Development of a Simple Radiometric Calibration System for Multispectral Images of an Unmanned Aerial Vehicle

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ABSTRACT: An Unmanned Aerial Vehicle (UAV)-based remote sensing (RS) technique is a useful tool to observe spatial variation in crop growth conditions. To ensure the reliability of UAV-based RS images and acquire surface reflectance, the radiometric calibration using pseudo-invariant tarps has been generally used. While calibration tarps are used in general, it is difficult to apply them on multiple sections of a large field requiring multiple images. In addition, using calibration parameters from the tarps measured one time for multiple images can cause errors due to differences in an image acquisition time. Therefore, a calibration method integrated into a UAV is required to perform practical calibration. In this study, we aim to develop a standalone UAV-based calibration system without the calibration tarps through the quantification of sensor responses of a multispectral camera, which varies with an intensity of incident light. To develop the standalone UAV-based calibration system, we assembled a UAV with four propellers and a dimension 680 mm in wing's length and 250 mm in height. The system was composed of a multispectral camera (Tetracam, Inc., CA, USA) with green, red, and near-infrared filters to acquire spectral images. A line quantum sensor (LI-COR, Inc., NE, USA) was used to measure the intensity of the incident light to obtain input parameters of the calibration algorithm. We first constructed a library of sensor responses using pseudo-invariant tarps according to the intensity of incident light, and the relationship between the two factors was determined. The calibrated images will be validated using the reflectance measured in crop fields. We report the evaluation outcome of the UAV-based calibration system. We also present spatial information on the crop growth conditions based on spectral indices. Our study result suggests that the formulated standalone UAV-based RS system would be useful for practical and applied image processing for UAV-based RS images.

1. Introduction

An Unmanned Aerial Vehicle (UAV)-based remote sensing (RS) technique has been widely used for monitoring crop growth as a UAV allows to acquire image data frequently at a lower cost and a better spatial resolution than any other aviation RS platforms (Hunt et al., 2010; Jeong et al., 2018). Before UAV images can be practically adopted, radiometric calibration is an important procedure in most progressive applications using the images, which includes converting digital number (DN) to reflectance in the image data. A calibration approach based on invariant reference tarps have been generally employed because it is simple and accurate (Nebiker et al., 2008; Laliberte et al., 2011). While images can be taken compliantly at the same time or before or after the flight, this approach can result in some errors in the case of compositing multiple images for a large area due to the time difference between the tarp image and the other images taken excluding the tarps. Performing the approach includes an inefficiency that the reference tarps should be always carried or included in multiple images using many replicas of the tarps. In addition, the reference reflectance of the tarps may inevitably change over time due to contamination of dusts or the color fading (Jeong et al., 2016). This can undesirably affect quality of the calibrated image. Therefore, there is a need for a way to complement these limitations by integrating a calibration method into a UAV. In this study, we aim to develop a standalone UAV-based calibration system without the calibration tarps through the quantification of sensor responses of a multispectral camera, which varies with an intensity of incident light.

2. Materials

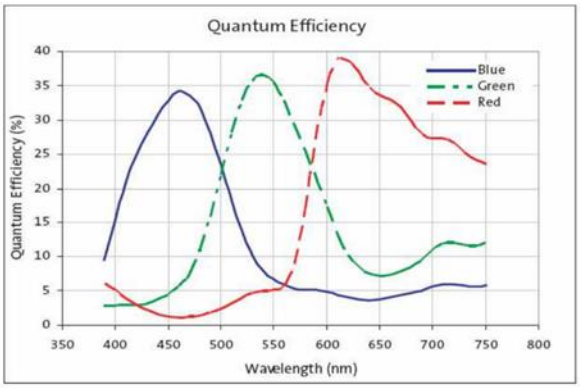
2.1. UAV

To develop a standalone UAV-based calibration system, we assembled a UAV with four propellers and a dimension of 680 mm in wing's length and 250 mm in height. This configuration is relatively stable compared to other types of UAVs, such as helicopters or fixed wing UAVs. The aerial vehicle can hover for 25 minutes using a rechargeable battery of 8,000 mAh.

2.2. Multispectral camera

We used an ADC Micro multispectral camera (Tetracam Inc., CA, USA) in this study (Figure 1). The camera weighs 90 g, mounting three band sensors with a dimension of 6.55 × 4.92 mm for each. Each sensor can take images at a pixel resolution of 3.12 micron. The three multispectral sensors acquire images in the wavebands of green (520–600 nm), red (630–690 nm), and near infrared (760–900 nm), having a detection capacity of a waveband range of 520–920 nm. It is possible to combine images using the PixelWrench2 software (Tetracam Inc., CA, USA).

(a)



(b)

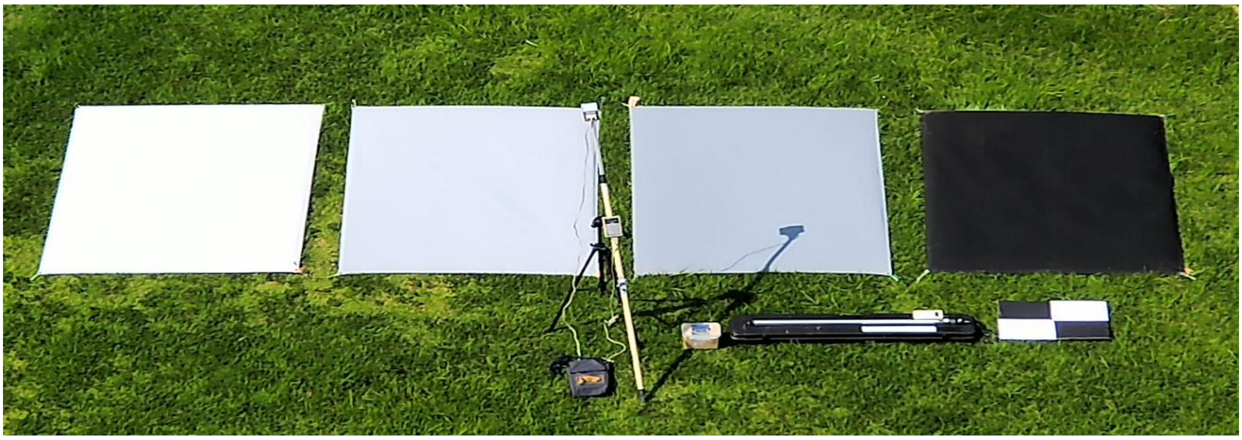
Figure 1. (a) ADC Micro multispectral camera (Tetracam, Inc., CA, USA) and (b) spectral response characteristics of the camera for blue that is blocked for NIR sensing, green, and red, employed in this study (www.tetracam.com).

2.3. Reference tarps

For converting DN to surface reflectance values, we used reference reflectance tarps (Figure 2a). The tarps are chemically treated so as to provide the stable reflectance needed for calibration. In this study, we used four tarps to calibrate UAV images. Each tarp has a dimension of 1.0 × 2.0 m, showing reflection values at 0.035, 0.2, 0.32 and 0.51. The tarps were designed to quantify the visible and NIR spectrums. We laid out the tarps for configuration, avoiding any interference. We used data from three standard reflectance tarps (grey, pearl grey, and white), excluding data from the black tarp.

2.4. Multispectral radiometer and irradiance sensor

Ground reflectance was obtained using a multispectral radiometer (CROPSCAN Inc., MN, USA) to calibrate and evaluate UAV images. The equipment comprises 16 wavebands from 450 to 1,750 nm with upward and downward sensors. These sensors measure incoming and reflected radiation values simultaneously, which provide stable reflectance in a cloudy sky condition. The intensity of the incident light was measured using a line quantum sensor (LI-COR, Inc., NE, USA).



(a)

(b)

Figure 2. (a) Four reference tarps with reference reflectivity at 0.51, 0.32, 0.21, and 0.031 from left in order (b) Line Quantum Sensor (LI-COR, Inc., NE, USA) used to measure light intensity.

3. Methods

In this study, field experiments were carried out several times under various light intensity conditions to quantify UAV images at Chonnam National University, Gwangju in 2019. The UAV images were taken approximately at the local noon ± 45 min to minimize errors caused by change in sun angles. The camera exposure was set to 50 % with a shutter speed of 1 ms, which was defined using the TETRACAM software to obtain consistent digital values. The intensity was measured at the same time when the UAV takes images. A total of 12 evaluation points was measured.

Three processes were applied to calibrate UAV images as follows. First, DN values were obtained based on various light intensity levels that were obtained with fixed values of the camera sensor exposure and the shutter speed above mentioned. Second, based on the DN values, the light intensity information from UAV images was used to create correction equations for the three reference tarps. Third, reflection values of the UAV images were calculated through applying the correction equations.

We constructed calibration equations based on the relationships between tarp DNs obtained using the multispectral camera and the light intensity measured using the line quantum sensor. Comparisons were made between DNs of the tarps from the multispectral camera and true irradiance from the line quantum sensor to derive calibration equations.

4. Results

Linear relationships between the light intensity and the DN values could be defined presenting a high correlation between the DNs and the light intensity (Figure 3 and Table 1). The coefficient of determination (R^2) values ranged from 0.992 to 0.999. From these relations, we estimated digital numbers corresponding to the light intensity values of 350, 847 and 1,460 μmol in the UAV images, converting them into reflection values. The equations were used to evaluate and calibrate DN values. When the DN values were converted to the reflection values, high correlations were shown (Table 2). The R^2 values ranged from 0.996 to 0.999.

As a result, the error rates of the estimated and modified reflectance estimated at the light intensities of 350, 847, and 1,460 μmol are very low (Figure 5). Root mean square errors between the estimated reflection values and the actual reflection values based on the relationships were 0.0049, 0.0061, and 0.0068 for NIR, red, and green, respectively.

5. Discussion and Conclusion

We assume that there is a high correlation between intensity of incident light and reflectance from the UAV-based RS camera used in this study. Multispectral cameras cannot get direct information on incident light. Ground reference tarps are generally used to acquire the reliable data source of UAV-based RS images based on a radiometric calibration process. Depending on the weather conditions, the use of these reference tarps or panels can be uncomplimentary and sometimes decrease the accuracy especially in cloudy days. Therefore, we propose a calibration approach using empirical equations based on light intensity. Intensity of incident light data can be collected easily using light sensors. As shown in Figure 5, the current fabricated scheme is reliably accurate because a multispectral camera can be compensated based on the illuminance at the moment when the subject image is taken. Therefore, we believe that the radiometric correction scheme employed in this study is a practical approach in comparison with any other conventional approaches utilizing tarps.

A limitation in this study includes that the light intensity data in visible light only were measured using a line quantum sensor. Therefore, if a quantum sensor can measure solar radiation in not only visible but near-infrared portions, we assume that an improvement could be made since more reliable equations can be obtained.

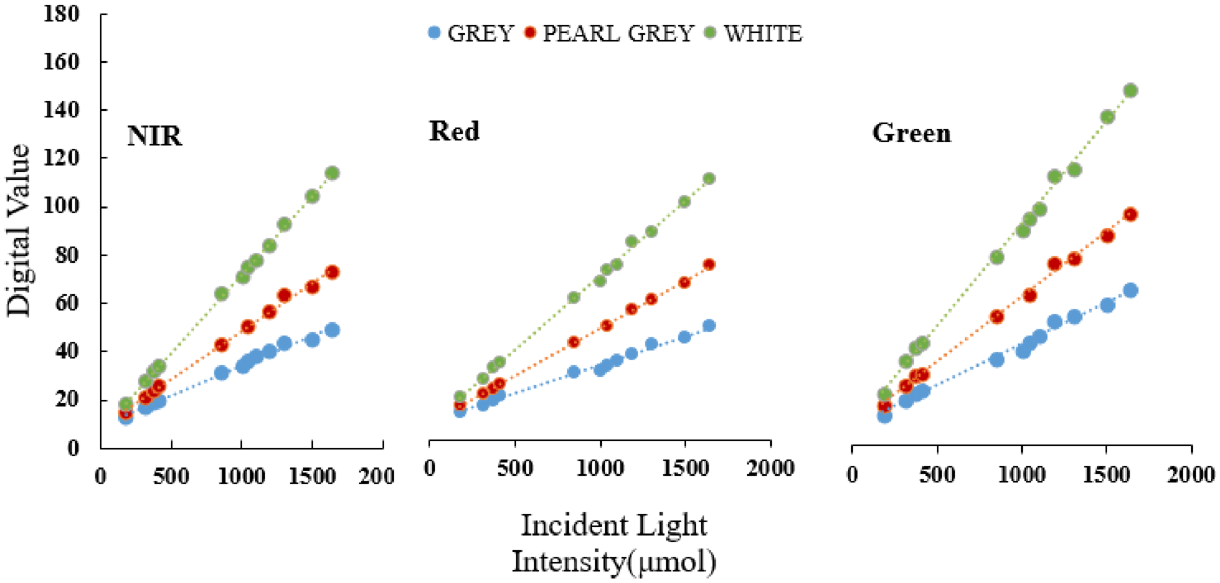


Figure 3. Relationships between DN values and incident light intensity of three reference tarps (grey, pearl grey, and white) for the wavebands of green, red, and near infrared (NIR).

Table 1. Linear regression equations (Figure 3) and the coefficient of determination (R^2) values.

Waveband	GREY	PEARL GREY	WHITE
NIR	$y = 0.025x + 9.594$ $R^2 = 0.992$	$y = 0.040x + 9.017$ $R^2 = 0.997$	$y = 0.065x + 7.159$ $R^2 = 0.999$
RED	$y = 0.025x + 7.593$ $R^2 = 0.992$	$y = 0.041x + 7.287$ $R^2 = 0.999$	$y = 0.064x + 6.411$ $R^2 = 0.998$
GREEN	$y = 0.035x + 7.787$ $R^2 = 0.993$	$y = 0.054x + 7.951$ $R^2 = 0.998$	$y = 0.086x + 7.160$ $R^2 = 0.997$

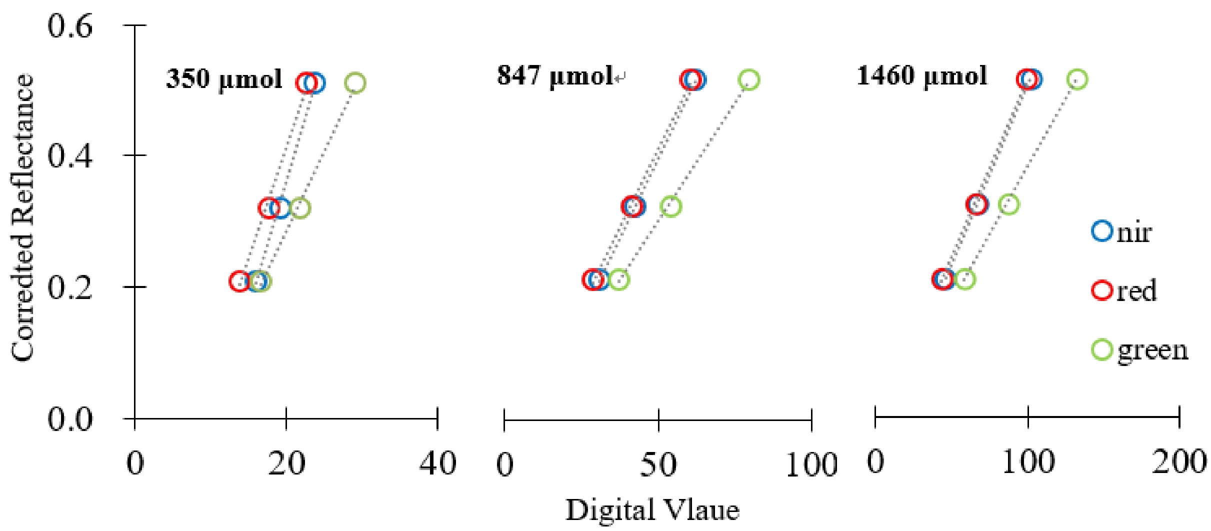


Figure 4. Relationships between corrected reflectance and estimated tarp digital values for the wavebands of green, red, and near infrared (NIR).

Table 2. Linear regression equations (Figure 4) and the coefficient of determination (R^2) values.

	350 µmol	847 µmol	1460 µmol
NIR	y = 0.026x - 0.268 R^2 = 0.999	y = 0.010x - 0.084 R^2 = 0.999	y = 0.005x - 0.037 R^2 = 0.999
Red	y = 0.024x - 0.185 R^2 = 0.996	y = 0.009x - 0.062 R^2 = 0.997	y = 0.005x - 0.029 R^2 = 0.998
Green	y = 0.018x - 0.144 R^2 = 0.998	y = 0.007x - 0.056 R^2 = 0.999	y = 0.004x - 0.031 R^2 = 0.999

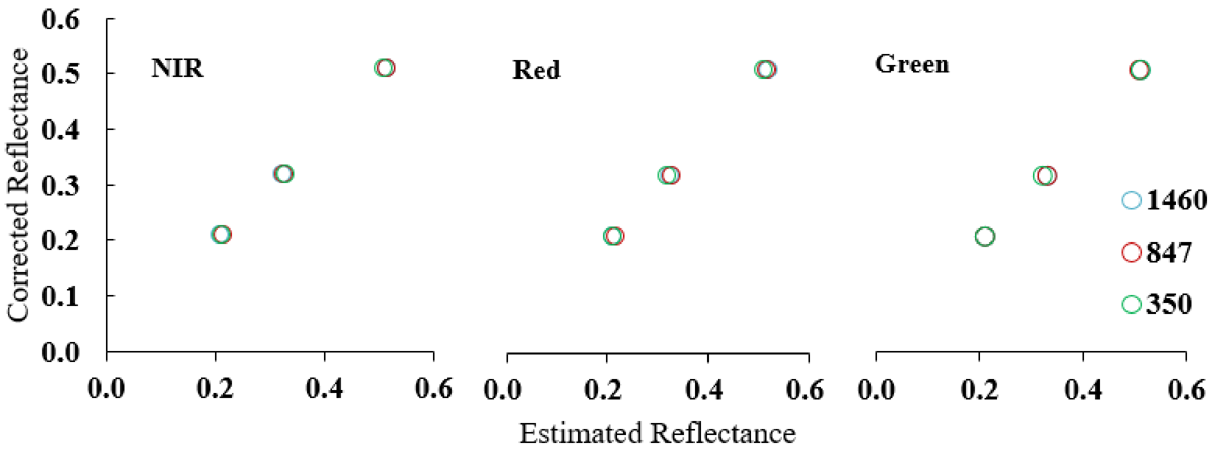


Figure 5. Comparisons between corrected reflectance using the UAV-based image calibration method and estimated reflectance of the three reference tarps at the light intensity values of 350, 847 and 1,460 µmol in UAV images for the wavebands of green, red, and NIR.

6. References

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