Determining Optimum Mission Parameters to Achieve High Spatial Accuracy Using Small UAS Photogrammetry Without Ground Control

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Abstract

This project examined the accuracy of the WingtraOne small Unmanned Aerial System (UAS) to determine optimum mission parameters for achieving highest absolute spatial accuracy, without the use of ground control. Three mission parameters were evaluated for the effects on absolute accuracy: Flight Altitude, Image Overlap (forward and side), and GNSS static data collection rate. After analyzing the data from 24 test flights, no statistically significant difference was observed. While trends were observed in the data, additional testing is required to determine statistically valid conclusions.

Introduction

Utilizing UAS to perform mapping missions using photogrammetry has become commonplace since the promulgation of Federal Aviation Administration (FAA) rules for small, unmanned aircraft systems (UAS) in 14 CFR Part 107. The cost and convenience of small UAS are attractive factors to end-users as opposed to traditional airborne imagery. However, most small UAS are not equipped with high-precision inertial measurement units (IMU) and, therefore, require ground control targets to be established prior to flight. Advances in sensor technology have allowed some small UAS manufacturers to achieve high-accuracy data without high-precision IMUs or the establishment of ground control targets. Headquartered in Switzerland, Wingtra is the world's leading vertical takeoff and landing (VTOL) drone producer for mapping, survey, and mining industry professionals. The WingtraOne UAS is equipped with a high-precision post-processed kinematic (PPK) GNSS receiver and high-resolution, full-frame 35mm digital single-lens reflex (DSLR) camera. The WingtraOne UAS is designed to provide survey-grade accuracy without the need for ground control points. This project evaluated several flight parameters to determine the optimum configuration to achieve the highest absolute spatial accuracy.

Methodology

Surveying

In order to evaluate the UAS accuracy, a project area with ground control points was established. A seven-acre, grassy field was selected as the project site (Figure 1). This site is located within the Boy Scouts of America, Avondale Scout Reservation (Camp Avondale) in Clinton, Louisiana, approximately 30 miles northeast of Baton Rouge. The location was chosen for its remote location and its topography. In South Louisiana, it is difficult to find locations with terrain relief. At this site in Camp Avondale, the terrain has an elevation difference of approximately 17 feet.

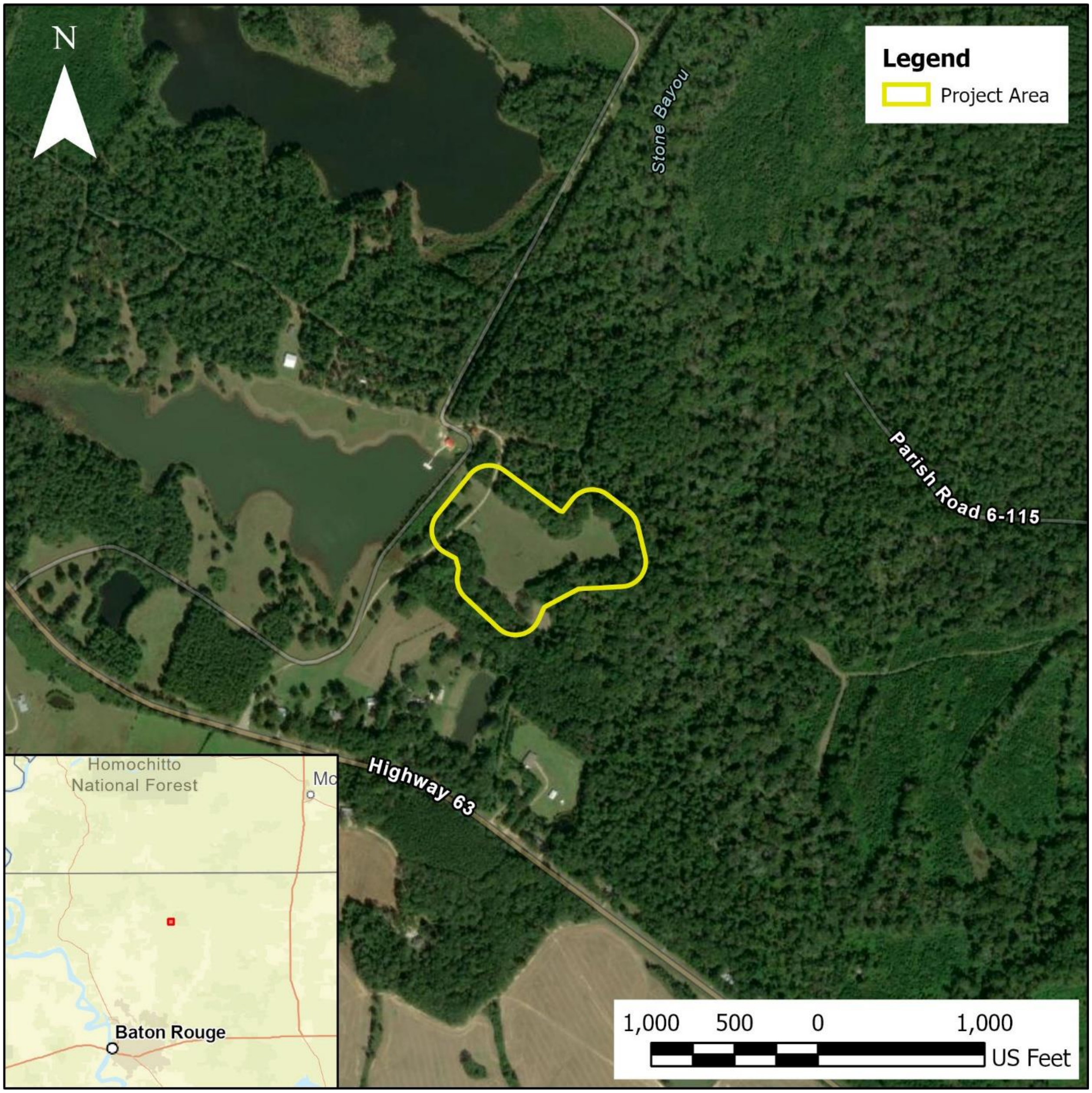


Figure 1 – Project site location within the Boy Scouts of America, Avondale Scout Reservation.

A series of twenty (20) ground control targets were distributed around the project site. The targets were constructed from a 12-inch by 12-inch aluminum sheet with 6-inch black and white checkerboard pattern printed on matte finish adhesive vinyl (Figure 2). A 3/8-inch hole was drilled in the center to accommodate a 6-inch long by ¼-inch diameter survey mag hub. Figure 3 illustrates the distribution of the ground control targets throughout the project area.

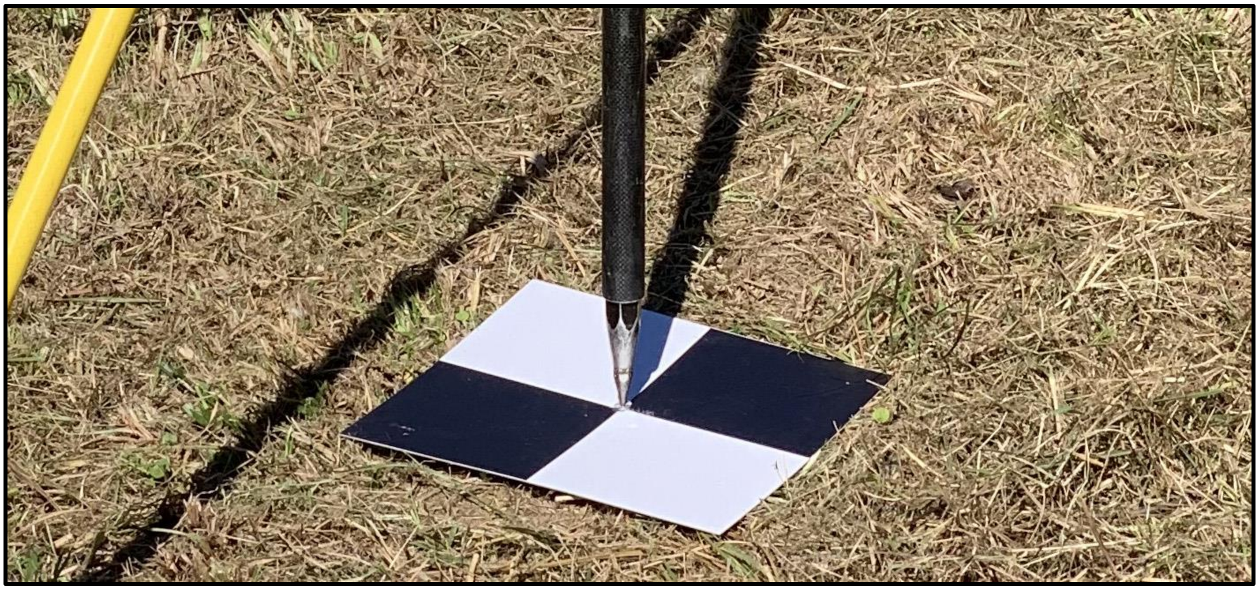


Figure 2 – Ground control target, constructed from 12-inch square aluminum sheet.

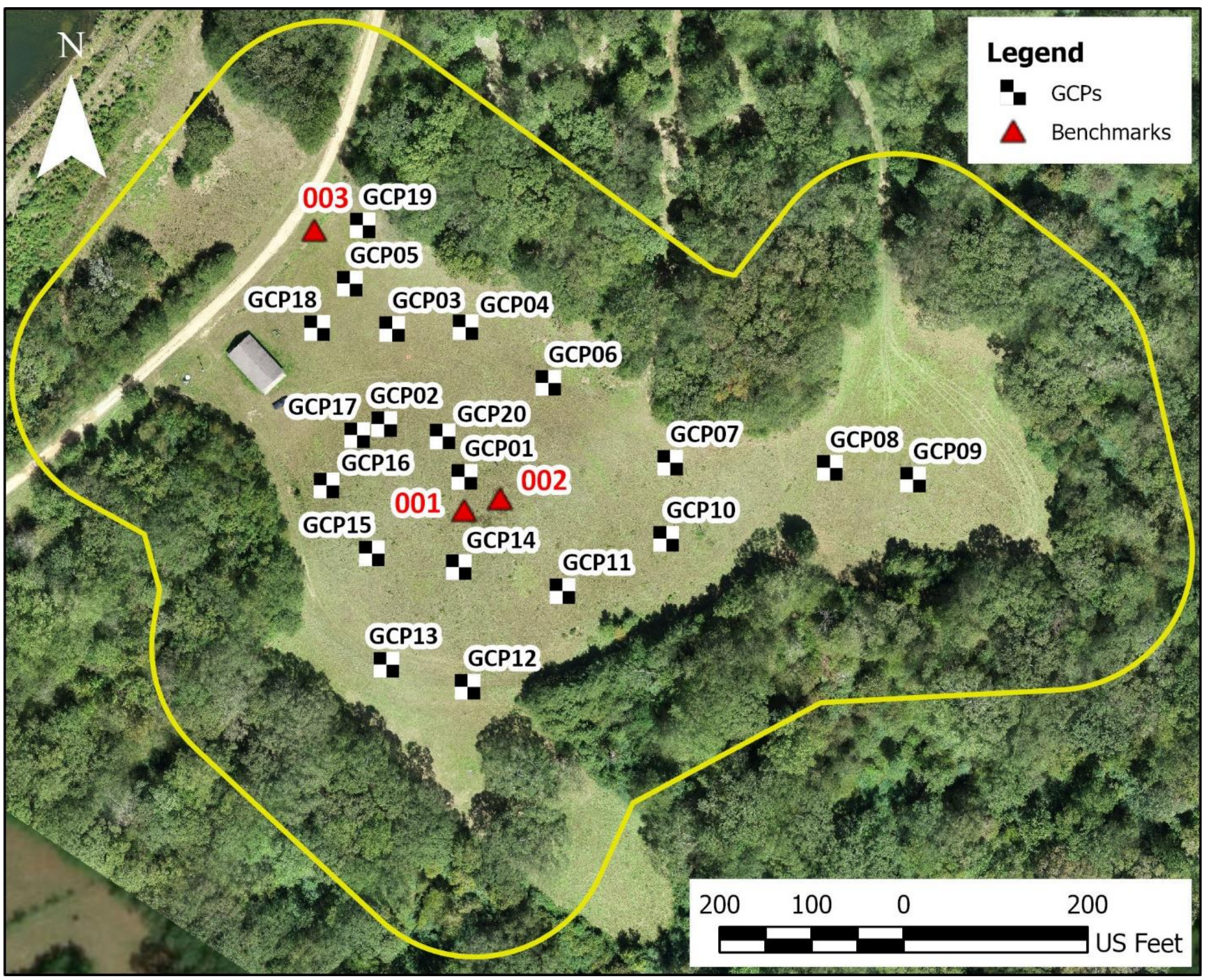


Figure 3 – Distribution of ground control targets throughout project site.

To establish the precise location of each ground control target, numerous surveying and geomatic procedures were performed, as outlined below:

1. Establish local primary benchmark using static GNSS
2. Establish secondary benchmarks using RTK GNSS
3. Setup total station using secondary benchmarks
4. Measure ground control point (GCP) locations using total station

Establish Primary Benchmark

An 18" long, #3 rebar was driven into the ground at the center of the project site. A plastic survey cap was installed on the end of the rebar. A SECO two-meter GPS tripod was setup on the benchmark location. A Trimble R6 Model 4 GNSS receiver was installed on the tripod and connected to an external battery power source (Figure 4).

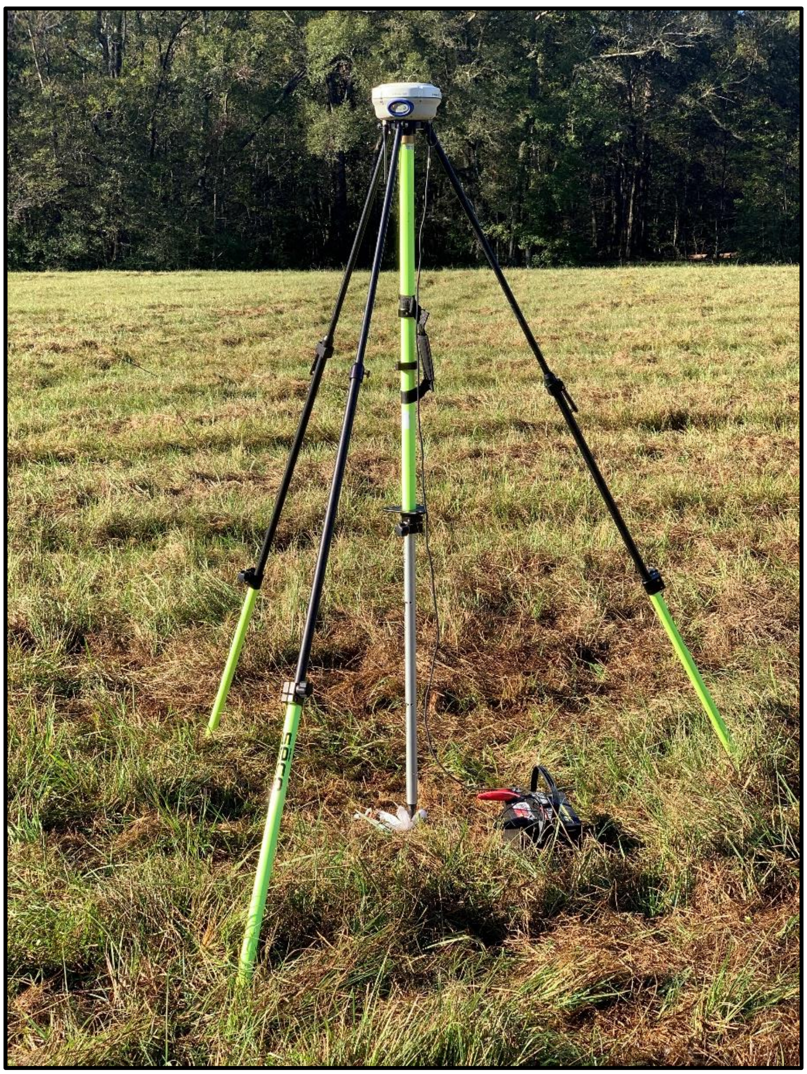


Figure 4 – Trimble R6-4 GNSS receiver setup on primary benchmark (PT001).

A Trimble T10 tablet, installed with Trimble Access field surveying software, was connected to the R6-4 receiver via Bluetooth connection. A job was created in Access and configured using Louisiana State Plane, South Zone, NAD83(2011), NAVD1988, Geoid 18, US feet. Using the Louisiana State University (LSU) C4GNet real-time network, a temporary location of the primary benchmark (PT001) was measured using the Observed Control Point survey style. This survey style was configured to obtain 180 epoch measurements.

Once the initial location of PT001 was obtained, the R6-4 receiver was configured as an RTK base station. The receiver was configured to record static GNSS data as well as broadcast RTK corrections. The static GNSS data would be processed later using NOAA's Online Positioning User Service (OPUS) and PT001 corrected in Trimble Business Center (TBC).

Establish Secondary Benchmarks

Two secondary benchmark locations were set with rebar and plastic caps, similar to the primary benchmark location. PT002 was set for the total station and PT003 was set for the backsight. A Trimble R2 GNSS receiver was configured as a rover and connected to the R6-4 base station using RTK UHF radio. The location of each secondary benchmark was obtained using two separate observed control point measurements, 30 minutes apart. The two observations were averaged to obtain the final measurements for the secondary benchmarks.

Total Station Setup

A Trimble S5 5" robotic total station was utilized for this project. The total station was setup on PT002 and a backsight prism was setup on PT003 (Figures 5 and 6, respectively). The instrument and tribrach were placed on the tripod and centered over PT002. Using the adjustment dials, the instrument was visually leveled initially using the sight vials, then finally using the electronic setup routine. From Trimble Access, a standard station setup was performed using PT002 as the instrument location and PT003 as the backsight point. The residual errors were within default tolerance and the station setup was stored.

Measure Ground Control Points

A Trimble MT1000 prism was used to measure the locations of the GCPs. The MT1000 was placed on an adjustable prism rod with bipod, with the height set to 6.5 feet. At each GCP location, the prism rod was set on the mag nail and leveled with the bipod (Figure 7). Using Trimble Access on the T10 tablet, the measure rounds feature was utilized to obtain the location of the point. The MT1000 prism was set to semi-active mode, for more accurate measurements. The points were measured using two rounds of two observations each with both faces, for a total of eight (8) observations per point. The eight observations were averaged to obtain the final point measurement. Table 1 presents the accuracies of the twenty ground control point measurements. Figure 8 illustrates the relationship between accuracy and slope distance for each GCP.

Figure 5 – Trimble S5 5” robotic total station setup on PT002.

Figure 6 – Backsight prism setup on PT003.

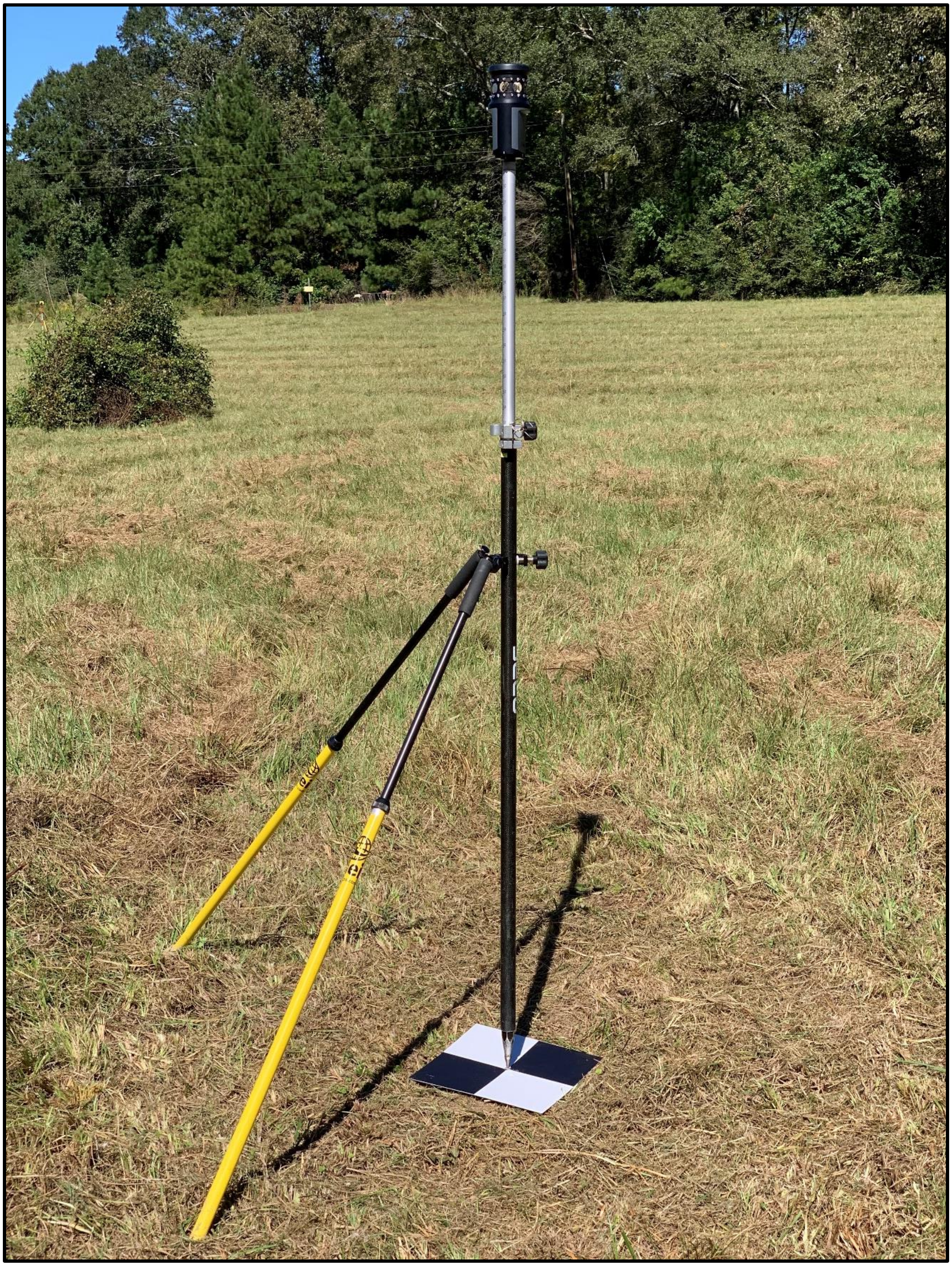


Figure 7 – Trimble MT1000 prism, with prism rod and bipod, setup on a GCP.

Table 1 – Accuracy of ground control point measurements.

Point	Slope Distance (ft)	Hor Err (sec.)	Ver Err (sec.)	Hor Err (ft)	Ver Err (ft)
GCP01	45.429	3.2	17.0	0.0014	0.0075
GCP02	149.620	1.6	4.5	0.0023	0.0065
GCP03	218.669	1.4	5.0	0.0030	0.0106
GCP04	190.073	1.5	4.8	0.0028	0.0088
GCP05	284.962	*	4.8	*	0.0133
GCP06	136.403	0.8	6.7	0.0011	0.0089
GCP07	189.072	2.3	6.3	0.0042	0.0116
GCP08	360.216	1.4	3.9	0.0049	0.0136
GCP09	449.485	2.1	3.3	0.0092	0.0144
GCP10	185.770	1.7	5.1	0.0031	0.0092
GCP11	121.158	1.5	4.7	0.0018	0.0055
GCP12	207.511	1.5	3.3	0.0030	0.0066
GCP13	218.749	1.5	2.8	0.0032	0.0059
GCP14	87.020	1.6	9.8	0.0014	0.0083
GCP15	151.625	2.1	5.2	0.0031	0.0076
GCP16	189.246	0.9	5.3	0.0017	0.0097
GCP17	169.862	2.3	5.3	0.0038	0.0087
GCP18	271.861	1.0	2.7	0.0026	0.0071
GCP19	332.352	1.4	4.2	0.0045	0.0135
GCP20	92.148	3.0	9.7	0.0027	0.0087
			mean	0.0031	0.0093
			SD	0.0018	0.0026

* Error in data collector did not store horizontal accuracy for GCP05

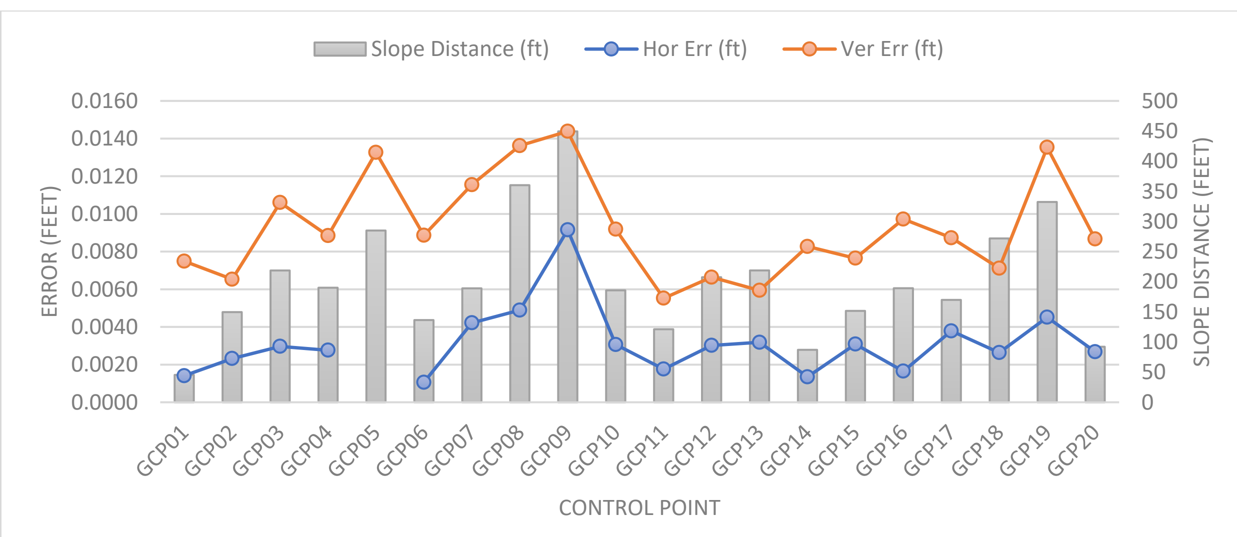


Figure 8 – Graph of GCP measurement accuracy relative to slope distance.

Unmanned Aerial System Mission Planning

The UAS utilized in this project is a WingtraOne, first generation, VTOL (Figure 9), with the following characteristics and specifications:

WingtraOne UAS	
Drone type	Tailsitter vertical take-off and landing (VTOL)
Weight	3.7 kg (8.1 lb)
Max. payload weight	800 g (1.8 lb)
Wingspan	125 cm (4.1 ft)
Battery capacity	Two 99 Wh batteries (a pair of batteries required)
Radio link	Bi-directional 10 km (6 mi) in direct line of sight

PPK Module	
Weight	100 g (0.22 lb)
Constellations	GPS, GLONASS
Bands	L1, L3, L3 (GLONASS only), L5 (GPS only)
Logging Frequency	10 Hz

Sony RX1RII DSLR Camera	
Weight (incl. mount)	590 g (1.27 lb)
Sensor type	Full frame
Sensor size x	35.9 mm (1.41 in)
Sensor size y	24 mm (0.94 in)
Mega pixel	42.4
Lens	35 mm lens

Figure 9 – WingtraOne UAS, equipped with Sony RX1RII camera and PPK system.

When planning a UAS mission, multiple flight parameters and PPK settings must be established. The mission parameters should be optimized based on the project type, processing software, and desired end products. For this project, Pix4Dmapper photogrammetry software was utilized to process the UAS data.

> *Pix4Dmapper is an image processing software that is based on automatically finding thousands of common points between images. Each characteristic point found in an image is called a keypoint. When two keypoints on two different images are found to be the same, they are matched keypoints. Each group of correctly matched keypoints will generate one 3D point. When there is high overlap between 2 images, the common area captured is larger and more keypoints can be matched together. The more keypoints there are, the more accurately 3D points can be computed.* (Pix4D)

Based on the methodology for generating 3D points, it seems that higher resolution images with higher overlap would result in better, more accurate 3D points. Therefore, this project evaluated the following two flight parameters, which should directly correlate to 3D point accuracy:

1. Flight Altitude: Flights were performed at 200, 300, and 400 feet above ground level
2. Image Overlap: Flights were performed with 70% forward and 70% side overlap, 85% forward and 70% side overlap, 70% forward and 85% side overlap, and 85% forward and 85% side overlap

In addition to these flight parameters, the rate in which GNSS static data was collected was also evaluated. Flights were performed with GNSS static data collection rates of 1.0 second (1 hertz), 0.5 seconds (2 hertz), and 0.2 seconds (5 hertz). The WingtraOne flies at approximately 35mph and logs PPK data at a rate of 10 hertz, so faster static collection rates could increase PPK post-processing accuracy.

Table 2 outlines the flight parameters for this project. The project area polygon was loaded into WingtraHub, the flight planning software (Figure 10). A separate flight plan was created for each mission variable. Within a single flight plan, the project area was flown three times by the WingtraOne UAS without landing. A total of 5,462 images were acquired for all flights.

Table 2 – UAS flight plan parameters.

Three flights will be conducted for each variable parameter:
1. Altitude:
a. Fixed Parameters
i. Static Collection Rate: 2 hz
ii. Image Overlap: 70% forward / 70% side
b. Variable Parameter (Altitude):
i. 200ft
ii. 300ft
iii. 400ft
2. Image Overlap:
a. Fixed Parameters
i. Static Collection Rate: 2 hz
ii. Altitude: 400 ft
b. Variable Parameter (Image Overlap):
i. 70% forward / 70% side (same as FL 1-3)
ii. 85% forward / 70% side
iii. 70% forward / 85% side
iv. 85% forward / 85% side
3. Static Collection Rate:
a. Fixed Parameters
i. Image Overlap: 85% forward / 70% side
ii. Altitude: 400 ft
b. Variable Parameter (Static Collection Rate):
i. 1hz
ii. 2hz (same as FL 2-2)
iii. 5hz

Figure 10 – Flight 1-1 in the WingtraHub flight planning software.

<u>Data Processing</u>

Once the data acquisition was completed, the PPK image geotags were processed using WingtraHub. A csv geotag file and processing report (Figure 11) was generated for each flight. The csv geotag file contained the following information for each image (Table 3a):

- Latitude
- Longitude
- Ellipsoid height (m)
- Omega (degrees)
- Phi (degrees)
- Kappa (degrees)
- Horizontal accuracy (m)
- Vertical accuracy (m)

Processing Report

Generated by WingtraHub v2.3.0

Project summary

Project	Masters Project FL 1_1 Flight 01
Flown	2021/10/17 14:59 UTC
Processed	2021/10/18 12:53 UTC
Camera	RX1RII
Images	1129

Geotagging summary

Output coordinate system	Geodetic ellipsoidal height (NAD83 (EPSG:6318))
PPK processed	Yes
Base file(s)	55462901.21g 55462901.21n 55462901.21o
Base	Magee CP001
Base location	Geodetic ellipsoidal height (NAD83 (EPSG:6318)) 30° 50' 41.6130000" N, 90° 58' 18.6265600" W, 34.48500 m 30.8448925000°, -90.9718407111°, 34.48500 m
Base antenna offset	East: 0.00000 m, North: 0.00000 m, Up: 2.00000 m
Detected base antenna type	TRMR6-4 NONE

Quality Summary

Matching	1129 images tagged.
PPK fix	100.00%
Mean accuracy	0.02 m horizontal, 0.03 m vertical
Warnings	None
Infos	None

Figure 11 – WingtraHub PPK processing report for Flight 1-1.

The geotag csv was imported into Trimble Business Center and converted into grid coordinates (Louisiana State Plane, South Zone, NAD83(2011), NAVD1988, Geoid 18, US feet). The converted image center data was exported to a csv and merged with the remainder of the geotag data to create an image geotag file in US feet grid coordinates (Table 3b).

As previously discussed, Pix4Dmapper software (v4.6.4) was utilized to process the UAS imagery (Figure 12). A new project was created for each iteration of each flight, for a total of 24 separate P4D projects. The images were loaded into the project, the correct coordinate system was specified, and the geotags imported from the appropriate csv file. The surveyed GCPs were loaded into the project using a csv file.

Table 3a – Example WingtraHub geotag output file after PPK processing.

# Image Name	Latitude [Decimal Degrees]	Longitude [Decimal Degrees]	Altitude [Meter]	Omega [Degrees]	Phi [Degrees]	Kappa [Degrees]	Accuracy Horizontal [Meter]	Accuracy Vertical [Meter]
Masters_Project_FL_1_1_Flight_01_00002.JPG	30.84619491	-90.97283231	110.5117905	0.48170877	-3.47279918	-74.87833275	0.02	0.03
Masters_Project_FL_1_1_Flight_01_00003.JPG	30.84619409	-90.97269217	111.6745117	-3.6388854	-2.01970213	-72.98791018	0.02	0.03
Masters_Project_FL_1_1_Flight_01_00004.JPG	30.84619607	-90.97255864	112.6840248	-3.69445848	1.61849191	-74.95960478	0.02	0.03
Masters_Project_FL_1_1_Flight_01_00005.JPG	30.84619766	-90.97242499	112.4466092	-0.76098112	2.06643099	-73.17438491	0.02	0.03
Masters_Project_FL_1_1_Flight_01_00006.JPG	30.84619805	-90.97228814	111.6616436	-1.7358333	-0.97845114	-72.44691752	0.02	0.03
Masters_Project_FL_1_1_Flight_01_00007.JPG	30.84619937	-90.97215508	112.1078489	-1.01253144	-2.05541128	-72.86189302	0.02	0.03
Masters_Project_FL_1_1_Flight_01_00008.JPG	30.84620089	-90.97201595	113.5693044	0.0210354	3.88805442	-73.84152086	0.02	0.03
Masters_Project_FL_1_1_Flight_01_00009.JPG	30.8462006	-90.97187279	112.5585234	-6.04105817	1.9408076	-76.5931013	0.02	0.03
Masters_Project_FL_1_1_Flight_01_00010.JPG	30.84620936	-90.9717449	112.3520945	-20.84693335	-7.7489386	-66.51110357	0.02	0.03

Table 3b –WingtraHub geotag output file converted to state plane feet.

# Image Name	North [Feet]	East [Feet]	Elevation [Feet]	Omega [Degrees]	Phi [Degrees]	Kappa [Degrees]	Accuracy Horizontal [Feet]	Accuracy Vertical [Feet]
Masters_Project_FL_1_1_Flight_01_00002.JPG	853429.806	3393974.996	451.578	0.48170877	-3.47279918	-74.87833275	0.065616	0.098424
Masters_Project_FL_1_1_Flight_01_00003.JPG	853429.645	3394018.979	455.393	-3.6388854	-2.01970213	-72.98791018	0.065616	0.098424
Masters_Project_FL_1_1_Flight_01_00004.JPG	853430.498	3394060.885	458.705	-3.69445848	1.61849191	-74.95960478	0.065616	0.098424
Masters_Project_FL_1_1_Flight_01_00005.JPG	853431.207	3394102.828	457.926	-0.76098112	2.06643099	-73.17438491	0.065616	0.098424
Masters_Project_FL_1_1_Flight_01_00006.JPG	853431.484	3394145.776	455.35	-1.7358333	-0.97845114	-72.44691752	0.065616	0.098424
Masters_Project_FL_1_1_Flight_01_00007.JPG	853432.095	3394187.536	456.814	-1.01253144	-2.05541128	-72.86189302	0.065616	0.098424
Masters_Project_FL_1_1_Flight_01_00008.JPG	853432.787	3394231.197	461.609	0.0210354	3.88805442	-73.84152086	0.065616	0.098424
Masters_Project_FL_1_1_Flight_01_00009.JPG	853432.823	3394276.13	458.293	-6.04105817	1.9408076	-76.5931013	0.065616	0.098424
Masters_Project_FL_1_1_Flight_01_00010.JPG	853436.136	3394316.255	457.616	-20.84693335	-7.7489386	-66.51110357	0.065616	0.098424

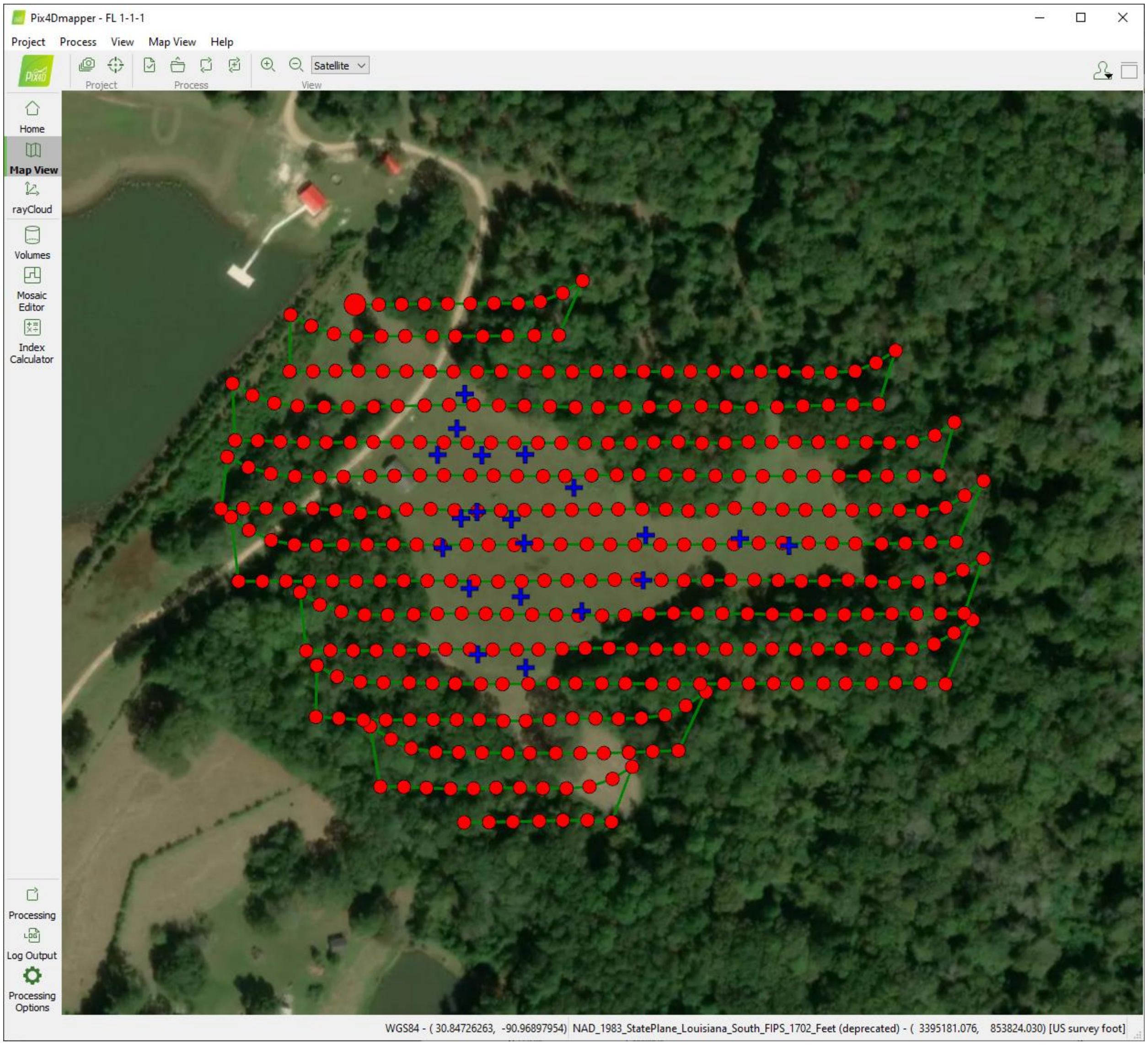


Figure 12 – Pix4Dmapper project for Flight 1-1, iteration 1.

Pix4Dmapper processes UAS imagery in a series of three steps:

1. Initial Processing – Computation of keypoints, automatic aerial triangulation, and block bundle adjustment.
2. Point Cloud Densification and 3D Mesh – Creation of dense point cloud using keypoints generated from step 1. Dense point cloud used to generate mesh surface composed of triangles.
3. Output Generation – Creation of output products, such as orthomosaic, digital surface model, digital terrain model, and contour lines.

Once the initial processing has been completed, GCPs can be marked as checkpoints to determine residual errors. Therefore, for this project, only Step 1 – Initial Processing was performed. Options chosen for the initial processing are illustrated in Figures 13a through c.

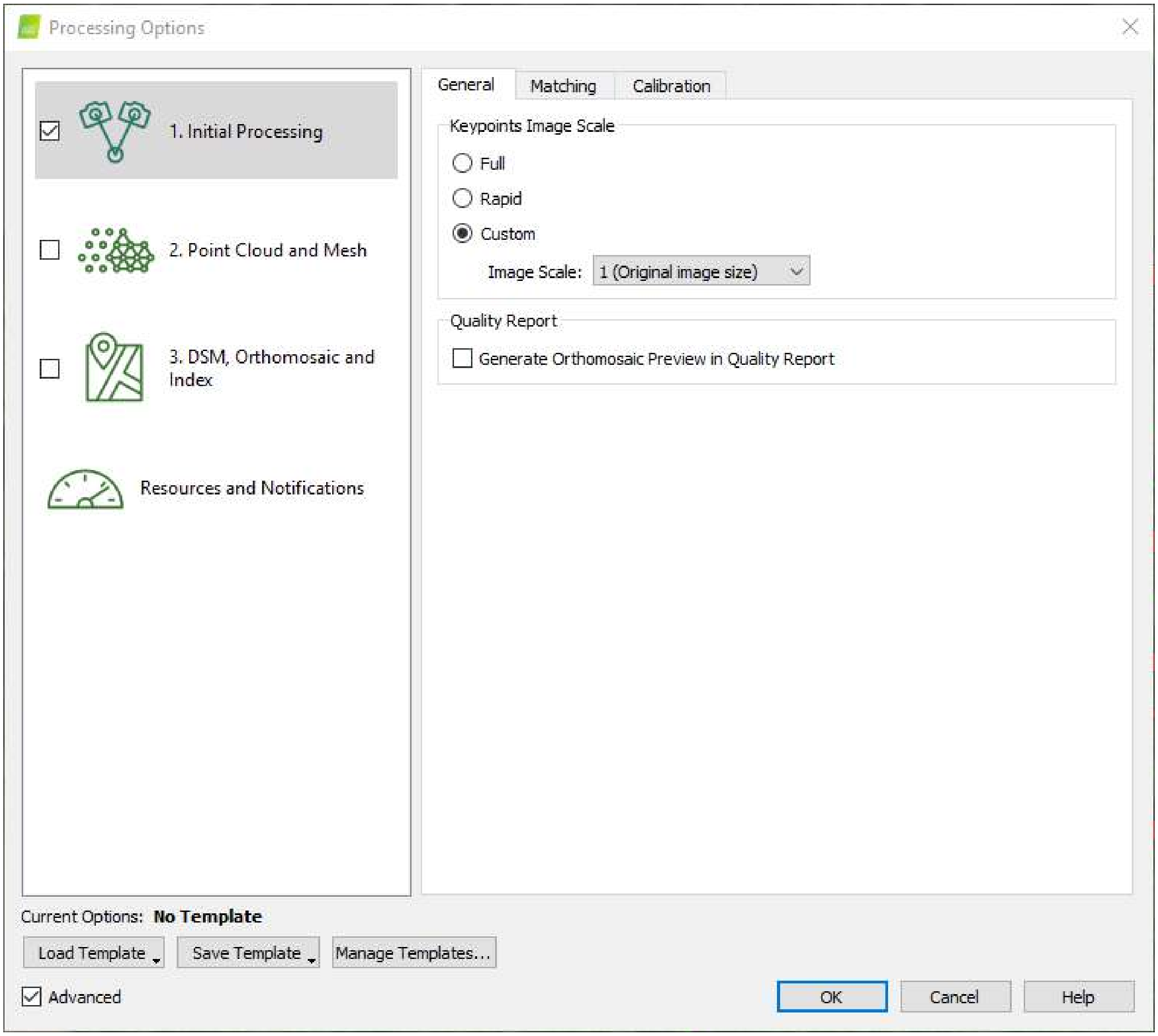


Figure 13a – Pix4Dmapper initial processing options - general.

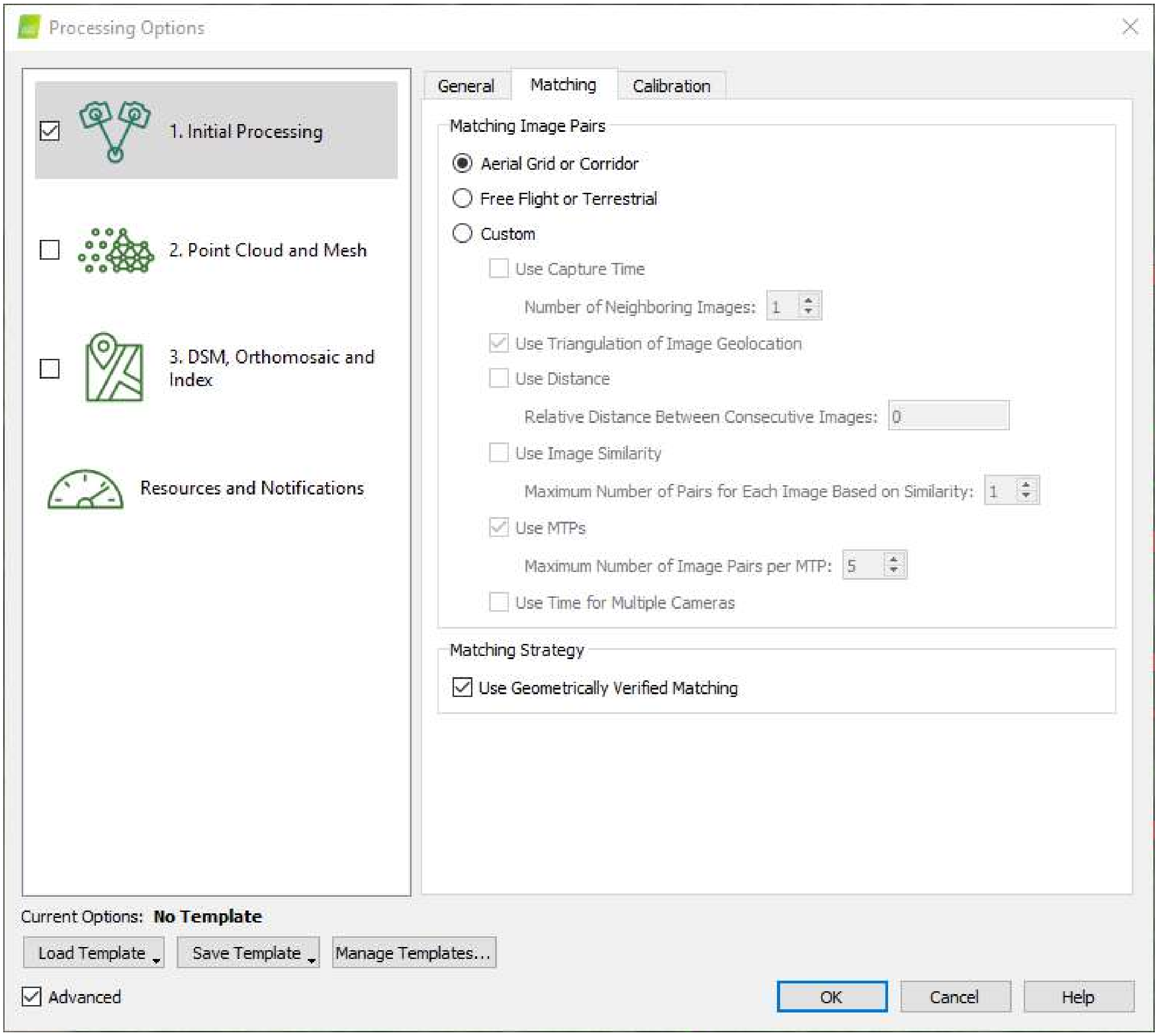


Figure 13b – Pix4Dmapper initial processing options - matching.

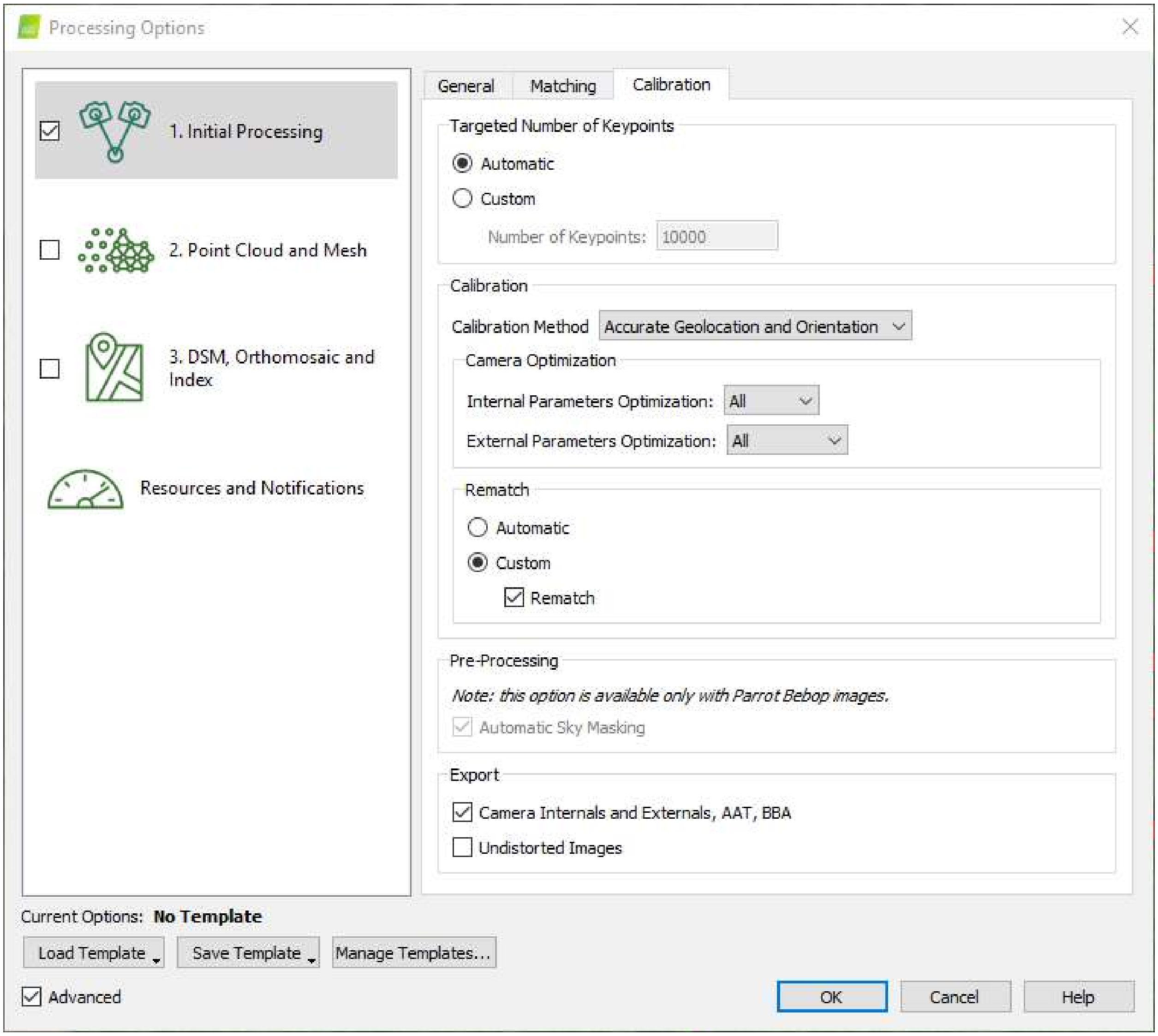


Figure 13c – Pix4Dmapper initial processing options - calibration.

Once the initial processing had been completed for each project, the GCP locations were marked as checkpoints using the rayCloud window in Pix4Dmapper (Figure 14). For each GCP, the point was set as a check point and the center of the target was marked at as high a zoom level as possible. The target was marked in every visible image in the project. Depending on image overlap, each GCP target was marked on 10-65 images. Once all the GCPs had been marked, the project was reoptimized to calculate the checkpoint residual errors. The residual errors show the accuracy of the GCP point locations derived from the photogrammetric model, using PPK geotag data only, relative to the surveyed locations. The Pix4Dmapper quality report provides a processing summary for each project as well as a table of checkpoints and residual errors (Figures 15a and b).

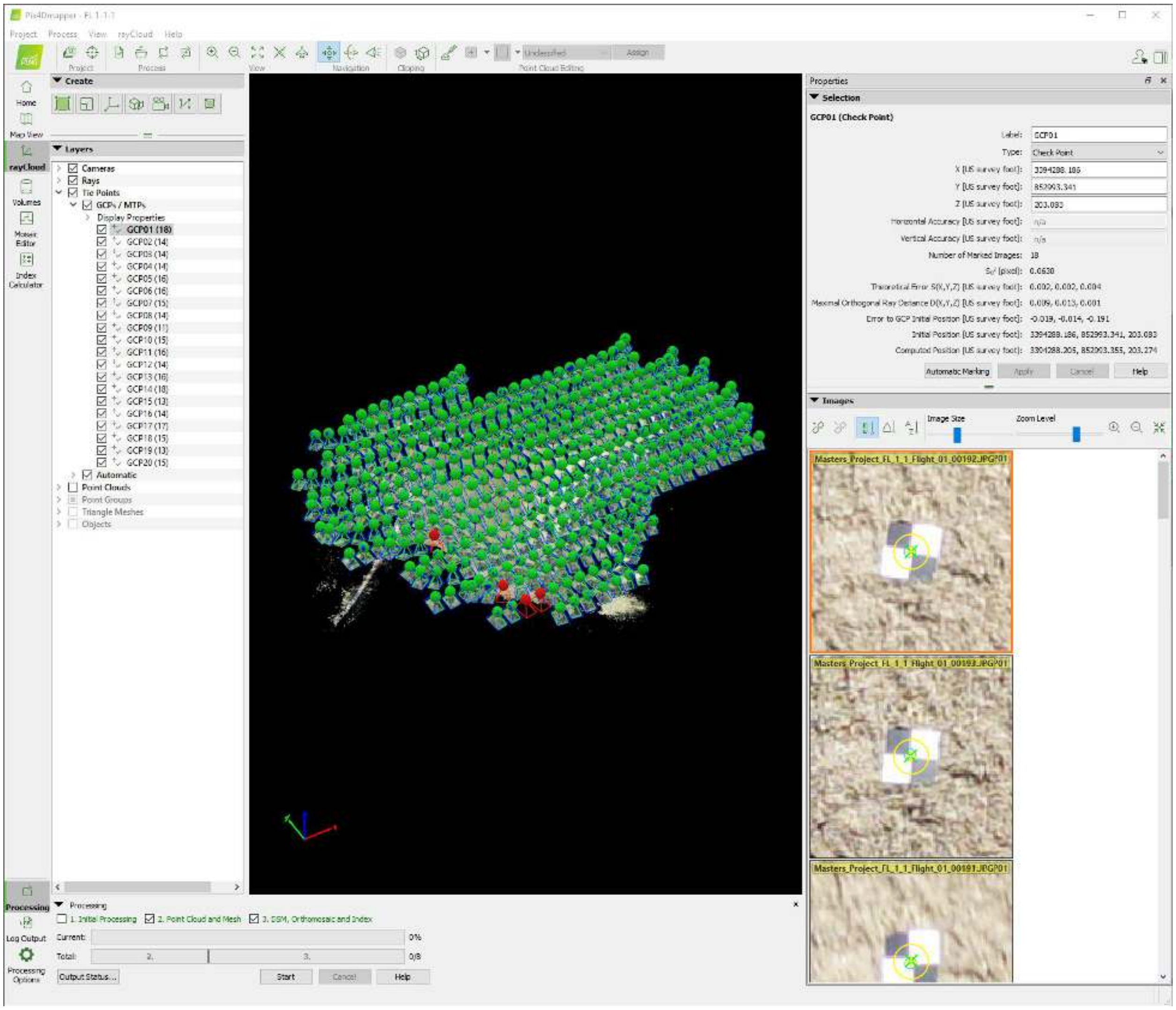


Figure 14 – Marking GCP locations as checkpoints in Pix4Dmapper rayCloud.

Quality Report - FL 1-1-1

Online Support

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	FL 1-1-1
Processed	2021-10-19 19:24:14
Camera Model Name(s)	DSC-RX1RM2_35.0_7952x5304 (RGB)
Average Ground Sampling Distance (GSD)	0.96 cm / 0.38 in

Quality Check

Images	median of 97270 keypoints per image	✔
Dataset	370 out of 374 images calibrated (98%), all images enabled, 4 blocks	⚠
Camera Optimization	0.16% relative difference between initial and optimized internal camera parameters	✔
Matching	median of 6059.51 matches per calibrated image	✔
Georeferencing	yes, no 3D GCP	⚠

Calibration Details

Number of Calibrated Images	370 out of 374
Number of Geolocated Images	374 out of 374

Initial Image Positions

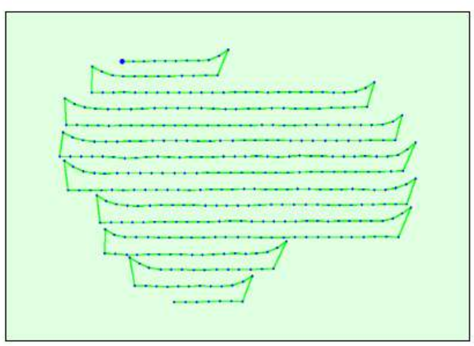


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

Computed Image/GCPs/Manual Tie Points Positions

Display Automatically after Processing

Close

Figure 15a – Pix4DMapper quality report for Flight 1-1, iteration 1.

Quality Report - FL 1-1-1

Online Support

Ground Control Points

0 out of 20 check points have been labeled as inaccurate.

Check Point Name	Accuracy XY/Z [US survey foot]	Error X [US survey foot]	Error Y [US survey foot]	Error Z [US survey foot]	Projection Error [pixel]	Verified/Marked
GCP01		-0.019	-0.014	-0.191	0.310	18 / 18
GCP02		-0.033	-0.002	-0.195	0.263	14 / 14
GCP03		-0.024	-0.016	-0.228	0.368	14 / 14
GCP04		-0.016	-0.031	-0.208	0.357	14 / 14
GCP05		-0.021	-0.003	-0.200	0.337	16 / 16
GCP06		0.014	0.004	-0.203	0.411	16 / 16
GCP07		0.043	-0.041	-0.189	0.246	15 / 15
GCP08		0.038	-0.081	-0.096	0.412	14 / 14
GCP09		-0.009	-0.175	-0.109	0.409	11 / 11
GCP10		0.007	-0.042	-0.144	0.478	15 / 15
GCP11		0.010	-0.081	-0.203	0.353	16 / 16
GCP12		-0.039	-0.068	-0.216	0.414	14 / 14
GCP13		-0.053	-0.041	-0.162	0.402	16 / 16
GCP14		-0.026	-0.025	-0.196	0.318	18 / 18
GCP15		-0.034	-0.030	-0.195	0.409	13 / 13
GCP16		-0.044	-0.001	-0.194	0.356	14 / 14
GCP17		-0.036	0.006	-0.235	0.294	17 / 17
GCP18		-0.032	0.020	-0.225	0.436	15 / 15
GCP19		0.012	0.048	-0.201	0.469	13 / 13
GCP20		0.010	0.002	-0.205	0.431	15 / 15
Mean [US survey foot]		-0.012516	-0.028506	-0.189807		
Sigma [US survey foot]		0.026394	0.046296	0.035269		
RMS Error [US survey foot]		0.029211	0.054368	0.193056		

Localisation accuracy per GCP and mean errors in the three coordinate directions. The last column counts the number of calibrated images where the GCP has been automatically verified vs. manually marked.

Display Automatically after Processing　Close

Figure 15b – GCP checkpoints table in Pix4DMapper quality report for Flight 1-1, iteration 1.

Results

Tables 4a through 4c provide the summary of results illustrating the root mean squared errors (RMSe) of the twenty GCP check points for all 24 flights. Figures 16a through 16c provide box and whisker charts of the results. Figure 17 presents a combined box and whisker chart for all of the flight options.

Table 4a – UAS flight option 1, variable altitude, error results.

Option	Altitude	PPK Rate	Fwd Lap	Side Lap	GSD
1-1	200	0.5s	70	70	0.032
1-2	300	0.5s	70	70	0.045
1-3	400	0.5s	70	70	0.058

RMSe (feet)

X			Y			Horizontal			Vertical		
Flight			Flight			Flight			Flight		
1	2	3	1	2	3	1	2	3	1	2	3
0.029	0.066	0.021	0.054	0.076	0.038	0.062	0.100	0.044	0.193	0.228	0.217
0.021	0.022	0.035	0.044	0.033	0.052	0.049	0.040	0.062	0.092	0.206	0.130
0.031	0.027	0.022	0.023	0.068	0.026	0.039	0.074	0.034	0.107	0.267	0.036

Option	Altitude	PPK Rate	Fwd Lap	Side Lap	GSD
1-1	200	0.5s	70	70	0.032
1-2	300	0.5s	70	70	0.045
1-3	400	0.5s	70	70	0.058

Mean			
X	Y	H	Z
0.039	0.056	0.069	0.213
0.026	0.043	0.050	0.143
0.027	0.039	0.049	0.137

SD			
X	Y	H	Z
0.020	0.015	0.024	0.015
0.006	0.008	0.009	0.047
0.004	0.021	0.018	0.096

Table 4b – UAS flight option 2, variable overlap, error results.

						RMSe (feet)											
						X			Y			Horizontal			Vertical		
						Flight			Flight			Flight			Flight		
Option	Altitude	PPK Rate	Fwd Lap	Side Lap	GSD	1	2	3	1	2	3	1	2	3	1	2	3
1-3	400	0.5s	70	70	0.058	0.031	0.027	0.022	0.023	0.068	0.026	0.039	0.074	0.034	0.107	0.267	0.036
2-2	400	0.5s	85	70	0.057	0.018	0.026	0.014	0.036	0.029	0.018	0.040	0.039	0.023	0.146	0.109	0.061
2-3	400	0.5s	70	85	0.056	0.051	0.036	0.037	0.045	0.035	0.045	0.068	0.050	0.058	0.074	0.166	0.210
2-4	400	0.5s	85	85	0.063	0.039	0.021	0.022	0.071	0.046	0.044	0.081	0.051	0.049	0.157	0.090	0.131

						Mean				SD			
Option	Altitude	PPK Rate	Fwd Lap	Side Lap	GSD	X	Y	H	Z	X	Y	H	Z
1-3	400	0.5s	70	70	0.058	0.027	0.039	0.049	0.137	0.004	0.021	0.018	0.096
2-2	400	0.5s	85	70	0.057	0.019	0.027	0.034	0.105	0.005	0.007	0.008	0.035
2-3	400	0.5s	70	85	0.056	0.041	0.042	0.059	0.150	0.007	0.005	0.007	0.057
2-4	400	0.5s	85	85	0.063	0.027	0.054	0.060	0.126	0.008	0.012	0.014	0.028

Table 4c – UAS flight option 3, variable static collection rate, error results.

						RMSe (feet)											
						X			Y			Horizontal			Vertical		
						Flight			Flight			Flight			Flight		
Option	Altitude	PPK Rate	Fwd Lap	Side Lap	GSD	1	2	3	1	2	3	1	2	3	1	2	3
3-1	400	1.0s	85	70	0.063	0.027	0.033	0.025	0.022	0.032	0.048	0.035	0.046	0.054	0.149	0.227	0.110
2-2	400	0.5s	85	70	0.057	0.018	0.026	0.014	0.036	0.029	0.018	0.040	0.039	0.023	0.146	0.109	0.061
3-3	400	0.2s	85	70	0.057	0.041	0.018	0.029	0.066	0.040	0.032	0.078	0.044	0.043	0.319	0.131	0.148

						Mean				SD			
Option	Altitude	PPK Rate	Fwd Lap	Side Lap	GSD	X	Y	H	Z	X	Y	H	Z
3-1	400	1.0s	85	70	0.063	0.028	0.034	0.045	0.162	0.004	0.011	0.008	0.049
2-2	400	0.5s	85	70	0.057	0.019	0.027	0.034	0.105	0.005	0.007	0.008	0.035
3-3	400	0.2s	85	70	0.057	0.029	0.046	0.055	0.199	0.010	0.015	0.016	0.085

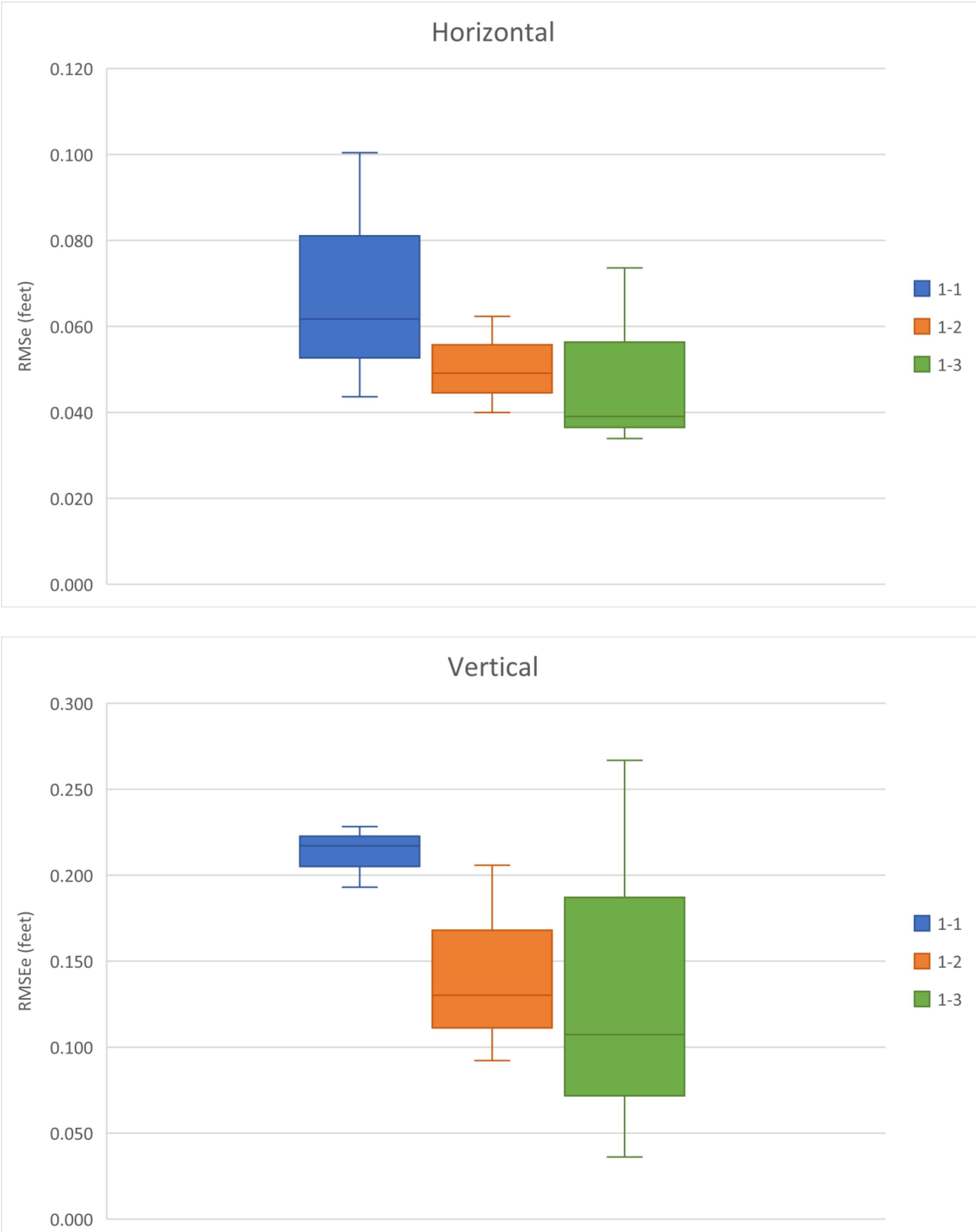


Figure 16a – UAS flight option 1, variable altitude, error results box and whisker chart.

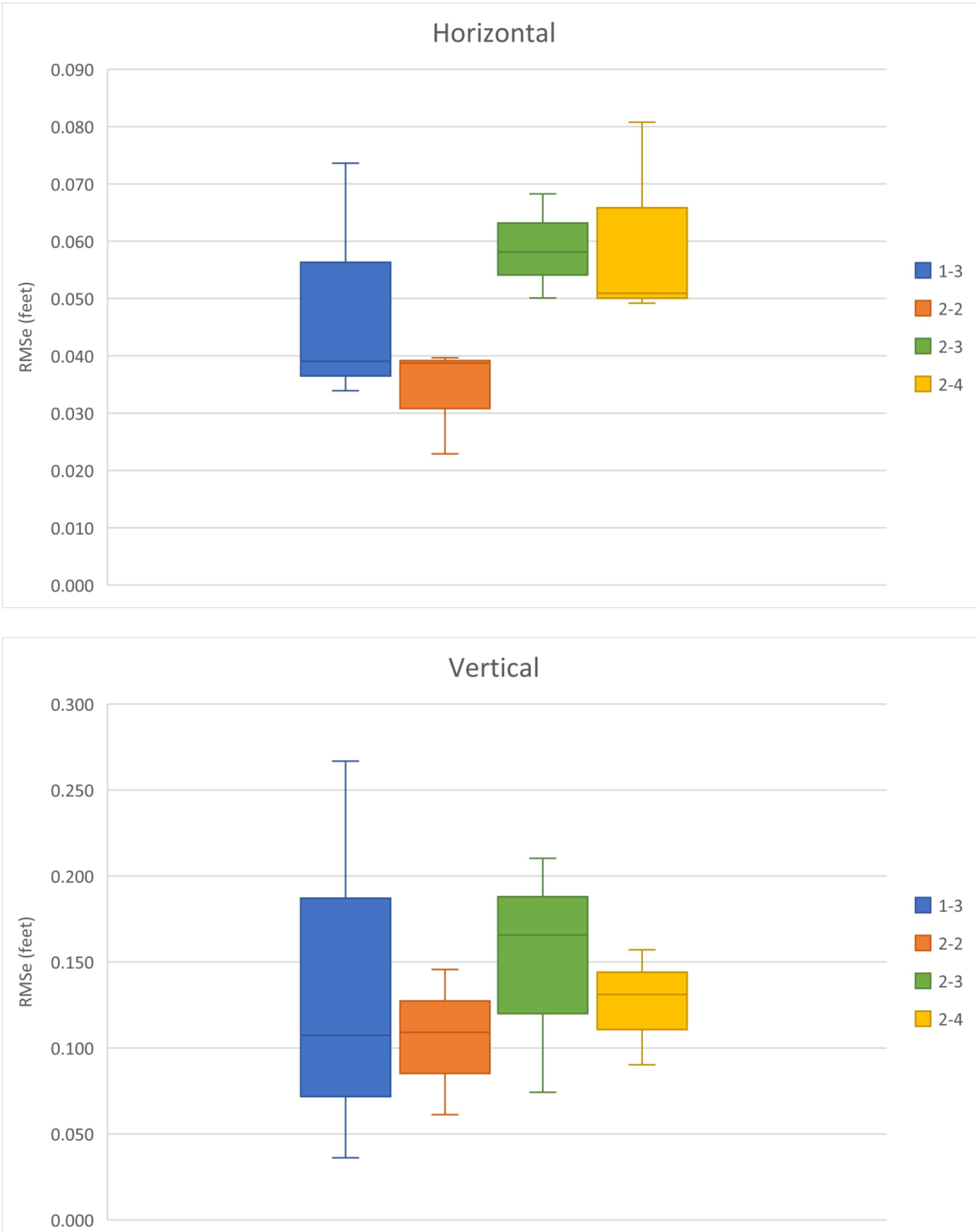
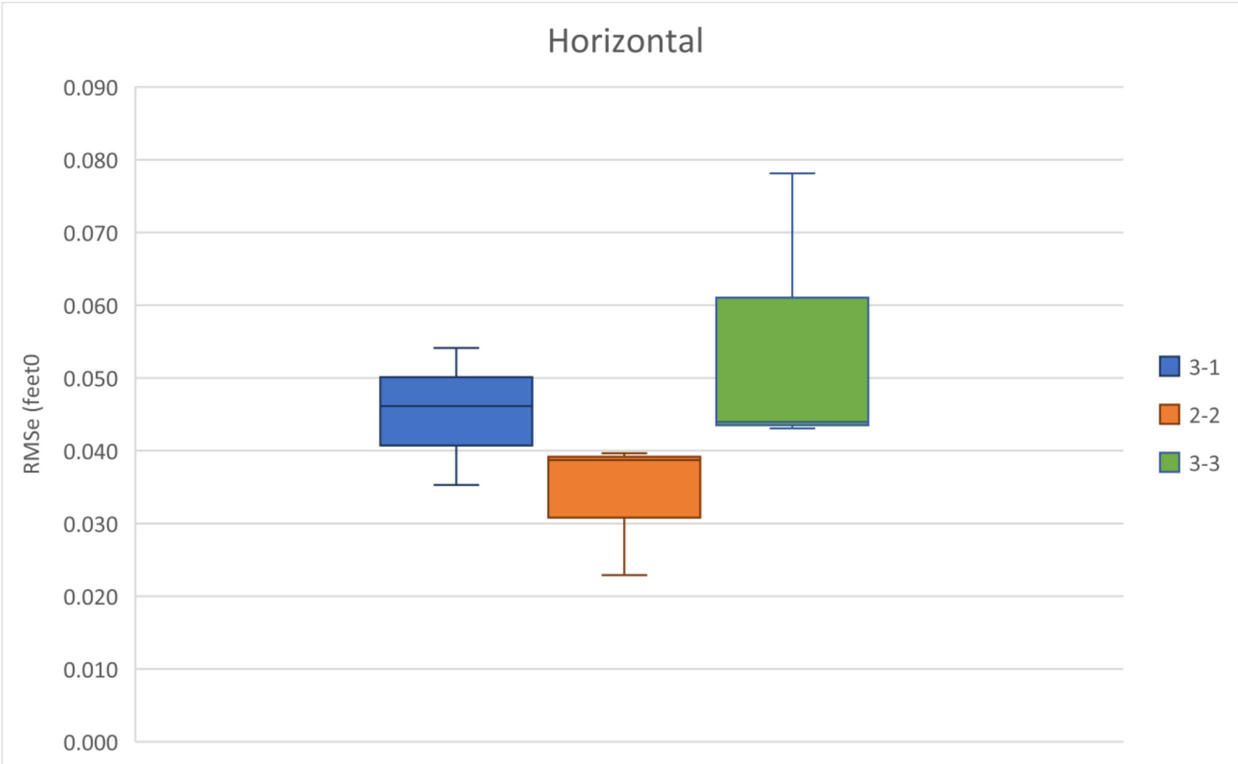


Figure 16b – UAS flight option 2, variable overlap, error results box and whisker chart.



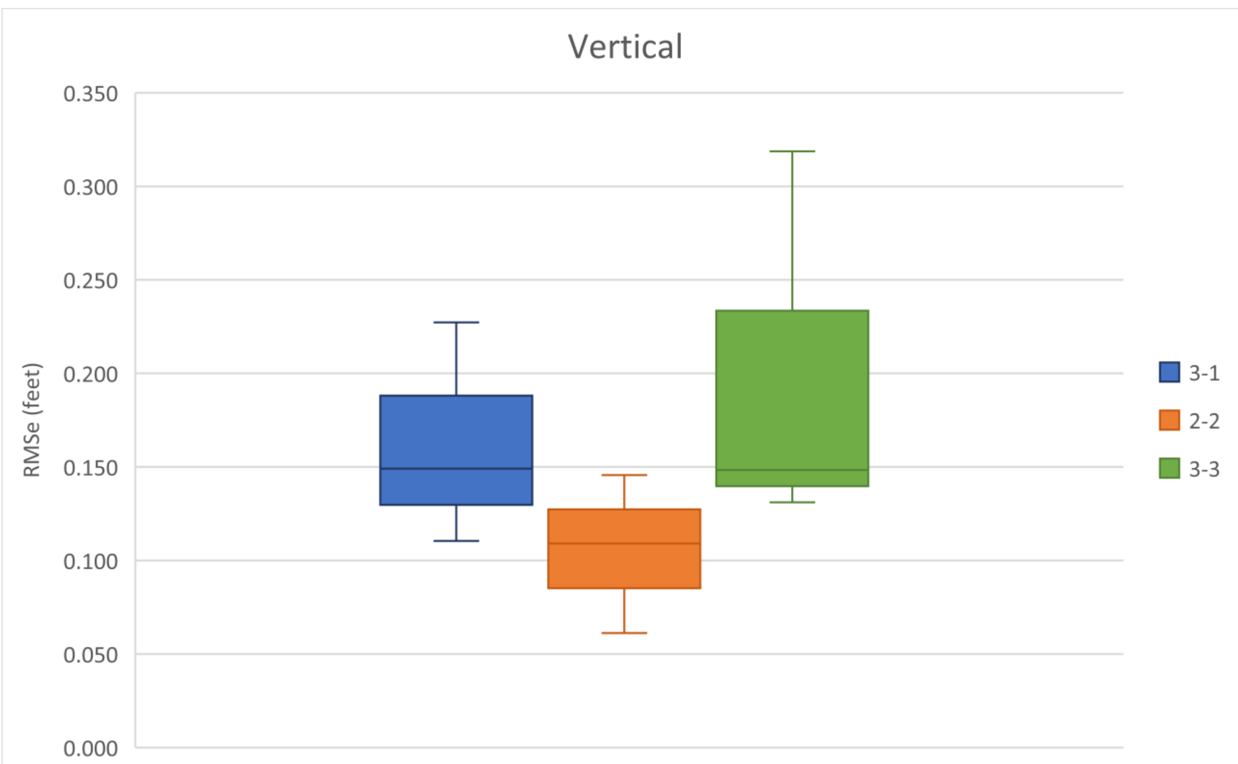


Figure 16c – UAS flight option 3, variable static rate, error results box and whisker chart.

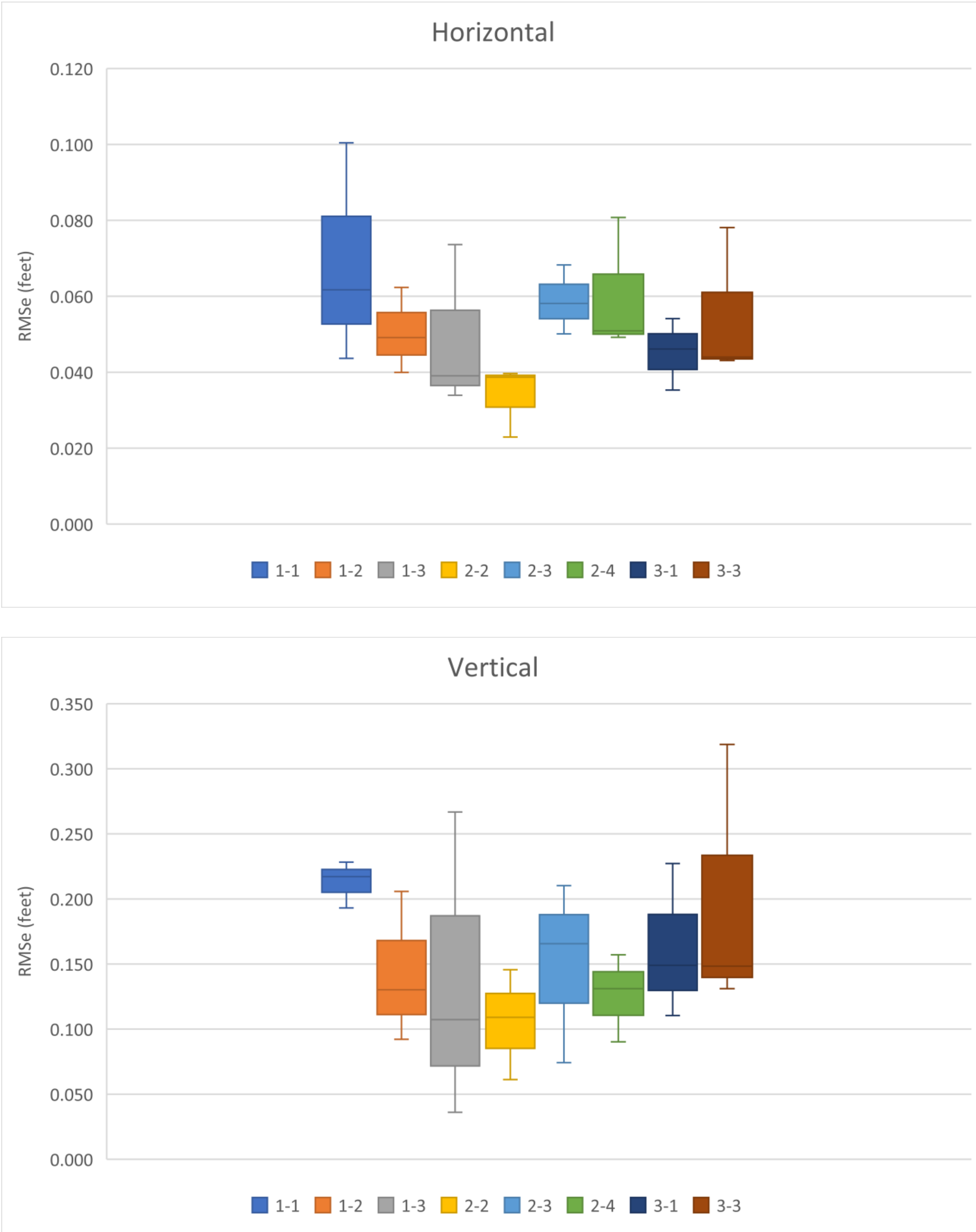


Figure 17 – Combined UAS flight options error results box and whisker chart.

Data Analysis

In order to measure the accuracy of the 3D points derived from the UAS imagery, the accuracy of the surveyed ground control check points needs to be evaluated. According to the American Society of Photogrammetry and Remote Sensing (ASPRS) Positional Accuracy Standards for Digital Geospatial Data, the "independent source of higher accuracy for checkpoints shall be at least three times more accurate than the required accuracy of the geospatial data set being tested" (ASPRS, 2014). As shown in Table 1, the mean horizontal and vertical RMSe of the ground control points are 0.0031 and 0.0093 feet, respectively. The lowest GSD evaluated is 0.032 feet, which correlates to the 200-foot flights. The horizontal and vertical accuracy of the ground control check points are 10.3 and 3.4 times the lowest GSD, respectively. Therefore, the ground control check points can be utilized for evaluating the accuracy of the UAS derived data.

After analyzing the results of the UAS data processing, no statistically significant difference was observed in horizontal or vertical 3D point accuracy between the flight options. To better understand the results, an examination of the underlying photogrammetric processing was performed. Pix4DMapper is based on Structure from Motion (SfM) algorithms to automate the generation of image Exterior Orientation Parameters (EOP). "The EOPs of the involved imagery can be either derived through an indirect geo-referencing procedure using tie and control points or a direct geo-referencing process through the implementation of a GNSS/INS unit on-board the mapping platform. While the latter approach has the practical convenience of simplifying the geo-referencing process, it requires significant initial investment for the acquisition of a high-end GNSS/INS Position and Orientation System (POS) – especially, when seeking high level of reconstruction accuracy." (He et al, 2017).

While the WingtraOne UAS is equipped with a high-precision PPK GNSS receiver, it is not equipped with a high-precision INS unit. Therefore, the image EOPs must be generated using the Pix4DMapper SfM algorithms. While the exact Pix4DMapper SfM algorithms are not published, based on the software processing options available to the end-user, it appears that the Scale Invariant Feature Transform (SIFT) method is utilized. The SIFT approach searches for features "that have many properties that make them suitable for matching differing images of an object or scene. The features are invariant to image scaling and rotation, and partially invariant to change in illumination and 3D camera viewpoint. They are well localized in both the spatial and frequency domains, reducing the probability of disruption by occlusion, clutter, or noise. Large numbers of features can be extracted from typical images with efficient algorithms. In addition, the features are highly distinctive, which allows a single feature to be correctly matched with high probability against a large database of features, providing a basis for object and scene recognition. An important aspect of this approach is that it generates large numbers of features that densely cover the image over the full range of scales and locations." (Lowe 2004)

Therefore, the mapping scene needed to be evaluated to determine the types of features present in the images, which can impact keypoint generation and ultimately the accuracy of the EOPs. As can be seen in Figures 4 through 7, the project site is a grassy field with few distinguishing features. The field had not been mowed in several months and the grass was approximately 12-18-inches tall. The lack of distinguishing features creates a challenging environment for SfM algorithms to generate quality feature matches and can result in a lower level of reconstruction accuracy.

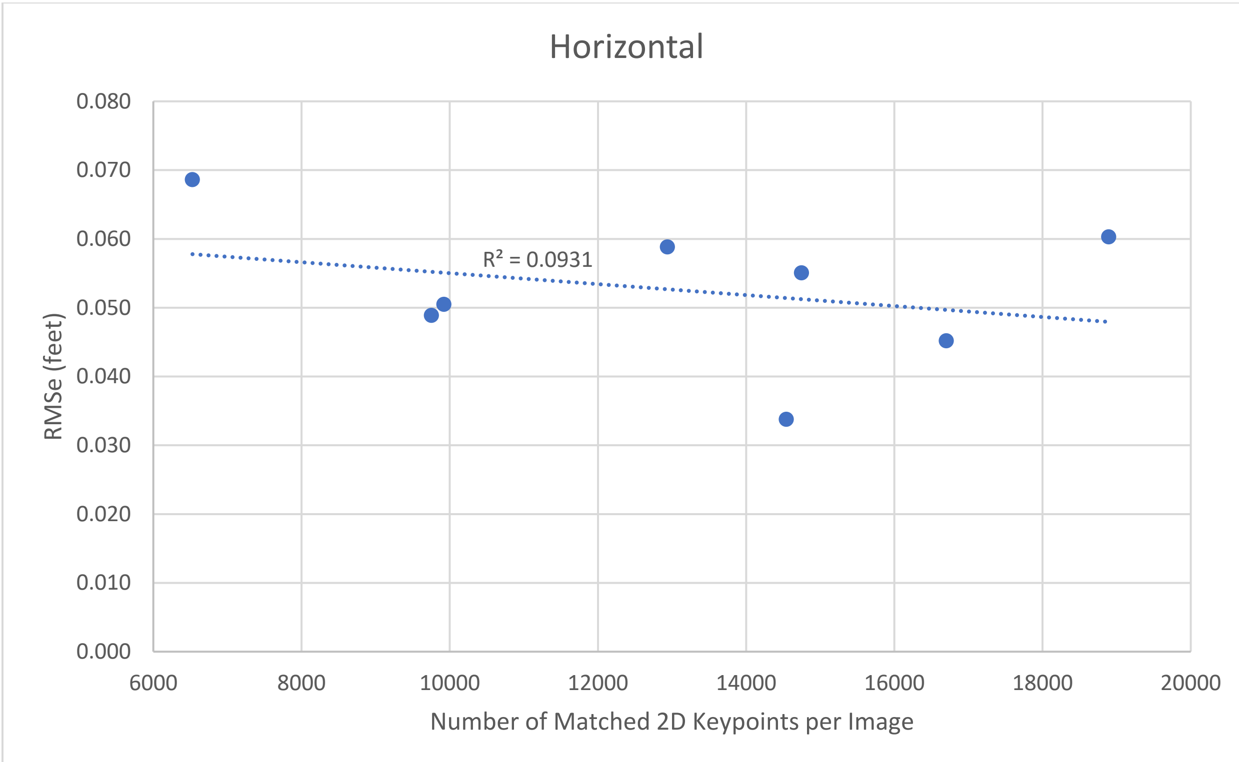
Lower flight altitudes result in a smaller ground sample distance, which should allow for more accurate keypoint generation. High image overlap should result in more keypoints being generated. The Pix4DMapper quality report provides information on the keypoints generated from the SfM algorithms. A closer examination of the Pix4DMapper quality reports reveals a small correlation between the number of matched keypoints per image and 3D point accuracy. Table 5 presents the number of matched 2D keypoints per image and mean 3D point accuracy for each flight option. Figure 18 contains scatter plots, which illustrate the small correlation between the number of keypoints and 3D point accuracy. As the number of matched 2D keypoints per image increases, there is a slight decrease in horizontal and vertical RMSe. While this correlation is expected, it was anticipated that the 200-foot flight would result in higher accuracy as compared to the 400-foot flight.

A whitepaper prepared by Wingtra presented results from 23 test flights performed in Zurich, Switzerland and Phoenix, Arizona (Wingtra 2018). The Wingtra research was performed in a similar fashion to this project (same model UAS, PPK system, and camera), so the results can be directly compared. The test flights performed in the Wingtra research were flown at an altitude of 62m (203feet) with 80% forward and side overlap. The 14 test flights in Switzerland resulted in a horizontal and vertical RMSe of 0.023feet and 0.085feet, respectively. The 9 test flights in Arizona resulted in a horizontal and vertical RMSe of 0.033feet and 0.082feet, respectively. The Wingtra test flights resulted in a higher absolute accuracy than this project.

Based on the analysis of all the data presented, it appears that the challenging, low-texture environment of tall grasses affected the SfM reconstruction. Since the chosen project area was less than ideal for high accuracy SfM, no statistically significant difference was observed in horizontal or vertical 3D point accuracy between the flight options.

Table 5 – Matched keypoints generated for each UAS flight mission.

						Number of Matched 2D Keypoints per Image					
						Flight				Mean RMSe (feet)	
Option	**Altitude**	**PPK Rate**	**Fwd Lap**	**Side Lap**	**GSD**	**1**	**2**	**3**	**Mean**	**Hor**	**Ver**
1-1	200	0.5s	70	70	0.032	6,060	6,370	7,156	6,529	0.069	0.213
1-2	300	0.5s	70	70	0.045	10,170	10,138	9,461	9,923	0.050	0.143
1-3	400	0.5s	70	70	0.058	10,426	9,800	9,035	9,753	0.049	0.137
2-2	400	0.5s	85	70	0.057	14,785	14,372	14,470	14,542	0.034	0.105
2-3	400	0.5s	70	85	0.056	12,432	13,092	13,295	12,939	0.059	0.150
2-4	400	0.5s	85	85	0.063	19,754	18,421	18,508	18,894	0.060	0.126
3-1	400	1.0s	85	70	0.063	17,807	16,287	16,016	16,703	0.045	0.162
3-3	400	0.2s	85	70	0.057	14,978	14,605	14,662	14,748	0.055	0.199



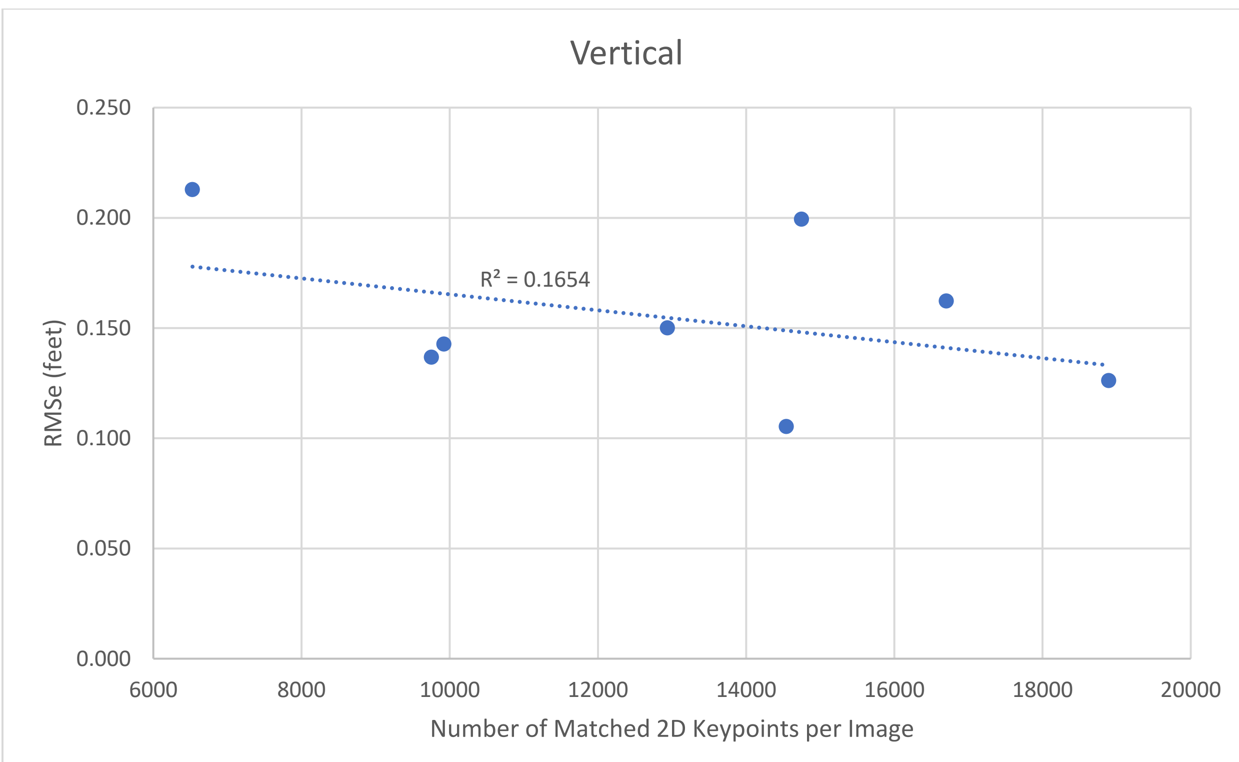


Figure 18 – Scatter plots illustrating the correlation between number of keypoints and RMSe.

Conclusion

The WingtraOne UAS, equipped with PPK GNSS and high-resolution camera, can produce survey-grade results without the need for ground control points. This project demonstrated that a flight plan that results in a higher number of matched keypoints will generally result in higher absolute accuracy. It was also determined that a low-texture flight area can affect the accuracy of the structure from motion reconstruction. No statistically significant difference was observed in horizontal or vertical 3D point accuracy between the flight options in this project. More flights need to be performed in a more suitable test environment in order to determine optimal flight parameters to achieve the highest absolute accuracy for UAS-derived spatial data.

References

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