RELATIVE RADIOMETRIC CALIBRATION OF UAV IMAGES FOR IMAGE MOSAICKING

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ABSTRACT:

Since UAV images are taken at a low altitude, compared to satellite or aerial images, they usually have narrow ground coverage. In order to use them over a large area of interest, it is essential to mosaic them into a large image. In addition, UAV images may have different brightness values at the same ground locations according to different weather conditions and relative position between sun and sensor at the time of photographing. To mosaic a large number of UAV images, it is essential to calibrate different brightness values through a relative radiometric calibration method. In this paper, we propose a relative radiometric calibration method of UAV images capable of reducing over-calibration and minimizing error transfers during image mosaicking. We applied a gain compensation technique to minimize the effect of exposure difference when generating mosaic image. We also applied an image blending technique to remove seamlines among adjacent images to merge. As a result, smooth mosaic images were generated without any noticeable brightness difference around seamlines. For quantitative validation, differences in brightness values in overlapping areas were calculated. The differences have been decreased after applying the proposed method. The results indicated that the proposed method could generate a natural mosaic image by correcting differences in brightness values and removing seamlines of UAV images. Our method has an advantage of being able to calibrate differences in brightness values only with DN values.

1. INTRODUCTION

Unlike satellites and aircrafts, unmanned aerial vehicle (UAV) has an advantage of acquiring data easily at a low cost. Demand for UAV is increasing simultaneously with use of UAV in various fields like Generating of 3D model and Surveying. Since UAVs generally fly at lower flight altitude than satellites or aircrafts, users can acquire high spatial resolution images. However, ground coverage becomes narrow due to photographing at the low flight altitude. For a large area of interest, number of images to be processed increases. For analysis and utilization through UAV images, a process of merging a larger number of images into a single mosaic image is essential.

Brightness values of UAV images are affected by various external factors such as shadow and reflection of sun light depending on the shooting time. Brightness values in adjacent images may be different even at a same point of ground. When UAV images are merged without brightness value correction, an unnatural mosaic image is generated. Therefore, it is essential to calibrate different brightness values through a relative radiometric calibration method. As such an attempt, a method of calibrating using tie point obtained in geometry calibration step was developed (shin et al., 2020b). A method of correcting color between images using histogram matching method has also been proposed (Niu et al., 2018). However, these methods showed a limitation in processing a large number of images. As many images were processed, errors occurring in brightness value calibration step were also accumulated and transferred to the next image processing. Images processed at later stage often appeared too dark or too bright. Therefore, we aimed to develop a relative radiometric calibration method for UAV images that can reduce overcompensation and minimize error propagation.

In this study, to generate a natural mosaic image, we calibrated a brightness value using a gain compensation technique and removed seamlines using a blending technique. The gain compensation technique estimates a coefficient for correcting brightness value of an image by calculating brightness value of overlapping region between images. The blending technique is a method of blending brightness values between images by applying weights around seamline.

The proposed method was applied to various UAV image dataset. As results, smooth mosaic images were generated without any noticeable brightness difference around seamlines. For quantitative validation, differences in brightness values in overlapping areas were calculated. The differences have been decreased after applying the proposed method. The results indicated that the proposed method could generate a natural mosaic image by correcting differences in brightness values and removing seamlines of UAV images. Our method has an advantage of being able to calibrate differences in brightness values only with DN values.

2. DATA

In this study, four datasets acquired from small-size UAVs were used. Images of dataset (a) and (b) were acquired using DJI's Phantom4 RTK, and mounted camera is DJI's FC6310R with focal length of $8.8\,mm$ and pixel size of $2.41\,\mu m$. The (c) and (d) dataset images were acquired using KevaDrone's KD-2 Mapper, and mounted camera is SONY's DSC-RX1RM2 with a focal length of $35\,mm$ and pixel size of $4.51\,\mu m$ (Table 1). The dataset (a) and (d) were acquired over hilly landscape while (b) and (c) over flat agricultural land.
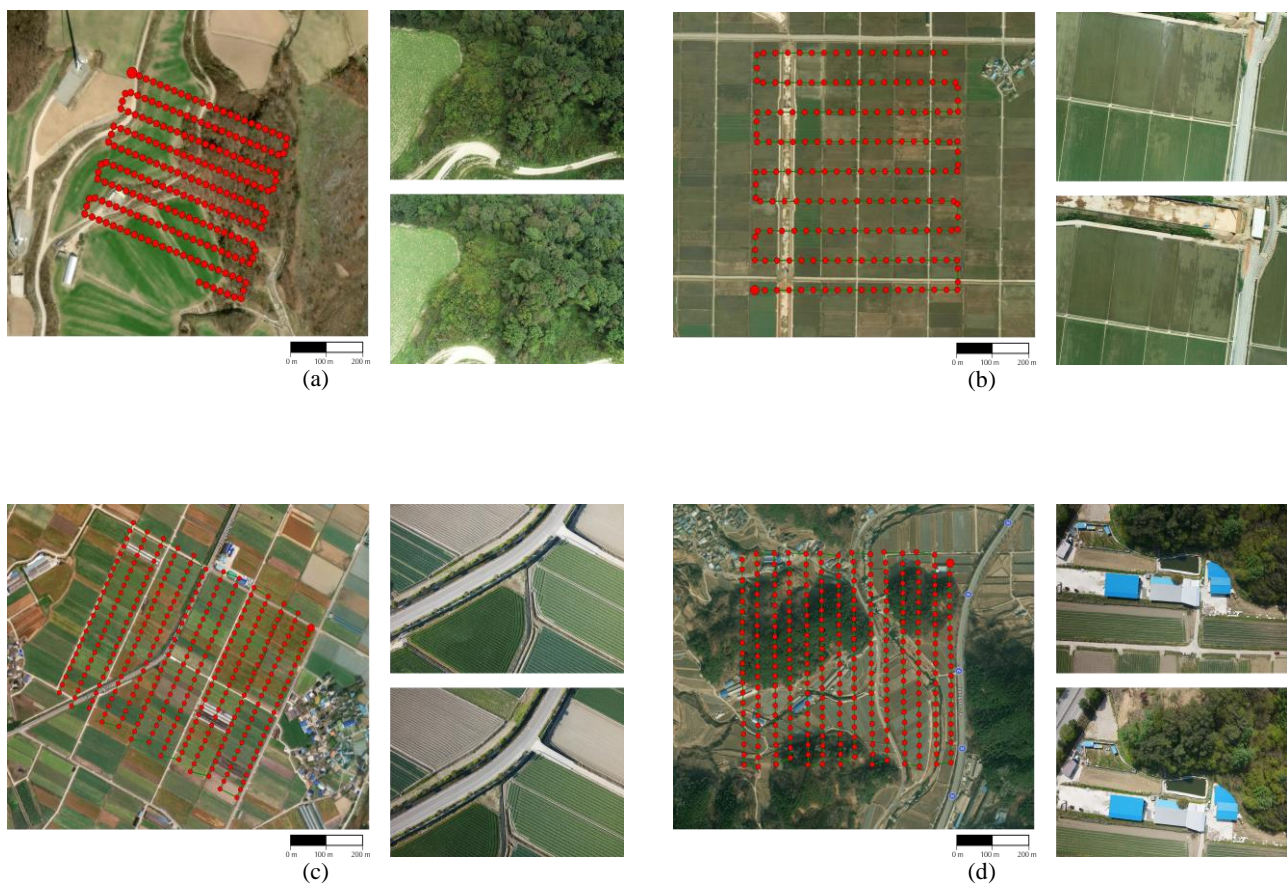
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(a)

(b)

(c)

(d)

Figure 1. Flight trajectory and locations of acquired images

Dataset	(a) and (b)	(c) and (d)
UAV	Phantom 4 RTK	KD-2 Mapper
Camera	DJI FC6310R	DSC-RX1RM2
Sensor Size	$13.2 \times 8.8\ mm$	$35.9 \times 24.0\ mm$
Pixel Size	$2.41\ \mu m$	$4.51\ \mu m$
Focal Length	$8.8\ mm$	$35.0\ mm$

Table 1. Flight trajectory and locations of acquired images

Figure 1 shows the flight path of the used dataset and the location of the acquired images. And the two images on the right show examples of severe differences in brightness values at the same location for each dataset. Each dataset was photographed and acquired at a different flying height, and Table 2 shows characteristics of the datasets.

Dataset	(a)	(b)	(c)	(d)
Image Size	5472×3648 pixels		7952×5304 pixels	
Image Number	236	175	306	307
Flying Height	$100m$	$180m$	$100m$	$150m$
Image GSD	$2.7cm$	$5cm$	$1.3cm$	$2.0cm$

Table 2. characteristics of datasets

3. PROPOSED METHOD

There are two main processing parts for generating natural mosaic images in the relative calibration method proposed in this study. One is a relative radiometric calibration method using gain compensation, and the other is a seamline removal method using image blending method. The relative radiometric calibration method estimates an optimal correction coefficient for each image to minimize brightness differences between neighbouring images. The correction coefficient is ~~simply~~ multiplied to brightness values of the corresponding image, thereby reducing the difference in brightness values between images. The blending method is applied near a seamline among two adjacent images. This method removes seamline generated during image merging by applying adaptive weights according to the distance of a pixel location to the seamline.

Geometric mosaic processing was performed using self-developed SW. The mosaic method of SW was processed by combining TIN (Triangulated Irregular Network) based on extracted image feature points. In this study, mosaic images were generated by applying the proposed method for brightness value correction and seamline removal to algorithm of corresponding SW. Figure 2 shows the process of generating a mosaic image by applying the proposed method excluding a geometric image merging part.
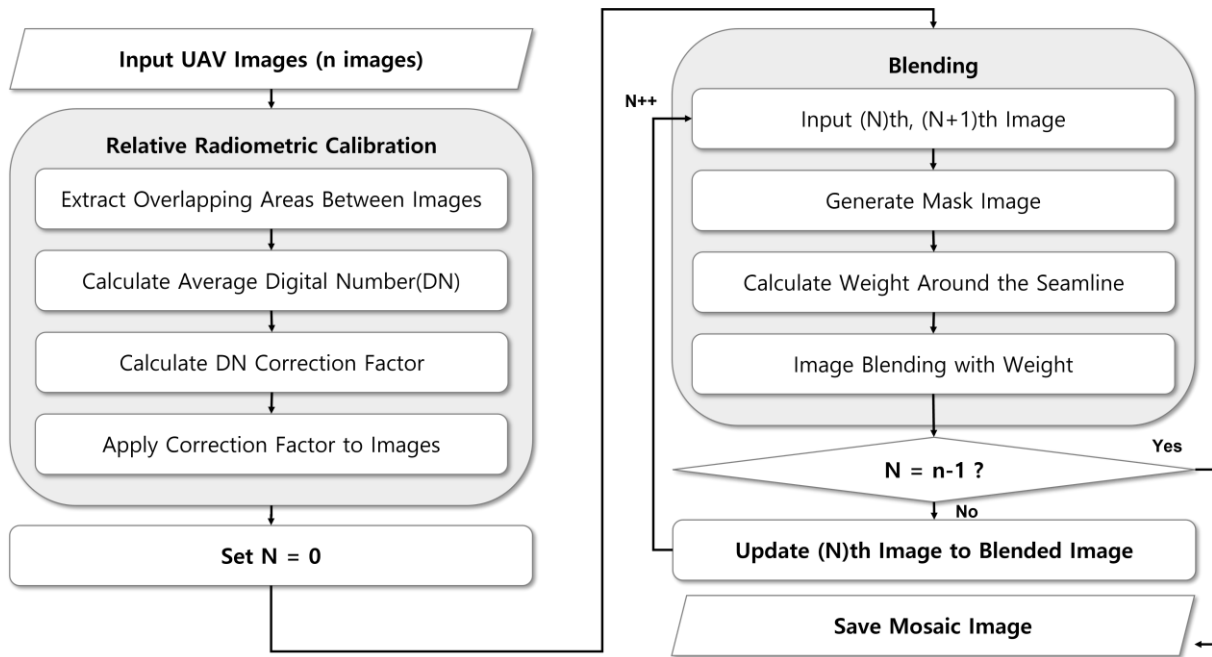
Figure 2. Process for generating mosaic image of proposed method

3.1. Relative Radiometric Calibration Method

In this study, the relative radiometric calibration method for brightness value correction was performed using the gain compensation algorithm. The gain compensation method estimates a gain value that minimizes the difference by measuring the difference in brightness value occurring in the overlapping regions between images (Brown and Lowe, 2007). The images were calibrated by multiplying estimated gain value to image digital number (DN) values. The applied gain value was estimated individually per image. Error formula calculated in overlapping area after applying gain is shown in Equation (1). To estimate the optimal gain values per image, we converted the error formula into an equation for matrix calculation and estimated the gain value to minimize the error using the least squares method. In this study, we set standard deviation of DN to 10 and gain to 0.2.

$$e = \frac{1}{2}\sum_i \sum_j N_{i,j}\left(\left(\frac{g_i I_{i,j} - g_j I_{j,i}}{\sigma_{DN}}\right)^2 + \left(\frac{1-g_i}{\sigma_g}\right)^2\right) \qquad (1)$$

where $N_{i,j}$ = number of pixels in overlapping area
   g = gain value
   I = average DN value of overlapping area
   σ_{DN} = standard deviation of normalized DN value
   σ_g = standard deviation of normalized gain value

The formula converted to a matrix calculation formula to obtain the optimal gain values is shown in Equation (2). When the number of input images is N, the size of gain(g) matrix is N×1, the size of A matrix is N×N, and the size of B matrix is N×1. The matrix B is configured as shown in Equation (3), and for example, in the case of b_0, it is a value obtained by adding both the first image and the number of overlapping pixels of all images.

$$g = (A^T A)^{-1} A^T B \qquad (2)$$

$$b_n = 100 \times \sum_{i=0}^{N} N_{ni} \qquad (3)$$

$$A = \begin{bmatrix} A_{00} & \cdots & A_{0(N-1)} \\ \vdots & \ddots & \vdots \\ A_{(N-1)0} & \cdots & A_{(N-1)(N-1)} \end{bmatrix} \qquad (4)$$

$$A_{ii} = b_i + \sum_{j=0}^{N-1} \frac{2}{100} I_{ij}^2 N_{ij} , (i \neq j) \qquad (5)$$

$$A_{ij} = -\frac{2}{100} I_{ij} I_{ji} N_{ij} , (i \neq j) \qquad (6)$$

The value of matrix A is as shown in Equation (4), and the detail elements are as shown in Equation (5) and (6). The operation with the same image is not included as the condition $(i \neq j)$. Finally, the gain matrix is calculated as shown in Equation (2), and the gain matrix is applied to the images to correction the brightness value. Figure 3 shows the concept of applying the gain compensation algorithm.
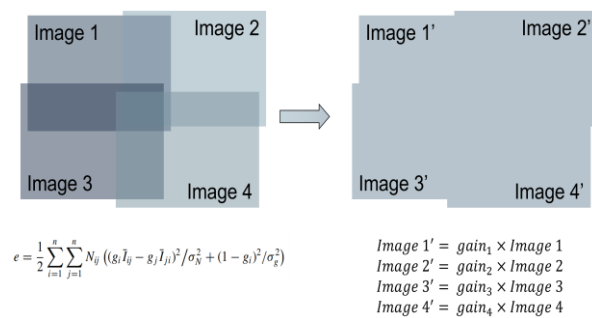

$$e = \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} N_{ij} \left((g_i \bar{I}_{ij} - g_j \bar{I}_{ji})^2/\sigma_N^2 + (1-g_i)^2/\sigma_g^2\right)$$

Image 1' = gain₁ × Image 1
Image 2' = gain₂ × Image 2
Image 3' = gain₃ × Image 3
Image 4' = gain₄ × Image 4

Figure 3. Concept of gain compensation algorithm

3.2. Image Blending Method

Even when the brightness values of the image are corrected by the relative radiometric calibration, there are still remaining parts where the brightness value difference in the seamline between adjacent images. This is because the brightness values do not match perfectly around seamline. Therefore, in the proposed method, the effects of seamline are removed by applying an image blending method after the relative radiometric calibration. The image blending method is applied for image composition with applying adaptive weights to image pixels. As shown in Figure 4, weights were gradually given according to distance from seamline within overlapping area. And a weight mask image was generated by applying weight mask image to remove an effect of different brightness around seamline.
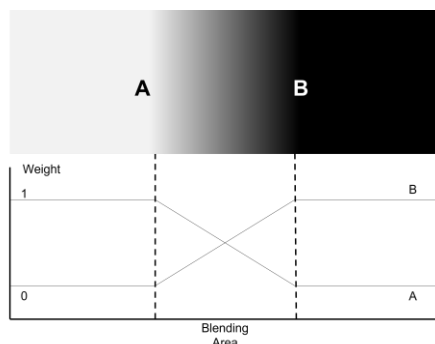
Figure 5 is an example of applying the blending method used in this study to two images. As shown in the Figure 5, seamline is determined by the reference image and the area of image to be newly merged, and when the seamline is determined, the area of blending is calculated. Finally, the blending method is applied by repeating for all images and mosaic image is generated. Our SW uses the TIN based mosaic method. Since the image-based method projects images on a mosaic plane, there are case where the relative matching between images does not match within the overlapping area. On the other hand, the TIN based mosaic image was well matched in the overlapping area. Therefore, it was possible to set a wide blending area in this study.
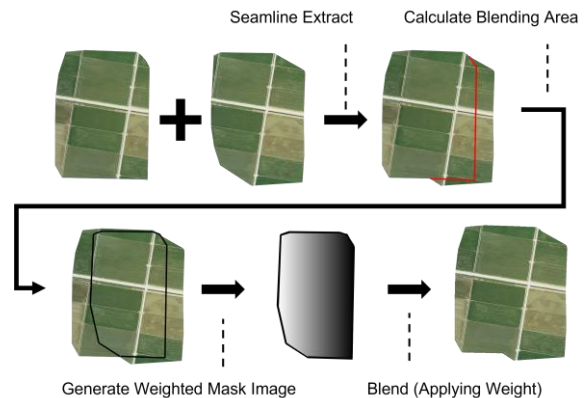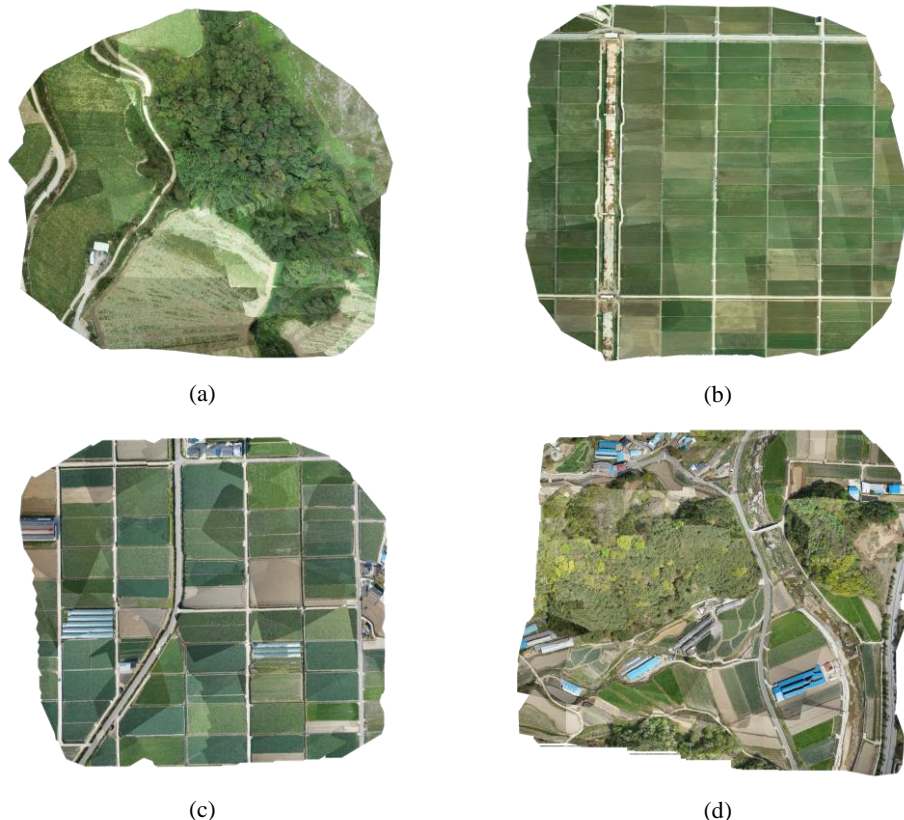

Figure 4. Blending method with weighted mask image

Figure 5. Blending process of two image

(a)

(b)

(c)

(d)

Figure 6. Mosaic images before applying the proposed method

(a)

(b)

(c)

(d)

Figure 7. Mosaic images after applying the proposed method

4. RESULT AND DISCUSSIONS

4.1. Result of Mosaiced Image

Mosaic images before and after applying the proposed method were generated to confirm the result of the relative radio matric calibration and image blending method. And mosaic images were generated using the self-developed SW. Figure 6 showed the result of mosaicked images generated from original images before applying the gain compensation method and the image blending method. Since brightness value of original image was not calibrated, unnatural mosaic images were generated due to difference in brightness value around seamline.

In the case of dataset (a), there are images taken at a high altitude. At the time of photographing, weather conditions were not good, and there was a difference in brightness due to thin clouds during the flight. Dataset (b) and (c), this is due to total reflection by the water surface, and dataset (d), this is due to automatic exposure setting. It was a mosaic image that was well matched between original images, but an unnatural mosaic image was generated because it did not correct the difference in brightness value between images and remove the seamline effect.

Figure 7 showed mosaic images generated after applying the gain compensation method and image blending method. When the result image was visually inspected, smooth mosaic images were generated without any noticeable brightness difference around seamline.

4.2. Quantitative Validation

For quantitative validation, differences in DN values in overlapping areas were calculated. All datasets were 8-bit images of three channels with DN values ranging from 0 to 255. Table 3 shows the average and standard deviation of the difference in brightness values in the overlapping area before and after the proposed method was applied. Except for dataset (b), the mean values of difference in brightness before applying the proposed method were 18 or more, which could be visually confirmed in Figure 6. These datasets decreased the mean value of difference in brightness value to 7 or less by applying the proposed method. In addition, the dataset (b) was also decreased from the original difference value. As a result, the differences have been decreased after applying the proposed method for all datasets.

Dataset	Before		After	
	Mean (DN)	RMSE (DN)	Mean (DN)	RMSE (DN)
(a)	18.29	25.58	6.45	10.25
(b)	5.04	7.39	4.45	6.56
(c)	19.96	25.65	6.18	9.08
(d)	21.89	28.37	6.52	10.23

Table 3. characteristics of datasets

5. CONCLUSIONS

In this study, we proposed a method for correcting the brightness values and removing seamlines to generate natural mosaic images of UAV. The verification of the proposed method was conducted through qualitative evaluation comparing mosaic images and quantitative validation through DN value analysis. Through this, the applicability of our proposed method was confirmed. It could correct the brightness values only with the DN values in images without information on the environment that can affect the brightness value of the image. The proposed method was integrated into a self-developed SW for seamless mosaic image generation. As a result, accurate overlapping area calculation was possible, and the effect of the relative radiometric calibration and image blending of proposed method could be maximized. Recently, research has been conducted to generate a reflective image by installing a reference reflectance target or installing an irradiance sensor to convert an image into an actual reflectance. Accordingly, when our proposed method is integrated to this research, an actual reflectance mosaic image obtained by merging a large number of images should be generated. Finally, our method should enable UAV images to be used an input data for various studies such as crop monitoring and crop classification map production.

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