MODULE 7
ACQUISITION AND PROCESSING OF BASE DATA
GROUP ASSIGNMENT

BY: GROUP 6

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List of Contents

List of Figure

List of Table

1. **Introduction**
   a. Background
      This task is done for building the understanding of fundamental concept in base data acquisition using photogrammetry. Photogrammetry is an art and science of making 3D measurements from photographs, and in such it is one of the major map production processes. For producing the base map, it requires the good quality of the base data. One of the base data is orthophoto. This report consists of sequential process for producing the orthophoto, especially from the digital aerial photo.
   b. Objectives
      Objective of this task is generating a DSM (Digital Surface Model) and an orthophoto mosaic from aerial images. By doing this task, the following questions could be solved:
         i. Which parameter need to be used during the task
         ii. How to generate the orthophoto from digital aerial images
         iii. How to assess the quality for each of produced product
   c. Data input
      For this task, we use some input as follow:
         i. 6 Digital aerial photos in Enschede
         ii. Camera calibration report
         iii. GPS (Global Positioning System)/IMU (Inertial Measurement Unit) data for each of aerial image
         iv. Location of the GCPs (Ground Control Point)

2. **Method**
   The workflow for generating the orthophoto can be seen in Figure 1. This workflow has been done using ERDAS Imagine 2016 software which provides bundle block adjustment function. The detailed parameter setting in this report mainly shown based on the software.

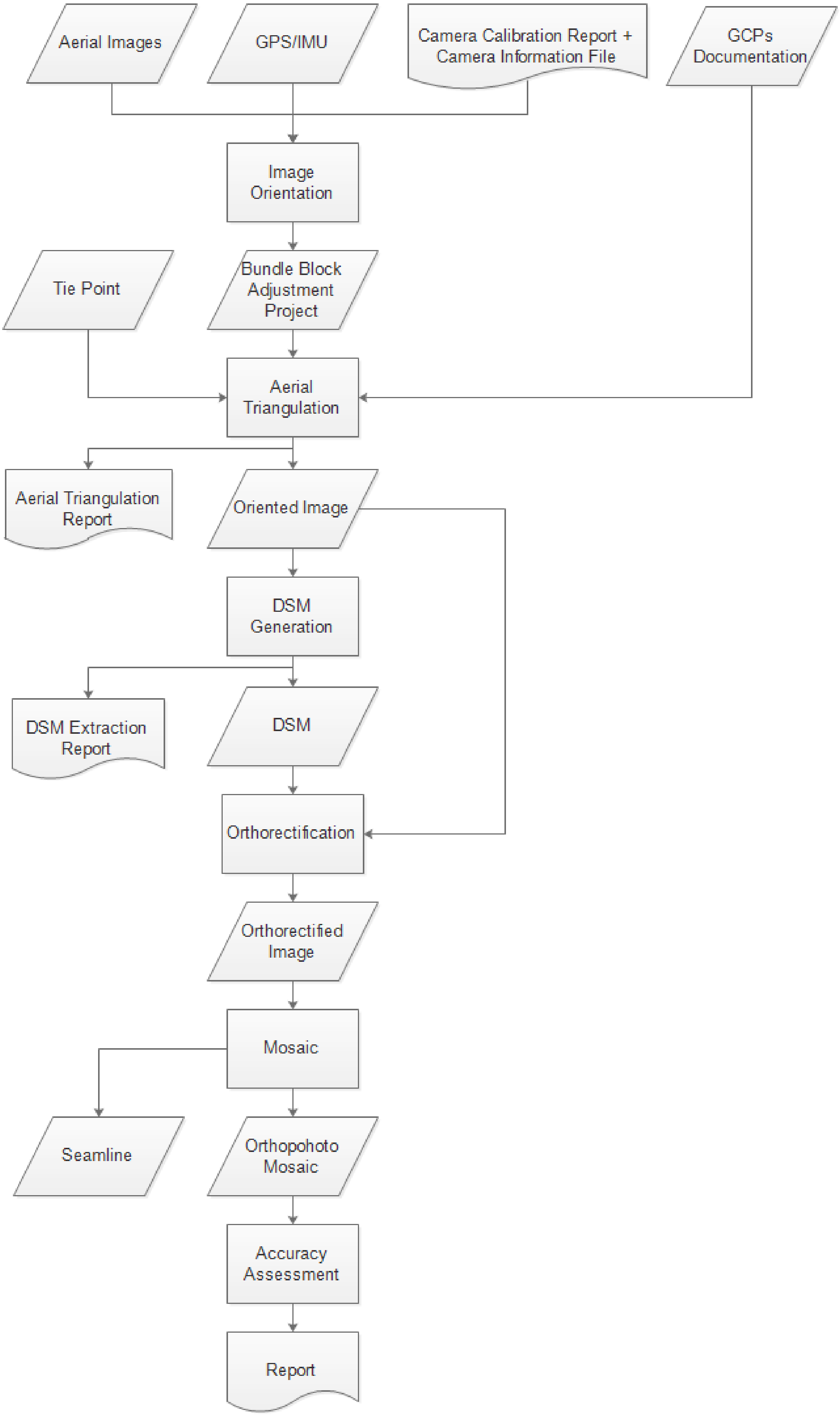


Figure 1 Workflow for orthophoto generation

The detailed process for each step explain as follow:

a. Project Setup

After inspecting the input data given, we can conclude that the images are coming from the digital aerial photo. We set up the photogrammetric project by the following steps.

Step 1. Create a block project

The photogrammetric workflow was done using Leica Photogrammetric Suite (LPS) under the toolbox IMAGINE Photogrammetry as seen Figure 2.

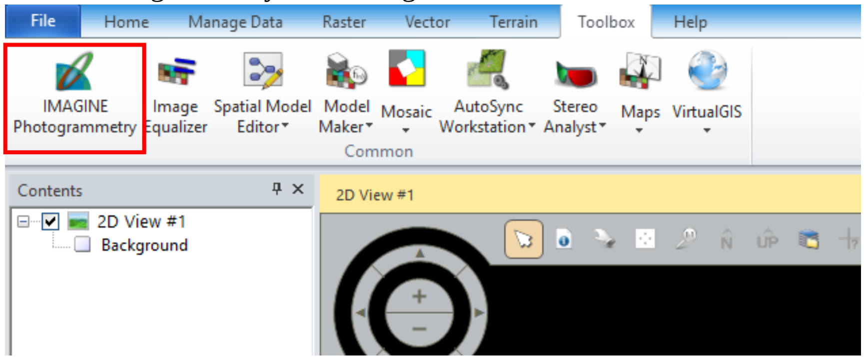


Figure 2 IMAGINE Photogrammetry function

We create a new project and name it as "GFM2_M7_2018_GR6-Enschede" in the project manager windows as shown in Figure 3.

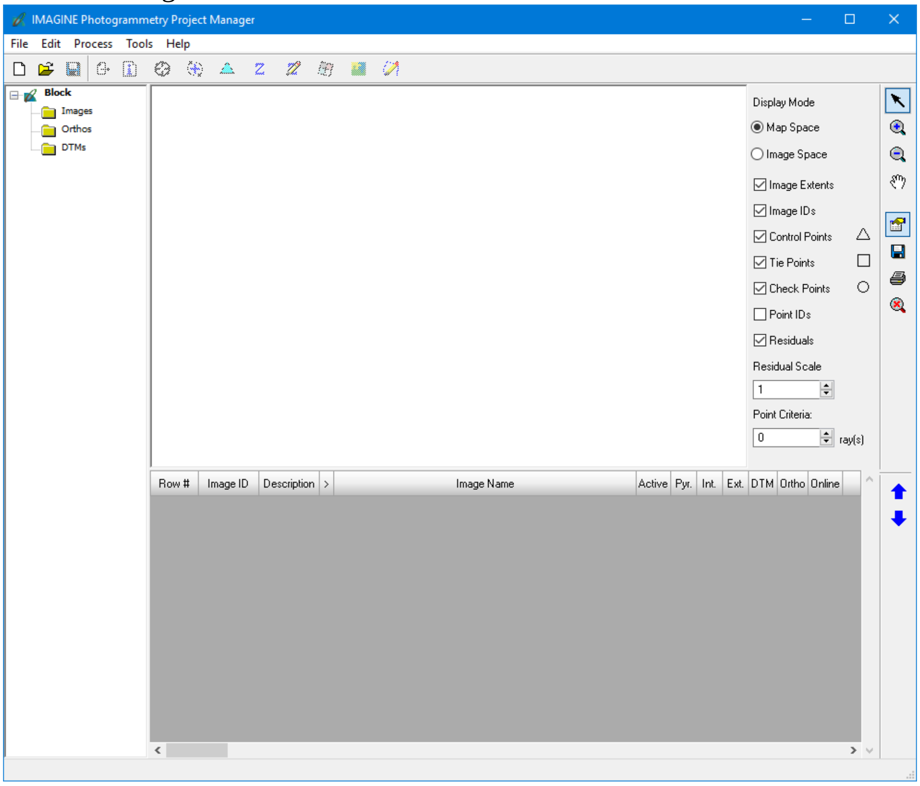


Figure 3 IMAGINE Photogrammetry project manager window

Step 2. Specify the geometric model

Because the images in the project are aerial images from a digital camera, the "Geometric Model Category" has been set to Digital Camera, as shown in Figure 4.

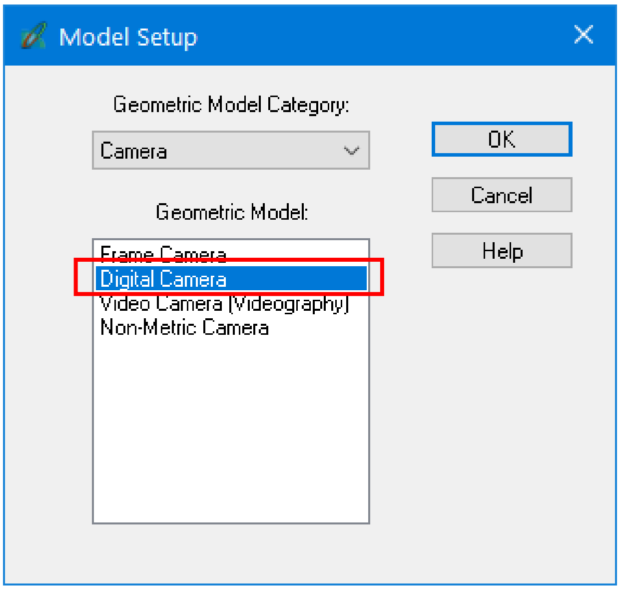


Figure 4 Photogrammetric block setting - Geometric model category

Step 3. Choose the coordinate system

Coordinate system for this task is RD New. Both horizontal and vertical coordinate systems are set up, as shown in Figure 5.

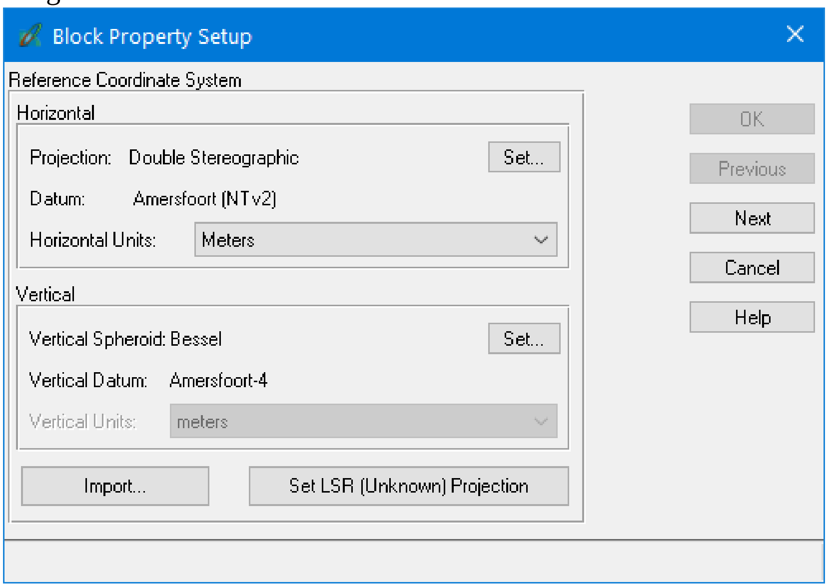


Figure 5 Photogrammetric block setting - Reference coordinate system

Step 4. Setting average height

The average flying height means the height of the camera on the airplane above the ground. The average flying height has been calculated by the following way. The average terrain altitude of the study area is known as 40m. According to the GPS/IMU data, which provides the position of the camera during the image acquisition, we can calculate the average height (Z value) is 1206.333m. This value is calculated from the 42 positions which are given in the "GFM2_M7_2015_Enschede.dat" file (the height information given in the 5th column). So, from this information we can calculate the average flying height:

$$
\begin{aligned}
&average\ flying\ height \\
&= average\ height\ of\ the\ known\ data\ points - mean\ terrain\ altitude \\
&= \frac{1}{42} * \sum_{i=1}^{42} (z_i) - 40
\end{aligned}
$$

$= 1166.333$ meters

This value is assigned to the project file as Figure 6.

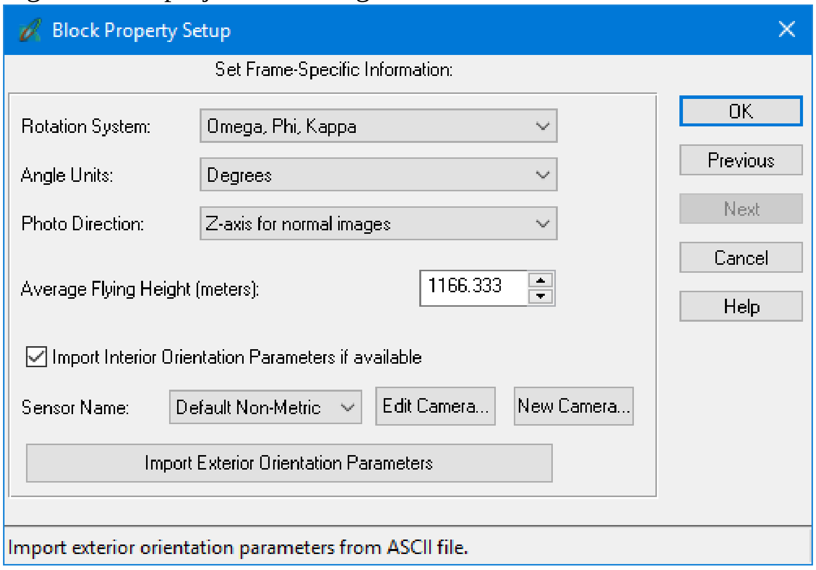


Figure 6 Photogrammetric block setting – Average flying height

Step 5. Import interior orientation parameter

The interior orientation (IO) parameter is given in the file "UCD_SU_1_0037.cam" which contains the focal length, the principal point position and other camera information. The IO parameter is imported to the project, by loading the file "UCD_SU_1_0037.cam". The camera information which already loaded shown in Figure 7.

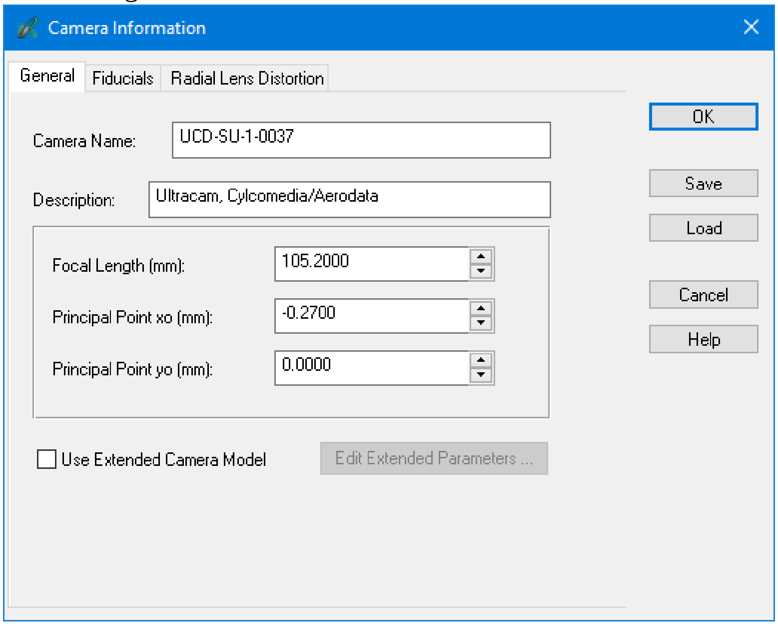


Figure 7 Camera information

Step 6. Import exterior orientation parameter

To obtain the exterior orientation (EO) parameter, GPS/IMU data (GFM2_M7_2015_Enschede.dat) is imported to the project. The correct format for importing the input data is needed, e.g., a proper separator, in this task using WhiteSpace. Settings in this step is shown in Figure 8.

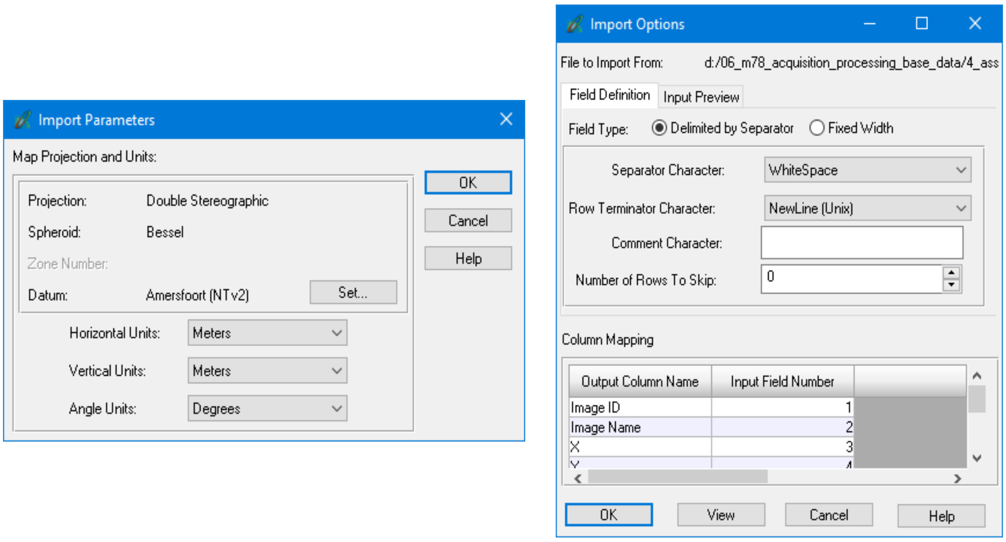


Figure 8 Import the exterior orientation parameter

Information for all images is shown in the project after importing finishing the step 6. But, only 6 images will be used for the task of the Group 6.

Step 7. Import the images

The following images are used for doing the task of Group 6:

1) 255845_472089_35
2) 255851_471285_35
3) 256145_472088_35
4) 256152_471281_35
5) 256444_472088_35
6) 256450_471275_35

Selecting and attaching the correct images will make images online and change the colour of labels ‘Pyr.’ and ‘Online’ in bottom window from red to green for corresponding images. The result of attaching 6 images is shown in Figure 9. After that, the other images are removed in the project.

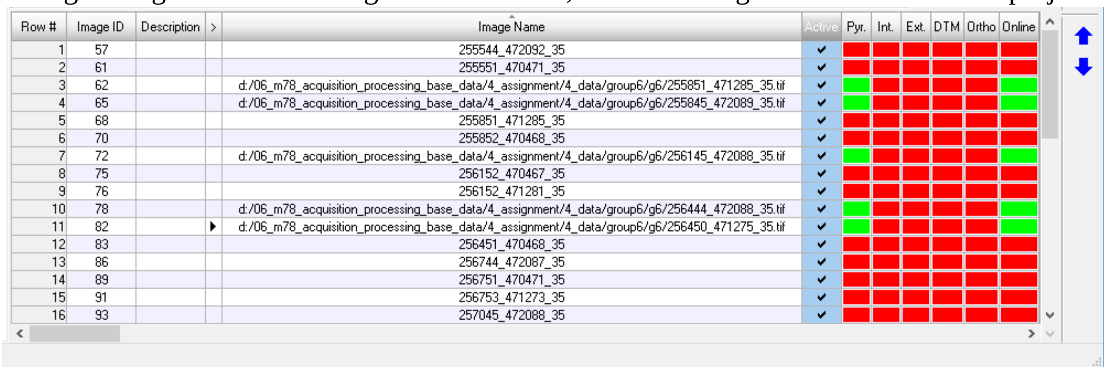


Figure 9 Attach images to the project

Step 8. Input the pixel size information

To complete the IO set up, we need to input the pixel inside the project as Figure 10. In this task, we use information from the camera calibration report, 9 microns, which is the pixel size of the panchromatic spectral. The IO parameter should be applied to all images.

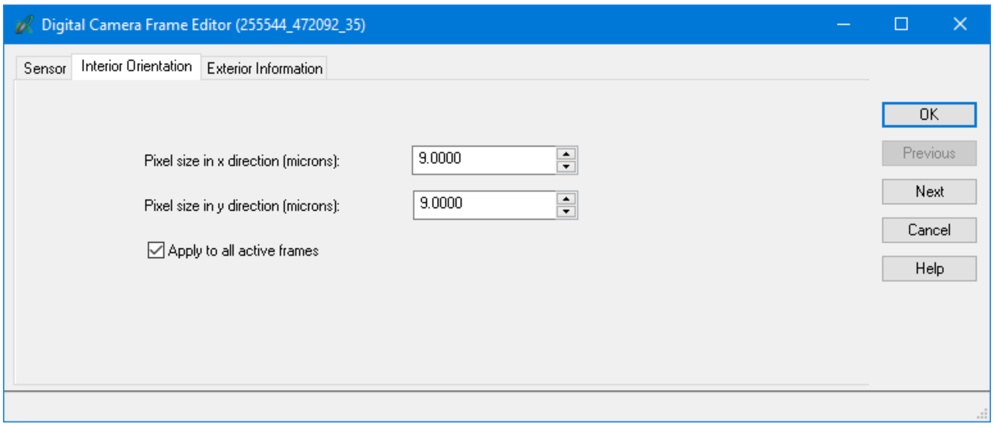
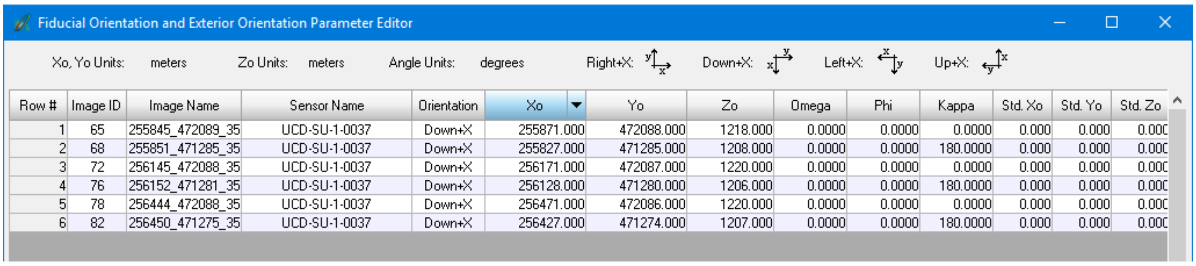


Figure 10 Pixel size of the images

Step 9. Check the project setup result

Result for setting the project can be seen in Figure 11. Make sure the orientation already set to Down+X.



Row #	Image ID	Image Name	Sensor Name	Orientation	Xo	Yo	Zo	Omega	Phi	Kappa	Std. Xo	Std. Yo	Std. Zo
1	65	255845_472089_35	UCD-SU-1-0037	Down+X	255871.000	472088.000	1218.000	0.0000	0.0000	0.0000	0.000	0.000	0.00C
2	68	255851_471285_35	UCD-SU-1-0037	Down+X	255827.000	471285.000	1208.000	0.0000	0.0000	180.0000	0.000	0.000	0.00C
3	72	256145_472088_35	UCD-SU-1-0037	Down+X	256171.000	472087.000	1220.000	0.0000	0.0000	0.0000	0.000	0.000	0.00C
4	76	256152_471281_35	UCD-SU-1-0037	Down+X	256128.000	471280.000	1206.000	0.0000	0.0000	180.0000	0.000	0.000	0.00C
5	78	256444_472088_35	UCD-SU-1-0037	Down+X	256471.000	472086.000	1220.000	0.0000	0.0000	0.0000	0.000	0.000	0.00C
6	82	256450_471275_35	UCD-SU-1-0037	Down+X	256427.000	471274.000	1207.000	0.0000	0.0000	180.0000	0.000	0.000	0.00C

Figure 11 Project setup result

b. Sensor Orientation

Sensor orientation use the aerial images, GPS/ IMU data and camera calibration file as input. An overview of the sensor orientation step can be seen in Figure 12.

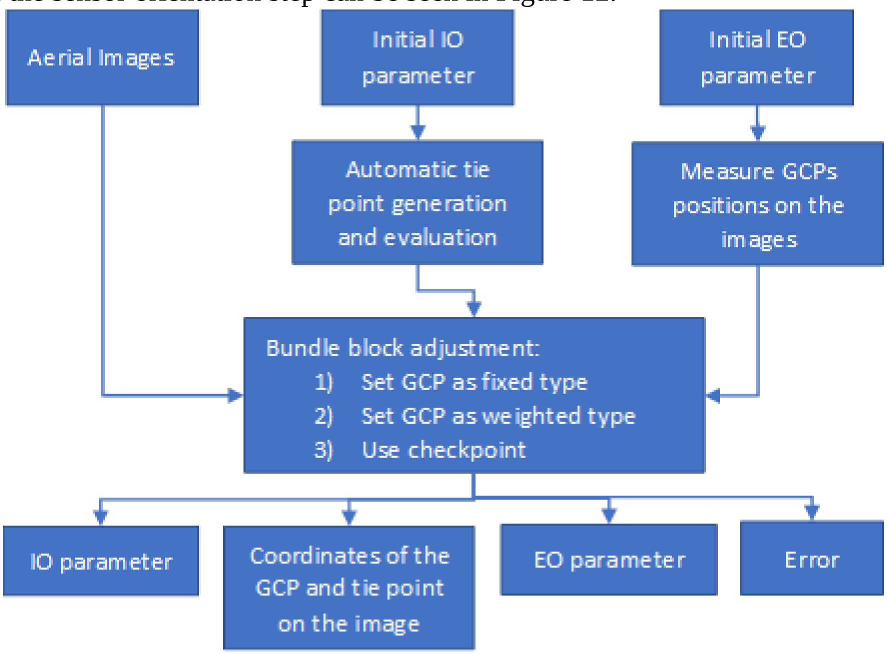


Figure 12 Overview of sensor orientation

Step by step processing as follow:

Step 1. Measure GCP positions on the image

Based on the GCP documentation file, the locations of GCPs (x_reference, y_reference, z_reference) on the ground is known. We import the GCP into the block by load the file

"GFM2_GA_GCPs_COORD.txt". From the 15 points which is found within the block, see Figure 13, some point considered to be the check point later.

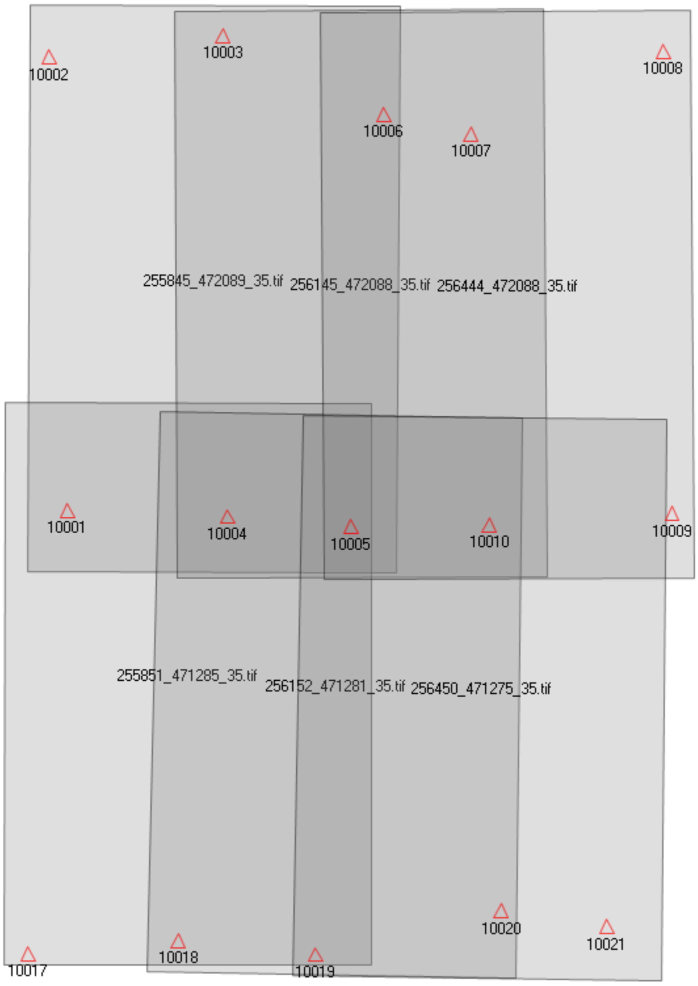


Figure 13 Position of the points on the block

After imported, we measure each GCP position in each of the image. If a GCP is in multiple images, then all its position in each image need to be measured, see Figure 14. The method of detecting the position of GCPs on image is visual identification. GCP documentation file provides the overview of position of each GCP in the image. By zooming in the images, we are able to find the location that is the same as the location in the picture. Then we measure the GCPs. After this step, each GCP has image coordinates in its relevant images, see Figure 16. These image coordinates will be useful in generating tie points.

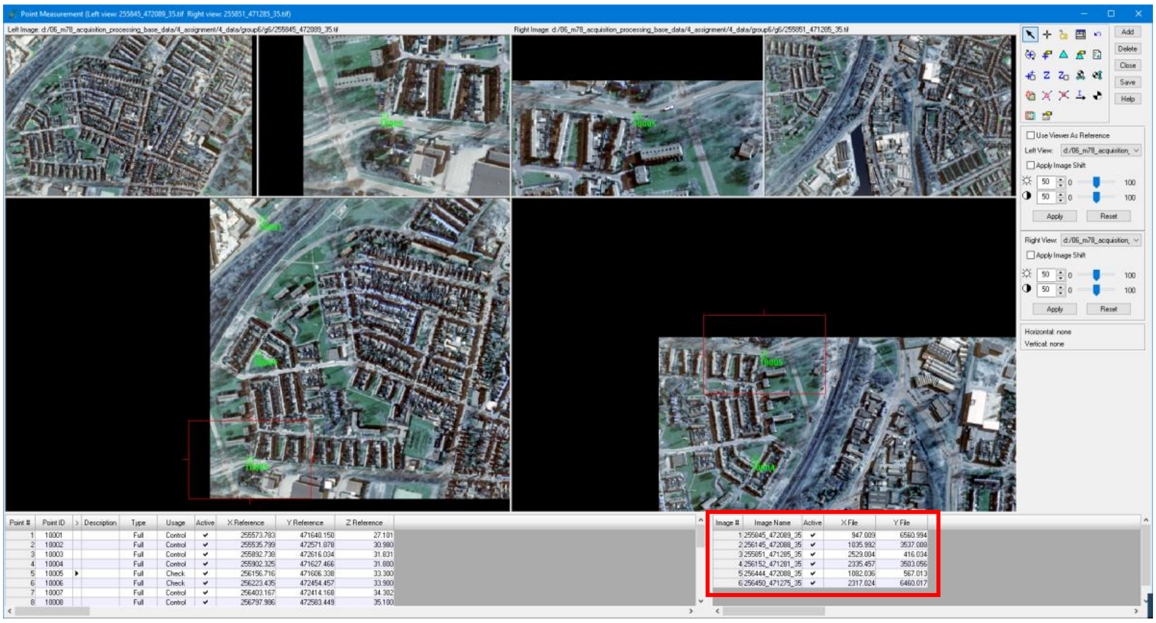


Figure 14 Point 10005 which is located in the 6 images

Step 2. Automatic tie point generation

After measuring all the GCPs in images, tie points can be generated by ERDAS automatically. Average point success rate is 100.00% and Average pattern success rate is 74.00%, shown in Figure 15. The threshold is 60%. So, it satisfies the requirement.

The Autotie Summary Report

Image ID	Number of Intended Points	Number of Points Found	Number of Patterns	Point Success Rate	Pattern Success Rate	Image Name
65	25	39	25	100.00%	60.00%	255845_472089_35
68	25	37	25	100.00%	64.00%	255851_471285_35
72	25	52	25	100.00%	88.00%	256145_472088_35
76	25	46	25	100.00%	100.00%	256152_471281_35
78	25	35	25	100.00%	64.00%	256444_472088_35
82	25	35	25	100.00%	68.00%	256450_471275_35

Average Point Success Rate: 100.00%
Average Pattern Success Rate: 74.00%
Total unique tie points found: 87

Figure 15 Tie point summary

Step 3. Bundle block adjustment

The initialization of EO parameters have been imported in the setup. The goal of bundle block adjustment is to find out the mathematical relationship between the images contained inside the project file. After the relationship between the image space and the terrain space found, we can measure the terrain coordinate from the images. (Intergraph, 2014)

Bundle block adjustment is divided into 2 sub-steps:

Sub-step 1) Set GCP as fixed, run triangulation

Sub-step 2) Set GCP as weighted, run triangulation

We accept the triangulation result based on 2 conditions when 1) the number of active GCPs that are used in the triangulation is higher and 2) total image unit-weight RMSE should be less than 0.35pixel. The parameter result will be accepted only when both criteria are satisfied. If RMSE is higher than 0.35pixel, then the problematic points need to be detected. The way of detection is using residual plot. The point with longest line of residual will be reviewed in the images. After inspection, if we are sure that this point is measured accurately in image, then we will keep it. If this point indeed doesn’t have a correct position in image, then we correct its position based on the GCP documentation file or we inactivated it. So, in the next run of triangulation, this point will be excluded from the calculation.

Sub-step1. Assume GCPs are fixed, run the triangulation.

This means that we assume the location of GCPs that we measured on images are considered as fixed. The overview of the sub-step 1 as Figure 16.

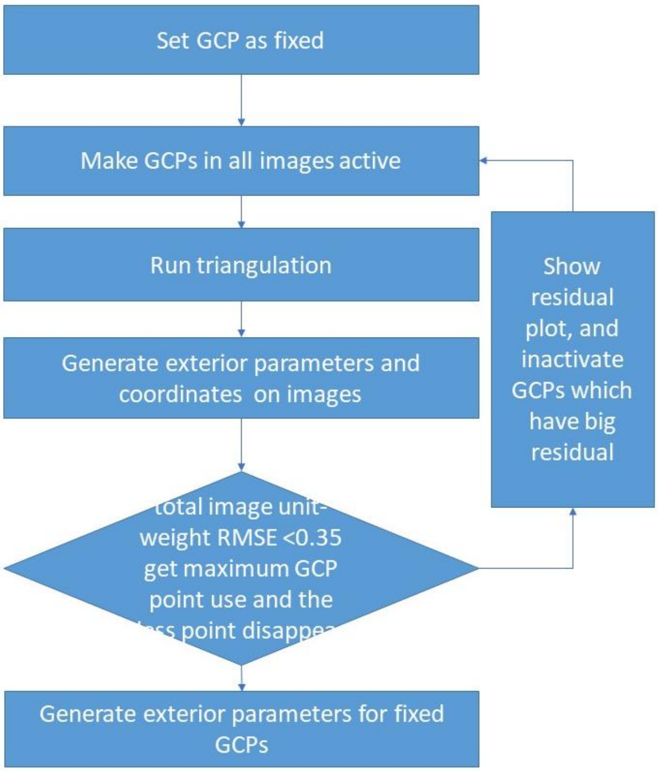


Figure 16 Sub-step 1 workflow

When setting the triangulation for fixed type of GCP, advanced robust checking is selected as the model of blunder checking. Because it is theoretically perfect. It uses a robust iterative weight function based on the redundancy of each observation. “A blunder is considered a gross error resulting from incorrect data entry or incorrect measurement of ground points on the imagery. If an erroneous point is detected by blunder checking, the software automatically omits it from calculations.”(Intergraph, 2014)

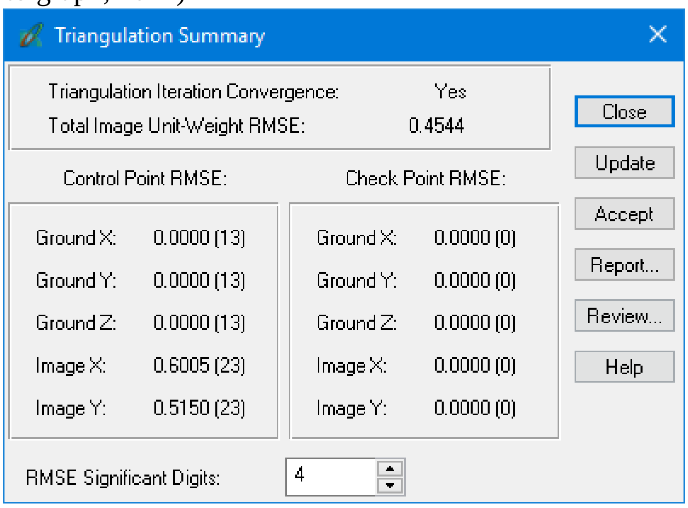


Figure 17 Triangulation summary for the fixed type of GCP

Figure 17 shows the first run of triangulation with fixed type of GCP setting. This summary shows that the triangulation iteration convergence has been reached. Total image unit-weight RMSE =

0.4544 which is larger than 0.35, so we review the report and show the residual plot to inspect which point contributes for the error.

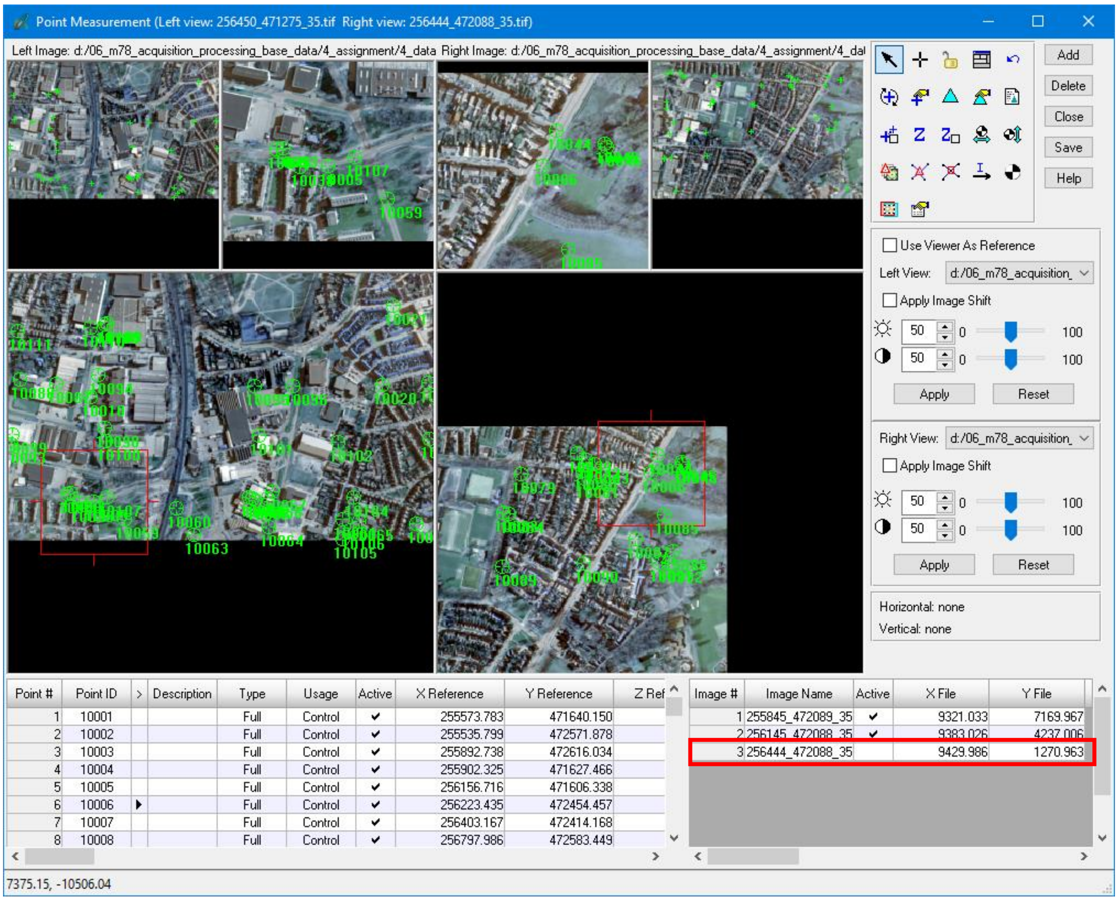


Figure 18 example of GCP which turn to not active after triangulation

Figure 18 show point 10008 as an example that some of the point are not active after triangulation. Because we need the GCP, we need to make sure that the all GCP is active for all images. So, this point will be included in the second run of triangulation with fixed type of GCP, the blunder points that contributes to the error assume coming from the tie points, not from the GCP, see Figure 19.

Point #	Point ID	>	Description	Type	Usage	Active	X Reference	Y Reference	Z
106	10106			None	Tie	✔	256070.188	470910.673	
107	10107			None	Tie	✔	256167.839	471570.176	
108	10108			None	Tie	✔	256636.990	471568.202	
109	10109			None	Tie	✔	256640.676	471564.253	
110	10110			None	Tie	✔	256627.585	471609.403	
111	10111			None	Tie				

Figure 19 example of inactive tie point after triangulation

Run the second triangulation with fixed type of GCP and the result shown in Figure 20. RMSE means the difference between calculated coordinates and the measured coordinates. No check points are involved in the triangulation, so RMSE of check point is all zero. Ground control point are set as fixed, so RMSE of control point in ground space are all zero. Total image unit-weight RMSE is better than the first run.

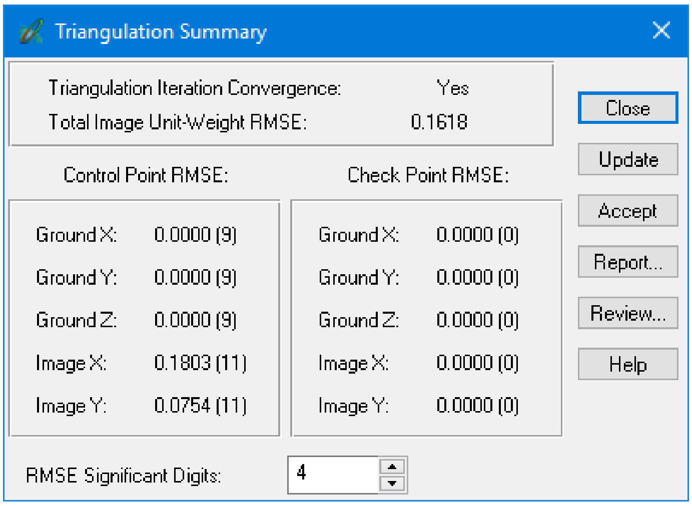


Figure 20 Final triangulation summary for the fixed type of GCP

After accepting the value, the position of the GCP as shown in Figure 21.

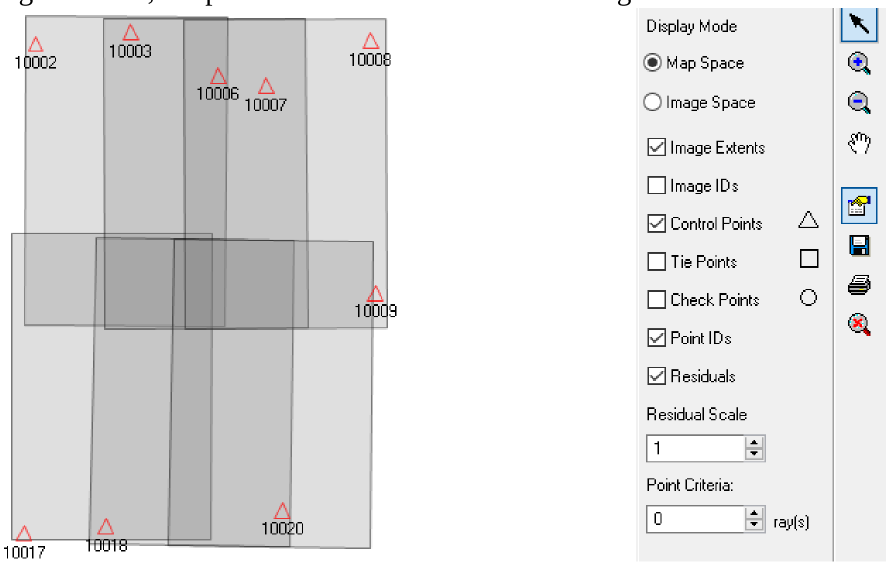


Figure 21 Final triangulation summary for the fixed type of GCP

Sub-step 2. Assume GCPs are weighted, run the triangulation.

The overview of sub-step 2 shown in Figure 22. We assume the location of GCPs that we measured on images are has some error which coming from the GPS measurement and represent by its standard deviation, see Figure 23. This assumption is more realistic than the assumption that "GCPs are fixed".

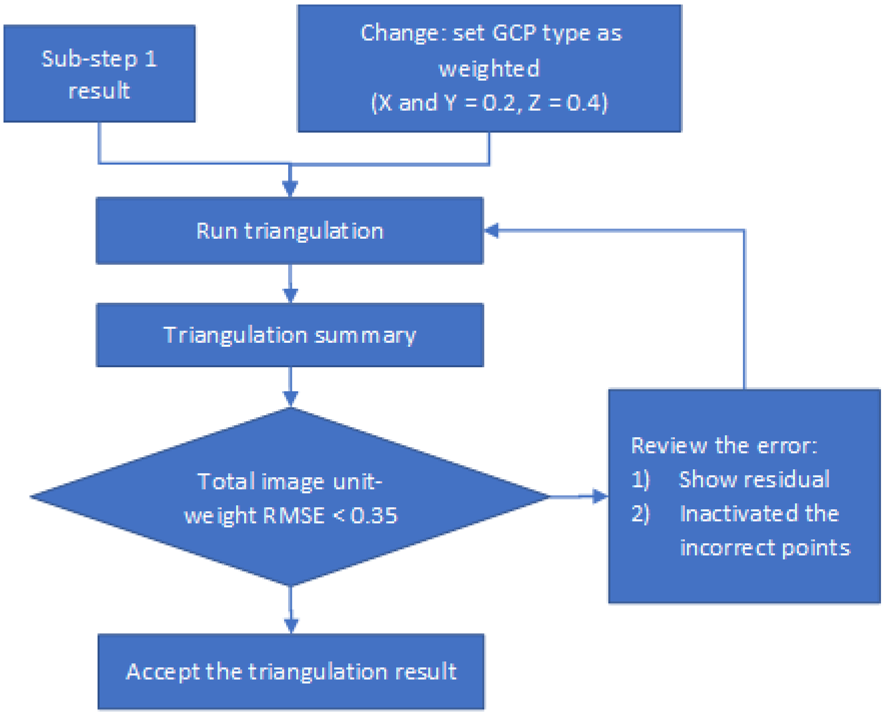


Figure 22 Sub-step 2 workflow

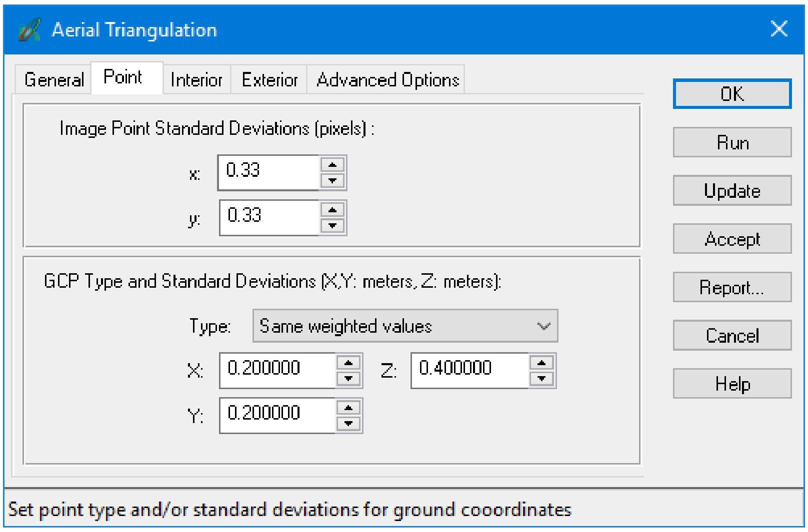


Figure 23 Setting for weighted type of GCP

For evaluating the ground RMSE, we can calculate theoretical ground point RMSE according to the data input.

<u>Theoretical estimation for ground point RMSE</u>

H = 1166.333 m ~ 1200 m
C = 105.20 mm ~ 105 mm
Pixel size = 9 micron
Image scale = 11104
Average base = 300.0874 ~ 300

Spx = 0.5 pix * cell size = 0.5 * 9 micron = 4.5 micron
Sx = 0.7 pix * cell size = 0.7 * 9 micron = 6.3 micron

Mb = H/ c = 1200 meter / 105 mm = 11428 ~ 11500
Sh = H/b * Mb * Spx = 1200 m / 300 m * 11500 * 4.5 microns = 0.207 m
Sx = Mb * Sx = 11500 * 6.3 micron = 0.072 m; Sy = Sx = 0.072 m

Figure 24 show triangulation summary with the total image unit-weight RMSE = 0.1412 < 0.35. so, this is acceptable. In the meanwhile, it has been noticed that 0.1412 < 0.1618 (total RMSE of fixed GCP). The ground RMSE for X = 0.0254 < Sx, for Y = 0.0435 < Sy. For Z = 0.0684 < 0.207. All of them are comply with the targeted RMSE from Theoretical estimation for ground point RMSE.

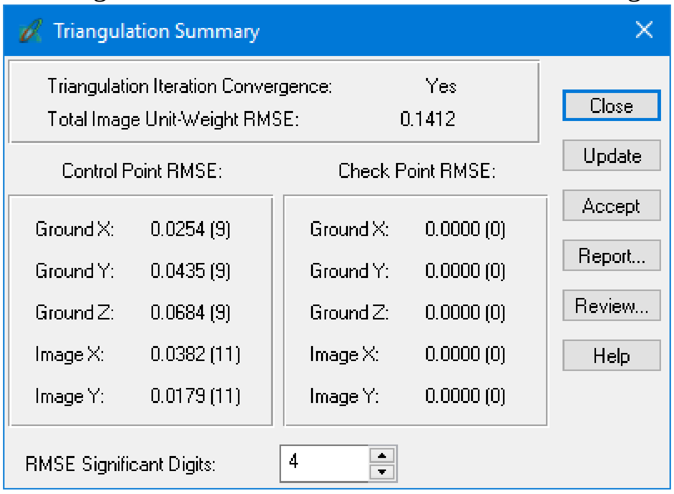


Figure 24 Triangulation summary for weighted value of GCP

Step3. Assigning the check points

Check points are used for evaluating the accuracy of the triangulation. Therefore, check points are not needed to calculate the parameters (to perform the triangulation). The workflow for this step as Figure 25.

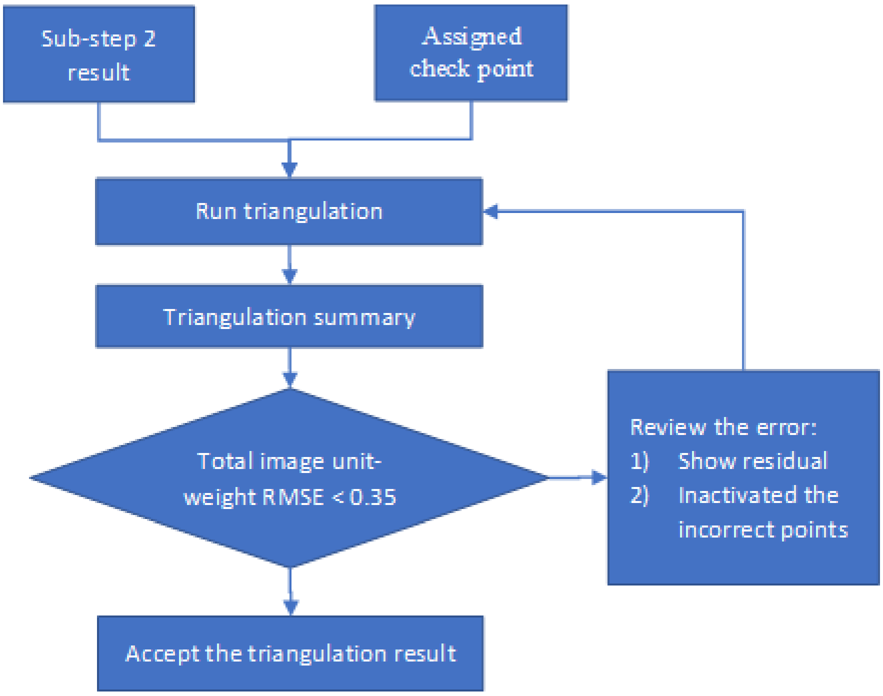


Figure 25 Sub-step3 workflow

The check points that we chose are point 10003, point 10007, and point 10018. Check point should be surrounded by GCPs (inside the blocks area). Because it is meaningless to check the accuracy in the area out of the GCPs. Therefore, we choose points 10003, 10007, and 10018 as check point. Point 10020 should have been a check point. However, the control point 10021 has a relatively low accuracy (omitted during the blunder checking). So, we didn't change the point 10020 to check point. See Figure 26 for final point distribution.

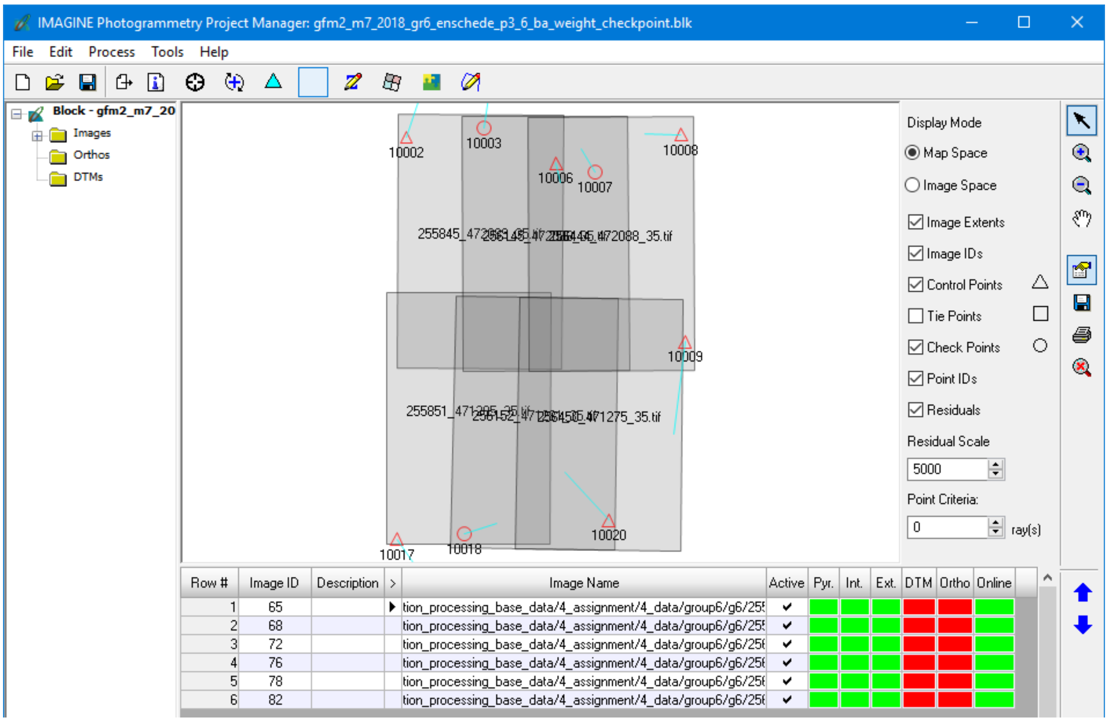


Figure 26 Distribution of GCP and check point

c. DSM generation

This step using eATE in ERDAS Imaging Photogrammetry to automatically extract DSM after the block adjustment process. Terrain Model refinement option allows us to filter out individual points, smooth the process, or specify special algorithms in specific areas that are needed. We can get expected product as point cloud format and accuracy evaluation report automatically. For generating high-resolution surface information from stereo imagery, our input images were orientated in earlier step of Image Orientation.

Step 1. Open the project file

We active render raster function to get an impression about the area need to be dealing with, the input images were orientated, showed in Figure 27.

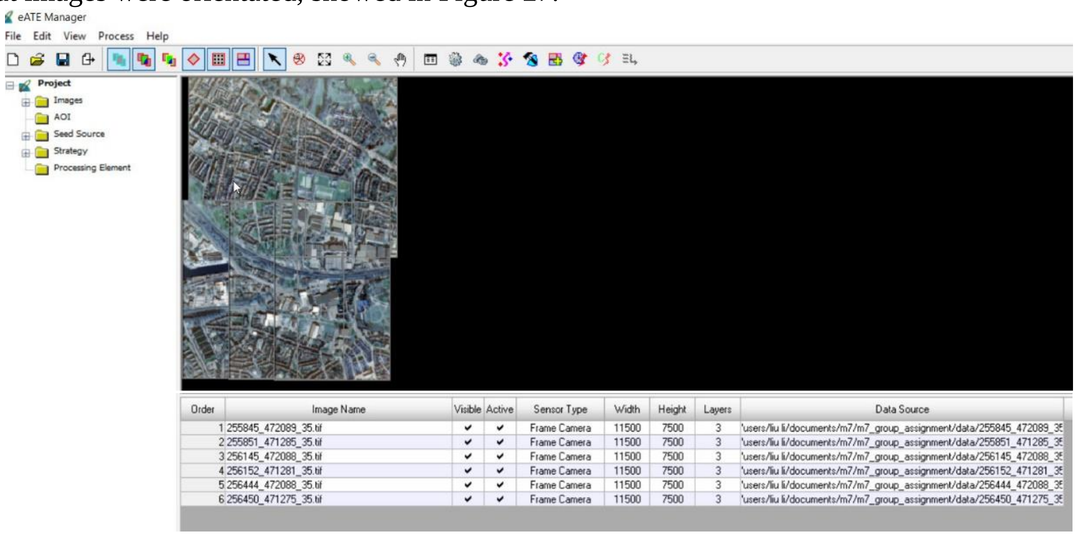


Figure 27 Oriented images as input

Step 2. Setting the output

From the range that was given for the DSM cell size (5-10 m), we chose 5 m as cell size for the following contour map and orthophoto generation because with 5m GSD so that we can get details as much as possible. The smaller the sampling interval the higher the accuracy of the DSM, as Figure 28 shows cell size parameter setting.

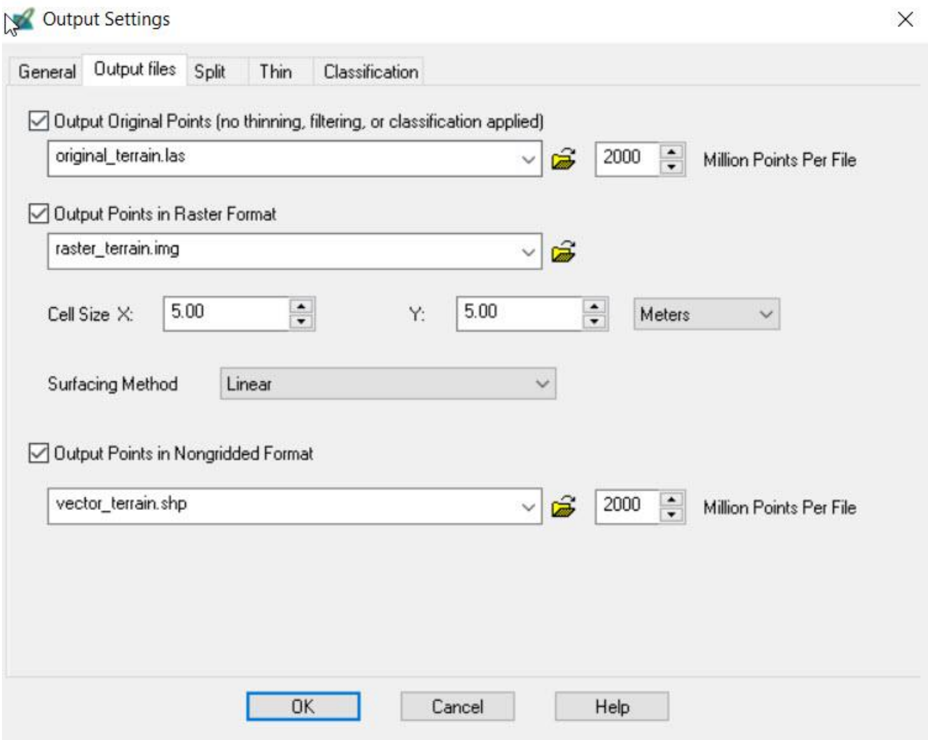


Figure 28 Cell size setting

Step 3. Setting the pyramid level
We set the pyramids level parameters of 0. Interpolate uncorrelated points is spike. Spike points are removed from smooth surface and their elevations are calculated based on lower level of pyramid. The lower pyramid, the better result but takes longer time, as Figure 29 shows pyramid parameter setting.

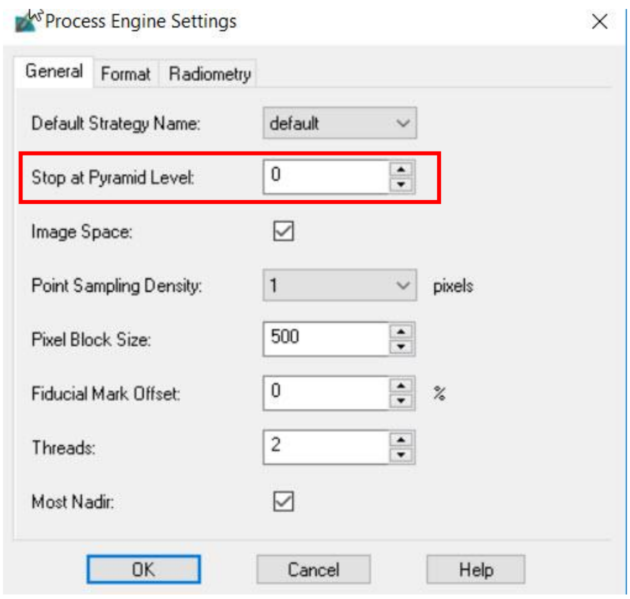


Figure 29 Pyramid level setting

Step 4. Run the DSM generation
After parameters setting, we generate DSM. It took us approximately about 6 hours to finish this program. Then we view our DSM product in ERDAS with 2D and 3D view, and DSM extraction report for each pair of images. We use allowed DSM error as DSM accuracy assessment indicator. To calculate the allowed DSM error as below：

OPSG (GSD of the orthophoto) defined using 20 cm cell size = 0.20 meter
Good pixel size for viewing with unaided eyes: o = 80 micron

Factor scale of the orthophoto result = OPSG / 80 mikron = 0.20 meter / 80 mikron = 2500

Maximum error in orthophoto (dr_{max}) = 0.5 mm * 2500 = 1250 mm = 1.25 meter

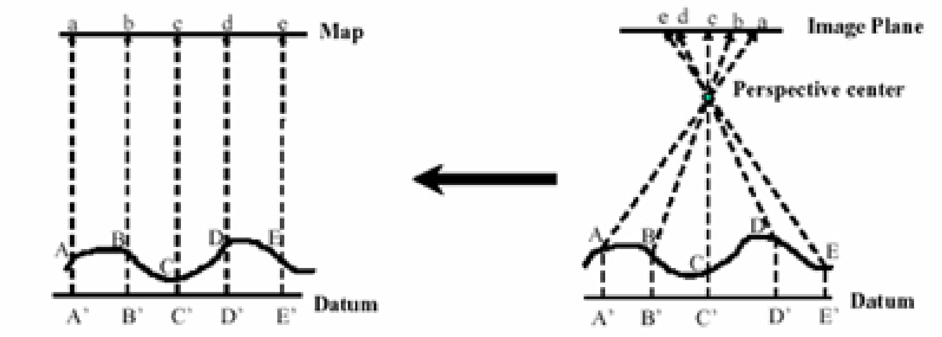
Tan α= r / c = 51.75 mm / 105.2 mm = 0.491 ~ 0.5

Maximum error in DSM (dh) < dr_{max} / tan α = 1.25 meter / 0.5 = 2.5 meter

This value then compares with the DSM accuracy from the DSM extraction report file to assess the quality of the DSM.

d. Orthorectification and Mosaic

After generating the DSM, the next step is producing orthophoto by orthorectification process. Orthorectification corrects the effect of sensor tilt and relief displacement, especially for the high object above the terrain. Figure 30 shown the transformation from the perspective view to the orthogonal view (Dr. F. I. Okeke, 2010)



- Orthogonal Projection
- Uniform scale
- No relief displacement

- Perspective projection
- Non-uniform scale
- Relief displacement

Figure 30 Transformation during orthorectification process

i. Orthophoto

Backward Projection is used for generating the orthophoto by projecting back the pixel in the output image to the input image. The input image is the image from sensor orientation result and the output is 6 orthophoto.

Step 1. Defining Orthophoto Properties

- Define cell size for the orthophoto (OPSG) in this task is 20 cm, which is 2 times larger than the GSD original aerial images (10cm) as shown in Figure 31.
- The rule of thumb that need to be considered for defining the pixel size of the orthophoto is the pixel size in units on the ground should be smaller than smallest object of interest and cannot smaller than the original GSD (original GSD = 0.1 m)

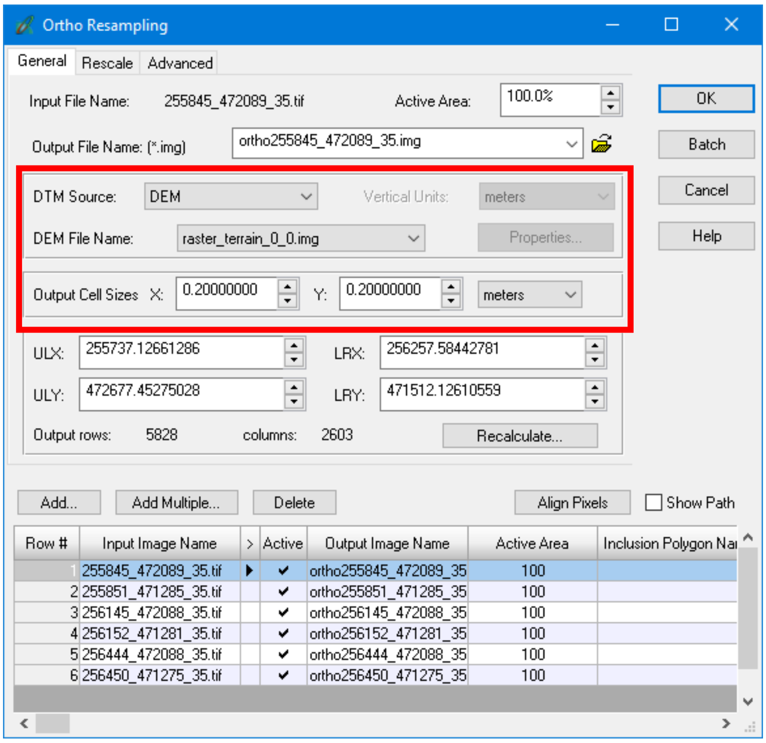


Figure 31 Orthorectification setting window

Step 2. DSM Interpolation

After specifying the output cell size, the height will be interpolated using the elevation model. In this task, we use DSM by specifying the source of DSM file as shown in Figure 31.

Step 3. Image Interpolation

For resampling method, we choose the bilinear interpolation, as shown in Figure 32, because it is moderate method instead of the nearest neighbour and the cubic convolution. Also, for further use, this orthophoto will be used as the base data for mapping, so we need to provide good visualisation for interpretation purpose. Bilinear interpolation taking account its 4-neighbourhood pixel for calculation.

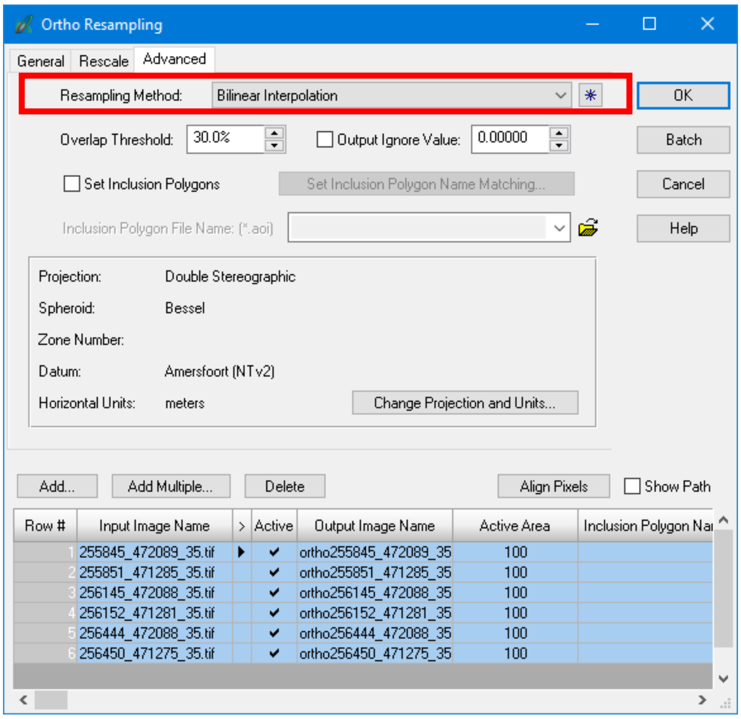


Figure 32 Image interpolation setting

Image distortion in orthophoto result consist of:

a. Radiometric Distortion

Radiometric problem will affect the image visualisation, for example poor contrast, deficient brightness, hot spot effect, different brightness, different shadow. This distortion comes from the different time of capturing the images.

b. Geometric Distortion

i. Relief displacement

Relief displacement is the displacement of the position of the object on the images because of its height above the ground, for example very high building. This distortion effect is radial with respect to the nadir point.

ii. Double mapping effect

It is happened because of the obscured area. But this effect is solved by construct Z-buffer image that will leave the occluded area empty.

iii. Effect of the single value that can be stored by the DSM

iv. Effect of the DSM in the terrain

This effect can be estimated as follow:

Table 1 Effect of DSM in the terrain

dr_{max}	:	0.5mm (estimation)
Orthophoto scale	:	2500
dr_{max} in the terrain	:	0.5 mm x 2500 = 1250 m = 1.25m

This error can be visualised by displaying the stereo pair of orthophoto images.

ii. Mosaic

Result from the orthorectification process is single image that in orthogonal view. To produce one orthophoto which cover the whole area, we need to mosaic the orthophoto. Based on the exercise, the best appearance result for generating mosaic is combination of this setting:

Step 1. Set the elevation source

For processing the mosaic, we use the raster file of the DSM with cell size 5x5 m as Figure 33.

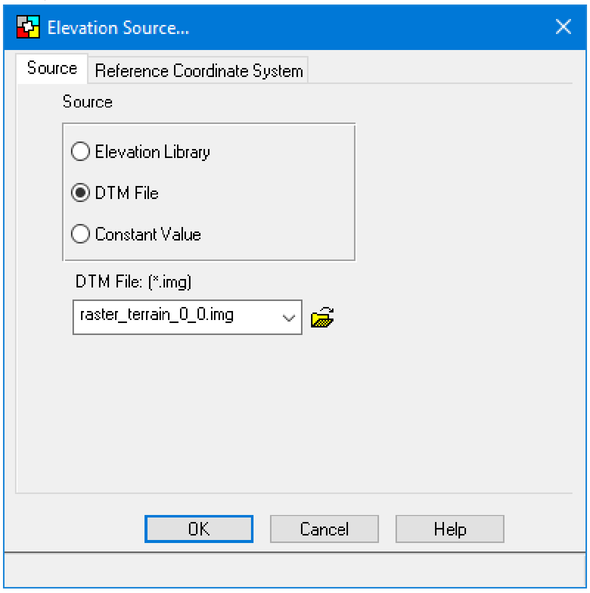


Figure 33 Set the elevation source

Step 2. Determine the cell size of the orthophoto

Cell size for the output is determined using 20 cm cell size as Figure 34.

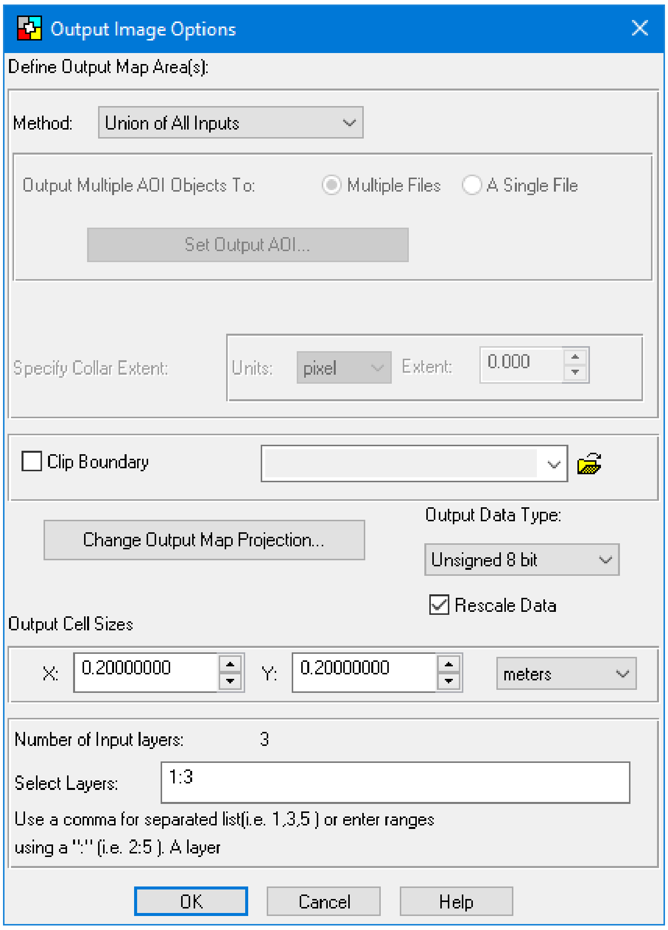


Figure 34 Set the elevation source

Step 3. Seamline generation

The seamline or cutline is the line that is used for separating between two images as the footprint to define which raster in the mosaic will be used in the mosaic. The seamline automatically generated for the block using "most nadir seamline" setting, see Figure 35. "The most nadir seamline will be generated in the area where the images overlap and where the pixel's off-nadir angle to either image is the same." (ERDAS IMAGINE, n.d.-b)

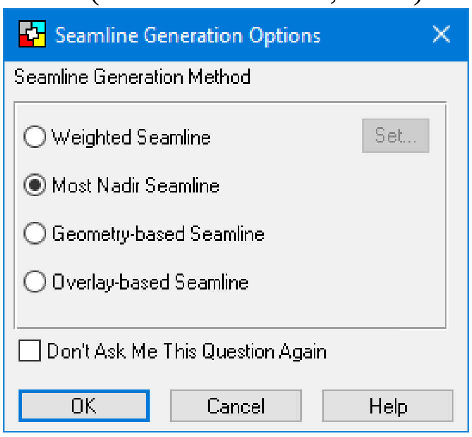


Figure 35 Seamline option setting

For softening the cutline (adjust the radiometry) along the cutline, we use feathering setting, see Figure 36. This setting will locally soften the transition between 2 different images along the seamline in radius as specified.

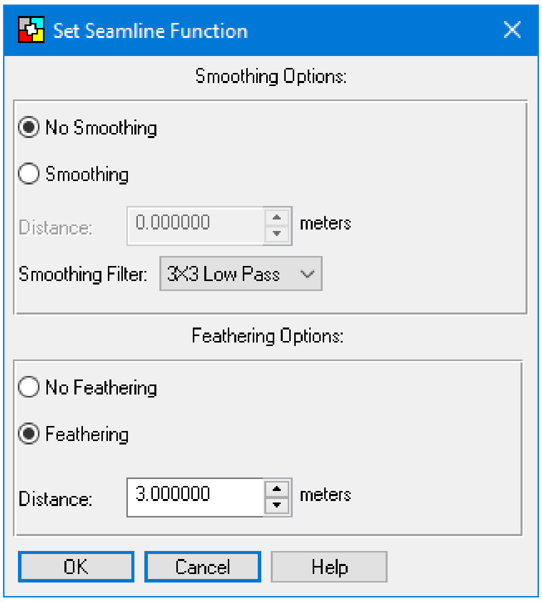


Figure 36 Feathering setting

Step 4. Colour correction

Colour correction do the radiometric adjustment in order to make the mosaic result good to visualise. The adjustment is applied for all the images (whole block). We use image dodging for adjusting the radiometric of the mosaic as shown in Figure 37.

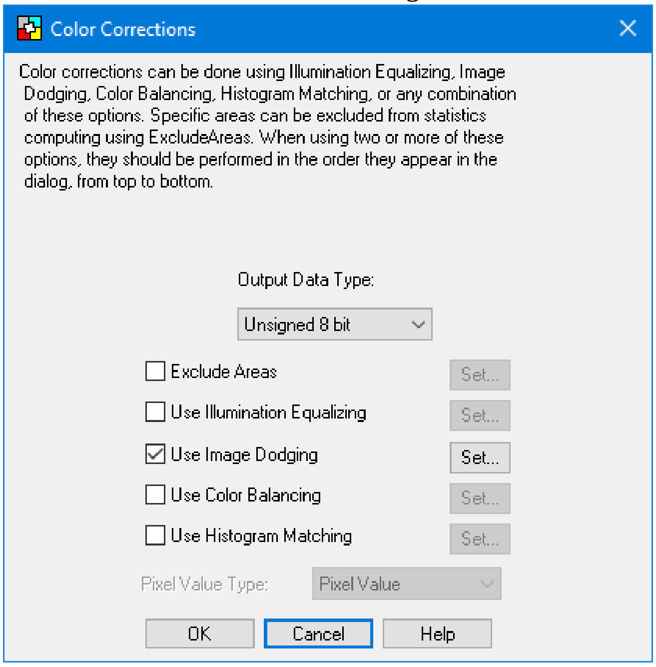


Figure 37 Feathering setting

Step 4. Run the mosaic

iii. Quality Assessment

The assessment including:

a) Radiometric quality

Check for the radiometric adjustment result of the mosaic by visually examined the image of mosaic result.

b) Geometric quality

Check for the planimetric accuracy using check point. In this task, we use 3 points: 10003, 10007, 10018. We compare the ground coordinate from the GPS measurement and from the image measurement using orthophoto mosaic.

3. Result and Discussion

a. Sensor Orientation

Result from the sensor orientation process shown in triangulation summary as Figure 38.

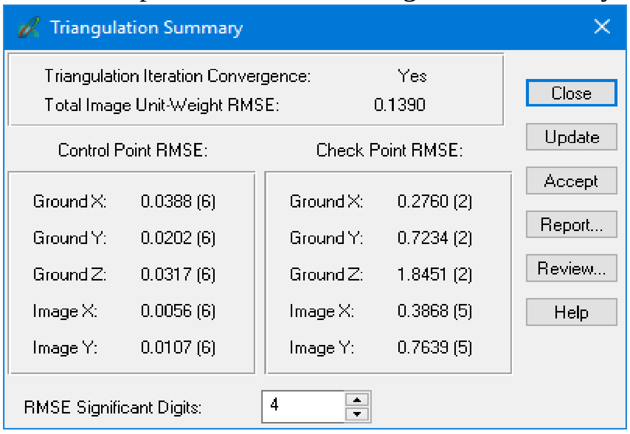


Figure 38 Final aerial triangulation summary

Comparison with the calculated RMSE as describe in Table 2.

Table 2 RMSE comparison from triangulation report

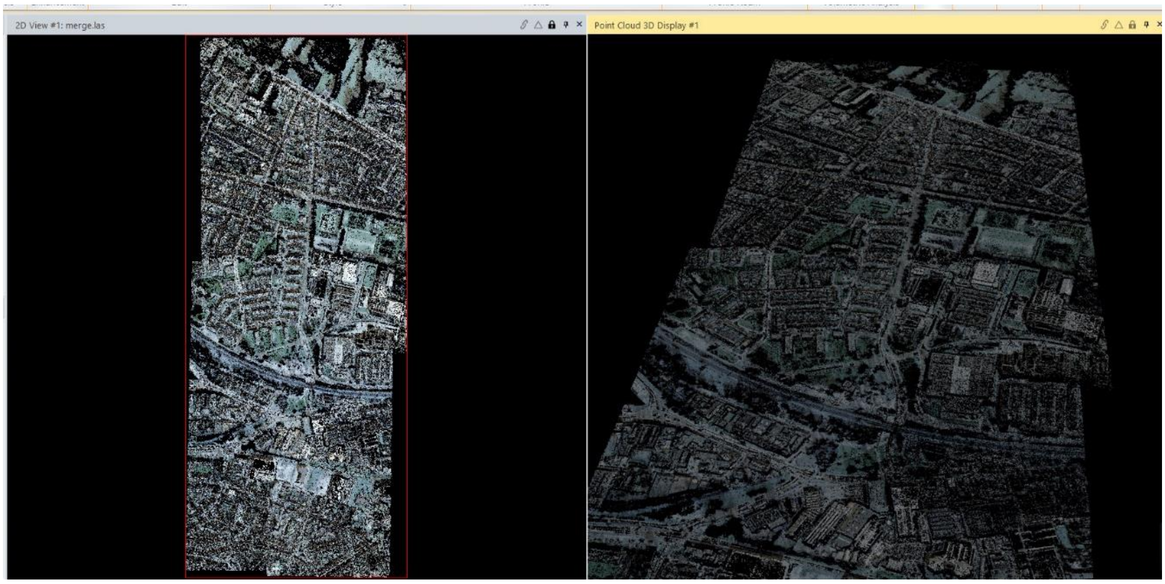
Control Point RMSE	Triangulation result	Estimated/ Calculated
Ground X (m)	0.0388	0.072
Ground Y (m)	0.0202	0.072
Ground Z (m)	0.0317	0.207
Image X	0.0056	0.35
Image Y	0.0107	0.35
Total image unit - weighted	0.1390	0.35

The error in ground coordinate shows the differences between measured ground coordinates in field and calculated ground coordinates in from the block adjustment. The ground error in this step derived from the GPS measurement in the field, GCP measurement in the image which is using visual identification, and from the triangulation process. Visual identification will depend on the human capacity (how well they recognise the object in image, the ability of human eye for detecting the same object between 2 images) and the instrument that is used to show the image (how well is the images displayed).

The error in image coordinate coming from the triangulation process which also influenced by the acquisition process and sensor that is used.

b. DSM Generation

DSM product with 2D and 3D view in ERDAS showed in Figure 39. From the *.las file, we can see that some area is blank (no point) generated. This area will be interpolated in the raster file using the nearest point from the surrounding.



(a)

(b)

Figure 39 a. DSM product *.las file in 2D view (left) and 3D view (right) b. DSM raster

Example of DSM extraction report showed in Figure 40. This result shows us that 90 percent of the position in the dataset will have an error with respect to the true height that is equal to or smaller than 0.527 m.

Output surface

Minimum Z	Average Z	Maximum Z	Std deviation	RMSE	Mean error	LE90
-15.088	35.193	90.210	0.314	0.320	-0.062	0.527

Output points	Matched points	Time	Points per second	Total time
13519320	48759495	01:03:09	12869	01:29:12

Matching output quality

Excellent	92.882
Good	7.118
Fair	0.000
Isolated	0.000
Interpolated	0.000

Figure 40 DSM extraction report of pair 256145_472088_35 and 256444_472088_35

Accuracy comparison of 4 pairs DSM generated from the block is shown in Table 3. The maximum accuracy allowed is 2.5 m based on the calculation.

Table 3 DSM accuracy from DSM extraction report

Image Pairs	Generated Accuracy (m)
255845_472089_35 and 256145_472088_35	0.373
255851_471285_35 and 256152_471281_35	0.199
256145_472088_35 and 256444_472088_35	0.527
256152_471281_35 and 256450_471275_35	0.317

From table above, we can conclude that the accuracy of all generated DSM is comply the requirement to generate the orthophoto with cell size 20cm.

Contour map with 2 m intervals are shown in figure 6. From DSM report, the LE90 for Z value is about 0.5m. Based on the rule: To obtain contours meeting the "90% criterion", the RMSE of the DTM should not be larger than 1/3rd of the contour interval and preferably as small as 1/5th of the contour interval. 2m interval contour line shows in Figure 41 and Figure 42.

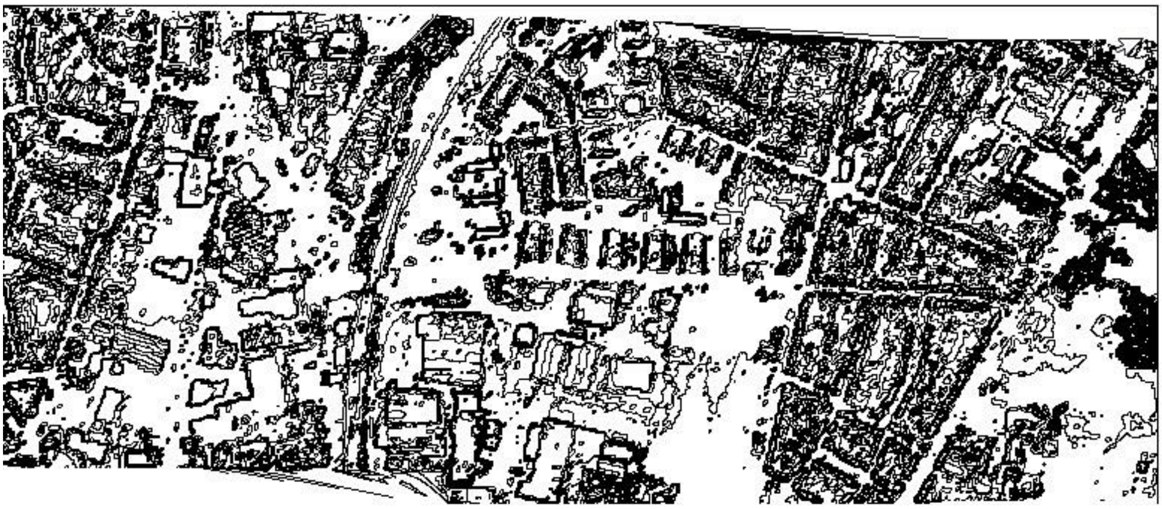


Figure 41 Contour line map (overview)

Figure 42 Contour line map (detail)

Accuracy for the DSM can be calculated using the check point as shown in Table 4.

Table 4 DSM Accuracy using check point

Points	Z value from field measurement	Z value from the DSM raster	dZ^2
10003	31.83136	29.840856	3.962110155
10007	34.30217	32.221859	4.327702178
10018	31.72377	30.367773	1.838730576

Sum = 10.12854291

Average = 3.37618097

RMSEz = 1.837438698

Accuracy (1.960*RMSEz) = 3.180238899

This is more than the allowed error in the DSM using the 20 cm cell size for the orthophoto which is 2.5 m.

c. Orthorectification and Mosaic

Figure 43 shows the result of orthorectification for the 6 images and Figure 44 shows the result of the mosaic.

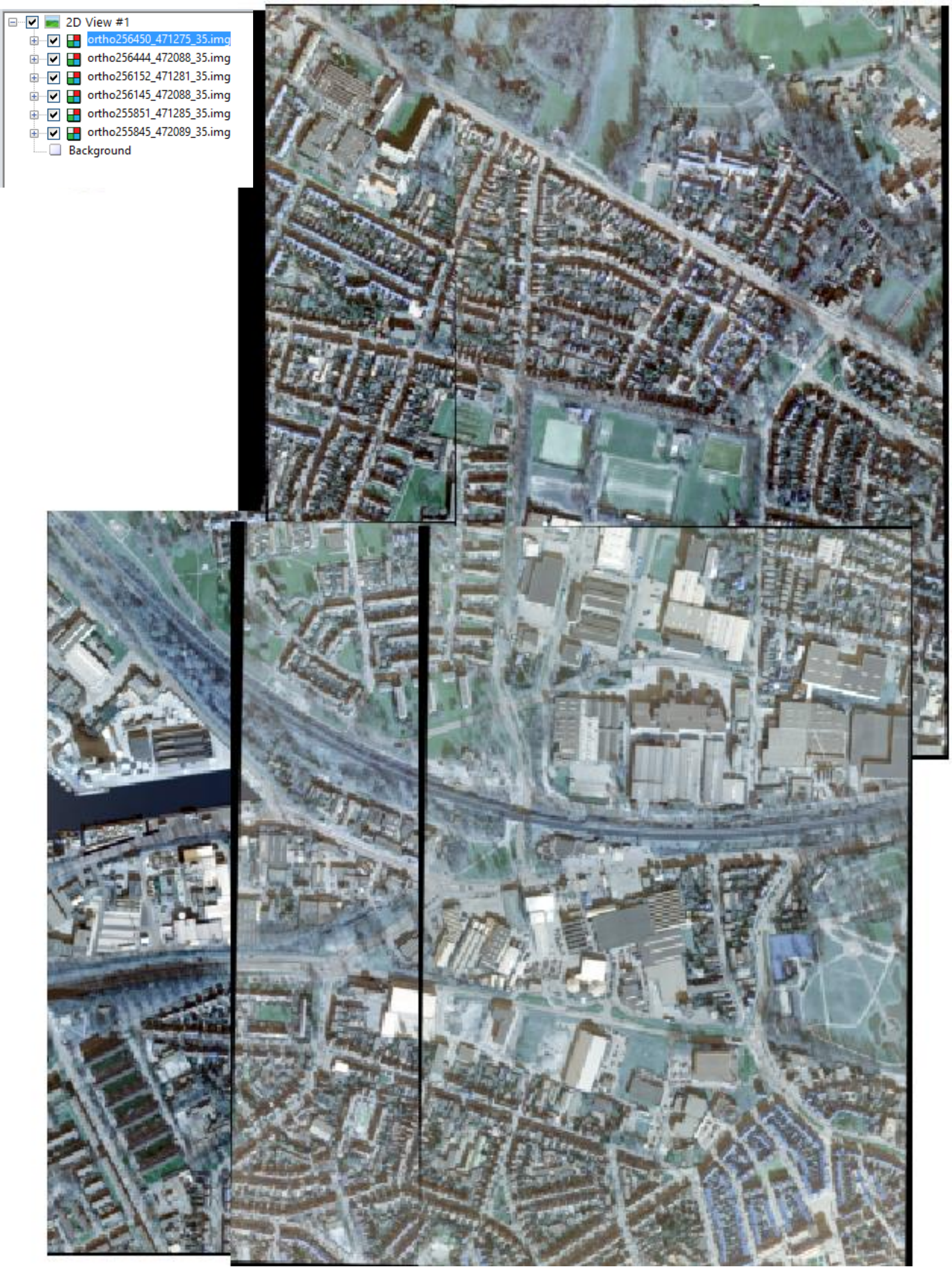


Figure 43 Orthorectification result

Figure 44 Orthophoto mosaic result

d. Quality Assessment for Orthophoto and Mosaic

Image distortion effect on the images:

a. Radiometric Distortion

After looking at the orthophoto result, there are radiometric problem (different contrast and brightness) can be seen between the images because of the different exposure. We can see clearly the border of the image as Figure 45.

Figure 45 Radiometric problem between 2 images before mosaic

This effect is removed after the mosaic step as shown in Figure 46.

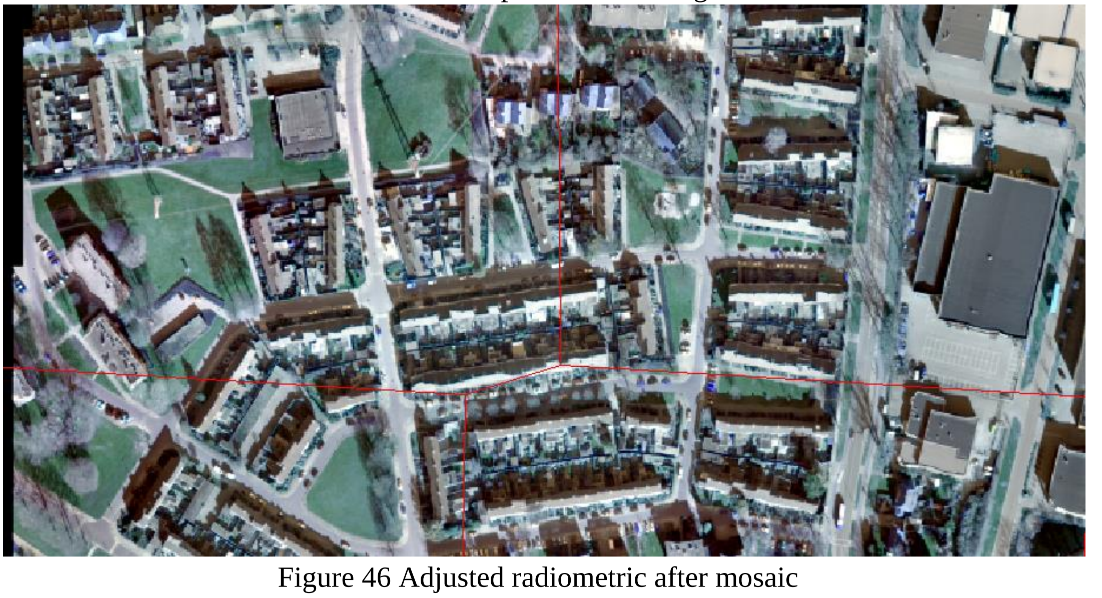


Figure 46 Adjusted radiometric after mosaic

b. Geometric Distortion

Geometric distortion for this result examine by visually seen the orthophoto result.

i. Relief displacement still appear in some locations shown in Figure 47. This problem is caused by very high object above the ground. This is also affected by the resolution of the DSM.

Figure 47 High object above the ground

ii. Effect of the single value that can be stored by the DSM

This effect can be seen on the object that have 2 height value, in this block area can be seen that the railway (over the road) should be has the straight line. But in Figure 48, we can see that it is not.

Figure 48 Railway over the road

iii. Effect of the DSM in the terrain

This error can be visualised as in Figure 49.

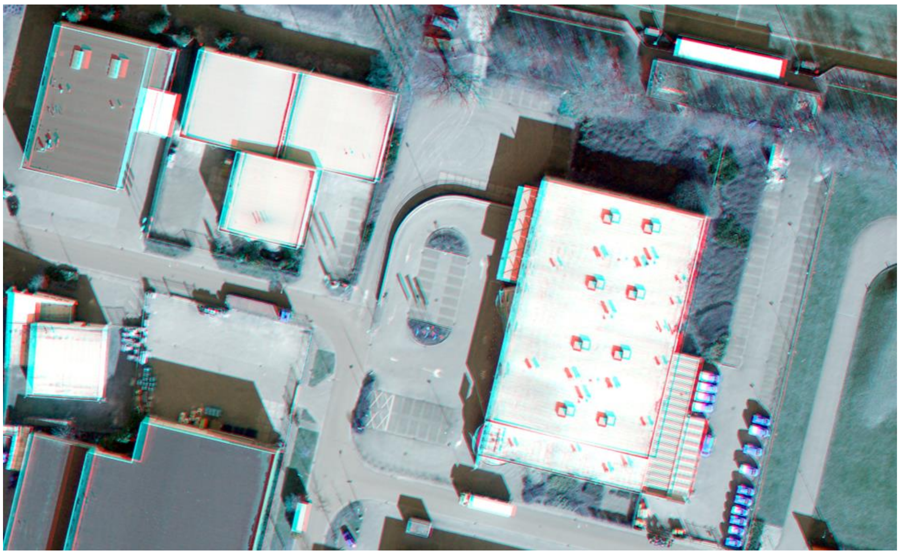


Figure 49 Different colour (red and blue shadow) in the left orthophoto and the right orthophoto that is overlap

iv. Orthophoto accuracy

The orthophoto accuracy calculated using the check points to represent the geometric quality shown in Table 5.

Table 5 RMSE of the orthophoto mosaic

Points	Coordinate from field measurement		Coordinate from image measurement		$dX^2 + dY^2$
	X	Y	X	Y	
10003	255892.7377	472616.0339	255892.4321	472615.7283	0.186775386
10007	256403.1671	472414.168	256403.3169	472414.0498	0.036427786
10018	255801.1188	470755.3455	255801.0236	470756.5361	1.426665216

$\Sigma(dX^2 + dY^2) = 1.649868387$

Average = $\Sigma(dX^2 + dY^2) / 3 = 0.549956129$

RMSEh = sqrt(average) = 0.74159027

Accuracy (1.7308*RMSEh) = 1.28354444 ~ 1.28 m

4. Conclusion

a. Conclusion

After completing the task by going through the photogrammetry orientations and come up with some of its products, we can conclude as follow:

i. Every step using different parameter which will correlate each other. The parameter that we choose during the triangulation will affect the rest of the workflow. Parameter for each step as explained in the method part.

ii. Generate the orthophoto from digital aerial images using photogrammetry workflow can be done using the available software, in this task using ERDAS Imagine 2016 software, which provides bundle block adjustment function by doing the following task:

   a. Setup the project file
   b. Sensor Orientation
   c. DSM Generation
   d. Orthorectification
   e. Mosaic Ortho

iii. Assess the quality for each of produced product including:

   a. Triangulation quality by checking the image and ground RMSE from the triangulation summary

b. DSM quality by using the DSM extraction report that generated from the software
c. Orthophoto and mosaic quality by visually inspecting the image and calculating the accuracy using the check point

b. Limitation and Recommendation
   i. For this task, we are using 5 m cell size of the DSM which means that the height value of 1 cell size DSM area will be interpolated and become the same. It means that it loses some information. To improve the DSM, we can use the smaller size of the cell. Besides that, we can do manual editing to filling the blank area of the *.las DSM and/ or adding the breakline for the discrete changing of height area. But it will need more time and an experienced operator.
   ii. For improving the result of the orthophoto, we can manually edit the seamline for example for avoiding the building.

5. Answer the Question

a. Question 1: Why did not you measure fiducial marks for interior orientation of the sensor?
   Answer: We use image which using digital camera, instead of catalogue camera. Fiducial marks are used in analogue camera to determine the image coordinate. But, in digital image from the digital camera, it uses row and column to determine the image coordinate.
b. Question 2: What criteria and indications (from the points table or triangulation report) did you use to analyse and find the "problematic" points (tie and control)?
   Answer:
   - RMSE result from the triangulation report/ summary
     There are 2 criteria which need to be satisfied. Criteria 1) accuracy should be in the acceptable range. In this case, RMSE in total image should be less than 0.35 pixel and for Ground RMSE is 0.072 for X and Y, 0.207 for the Z and 2) maximize the use of number of GCPs that participate in the adjustment, because some points are disable/ become inactive during the triangulation process.
   - The residual plot
     By plot the residual and display in map space, the point with longest line of residual need to be reviewed in the images. It possibly not located in the right position (based on the GCP documentation). After checking the measurement, if we are sure that this point is measured accurately in image, then we keep it. If this point indeed doesn't have a correct position in image, then we correct its position, or we make it inactive. So, in the next run of triangulation, this point will be excluded.
c. Question 3: What is the result of the accuracy assessment of your final Bundle Block Adjustment?
   Answer:
   - Total image unit-weight RMSE = 0.1390 < 0.35.
   - Ground Z: 0.0388 < 0.207; Ground X: 0.0388 and Ground Y: 0.0202 < 0.072

   They are all in the acceptable range. So, the accuracy of final Bundle Block Adjustment is acceptable.
d. Question 4: Give the option that you set for the DSM generation and explain how this option affect produced data
   Answer: The whole process is illustrated in DSM Generation part and two important parameters are cell size and pyramid level for producing the raster grid DSM. This parameter determines the details of DSM output and the accuracy.
   With 5 m cell size we got a more detail DSM product instead of using 10 m cell size. If we use 10 m cell size (bigger cell size), it will produce coarser DSM product because of the interpolation effect when storing the DSM as raster grid.
   For pyramid level, we use level 0 because the DSM product with this setting will be more detailed. Although choosing pyramid level 1 or 2 will speed up the process, what we want is a DSM including more details.
   That a balance between requirement and time-consuming.

e. Question 5: How did you assess the quality of the final DSM? What are the criteria for assessing the quality of generated DSM?
Answer**:** First, we can use generated contour line to roughly check whether there is DSM error, all the contour lines must be closed. If we find obviously DSM errors, we can backwards to the work. Second, we can visually check the accuracy of DSM by checking if the cursor on the left and right mage of a stereo pair is centred over the same feature. Third, we use mathematics calculation to check the accuracy using the tie point which done automatically using the DSM extraction report for each of pair. Fourth, using the check point.

f. Question 6: Does your DSM require further manual editing? Why? In which area?
Answer**:** for this task we did not do any manual editing. But, in further work, it may need editing in the object that has discrete changing of height by adding the breakline (because of the cell size, the height is interpolated based on the cell). And also possible for adding the point in blank area for the *.las file.

g. Question 7: Can we use the automatically extracted tie point as reference data for checking the DTM accuracy? Why? If the answer is "Yes", what kind of restriction (rules) have to applied on using these tie points?
Answer: Yes, we can use the extracted tie point as reference data like the DSM extraction report generated which automatically derived from the software which using FOM. "FOM is the Figure of Merit. When a check point falls within the same pixel as a correlated point, that FOM is reported and the elevations are compared directly. Otherwise, an elevation at the check point location is interpolated for comparison and one of the following symbols are reported". (ERDAS IMAGINE, n.d.-a)
The height for this tie point is calculated based on the interpolation from the DSM raster and compare to the elevation value of the point which coming from the triangulation process. So, it is not compare with the value from the field measurement. Both are coming from the calculation.

h. Question 8: How can you visually examine the quality of your orthophoto?
Answer: we can visually assess the quality for the radiometric and geometric distortion
- radiometric distortion
    - different contrast and brightness: can be seen in the border of the image and clearly seen in the boundary of 2 images
- geometric distortion
    - relief displacement: looking at the building area, especially high building or another object that has height above the terrain
    - double mapping effect: similar to the relief displacement
    - single value of height that can be stored in DSM: looking at object which has more than 1 height above the ground, for example, bridge
    - effect of the DSM error in the terrain: display the orthophoto as stereo pairs, looking at the area that has different colour (red and blue)

i. Question 9: Are there any distortion that remain in the orthophoto? If yes, which are them and what caused those distortion? What can be done to generate a more accurate orthophoto?
Answer: Yes.
- relief displacement caused by the DSM → generate more accurate DSM for example by using smaller cell size. From calculation, the maximum allowed in the DSM is 2.5m. So, it suggested to use cell size 2.5m. Manually editing the DSM for representing more real surface.
- radiometric distortion between 2 or images caused by the different exposure → mosaic

j. Question 10: consider your group as a scientific team that will use a) the DSM and b) the orthophoto mosaic for further analysis. The positional accuracy of the data is of high importance as it will further affect the quality of your scientific results. How could you access the positional accuracy? Describe the methodological approach that you would follow (any method and equipment can be used)
Answer: To access the positional accuracy of the data, we need reference positional data ("true position") and quantizing the positional errors between reference data and position in those DTM and orthophoto mosaic productions.

i. Acquisition of the reference data

Ground control points can be the reference data in accessing the positional accuracy. A ground control point is a feature that can clearly identify in the image for which the accurate ground coordinates of this point is known. Those ground coordinate of those GCPs can be collected from several sources, such as existing documents from other researchers or official ways and ground surveys.

For existing documents, if there are some GCPs located in the areas which are also included in DSM or orthophoto mosaic productions, we can identify all the available GCPs according to the images we want to use, then collect these GCPs information from existing documents as reference data. But when the same GCPs and the same positional data are used both in the process of generating DSM or other productions and the process of calculating the accuracy of those productions, the result will show those productions have relatively higher accuracy which is not reasonable enough, because those productions are based on these GCPs.

For ground surveys, surveyors will verify the accurate positional information of GCPs in the area that we are interested in. Before surveying, we will determine some identifiable points in DSM and orthophoto mosaic production considering the distribution of these points. The result of ground surveys and the corresponding position of that points in images will be reference data.

ii. Quality assessment of the DSM

After obtaining the reference data, quality assessment of DSM can be performed by comparing the DSM with reference data. We will choose Root Mean Square Error(RMSE) as the parameter to evaluate the quality of a surface fit to reference data. The RMSE represents the sample standard deviation of the differences between predicted values and observed values. The value of RMSE can be calculated by software automatically, and the criteria of what level of RMSE is acceptable depends on the specific research requirements.

On the other hand, error in the orthophoto can be caused by a DSM-error, thus the requirement of orthophoto will also be one constraint for DSM.

iii. Quality assessment of the orthophoto mosaic

Using the reference data against the positional information in orthophoto then compare. The RMSE will be used to calculate the accuracy of the orthophoto mosaic.

The reference data that can be used for measuring the accuracy is only the point that is not used as control point during the processing the image. For example, point 1 is already used as control in triangulation step, so we can not use it as reference data for checking the accuracy. The other criteria of the reference data for checking is same as the criteria of reference data for control point that is used for calculation during the processing.

6. References

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