7. Radiometric calibration

Radiometric calibration is a necessary procedure if we are interested in the spectral information reflecting from the objects that can be used for differentiating the objects from each other. Calibration precision becomes more important the lesser the differences of spectral information are between different objects. However, for accurate calibration certain preparations are necessary already before the UAV flight.

Light reflectance value is a parameter inherent to any physical object, giving a lot of information on the object. Reflectance value is thus one of the most common outputs regarding remote sensing data (Hakala *et al.*, 2018). It shows the measure of light that is reflected from a surface when illuminated by a light source (Clemens, 2012). In the case of UAV surveillance, when photographing an object we get a digital number (DN) to denote the pixel value of each sensor. Radiometric calibration is a process during which DNs are converted into reflectance value.

Calibration might prove to be difficult since numerous factors have to be taken into consideration: camera features and processing, environmental- and illumination conditions (Lebourgeois et al., 2008). There are several examples in academic literature of radiometrically corrected UAV images (see Berni et al., 2009; von Bueren et al., 2015), and images without corrections (see Lebourgeois et al., 2008; Nebikera et al., 2008), in which case direct DN values that have not been converted into reflectance values have been used for data analysis.

UAV surveillance is a relatively new field and in comparison to, for example, satellite surveillance, radiometric calibration procedures have not yet become standardised; thus, there are several different work flows for conducting and organizing the calibration procedure (Tagle, 2017). However, a few generalizations are already available for both multispectral camera image calibration (see Aasen *et al*., 2018; Cao *et al*., 2020; Olsson *et al*., 2021) as well as for the calibration of thermal camera images (see Kelly *et al*., 2019; Aragon *et al*., 2020).

One of the easiest and more common methods of acquiring reflectance value is the *Empirical Line Method* (ELM) that requires quite a moderate amount of extra work outside and enables a later conversion of DN images into reflectance values (Aasen *et al*., 2015). For that, we need to take a photo before and after the flight of the corresponding calibration panel, the reflectance values of which have been measured in laboratory conditions and are thus precisely known. Generally, if you purchase a multispectral camera, the manufacturer supplies at least one such panel with precise reflectance value.

Calibration panel needs to be photographed just before and immediately after the flight. Such photos enable us to make conclusions on the changing illumination conditions and average the differences. When photographing, take into consideration that:

- the calibration panel is clean;
- no shadows or reflections are left on the image (E.g. from a neon safety vest);
- when photographing the calibration panel, it is advisable to imitate the geometry of the sun-calibration panel camera: the panel needs to be positioned horizontally and when taking vertical aerial photos, the panel also needs to be photographed vertically.

Radiometric calibration can be a very complicated process, since we need to correct both camera and sensor distortions and differences resulting from illumination conditions and environment (Aasen *et al*., 2015; Clemens, 2012). Luckily, radiometric calibration has already been integrated into multiple workflows and it is supported by camera manufacturers. For example, the radiometric calibration of

MicaSense multispectral cameras is supported by two most common software (Agisoft Metshape and Pix4D) that produce UAV image photogrammetry. In such a case, radiometric correction mostly means taking pictures of the calibration panel before and after the flight, and then choosing an extra configuration possibility of the programme. Unfortunately, it has not been documented, what exactly such programmes do with the images. What is more, automatic calibration uses the so-called generalised images and corrections that are not calibrated for each concrete sensor.
The main steps in radiometric correction have been summed up based on Aasen *et al*. (2015), Clemens (2012) and Tagle (2017) as follows:

1. It is recommended to avoid camera processing when taking pictures, i.e. turn off all the different options for improving image quality.
2. During post-processing, it is advisable to remove dark currents caused by camera electronics and vignette effects caused by optics. When problems occur, use suitable image masks, or, in case of dark current, signal strength threshold.
3. Images need to be corrected for the angle of solar radiation and changes in illumination conditions using data provided by Incident Light Sensor (ILS). In addition to that, DN of images is converted into absolute scale of brightness (absoluutse skaalaga kirksuseks), taking into consideration shutter speed and the sensitivity of the aperture and sensor.
4. With the help of photos taken from the calibration panel, we can find a linear correlation between brightness and reflectance value of the panel. Using this coefficient, we will be able to convert all the images into reflectance values.

A calibration procedure like this must be conducted for each spectral band separately.

A multitude of different instructions on different levels exist for radiometric calibration; we hereby only refer to some of them:

1. Manuals on the home pages of Agisoft Metashape and Pix4D photogrammetry software instruct how to conduct radiometric calibration in their software. Generally, we need to make some choices in the programme and the rest will be conducted automatically, concealed from the user.
2. MicaSense, the largest manufacturer of multispectral cameras, has instructions and Python scripts in Github for the calibration of images with their cameras, in which the entire process is described in detail.

As a rule, at least some calibration is necessary for any type of mapping data, since it is only this way we can acquire compatible information from the data collected at different moments in time.

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