

RADIOMETRIC CALIBRATION PERFORMANCE OF A MULTISPECTRAL CAMERA WITH A SINGLE SENSOR AND MULTIPLE HEADS

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ABSTRACT:

Radiometric calibration of remote sensing images can be performed with many existing techniques. The selected method depends on the sensor type, application and user's prior knowledge. The main objective of this study was to analyse the radiometric calibration technique proposed by Agrowing to process the data acquired for a multispectral camera with a single sensor and multiple heads. This radiometric calibration can be done in a simple way by a regular user and just needs an image from the X-rite Classic 24, a small panel with 24 colours, under the same viewing angle as the data acquisition. The dual-head camera was used to acquire images in two illumination conditions. The non-calibrated and calibrated DN pixels values were evaluated by comparing the reflectance factor calculated from radiance measurement, acquired by a ASD spectrometer followed by a linear adjustment. The results show that in the visible bands the non-calibrated and calibrated DN have a strong correlation with ASD reflectance factor. The NIR band presents the weakest correlation, but with a slight improvement after the radiometric calibration. The red-edge band presented a larger improvement with the application of the calibration procedure.

1. INTRODUCTION

Radiometric calibration is an essential processing step in remote sensing with images from drones and ground-based mobile systems. Unlike systems onboard orbital platforms, sensors instrumented carried by Unmanned Aerial Vehicles (UAV), and ground-based mobile platforms have not been rigorously calibrated and validated, such as Landsat series, MODIS and Sentinel-2. The quality of data under different light conditions is important when using the digital number (DN) values in agriculture applications. There are many ways to calibrate digital images, such as using targets or panels with reference values and light sensors to obtain irradiance measurement (Cao et al., 2019).

Each multispectral sensor system has its unique physical properties. Generally, manufacturers' calibration methods are proprietary and consist of a comparison of multispectral sensor measurements against a calibrated spectrometer or reference targets.

The solution for these task needs to be practical and accurate to the regular user. In most situations, the user's technical ability is limited to access the quality of the acquired data. Therefore, camera manufacturers often offer solutions for radiometric calibrations. An example is the MicaSense camera, which uses a Calibrated Reflectance Panel (CRP) to calibrate the sensor and convert raw data to reflectance images. According to MicaSense (2019), the calibration data is provided as absolute reflectance (values between 0.0 and 1.0) in the range from 400 nm to 850 nm (in increments of 1 nm). The calibration curve can be simplified by 5 reflectance values, one for each one of the 5 bands of the camera, by averaging the reflectance values in the calibration curve across the bandwidth of each band (MicaSense, 2019).

One new type of multiple head camera has been developed by Agrowing, an Israeli company developing technology for digital agriculture. Agrowing (Agrowing, 2022) design uses existing and well-proven sensors, such as Sony, adapting these cameras with filters and special multi-lenses mounts. (Tommaselli et al., 2020). They offer three groups of multi-lenses systems: a dual-head system with different filter sets to produce 4 spectral bands for Normalized Difference Vegetation Index (NDVI) or Red Edge configurations; a four heads system, which can produce up to 10 spectral bands and; a six heads system, which can produce up to 14 spectral bands.

The radiometric calibration technique proposed by Agrowing relies on the use of an X-Rite Classic 24 panel as a calibrated reference in their software, Agrowing Basic. This panel is commonly used in colourimetric calibration. In this case, the radiometric calibration is applied considering only five targets that are part of the greyscale tiles. A close picture of the X-Rite ColorChecker before the fly or ground acquisition is taken for the radiometric calibration. The application data and the picture of the target must be acquired under the same lighting condition.

The aim of this work is to evaluate the radiometric calibration of Agrowing using colourimetric X-rite ColorChecker greyscale targets. This camera is designed for several agricultural applications and is important to know if the solution proposed by the company is appropriate and ensures the required data quality.

2. MATERIALS AND METHODOLOGY

2.1 Materials and experiments

The Agrowing camera used in this study was an Alpha 6000 model. This model is a multi-lenses camera with a two-heads

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system; the Red-edge lens was chosen, producing 4 spectral bands (Fig. 1.a). There are two channels in the visible spectral range (450 and 550 nm), one channel in the red-edge region (710 nm), and one channel in the infrared (850 nm). All bands are acquired instantaneously and are generated by combining the camera Bayer filter and the customised lenses filters, after removing the original infrared filter from the camera. Fig. 1.a shows an example of a raw image of a calibration panel acquired by a dual-head system. Table 1 provides the technical features of the Agrowing sensor used in this work. Tommaselli et al., 2020 described the operation of acquisitions with this type of system.

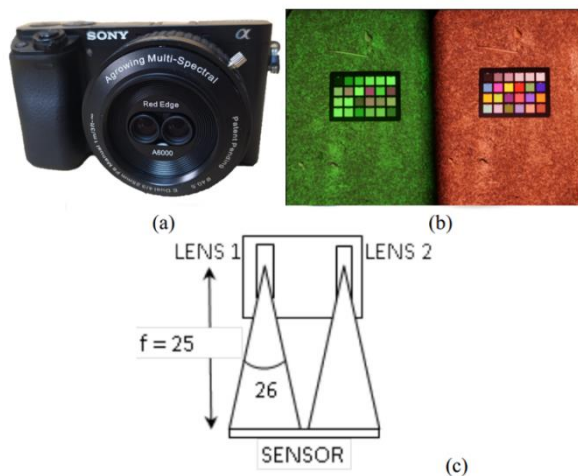


Figure 1. (a) Multispectral camera with two heads; (b) original frame collected with an Agrowing dual-head; (c) and the diagram for the dual-head camera (adapted from Tommaselli et al., 2019).

Type	Dual lens single mount
Spectral bands for Red-Edge lens (FWHM)	450 (20), 550 (20), 710 (15), 850 (20) nm
Field of view	45.90
Lens distortion	<1%
Effective focal length	25 mm
Aperture	Fixed F6
Size of cropped image band	2512 x 3976 pixels
Lens weight	150 gr
Total sensor weight including battery	580 gr

Table 1. Technical features of Agrowing sensor (Agrowing, 2022).

Agrowing Basic (Aw Basic) is the software provided by the company to process raw images and perform some operations such as alignment verification, calculation of several vegetation indexes, and radiometric calibration in the experimental version. The platform supports X-Rite Classic 24 calibration panel (Fig. 2) for radiometric calibration.

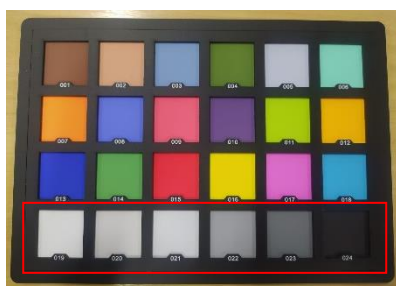


Figure 2. X-rite Classic 24 panel with greyscale highlighted.

The spectrometer FieldSpec® Handheld from Analytical Spectral Devices (ASD), with a spectral range from 325 to 1075 nm, attached with foreoptic accessory, which limits the field of view (FOV) to 10°, was used to obtain radiance measurements of the greyscale panel and the vegetation (Fig. 3). These measures were used to calculate the Hemispherical Conical Reflectance Factor (HCRF). The greyscale panel was made with ethylene vinyl acetate material in four colours: white, grey, dark grey, and black. The vegetation target was a bush inside of São Paulo State University (UNESP) in Presidente Prudente, in the western region of São Paulo State.

From the HCRF, of each measurement, the references spectra were resampled into a single spectra sample, which was convolved with the spectral response of the Agrowing Alpha 6000 as shown in Equation 1 (Kiddar and Haar, 1995; Schowengerdt, 1997).

$$R_i = \frac{\int_{\lambda_1}^{\lambda_2} R_\lambda S_\lambda d\lambda}{\int_{\lambda_1}^{\lambda_2} S_\lambda d\lambda} \quad (1)$$

Eq. 1 convolves R_λ (the reflectance measured by the spectrometer at wavelength λ) with R_i (the reflectance corresponding to the band i of the multispectral sensor) between λ_1 and λ_2 , with S_λ being the spectral response at wavelength λ . Performing the spectral simulation, it was possible to compare the results with radiometrically calibrated and non-calibrated images by Agrowing Basic.



Figure 3. Grey scale panel and the vegetation target.

2.2 Acquisition

The images acquisition with Agrowing camera was carried out simultaneously with ASD spectroradiometer measurement. The experiment was performed in February at different times during the day. Because of weather conditions, only two datasets were chosen for this work. Table 2 presents some information about the weather and solar angles at the time of acquisition. On the 11:30 am acquisition, the tree was partially shaded and on the 3:30 pm the vegetation was completely illuminated. Thus, it is possible to evaluate the radiometric calibration under two different scenarios.

Local Time	Azimuth	Elevation	Zenith	Weather condition
11:30 am	55.80°	69.32°	20.68°	Sun and clear sky
3:30 pm	279.96°	47.20°	42.80°	Cloudy with a diffuse sun illumination

Table 2. Information about the weather and solar angles of acquisition.

Data acquisition was performed with the Agrowing camera 3 meters far from the bush with the greyscale panel and 50 centimetres far from the X-rite Classic 24 panel. The Agrowing Alpha 6000 was adjusted with a fixed ISO of 100, a 1/100 s shutter speed, and the lens focused to a distance of 0.5 m for X-rite Classic panel acquisition and 3 m to infinite when acquiring images of vegetation target.

2.3 Calibration process

Several steps were followed to evaluate the radiometric calibration proposed by Agrowing, using X-rite Classic 24 ColorChecker targets. In the Aw Basic software, the multi-lenses system was indicated, and the X-rite Classic 24 panel raw image was uploaded. The system indicates whether the target was matched successfully, as it is shown in Fig. 4. Then, the radiometric calibration based on the X-rite Classic 24 panel image can be applied to the remaining data.

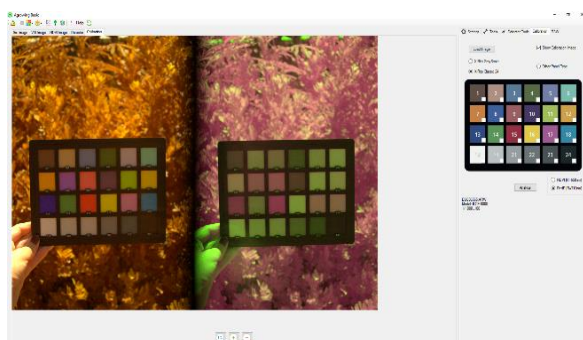


Figure 4. Processing in the Agrowing Basic software.

Usually, after a radiometric calibration process, it is expected that the values represent the reflectance factor, since before this step the radiance is given as a DN, that is, a radiance in an unknown scale. However, Aw Basic calibration software performs with a different strategy. The output data is kept in DN value, from 0 to 255 for 8 bits radiometric resolution (Cao et al., 2019).

The values of the calibrated and non-calibrated image's pixels were compared to the ASD spectrometer reflectance factor for the two acquisition times.

3. RESULTS AND DISCUSSION

Concerning the radiometric calibration procedure, some issues in the matching of X-rite Classic 24 panel on Aw Basic were observed. In some cases, the calibration tool did not recognise the target for radiometric calibration, even with a good image covering all target area. Fig. 5 shows the wrong match in the shades of grey on the inferior row of the panel where the colour 020 was confused with 019.



Figure 5. An example of a wrong match in the calibration tool.

The solution to this problem was to rotate the X-rite Classic 24 panel and acquire images on the four positions (0°, 90°, 180° of rotation). Fig. 6 shows the ColorChecker panel rotated 90° left on a successful match in the calibration tool.

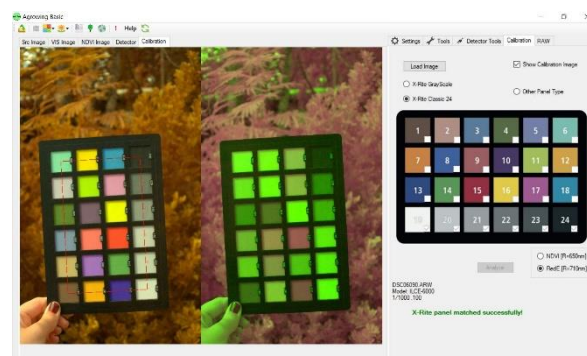


Figure 6. A successfully matched with an X-rite Classic 24 panel rotated 90° left.

Results from the non-calibrated and calibrated images at 11:30 am can be seen in Fig. 7 with a false colour composition. Comparing both images, it is notable that in the non-calibrated image the shades are less dark, while the calibrated image presents increased shades; in the illuminated areas of the tree, the light looks more intense.

The relationships between pixels values and ASD reflectance factor calculated by spectrometer measurement for the four colours of the greyscale target (white, grey, dark grey, and black) and two vegetation samples are shown in Fig. 8. For the visible bands (450 and 550 nm), the correlation between pixels values and ASD reflectance factor was strong, and the relationships are well modelled by a linear regression with coefficients determination values higher than 0.97. However, in the blue band (450 nm), there was a slight decrease in the determination coefficient after radiometric calibration, from 0.9854 to 0.9747, which was not expected.

The larger increase in the coefficient of determination caused by radiometric calibration was in the red-edge band (centred on 710 nm), from $R^2 = 0.7915$ to $R^2 = 0.894$. Also, the green points, representing vegetation, become slightly more spread in the non-calibrated than in calibrated scatter plot, indicating an improvement in the data quality after calibration. Considering that this region in the electromagnetic spectrum is important and sensitive for spectral behaviour of the vegetation, including diseases detection, this improvement can benefit results in agriculture applications, for example.

Even considering that the greyscale target and the tree were not under an ideal illumination situation, because of the shadows, in general, the relationships are strong both for the calibrated and non-calibrated images. The weakest relationships were obtained for the longest wavelength band (850 nm), with $R^2 = 0.7463$ and $R^2 = 0.7468$, for non-calibrated and calibrated, respectively. For this band there were no changes in the result after calibration. It is important to consider that the NIR band is fundamental since it provides information in a spectrum region where vegetation has high reflectance due to its internal structure and leaf morphology (Kumar et al., 2001). Also, NIR is commonly used in several vegetation indices, including the NDVI index. Red-edge and NIR bands are used together in other vegetation indices, such as red-edge chlorophyll index and modified anthocyanin reflectance index (Gitelson, Keydan and Merzlyak, 2006).

Results from the non-calibrated and calibrated images at 3:30 pm can be seen in Fig. 9, with a false colour composition. The image acquired at 3:30 pm also presents the shadows intensified after the radiometric calibration, like the image acquired at 11:30 am. However, in this case, the shadows were less intense and caused by the branches of the vegetation.

Scatterplots and adjusted lines between the ASD reflectance and Agrowing calibrated and non-calibrated digital number for acquisition at 3:30 pm, are shown in Fig. 10. Overall, there are the linear relationship between the Agrowing calibrated and non-calibrated DN and ASD reflectance factor, as expected. However, radiometrically calibrated pixels show a slightly better fit with ASD reflectance factors than non-calibrated. Also, it is noticeable a reduction in the DN values of the pixels in calibrated Agrowing images.

However, unexpected results occurred for the band 450 nm, in the studied case. The determination coefficient were $R^2 = 0.9846$ for Agrowing non-calibrated DN and $R^2 = 0.9694$ for the calibrated image. For the band 550 nm, both products presented a good correlation with ASD reflectance values, with R^2 presenting a discrete improvement from 0.9807 to 0.9877. Again, the red-edge channel presented larger improvements with the radiometric calibration than other channels: from $R^2 = 0.9705$ to $R^2 = 0.9940$. The NIR channel presented the worst adjustment but still with an improvement in calibrated DN, from $R^2 = 0.8091$ to $R^2 = 0.9394$.

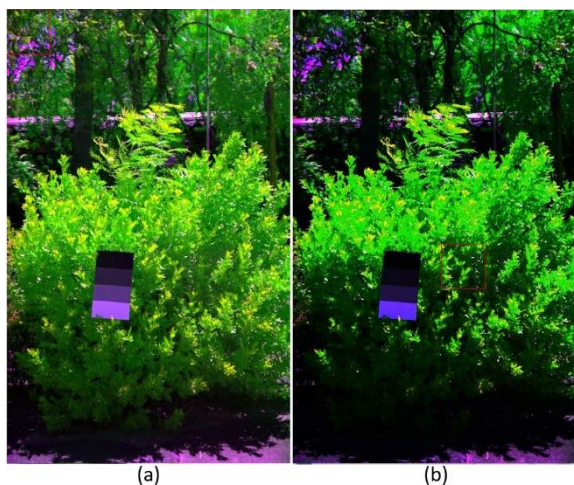


Figure 7. Image taken at 11:30 am (a) non-calibrated and (b) calibrated radiometrically. False colour composition R(550 nm) G(850 nm) B(450nm).

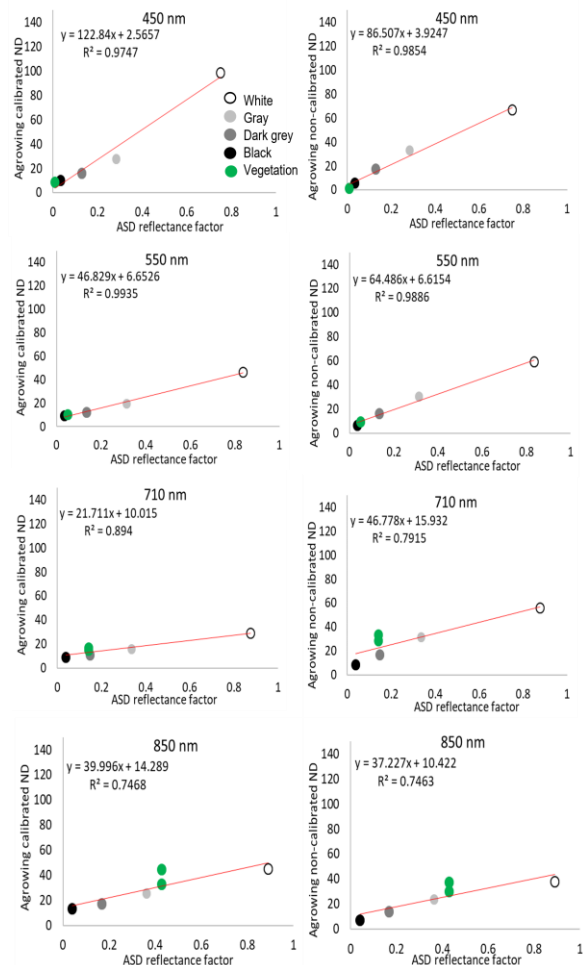


Figure 8. Scatterplots and adjusted lines between the ASD reflectance and Agrowing calibrated and non-calibrated digital number at 11:30 am acquisition.

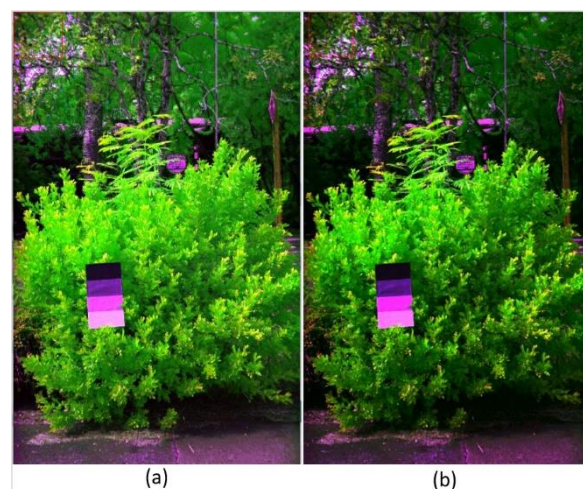


Figure 9. Image taken at 3:30 pm (a) non-calibrated and (b) calibrated radiometrically. False colour composition R(550 nm) G(850 nm) B(450nm).

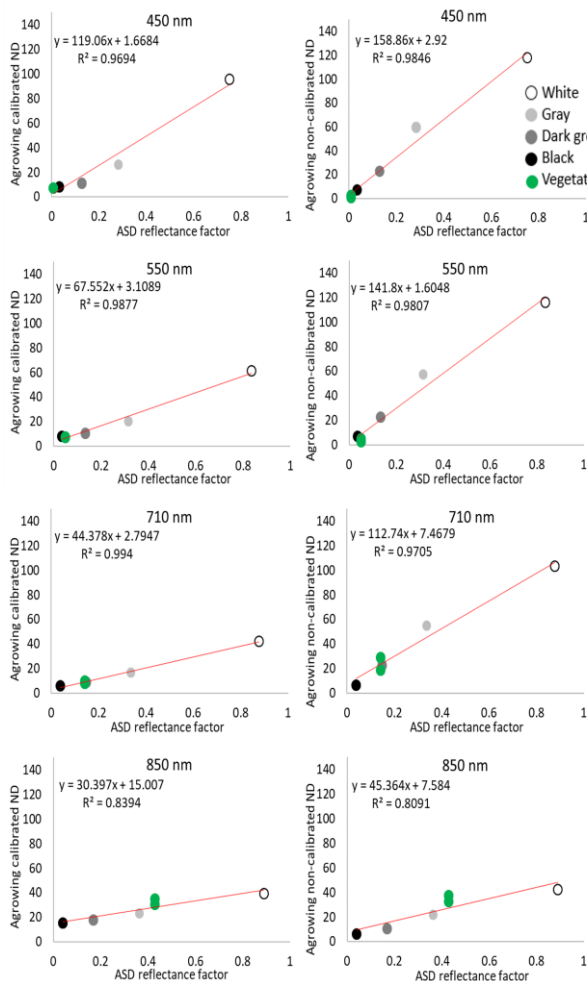


Figure 10. Scatterplots and adjusted lines between the ASD reflectance and Agrowing calibrated and non-calibrated digital number, for 3:30 pm acquisition.

Finally, some issues with co-registration between the NIR band regarding the remaining bands were observed: detail can be seen in Fig. 11. When the closest object (the tree with the greyscale panel) has all bands aligned, the background objects (vegetations and a build) are misaligned. This misregistration is caused by parallax resulting from the different viewpoint of each camera and the short camera range. This problem is common in any multi-lens camera and cannot be avoided when the range varies. One way to solve this problem is the generation of multispectral point clouds, instead of 2D images.

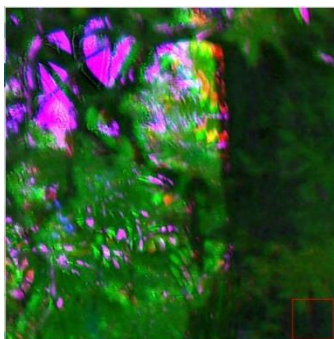


Figure 11. Detail of a misaligned caused by parallax artefacts.

4. CONCLUSION

In this paper, the radiometric adjustment proposed by Agrowing for multispectral images using the X-rite Classic 24 panel was assessed. Compared with multi-sensor technologies, the multispectral camera with a single sensor and multiple heads with a simultaneous exposure is advantageous. Also, this camera has a good cost-benefit ratio, and in the developed studies, radiometric performance has shown to be satisfactory.

Even though, it is not possible to do a definitive assessment of the performance of radiometric calibration, since the proprietary algorithm to convert raw pixel values to calibrated DN is not released by the manufacturer. Since the reflectance factor is not produced by this algorithm but a transformation that improves the degree of correlation with the ASD reflectance factor is applied.

Furthermore, the process is fast and easy. The user just needs to acquire images from the colourimetric panel in different positions, to assure a successful match in the software. Then, in the processing step, the parameters are applied to the all corresponding dataset.

Generally, the radiometric calibration presented good performance for the two illumination scenarios. The blue band is the only one that does not show improvements after calibration. The values of the green band presents a strong correlation with the ASD reflectance factor for non-calibrated and calibrated images. Red-edge and NIR bands, important in agriculture applications, present satisfactory improvements in the determination coefficient after radiometric calibration.

Finally, more experiments with the camera and their processing steps need to be explored. For future works, it is recommended the assessment of aerial images provided by UAVs.

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