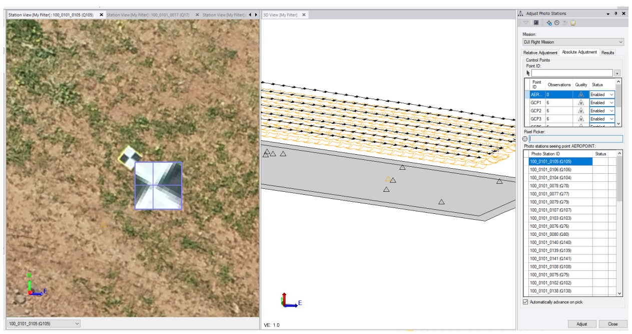
Workflow Bulletin

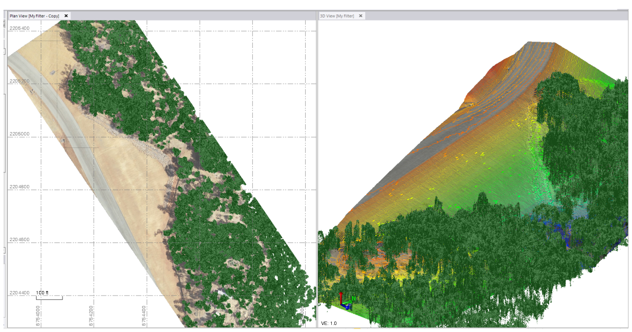
GEOSPATIAL
OCTOBER 2022

TRIMBLE BUSINESS CENTER (TBC)
AERIAL PHOTOGRAMMETRY CONCEPTS + WORKFLOWS

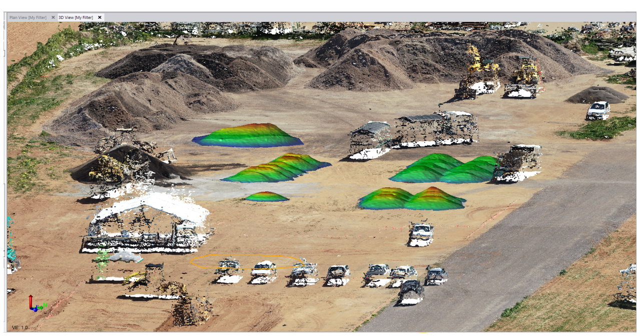
This bulletin, updated for version 5.80 released in October 2022, describes critical photogrammetric concepts and how Trimble Business Center (TBC) applies those concepts to adjustment and deliverable creation workflows for survey and construction professionals.



START WITH AUTOMATIC TIE-POINT EXTRACTION AND GROUND CONTROL POINT GEO-REFERENCING



CREATE POINT CLOUDS, RASTER DSM, AND ORTHOMOSAICS FROM THE UAV IMAGES



INTEGRATE WITH OTHER DATA AND COMPLETE YOUR SURVEY WORKFLOWS LIKE TOPOGRAPHIC MAP CREATION, COMPUTE SURFACES AND VOLUMES, OR CREATE STAKEOUT POINTS

https://geospatial.trimble.com/ https://trimble.com/tbc

Hardware makes and models supported

Photogrammetry

TBC now supports adjusting **image** data from:

Vendor	Drone	Model Name	TBC Version
DJI	Phantom 4 Advanced	FC6310	5.50
DJI	Phantom 4 RTK	FC6310R	5.40
DJI	M300 P1	ZenmuseP1	5.50
DJI	M300 L1	EP800	5.60
Quantum-Systems	Trinity F90+	Sony RX1RMII	5.80
MicroDrones	mdMapper1000DG	Sony RX1RMII	5.70
MicroDrones	mdLiDAR3000	Sony RX1RMII	5.80
MicroDrones	mdLiDAR1000LR	mDGLite	5.70
MicroDrones	mdLiDAR1000LR	mdLiDAR1000LR	5.70
Wingtra	WingtraOne	Sony RX1RMII	5.80
Wingtra	WingtraOne	ILCE-6100	5.80
Drones at the moment only supported via JXL (TBC v5.8)			
SenseFly	S.O.D.A.	S.O.D.A.	4.10
SenseFly	albris	albris	4.10
SenseFly	eBee X	senseFly Aeria X	4.10
SenseFly	Aeria X	senseFly Aeria X	4.10
Delair	UX11	UX11-3B	5.00
Trimble Gatewing	X100	GR DIGITAL 4	3.70
Trimble	UX5	ILCE-7R	3.70

LiDAR

TBC supports point cloud data from any UAV LiDAR source via point cloud file imports. TBC supports the following formats:

- .e57, .fls, .las, .laz, .pts, .ptx, .tdx/.tzf, .xyz, .yxz

Field Data Collection

High-precision UAV data for greatest positional accuracy

TBC can leverage high-precision UAV data directly from supported sensors or by using the GNSS Baseline Processor to post-process GNSS trajectories to best position the UAV images.

For example, high-precision data from DJI sensors is used upon import into TBC when the accuracy of the RTK precision is already tagged to the raw image data, it can be automatically read in TBC and no further action is needed from the user.

For GNSS trajectories that need to be post-processed, you can use the *Process Baselines* command, which will use the UAV GNSS trajectory (such as a RINEX file) against an imported base correction station such as a local base (*.t0x, from Trimble, RINEX from third-parties) or CORS data from a VRS network. You can import CORS and other base data using the *Internet Downloads* command in the Photogrammetry ribbon.

Leveraging high-precision data can meet project requirements, but a manual **absolute adjustment** with ground control points (GCPs) can be performed in the adjustment workflow to achieve further accuracy. Using GCPs can help with:

- georeferencing aerial photogrammetry deliverables to known or local coordinate systems
- improving the camera calibration, particularly the focal length, for a more precise adjustment
- correcting systematic global shifts between GNSS data and GCP location(s)

The decision to complete an absolute adjustment depends on the quality from the UAV imported into TBC as well as the desired outcome for the deliverables.

Baseline Processing for GNSS Trajectories

TBC supports GNSS trajectory baseline processing from:

Vendor	Drone	Model Name	TBC Version
DJI	M300 P1	ZenmuseP1	5.80
DJI	Phantom 4 RTK	FC6310R	5.50

TBC checks during the import of the JPG images for other relevant files.
In case you did run your drone flight with the **DJI M300 P1** or the **DJI Phantom 4 RTK** in RTK mode and collected during the flight a complete RTK data set, you will find in the image folder following important files for baseline processing:

- <name>_Timestamp.MRK
- <name>_PPKOBS.obs

These files are imported automatically during the import of your drone images (and need to be imported together with the drone images, to assure the correct tagging of the trajectory data to the images, therefore do not delete single images of the flight, but keep the data set with all flown images).

The **MRK** and **OBS** files are your kinematic trajectory data from your RTK process.
Additionally to the kinematic data from your drone (the rover) you need to collect your static base station data (receiver) during the complete process time of your drone flight to perform a successful baseline processing correction.
This can be a

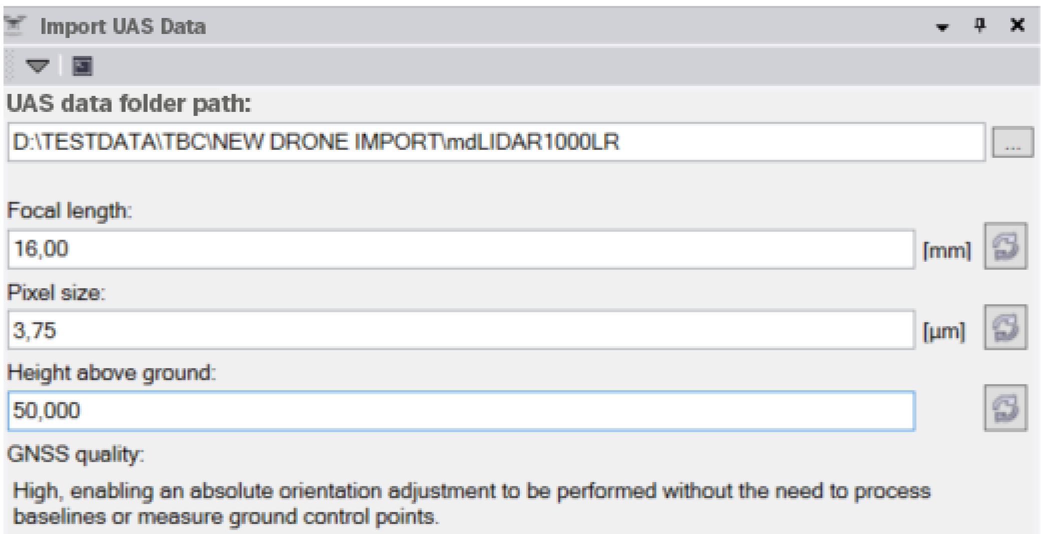
- local base (*.t0x, from Trimble),
- local base (RINEX from third-parties), or
- CORS data from a VRS network

Import UAS Data

There are three ways to import your drone data.

- *Drag & Drop your image folder into the TBC Plan View*
- *Select from Photogrammetry > Import UAS Data*
- *Select from Home > Import the image folder*

After selecting one of the above import methods, a new Import UAV Data dialog displays key parameters extracted from UAS image metadata (for example, camera focal length, pixel size, UAV height above ground, and GNSS quality and whether GCPs are required).



Because these parameters are critical to the success of UAS data processing and deliverables creation, this dialog provides an opportunity to verify the parameters are complete and correct and, if necessary, make any changes prior to import.

This offers for the future a much more flexible way to support other drones, which do not store all necessary data in the metadata fields of the drone (e.g. EXIF, XMP).

Adjustments

There are three adjustment workflows available in TBC v5.60 and later:

- *Adjust Photo Stations*
- *Adjust Photo Stations with GCPs*
- *Send to UASMaster*

The Advanced UAS command has been removed from TBC v5.60 and later versions.

Adjust Photo Stations workflow

Relative adjustment

The **relative adjustment** within the *Adjust Photo Stations* command runs a tie-point extraction and performs radiometric and brightness (e.g. vignetting) corrections. This process automatically connects all images based on photo observations. After photos are successfully oriented through the relative adjustment process, an absolute adjustment may be performed automatically or manually (as described below) to ensure even higher precision for the creation of the most accurate deliverables.

Radiometric and vignetting corrections

A **radiometric correction** on each UAV photo is completed during the automatic tie-point extraction step in the Relative Adjustment within the *Adjust Photo Stations* workflow.

The radiometric corrections compensate for over- or under-lit areas within images due to image exposure, focal length, azimuth/elevation of the sun, and atmospheric conditions, resulting in images that are more evenly lit, and in which fine detail is more easily discernible. The radiometric corrections, which are applied very quickly and with minimal impact on processing time, are contained in small RDX (.rdx) files stored in the user’s project folder (one for each photo image).

TBC then uses the correction information when creating the point cloud to adjust for color, intensity, and contrast differences and improves the ultimate deliverables with a more realistic colored point cloud and orthomosaic.

For example, the following two images both capture the same tie-point from different sensor positions in the same UAV flight. The two images on the left have sharply different contrasts, shown in both the RGB histogram and the image itself. After the radiometric correction, the RGB histogram and the image are more consistent relative to each other.

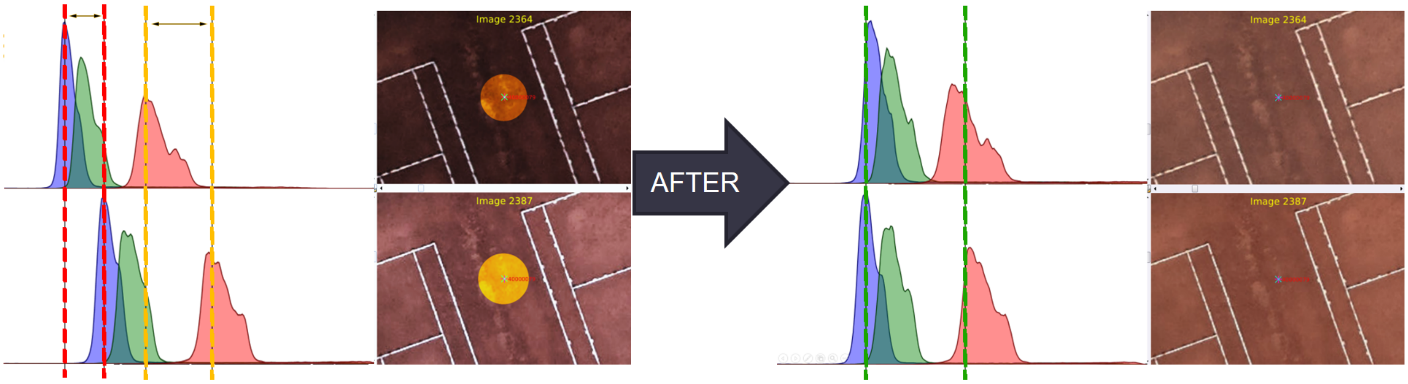


IMAGE CONSISTENCY + QUALITY IMPROVEMENTS AFTER THE RADIOMETRIC CORRECTION

In addition, a general **vignetting correction** is applied during the radiometric correction. Vignetting occurs when there is more light in the center of the camera sensor center and less light in the corners. The vignetting correction does not add any additional files or significant computation time to the processing workflow.

IMAGES WITH NO RADIOMETRIC OR VIGNETTING CORRECTION APPLIED

IMAGES WITH RADIOMETRIC OR VIGNETTING CORRECTION APPLIED

Radiometric and vignetting correction helps to get better results in the following situations:

- When the flights have extreme radiometric differences (for example, from different flight epochs, different days, or different illumination)
- When images are overexposed (for example, from direct sunshine or any other light source)
- When images are underexposed (for example, from long shadows or dark focus areas)

Absolute adjustment based on high-precision GNSS

If high-precision GNSS is provided, for example from a post-processed GNSS trajectory or tagged in the EXIF headers of the images, the *Adjust Photo Station* command runs an **absolute adjustment** automatically after a successful relative adjustment. The absolute adjustment adds GNSS orientation values and calculates a new camera calibration. These new orientations and camera calibration are updated in the adjustment report.

If GCPs were used in the flight mission, it is recommended (but not required) to include them in the adjustment via the *Adjust Photo Stations with GCP* workflow before creating deliverables.

Adjust Photo Stations with GCPs workflow

After successfully completing the Adjust Photo Stations workflow described above,you have the option to further process with an **absolute adjustment based on Ground Control Points (GCPs)**.

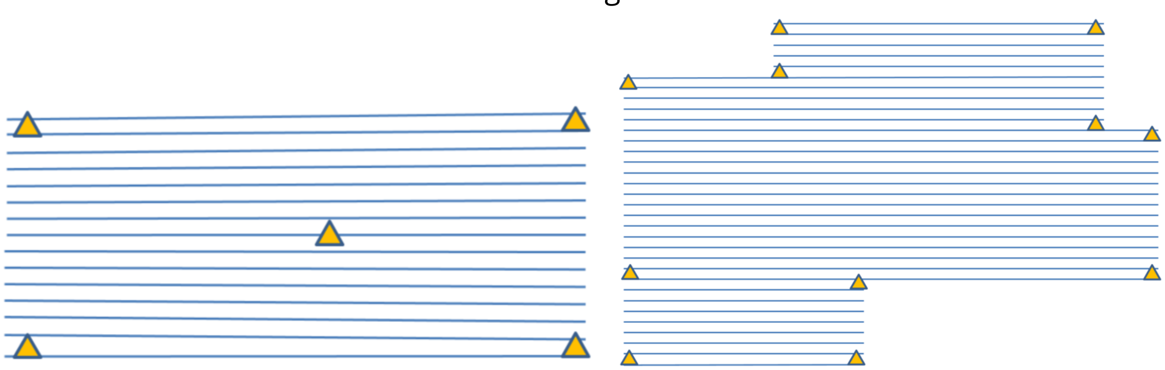
Absolute adjustment based on ground control points (GCPs)

The absolute adjustment is a manual process to match high-precision ground control point (GCP) coordinates to the corresponding GCPs captured in the UAV imagery. The decision to complete an absolute adjustment should be based on the positional and rotational quality from the UAV and the desired deliverables usage.

Even with high-quality GNSS UAV image positions, measuring even a single survey- or control-grade GCP helps to improve the quality of the adjustment and the deliverables. GCPs should be included in several UAV images, clearly visible, and with a proper viewing angle (high angle of incidence from the UAV).

When performing an absolute adjustment with GCPs without high-quality GNSS, the *Adjust Photo Stations with GCPs* requires a minimum of three evenly distributed GCPs that are not aligned along a straight line.

Trimble recommends following the standard photogrammetric ground control point distribution of block configurations. There are many ways to establish a stable block configuration, but basically, GCPs should be located in the corners of the flight area.



TWO IDEAL OPTIONS FOR GCP PLACEMENT FOR FLIGHT AREAS

GCP Measurement Recommendations

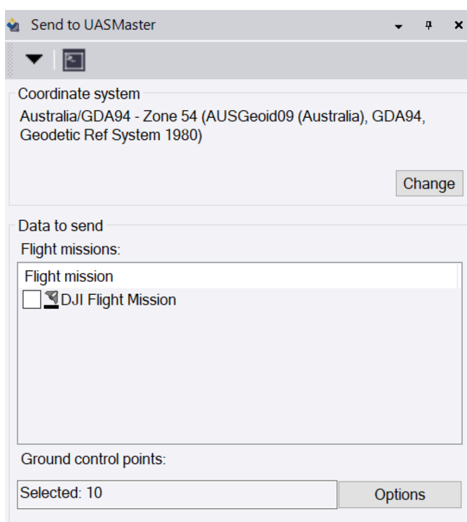
UAV projects are often flown with a high overlap (80/80%) which then includes the GCPs in many images. In the manual measurement process, you can measure the GCPs from all possible images (which would be the most reliable solution but time consuming). Generally speaking, six observations to a given GCP is sufficient. It is recommended to have GCP observations from different strips or flight lines, as this helps block stability and solves some camera related systematic errors.

It is best to avoid blurred observations and to measure the GCP at the highest resolution of the image.

Send to UASMaster workflow

You also have the option to use the complete Trimble UASMaster product to adjust UAV data and create deliverables. There are several advantages of starting a project in TBC and then moving the data into UASMaster, such as performing initial quality checks on the UAV data or GCP positions with other survey data, or setting a coordinate system or local site.

While TBC offers streamlined workflows for surveyors, UASMaster offers more setup parameters and generic third-party UAV support; additional settings for camera calibration, adjustments and orientations; options to manually measure tie-points; additional tools when adjusting to GCPs; additional orthomosaic creation approaches; and more deliverable editing tools.



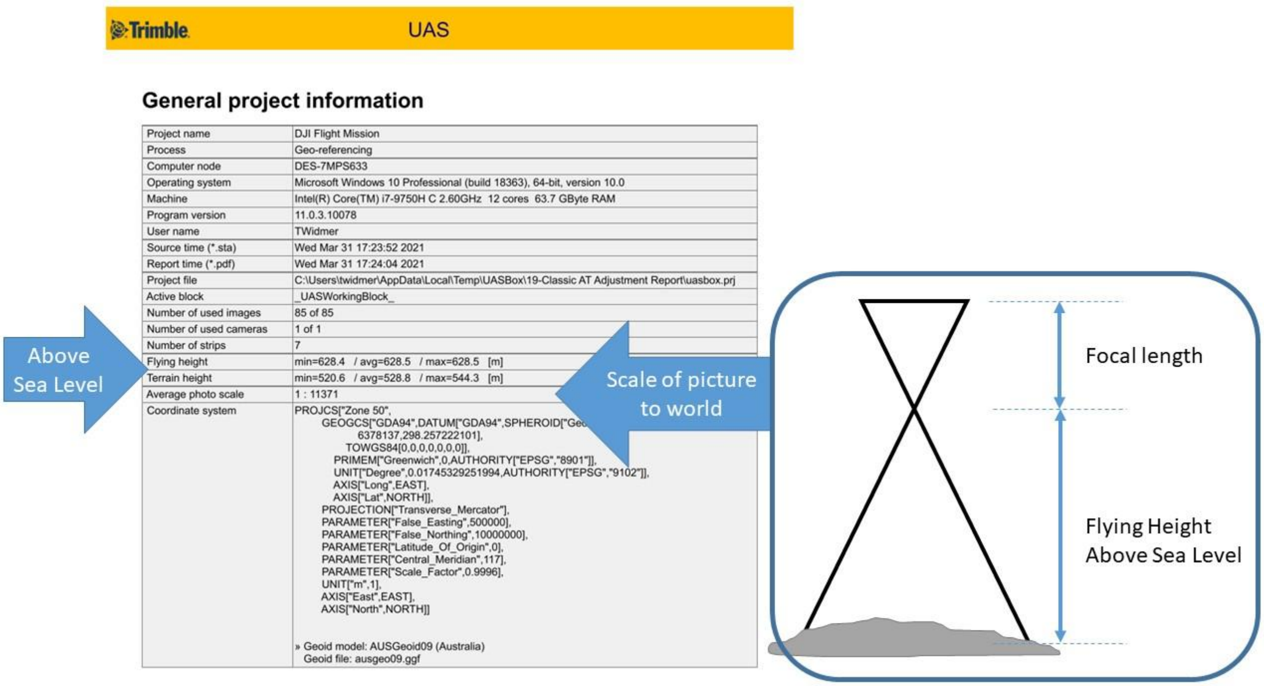
USER OPTIONS WHEN SENDING UAV DATA TO UASMASTER FOR PROCESSING

You can also complete your adjustments in UASMaster, then bring the deliverables back into TBC by using the *Send to Trimble Business Center / Survey Office* command in UASMaster.

For more information on Inpho UASMaster, visit the homepage, view the video tutorials on YouTube, or contact your local Trimble Geospatial Distribution Partner.

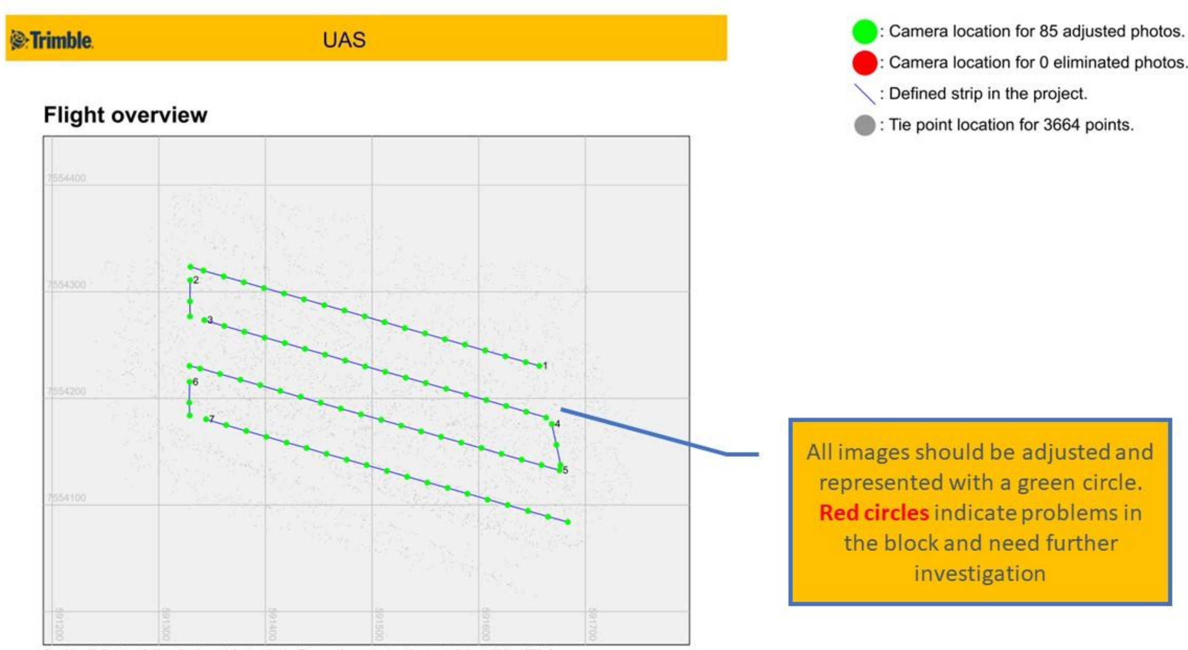
Adjustment Report

Adjustment reports are generated after the relative and absolute adjustment steps are complete and contain detailed analysis and data on the adjustment results. See the screenshots and explanations below from a typical aerial photogrammetry report in TBC.



General project information

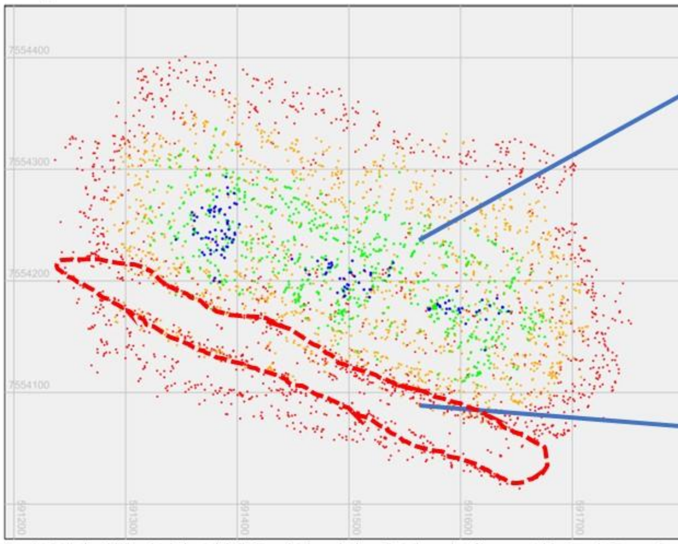
Project name	DJI Flight Mission
Process	Geo-referencing
Computer node	DES-7MPS633
Operating system	Microsoft Windows 10 Professional (build 18363), 64-bit, version 10.0
Machine	Intel(R) Core(TM) i7-9750H C 2.60GHz 12 cores 63.7 GByte RAM
Program version	11.0.3.10078
User name	TWidmer
Source time (*.sta)	Wed Mar 31 17:23:52 2021
Report time (*.pdf)	Wed Mar 31 17:24:04 2021
Project file	C:\Users\twidmer\AppData\Local\Temp\UASBox\19-Classic AT Adjustment Report\uasbox.prj
Active block	_UASWorkingBlock_
Number of used images	85 of 85
Number of used cameras	1 of 1
Number of strips	7
Flying height	min=628.4 / avg=628.5 / max=628.5 [m]
Terrain height	min=520.6 / avg=528.8 / max=544.3 [m]
Average photo scale	1 : 11371
Coordinate system	PROJCS["Zone 50", GEOGCS["GDA94",DATUM["GDA94",SPHEROID["Ge 6378137,298.257222101], TOWGS84[0,0,0,0,0,0,0]], PRIMEM["Greenwich",0,AUTHORITY["EPSG","8901"]], UNIT["Degree",0.01745329251994,AUTHORITY["EPSG","9102"]], AXIS["Long",EAST], AXIS["Lat",NORTH]], PROJECTION["Transverse_Mercator"], PARAMETER["False_Easting",500000], PARAMETER["False_Northing",10000000], PARAMETER["Latitude_Of_Origin",0], PARAMETER["Central_Meridian",117], PARAMETER["Scale_Factor",0.9996], UNIT["m",1], AXIS["East",EAST], AXIS["North",NORTH]] » Geoid model: AUSGeoid09 (Australia) Geoid file: ausgeo09.ggf



Graphic with 7 strip definitions for the aerial triangulation. The area has a planimetric extent of about: 606 x 477 [m].

Trimble UAS

Tie point distribution



Tie point distribution of 3664 points in the statistic file. The point size and colour reflects the number of images containing the point. The area has a planimetric extent of about: 606 x 477 [m] and a height range of about: 521 - 544 [m].

: Point found in (0-6) images.
: Point found in (7-12) images.
: Point found in (13-18) images.
: Point found in (>18) images.

The graphic gives a good indication about the **block overlap**.
Green and **blue** areas are better overlapped.
Orange is ok.
Red should mainly be at the edge of the block.

Larger holes in the block are common, but need further investigation. They can occur if e.g. Forest, water, weak texture or occlusion are given.
Good flight planing (daylight, season, water level, overlap, etc...) can minimize the holes.

Trimble UAS

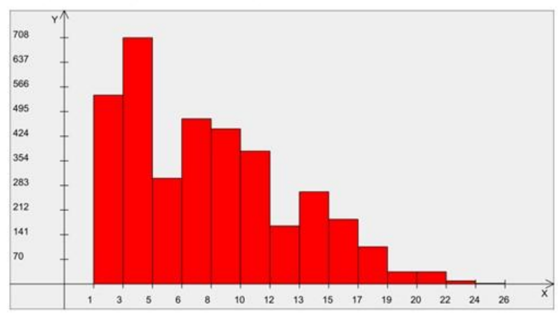
Image points

Frequency of image point observations in the photos

X	Number of image points (Y)	%
>0 - 1	0	0.00
>1 - 3	543	14.82
>3 - 5	708	19.32
>5 - 6	304	8.30
>6 - 8	475	12.96
>8 - 10	446	12.17
>10 - 12	382	10.43
>12 - 13	167	4.56
>13 - 15	265	7.23
>15 - 17	186	5.08
>17 - 19	107	2.92
>19 - 20	35	0.96
>20 - 22	35	0.96
>22 - 24	9	0.25
>24 - 26	2	0.05

Appearance of 3664 image points from the statistic file. The table contains all image observations of the points.

Histogram for image point frequency in the photos



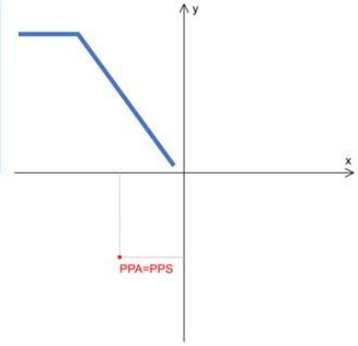
Graphic for 85 photos and 3664 image points. Number of image points (Y) within a given range for number of photos (X).

Overlap (%) [InStrip / CrossStrip]	Points probably only in one strip	Probably max. value	Height Accuracy	True Ortho Quality
60/60	0 - 3	6	Better	Worse
70/70	0 - 3	12	Normal	Possible
80/80	0 - 4	16	Worse	Good

The table gives a good indication about the **connectivity**.
In Strip overlap and **cross-strip overlap** are main factors for the values.
For projects with **80% In Strip Overlap** we want to have many points with > 4.
For projects with **60% In Strip Overlap** we want to have many points with > 3.
These points connect multiple strips and give a better block connectivity and stability

Trimble UAS

Typically we want the PPA/PPS value to be **close to the center**. If the X,Y values are multiple numbers of pixel size [careful mm or micron], it indicates the lense was not installed properly.
PPA/PPS is very small for photogrammetric cameras, but larger for consumer-grade cameras.



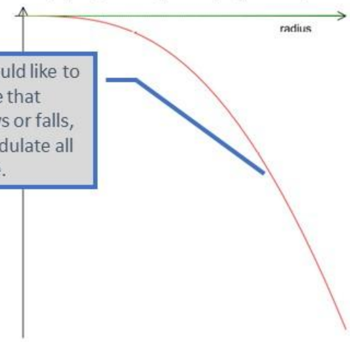
Camera

Camera data (1218)

Manufacturer		
Model	UAS_Digital	
Serial number		
Sensor (width / height) [pixel]	5472	3648
Pixel size (x / y) [micron]	2.3997	2.3999
Ground sampling distance (x / y) [m]	0.0273	0.0273
Camera calibration	Calibrated	
Distortion type	Coefficients	
Additional parameters	OFF	
Focal length [mm / pixel]	8.7770	3657.3910
Standard deviation [mm / pixel]	0.0143	5.9459
Focal length (Fx / Fy) [pixel]	3657.4869	3657.2952
Principal point (x / y) [mm | pixel]	-0.0321 | 2722.1124	-0.0423 | 1841.1360
Standard deviation (x / y) [mm | pixel]	0.0004 | 0.1863	0.0004 | 0.1546
Distortion parameter: K0 / K1	0.000000E+00	-3.450563E-03
K2 / K3	1.768225E-05	-6.135841E-08
K4 / K5	0.000000E+00	0.000000E+00
K6 / K7	0.000000E+00	0.000000E+00
P1 / P2	-1.399905E-05	-2.807618E-05
P3 / P4	0.000000E+00	0.000000E+00

Compare calibrated values of **Pixel Size** and **Focal Length** to original value. They should not differ too much.

Principle point (x=-0.0321, y=-0.0423 [mm]) in the image.

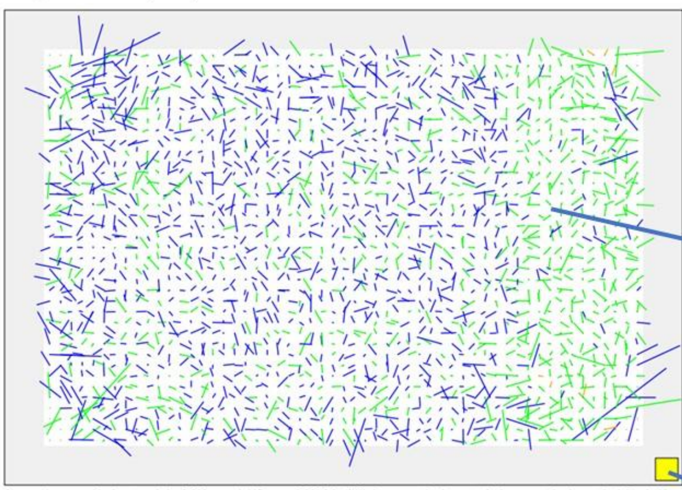


In general we would like to have a curve that **constantly** grows or falls, but does not undulate all the time.

Table shows the results after the camera calibration bas been performed.

The dashed green lines show the magnitude of the decentering distortions on the four image diagonals. This gives an impression of what will be missed if only radial distortion components are used.

Image residuals (1218)

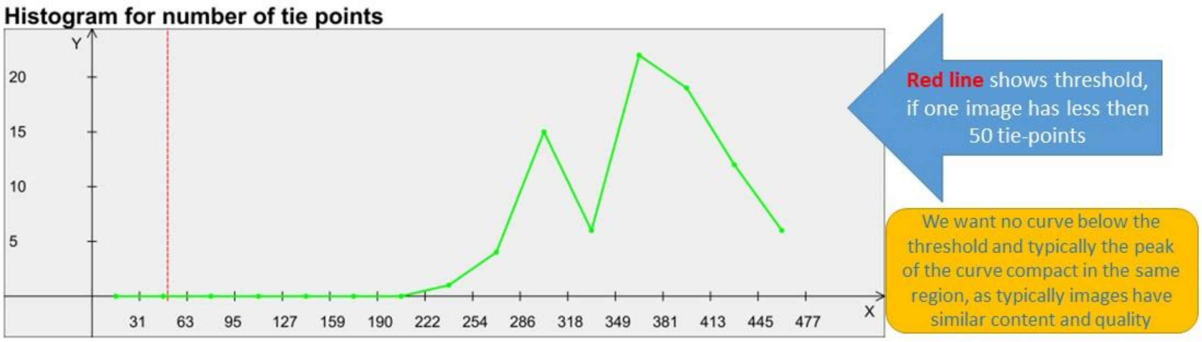


Average image residual vectors (min=0.003, avg=1.415, max=6.863 [pixel]) for image matrix elements. An image matrix element is defined with about (100 x 100) pixels. Image residual is defined as: residual = observed - adjusted. Number of invalid image residual vectors outside the graphic: 9.

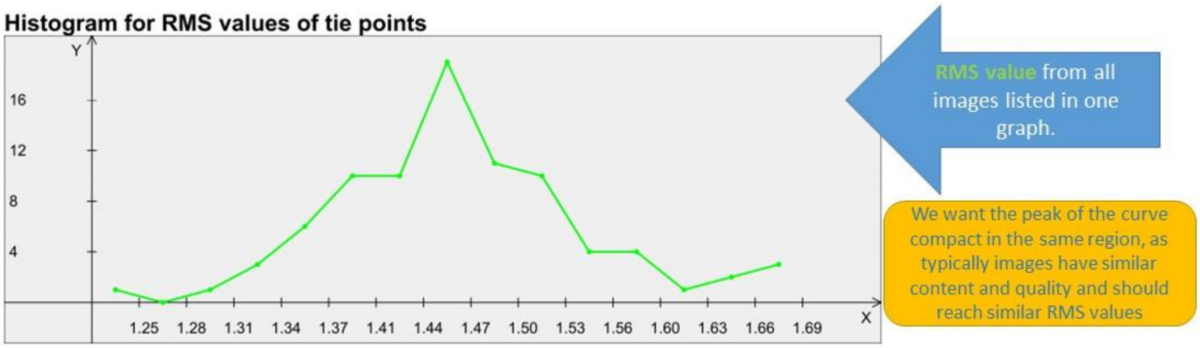
: Scale for the residual vectors. Symbol in the graphic is correlated to 1 [pixel] in the image.
: Average image residual vector for points in (0-2) images.
: Average image residual vector for points in (3-4) images.
: Average image residual vector for points in (5-10) images.
: Average image residual vector for points in (>10) images.

Graphic shows the residuals of the lense in a grid point view.
We want to have **no systematic pattern** of vectors.

Images with **larger pixel size (> 4 micron)** should be able to reach an average residual smaller 1 [pixel]. Images with **pixel Size 2-4 micron** should generally be better than 1.5 [pixel]. Images with **very small pixel size (< 2 micron)** are typically low-cost sensors and tend to be less accurate. The yellow box represents the size of 1 pixel, helping us to understand the length of the displayed vectors in the graph.



Graphic for 85 photos with 1 cameras. Evaluation criteria: [# of points/photo] < Thr (=50 [points/photo]).



Graphic for 85 photos with 1 cameras. Evaluation criteria: [RMS] > Thr (=3.97 [pixel]).

Trimble. UAS

Block adjustment results

Accuracy

Sigma naught	3.1718 [micron]
	1.3217 [pixel]

Quality of each individual tie-point measurement relative to pixel size of camera

Mean standard deviation of translations

X [m]	Y [m]	Z [m]	Total [m]
0.0159	0.0151	0.0140	0.0260

How accurate are the photo positions adjusted (calculated) in the air

Mean standard deviation of rotations

Omega [deg]	Phi [deg]	Kappa [deg]
0.00999562	0.00968242	0.00645555

How accurate are the photo rotations adjusted (calculated) in the air

Mean standard deviation of terrain points

X [m]	Y [m]	Z [m]	Total [m]
0.0249	0.0313	0.0610	0.0730

How accurate are the tie-point positions adjusted (calculated) on the ground

RMS values for GNSS

X [m]	Y [m]	Z [m]	Total [m]
0.0249	0.0254	0.0144	0.0384

Standard deviation of the GNSS. High-precision GNSS should be within its accuracy

RMS values for IMU

Omega (X) [deg]	Phi (Y) [deg]	Kappa (Z) [deg]	Total [deg]
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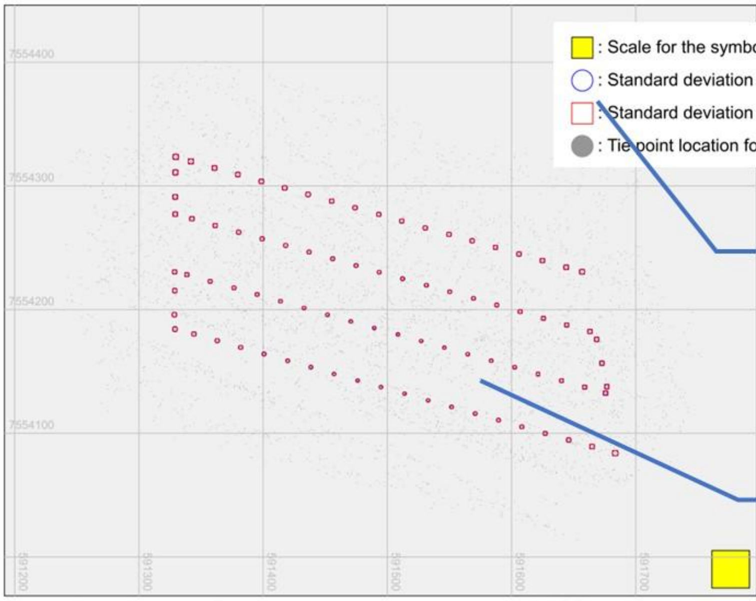
UAS

Exterior orientation (X,Y,Z) standard deviations (1218)



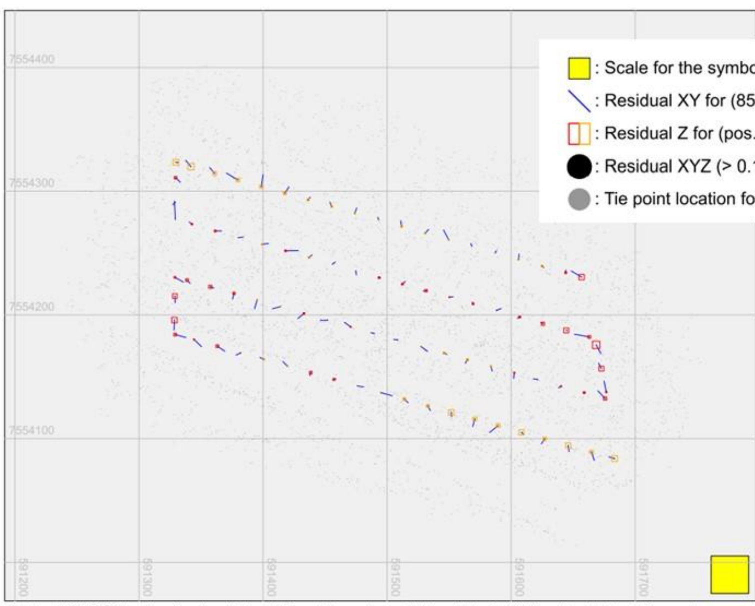
Graphic with 85 photos from the project. The camera locations are shown with its standard deviations for XYZ. The area has a planimetric extent of about: 606 x 477 [m].

Please check **avg. value** and **max. value** for the standard deviations. Size does not matter here, error elipses are displayed based on a scale factor (see yellow box).
Error ellipses tend to get **larger at the border** of the block. If enough GCPs are used, we assume that **outside the GCP area** error ellipses become **larger**.

Graphic shows the standard deviation of each single photo. We want to have **circular & similar size** for the **error ellipses**.

UAS

GNSS residuals (observed - adjusted) (1218)



Graphic with 85 GNSS locations from the adjustment. The points are shown with its residuals for X,Y,Z from the adjustment. The area has a planimetric extent of about: 606 x 477 [m]. Residual is defined as: residual = observed - adjusted.

We do not want to see systematic effects in the GNSS residuals, but randomized vectors all over the block. There are many possibilities for systematic effects in the GNSS, therefore we recommend to have enough **GCPs** allowing to **run a global shift** in the adjustment process.

Ground control points

Ground control point residuals (given - adjusted)

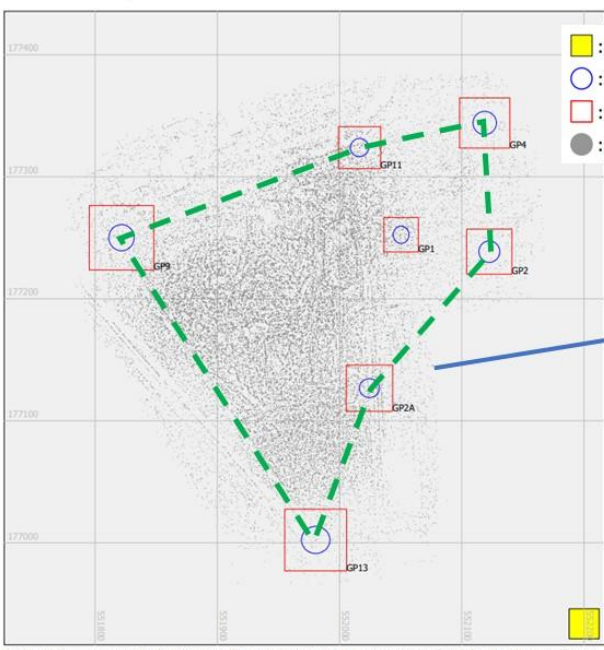
ID	Fold	X [m]	Y [m]	Z [m]	Total [m]	Remark
GP1	12	-0.0435	-0.0753	-0.5013	0.5088	
GP11	15	0.0019	0.0385	-0.2730	0.2757	
GP13	3	0.1054	-0.0781	0.4360	0.4553	
GP2	10	-0.0534	-0.1902	0.0613	0.2068	
GP2A	11	0.0188	0.0960	-0.5629	0.5714	
GP4	11	-0.0522	0.0915	0.6539	0.6623	
GP9	12	0.0232	0.1175	0.1860	0.2212	
Maximum		0.1054	-0.1902	0.6539		
Mean		0.0000	0.0000	0.0000		
Sigma		0.0570	0.1161	0.4653		
RMSE(x,y,z)		0.0527	0.1074	0.4307		
RMSEr		0.1197	SQRT(RMSEx * RMSEx + RMSEy * RMSEy)			
ACCr (at 95% Confidence Level)		0.2072	RMSEr * 1.7308			
ACCz (at 95% Confidence Level)		0.8443	RMSEz * 1.9600			

The table shows the residuals from each single GCP, comparing the given coordinate with the adjusted coordiante (this is the „mean" value from all observations [fold value] which have been included into the adjustment).

Mean value should be close to „0".
Sigma value should be at the same level as the RMS.
RMSE should be similar to the used GSD for the process.
In this example the RMSE value (especially the Z-value) is too large, indicating to check the adjustment and the factors influencing the height.

The ACCr and ACCz values are different statistic values for adjustment, using only 95% of measurements (observations) for the calculation. This value tends to give a more realistic quality for position and height accuracy. Both RMSE and ACC are common statistic values used in adjustment.

Ground control point standard deviations



Graphic with 7 ground control points from the project. The points are shown with its standard deviations for XYZ from the adjustment. The area has a planimetric extent of about: 492 x 519 [m].

: Scale for the symbols. Symbol in the graphic is correlated to 0.011 [m] in the object.
: Standard deviation XY for 7 ground control points (min=0.0082, avg=0.0108, max=0.0138 [m]).
: Standard deviation Z for 7 ground control points (min=0.0121, avg=0.0173, max=0.0227 [m]).
: Tie point location for 71597 points.

Graphic shows the standard deviations for each single GCP in the block.
We wanto to see here a good GCP distribution for the block.
Typically we want to have in each corner of the block a GCP.
If we **draw a polygon** around the GCPs at the border of the block, we want the polygon to represent the block as good as possible. Photos outside the polygon tend to be less accurate orientated as photos inside the polygon.

Deliverables

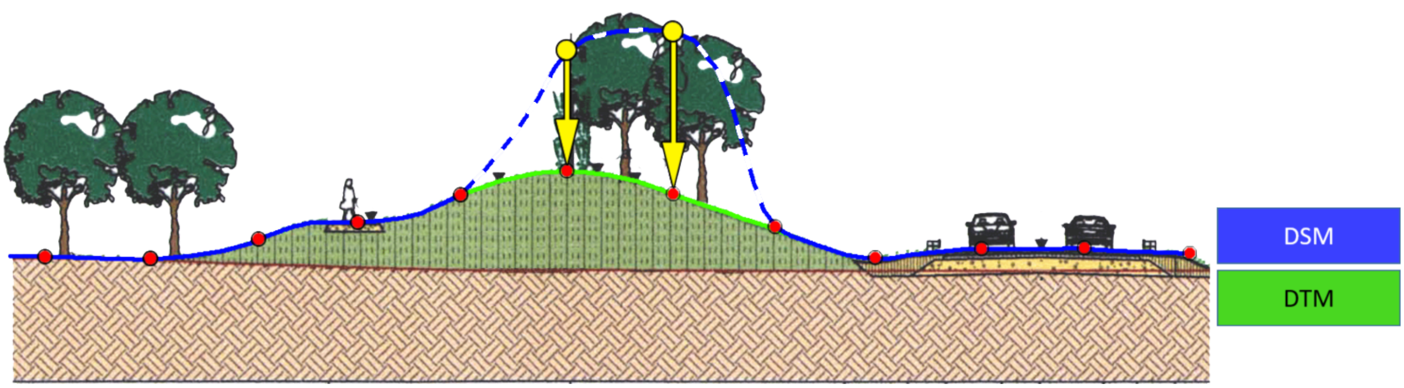
Once the desired adjustments have been completed, **point cloud**, **raster DSM** image, and/or **orthomosaic** (orthophoto) deliverables can be created in the *Create Deliverables* command.

You can define and select a boundary limiting the deliverables extent. If no boundary is selected, the flight plan will be considered as the default boundary. Applying a boundary will reduce the adjustment and deliverable creation time.

Note that in order to create an orthomosaic, the corresponding point cloud and raster DSM will be created in the background as a by-product. Therefore, if the orthomosaic is the required deliverable, the point cloud and raster elevation model can be added to the selection without a significant increase in processing time.

Point Cloud

TBC can generate elevation-based point clouds in the form of Digital Terrain Model (DTM) and Digital Surface Model (DSM).



DIFFERENCE BETWEEN THE DSM + DTM POINT CLOUD

Digital Terrain Model (DTM)

A DTM point cloud requires the least amount of time to create. It represents the bare terrain; it does not model elevated objects such as vegetation or buildings.

POINT CLOUD REPRESENTING DTM ELEVATION MODEL

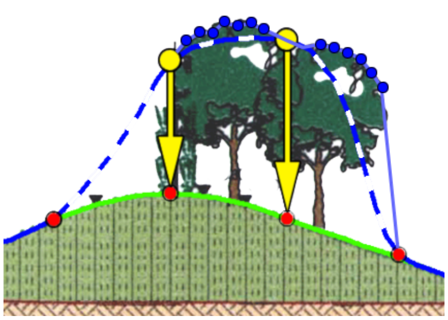
A DTM point cloud has the advantage of representing the terrain with a reduced amount of points and does not include a point for each pixel of the captured image.

Digital Surface Model (DSM)

A **DSM** point cloud accurately describes the visible surface, including elevated objects such as vegetation or buildings.

POINT CLOUD GENERATED USING DSM ELEVATION MODEL (INCLUDES ELEVATED OBJECTS)

The DSM point cloud creation process applies automatic image matching to every pixel of the captured image[1]. This allows extreme height changes in the surface to be precisely monitored and measured. Complex terrain structures (rocks, embankment changes, terraces, trees, building sites, etc.) enable precise calculations.



DSM + DTM DIFFERENCE, IN DETAIL

The illustration to the left shows the denser DSM point cloud (blue circles) on top of the trees, which are needed to model the true position of the canopy.

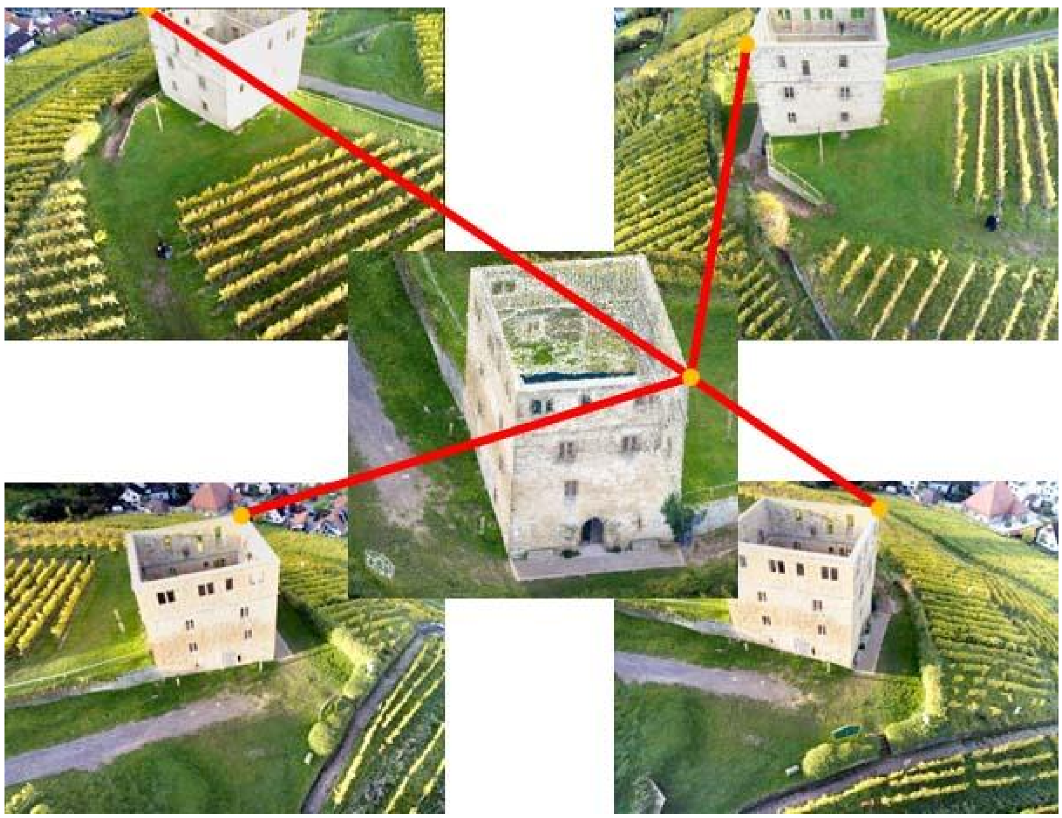
The DTM elevation (red circles) is not sufficient to model the canopy correctly. Even if the DTM points are placed at the correct height position (yellow circles), it will not be the correct representation (blue dashed line) of the canopy .

[1] Depending from used image level and for time-reduction, some parameters use only every 2nd or 3rd or lexxer pixel for its final result

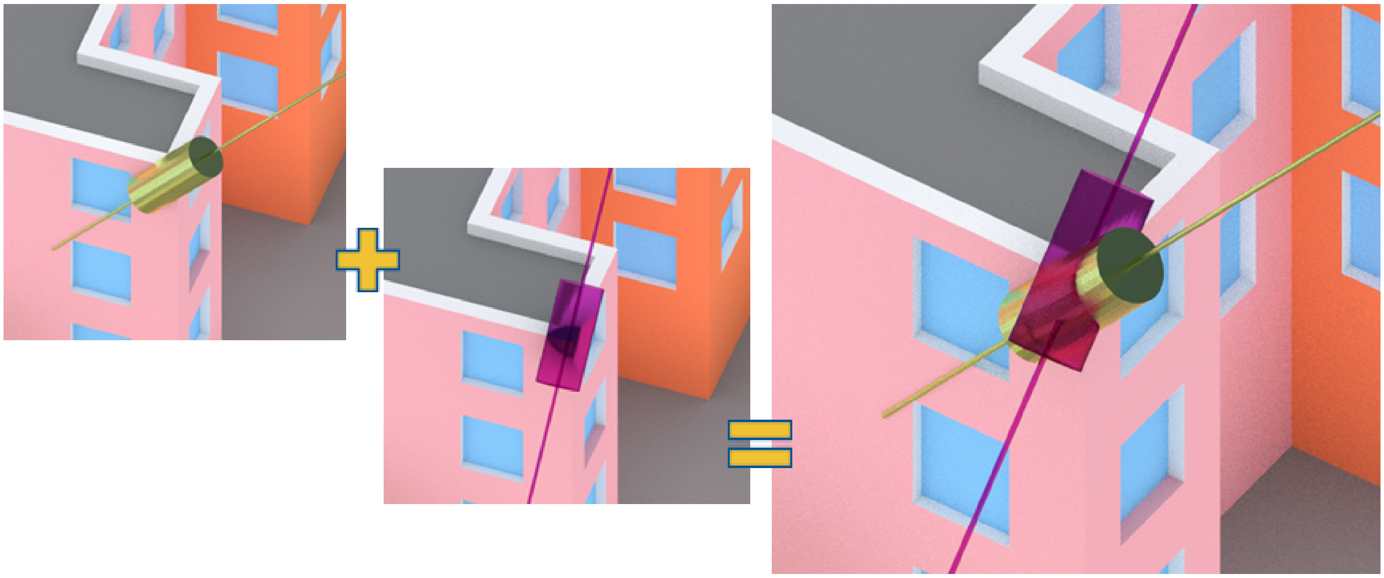
Digital Surface Model - Highest Quality (DSM HQ)

TBC v5.60 and later offer the *Digital Surface Model (Highest Quality)* option, which uses **Semi-Global Matching (SGM)** algorithm to provide cleaner and sharper edges in both orthomosaic and point cloud. The method runs additional processes such as stereo-model selection, multi-point matching, raw point cloud filtering for facade corrections and edge enhancements, and disparity map improvements for uncertain areas to deliver the best possible results.

To illustrate these improvements, the graphic below shows how multiple images can measure the same corner of the building. Combining different stereo-models for the same reference image allows for a multi-point matching. Each stereo-model pair creates a probability of how accurate the point can be measured.



BUILDING CORNER MEASURED FROM MULTIPLE PHOTO STATIONS



THE PROBABILITY OF MATCHING THE REAL-WORLD POSITION FROM MULTIPLE PHOTO STATIONS IS SHOWN IN THE CYLINDER (PURPLE, YELLOW)

Combining two probabilities increases the accuracy and probability of the final matched point lying in the intersection of the two cylinders.

Therefore, it is very helpful to have a strong overlap of images in the flight mission when running the *Digital Surface Model (Highest Quality)*. It is recommended that the flight mission include 80% in-flight overlap and 80% lateral overlap. This method creates a **true orthomosaic**, as detailed in the "Orthomosaics" section below.

Raster DSM

The Raster DSM is an interpolated point cloud image created from the point cloud deliverable. One of the benefits of the Raster DSM is the interpolation of gaps. If the original point cloud wasn't able to generate points for some areas due to insufficient overlap or very low texture or resolution, the Raster DSM can fill gaps. Some raster formats (like the inpho SCOP DTM in TBC) can remember if one raster point was interpolated from the previous point or if the interpolation was needed because there was a gap.

As the raster solution always interpolates, it is mainly used for DTM products. It is strongly recommended to set the raster density lower than the point cloud density.

Orthomosaics

The Orthomosaic, or orthophoto, product is strongly correlated with the delivered elevation model and the quality and overlap of the drone images.

Using the Digital Terrain Model and the Digital Surface Model elevation options, TBC creates a **classic orthomosaic**.

Using the Digital Surface Model (Highest Quality) elevation option, TBC creates a **true orthomosaic,** fully automatic.

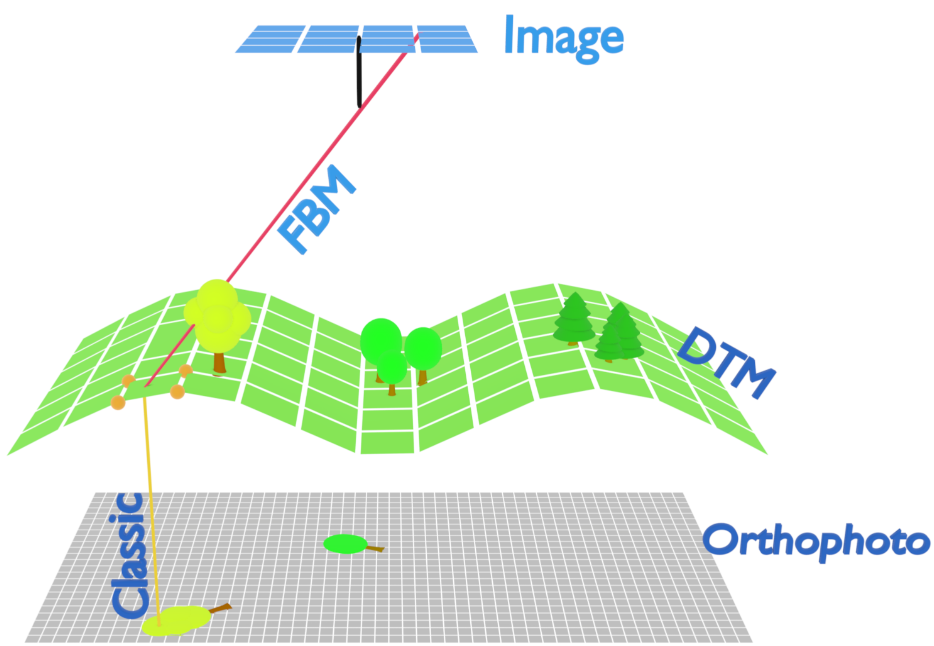
Classic Orthomosaic

The classic orthomosaic creation process uses interpolation methods to calculate for each pixel of the captured image the accurate georeferenced position in the ortho.

The DTM does not necessarily need the same raster distance as the final classic orthomosaic. Each orthomosaic pixel determines the related DTM height and will be re-projected with the given camera information to the image frame sensor.

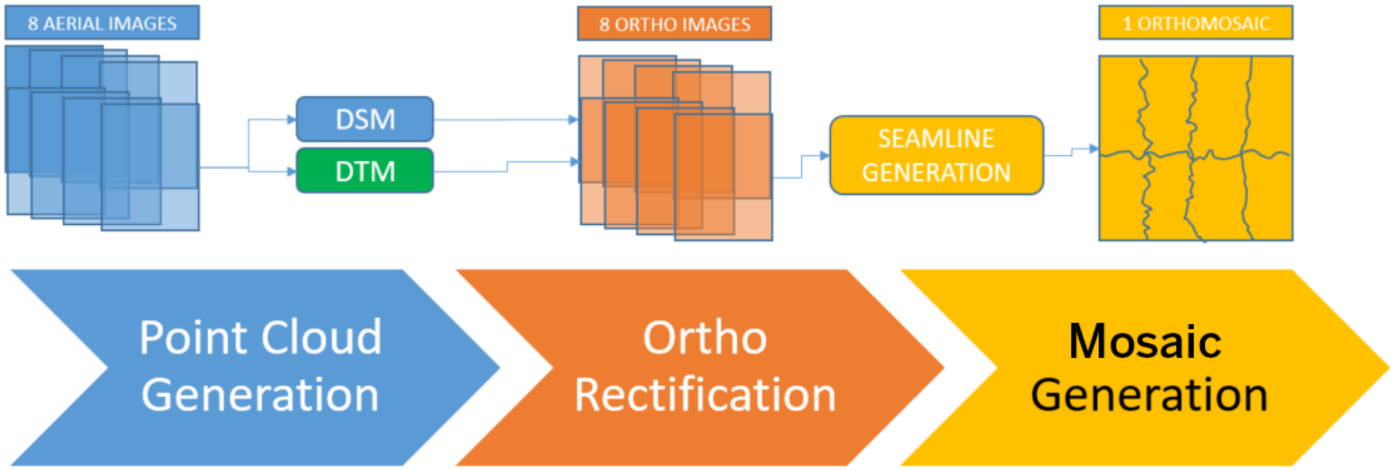
In the image below, the red line represents the site line projected to the DTM. TBC then interpolates the corresponding height from the four surrounding [X,Y,Z] coordinates of the raster (orange circles) and calculates the high resolution orthophoto pixel.

As long as the DTM does not include extreme height errors, the interpolation method of height for each ortho pixel is a very common method for the ortho production and is known as **classic orthomosaic** generation.



CLASSIC ORTHOMOSAIC CREATION, FROM UAV IMAGES TO DTM TO ORTHO

Classic orthomosaics are typically the main deliverable required for rapid mapping projects such as mining and agricultural application or any open terrain without dense building construction. Objects such as tall buildings or trees can lean in the orthomosaic, but using image-centric selection of all drone images reduces the leaning effect and can result in high quality classic orthomosaic images for the built environment.



ORTHOMOSAIC CREATION PROCESS FOR CLASSIC ORTHOS

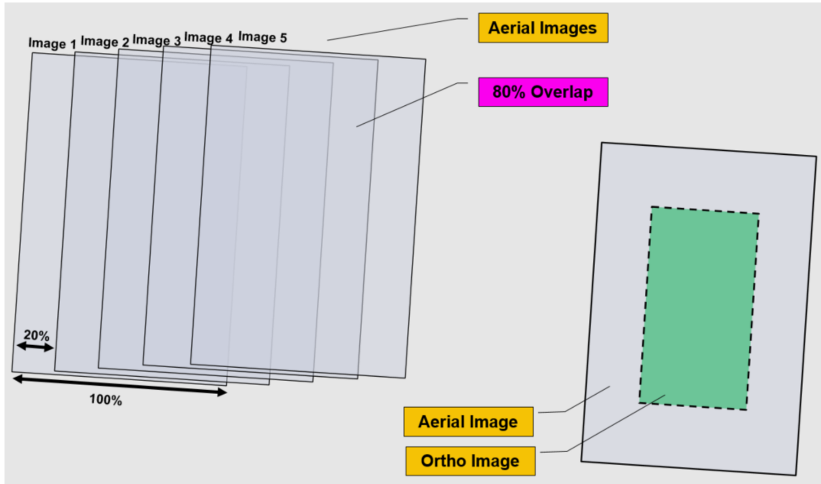
Point Cloud Generation Process

Described in previous sections, the point cloud is required to create the orthomosaic. The point clouds can be used for example in open mines and earthwork volume computations.

Ortho Rectification Process

The ortho rectification process is completely embedded in TBC and runs automatically during the orthomosaic creation process. To increase the quality of the final orthomosaics and improve the performance in the orthophoto generation, TBC uses the central part of images (the green area in the graphic below). When the image-centric areas of each image are selected, TBC ortho rectifies each pixel on the ground only one time, which decreases the amount of redundancy for the orthomosaic pixels. This reduces the overall processing time and avoids usage of image content in the furthest parts of the drone image. In this way the quality of the orthomosaic will be improved, as tall buildings “lean” stronger in the corners of the drone image and occlude larger areas. TBC avoids these critical parts of the aerial images and creates orthomosaics with less occluded content, giving the user a more natural orthomosaic product.

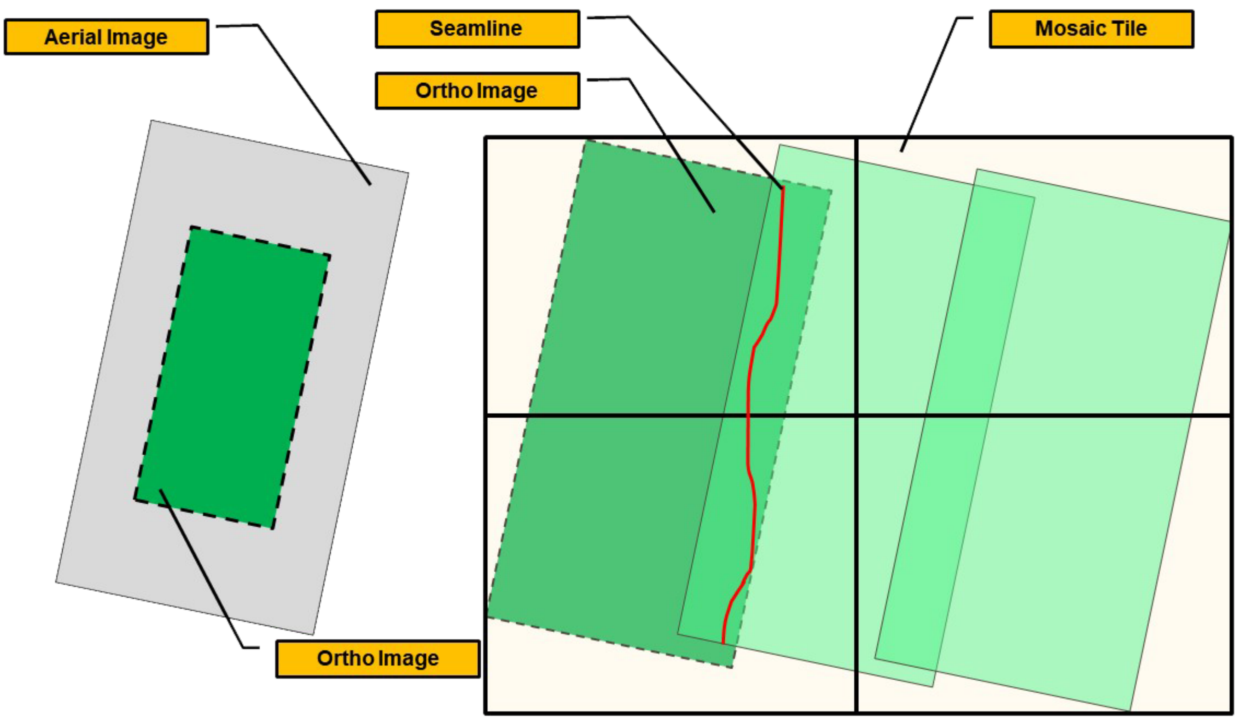
This means, users can increase the quality and completeness of the final orthomosaic even more, by flying high overlap in both flight direction and laterally between flight lines.



BENEFITS OF FLYING WITH HIGH OVERLAP FOR THE ORTHOMOSAIC CREATION

Mosaic Generation Process

After rectification of the images, the created ortho images are overlapped with a smaller coverage. The mosaic generation process then stitches the ortho images by sewing them over a seamline along the overlap area of the orthomosaics and combines them into a single mosaic image.



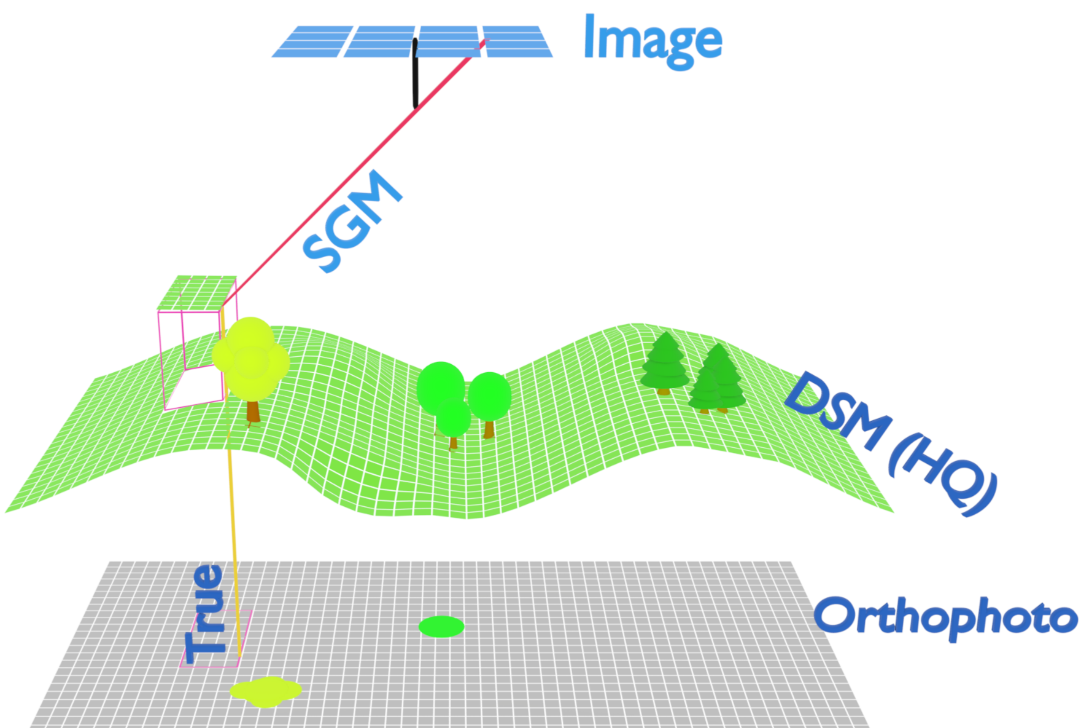
TILING + SEAMLINING OF ORTHOMOSAIC CREATION

For better user experience, TBC creates one single mosaic TIFF tile when the size does not exceed the 4GB limitation of TIFF images. If the final mosaic product is larger, TBC automatically splits the result into multiple mosaic tiles.

True Orthomosaic

Using the Digital Surface Model (Highest Quality), TBC creates a **true orthomosaic** fully automatic.

The true orthomosaic is based solely on the point cloud, without any ortho rectification and seamline generation steps.

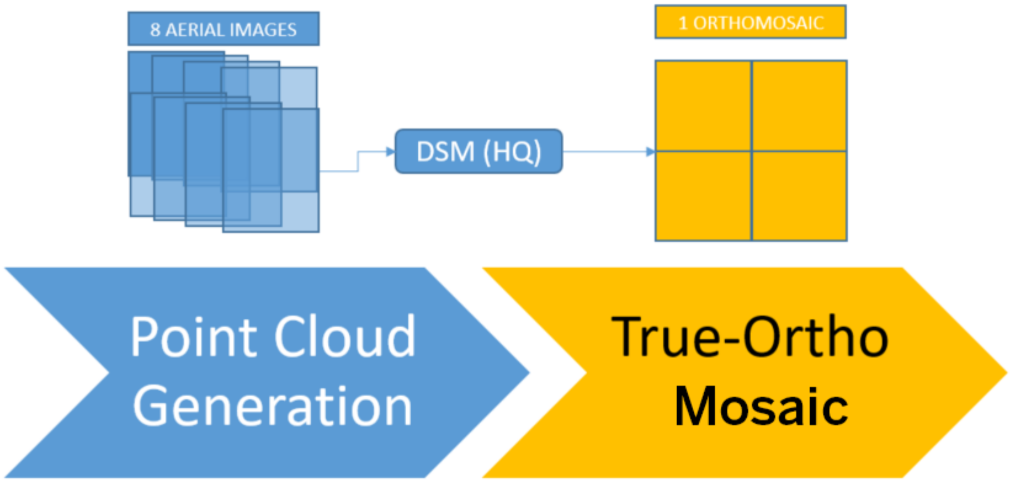


TRUE ORTHOMOSAIC CREATION, FROM UAV IMAGES TO DSM (HQ) TO ORTHO

Each final orthomosaic pixel needs a corresponding matched point in the point cloud.
To create the true orthomosaic as accurately as possible, the point cloud density should match the ortho image to avoid interpolation and incorrect ortho rectification of single pixels.

True orthomosaics provide the most accurate representation of the visible surface, but the correct height for each pixel can be challenging. Incorrect heights distort the final true orthomosaic image. Another challenge is the occlusion of surface areas. Buildings, trees or other surface objects can block the view to the ground surface, thereby creating an inaccuracy representation in the ortho.

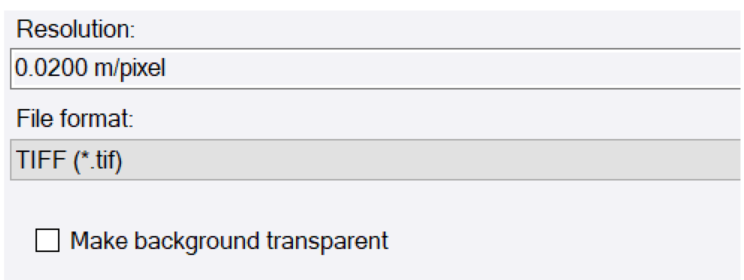
True orthomosaics are very useful for dense representations of complex projects. Depending on the level of detail required for building roof edges in city areas, this solution is a strong option in urban environments.



ORTHOMOSAIC CREATION PROCESS FOR TRUE ORTHOS

Transparent background option for orthomosaic creation

Orthomosaics can be created with transparent background pixels for areas and edges that are not covered in the imagery. This option will add an additional color channel to the orthomosaic that contains the transparency information, causing the file size to increase by up to 30%. It is recommended that you select the *TIFF with JPEG compression* option when selecting the transparent background option to reduce the file size.



CREATE CLEAN EDGE ORTHOMOSAICS WITH THE TRANSPARENT OPTION

Solution Recommendations

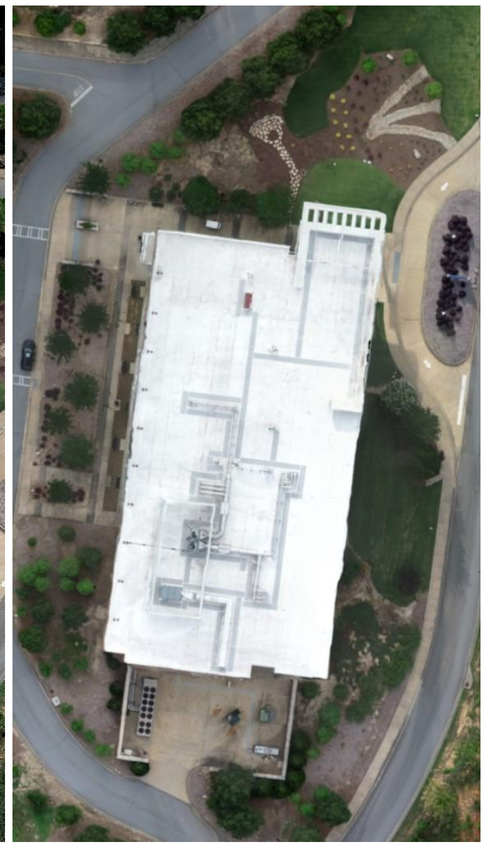
The following chart can guide you better in choosing the best options and deliverables for your aerial photogrammetry projects.

Application	Elevation Type	Image Overlap (% forward / % lateral)	Comments
Urban City Mapping	DSM (HQ)	80 / 80	**Main Target:** ● Sharp Building edges with correct geo-referencing of all man-made objects (buildings, fences, walkways, etc.) **Challenges:** ● Very accurate camera calibration ● Strong overlap of images ● Good image resolution (not blurred or bad illumination)
Agriculture	DTM	60 / 60	**Main Target:** ● Complete coverage of project with orthophotos **Challenges:** ● Descend accuracy of terrain model without spending large amount of time in manual terrain editing
Mining	DSM	80 / 80	**Main Target:** ● Point Cloud modeling terrain changes ● Contour Lines ● Surface Model for calculations (e.g. Volume) **Challenges:** ● Shadows in low textured soil areas ● Extreme height differences in the terrain (min-max) can have an influence in the relative adjustment
Road Construction	DSM	80 / 60	**Main Target:** ● Point cloud with enough details to model complex structures at the construction site **Challenges:** ● Many objects causing occlusions in the images ● 3D scenarios (blocking, overlapping, intersecting) ● Corridor mapping projects

Project Examples

Application	Point Cloud	Ortho	Sensor	Overlap %	n° of Images
Urban City	DSM	2 cm	DJI P4	80/80	157

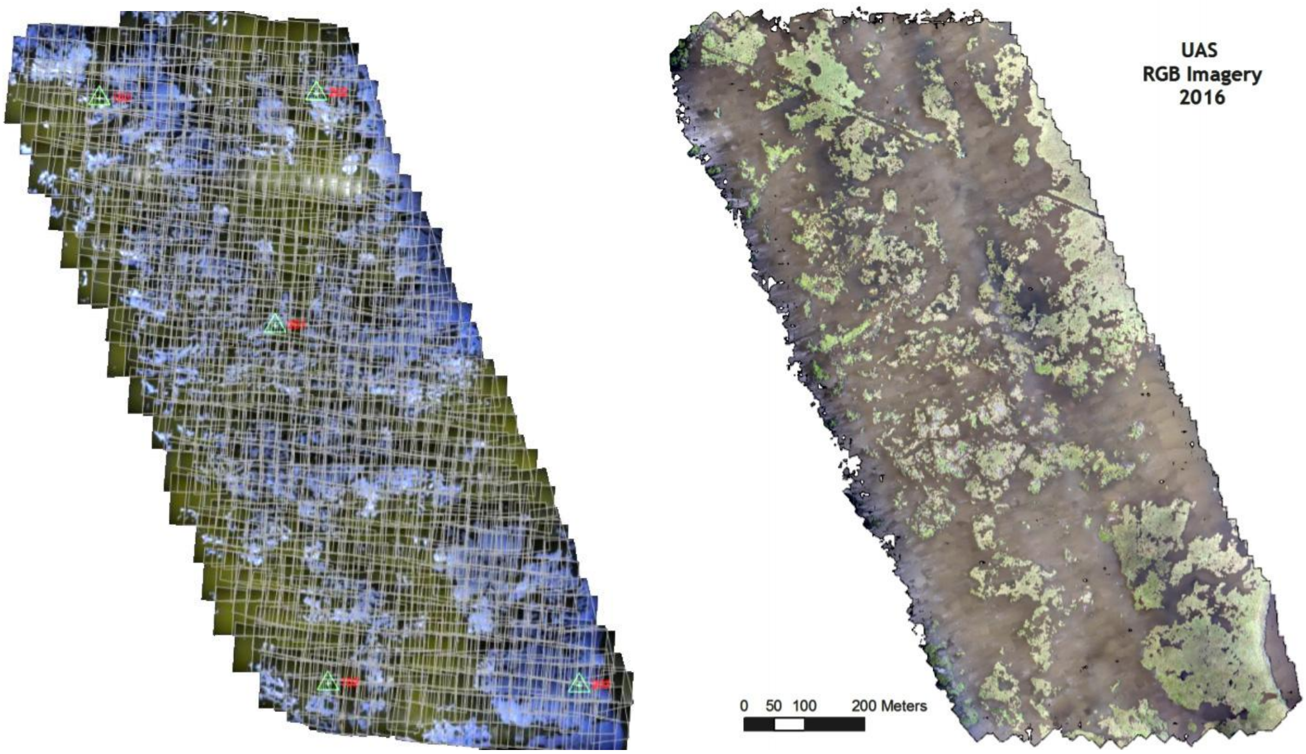
Site-based topography project created to gain a 3D surface contour map and building layout for a multi-story office complex and surrounding grounds.



Application	Point Cloud	Ortho	Sensor	Overlap	n° of Images
Land Management	**DTM**	**4 cm**	**UX5**	**70/70**	**4106**

Map wide-scale areas of vegetation across both swampy and land terrain. While the processing was completed in UASMaster and leverage eCognition, the same adjustments can be performed in TBC's Aerial Photogrammetry workflows.

Learn more about the project here and well as the story on YouTube and background information.



DTM-BASED ORTHOMOSAIC FOR WETLAND MAPPING IN LOUISIANA, UNITED STATES, AT 3-5 CM PIXEL RESOLUTION

For more information…

- View the in-product and context-sensitive TBC Help via clicking the F1 key or the icon at the top right within TBC
- Complete the TBC Aerial Photogrammetry eLearning Lesson Plan on learn.trimble.com (free Trimble ID required to sign-in).
- Download, review, and complete the TBC Aerial Photogrammetry tutorials in the *Working with aerial photogrammetry* section.
- Watch and review the TBC Survey and Construction Aerial Photogrammetry Youtube playlist videos
- Contact your local Trimble Geospatial Distribution Partner