc. The IMU is also used to acquire the external parameters corresponding to image lines for following processes of image calibration and processing. The spectral range is 400 ~ 1000nm, and the spectral resolution, number of spectral bands and FOV are 5@500 nm, 212 and 72° respectively for HOPE imager. Before starting to operate the HOPE imager, we have to perform the spectral registration to fix the spectrum and the radiometric measurement to derive the radiometric calibration parameters of imager in laboratory. The spectral range of HOPE imager covers blue to Near-Infrared bands and out of human's visibility. Because of the high spectral and spatial resolution, there're many applications by hyperspectral imagers including the monitoring and applications in agriculture, forest and ecological environment, and the exploitation and investigation in minerals and energy resources.

2. Radiometric calibration in laboratory

The purpose of radiometric calibration in laboratory is to eliminate the distortions of images introduced by the sensor itself. In order to recover the resolution of hyperspectral images, the spectral calibration of a hyperspectral imager in laboratory includes 2 important items: the spectral registration and the radiometric calibration as the following discussing.

2.1 Spectral Registration

Hyperspectral images form a three-dimensional (3D) cube, composed of cross-track (x), along-track (y), and spectrum (λ) dimensions. Due to the fall-off effect and the misalignment of sensors, the response of each CCD pixel is different from each other, and the radiometric calibration processes can recover the correct radiance. The purpose of registration is to get the correct response for different wavelength of light source.

In order to register the spectral wavelengths , we use the spectral pattern of standard light source to correct the spectral response so the HgAr light source of Oriel is pointed and photoed by HOPE. The image of the HgAr light source showed as Fig.1(a), the cross axle and along axle represent spectral and spatial axes respectively and the profile of the yellow line shows the spectrum of HgAr light as Fig.1(b). According to Fig.1(b), we use the least square function to compute positions of each bands correspond with the standard wavelengths of HgAr light so we could correct smile effect by image processes and get the CCD positions respond to spectrum.

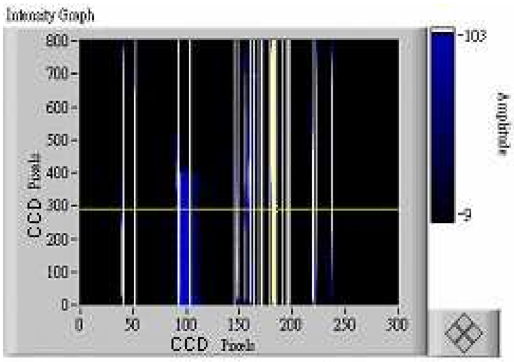


Fig. 1(a) the response of HgAr

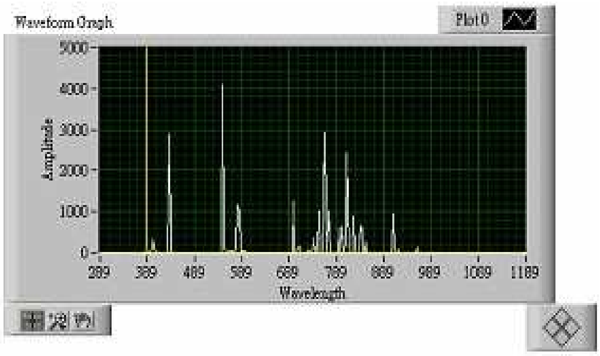


Fig. 1(b) the profile of yellow line

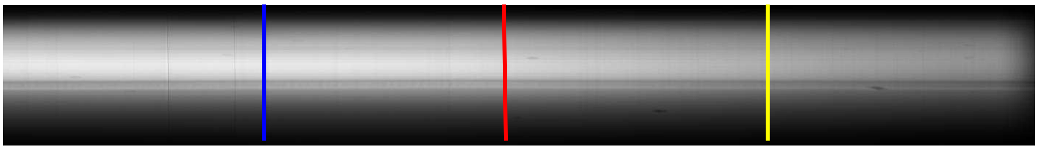
Table 1 is the spectral registration results for HOPE hyperspectral imager. The left column is the standard wavelengths of HgAr light and the right column is the registered wavelengths of HOPE. There are 212 bands of HOPE and the misregistrations is less than1nm after the spectral registration process.

Standard wavelength of HgAr (nm)	Calibrated wavelength of HOPE (nm)
546.08	546.33
578	577.62
696.54	696.83
763.51	763.23
811.53	811.62
842.46	842.41

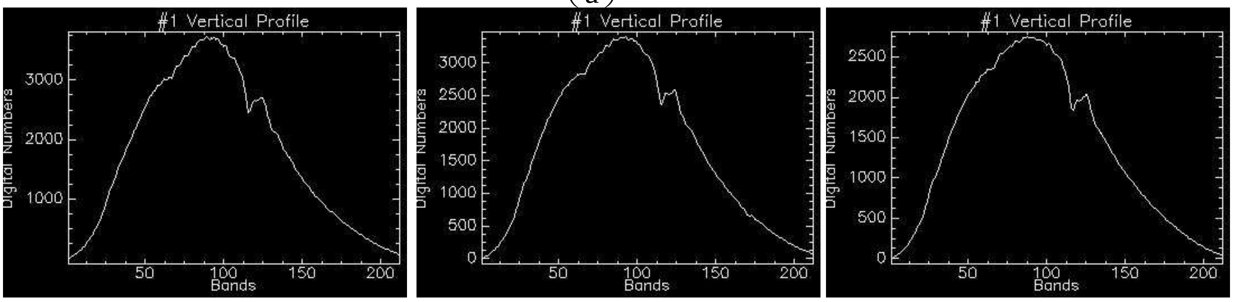
Table 1. Spectral registration results for HOPE hyperspectarl imager

2.2 Radiometric Calibration

After completing spectral registration, the radiometric calibration is based on the integrated sphere with large aperture. By taking images of the flat field, we can get the readout of every pixel and the radiances acquired by a calibrated spectral-radiometer at the same time. Fig.2(a). is the flat field image and Fig.2(b) represents the different responses of spectrum at the different spatial positions so-called the fall-off effect



（a）



Blue：353 Red：706 Yellow：1059

（b）

Fig. 2 (a) image of flat field;(b) the profile of blue, red and yellow lines.

In order to get the right pixel response, we have to establish spectral and spatial calibration model. As different intensity radiance and images acquired sychronally, we can find the relationship between radiance and digital number. Here we use linear function to fit the relationship as formula (1) shows. 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 digital number; m_i is offset of dark signal.

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

3. Experiments

Integrated sphere uses tungsten halogen bulbs as light source A with color temperature of 2300 ~ 2800K adopted for our experiments. Due to diffraction and fall-off effects of lens and the property of CCD sensor, the radiances and image responses in the range of blue band are both smaller than the other bands using the standard light source A as experiments. Hence the parameters of HOPE radiometric calibration can’t be derived correctly because of the scale error of measurements.

In order to promote the color temperature of experimental light source, we adopt the mixed light source for experiments by adding the light source xenon with high color temperature of 6000K to improve spectral response of blue bands into the integrated sphere. The green, blue and red curves represent tungsten halogen, xenon and combined light source spectrums respectively in Fig.3 (Mahajan & Jung, 2008). As it shows the combined light source spectrum could raise the radiance of blue bands and also weaken the sharp picks that could effect the calibration parameters.

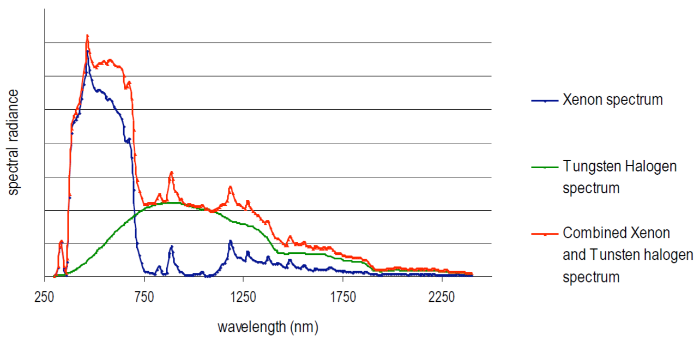


Fig. 3 The relative spectrums of tungsten halogen and xenon light sources (Mahajan & Jung, 2008).

3.1 Experimental Devices

The structure of experiments and data processing for spectral calibration is shown as Fig.4. We use HOPE to get hyperspectral images and ASDi (spectral radiometer) to acquire radiance of spectrum. Here are the specifications of HOPE and ASDi as Table 2 shows.

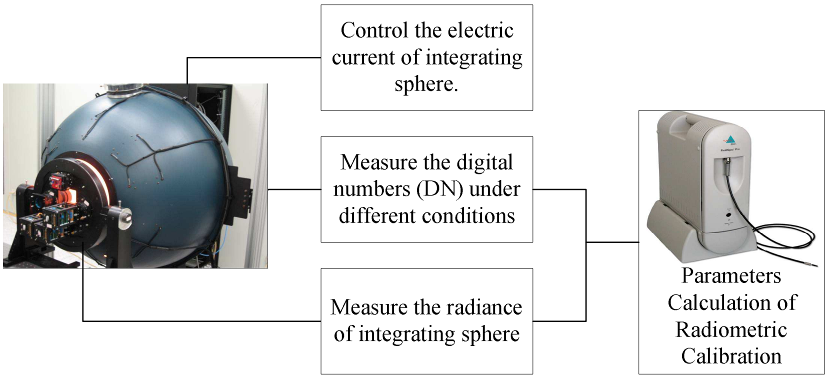


Fig. 4 Structure of experiments and data processing for spectral calibration

	HOPE hyperspectarl imager	ASDi spectral radiometer
Spectrum range	400nm～1000nm	350nm～2500nm
Resolution	5 @ 500nm	3 @ 700nm 10 @1400nm/2100nm
Spectrum band number	212	2150
FOV	72°	fiber
Wavelength accuracy	± 0.8 nm	± 1 nm

Table 2. Specifications of HOPE hyperspectarl imager and ASDi spectral radiometer

In order to add xenon light into integrated sphere, we design a device as Fig. 5 shows. To avoid the light pattern affect images, the device is pointed 45 degree and put about 30 cm distances beneath the aperture and make sure the FOV of HOPE and ASDi are included.

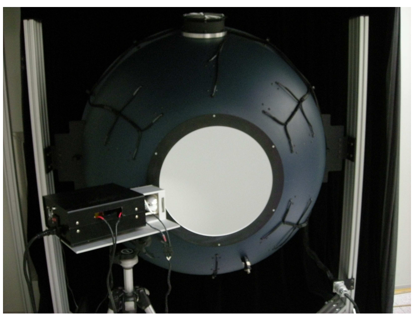
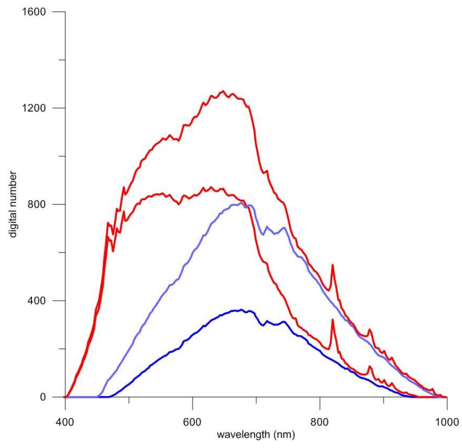
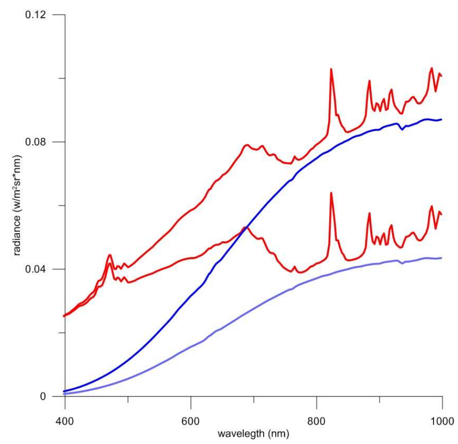


Fig. 5 xenon light source device.

Because the xenon light source is external device, we can’t adjust the intensity. To get different intensity of radiance and CCD response, we switch numbers of tungsten halogen bulbs. The variance of radiance and CCD response as Fig. 6(a) and Fig. 6(b) shown respectively. The blue curves represent only tungsten halogen light used and red curves represent the result of combined light sources. We can find both promotion of CCD responses and radiance in the blue bands when combined light sources used but the picks in NIR bands are not weaken effectively. We separate the spectrum into 2 sections to calculate the calibration parameters : 400~750nm spectrum use the combined parameters and behind 750nm spectrum use only tungsten halogen parameters.



(a)

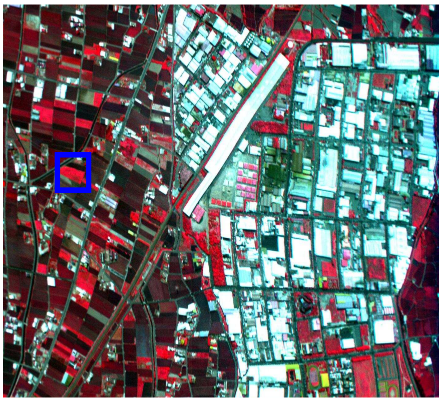


(b)

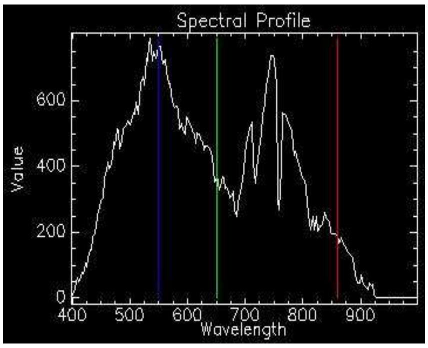
Fig. 6 (a) CCD response of HOPE; (b) radiance of ASDi.

3.2 Hyperspectral Images Radiometric Calibration

The experimental aerial hyperspectral images are taken during the period of transplant rice seedlings in Apr. 2009 so parts of lands are full of water. Plants have strong reflective in NIR bands so we can discriminate easily when we use the fake color images as shown in Fig.7(a). The right part of original image is darker than the left part that shows the fall-off effect. We choose one point in the blue square which could be plant and it's spectrum shown in Fig. 7(b).



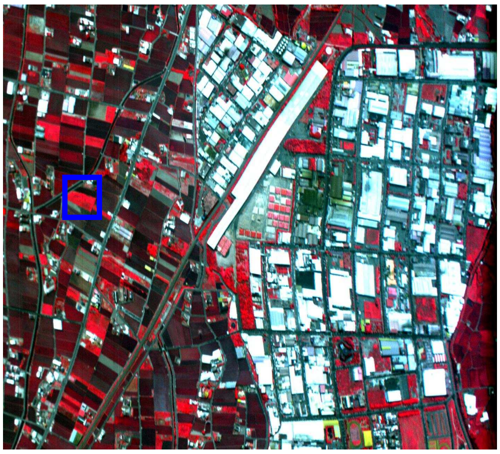
(a)

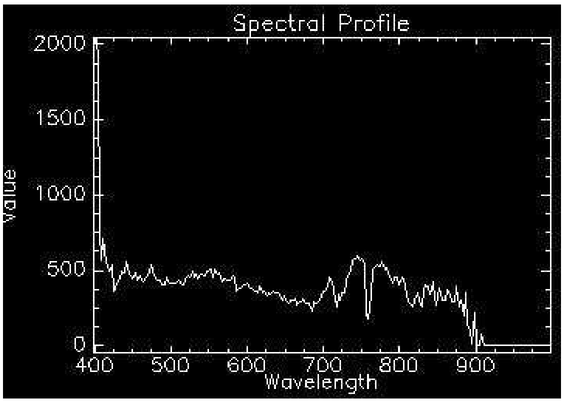


(b)

Fig.7 (a) original image of HOPE; (b) spectrum of one point in blue square.

After radiometric calibration computation, the calibrated image is shown as Fig.8 (a). The color tones of image are more uniform and darkness of the right side of image is also corrected. The corrected rice spectrum is shown as Fig.8 (b). When solar radiation goes through the atmosphere affected by atmospheric absorption, there are some characters on rice spectrum. There are an atmospheric oxygen absorption band near 760 nm and an atmospheric vapor absorption band near 900 nm, so these cause the valley shapes on the spectrum. Near a absorption valley at about 750 nm, the reflection increases rapidly so-called "red edge effect" that is one of characters of plant spectrum.





（a） （b）

Fig.8 (a) calibrated image of HOPE; (b) calibrated spectrum of one point in blue square.

4. Conclusions

After completing the above processes and data computations, we'll implement radiometric calibration process to recover the radiance of ground features. But this radiometric calibration in laboratory doesn't include the atmospheric radiometric correction yet, resulting the difference in vegetation reflectance curve. We'll attempt to use multi-wavelength linear regression method with interpolation algorithms to get calibration parameters, and add the atmosphere radiometric correction to restore the spectral characteristics of features.

5. References

Mouroulis, P. and McKerns, M.M., 2000, "Pushbroom Imaging Spectrometer with High Spectroscopic Data Fidelity: Experimental Demonstration", *Society of Photo-Optical Instrumentation Engineers*, Vol. 39(3), pp.808-816.

Winter, E.M., 2001 "The Development of a Hyperspectral Sensor: A Data Processing Viewpoint", Proc. of IEEE 2001 Aerospace Conference, Vol. 4, pp.4/1979 - 4/1984.

Gao, B.C. , Montes, M.J. and Davis, C.O. , 2004, "Refinement of Wavelength Calibrations of Hyperspectral Imaging Data Using a Spectrum-matching Technique", *Remote Sensing of Environment*, Vol.90, pp.424-433.

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.