HACETTEPE UNIVERSITY
DEPARTMENT OF
GEOMATICS ENGINEERING

GMT 333 - PHOTOGRAMMETRY

Homework -3

CONTENTS

ABDULSAMET TOPTAŞ – 21905024

1. Executive Summary ;

- Brief summary of the processes ı have performed ;

Using the Pix4D software, a 3D map of the Beytepe campus was produced by using aerial images, camera parameters, orientation parameters, and GCPs with known coordinates on the ground. Briefly, the process involved opening the images of the campus taken from the air in the program environment using a known coordinate system and datum appropriate for the area. The camera model and camera position (external orientation parameters) data were entered. Then, the "inertial processing" process, which is the foundation of the next steps in creating a 3D map, was carried out. The purpose of this process is to create Keypoints (tie points), find images with the same tie points (keypoint matching), optimize the camera model (calibrate the orientation parameters), and perform geolocation GPS/GCP (measurement of image surfaces). After this step is completed, previously measured GCPs based on a known coordinate system on the ground were loaded and marked as "control points (3D)" or “check points” in every image that saw these points. The "Re-optimize" process was performed and a quality report was obtained. This report provides all types of information about the process, such as the errors in the balancing of GCPs, camera parameters, and curvatures. Finally, the "Point cloud and mesh" process was carried out, ensuring that the shapes, positions, and soft surfaces of objects have the correct colors.

- The procedure shortly and What ı have learned ;

I implemented the process described above using the tutorial shared with the assignment, but in addition, I also gained additional information about this process from the lecture notes and the internet. In short, I learned what the necessary data is for a 3D model or map and at which steps this data is processed. As examples of the information I learned, I can give the following: image processing (analyzing images to extract information about the position and shape of objects), point cloud creation (creating a series of points in 3D space representing the surface of objects), mesh creation (applying color and texture information to a mesh to create a more realistic and detailed 3D model), orthomosaic and DSM creation (correcting errors caused by slope, curvature, and elevation differences in digital images and creating orthophoto images by transforming them into a vertical projection). This project can help us monitor changes in an area over time, and can be used for planning and designing projects such as building construction or infrastructure development.

2. Processing of Beytepe UAV images ;

- Camera Characteristics ;

- **Brand :** Ricoh
- **Model :** GR GRLENS
- **Maximum Image Resolution :** 4928 x 3264
- **Minimum Focal Length :** 18.3 mm
- **Maximum Focal Length :** 28 mm

- **Distortions :** Distortion is a lens aberration that causes straight lines in the scene to appear curved or distorted in the final image. Distortion values can be seen from the image in Figure 1.
- **Image Formats Supported / Camera File System :** RAW , JPG / Exif 2.3
- **Color Space :** RGB
- **Fastest Camera Shutter Speed :** 1/4000 s
- **Slowest Camera Shutter Speed :** 300 s
- **Sensor Dimensions :** 23.500 mm x 15.565 mm

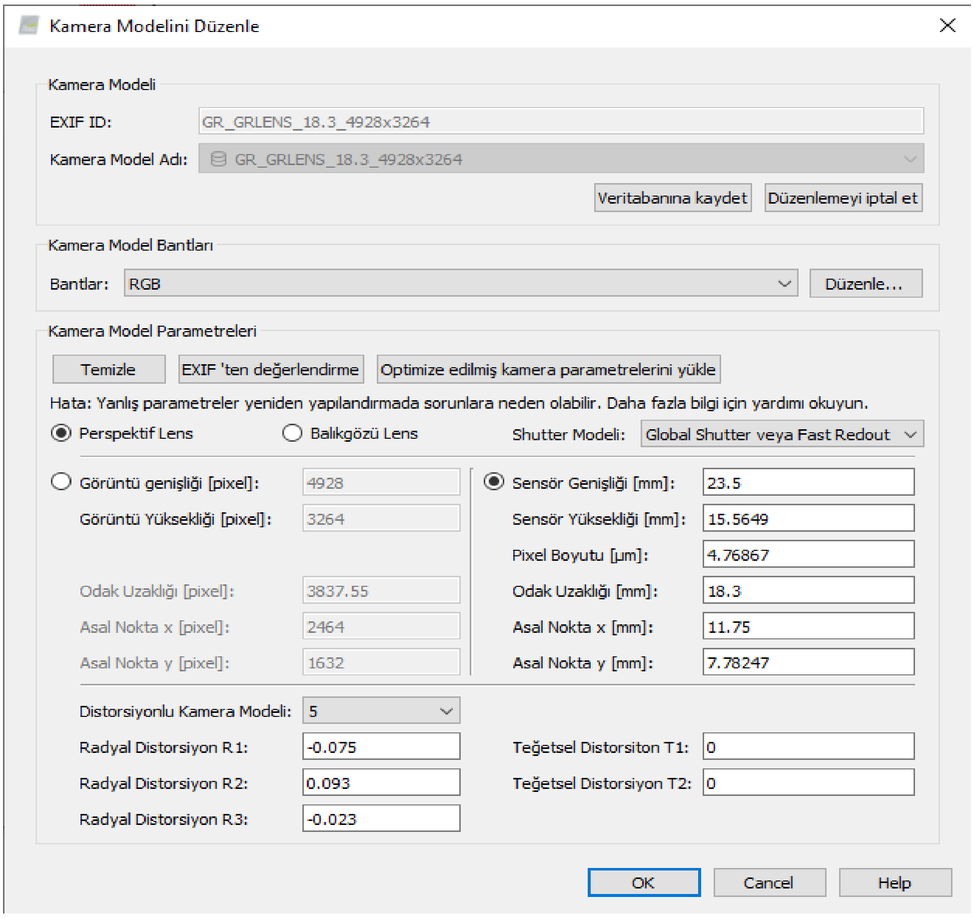


Figure 1 : Camera Characters in Pix4D

The camera characteristics were examined through the Pix4D program and quality reports. In addition to this, important information was noted after researching the camera on the internet.

- Photogrammetric Block ;

- **Number of Images :** 28
- **Number of Calibrated Images :** 28
- **Number of Geolocated Images :** 28
- **Number of GCPs :** 9 but there are 2 GCPs that the images provided don't see, so it's 7

- **Median of** 45455 **keypoints per image**
- **Number of Strips :** 27
- **median of** 10674.8 **matches per calibrated image**
- **Number of 2DKeypointObservations for Bundle Block Adjustment :** 329161
- **Number of 3DPoints for Bundle Block Adjustment :** 130594
- **Number of Generated Tiles :** 1
- **Number of 3D Densified Points :** 992173

- Overview of the processing steps ;

- Aerial photographs of the relevant region were taken with the help of drones4

- GCP points (X,Y,Z coordinates) connected to a specific coordinate system previously established with GPS in the field were recorded in a text document

- Image coordinates obtained from the drone in a certain coordinate system and Roll, Pitch and Yaw (Omega, Phi and Kappa) angles representing the movement of the drone were recorded in a text document

- In the Pix4D program, images are loaded depending on a certain coordinate system, and image coordinates and camera positions are also loaded. In addition, the camera model is automatically defined, if not it must be entered manually

" There are two important processes when creating 3D models and maps from photo data: "Initial Processing" and "Point Cloud and Mesh Processing". These two processes are important steps during model and map creation and directly affect the quality of the model and map."

- Initial Processing has started. This process includes automatically detecting the position and angle information of the photos and matching between the photos. For example, Keypoints (tie points) creation, keypoint matching, camera model optimization and measurement of image surfaces. At the end of this process, a quality report should be obtained. It contains all the information about the process (errors and parameters etc.) in the quality report.

- Finally, Point Cloud and Mesh Processing began. This process involves determining the positions of the photographs relative to each other to create points and connecting these points to create a 3D model. Point Cloud and Mesh Processing is an important step in the creation of a model and map because this process allows for the details in the photographs to be accurately detected, resulting in the creation of a detailed (having accurate shapes, positions, soft surfaces, and correct colors) and accurate model and map.

3. Evaluation of Quality report ;

At the end of the project, I obtained 3 "Quality Reports". The report I obtained after Initial Processing, after importing and marking GCPs, and finally after Point cloud and Mesh Processing. In this section, I will consider the last quality reference "beytepe_project_afterpointcloudandmesh_report"

Now let's analyze by taking sections from these reports.

As seen in Figure 2, the project construction date, project name, camera model, GSD ratio and covered area (The 2D area covered by the project) information are included.

Summary

Project	beytepe_project
Processed	2023-01-02 19:41:57
Camera Model Name(s)	GR_GRLENS_18.3_4928x3264 (RGB)
Average Ground Sampling Distance (GSD)	1.96 cm / 0.77 in
Area Covered	0.030 km^2 / 2.9694 ha / 0.01 sq. mi. / 7.3413 acres

Figure 2 : Summary Part

There is some information as seen in Figure 3. These are median information of 45455 key points per image (Key points represent characteristic points detectable in images), Number of calibrated active images (i.e. number of images used to reconstruct the model), Number of matches per median of calibrated image, Georeference project geographic referenced).

Quality Check

Images	median of 45455 keypoints per image	✓
Dataset	28 out of 28 images calibrated (100%), all images enabled	✓
Camera Optimization	0.55% relative difference between initial and optimized internal camera parameters	✓
Matching	median of 10674.8 matches per calibrated image	✓
Georeferencing	yes, 4 GCPs (4 3D), mean RMS error = 0 m	✓

Figure 3 : Quality Check Part

Images displayed are low resolution preview of Orthomosaic and DSM before step 2. They provide a visual inspection of the quality of the initial calibration. We see this in Figure 4

Preview

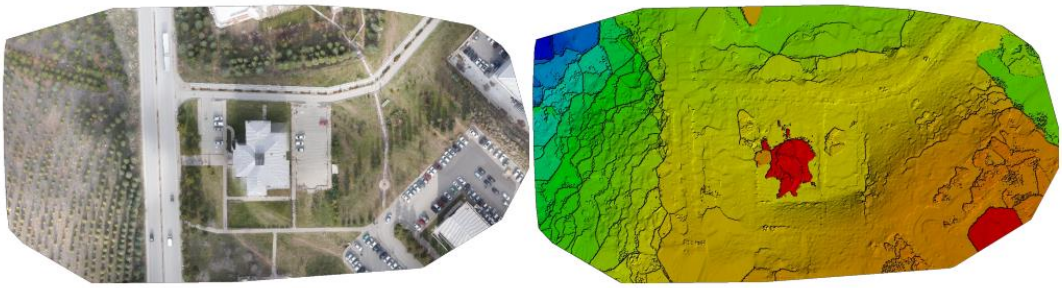


Figure 4 : Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification

In Figure 5 you can see the number of images calibrated, i.e. the number of images used for reconstruction versus the total number of images in the project, and the number of geolocated images

We see a graph in Figure 6. This chart is useful for examining the geolocation of images. If this chart does not match the flight plan, there may be issues with the direction, scale, and/or geographic location of the mapping and results.

Calibration Details

Number of Calibrated Images	28 out of 28
Number of Geolocated Images	28 out of 28

Figure 5

Initial Image Positions

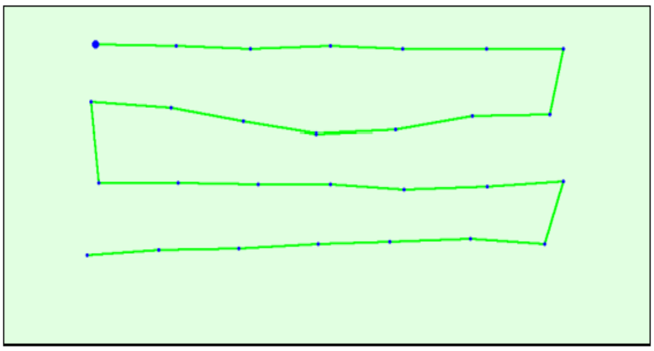


Figure 6 : Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot

We see a graph in Figure 7. This graph shows the difference between the initial and calculated image positions, the difference between the initial and calculated positions of GCPs/Control Points (if any), the positions of MTPs (if any), and the uncertainty ellipses of absolute camera positions.

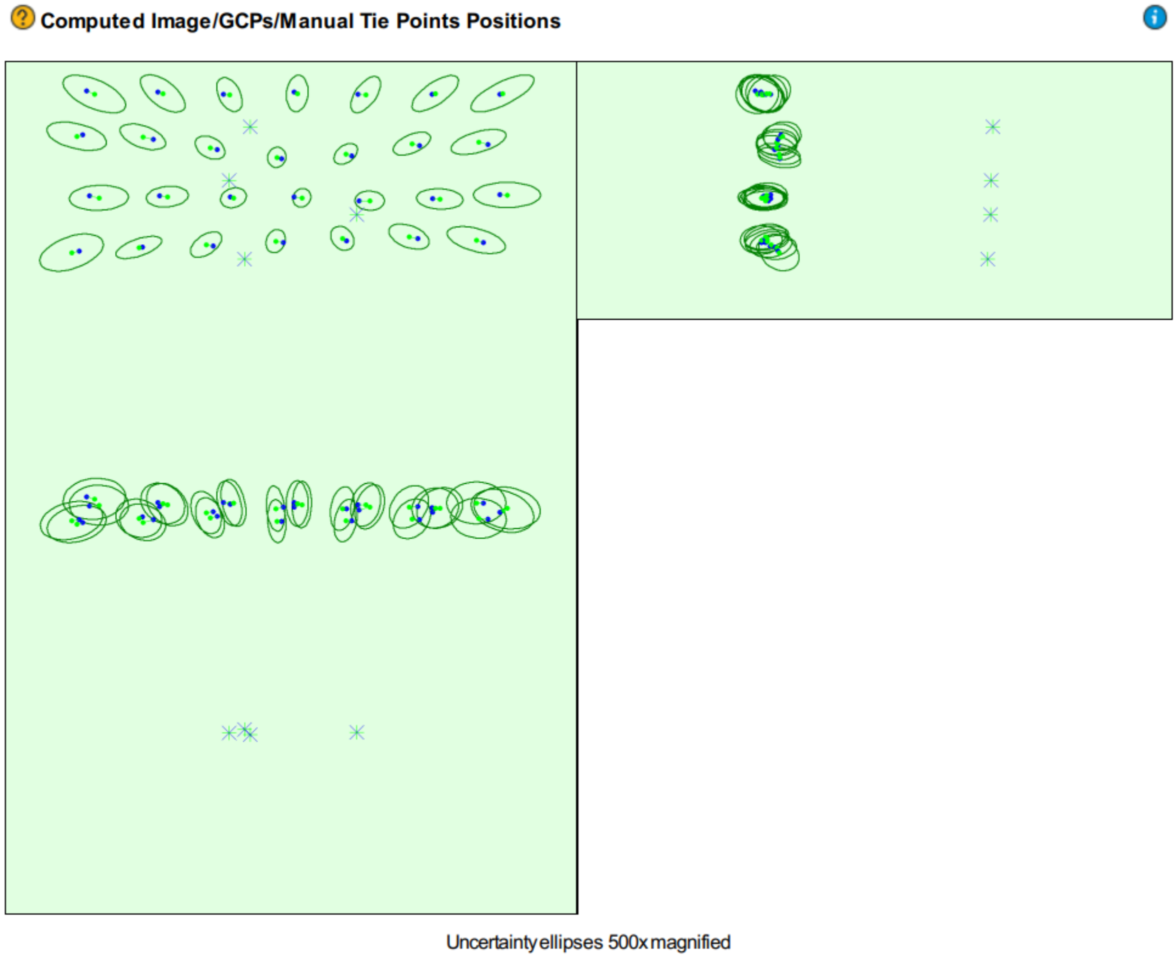


Figure 7 : Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

In Figure 8, we see the external orientation values, which are the camera parameters. In projects with GCPs, a large sigma may indicate that some areas of the project (usually those far from any GCP) have been reconfigured less accurately and may benefit from additional GCPs. Here we see that both mean and sigma values are reasonable.

Absolute camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.019	0.013	0.020	0.008	0.011	0.002
Sigma	0.007	0.003	0.001	0.002	0.004	0.000

Figure 8 : Absolute camera position and orientation uncertainties

In Figure 9 you can see the number of overlapping images calculated for each pixel of the Orthomosic. Red and yellow areas indicate low overlap where poor results can be produced. Green areas indicate that more than 5 images overlap for each pixel. Quality results will be produced as long as the number of key point matches for these areas is also sufficient.

Overlap

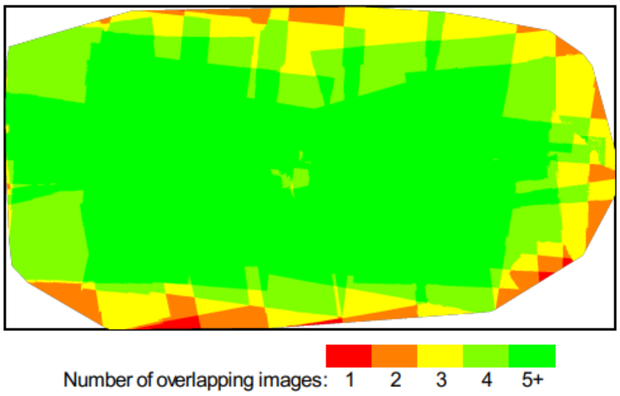


Figure 9

In Figure 10 you can see the number of automatic anchor points in all images used for AAT/BBA, the number of all 3D points created by mapping 2D points in the Images, and the Reprojection error in pixels averaged

Bundle Block Adjustment Details

Number of 2D Keypoint Observations for Bundle Block Adjustment	329161
Number of 3D Points for Bundle Block Adjustment	130594
Mean Reprojection Error [pixels]	0.139

Figure 10

In Figure 11 we see the 2D Table of Key Points. This table displays some statistics of key points and project matches.

2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	45455	10675
Min	27183	4445
Max	58430	20678
Mean	45170	11756

Figure 11

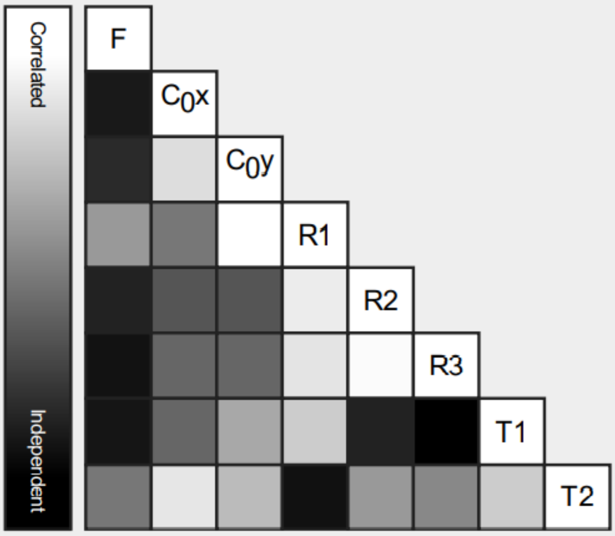
In Figure 12, you can see the camera parameters focal length, principal points and distortions. Here, the necessary information is in figure 11.

Internal Camera Parameters

GR_GRLENS_18.3_4928x3264 (RGB). Sensor Dimensions: 23.500 [mm] x 15.565 [mm]

EXIF ID: GR_GRLENS_18.3_4928x3264

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	3837.548 [pixel] 18.300 [mm]	2463.999 [pixel] 11.750 [mm]	1632.000 [pixel] 7.782 [mm]	-0.075	0.093	-0.023	0.000	0.000
Optimized Values	3858.847 [pixel] 18.402 [mm]	2464.076 [pixel] 11.750 [mm]	1663.263 [pixel] 7.932 [mm]	-0.074	0.099	-0.029	-0.000	-0.000
Uncertainties (Sigma)	0.787 [pixel] 0.004 [mm]	0.170 [pixel] 0.001 [mm]	0.118 [pixel] 0.001 [mm]	0.000	0.001	0.001	0.000	0.000



The correlation between camera internal parameters determined by the bundle adjustment. White indicates a full correlation between the parameters, ie. any change in one can be fully compensated by the other. Black indicates that the parameter is completely independent, and is not affected by other parameters.

The number of Automatic Tie Points (ATPs) per pixel, averaged over all images of the camera model, is color coded between black and white. White indicates that, on average, more than 16 ATPs have been extracted at the pixel location. Black indicates that, on average, 0 ATPs have been extracted at the pixel location. Click on the image to the see the average direction and magnitude of the re-projection error for each pixel. Note that the vectors are scaled for better visualization. The scale bar indicates the magnitude of 1 pixel error.

Figure 12

In Figure 13, we see the 3D Points from 2D Keypoint Matches Table. Multiple 2D matched key points are triangulated together using camera parameters to create a 3D point. 3D points created from 2-3 images are less accurate than 3D points created from a larger number of images.

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	92306
In 3 Images	21844
In 4 Images	8819
In 5 Images	4046
In 6 Images	2155
In 7 Images	881
In 8 Images	474
In 9 Images	68
In 10 Images	1

Figure 13

The table in Figure 14 shows us the following. Calculated image positions with links between matching images. The darkness of the links indicates the number of matching 2D key points between images. Bright links indicate weak links and require manual ports or more images. Dark green ellipses indicate the relative camera position uncertainty of the beam block adjustment result.

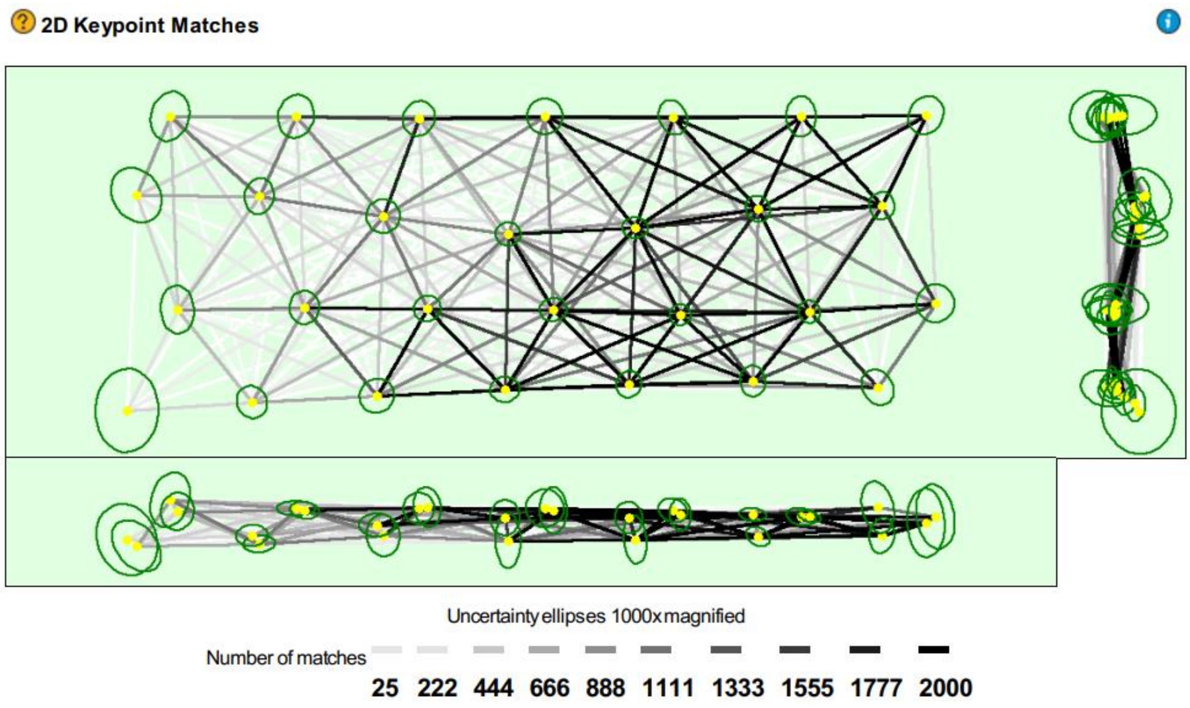


Figure 14

This table in Figure 15 provides information on how well Ports restrict images. The average relative camera position uncertainty should be within a few times the GSD, the average direction uncertainty should be less than 0.1 degree. A large sigma may indicate that parts of the project are not well calibrated.

We can see that the values in this project are reasonable

Relative camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.004	0.005	0.005	0.006	0.009	0.002
Sigma	0.001	0.002	0.002	0.002	0.004	0.000

Figure 15

In Figure 16 we see the localization accuracy per GCP and the average errors in the three coordinate directions. The last column counts the number of calibrated images where GCP was automatically verified and manually flagged. GCPs are used to evaluate and fix a project's georeference. 3 GCP is the minimum value for geolocating (scaling, guiding, positioning) a project. Optimal accuracy is usually achieved with 5 - 10 GCP.

In this part, I chose 4 Controls and 3 Check points. There were 9 GCPs in total, but 2 of them were not seeing any images. Here we see that the GCPs have a low amount of errors. There can be many reasons for this, these may be the accuracy of the GCP coordinates, their good distribution and numerically adequate, or precision marking on images.

Geolocation Details

Ground Control Points

GCP Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
P1 (3D)	0.020/ 0.020	0.000	0.000	-0.000	0.039	18 / 18
P2 (3D)	0.020/ 0.020	-0.000	-0.000	0.000	0.038	13 / 13
P3 (3D)	0.020/ 0.020	0.000	-0.000	-0.000	0.034	13 / 13
P4 (3D)	0.020/ 0.020	0.000	0.000	0.000	0.037	10 / 10
Mean [m]		0.000002	-0.000001	0.000026		
Sigma [m]		0.000126	0.000107	0.000096		
RMS Error [m]		0.000126	0.000107	0.000100		

0 out of 3 check points have been labeled as inaccurate.

Check Point Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
P5		-0.0002	-0.0004	-0.0002	0.0264	8 / 8
P6		0.0019	0.0008	-0.0140	0.0380	8 / 9
P7		-0.0007	0.0009	-0.0027	0.0497	13 / 13
Mean [m]		0.000317	0.000440	-0.005629		
Sigma [m]		0.001113	0.000618	0.006004		
RMS Error [m]		0.001157	0.000759	0.008230		

Figure 16 : GCPs and its errors

This table in Figure 17, displays the percentage of geolocated and calibrated images with a geolocation error in X,Y,Z within a predefined error interval. This table also evaluates the quality of the image geolocation. A high percentage of images with a high error may indicate:

- Noise in the GPS device.
- Poor synchronization between the GPS device and the camera.
- Errors in the geotagging process.

Absolute Geolocation Variance

Min Error [m]	Max Error [m]	Geolocation Error X [%]	Geolocation Error Y [%]	Geolocation Error Z [%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	0.00	0.00
-6.00	-3.00	28.57	0.00	0.00
-3.00	0.00	21.43	46.43	50.00
0.00	3.00	17.86	53.57	50.00
3.00	6.00	32.14	0.00	0.00
6.00	9.00	0.00	0.00	0.00
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		-0.003128	0.001751	0.013147
Sigma [m]		3.318688	0.784271	0.808167
RMS Error [m]		3.318690	0.784273	0.808274

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Geolocation Bias	X	Y	Z
Translation [m]	-0.003128	0.001751	0.013147

Bias between image initial and computed geolocation given in output coordinate system.

Figure 17

This table in Figure 18 displays the percentage of geolocated and calibrated images that have a Relative Geolocation Error between -1 and 1, -2 and 2 and -3 and 3. Relative Geolocation Error A high percentage of images that are less than -3 or greater than 3 may indicate an incorrect value for the geolocation accuracy (user-given) of the image.

In the other table, we see the geolocation RMS error of the orientation angles given by the difference between the initial and calculated image orientation angles.

Relative Geolocation Variance

Relative Geolocation Error	Images X [%]	Images Y [%]	Images Z [%]
[-1.00, 1.00]	96.43	100.00	100.00
[-2.00, 2.00]	100.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientational Variance	RMS [degree]
Omega	1.902
Phi	2.171
Kappa	6.627

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Figure 18

And below you can see the details of the project results ;

Initial Processing Details

Coordinate Systems

Image Coordinate System	WGS 84 / UTM zone 36N (EGM96 Geoid)
Ground Control Point (GCP) Coordinate System	WGS 84 / UTM zone 36N (2D)
Output Coordinate System	WGS 84 / UTM zone 36N (2D)

Processing Options

Detected Template	No Template Available
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Low (Fast)
Minimum Number of Matches	3
3D Textured Mesh Generation	yes

3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LOD	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density Divider: 1
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes

Results

Number of Generated Tiles	1
Number of 3D Densified Points	992173
Average Density (per m^3)	98.75

DSM, Orthomosaic and Index Details

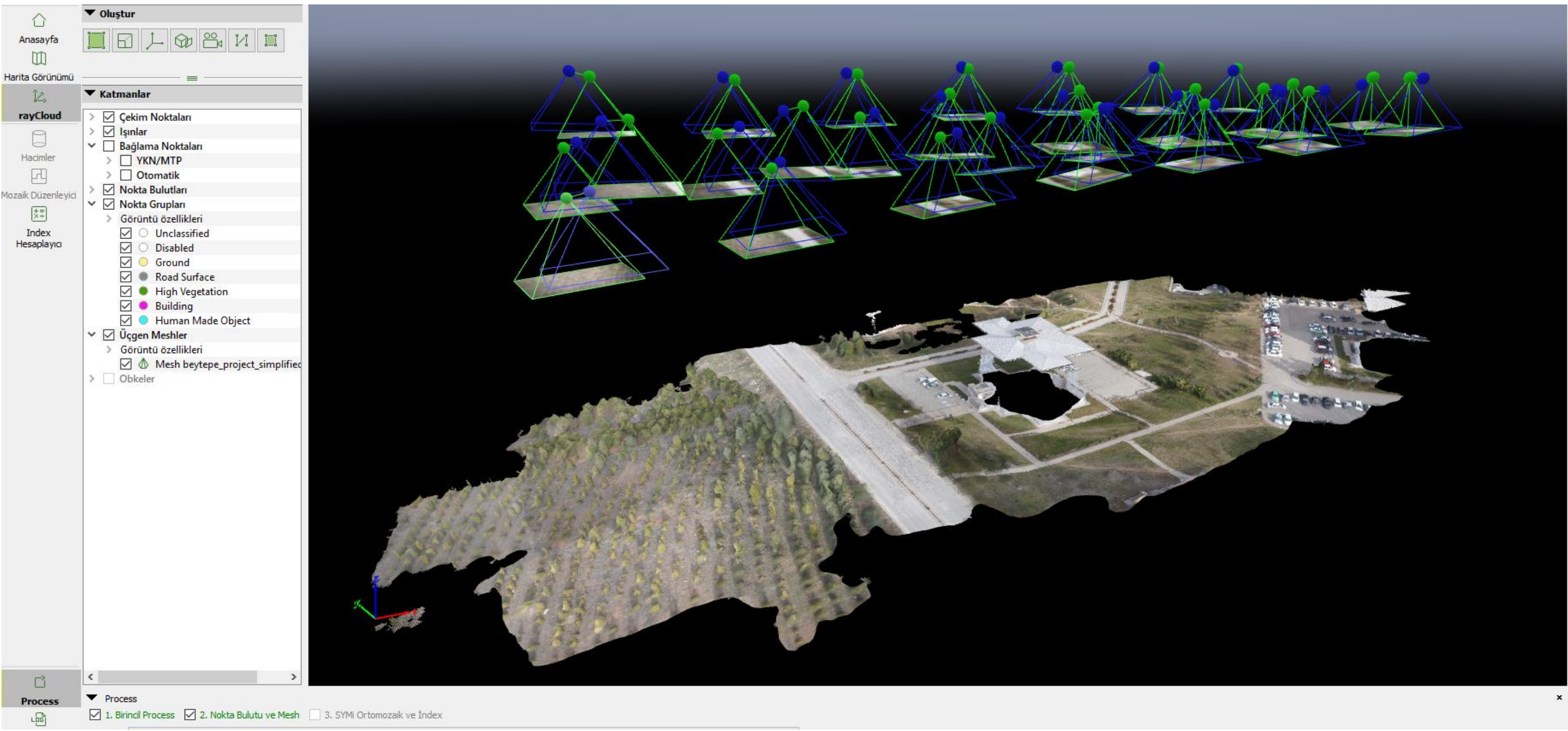
Processing Options

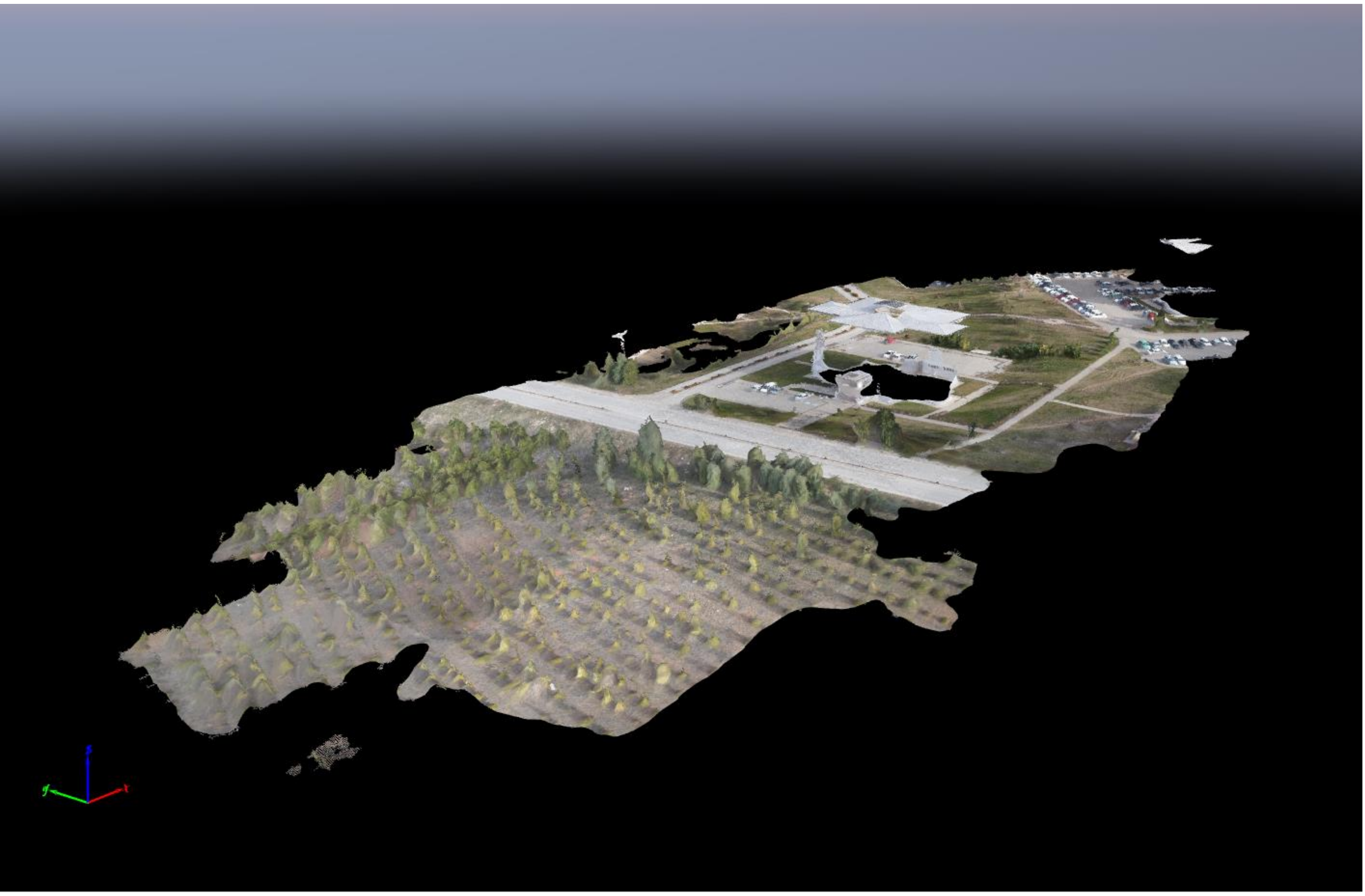
DSM and Orthomosaic Resolution	1 x GSD (1.96 [cm/pixel])
DSM Filters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp

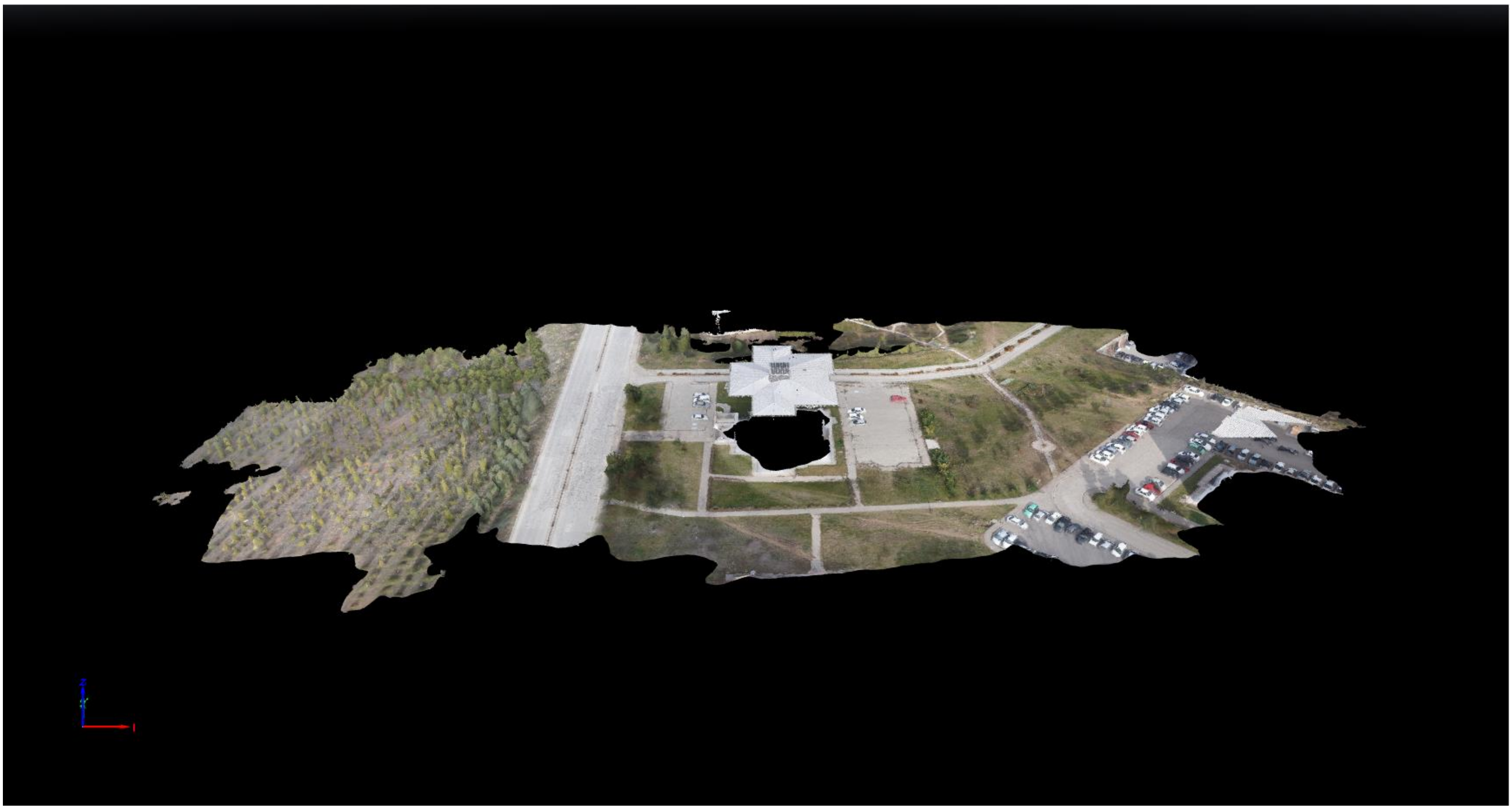
Reference

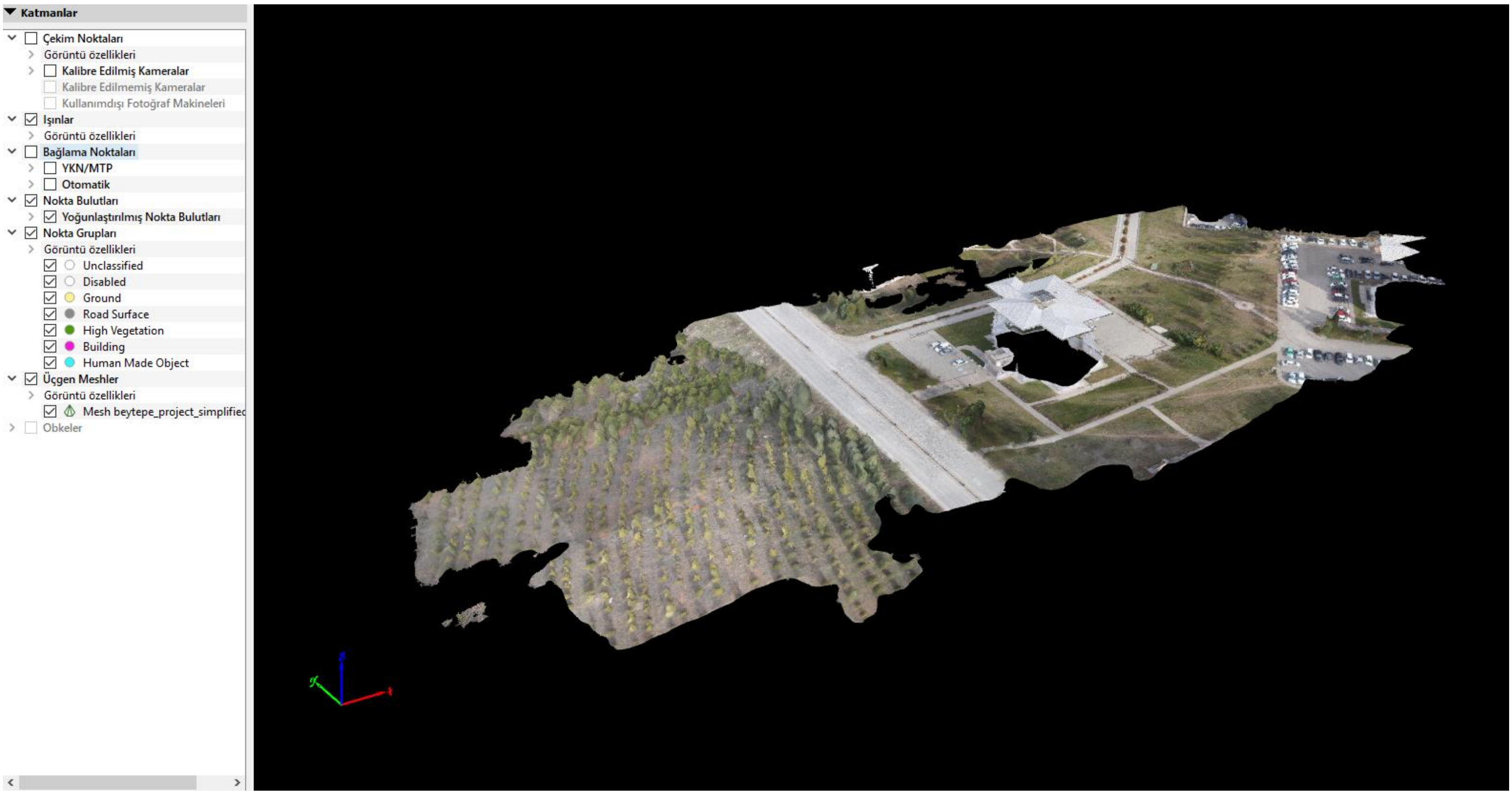
For reference, I can say that I have referenced the Pix4D support site and the Quality Report booklet on the Pix4D site.

4. Show Point Cloud and 3D Textured Mesh results with screenshots ;


Anasayfa
Harita Görünümü
rayCloud
Hacimler
Mozaik Düzenleyici
Index Hesaplayıcı
Process
Oluştur
Katmanlar
Çekim Noktaları
Işınlar
Bağlama Noktaları
YKN/MTP
Otomatik
Nokta Bulutları
Nokta Grupları
Görüntü özellikleri
Unclassified
Disabled
Ground
Road Surface
High Vegetation
Building
Human Made Object
Üçgen Meshler
Görüntü özellikleri
Mesh beytepe_project_simplified
Obkeler
Process
1. Birincil Process
2. Nokta Bulutu ve Mesh
3. SYM Ortomozaik ve İndex






Katmanlar
Çekim Noktaları
Görüntü özellikleri
Kalibre Edilmiş Kameralar
Kalibre Edilmemiş Kameralar
Kullanımdışı Fotoğraf Makineleri
Işınlar
Görüntü özellikleri
Bağlama Noktaları
YKN/MTP
Otomatik
Nokta Bulutları
Yoğunlaştırılmış Nokta Bulutları
Nokta Grupları
Görüntü özellikleri
Unclassified
Disabled
Ground
Road Surface
High Vegetation
Building
Human Made Object
Üçgen Meshler
Görüntü özellikleri
Mesh beytepe_project_simplifie
Obkeler