Mavic 3M Image Processing Guide

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I. Key EXIF and XMP information in images taken using the Mavic 3M

【EXIF】IFD0				
Key	Value example	Type	Unit	Meaning
Bits Per Sample	16	integer	-	Number of bits per pixel. 8 or 16.

【EXIF】GPS				
Key	Value example	Type	Unit	Meaning
GPS Time Stamp	02:47:57	string	-	GPS time when photo was taken.
GPS Date Stamp	2023:03:09	string		GPS date when photo was taken.

【XMP】drone-dji				
Key	Value example	Type	Unit	Meaning
Version	1.6	string	-	XMP version.
Image Source	MS_NIR_CAMERA	string	-	Camera type.
Gps Status	RTK	string	-	GPS Status. "Normal"/"RTK"/"Invalid".
Altitude Type	RtkAlt	string	-	Elevation type. "PressureAlt"/"GPSFusionAlt"/"RtkAlt".
Gps Latitude	22.000000° N	float	-	GPS latitude when photo was taken.
Gps Longitude	113.000000° E	float	-	GPS longitude when photo was taken.
Absolute Altitude	+50.000	float	meter	Absolute altitude (geodetic altitude) when photo was taken.
Relative Altitude	+0.000	float	meter	Relative altitude (relative to the altitude of takeoff point) when photo was taken.
Gimbal Roll Degree	+0.00	float	degree	Gimbal roll angle when photo was taken (NED coordinate system, the rotation order is ZYX).

Gimbal Yaw Degree	+0.00	float	degree	Gimbal yaw angle when photo was taken (NED coordinate system, the rotation order is ZYX).
Gimbal Pitch Degree	+0.00	float	degree	Gimbal pitch angle when photo was taken (NED coordinate system, the rotation order is ZYX).
Flight Roll Degree	+0.00	float	degree	Aircraft roll angle when photo was taken (NED coordinate system, the rotation order is ZYX).
Flight Yaw Degree	+0.00	float	degree	Aircraft yaw angle when photo was taken (NED coordinate system, the rotation order is ZYX).
Flight Pitch Degree	+0.00	float	degree	Aircraft pitch angle when photo was taken (NED coordinate system, the rotation order is ZYX).
Flight X Speed	+0.00	float	m/s	Flight speed in the north direction when photo was taken.
Flight Y Speed	+0.00	float	m/s	Flight speed in the east direction when photo was taken.
Flight Z Speed	+0.00	float	m/s	Flight speed in the elevation direction when photo was taken.
Cam Reverse	0	integer	-	Whether the camera is in reverse or not. 0: Normal, 1:Reverse. Fixed 0.
Gimbal Reverse	0	integer	-	Whether the gimbal is in reverse or not. 0: Normal, 1:Reverse. Fixed 0.
Self Data			-	Customized data.
Rtk Flag	50	integer	-	RTK status. 0: Failed to position. 16: Single point positioning (meter-level accuracy). 32~49: Floating point solution positioning (decimeter-level to meter-level accuracy). 50: Fixed solution positioning (centimeter-level accuracy).

Rtk Std Lon	0.01224	float	-	RTK positioning standard longitude deviation.
Rtk Std Lat	0.01624	float	-	RTK positioning standard latitude deviation.
Rtk Std Hgt	0.03406	float	-	RTK positioning standard elevation deviation.
Rtk Diff Age	1.60000	float	-	RTK difference age (connection age).
NTR IP Mount Point	MOUNTPOINT_ NAME	string	-	Mount point of network RTK.
NTR IP Port	1234	integer	-	Port of network RTK.
NTR IP Host	123.123.123.123	string	-	IP address or domain name of network RTK.
Surveying Mode	1	integer	-	Whether the photo is suitable for mapping operation or not. 0: Not recommended as the accuracy cannot be guaranteed. 1: Recommended as the accuracy can be guaranteed.
Dewarp Flag	0	integer	-	Whether the camera parameters have been dewarped or not. 0: Not dewarped. 1: Dewarped. Fixed 0.
Dewarp Data	2022-10-24; 2200.899902343750, 2200.219970703125, 10.609985351562, -6.575988769531, 0.008104680106, -0.042915198952, -0.000333522010, 0.000239991001, 0.000000000000	string	-	Camera parameters for dewarping. (yyyy-mm-dd; fx,fy,cx,cy,k1,k2,p1,p2,k3). yyyy-mm-dd: Calibration date. fx,fy: Calibrated focal length (unit: pixel). cx,cy: Calibrated optical center position (unit: pixel, origin point: photo center). K1,k2,p1,p2,k3: Radial and tangential distortion parameters.
Calibrated Focal Length	2170.000000	float	pixel	Designed focal length of lens (unit: pixel). 4.34[mm] / 2.0[um/pixel] = 2170.0[pixel].

Calibrated Optical Center X	1296.000000	float	pixel	X coordinate of the designed optical center position (unit: pixel).
Calibrated Optical Center Y	972.000000	float	pixel	Y coordinate of the designed optical center position (unit: pixel).
UTC At Exposure	2023:03:09 02:47:57.725671	string	-	UTC when the camera is exposed.
Shutter Type	Electronic	string	-	Shutter type. Fixed “Electronic”.
Camera Serial Number	5J4O3AIRBAD00F	string	-	Camera serial number.
Drone Model	M3M	string	-	Aircraft model.
Drone Serial Number	1581F5FKD229N0010056	string	-	Aircraft serial number.
Capture UUID	3377fb05b357448fb877023daebbaed3	UUID V4	-	Unique label for one capture.
Relative Optical Center X	0.000000	float	pixel	Disparity on X direction relative to NIR band.
Relative Optical Center Y	0.000000	float	pixel	Disparity on Y direction relative to NIR band.
Dewarp HMatrix	1.716200, 0.000000, 415.752014, 0.000000, 1.716200, 309.813995, 0.000000, 0.000000, 1.000000	string	-	Designed homography matrix from designed image plane into designed RGB image plane.
Calibrated HMatrix	9.891065e-01, 1.740813e-02, -1.592078e+01, -1.568817e-02, 9.885082e-01,	string	-	Calibrated homography matrix from real image plane into designed image plane.

	3.766531e+01, 1.083204e-06, 5.127963e-07, 1.000000e+00			
Vignetting Flag	0	integer	-	Vignetting compensation flag. 0: Disabled, 1: Enabled. Fixed 0.
Vignetting Data	-0.000070832, 1.829488e-06, -5.307911e-09, 8.820567e-12, -6.663875e-15, 1.885447e-18	string	-	Coefficients of vignetting compensation. (k[0], k[1], k[2], k[3], k[4], k[5]).
LS_type	1	integer	-	Sunsensor type. Fixed to 1.
LS_status	2	integer	-	Sunsensor status. 0: Invalid state due to insertion of USB dongle. 1: Valid state. 2: Valid and compensating state.
Package_idx	165	integer	-	Sequence number of captured Sunsensor data.
Cfg_cnt	1	integer	-	For Sunsensor calibration usage.
Raw Data	11682.000 10389.000 12836.000 9945.000	string	-	Sunsensor raw values. Order: Green, Red, RedEdge, NIR.
Band Name	NIR	string	-	Band name. Green/Red/RedEdge/NIR.
Band Freq	860(+/-26)nm	string	-	Narrow band wavelength. Format is "Central wavelength(+/-HWHM)nm".
Irradiance	2000.000	float	-	Sunsensor value after compensation by built-in algorithm.
Sensor Gain	1.044	float	-	Gain coefficient of the multispectral image sensor.
Exposure Time	1000	integer	micro-second	Exposure time of the multispectral image sensor.

Sensor Gain Adjustment	1.002	float	-	Gain compensation coefficient of the multispectral image sensor relative to standard NIR module.
Sensor index	4	integer	-	Green:1, Red:2, RedEdge:3, NIR:4
Black Level	3200	integer	-	Black level. 3200@16bit or 12@8bit.
Drone ID	1581F5FKD229N0010056	string	-	Same as Drone Serial Number.

How to calculate NDVI values using images and multispectral sunlight sensor values from the Mavic 3M?

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

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

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,

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

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 multispectral sunlight sensor) and the incident light (i.e. the signal value of the camera images) are in the same unit. Also, the multispectral 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,

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

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

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

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

$$\left(\frac{NIR_{camera} \times pCam_{NIR}}{NIR_{LS} \times pLS_{NIR}} - \frac{Red_{camera} \times pCam_{Red}}{Red_{LS} \times pLS_{Red}} \right) / \left(\frac{NIR_{camera} \times pCam_{NIR}}{NIR_{LS} \times pLS_{NIR}} + \frac{Red_{camera} \times pCam_{Red}}{Red_{LS} \times pLS_{Red}} \right) \quad \text{(Eq. 6)}$$

The following section will explain how NDVI is calculated using multispectral images from the Mavic 3M's NIR and Red bands.

Firstly, the multispectral images from the Mavic 3M need to be corrected and aligned due to vignetting, lens distortion, slight difference in position, optical accuracy and exposure time between different bands. Here is how:

- Step 1: Vignetting correction
  We apply the vignetting correction model shown in Eq. 7 to the input image $I_{(x,y)}$.

  $$I_{(x,y)} \times (k[5] \cdot r^6 + k[4] \cdot r^5 + \cdots + k[0] \cdot r + 1.0) \quad \text{(Eq. 7)}$$

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

  $$r = \sqrt{(x - \mathrm{Center}X)^2 + (y - \mathrm{Center}Y)^2} \quad \text{(Eq. 8)}$$

  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.

- Step 2: Distortion correction
  Distortion correction is a regular process in image processing. The Mavic 3M has parameters for distortion correction in the metadata, which can be found in [Dewarp Data] in [XMP: drone-dji]. [k1, k2, p1, p2, k3] are the polynomial coefficients for the correction, 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 correction. For more information on distortion correction, 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
  Please note that changing the camera matrix in the "undistort()" function with "newcameramtx" should be avoided in order to obtain good results in subsequent steps.

- Step 3: Alignment of the phase and rotation differences caused by different camera locations and optical accuracy.
  In the XMP[drone-dji] of each band image file, find [Calibrated HMatrix]. This item represents the 3x3 transformation matrix for projective transformation from the individual physical image plane to the designed ideal image plane. Doing so is sufficient in correcting any differences in position and rotation between images for different bands captured in hover mode. For more information on the perspective transformation, please refer to the “warpPerspective()” function in OpenCV.
  https://docs.opencv.org/4.0.1/da/d54/group__imgproc__transform.html#gaf73673a7e8e18ec6963e3774e6a94b87

- Step 4: 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. 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 correcting and aligning the NIR and RED images.

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

$$NIR_{camera} = {(I_{NIR} \quad - I_{BlackLevel})}\Big/\left(NIR_{gain} * \frac{NIR_{etime}}{1e6}\right) \quad \text{(Eq. 9)}$$

Here,

- I_{NIR} and $I_{Blacklevel}$ are the normalized raw pixel value and normalized black level value, respectively. Since the bit number of the multispectral images can be found in [EXIF: Bits Per Sample] in the metadata, the normalization here is to divide the original number by 2^{bitnum}. The black level value can be found in [Black Level] in [XMP: drone-dji] in the metadata.

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

- NIR_{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.

