1.0 PURPOSE

The overall objective of the project was to create geospatial products of Hobb's Field, Mokelumne Hill, CA for the Mokelumne Hill Veterans Memorial Board. These products will be used to identify surface deviations for irrigation and landscaping purposes. In addition, these products will establish a general overview of the ball parks facilities, that can be used in planning future maintenance and enhancement projects at Hobbs's Field.

1.1 BACKGROUND

Mokelumne Hill, CA is a small former mining community in the foothills of the Sierra Nevada Mountains. The community is unincorporated and has limited resources available for infrastructure. Hobbs's Field was originally a water reservoir for the community, that was transformed into a baseball field in the mid 1980's. The field has been maintained by volunteers and the Mokelumne Hill Veterans Memorial District since its construction.

1.2 PROJECT SUMMARY

To complete the objective, I had to acquire a drone and flight planning apps suitable for remote image collection. Install software to create and fly preplanned flight paths. Fly the preplanned paths to collect georeferenced aerial imagery. Use ArcGIS Pro and PIX4D Mapper to import collected imagery, create orthomosaics and digital elevation models (DEM). Then use the generated files to create the final maps, imagery and CADD files of Hobb's Field.

2.0 DRONE ACQUISITION AND SOFTWARE / APPS

On March 29, 2021, while on vacation in Montana, I acquired a DJI Phantom 4 Pro V2 drone and downloaded the corresponding apps for operating the drone, DJI Fly and DJI Go 4. The applications were easily installed and relatively intuitive in nature to operate. At that time, I had not settled on an image collection application. I was looking at several options including Drone Deploy, ESRI Drone 2 Map and PIX4D Capture. I eventually chose to use PIX4D Capture as my flight planning and image collection app. Cost was the determining factor. All the other applications required a subscription fee for licensing.

2.1 INITIAL FLIGHT AND SET UP

After viewing several DJI training videos and reading the supplied training materials and verifying that I was clear to fly through the FAA B4UFLY and DJI Fly (figure 2.1.0) I took my new drone out to make its initial training flights (figure 2.1.1).

The flight controls were straight forward, and the drone was forgiving to fly. Just take your thumbs of the "joystick" and it stops moving.

After flying several battery cycles in the backyard of my parents' home, while using my iPhone for attached to the drone controller, I made the decision to purchase an iPad for use with the drone. This made viewing and controlling the drone much easier.

Figure 2.1.0

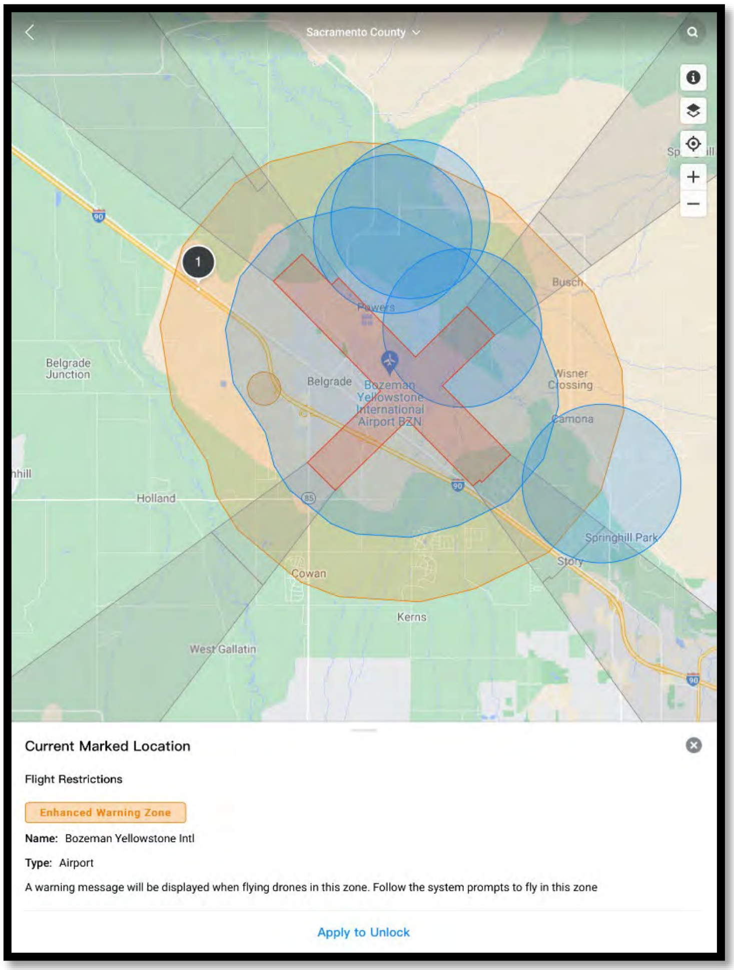
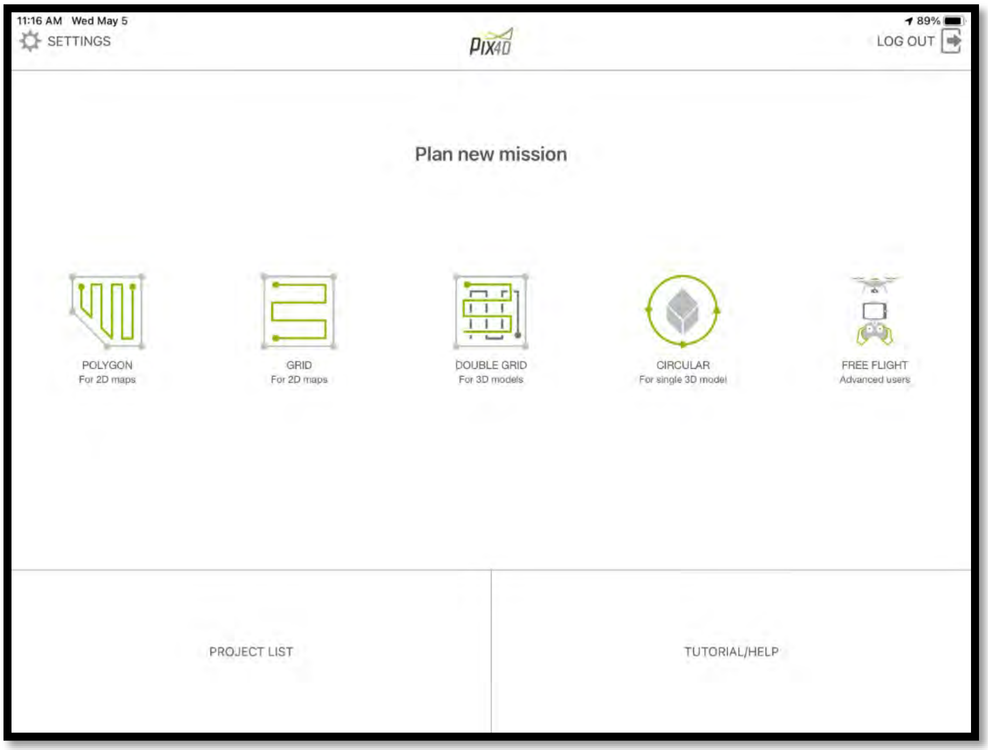


Figure 2.1.1

2.2 FIRST IMAGE COLLECTION

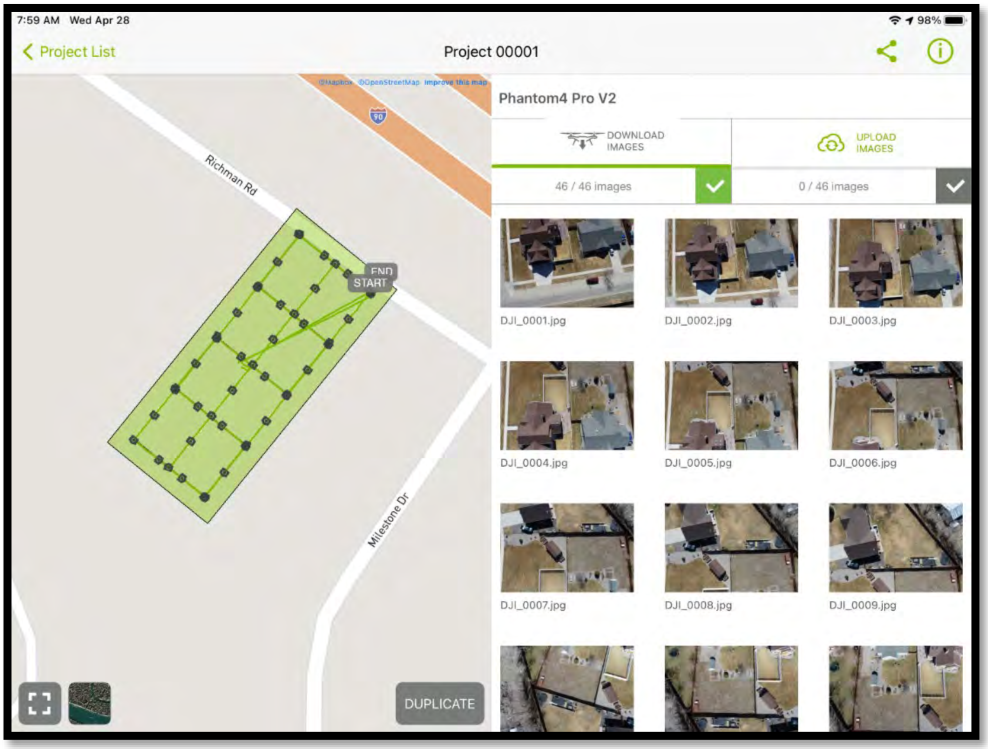
I made the decision to "practice" image collection and processing before going out to my main project location. Therefore, I started with collecting images of my parents' home. I planned the flight using PIX4D Capture. I set the flight plan to Double Grid (Figure 2.2.0). What I have since discovered is that when using this setting, the camera angle can only be set to a maximum of 80 degrees.

Figure 2.2.0



Upon completion of the mission, I had collected 46 images (Figure 2.2.1).

Figure 2.2.1



I downloaded the image data and began processing the images with ArcGIS Pro. I was able to process the images. However, the orthomosaics Image was severely distorted. I also discovered that ArcGIS Pro has a restriction on the length of your file path when uploading images.

2.3 AGGREGATE PIT FLIGHT

The next step was to collect images of a larger area. I contacted a project manager with AM Welles Inc, an excavation and road construction company, who has an aggregate pit in the area. They were collecting images with their drone at the time, and I was invited to join them.

On April 2, 2021 we arrived onsite, created a flight path (figure 2.3.0) and flew the mission. While planning the flight, we discussed flight the best flight altitudes for collecting images. I was told that in their experience 300 feet Above Ground Level (AGL) is the most effective altitude for their purposes. They fly these aggregate pits to determine the stockpile of materials they have available for their construction needs. I collected a total of 122 images during this flight. (figure 2.3.1)

Figure 2.3.0

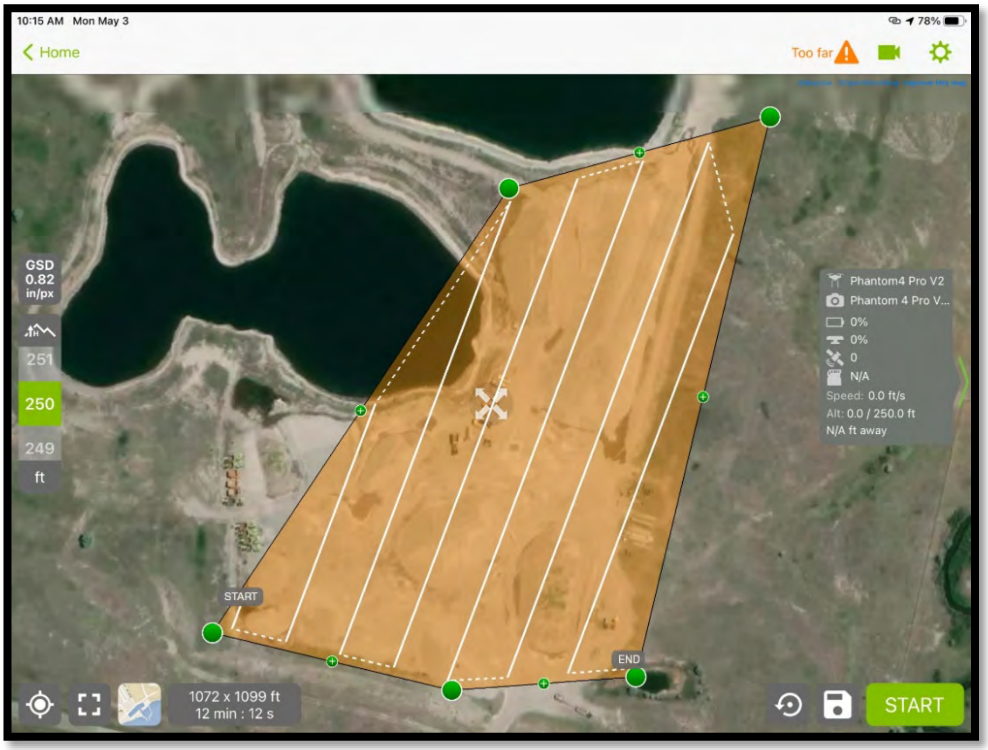
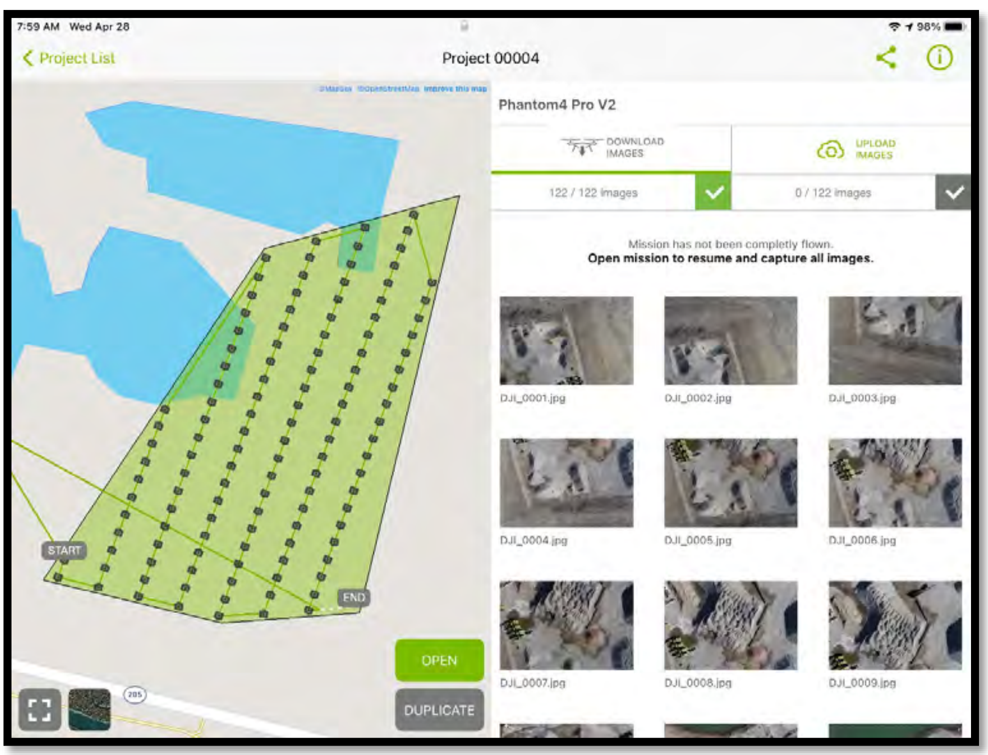


Figure 2.3.1



Rather than attempting to create the orthomosaics and DEM using ArcGIS Pro, I was offered the use of their software to create the files. It took approximately 45 minutes to process all 122 images and create the orthomosaics and DEM files.

3.0 HOBB'S FIELD DATA COLLECTION

Upon returning to California, I began to plan my flight to collect the images for Hobb's Field. I flew my initial flight to collect images of Hobb's Field on April 16, 2021. I set my flight altitude at 250 feet AGL. The area to capture was 606 ft by 465 ft. The flight time to capture the images was calculated to run 5 minutes and 57 seconds. During the flight I collected 54 images (figure 3.0.0)

I processed those through ArcGIS Pro. However, I repeatedly ran into an error out when creating the orthomosaics. I would get an error about Tie Points.

To reduce the effect of shadows and foliage as well as increase the number of tie points, I repeated the flight. This time I flew two missions on April 22, 2021. By flying two separate missions to collect images using the same flight path and increasing my altitude to 300 feet AGL, I hoped to improve accuracy of the images taken (figure 3.0.1). The first mission was flown at 10:45 am and the second flight was flown at 12:15 pm. In total I collected 72 images (figure 3.0.2)

Figure 3.0.1

Figure 3.0.2

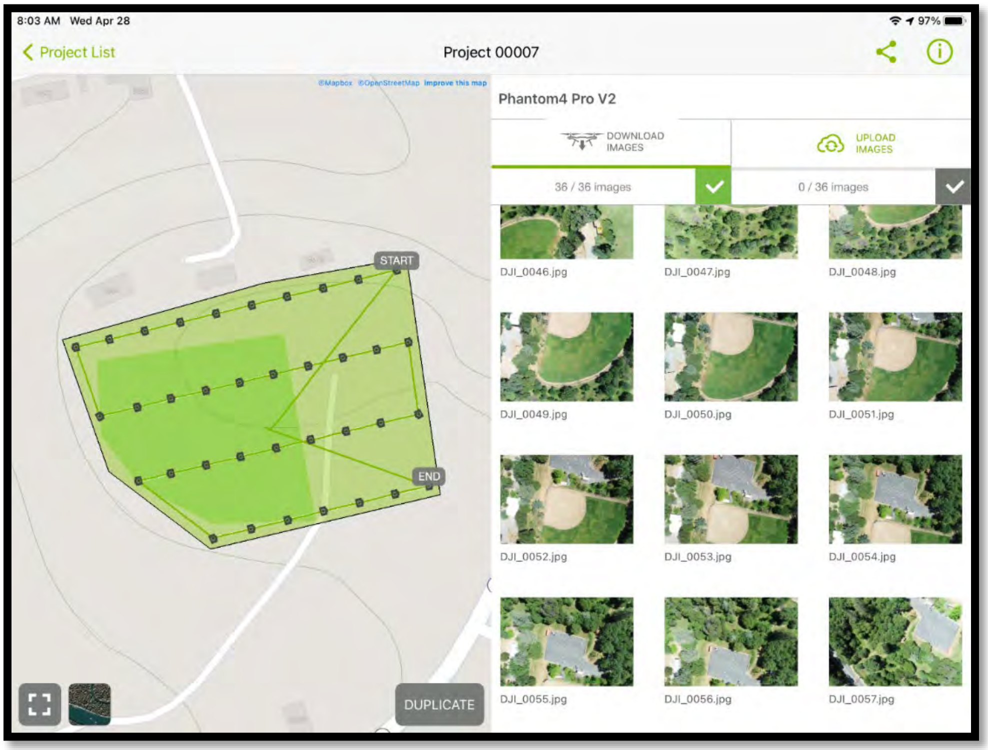
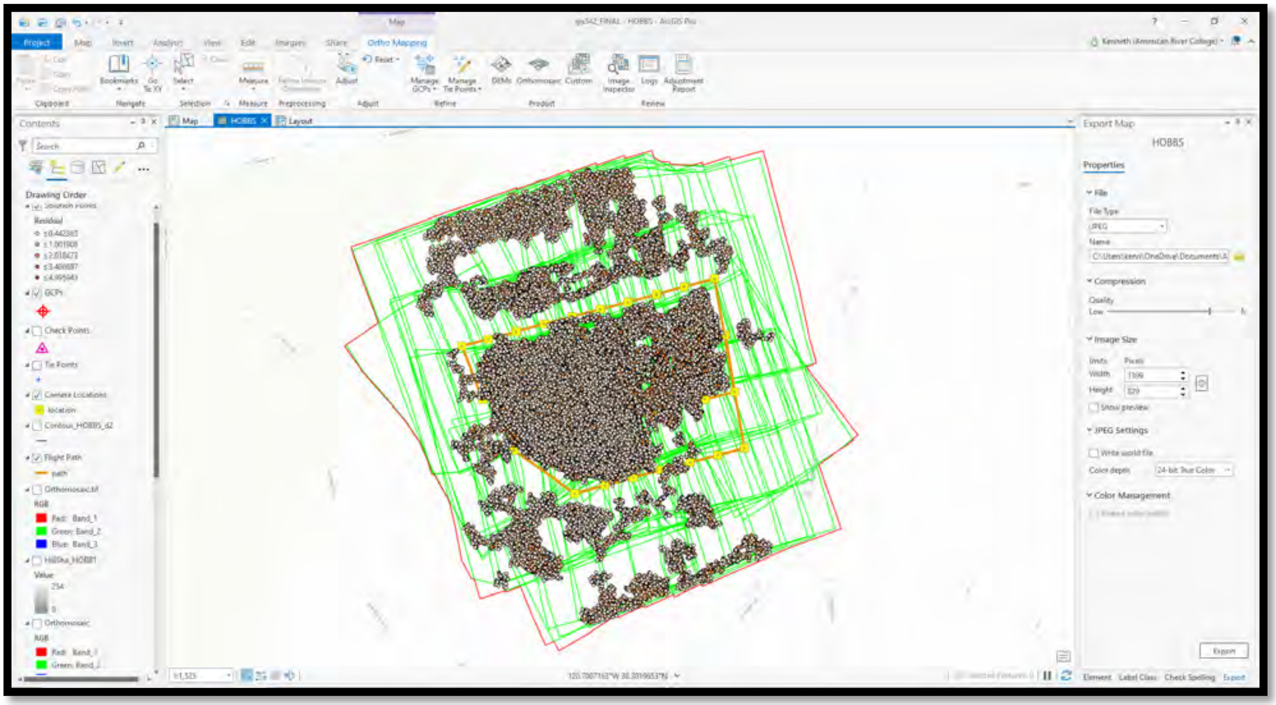


Figure 3.0.3

3.1 IMAGE PROCESSING

I chose to initially process the images using ArcGIS Pro using the settings established in class. This time I was able to create an orthomosaics and a digital elevation model. However, the results were greatly distorted and lacked tie points on the perimeter of the project area (figure 3.1.0).

Figure 3.1.0



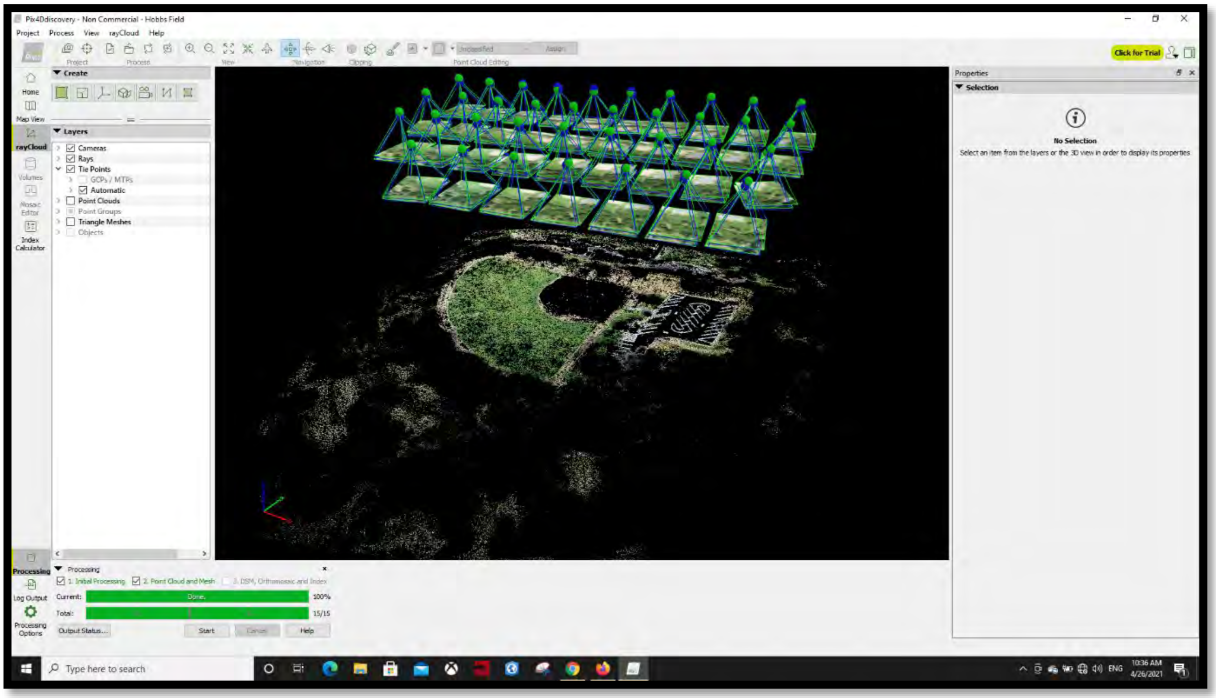
After reviewing the results from ArcGIS Pro (figure 3.1.1 and figure 3.1.2) I decided to process the images using PIX4D Mapper.

Figure 3.1.1

Figure 3.1.2.

I made used the default settings when importing the data in PIX4D Mapper and began the process. Within a few minutes I had the tie points mapped. (figure 3.1.3)

FIGURE 3.1.3



While viewing the processing report it was apparent that the software was able to locate significantly more tie points (key points) in comparison to ArcGIS Pro. (figure 3.1.5 and attachment 3) The median number of tie points per image equaled 3,720 using Pro (figure 3.1.4 and attachment 4) versus 14,310 per image with PIX4D Mapper (figure 3.1.5)

Figure 3.1.4

Summary of Tie Points

Min	820
Max	6374
Median	3720
Average	3680

Figure 3.1.5

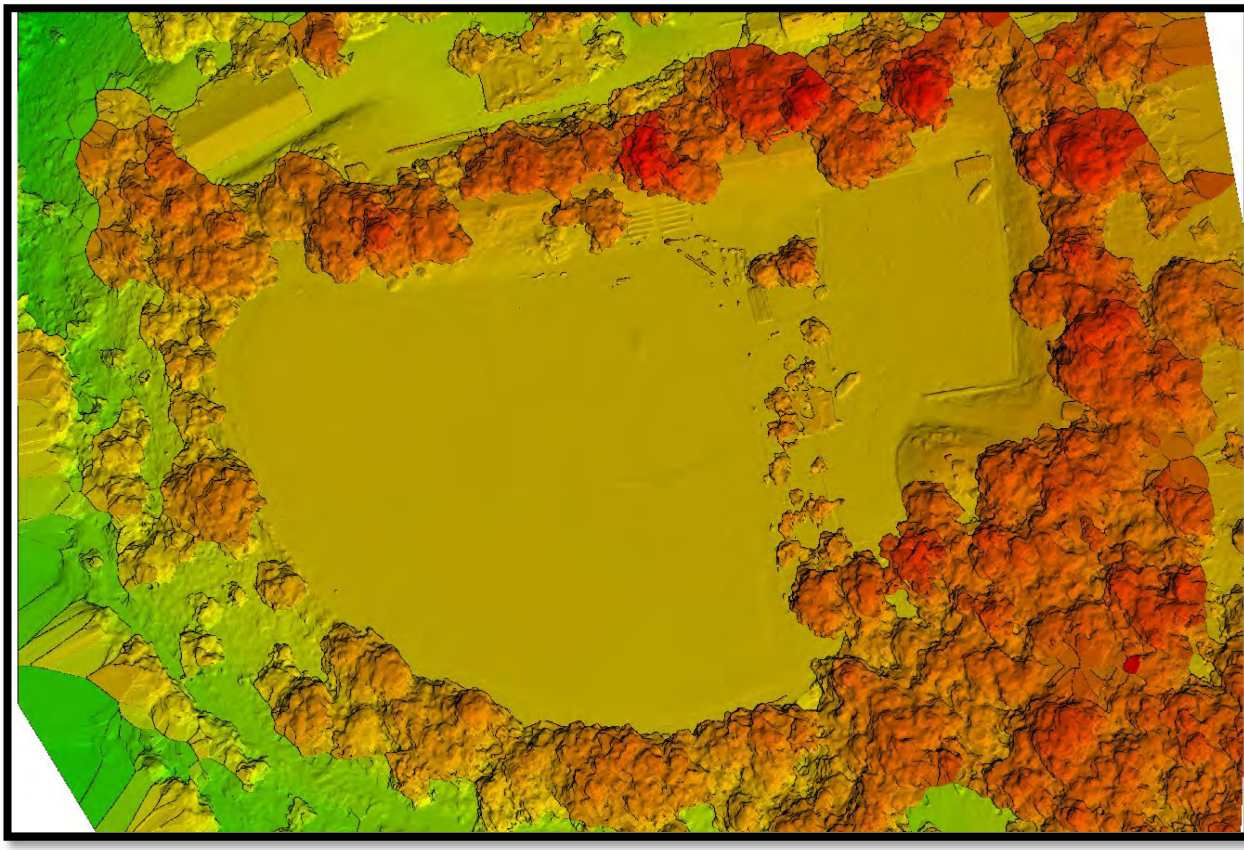
2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	61634	14310
Min	47606	5152
Max	74950	20690
Mean	60747	13676

This factor is what I believe allow PIX4D Mapper to produce a more detailed and accurate orthomosaics and DEM. (figure 3.1.6 and figure 3.1.7)

Figure 3.1.6

Figure 3.1.7

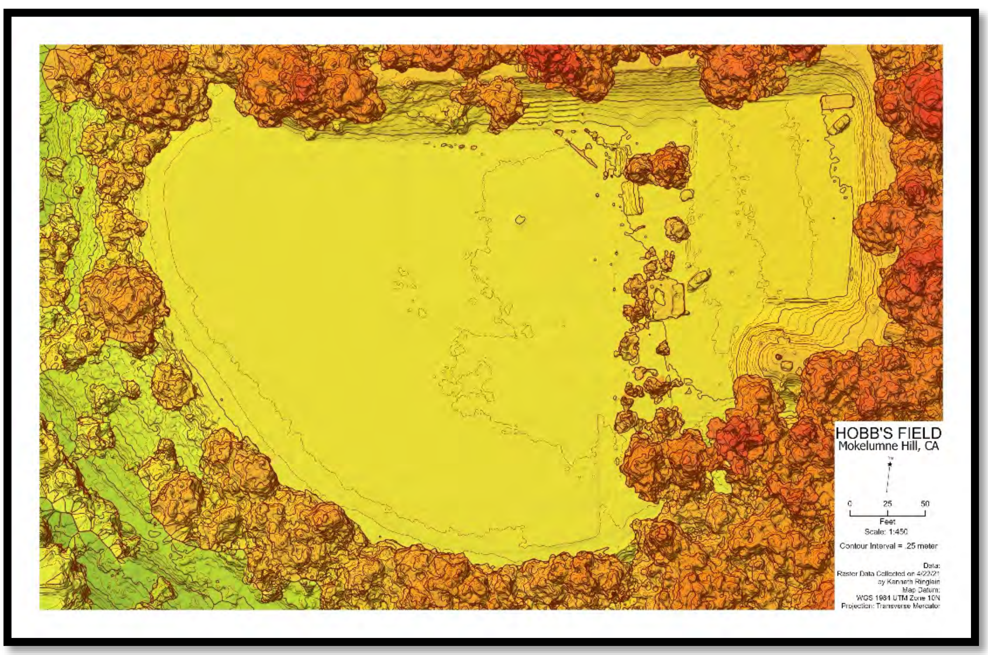


4.0 FINAL PRODUCTS

After creating the orthomosaics and DEM in PIX4D Mapper, I imported the files into ArcGIS Pro to create the final products for use by the Veterans Board. (figure 4.0.0 and figure 4.0.1) (Attachments 1 and 2)

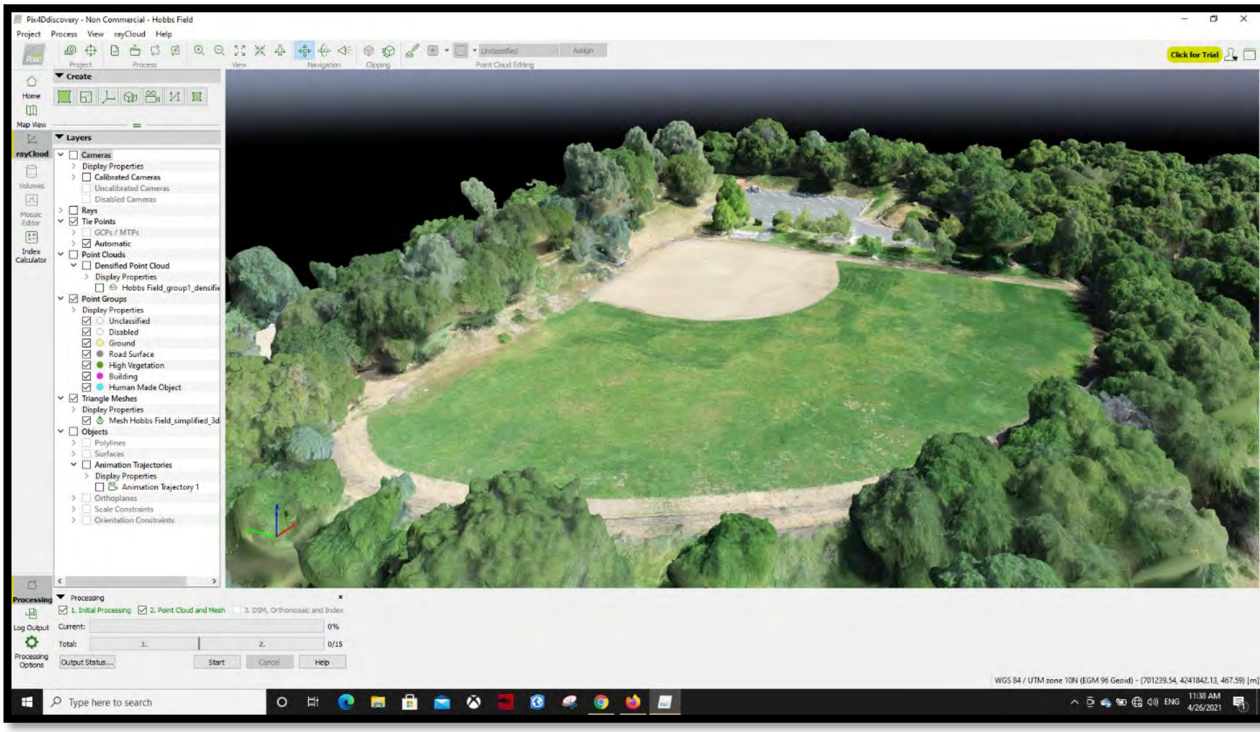
Figure 4.0.0

Figure 4.0.1



With the aid of PIX4D Mapper, I was able to create a 3d "Fly Over" of the ball field. Which may not be useful for irrigation or maintenance purposes. Will be useful for fund raising by the Veterans Board. (figure 4.0.2)

Figure 4.0.2



4.1 FINAL THOUGHTS

With a little research and a lot of YouTube watching, acquisition and setup of the drone and apps was relatively easy.

Flight planning can affect the success of the products you are able to create. Having the ability to adjust and re-fly the project area is a significant advantage.

Having access to software specifically designed for processing of aerial imagery was instrumental in the success of the project.

ArcGIS Pro enabled the creation of final products that met the overall goals of the project.

Results:

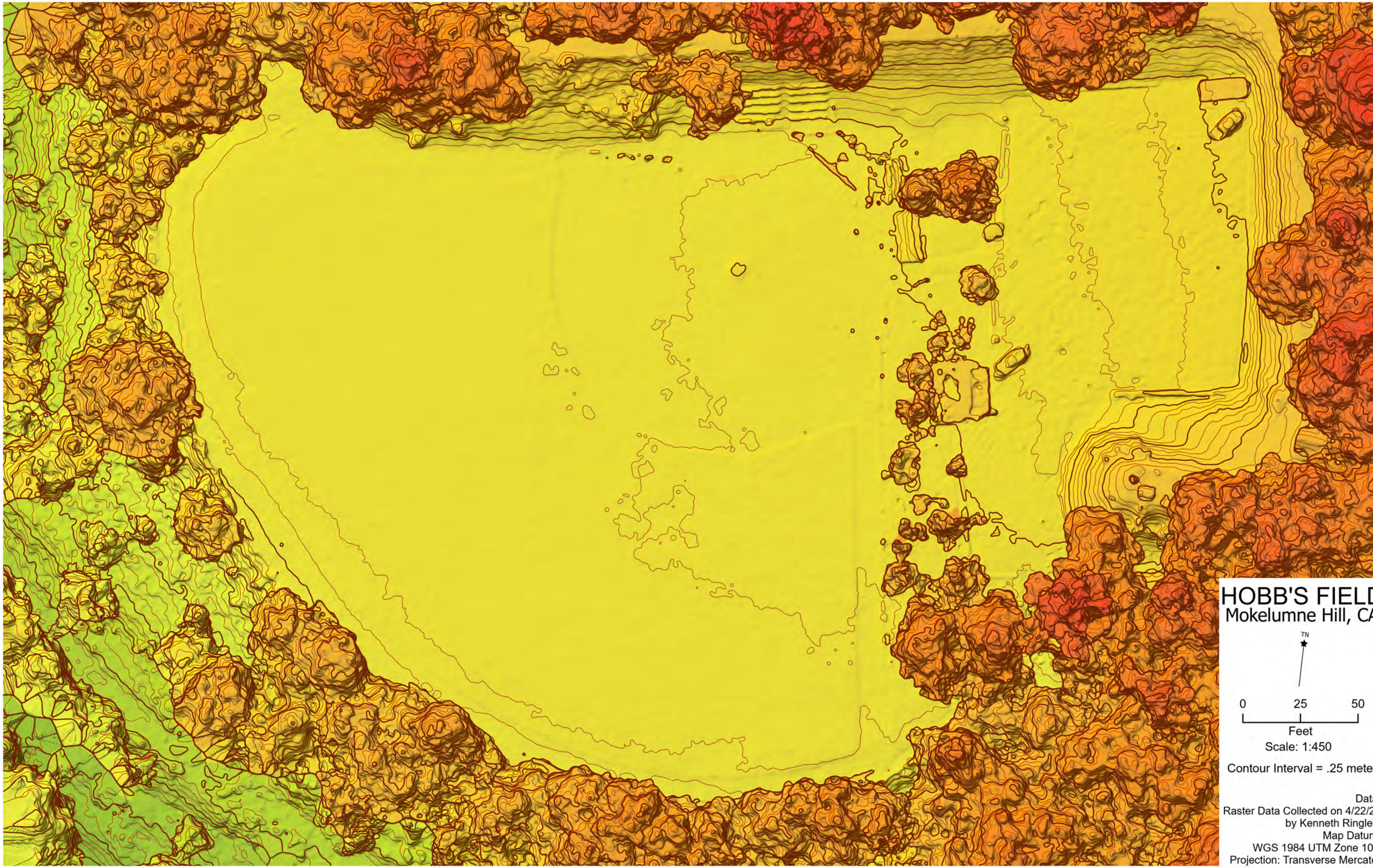
Data collection results were successful.

Image processing:

ArcGIS Pro – Results lacked detail and were not useful in creating accurate DEM or Orthomosaics Images. Required significantly more input from the analyst.

PIX4DMAPPER – Easily produces accurate detailed Orthomosaics Images and DEM.

Attachment 1



Attachment 2

Attachment 3

Adjustment Report

Project Name: HOBBS

Adjustment Summary

Project Name	HOBBS
Report Time	2021-5-7 13:22:34
Number of Input Images	72
Number of Adjusted Images	72
Number of Tie Points	265020
Number of Solution Points	84314
Mean Reprojection Error (pixel)	0.22
Ground Resolution (m/pixel)	0.025
Adjustment Type	Frame
Ground Control Points Involved in Adjustment	No

Summary of Tie Points

Min	820
Max	6374
Median	3720
Average	3680

Summary of Solution Points

2-Rays	51054
3-Rays	15484
4-Rays	6763
5-Rays	3435
6-Rays	2155
7-Rays	1318
8-Rays	906

9-Rays	707
10-Rays	479
11-Rays	360
12-Rays	316
13-Rays	228
14-Rays	177
15-Rays	179
16-Rays	121
17-Rays	105
18-Rays	69
19-Rays	76
20-Rays	66
21-Rays	58
22-Rays	42
23-Rays	36
24-Rays	28
25-Rays	31
26-Rays	23
27-Rays	15
28-Rays	18
29-Rays	8
30-Rays	7
31-Rays	11
32-Rays	9
33-Rays	5
34-Rays	6
35-Rays	4
36-Rays	2
37-Rays	7
38-Rays	2
39-Rays	2
40-Rays	1
41-Rays	1

Tie Point Projection Error Per Image

Min (Pixel)	0.18 (DJI_0010)
Max (Pixel)	0.29 (DJI_0021)
Median (Pixel)	0.22
Average (Pixel)	0.22

Camera Calibration

Focal Length (mm)	Principal Point X (mm)	Principal Point Y (mm)	Distortion Parameters
8.804	0.032	0.089	0.000e+00, -9.620e-05, 1.490e-07, 1.685e-08, 1.034e-04, 3.083e-04

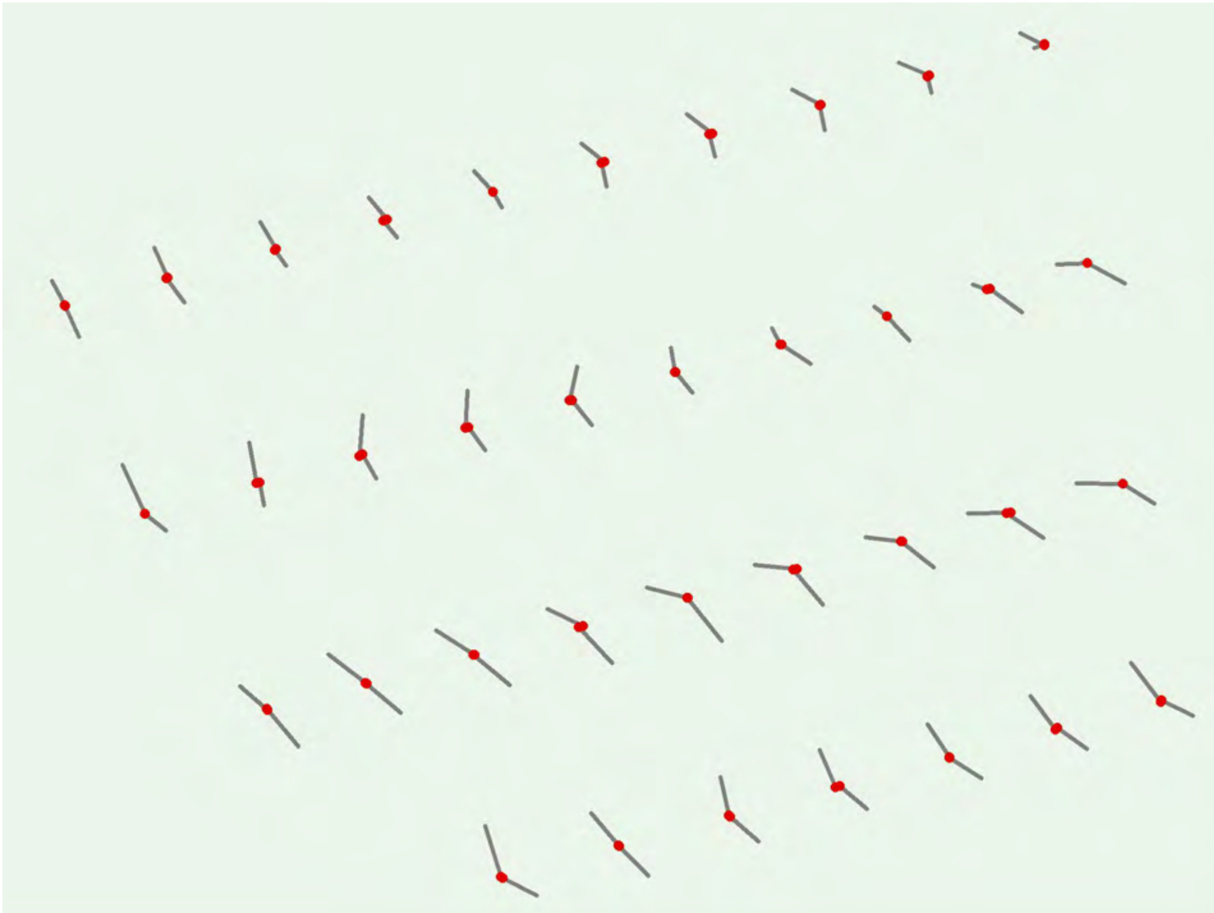
Principal point is a point on the image plane where a line from perspective center (camera lens), perpendicular to the image plane, intersects the image plane. X direction is parallel to the direction of image columns, and Y direction is parallel to the direction of rows. Position of Principal point is referenced to the physical center of image plane. Lens distortion parameters are defined by Brown-Conrady Model.

GPS Positioning Deviations

	dX (m)	dY (m)	dZ (m)
Min	-0.682	-0.629	-0.854
Max	0.547	0.739	1.269
Median	0.047	-0.033	-0.106
Average	0.000	-0.000	-0.000

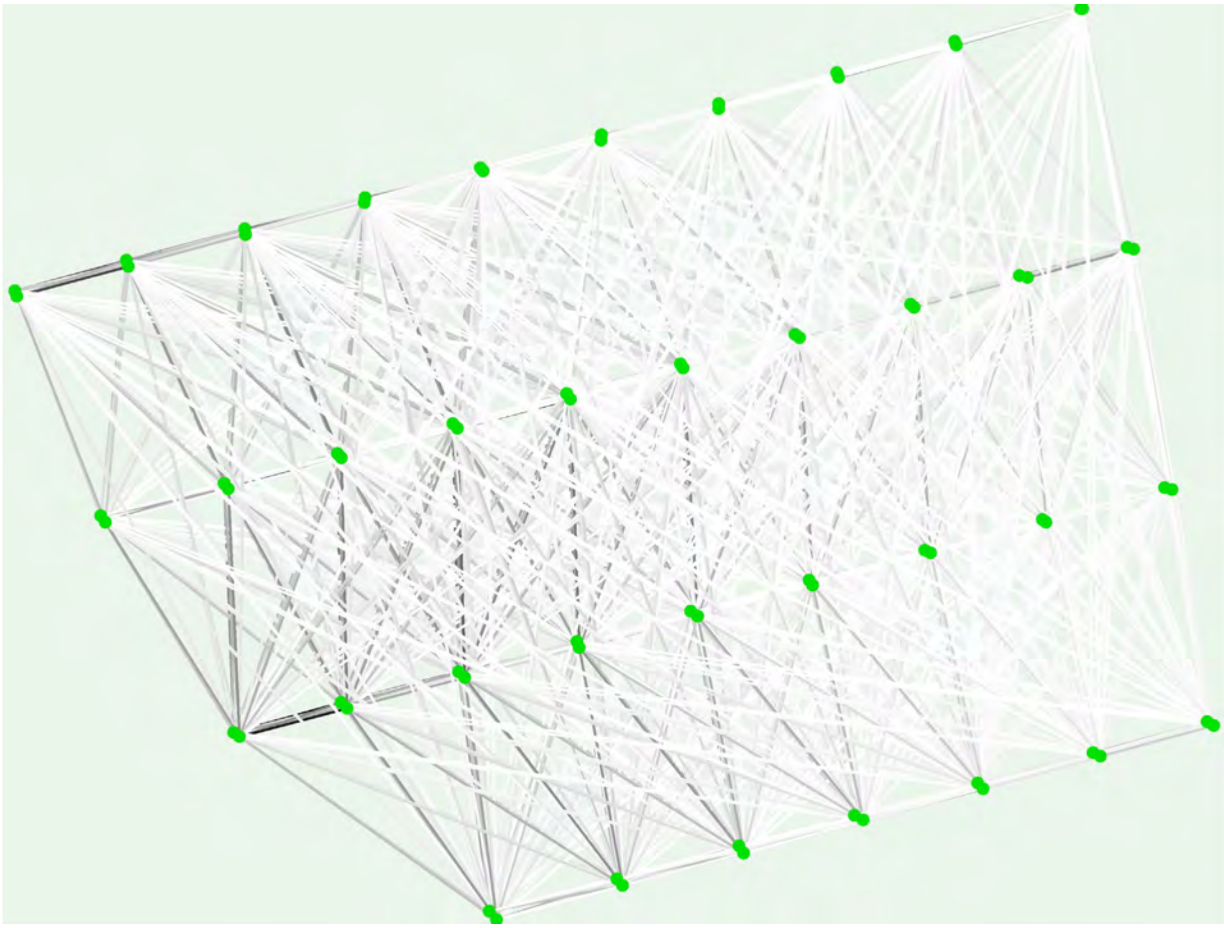
This table shows the image positioning change by adjustment if initial position information from GPS is available.

Initial GPS Positions and Adjusted Positions



Red points are initial position of images from GPS. Vectors in gray, exaggerated by 11X, indicate the positioning change by adjustment.

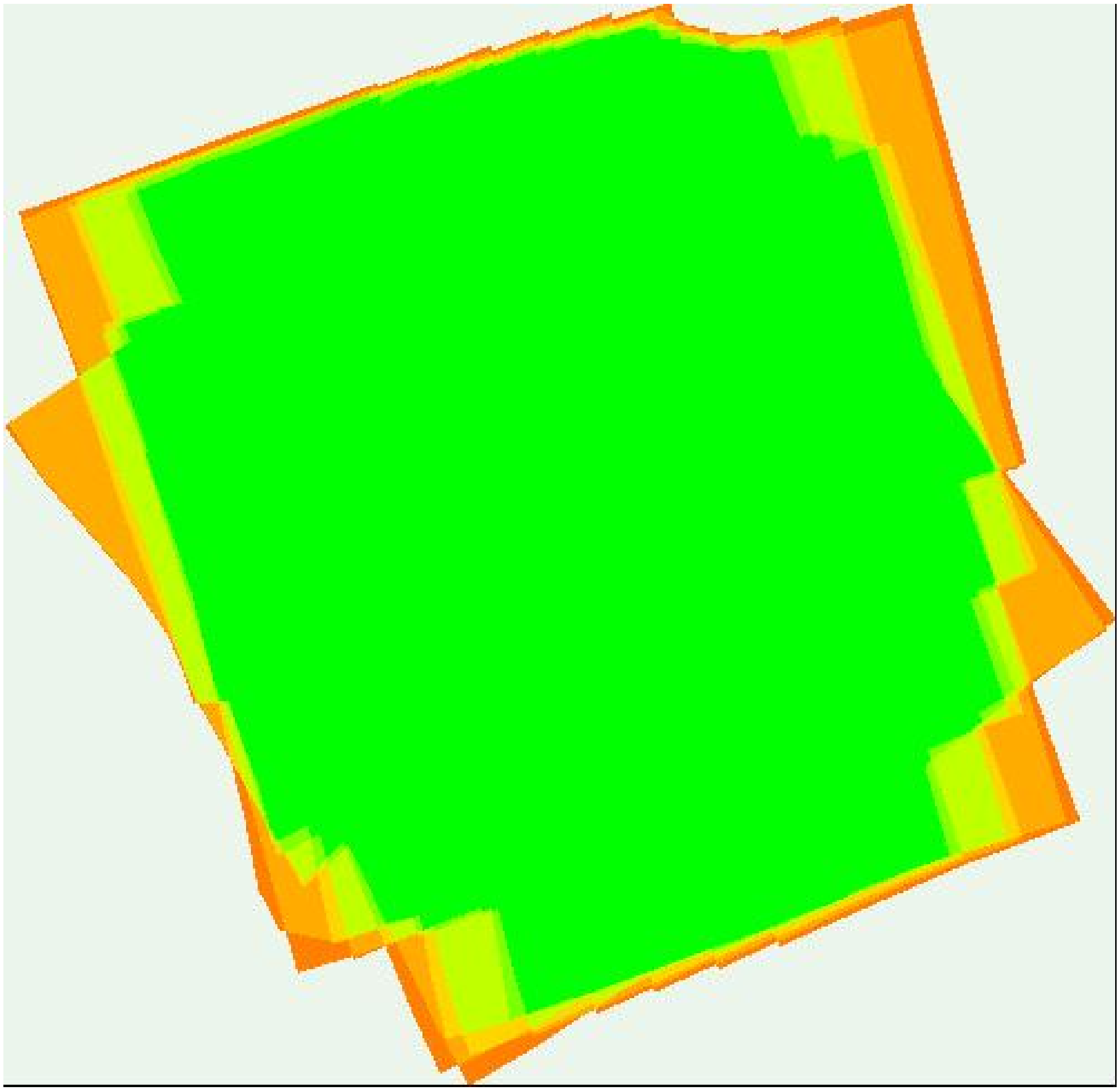
Cross Matches



Green points are image positions after bundle adjustment. A link between two images means tie points found between. Darker color of link means more tie points found.

Overlap Map

6+
5
4
3
2
1



Maximum Overlap: 43; Minimum Overlap: 2

Attachment 4

Quality Report

Generated with Pix4Dmapper version 4.6.4

Important: Click on the different icons for:

Help to analyze the results in the Quality Report

Additional information about the sections

Click here for additional tips to analyze the Quality Report

Summary

Project	Hobbs427
Processed	2021-04-28 08:41:44
Camera Model Name(s)	FC6310_8.8_5472x3648 (RGB)
Average Ground Sampling Distance (GSD)	2.50 cm / 0.98 in
Area Covered	0.056 km^2 / 5.5727 ha / 0.02 sq. mi. / 13.7776 acres
Time for Initial Processing (without report)	03m:19s

Quality Check

Images	median of 61634 keypoints per image	✓
Dataset	72 out of 72 images calibrated (100%), all images enabled	✓
Camera Optimization	0.94% relative difference between initial and optimized internal camera parameters	✓
Matching	median of 14310 matches per calibrated image	✓
Georeferencing	yes, no 3D GCP	⚠

Preview

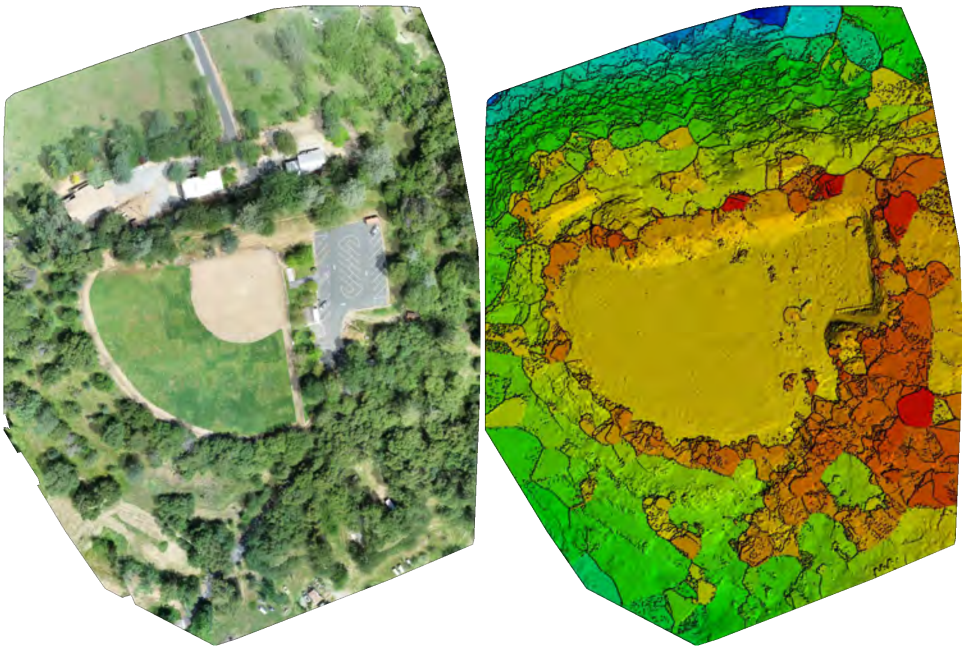


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

Number of Calibrated Images	72 out of 72
Number of Geolocated Images	72 out of 72

Initial Image Positions

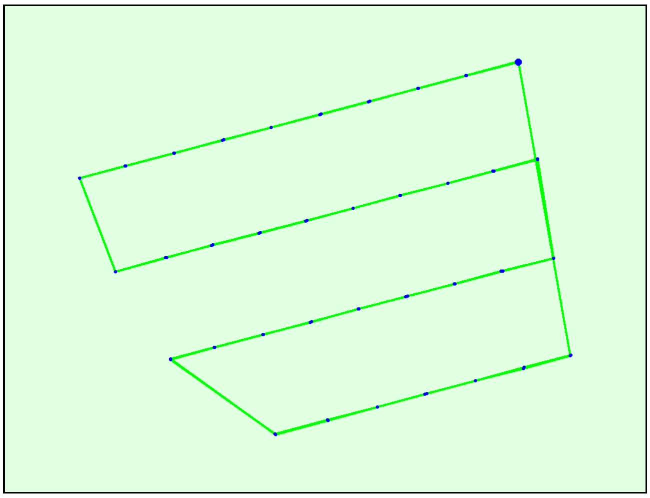
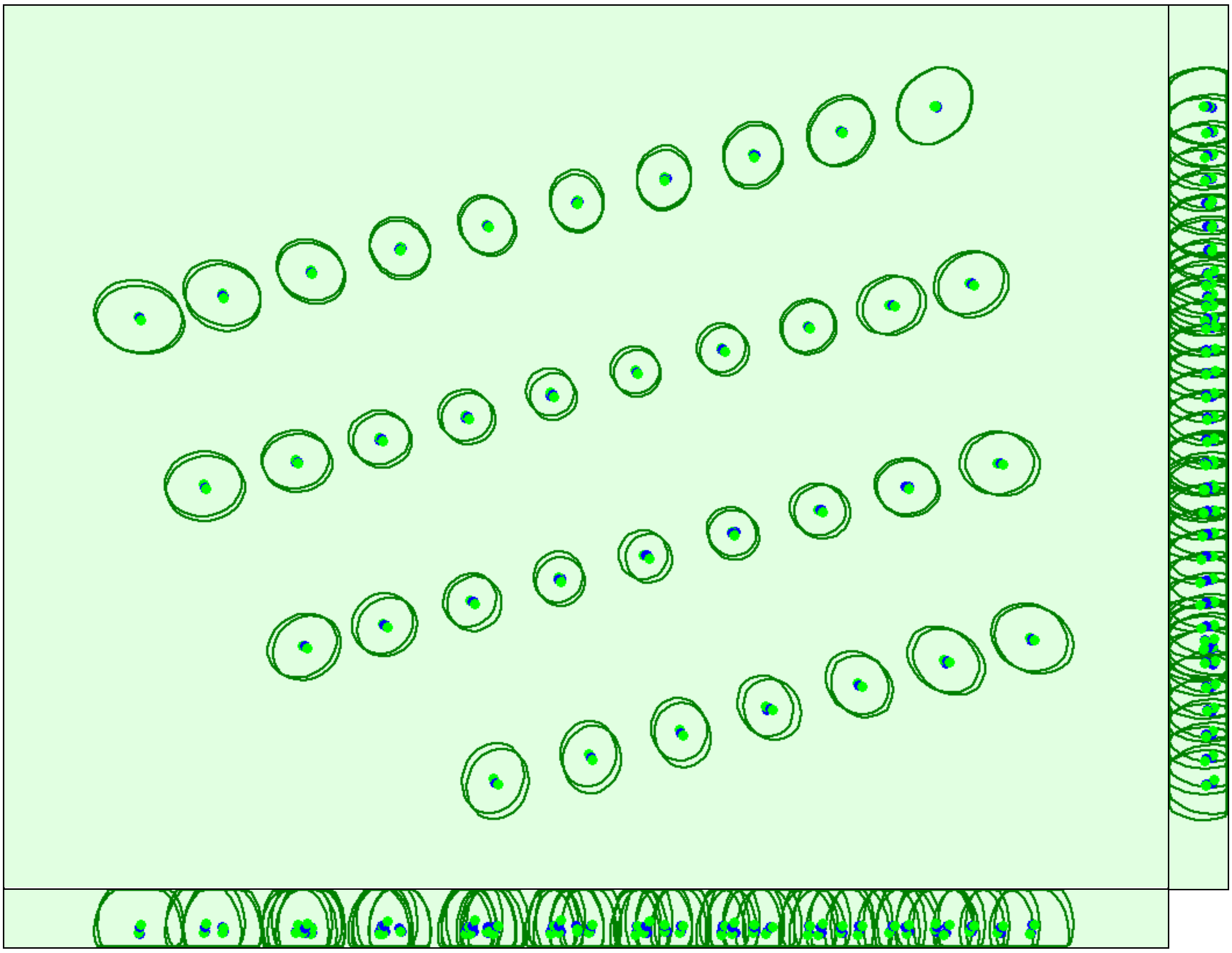


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

Computed Image/GCPs/Manual Tie Points Positions



Uncertainty ellipses 50x magnified

Figure 3: 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.

Absolute camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.122	0.119	0.194	0.057	0.057	0.061
Sigma	0.020	0.015	0.006	0.000	0.000	0.000

Overlap

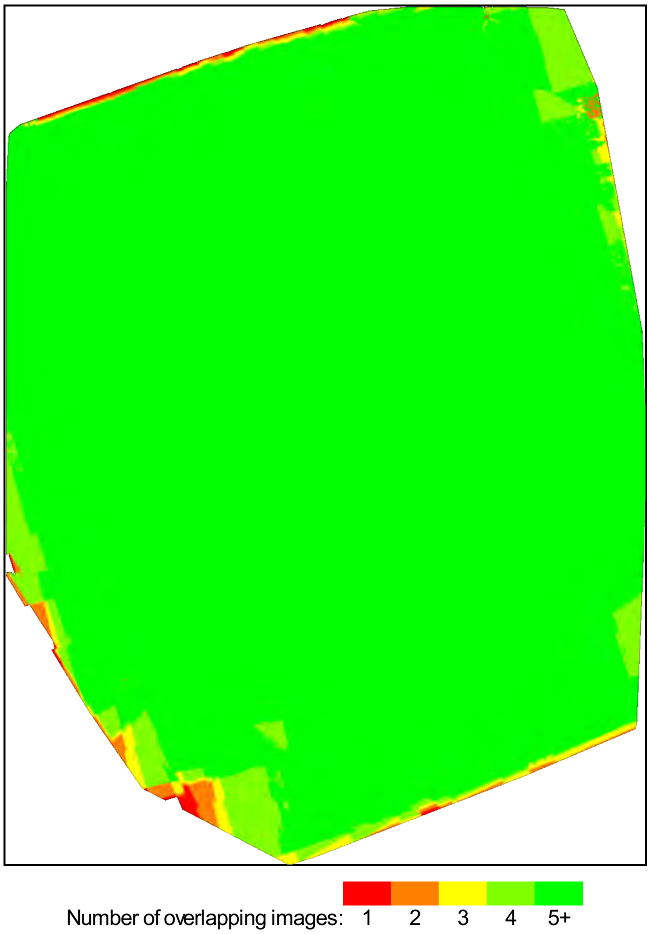


Figure 4: Number of overlapping images computed for each pixel of the orthomosaic.
Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

Bundle Block Adjustment Details

Number of 2D Keypoint Observations for Bundle Block Adjustment	984644
Number of 3D Points for Bundle Block Adjustment	319034
Mean Reprojection Error [pixels]	0.181

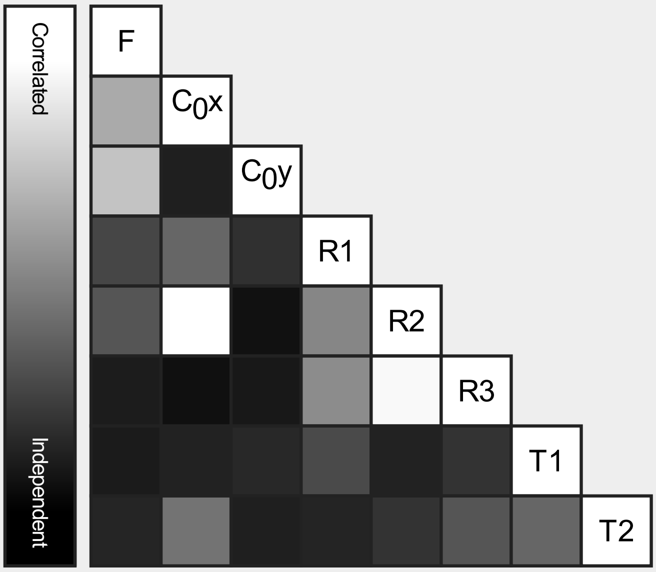
Internal Camera Parameters

FC6310_8.8_5472x3648 (RGB). Sensor Dimensions: 12.833 [mm] x 8.556 [mm]

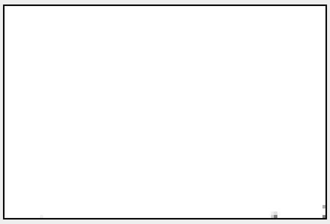
EXIF ID: FC6310S_8.8_5472x3648

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	3668.759 [pixel] 8.604 [mm]	2736.001 [pixel] 6.417 [mm]	1823.999 [pixel] 4.278 [mm]	0.003	-0.008	0.008	-0.000	0.000

Optimized Values	3634.099 [pixel] 8.523 [mm]	2748.304 [pixel] 6.446 [mm]	1785.416 [pixel] 4.187 [mm]	-0.013	0.003	0.005	-0.003	0.001
Uncertainties (Sigma)	1.866 [pixel] 0.004 [mm]	0.105 [pixel] 0.000 [mm]	0.106 [pixel] 0.000 [mm]	0.000	0.000	0.000	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.

2D Keypoints Table

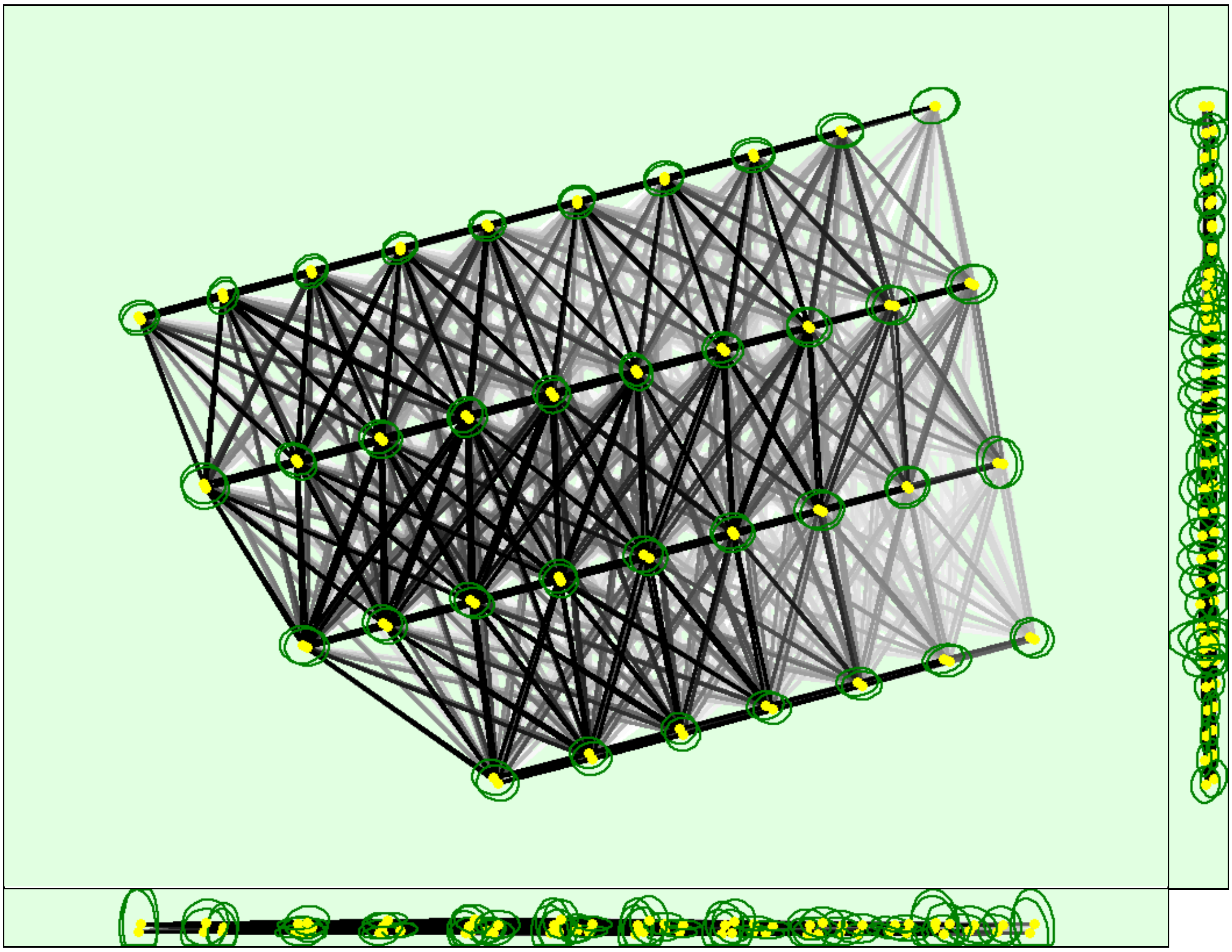
	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	61634	14310
Min	47606	5152
Max	74950	20690
Mean	60747	13676

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	210529
In 3 Images	48602
In 4 Images	21209
In 5 Images	11515
In 6 Images	6953
In 7 Images	4530
In 8 Images	3332
In 9 Images	2365
In 10 Images	1789
In 11 Images	1392
In 12 Images	1098
In 13 Images	864
In 14 Images	703
In 15 Images	592
In 16 Images	456
In 17 Images	406

In 18 Images	350
In 19 Images	315
In 20 Images	291
In 21 Images	269
In 22 Images	199
In 23 Images	184
In 24 Images	140
In 25 Images	156
In 26 Images	125
In 27 Images	124
In 28 Images	101
In 29 Images	91
In 30 Images	77
In 31 Images	58
In 32 Images	42
In 33 Images	30
In 34 Images	29
In 35 Images	38
In 36 Images	27
In 37 Images	18
In 38 Images	7
In 39 Images	11
In 40 Images	10
In 41 Images	5
In 42 Images	1
In 43 Images	1

2D Keypoint Matches



Uncertainty ellipses 1000x magnified

Number of matches

25 222 444 666 888 1111 1333 1555 1777 2000

Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.004	0.003	0.003	0.007	0.007	0.001
Sigma	0.000	0.000	0.002	0.004	0.004	0.000

Geolocation Details

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	0.00	0.00	0.00
-3.00	0.00	51.39	48.61	43.06
0.00	3.00	48.61	51.39	56.94
3.00	6.00	0.00	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]		-0.000197	-0.000418	0.000948
Sigma [m]		0.368082	0.375167	0.458560
RMS Error [m]		0.368082	0.375167	0.458561

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.

Relative Geolocation Variance

Relative Geolocation Error	Images X [%]	Images Y [%]	Images Z [%]
[-1.00, 1.00]	100.00	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	0.664
Phi	1.253
Kappa	3.555

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

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i7-10750H CPU @ 2.60GHz RAM: 16GB GPU: Intel(R) UHD Graphics (Driver: 26.20.100.7642), NVIDIA GeForce RTX 2070 (Driver: 26.21.14.4276)
Operating System	Windows 10 Home, 64-bit

Coordinate Systems

Image Coordinate System	WGS 84 (EGM 96 Geoid)
Output Coordinate System	WGS 84 / UTM zone 10N (EGM 96 Geoid)

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	Optimal
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
Time for Point Cloud Densification	08m:39s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	03m:57s

Results

Number of Generated Tiles	1
Number of 3D Densified Points	7237532
Average Density (per m^3)	162.61

DSM, Orthomosaic and Index Details

Processing Options

DSM and Orthomosaic Resolution	1 x GSD (2.5 [cm/pixel])
DSM Filters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp
Raster DSM	Generated: yes Method: Inverse Distance Weighting Merge Tiles: yes
Orthomosaic	Generated: yes Merge Tiles: yes GeoTIFF Without Transparency: no Google Maps Tiles and KML: no
Contour Lines Generation	Generated: yes Contour Base [m]: 0 Elevation Interval [m]: 0.5 Resolution [cm]: 100 Minimum Line Size [vertices]: 20
Time for DSM Generation	04m:38s
Time for Orthomosaic Generation	09m:30s
Time for DTM Generation	00s
Time for Contour Lines Generation	08s
Time for Reflectance Map Generation	00s
Time for Index Map Generation	00s