P4 Multispectral Image Processing Guide

v1.0 2020.07

I. Key EXIF and XMP information in images taken using the P4 Multispectral

【EXIF】MakerNotes				
Key	Value example	Type	Unit	Meaning
Make	DJI			
Pitch	+1.50	float	degree	Flight roll angle
Yaw	+0.00	float	degree	Flight yaw angle
Roll	+1.70	float	degree	Flight pitch angle
Camera Pitch	-89.90	float	degree	Gimbal roll angle
Camera Yaw	+0.00	float	degree	Gimbal yaw angle
Camera Roll	+0.00	float	degree	Gimbal pitch angle

【XMP】drone-dji				
Key	Value example	Type	Unit	Meaning
Absolute Altitude	+50.00	float	meter	Absolute altitude of the camera based on the ellipsoid model used
Relative Altitude	+0.00	float	meter	Relative altitude of the camera based on Home point
Gps Latitude	113.00	float	-	Latitude of camera position
Gps Longitude	22.00	float	-	Longitude of camera position
Gimbal Roll Degree	+0.00	float	degree	Gimbal roll angle
Gimbal Yaw Degree	+0.00	float	degree	Gimbal yaw angle
Gimbal Pitch Degree	+0.00	float	degree	Gimbal pitch angle
Flight Roll Degree	+0.00	float	degree	Flight roll angle
Flight Yaw Degree	+0.00	float	degree	Flight yaw angle
Flight Pitch Degree	+0.00	float	degree	Flight pitch angle
Flight X Speed	+0.00	float	m/s	Ground speed northern vector
Flight Y Speed	+0.00	float	m/s	Ground speed eastern vector
Flight Z Speed	+0.00	float	m/s	Ground speed vertical

Copyright © 2020 DJI All Rights Reserved.
www.rusgeocom.ru

Calibrated Focal Length	1913.3333	float	pixel	5.74[mm] / 3.0[um/pixel] = 1913.3333..
Calibrated Optical Center X	800	float	pixel	X-axis coordinate of the designed position of optical center
Calibrated Optical Center Y	650	float	pixel	Y-axis coordinate of the designed position of optical center
Rtk Flag	16	string	-	RTK status
Relative Optical Center X	0.00	float	pixel	Disparity on X direction relative to NIR band
Relative Optical Center Y	0.00	float	pixel	Disparity on Y direction relative to NIR band
Dewarp Data	2020-02-04; 1949.4499512, 1939.7700195, 28, -17, -0.4082, 0.3418, 0.00068, 0.00068, -0.3540	string	-	Distortion calibration parameter (calibrate_date;fx,fy,cx,cy,k1,k2,p1,p2,k3);
Vignetting Data	0.000218235, 1.20722E-06, -2.8676E-09, 5.1742E-12, -4.16853E-15, 1.36962E-18	string	-	Coefficients for Vignetting calibration (k[0], k[1], k[2], k[3], k[4], k[5])
Band Name	NIR	string	-	Name for each band
Band Freq	840(+/-26)nm	string	-	The frequency for each band
Irradiance	2000.000	float	-	Calibrated sunlight sensor value
Sensor Gain	1	float	-	Image Sensor gain for each band
Exposure Time	1000	string	micro-second	Exposure time for each band
Sensor Gain Adjustment	1.002	float	-	Parameter for individual difference correction (float),
Sensor index	5	integer	-	Blue:1, Green:2, Red:3, RE:4, NIR:5
CaptureUUID	-	UUID V1	-	Unique label for one capture;
DroneID	-	string	-	Unique label for one drone, similar to S/N

Copyright © 2020 DJI All Rights Reserved.

II. How to calculate NDVI values using images and spectral sunlight sensor values from the P4 Multispectral?

The general formula to calculate the Normalized Difference Vegetation Index (NDVI) is

$$\text{NDVI} = \frac{NIR_{ref} - Red_{ref}}{NIR_{ref} + Red_{ref}} \quad \text{(Eq. 1)}$$

Where X_{ref} represents the reflectance value of the X band, $NIR_{ref}\ and\ Red_{ref}$ are the reflectance values of the NIR and Red bands, respectively.

If we define $X_{reflected}$ and $X_{incident}$ as the reflected light and incident light of the X band, then,

$$NIR_{ref} = \frac{NIR_{reflected}}{NIR_{incident}},\ Red_{ref} = \frac{Red_{reflected}}{Red_{incident}}\ .$$

When the sunlight (i.e. the incident light) is reflected off of the target, multispectral cameras capture the reflected light of the target in the form of multispectral images, and the sunlight sensor captures the incident light to record sunlight sensor signal values. Hence,

$$NIR_{ref} = \frac{NIR_{reflected}}{NIR_{incident}} = \frac{NIR_{camera}}{NIR_{LS}} \times \rho_{NIR} \quad \text{(Eq. 2)}$$

$$Red_{ref} = \frac{Red_{reflected}}{Red_{incident}} = \frac{Red_{camera}}{Red_{LS}} \times \rho_{Red} \quad \text{(Eq. 3)}$$

Here, X_{camera} is the signal value obtained from multispectral images of the X band, while X_{LS} is the signal value obtained from the sunlight sensor of the same band. ρ_x is the conversion parameter between the camera and sunlight sensor signal values. When converting between these two signal values, make sure that the reflected light (i.e. the signal value of the camera images) and the incident light (i.e. the signal value of the spectral sunlight sensor) are in the same unit. Also, the spectral sunlight sensor and cameras should have the same photosensitivity, which means that the signal values of the multispectral images and sunlight sensor should be the same under the same lighting conditions. The camera and the sunlight sensor values have a linear relationship, therefore they can be converted from one to the other using ρ_x.

In addition, because the sensitivity can be different for each camera within the array and between different sunlight sensors, calibrations are required to ensure that cameras of different bands and different sunlight sensors have the same signal value under the same lighting conditions. *All bands are calibrated against the standard NIR band*. The calibration parameters are $pCam_x$ and pLS_x, respectively. Since $\rho_x = \rho_{NIR} \times \frac{pCam_x}{pLS_x}$, then,

Copyright © 2020 DJI All Rights Reserved.

$$NIR_{ref} = \frac{NIR_{reflected}}{NIR_{incident}} = \frac{NIR_{camera}}{NIR_{LS}} \times \rho_{NIR} \times \frac{pCam_{NIR}}{pLS_{NIR}} = \frac{NIR_{camera} \times pCam_{NIR}}{NIR_{LS} \times pLS_{NIR}} \times \rho_{NIR} \quad \text{(Eq. 4)}$$

$$Red_{ref} = \frac{Red_reflected}{Red_incident} = \frac{Red_{camera}}{Red_{LS}} \times \rho_{NIR} \times \frac{pCam_{Red}}{pLS_{Red}} = \frac{Red_{camera} \times pCam_{Red}}{Red_{LS} \times pLS_{Red}} \times \rho_{NIR} \quad \text{(Eq. 5)}$$

Therefore, we can use Eq. 6 to calculate NDVI.

$$\text{NDVI} = \frac{NIR_{ref} - Red_{ref}}{NIR_{ref} + Red_{ref}} =$$

$$\left(\frac{NIR_{camera} \times pCam_{NIR}}{NIR_{LS} \times pLS_{NIR}} - \frac{Red_{camera} \times pCam_{Red}}{Red_{LS} \times pLS_{Red}}\right) \Big/ \left(\frac{NIR_{camera} \times pCam_{NIR}}{NIR_{LS} \times pLS_{NIR}} + \frac{Red_{camera} \times pCam_{Red}}{Red_{LS} \times pLS_{Red}}\right)$$

(Eq. 6)

The following section will explain how NDVI is calculated using multispectral images from the P4 Multispectral's NIR and Red bands.

Firstly, the multispectral images from the P4 Multispectral need to be aligned due to the slight difference in position and exposure time between different bands. Here is how:

- Step 1: Alignment of the phase difference caused by different camera locations.
  In the XMP[drone-dji] image metadata file (DJI****.TIF), find [Relative Optical Center X] and [Relative Optical Center Y]. These two items represent the x direction offset and y direction offset of the physical positions between the current band and the NIR band in pixels. If the current band is NIR, both values will be 0. Doing so is sufficient in correcting any differences in position between images for different bands captured in hover mode.

- Step 2: Alignment of the difference caused by different exposure times.
  Before aligning, we recommend smoothing the images using a filter such as a histogram smoothing or a Gaussian filter, etc.
  Either of the two alignment methods outlined below would work:
  - Method 1. Apply an edge detection filter (ex. Sobel filter) to detect edge lines from the two images that need to be aligned. Then, apply an alignment algorithm such as the Enhanced Correlation Coefficient (ECC) Maximization to the images. For more information on the ECC maximization algorithm, please refer to the following URL https://docs.opencv.org/3.0-beta/modules/video/doc/motion_analysis_and_object_tracking.html
  - Method 2. A traditional way for alignment includes feature point detection and matching.

Copyright © 2020 DJI All Rights Reserved.

Feature point detection can be performed by using algorithms such as SIFT (Scaled Invariance Feature Transform), AKAZE, etc. An alignment matrix can be computed by using several pairs of matched feature points, and then applying the matrix to the to-be-aligned images.

NDVI can be calculated after aligning the NIR and RED images.

We will introduce how to obtain each factor in equation 6 using the NIR band as an example. Firstly, obtain two camera related values: NIR_{camera} and $pCam_{NIR}$.

$$NIR_{camera} = (I_{NIR} - I_{BlackLevel}) \times Correction \Big/ \left(NIR_{gain} * \frac{NIR_{etime}}{1e6}\right) \quad \text{(Eq. 7)}$$

Here,

- I_{camera} and $I_{Blacklevel}$ are the normalized raw pixel value and normalized black level value, respectively. Since the multispectral images of the P4 Multispectral are in 16-bit format, the normalization here is to simply divide the original number by 65535. Original black level value is 4096, which can be found in [EXIF: black level] in the metadata.

- *Correction* includes Vignetting correction and Distortion calibration. We apply the Vignetting correction model shown in Eq. 8 to the input image $I_{(x,y)}$.

$$I_{(x,y)} \times (k[5] \cdot r^6 + k[4] \cdot r^5 + \cdots + k[0] \cdot r + 1.0) \quad \text{(Eq. 8)}$$

r is the distance between pixel (x, y) and the center of the vignette in pixels, which can be obtained by

$$r = \sqrt{(x - \text{Center}X)^2 + (y - \text{Center}Y)^2} \quad \text{(Eq. 9)}$$

CenterX and CenterY are coordinates of center of the vignette, which can be found from the items [Calibrated Optical Center X] and [Calibrated Optical Center Y] in [XMP: drone-dji] in the metadata.

Matrix *k* shows the polynomial coefficients for Vignetting correction, which can be found from [Vignetting Data] in [XMP: drone-dji] in the metadata.

Distortion calibration is a regular process in image processing. If the NDVI orthomosaics are created using structure from motion (SFM) technology, which optimizes for camera distortion, this step can be skipped.

The P4 Multispectral saves parameters for Distortion calibration of each individual camera into the metadata, which can be found in [Dewarp Data] in [XMP: drone-dji]. [k1, k2, p1, p2, k3] are the polynomial

Copyright © 2020 DJI All Rights Reserved.
www.rusgeocom.ru

coefficients for the calibration, and fx, fy, cx, cy are the intrinsic parameters of camera. These 4 intrinsic parameters and the 2 parameters obtained in the Vignetting correction step above (CenterX, CenterY) make up the camera matrix [(fx, 0, CenterX+cx), (0, fy, CenterY+cy), (0, 0, 1)] for Distortion calibration. For more information on Distortion Calibration, please refer to the undistort() function in OpenCV. https://docs.opencv.org/3.0-beta/doc/py_tutorials/py_calib3d/py_calibration/py_calibration.html

- val_{gain} is the sensor gain setting (similar to the sensor ISO) which can be found as [*SensorGain*] in [XMP: drone-dji] in the metadata.

- val_{etime} is the camera exposure time, which can be found as [*ExposureTime*] in [XMP: drone-dji] in the metadata.

We can obtain the image signal value NIR_{camera} by following the steps above.

Further, parameter $pCam_{NIR}$ can be found in [$Sensor\ Gain\ Adjustment$] in [XMP: drone-dji].

Then, we need to obtain signal values relevant to the sunlight sensor, NIR_{LS} and pLS_{NIR}, and calculate their product $NIR_{LS} \times pLS_{NIR}$. The product of $NIR_{LS} \times pLS_{NIR}$ is saved as [*Irradiance*] in [XMP: drone-dji] in the metadata, which can be used in Eq. 6.

These are the steps for obtaining the desired information of the NIR band. The same steps can be used for the Red band. Finally, NDVI can be calculated using Eq. 6.

Copyright © 2020 DJI All Rights Reserved.
www.rusgeocom.ru