Calibration of UAV Multispectral Images for Uniform Reflectance Using Vignette and BRDF

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1. Introduction

UAVs (Unmanned Aerial Vehicles) are increasingly being used in a variety of applications due to their ability to capture high-resolution images and acquire data quickly. In fields such as agriculture, environmental monitoring, and disaster management, where images of large areas are required, the use of image mosaic techniques to stitch together multiple images is essential. However, during the image mosaicking process, seamlines often form at the junctions between individual images. These seamlines disrupt the continuity of the images, reducing the accuracy of analyses based on the data. Therefore, minimizing seamlines in UAV images is important to obtain reliable data over large areas. Traditional UAV image correction methods have relied on a single filter or a single flight pattern. These approaches often resulted in incomplete correction and did not effectively address the difference in reflectivity between row and column orientations, especially in low sidelap situations. To overcome these limitations, this study introduced a new approach. In this study, we applied both vignetting filters and BRDF (Bidirectional Reflectance Distribution Functions) filters simultaneously to correct non-uniform reflectance in aligned UAV images. This approach allows for more precise image correction compared to traditional single filter methods. We also performed three types of flights (vignette, BRDF dome, and validation) around a CRT (Calibrated Reference Tarp) to obtain the UAV images needed for this study. These different flight patterns allow for more comprehensive data collection. To compensate the images considering the weather conditions in the field, the irradiance and CRT radiance were measured with our own ROX (Reflectance bOX). To increase the reliability of the study, we also measured irradiance with a HOBO Solar Radiation (Silicon Pyranometer) Smart Sensor to validate the accuracy of ROX. The non-unit DN (Digital Number) of the image has been converted to unit radiance to obtain objective and consistent values. The vignette and BRDF filters were then applied to each image for calibration and accuracy was verified with a validation image. For only Vignette filter, the image in the row direction showed a greater difference in reflectance than the image in the column direction due to the lower sidelap. When both the vignette filter and the BRDF filter were applied, a uniform reflectance was obtained in both the column and row directions, and it was difficult to find the seam line with the naked eye. The multispectral image normalisation technique developed in this study is expected to be widely used in various remote sensing applications, as it enables images of uniform reflectance to be obtained without significantly increasing sidelap and overlap. This technology will significantly improve the accuracy and reliability of aligned UAV multispectral images, leading to more precise data analysis.

2. MATERIALS AND METHODS

2.1. Data Acquisition

2.1.1. DJI M3M(Mavic 3 Multispectral) Images

Source: (a) DJI Mavic 3M

Figure 1: Appearances of the equipment used.

Data collection for this study took place on 25 April 2024 at the main playground on the Yongdang campus of National Pukyong University, South Korea. In this study, we used a DJI M3M (Mavic 3 Multispectral) (Figure 1) with a total of four bands (Green, Red, Red Edge, NIR) to acquire multispectral images. Table 1 lists the wavelength range of each band.

Table 1 : DJI M3M Camera Band Wavelength.

Multispectral Camera Band	Wavelength Range (nm)

Green	560 ± 16
Red	650 ± 16
Red Edge	730 ± 16
NIR	860 ± 26

Source: DJI Mavic 3M Specs

Three types of flights (vignetting, BRDF dome and validation) were performed to obtain data for vignetting correction, BRDF correction and validation. The vignette flight was conducted at an altitude of 1.5 m, the maximum height at which the image could be filled with CRT, capturing nine images per spectral band. The BRDF dome flights ascended from a minimum altitude of 6.84 metres to a maximum altitude of 20 metres, acquiring 261 images per spectral band at different altitudes. Finally, a validation flight was conducted at an altitude of 110 metres, capturing 168 images per band. This flight was used to validate the correction method applied in the study and to assess the overall accuracy of the corrected images.

2.1.2. ROX & HOBO Data

Irradiance and CRT radiance data were collected using a self-made ROX (Figure 1) to correct the images to account for the irradiance conditions in the field. The data acquired with ROX allowed for precise atmospheric correction and reflectance calculations.

The HOBO smart sensor (Figure 1) continuously recorded the solar irradiance at the field throughout the flight. The irradiance data from the HOBO sensor was used to verify the accuracy of the ROX data, further ensuring the accuracy of the radiometric corrections applied to the UAV images.

2.2. The Research Method

The flowchart of this study is shown in Figure 2. To correct non-uniform reflectance in the aligned images, we adjusted the radiance values using irradiance data. We used our own python code to extract DN values from each image and convert them to Radiance. We converted DN values without units to Radiance values with units to get more reliable results.

The phenomenon of vignette, a reduction in brightness due to less light being incident towards the edges than towards the centre, is caused by the optical properties of the camera lens. This is especially noticeable with UAV cameras that use a wide field of view, which can lead to radiometric distortions that can cause errors in precise remote sensing operations such as reflectance calculations and vegetation index analysis.

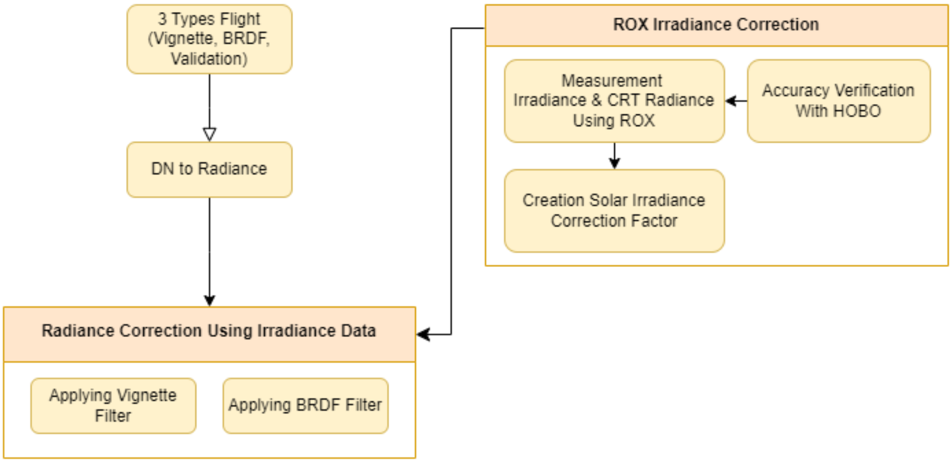

Figure 2 : Flowchart of the Research.

We utilized custom Python code for vignetting correction to extract the DN values from 20 pixels in the column and row directions at the center of each image. The vignetting equation, as given in Equation 1, is a sixth-order polynomial based on the radius from the center and the ratio between the center DN and the DN of any point in the image. Using this equation, vignetting parameters (k_0, k_1, k_2, k_3, k_4, k_5) were calculated and applied to correct each image.

$$\mathrm{k} = 1 + k_0 \times r + k_1 \times r^2 + k_2 \times r^3 + k_3 \times r^4 + k_4 \times r^5 + k_5 \times r^6 \quad (1)$$

In this study, BRDF were calculated using a 1-meter diameter inside CRT centered on dome flight. In this study, the BRDF was calculated using Equation 1, where the CRT was extracted from the BRDF dome image as a circle of 1 m diameter.

$$BRDF = f_{iso} + f_{geo}k_{geo}(\theta_\mathrm{i}, \theta_v, \varphi) + f_{vol}\mathrm{k}_{vol}(\theta_\mathrm{i}, \theta_v, \varphi) \quad (2)$$

3. Results and Discussion

(a) Before Correction

(b) Only Vignette Correction

(c) All
(Vignette & BRDF Correction)

Figure 3: Comparison of Aligned UAV Images Based on Correction Different Methods.

In Figures 3(a) and 3(b), the seamlines between individual image sections are clearly visible. In contrast, the image with both filters applied does not show any noticeable seamlines. This study shows that applying both filters simultaneously can significantly reduce seamlines without significantly increasing overlap.

4. Conclusion and Recommendation

Previous studies have attempted to minimise seamlines in UAV multispectral images by either significantly increasing the overlap or applying a single filter. However, there are few studies that have corrected the reflectance by applying two filters without significantly increasing the overlap rate, so a study was conducted to uniformly correct the reflectance of the image by simultaneously applying a Vignette filter and a BRDF filter. To do this, we performed different types of flights, which also sets us apart from other previous studies. By applying the Vignette and BRDF filters simultaneously, the seamlines were corrected to such a high level that they were not visible to the naked eye. This increases the reliability of the data obtained from the matched images. The reflectivity correction technique for UAV multispectral imagery developed in this study is expected to be highly useful in various fields that require UAV imagery over a wide area.

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