

Camera Requirements For Precision Agriculture

Radiometric analysis such as NDVI requires careful acquisition and handling of the imagery to provide reliable values. In this guide, we explain how Pix4Dmapper handles the images as well as what are the requirements for accurate and reliable radiometric mapping.

Introduction

The goal we are considering is a quantitative analysis of plant properties using remote sensing with digital images. The quantity of interest is the reflectance of the plants for different wavelengths, since the wavelength-resolved reflectance properties contain a lot of information about the plants. For example, chlorophyll absorbs red light (making plants look green) and reflects infrared, so the difference between red and infrared, such as computed by the NDVI, tells us something about the chlorophyll content.

The *reflectance* is what is required to perform index calculation such as NDVI, but the camera outputs only images. However, if one can estimate the influence of the *illumination* as well as the *sensor*, this image can be transformed in a good estimation of the reflectance:

Reflectance = Image / (Sensor * Illumination)

Illumination

• The spectral signature of the illumination

The sun does not emit the same amount of radiation in all wavelengths. The relative power of different wavelengths can vary depending on clouds, geometry, and shadow of the plants among others. This can be estimated using a radiometric calibration target.

• The total power of the irradiance

The total amount of irradiance can change due to changing conditions such as moving clouds. The amount of irradiance can be measured using an upward looking sensor. This is important to get absolute reflectance values but is not very important for NDVI computation.





Sensor

• Optical vignetting

Due to the lense and sensor geometry, not all parts of the sensor receive the same amount of light. This is mostly visible in the corners of the image. To compensate this effect it is possible to apply a vignetting correction.

• Dark current

Solid state sensors such as CMOS or CCDs are contaminated with noise caused by thermal stimulation of electrons which is called "dark current". To compensate this effect it is possible to subtract a dark frame. The dark current strongly depends on temperature.

• Spectral overlap

Single lense cameras such as the modified filter cameras normally have spectral overlap: the different bands are overlapping. For example, the infrared is contaminated with a bit of blue. To reduce this effect it is possible to apply a specific color matrix.

• Sensor sensitivity

The sensor does not usually capture the different wavelengths with the same sensitivity. For example, a CCD is much more sensitive to green than it is to infrared. A radiometric target can be used to compute and compensate for this effect.

• Linearly encoded values

The human eye perceives brightness in a nonlinear way. Therefore most consumer cameras save their images using a "gamma" correction. However to perform radiometric computation, the values should be encoded linearly. This is usually only done in Raw and Tiff images.

• ISO/aperture/exposure time

Cameras need to continuously adjust settings to adapt for the difference of brightness in each image. A darker image doesn't necessarily mean that it has less light, it might be that the exposure time was shorter. If acquired images are linear with respect to the sensor data (such as in Raw and Tiff images), it is possible to accurately combine images with different ISO/aperture/exposure time settings by correcting for the respective effects.

This list is still a simplified approximation. For a complete characterisation, one would need to look at the bidirectional reflectance distribution function (BRDF). However, the integrated reflectance (without considering the angular dependency) already gives some useful information.





In practice, there are usually two types of camera that are used to perform radiometric analysis such as NDVI:

A. Standard digital consumer camera with a modified filter

These cameras were not designed for radiometric fidelity, especially when using the JPG output. However, with careful handling of the Raw files as described below, they can be used as a measurement device. There are usually two ways of modifying the filters that either provide infrared or red-edge instead of one of the other bands. However, the measurement is usually "broad band", meaning that the bands usually cover a rather large spectrum and often overlap a bit. The choice of specific filters depends entirely on what you are trying to measure and what index you try to compute, and does not influence the processing.

Note: We usually recommend to convert the Raw imagery to Tiff format. However, it is also possible to convert the Raw to JPG in a way that does not distort the data and where 99% of the information is preserved while reducing the size on disk of the images, which can be essential if the files need to be transferred through a network with limited bandwidth. This is explained at the end of this guide.

B. Specific multispectral camera (Airinov multiSPEC 4C, MicaSense RedEdge, Tetracam, ...)

These cameras are designed for radiometric fidelity and the manufacturer usually provides the tools to correctly produce accurate results. The cameras that have a single sensor are usually broad band and very similar to the category above. The cameras that come with multiple sensors are usually narrow band and this usually allows to compute more indices from a single flight and also gives access to an extended set of indices.

www.pix4d.com EPFL Innovation Park - Building D 1015 Lausanne, Switzerland +41 21 552 05 93

CONVERT + DELIVER



Before flight	Captured images	Preprocess images	ed Reflectance images 4	Reflectance map	5	Prescription map
Steps	1	2	3	4	5	6
Filter modified camera	Before taking images: -set to save Raw images -keep Iso and aperture constant -Before each flight, take a picture of a radiometric target	Convert Raw to Tiff -keep linear values -keep white balance neutral -save as 16bit Tiff In addition perform correction for -vignetting -dark current	Import Tiff in Pix4Dmapper Perform radiometric calibration using the picture of the target and its known albedo values.			
Multi spectral cameras	Before taking images: -Before each flight, take picture of a radiometric target -Make sure to follow camera specific guidelines	Most correction applied automatically to the images by the camera firmware or postprocessing software Check with manufacturer if manual steps are required (for example, vignetting correction for Tetracam)	Import Tiff in Pix4Dmapper Perform radiometric calibration using a target only if not already done in the previous step by the firmware or postprocessing software			
Any images			Pix4Dmapper reads images - if dark current information is in Exif, performs dark current correction - if vignetting model info is in Exif, performs vignetting correction - if spectral overlap matrix is available in Exif, performs unmixing - if ISO/aperture/exposure information is in the Exif and the image is not deemed already processed (e.g. jpegs from camera firmware), performs brightness adjustment - if sun irradiation is in Exif, does illumination correction per image - if calibration target widget used, performs balancing of the different bands to compensate for sun illumination - if sensor sensitivity is in Exif, performs sensor adjustment per band (which is overridden if using calibration target widget)	After geometrical calibration, multiple values are gathered to produce the reflectance map. Values in the center of each image are given more importance. Values the closest and the most perpendicular to the terrain are given more importance.	Each reflectance goes through a user provided formula. In case of NDVI, each pixel from the index map will be computed as a ratio of subtractions and additions of the infrared and red bands.	Statistics of the index map are computed and the index values are split in a user defined number of classes (5 by default) using a user defined algorithm (equal area by default) The index map is then subsampled (6 meters by default) and pixels of the same class are grouped together. These polygons are then saved in a vectorial SHP file together with user provided comments and rate.



Step 1

It is recommended to take a picture of a radiometric calibration target with known reflectance value for each band of the camera just before the flight. The radiometric calibration target should reflect the light equally in every direction and is often made from teflon material. The reflectance values are usually provided along with the target by the manufacturer and can be entered in Pix4Dmapper. These targets can be bought in most photographic equipment shops and allow to perform the estimation of the illumination coloring to remove its effect. Failing to estimate light color bias may result in distorted NDVI values especially if it is overcast or early morning/evening.

It is also recommended to keep the ISO and aperture settings of the camera constant, only using the exposure time to compensate for different illumination while capturing the images.

Although Pix4Dmapper is able to correct for the joint effect of these 3 values, in general it is more accurate to compensate the exposure difference than the two other parameters.

For filter-modified consumer cameras, it is imperative not to use the JPG produced by the camera. The values have been heavily distorted to be visually appealing and this process is not reversible. Such an image will lead to heavily stretched and distorted NDVI. However, the Raw images (in whatever format, .raw, .dng, ...) do preserve the radiometric linearity and should be used instead of JPG.

Step 2

Before feeding the images to Pix4Dmapper, the images have to go through some corrections that are necessary for accurate results.

The most essential corrections are vignetting and dark current.

www.pix4d.com EPFL Innovation Park - Building D 1015 Lausanne, Switzerland +41 21 552 05 93





How to compute optical vignetting?

Optical vignetting is the effect that usually darkens the border and corners of the image. It is not the same as geometrical lens distortion that bends straight lines, and the geometrical effect does not need to be corrected in advance as Pix4Dmapper automatically corrects it. The model is usually expressed as a polynomial. The equipment required to compute it is a perfectly white surface that reflects light evenly in all directions as well as a homogenous lighting. Many software packages such as Adobe Lense tool or Lensfun can compute the vignetting model. To apply this model we recommend using UFRaw as described below.

How to compute dark current?

Dark current is an effect that happens in most sensors and adds a pattern on the sensor. A way to model this effect is to take an entirely dark image (by covering the lens) and to subtract this image to all subsequent images. To apply this model we recommend using UFRaw as described below.

In addition, the output values need to be linearly encoded, the white balance should be neutral and identical for all images, and images should be saved in 16bit depth to avoid clipping.

When using a dedicated multispectral camera, these corrections are usually performed by the firmware or by a dedicated post processing software. Check with your camera manufacturer to get more details.

When using a filter-modified camera, these correction are usually not applied to the Raw images. We recommend to use a software such as UFRaw to properly produce Tiff outputs from the Raw images.

- 1. Open UFRaw
- 2. Select Manual WB
 - a. Set each Chan. multipliers to 1.000
 - b. Optionally add a dark frame to remove dark current
- 3. (Optional) Under lens correction, enable Optical vignetting. Select 6th order polynomial model and apply the values that you might have computed using http://lensfun.sourceforge.net/calibration-tutorial/lens-vignetting.html
- 4. Under color management, set gamma to 1, linearity to 1, output intent and display intent to Absolute colorimetric, and the output bit depth to 16.
- 5. Finally save the the image as a Tiff and make sure to embed the Exif in the output.





Step 3

When reading the images, Pix4Dmapper can perform additional computations:

1) If the dark current is available in the Exif, it is corrected (Xmp.Camera.BlackCurrent, or Exif.Image.BlackLevel and Exif.Image.BlackLevelRepeatDim)

2) If a vignetting model is available in the Exif, it is applied. There are two vignetting models available:

• 2D-polynomial:

$$v = \sum_{i, j=0}^{N} c_{ij} \left(\frac{x}{w}\right)^{i} \left(\frac{y}{h}\right)^{j}$$

with pixel coordinates (x, y) and image width w and height h. Exif tags: Xmp.Camera.VignettingPolynomial2DName and Xmp.Camera.VignettingPolynomial2D.

• Radially symmetric polynomial:

$$v = 1 + \sum_{i=1}^{N} c_i r^i$$
 with $r = \sqrt{(x - c_x)^2 + (y - c_y)^2}$

and centre point cx, cy. Exif tags: Xmp.Camera.VignettingPolynomial and Xmp.Camera.VignettingCenter.

3) If the ISO/aperture/exposure are available in the Exif and the image is in Tiff format, then Pix4Dmapper will correctly compensate for the difference in brightness of the images:

$$p' = p \frac{k^2}{\tau K}$$

with ISO *K*, aperture f number *k*, and exposure time τ . The Exif tags read by Pix4Dmapper are:

Exif.Photo.ISOSpeedRatings

Exif.Photo.FNumber

Exif.Photo.ExposureTime

4) If the sensor band sensitivity is available in the Exif, Pix4Dmapper performs sensor adjustment per band (overridden if using calibration target widget). The Exif tag is Xmp.Camera.BandSensitivity



How to compute the sensor band sensitivity?

The sensitivity of the bands of the sensor is modeled as a number (per band) that will multiply this specific value. The equipment required to compute the sensitivity is a radiometric calibration target, as well as a controlled light with known illumination properties. The relative band sensitivity is then the image divided by the illumination and the target reflectance. Note that this value is overridden if a calibration target is used in the workflow.

5) If a color correction matrix is available in the Exif as Xmp.Camera.ColorTransform, spectral overlap is corrected.

How to compute spectral overlap model?

Computing the values of this matrix is not a trivial task and requires a spectrometer. Special laboratories can provide such services. The model is a 3x3 color matrix.

6) If there is an upward looking irradiation sensor during the flight, and if this information is stored in the Exif, then Pix4Dmapper will adjust each image for the change of light, as well as provide absolute reflectance values. The tag read is Xmp.Camera.Irradiance.

7) If the calibration target widget used, Pix4Dmapper performs balancing of the different bands to compensate for sun illumination.

Step 4

After geometrical calibration, multiple values are gathered to produce the reflectance map. Values on the center of each images are given more importance. Values closer and the more perpendicular to the terrain are given more importance.

Step 5

Each reflectance goes through a user provided formula. In the case of NDVI, each pixel from the index map will be computed as a ratio of subtractions and additions of the infrared and red bands.

Step 6

Statistics of the index map are computed and the index values are split in a user defined number of classes (5 by default) using a user defined algorithm (equal area by default)

www.pix4d.com EPFL Innovation Park - Building D 1015 Lausanne, Switzerland +41 21 552 05 93

CONVERT + DELIVER



The index map is then subsampled (6 meters by default) and pixels of the same class are grouped together. These polygons are then saved in a vectorial SHP file together with user provided comments and rate.

The following table indicates which corrections are made to the images. For example, Pix4Dmapper applies dark current correction for the Micasense RedEdge since the camera writes the appropriate tag in the EXIF. Pix4Dmapper does not apply dark current correction to Tetracam images since this correction is done by the firmware.

	multiSPEC 4C	MicaSense	Tetracam
Exposure correction	yes, puts values in Exif	yes, puts values in Exif	yes, PW2 puts values in Exif
Vignetting	yes, puts values in Exif	yes, puts values in Exif	manually through PW2
Dark current	yes, puts values in Exif	yes, puts values in Exif	yes by firmware
Spectral overlap	Narrow band, not required	Narrow band, not required	MCA: Narrow band, not required ADC: Broad band
Sensor sensitivity	yes, puts values in Exif	yes, puts values in Exif	yes through PW2
Linearly encoded values	yes	yes	yes
Irradiance amount	yes, puts values in Exif	no	yes, optional





How to convert Raw to JPGs in a proper way for radiometry fidelity in Pix4Dmapper?

If you really need small files, for example for transferring via limited bandwidth connections, using JPG files is often necessary. Since JPG files only support 8bit, you need to apply a gamma factor to preserve the dynamic range:

 $p' = 255 \left(\frac{p-\beta}{\alpha}\right)^{1/\gamma}$

It is important that this transform be reverted by Pix4Dmapper before using the data in order to keep linear values; it is only used to compress the data (in contrast to what consumer cameras do in order to have optically appealing images). Therefore, you need to save the applied transformation parameters in special Exif tags. Use a fixed gamma (e.g. 2.2) for all images and channels and of course a fixed white balance for all images (e.g. D65). Calculate α and β such that around 0.5% of the pixels are 0 and 255, respectively. Save α , β , γ for each channel in the Exif tags Xmp.Camera.TransformAlpha, Xmp.Camera.TransformBeta, and Xmp.Camera.TransformGamma, respectively. Then, in step 3, before doing anything else, Pix4Dmapper will revert the gamma transform using the parameters provided and transform values

back to linear.

www.pix4d.com EPFL Innovation Park - Building D 1015 Lausanne, Switzerland +41 21 552 05 93

CONVERT + DELIVER