Appendix B. As-Built UAV survey report



UAV As-Built Data Collection Report Sears Point Levee Adaptive Management Project

The UAV As-Built data collection consisted of the following elements described in this Appendix. The UAV as-built flight and ground control network survey took place on December 9, 2021.

Installation and survey of ground control points

Siegel Environmental installed the ground control point (GCP) network (Figure B-1). The GCPs consisted of 2'x2' black-and-white targets fixed onto the levee trail (Photo B-1) following contractor resurfacing of the levee post-construction and prior to the UAV flight day, and chalk paint crosses sprayed on the mudflat (Photo B-2) on the low tide the day of the UAV flight. Tides wash away these temporary chalk paint GCPs.



Photograph 1. Levee Ground Control Point



Photograph 2. Mudflat Ground Control Point

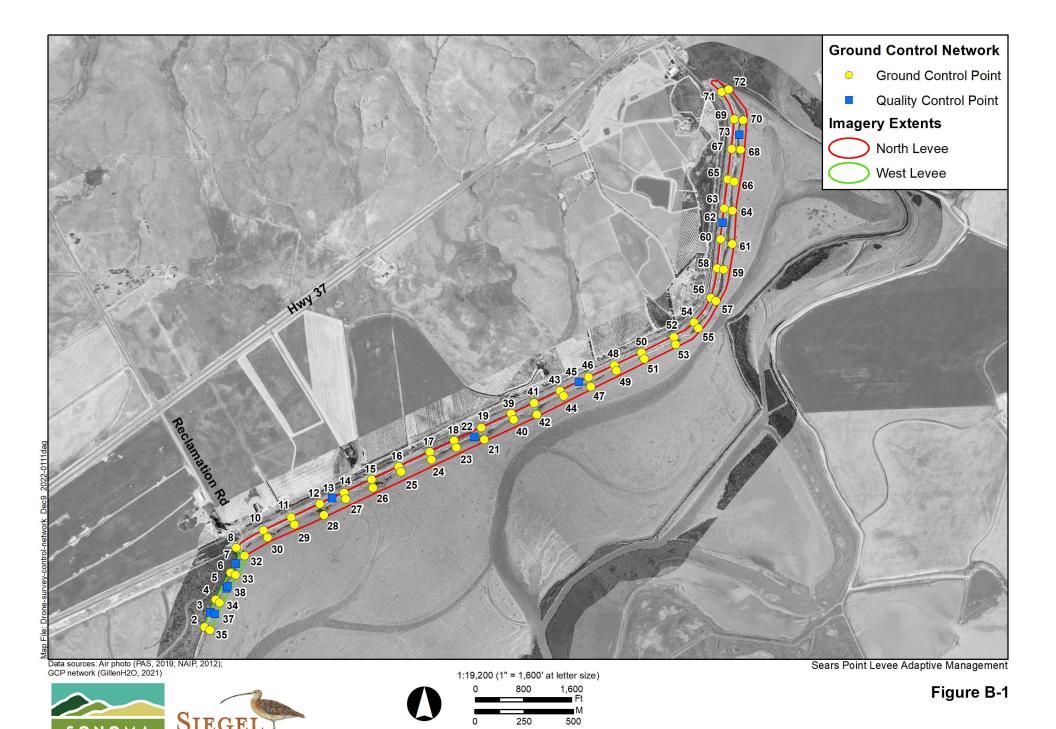
Appendix B: UAV As-Built Data Collection Report

Pacific Coast Habitat Survey conducted the topographic survey of the GCPs, utilizing real-time kinematic global positioning (RTK-GPS) equipment. Appendix B-1 provides the surveyor's report.

UAV Flight and Data Processing

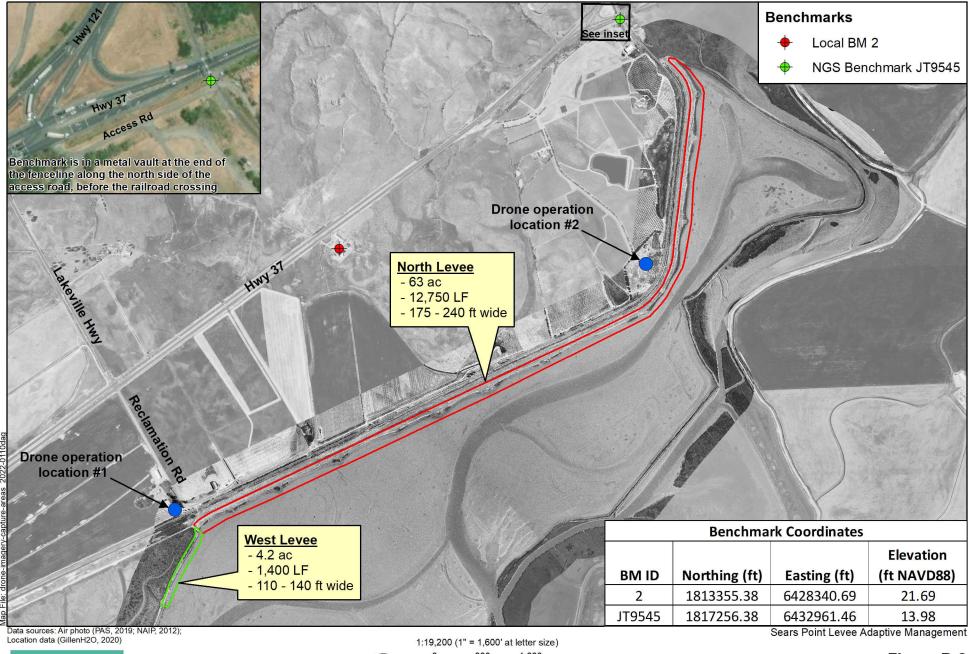
The San Francisco Estuary Institute (SFEI) carried out the UAV flight and data processing (see Appendix B-2). SFEI operated the UAV from adjacent non-federal property (Figure B-2). Data processing yielding the following work products:

- Orthorectified aerial image
- Photogrammetry-based Digital Surface Model, Digital Terrain Model, and point cloud
- Photogrammetry-based selected contour lines



ENVIRONMENTAL

December 2021 Post-Construction UAV Ground Control Network



SONOMA LAND TRUST





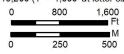


Figure B-2

Appendix B-1



December 09, 2021

Stuart Siegel Siegel Environmental

RE: Sears Point Post-Construction Ground Control Network

Project manager: Stuart Siegel
Chief surveyor: Darren Gewant
Date of survey: December 9, 2021

Equipment: Emlid RS2 / 2.00-meter carbon fiber topo rod / Aluminum bi-pod

Corrections: TOPNet Live

1. 0635 – Checked into project benchmark: JT 9545 (Figure 1).

- 2. Met Stuart Siegel on site, and worked together to establish control at three (3) different locales, working from south west corner of the project, proceeding North and East.
 - 1) pre-set levee aerials (Figure 2),
 - 2) pre-determined chalk-marked QA/QC targets and,
 - 3) field-fit mudflat targets.
- 3. Checked into (2) temporary benchmarks to determine GPS drift.
 - 4) Tbm1 metal bench post
 - 5) Tbm12.9 $\frac{1}{2}$ rebar with witness post
- 4. Checked out of survey at project benchmark: JT 9545
- 5. Processed survey data, and emailed points list to Dan Gillenwater for review and followed up with on-site conference call to discuss the survey and any immediate needs.
- 6. Scanned field notes (see Attached).



Figure 1. Check-in to project benchmark: JT9545



Figure 2. Typical aerial target survey.

11/=-	Appendix B-1	
3 1	SEARS POINT	>
		-
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110	clear into BM JT 95	45
7	6 MT (MP 3141 #	
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3	Eduipment EMUD 7352	2
71	+ 2.00 m 120	0
4,	Correction wetwork	
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Appendix B-1 12/9/21 Survey Desc JT9545 cleck in BW Not QAO MF NOT 15 W Rete in the Rain.

Sears Point SFEI UAS Survey - Data Collection Memo

Pete Kauhanen GIS Manager San Francisco Estuary Institute

_

UAS Survey Details

Date of data acquisition:

Dec 9th, 2021

Equipment used:

Mavic 2 Pro UAV

Hasselblad L1D-20C true color 20MP 1" sensor

Personel:

Remote Pilot in Command: Pete Kauhanen (FAA Certificate #: 3961556)

Visual Observers: Stuart Siegel, Darren Gewant

Processing summary:

See attached Sears Point UAS Product Processing Report.



Generated with Pix4DengineSDK version 5.0.45 Preview



Click here for additional tips to analyze the Quality Report	
--	--

Summary

Project	project
Processed	2021-12-21 22:26:49
Camera Model Name(s)	L1D-20c_10.3_5472x3648 (0K8TFB70024325) (RGB)
Average Ground Sampling Distance (GSD)	2.79 cm / 1.10 in
Area Covered	1.315 km ² / 131.5368 ha / 0.51 sq. mi. / 325.2028 acres

Quality Check

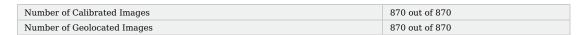
? Images	median of 63108 keypoints per image	②
? Dataset	870 out of 870 images calibrated (100%), all images enabled	②
? Camera Optimization	0% relative difference between initial and optimized internal camera parameters	②
? Matching	median of 32430.4 matches per calibrated image	②
? Georeferencing	yes, 57 GCPs (57 3D), mean RMS error = 0.06 US survey foot	②



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

Appendix B2

Calibration Details





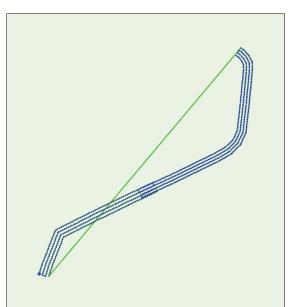
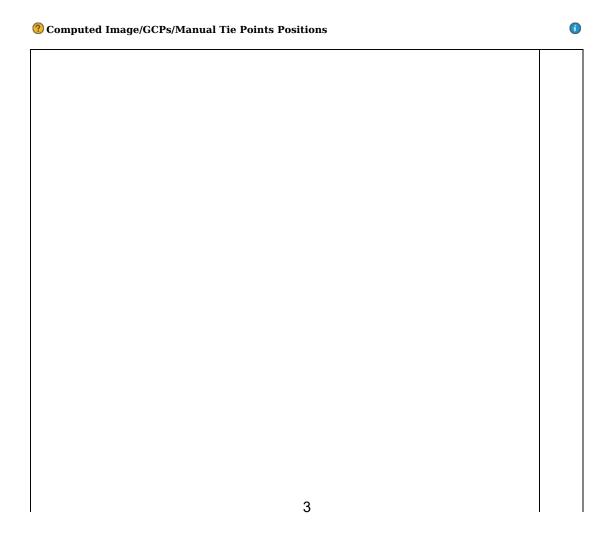
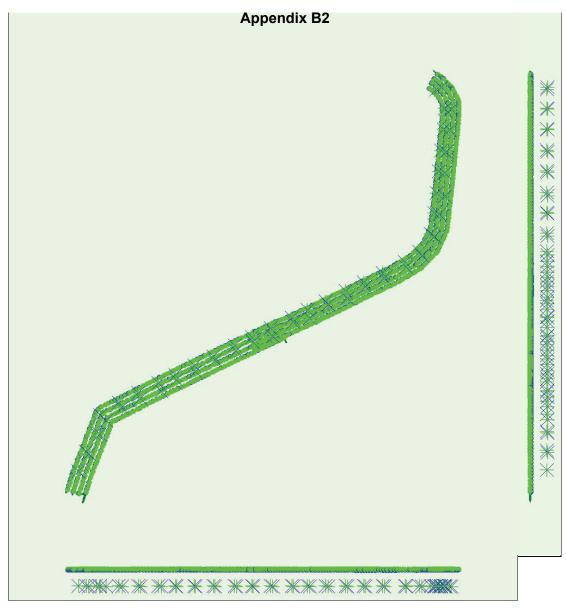


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.





Uncertainty ellipses 10x 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 [US Y [US Z [US Camera Camera Camera Phi Omega Kappa survey survey survey Displacement X Displacement Y $Displacement \ Z$ [degree] [degree] [degree] foot] foot] foot] [US survey foot] [US survey foot] [US survey foot] Mean 3.316 3.667 0.385 0.523 0.472 0.051 0.140 0.134 2.230 Sigma 3.296 3.858 0.196 0.548 0.466 0.034 0.070 0.063 1.916

② Overlap

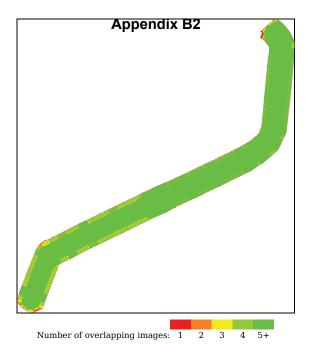


Figure 4: Number of overlapping images computed for each pixel of the orthomosaic.

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).

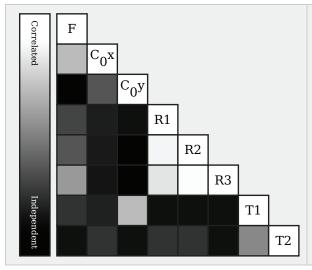
Number of 2D Keypoint Observations for Bundle Block Adjustment	26972489
Number of 3D Points for Bundle Block Adjustment	7184025
Mean Reprojection Error [pixels]	0.200

Internal Camera Parameters

L1D-20c_10.3_5472x3648 (0K8TFB70024325) (RGB). Sensor Dimensions: 12.825 [mm] x 8.550 \odot [mm]

EXIF ID: L1D-20c_10.3_5472x3648

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	4377.600 [pixel] 10.260 [mm]	2736.000 [pixel] 6.412 [mm]	1824.000 [pixel] 4.275 [mm]	0.000	0.000	0.000	0.000	0.000
Optimized Values	4377.552 [pixel] 10.260 [mm]	2733.155 [pixel] 6.406 [mm]	1826.123 [pixel] 4.280 [mm]	-0.009	0.024	-0.032	0.001	-0.000
Uncertainties (Sigma)	2.066 [pixel] 0.005 [mm]	1.239 [pixel] 0.003 [mm]	1.931 [pixel] 0.005 [mm]	0.001	0.002	0.003	0.000	0.000



The correlation between camera internal parameters determined by the bundle adjustment. White indicates a full correlation between the parameters, i.e. 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.

② 2D Keypoints Table

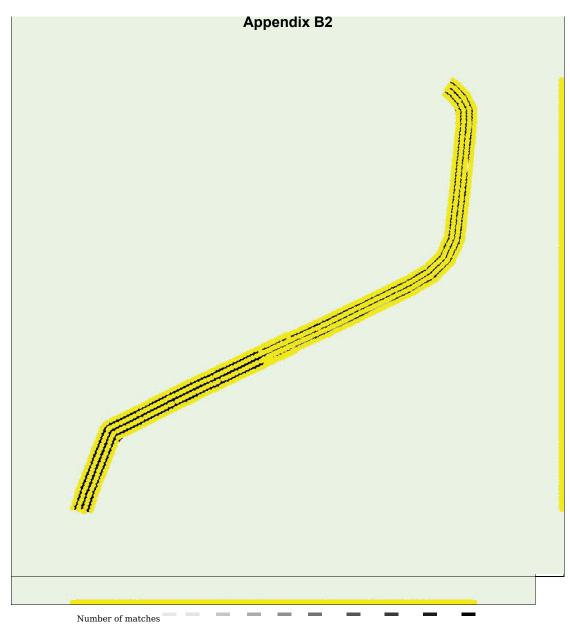
	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image		
Median	63108	32430		
Min	20377	1863		
Max	83423	58928		
Mean	61500	31003		

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed				
In 2 Images	3232028				
In 3 Images	1455380				
In 4 Images	845085				
In 5 Images	474608				
In 6 Images	294737				
In 7 Images	219947				

In 8 Images	168645 Appendix B2
In 9 Images	125776
In 10 Images	95153
In 11 Images	73385
In 12 Images	58841
In 13 Images	42902
In 14 Images	31101
In 15 Images	20781
In 16 Images	14773
In 17 Images	9987
In 18 Images	6312
In 19 Images	4177
In 20 Images	2911
In 21 Images	2261
In 22 Images	1751
In 23 Images	1222
In 24 Images	796
In 25 Images	507
In 26 Images	365
In 27 Images	183
In 28 Images	128
In 29 Images	96
In 30 Images	63
In 31 Images	35
In 32 Images	26
In 33 Images	17
In 34 Images	19
In 35 Images	16
In 36 Images	9
In 37 Images	1
In 38 Images	1

© 2D Keypoint 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.

Geolocation Details

1

? Ground Control Points

G

GCP 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
2GCP (3D)	0.020/ 0.020	-0.000	-0.006	0.028	0.203	5 / 5
4GCP (3D)	0.020/ 0.020	0.031	0.009	-0.095	0.221	5 / 5
6GCP (3D)	0.020/ 0.020	-0.082	0.026	0.069	0.336	6/6
8GCP (3D)	0.020/ 0.020	0.015	0.010	0.011	0.388	5/5
10GCP (3D)	0.020/ 0.020	0.024	-0.013	0.007	0.228	5/5
11GCP (3D)	0.020/ 0.020	0.050	-0.114	-0.064	0.233	5 / 5
12GCP (3D)	0.020/ 0.020	-0.014	0.066	0.048	0.383	5 / 5
14GCP (3D)	0.020/ 0.020	-0.034	-0.025	0.022	0.335	5/5
15GCP (3D)	0.020/ 0.020	0.019	0.065	0.044	0.402	5/5
16GCP (3D)	0.020/ 0.020	-0.068	0.025	0.017	0.146	5/5
17GCP (3D)	0.020/ 0.020	0.006	-0.019	-0.045	0.235	6/6
18GCP (3D)	0.020/ 0.020	-0.005	0.008	-0.001	0.215	6/6
19GCP (3D)	0.020/ 0.020	0.015	-0.011	0.001	0.446	10 / 10
21GCP (3D)	0.020/ 0.020	-0.030	0.007	0.033	0.512	6/6
23GCP (3D)	0.020/ 0.020	0.008	0.364	0.151	0.622	6/6
24GCP (3D)	0.020/ 0.020	0.000	-0.002	0.013	0.383	6/6
25GCP (3D)	0.020/ 0.020	0.002	0.010	0.013	0.383	5/5
26GCP (3D)	0.020/ 0.020	-0.014	-0.125	-0.058	0.371	5/5
		0.039	0.050	-0.058	0.401	
27GCP (3D)	0.020/ 0.020					5/5
28GCP (3D)	0.020/ 0.020	0.010	-0.067	-0.019	0.296	5 / 5
29GCP (3D)	0.020/ 0.020	-0.042	0.105	-0.123	0.320	6 / 6
30GCP (3D)	0.020/ 0.020	-0.026	-0.002	0.021	0.435	5 / 5
32GCP (3D)	0.020/ 0.020	-0.025	0.009	-0.046	0.456	6 / 6
33GCP (3D)	0.020/ 0.020	0.107	-0.056	-0.002	0.510	5 / 5
34GCP (3D)	0.020/ 0.020	-0.038	0.013	0.055	0.306	5 / 5
35GCP (3D)	0.020/ 0.020	0.000	0.000	0.000	n/a	0 / 5
39GCP (3D)	0.020/ 0.020	0.029	-0.074	-0.075	0.413	5 / 5
40GCP (3D)	0.020/ 0.020	-0.042	0.108	0.095	0.322	5 / 5
41GCP (3D)	0.020/ 0.020	-0.031	-0.019	0.068	0.433	5 / 5
42GCP (3D)	0.020/ 0.020	0.065	0.000	-0.055	0.491	5 / 5
43GCP (3D)	0.020/ 0.020	0.024	0.082	-0.052	0.288	5 / 5
44GCP (3D)	0.020/ 0.020	-0.033	-0.067	0.079	0.528	5 / 5
46GCP (3D)	0.020/ 0.020	-0.012	-0.004	-0.010	0.375	6/6
47GCP (3D)	0.020/ 0.020	0.026	-0.013	-0.019	0.361	5 / 5
48GCP (3D)	0.020/ 0.020	-0.002	-0.001	-0.016	0.330	5 / 5
49GCP (3D)	0.020/ 0.020	-0.011	0.021	0.017	0.417	5 / 5
50GCP (3D)	0.020/ 0.020	0.018	-0.018	-0.038	0.389	5 / 5
51GCP (3D)	0.020/ 0.020	-0.005	-0.010	0.039	0.378	5 / 5
52GCP (3D)	0.020/ 0.020	-0.033	0.005	0.006	0.433	5 / 5
53GCP (3D)	0.020/ 0.020	0.019	0.027	0.005	0.453	5 / 5
54GCP (3D)	0.020/ 0.020	-0.056	0.047	0.053	0.294	5 / 5
55GCP (3D)	0.020/ 0.020	0.053	-0.057	-0.006	0.338	5 / 5
56GCP (3D)	0.020/ 0.020	0.071	-0.125	-0.104	0.361	5 / 5
57GCP (3D)	0.020/ 0.020	-0.011	0.064	0.031	0.499	5 / 5
58GCP (3D)	0.020/ 0.020	0.124	-0.070	0.007	0.313	5 / 5
59GCP (3D)	0.020/ 0.020	-0.249	0.084	0.072	0.551	5 / 5
60GCP (3D)	0.020/ 0.020	0.044	0.004	-0.026	0.318	5 / 5
61GCP (3D)	0.020/ 0.020	-0.052	0.008	-0.043	0.367	5 / 5
63GCP (3D)	0.020/ 0.020	-0.023	0.011	0.016	0.210	5 / 5
64GCP (3D)	0.020/ 0.020	0.030	-0.017	0.023	0.441	5 / 5
65GCP (3D)	0.020/ 0.020	-0.109	-0.026	-0.043	0.284	5 / 5
66GCP (3D)	0.020/ 0.020	0.126	0.096	0.019	0.441	5 / 5
67GCP (3D)	0.020/ 0.020	-0.060	-0.017	0.047	0.278	5/5
68GCP (3D)	0.020/ 0.020	0.056	0.008	-0.005	0.299	5/5
69GCP (3D)	0.020/ 0.020	0.016	0.007	-0.076	0.373	5/5
70GCP (3D)	0.020/ 0.020	-0.012	-0. 6 09	0.016	0.666	5/5

71GCP (3D)	0.020/ 0.020	0.072 Ap	pendix B2	0.107	0.176	5/5
72GCP (3D)	0.020/ 0.020	-0.162	0.029	0.002	0.395	5 / 5
Mean [US survey foot]		-0.002231	0.006986	0.003177		
Sigma [US survey foot]		0.060971	0.068867	0.052855		
RMS Error [US survey foot]		0.061012	0.069221	0.052951		

0 out of 10 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
3QCP		0.0621	-0.2449	0.0324	0.3113	5 / 5
5QCP		-0.0890	0.2492	0.2086	0.4212	5 / 5
7QCP		-0.1905	0.0436	0.2449	0.3204	5 / 5
13QCP		-0.2445	-0.0804	0.0665	0.8967	5 / 5
22QCP		0.2472	-0.0326	0.2904	0.6387	6 / 6
37QCP		-0.3111	-0.2933	0.1274	0.5729	5 / 5
38QCP		0.1193	0.3576	-0.2076	0.4671	5 / 5
45QCP		-0.0489	-0.2392	-0.1132	0.3910	6 / 6
62QCP		-0.0116	-0.1413	0.1436	0.4066	5 / 5
73QCP		-0.2117	0.0723	-0.0502	0.3073	5 / 5
Mean [US survey foot]		-0.067855	-0.030890	0.074279		
Sigma [US survey foot]		0.167695	0.204528	0.152775		
RMS Error [US survey foot]		0.180903	0.206848	0.169875		

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.

? Absolute Geolocation Variance



Min Error [US survey foot]	Max Error [US survey foot]	Geolocation Error X [%]	Geolocation Error Y [%]	Geolocation Error Z [%]
-	-49.21	0.00	0.00	0.00
-49.21	-39.37	0.00	0.00	0.00
-39.37	-29.53	0.00	0.00	0.00
-29.53	-19.69	0.00	0.00	0.00
-19.69	-9.84	0.80	2.07	0.00
-9.84	0.00	55.06	46.78	51.38
0.00	9.84	43.10	49.20	47.59
9.84	19.69	1.03	1.84	1.03
19.69	29.53	0.00	0.11	0.00
29.53	39.37	0.00	0.00	0.00
39.37	49.21	0.00	0.00	0.00
49.21	-	0.00	0.00	0.00
Mean [US survey foot]		-7.634817	1.257784	-12.748772
Sigma [US survey foot]		4.305716	4.881917	3.183897
RMS Error [US survey foot]		8.765251	5.041342	13.140335

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 noints.

Geolocation Bias	X	Y	Z
Translation [US survey foot]	-7.634817	1.257784	-12.748772

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

? Relative Geolocation Variance



Relative Geolocation Error	Images X [%]	Images Y [%]	Images Z [%]
[-1.00, 1.00]	100.00	99.89	100.00
10			

[-2.00, 2.00] Appendi	B2 0.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [US survey foot]	16.404167	16.404167	32.808333
Sigma of Geolocation Accuracy [US survey foot]	0.000001	0.000001	0.000002

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

Geolocation Orientational Variance	RMS [degree]
Omega	0.952
Phi	0.813
Kappa	24.378

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

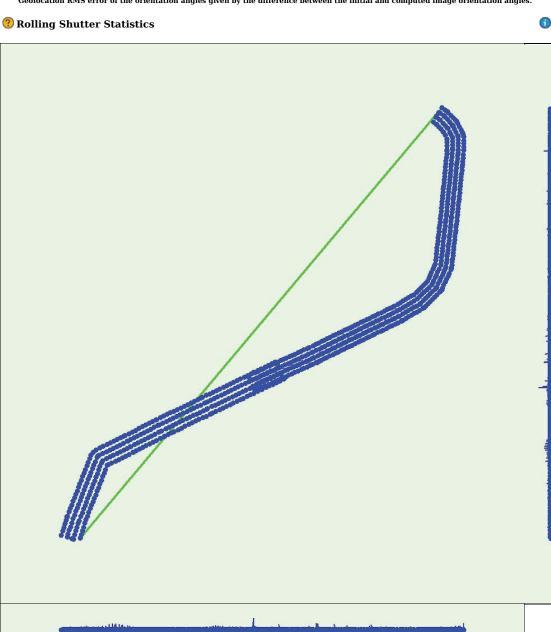


Figure 6: Camera movement estimated by the rolling shutter camera model. The green line follows the computed image positions. The blue dots represent the camera position at the start of the exposure. The blue lines represent the camera motion during the rolling shutter readout, re-scaled by a project dependant scaling factor for better visibility.

Median Camera Speed	24.4188 [US survey foot/s]
Median Camera Displacement During Sensor Readout)	2.2951 [US survey foot]
Median Rolling Shutter Readout Time	99.4793 [ms]

Initial Processing Detail Proc **System Information** CPU: Intel(R) Xeon(R) Platinum 8124M CPU @ 3.00GHz Hardware RAM: 41GB GPU: no info (Driver: unknown) Operating System Linux 4.14.252-195.483.amzn2.x86_64 x86_64 **Coordinate Systems** Image Coordinate System WGS 84 Ground Control Point (GCP) Coordinate System NAD83 / California zone 2 (ftUS) Output Coordinate System NAD83 / California zone 2 (ftUS) **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: yes Advanced: Keypoint Extraction Targeted Number of Keypoints: Automatic Calibration Method: Standard Internal Parameters Optimization: All prior Advanced: Calibration External Parameters Optimization: All Rematch: Custom, no DSM, Orthomosaic and Index Details **Processing Options** DSM and Orthomosaic Resolution 1 x GSD (2.79 [cm/pixel]) Noise Filtering: yes DSM Filters Surface Smoothing: yes, Type: Sharp Generated: yes Method: Inverse Distance Weighting Raster DSM Merge Tiles: yes Generated: yes Orthomosaic