OC Survey – sUAV Testing (Camera) - Equipment and Procedures

Purpose:

The purpose of conducting multiple sUAV mapping surveys under various conditions is to get a sense of the accuracies and repeatability one can achieve using the different georeference positioning techniques.

The three techniques performed are:

1. **LOKI & AIRGON CALIBRATION** – All photo locations have a +/-2cm accuracy position relative to the nearest CGPS station using the LOKI PPK GNSS system. Positions are computed on NAD83, Zone VI, OCS 2007.00 epoch horizontal and GPS derived orthometric height based on CGPS station NAD83, Zone VI, OCS 2007.00 epoch ellipsoid height with GEOID12B geoid model (close to NAVD88). The X4S camera calibration file is used during alignment to remove lens distortion.

2. **GCPs –** GCPs positions are constrained to align photos and remove lens distortions. All photo locations are +/- 300'. GCPs are +/-2cm accuracy position relative to local control stations NAD83, Zone VI, OCS 2007.00 epoch horizontal and local benchmarks orthometric height based on NAVD88, OCS 1995 adjustment. GCPs are constrained to position the flight relative to the desired datum and to remove distortions associated with the camera lens.

3. **LOKI & GCPs** – Alignment is computed using technique 1. Alignment is then shifted and constrained to select GCPs while using the camera calibration file to remove all lens distortions. Positions are computed based on the selected GCPs.

Each survey is processed using all 3 techniques if possible. Quality Control (QC) GCPs are set and analyzed for estimating accuracies. Root Mean Square Error (RMSE) values are computed by the alignment software. Residuals are a measure of how far from the regression line data points are; **RMSE** is a measure of how spread out these residuals are. In other words, it tells you how concentrated the data is around the line of best fit.

Equipment Used:

DJI Inspire II sUAV

DJI X4S Camera

LOKI PPK System

OC Survey – sUAV Testing (Camera) - Equipment and Procedures

Data Processing:

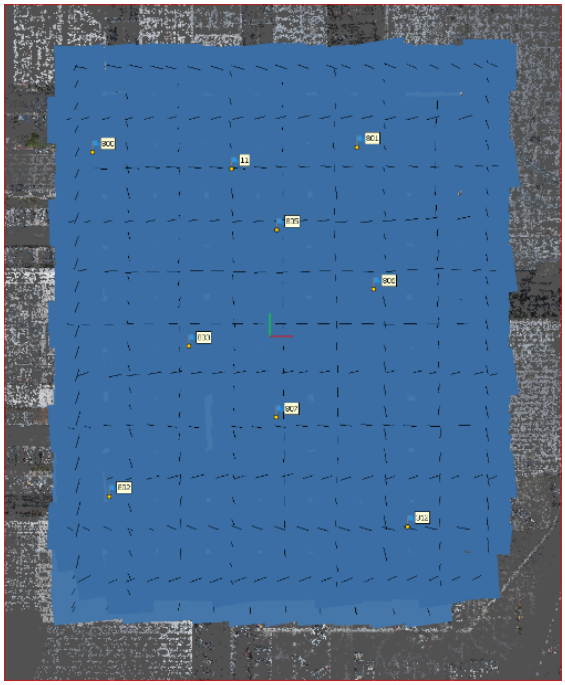
sUAV GNSS LOKI positions are computed using ASPSuite PPK processing software with SP3 precise orbits.

Photos are processed using Agisoft Metashape software with the following parameters:

1. Align Photos – High
2. Camera Calibration – "X4S 2x3 20181107 Airgon Calibration.xml", Fixed parameters – All
3. GCP weighting – 0.01604', GCP weighting for AGAIN – 0.0005', optimize
4. Build Dense Cloud – High, Mild
5. Build Mesh – Dense cloud, Arbitrary (3D), Face count High
6. Build Orthomosaic – EPSG:2230, Surface – Mesh, Blending - Mosaic
7. Export Points – LAS, EPSG:2230, Dense cloud, point colors
8. Export Ortho – EPSG:2230, background color – black, TIFF compression – LZW, JPEG quality – 90, Write Big TIFF file

OC Survey – sUAV Testing (Camera) - Equipment and Procedures

Glassell Yard



Distance from CCCS – 2.6 miles (4.2km)

https://www.ocgis.com/potree/1.6/Glassell_Yard_20190228.html

Field Control: GCPs based on legacy control points. Horizontal and vertical conventionally established.

Flight 1 (20190228)

NADIR - 100' AGL, forward 85%, side 75%, Flight time = 17min 00s, 419 Photos

GRID - 150' AGL, forward 85%, side 75%, camera angle 70, Flight time = 19min 18s, 427 Photos

Flight 2 (20190418)

NADIR - 100' AGL, forward 85%, side 75%, Flight time = 17min 00s, 419 Photos

GRID - 150' AGL, forward 85%, side 75%, camera angle 70, Flight time = 19min 18s, 427 Photos

45 DEGREE GRID - 125' AGL, forward 80%, side 60%, camera angle 60, Flight time = 6min 39s, 152 Photos

Flight 3 (20190501)

NADIR - 100' AGL, forward 85%, side 75%, Flight time = 17min 00s, 419 Photos

GRID - 150' AGL, forward 85%, side 75%, camera angle 70, Flight time = 19min 18s, 427 Photos

OC Survey – sUAV Testing (Camera) - Equipment and Procedures

Glassell Yard – LOKI & AIRGON CALIBRATION

Flight 1 (20190228)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
11	-0.0144344	-0.172549	-0.00151359	0.173159	0.344 (10)
312	-0.0221571	-0.140932	-0.0872505	0.167228	0.327 (10)
800	-0.00784793	-0.165103	-0.00601627	0.165399	0.444 (10)
801	-0.0450256	-0.162171	-0.029146	0.170811	0.346 (10)
802	-0.023062	-0.0978016	-0.0341758	0.106137	0.456 (10)
803	-0.0168047	-0.143707	-0.0114624	0.14514	0.475 (10)
805	-0.0287052	-0.152494	-0.0105295	0.155529	0.375 (10)
806	-0.0433749	-0.145586	-0.0501169	0.159963	0.314 (10)
807	-0.0367703	-0.144064	-0.0308831	0.151856	0.449 (10)
Total	**0.0291736**	**0.148554**	**0.038552**	**0.156223**	**0.397**

Table 5. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

Flight 2 (20190418)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
11	-0.0291328	-0.130137	0.0509373	0.142755	0.473 (10)
312	-0.00932235	-0.100209	0.0111125	0.101253	0.348 (10)
800	-0.028315	-0.143204	0.0742572	0.163778	0.289 (10)
801	-0.0483711	-0.0988896	0.0134209	0.110901	0.324 (10)
802	-0.0116004	-0.0974084	0.0574822	0.113698	0.507 (10)
803	-0.00795967	-0.117909	0.0253244	0.12086	0.467 (10)
805	-0.0273157	-0.116311	0.0278298	0.122674	0.314 (10)
806	-0.0343308	-0.104745	0.0220957	0.112421	0.296 (10)
807	-0.0278816	-0.109417	0.0399557	0.119775	0.500 (10)
Total	**0.0278432**	**0.114079**	**0.0411191**	**0.124419**	**0.401**

Table 5. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

Flight 3 (20190501)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
11	-0.0287045	-0.163398	0.0144316	0.166527	0.345 (10)
312	-0.0342183	-0.0950647	-0.04357	0.11003	0.400 (10)
800	-0.00657942	-0.168143	0.0325838	0.171397	0.407 (10)
801	-0.0595144	-0.136491	-0.0141138	0.14957	0.379 (10)
802	-0.0118149	-0.0845742	0.0268733	0.089524	0.392 (10)
803	-0.00920676	-0.122922	0.0137027	0.124025	0.266 (10)
805	-0.0403809	-0.143677	0.0293216	0.152096	0.333 (10)
806	-0.054619	-0.117737	-0.0189245	0.131161	0.385 (10)
807	-0.0339611	-0.110884	0.00375068	0.116029	0.408 (10)
Total	**0.0358572**	**0.129829**	**0.0247418**	**0.136944**	**0.371**

Table 5. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

OC Survey – sUAV Testing (Camera) - Equipment and Procedures

Glassell Yard – GCPs

Flight 1 (20190228)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
312	-0.0012765	0.00823428	-0.022847	0.0243191	0.204 (10)
800	-0.0147439	0.00920364	-0.0207786	0.0270895	0.193 (10)
801	0.0115619	-0.0128243	-0.0160298	0.0235604	0.079 (10)
802	0.00783456	-0.000357465	-0.00324032	0.00848574	0.120 (10)
805	0.00155745	-0.00108658	0.0358285	0.0358788	0.180 (10)
807	-0.0050698	-0.00308576	0.0267027	0.0273543	0.111 (10)
Total	**0.00858484**	**0.00739148**	**0.0231585**	**0.0257808**	**0.155**

Table 7. Control points.
X - Longitude, Y - Latitude, Z - Altitude.

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
11	0.0239645	-0.000198433	0.00534724	0.0245546	0.367 (10)
803	0.00894709	-0.00331114	0.00920906	0.0132598	0.397 (10)
806	-0.00373986	0.00344694	0.0185615	0.0192457	0.305 (10)
Total	**0.0149257**	**0.00276191**	**0.0123549**	**0.0195716**	**0.358**

Table 8. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

Flight 2 (20190418)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
312	-0.00295924	0.00236984	-0.0322986	0.0325204	0.079 (10)
800	0.00167647	-0.00555472	-0.0252023	0.0258616	0.135 (10)
801	-0.00278447	0.00177747	-0.0228752	0.0231125	0.182 (10)
802	0.00950057	0.0133024	-0.015036	0.0222102	0.101 (10)
805	0.00216886	-0.00786483	0.0204269	0.0219959	0.093 (10)
807	-0.00896821	-0.00297467	0.0174218	0.0198191	0.112 (10)
Total	**0.0056967**	**0.00691963**	**0.0229074**	**0.0245984**	**0.122**

Table 7. Control points.
X - Longitude, Y - Latitude, Z - Altitude.

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
11	0.00229747	-0.0107624	-0.00793264	0.0135659	0.284 (10)
803	0.00782153	0.00223066	0.00222871	0.00843322	0.451 (10)
806	-0.0110858	-0.00487021	0.00673692	0.0138564	0.308 (10)
Total	**0.0079446**	**0.00694078**	**0.00614491**	**0.0122086**	**0.355**

Table 8. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

Flight 3 (20190501)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
312	-0.00415983	0.0133977	0.000972575	0.0140623	0.108 (10)
800	-0.00599944	0.000614073	0.0061817	0.00863619	0.179 (10)
801	0.0101194	-0.00754546	-0.0144551	0.0191908	0.197 (10)
802	0.000956098	-3.76734e-005	-0.0153351	0.0153649	0.121 (10)
805	-0.000793283	-0.00625341	-0.00719795	0.00956791	0.191 (10)
807					
Total	**0.00560791**	**0.00742855**	**0.0103449**	**0.0139158**	**0.163**

Table 7. Control points.
X - Longitude, Y - Latitude, Z - Altitude.

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
11	0.00943303	-0.00265158	-0.0367243	0.0380091	0.230 (10)
803	0.00989001	-0.0046078	-0.0417185	0.0431217	0.154 (10)
806	0.00174337	0.00151342	-0.0221481	0.0222681	0.165 (10)
Total	**0.00795474**	**0.0031913**	**0.034543**	**0.0355904**	**0.186**

Table 8. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

OC Survey – sUAV Testing (Camera) - Equipment and Procedures

Glassell Yard – LOKI & GCPs

Flight 1 (20190228)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
312	0.0221075	-0.0198484	-0.050307	0.0584251	0.162 (10)
800	0.00145274	-0.0140627	0.00462058	0.0148734	0.261 (10)
801	-0.0114444	-0.00679389	0.0064621	0.0147949	0.162 (10)
802	-0.00683327	0.0211877	-0.0252573	0.0336681	0.246 (10)
Total	**0.0129279**	**0.0164833**	**0.0284246**	**0.0353098**	**0.213**

Table 6. Control points.
X - Longitude, Y - Latitude, Z - Altitude.

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
11	0.00737546	-0.0211564	0.0173288	0.0283245	0.184 (10)
803	0.00337906	-0.0100384	0.00451632	0.0115145	0.209 (10)
805	-0.000728603	-0.00555807	0.0157213	0.0166908	0.231 (10)
806	-0.00521255	-0.00236173	-0.015608	0.016624	0.188 (10)
807	-0.00587671	-0.0146247	-0.00610137	0.0169011	0.261 (10)
Total	**0.00506069**	**0.0126389**	**0.0130283**	**0.0188438**	**0.217**

Table 7. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

Flight 2 (20190418)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
312	0.00507259	-0.0151729	-0.0158071	0.0224903	0.129 (10)
800	0.00478758	-0.0130807	0.0289879	0.0321609	0.166 (10)
801	-0.0025936	0.00409554	0.013953	0.0147711	0.246 (10)
802	-0.00137345	0.00720846	-0.0067193	0.00994974	0.255 (10)
Total	**0.00378369**	**0.0108404**	**0.0182345**	**0.0215483**	**0.206**

Table 6. Control points.
X - Longitude, Y - Latitude, Z - Altitude.

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
11	0.0137681	-0.0134755	0.0343421	0.0393767	0.532 (10)
803	0.00789849	-0.00499527	0.00798328	0.0122911	0.411 (10)
805	0.00266385	-0.00641144	0.0272428	0.0281135	0.466 (10)
806	-0.00198763	-0.0110848	-0.00412498	0.0119933	0.263 (10)
807	-0.0139487	-0.0104198	0.00364363	0.0177881	0.416 (10)
Total	**0.0095662**	**0.00978871**	**0.0200777**	**0.0242991**	**0.427**

Table 7. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

Flight 3 (20190501)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
312	-8.79516e-005	-0.00143625	-0.00907689	0.00919023	0.190 (10)
800	-0.000502439	-0.00232487	0.00514517	0.00566835	0.238 (10)
801	-0.000298087	-0.00243117	0.00361745	0.00436868	0.211 (10)
802	0.00035396	-0.00170707	-0.00387551	0.00424958	0.178 (10)
Total	**0.000344356**	**0.0020182**	**0.00585167**	**0.0061995**	**0.205**

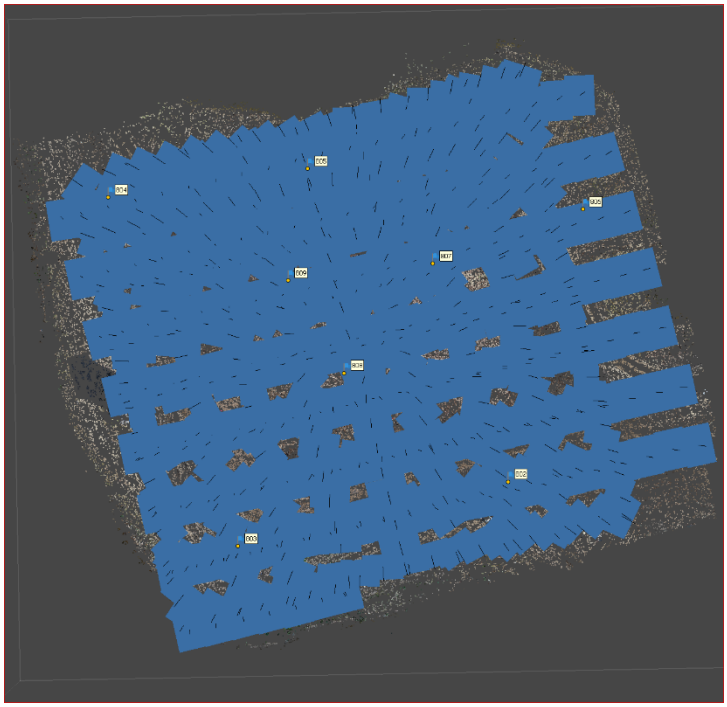
Table 6. Control points.
X - Longitude, Y - Latitude, Z - Altitude.

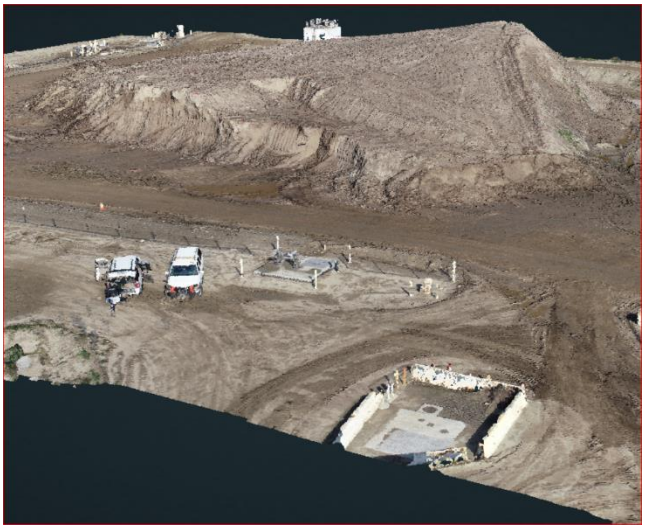
Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
11	0.00428657	-0.031091	0.0121255	0.033646	0.190 (10)
803	0.00779512	-0.0295054	-0.0250551	0.0394853	0.142 (10)
805	-0.00250153	-0.0282731	0.00928581	0.0298639	0.190 (10)
806	-0.00623493	-0.0234651	-0.0281979	0.0372103	0.195 (10)
807	-0.00573645	-0.0274955	-0.0234121	0.0365655	0.222 (10)
Total	**0.00560674**	**0.0280827**	**0.0209965**	**0.0355095**	**0.190**

Table 7. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

OC Survey – sUAV Testing (Camera) - Equipment and Procedures

Miller Basin Stockpile





Distance from CCCS – 0.5 miles (0.8km)

https://www.ocgis.com/potree/1.6/20190312_Miller_Basin.html

Field Control: GCPs based on static GPS observations from CCCS. Horizontal and vertical conventionally established.

Flight 1

NADIR - 100' AGL, forward 80%, side 70%, Flight time = 6min 36s, 159 Photos

GRID - 100' AGL, forward 80%, side 70%, camera angle 70, Flight time = 15min 19s, 335 Photos

No additional flights were made due to the changing conditions.

OC Survey – sUAV Testing (Camera) - Equipment and Procedures

Miller Basin – Flight 1 - 20190312

LOKI & AIRGON CALIBRATION

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
802	-0.0173104	0.0162981	0.0610423	0.0655091	0.710 (10)
803	0.106578	0.0588186	-0.000139681	0.121732	0.403 (10)
804	0.0162817	-0.00150808	-0.0571646	0.0594572	0.239 (10)
805	0.00720911	-0.0049701	0.0251067	0.0265899	0.688 (10)
806	0.00166522	-0.0517958	-0.0444945	0.0683032	0.542 (11)
807	0.0210113	0.0284729	0.0587144	0.0685533	0.455 (10)
808	0.0409881	0.024386	0.0985092	0.109447	0.352 (10)
809	0.0284677	0.0190542	0.0675465	0.0757364	0.754 (10)
Total	**0.0431716**	**0.0320224**	**0.0584359**	**0.0793976**	**0.547**

Table 5. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

GCPs

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
802	-0.0175544	0.00331994	0.0112823	0.0211298	0.562 (10)
803	0.0530316	0.00274805	-0.0161095	0.0554925	0.288 (10)
804	-0.0292162	0.0224331	-0.053693	0.0651135	0.216 (10)
805	-0.023009	0.00492713	0.0634163	0.0676411	0.552 (10)
806	-0.00329982	-0.0503278	-0.0880832	0.101501	0.176 (11)
807	0.0195947	0.0169188	0.0928899	0.0964299	0.355 (10)
Total	**0.0285726**	**0.0236827**	**0.0628206**	**0.0729636**	**0.386**

Table 7. Control points.
X - Longitude, Y - Latitude, Z - Altitude.

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
808	0.0141283	0.00715597	0.14909	0.149929	0.212 (10)
809	-0.00848188	0.0138915	0.132013	0.133013	0.357 (10)
Total	**0.0116523**	**0.0110495**	**0.140811**	**0.141723**	**0.294**

Table 8. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

LOKI & GCPs

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
802	-0.0216241	0.0107555	0.0359057	0.0432724	0.710 (10)
803	0.0852083	0.0490318	-0.0141799	0.0993259	0.403 (10)
804	-0.0135745	0.0105728	-0.0419727	0.0453625	0.238 (10)
806	0.00213919	-0.0405146	-0.0564789	0.0695405	0.542 (11)
808	0.0275404	0.0241914	0.0908447	0.0979615	0.352 (10)
Total	**0.0416542**	**0.0311712**	**0.0542119**	**0.0751375**	**0.479**

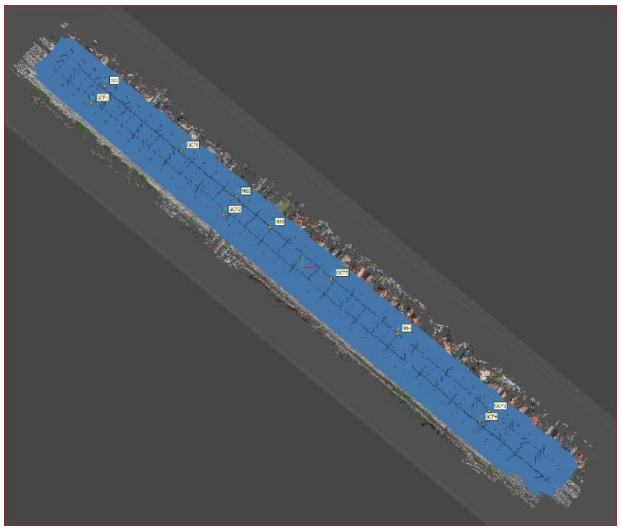
Table 6. Control points.
X - Longitude, Y - Latitude, Z - Altitude.

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
805	-0.00967415	0.008641	0.0311638	0.0337556	0.689 (10)
807	0.013835	0.0340985	0.0538343	0.0652093	0.455 (10)
809	0.0111079	0.0248638	0.0683733	0.0735969	0.754 (10)
Total	**0.0116674**	**0.0248703**	**0.0533673**	**0.0600227**	**0.646**

Table 7. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

OC Survey – sUAV Testing (Camera) - Equipment and Procedures

Como Channel



Distance from OEOC – 5.4 miles (8.6km)

https://www.ocgis.com/potree/1.6/como_channel.html

Field Control: GCPs based on MBI control network. Horizontal and vertical conventionally established.

Flight 1 – (20190314)

NADIR - 100' AGL, forward 80%, side 70%, Flight time = 12min 31s, 295 Photos

GRID - 110' AGL, forward 80%, side 60%, camera angle 70, Flight time = 21min 49s, 293 Photos

Flight 2 – (20190321)

NADIR - 100' AGL, forward 80%, side 70%, Flight time = 12min 31s, 295 Photos

GRID - 110' AGL, forward 80%, side 60%, camera angle 70, Flight time = 21min 49s, 293 Photos

Flight 3 – (20190417)

NADIR - 100' AGL, forward 80%, side 70%, Flight time = 12min 31s, 295 Photos

45 DEGREE GRID - 110' AGL, forward 80%, side 60%, camera angle 70, Flight time = 21min 49s, 293 Photos

ORBIT AROUND INTERSECTION, everything varies, 59 Photos

OC Survey – sUAV Testing (Camera) - Equipment and Procedures

COMO CHANNEL - LOKI & AIRGON CALIBRATION

Flight 1 – (20190314)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
901	0.213712	0.229862	-0.00492874	0.3139	0.694 (10)
902	0.0620841	0.086919	-0.0282148	0.110478	0.492 (10)
903	0.043858	0.0543284	0.0160594	0.071645	0.494 (10)
904	0.0282941	-0.0260917	-0.037079	0.0534433	0.496 (10)
GCP1	0.225358	0.218945	-0.220059	0.3836	0.677 (11)
GCP2	0.0917367	0.0667439	-0.0115491	0.114034	0.448 (10)
GCP3	-0.123782	-0.160106	0.0878233	0.22061	1.150 (10)
GCP4	-0.137217	-0.123947	0.246014	0.307757	0.694 (10)
GCP5	-0.00794772	0.0780469	0.058954	0.0981329	0.563 (10)
GCP6	0.121892	0.0916362	-0.00491431	0.152574	0.791 (14)
Total	**0.126698**	**0.131111**	**0.110792**	**0.213348**	**0.684**

Table 5. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

Flight 2 – (20190321)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
902	0.0107409	0.0941899	0.131777	0.162334	0.542 (10)
903	0.00830881	0.0818203	0.152026	0.172845	0.842 (10)
904	0.0169702	0.0655849	0.204707	0.215625	0.454 (7)
GCP1	0.0639367	0.0538434	0.115497	0.142572	0.398 (7)
GCP2	0.0375124	0.0822568	0.0982013	0.13348	0.393 (6)
GCP3	0.0164131	0.097523	0.229771	0.25015	0.832 (8)
GCP4	0.0212211	0.108609	0.196316	0.225358	0.605 (9)
GCP5	0.0167549	0.0628566	0.166245	0.178519	0.480 (7)
GCP6	0.031925	0.0642482	0.141685	0.158813	0.785 (8)
Total	**0.0297903**	**0.0809104**	**0.164793**	**0.185986**	**0.633**

Table 5. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

Flight 3 – (20190417)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
901	0.0379398	-0.0265956	-0.00683238	0.0468341	0.574 (10)
902	0.000180545	0.0293873	0.0311494	0.0428244	0.465 (10)
903	-0.00270091	0.0330529	-0.0099681	0.0346288	0.371 (10)
GCP1	0.0608876	-0.0326909	0.0203836	0.072052	0.869 (10)
GCP2	0.0109574	0.0253917	0.080077	0.084718	0.537 (10)
GCP6	0.0256027	0.00807454	0.0967882	0.100442	0.286 (10)
Total	**0.0314368**	**0.0272093**	**0.0537155**	**0.0679262**	**0.549**

Table 5. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

OC Survey – sUAV Testing (Camera) - Equipment and Procedures

COMO CHANNEL - GCPS

Flight 1 – (20190314)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
901	-0.0152896	0.0207215	0.0199118	0.032552	0.214 (11)
902	-0.0451109	0.00716651	-0.0281197	0.0536383	0.293 (10)
GCP1	0.0406108	-0.0130476	-0.0322147	0.0534534	0.359 (10)
GCP2	0.0114519	-0.0171322	0.016373	0.0263199	0.524 (10)
GCP3	-0.00369242	0.00379661	-0.0100629	0.0113714	0.405 (10)
GCP4	0.0113041	-0.000991095	-0.00740518	0.01355	0.534 (10)
Total	**0.0264278**	**0.0126484**	**0.0210125**	**0.0360546**	**0.403**

Table 7. Control points.
X - Longitude, Y - Latitude, Z - Altitude.

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
903	-0.0380192	0.00131421	-0.0188254	0.0424451	0.448 (10)
904	-0.0173399	-0.0178371	0.0282406	0.0376346	0.622 (10)
GCP5	-0.0142919	-0.0199784	0.0398538	0.0468158	0.297 (10)
GCP6	-0.0222342	0.0102472	-0.029558	0.0383802	0.334 (10)
Total	**0.0247222**	**0.014353**	**0.030058**	**0.041481**	**0.444**

Table 8. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

Flight 2 – (20190321)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
902	-0.0284462	0.0263441	0.0175907	0.042575	0.327 (10)
GCP1	0.062902	-0.0309679	-0.00922891	0.0707167	0.272 (5)
GCP2	-0.00900816	0.00820799	0.00721932	0.0141646	0.218 (10)
GCP3	0.039125	-0.00919762	0.0109807	0.0416646	0.337 (6)
GCP4	0.0404523	-0.0216265	-0.0129635	0.047667	0.214 (9)
Total	**0.0400354**	**0.0213199**	**0.0121273**	**0.0469515**	**0.274**

Table 7. Control points.
X - Longitude, Y - Latitude, Z - Altitude.

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
903	-0.037465	0.0354695	-0.0172557	0.054401	0.292 (8)
904	-0.0431866	0.00264912	-0.0179666	0.0468497	0.204 (10)
GCP5	-0.0373259	0.000824033	0.0256619	0.0453039	0.180 (10)
GCP6	0.0130381	-0.0118087	-0.00437752	0.0181273	0.266 (10)
Total	**0.034756**	**0.0187432**	**0.0180157**	**0.0434034**	**0.237**

Table 8. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

Flight 3 – (20190417)

Insufficient GCPs

COMO CHANNEL - LOKI & GCPs

Flight 1 – (20190314)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
902	-0.0212174	0.0229349	-0.0638222	0.0710596	0.340 (12)
903	-0.0258372	-0.00565702	-0.00623361	0.0271739	0.324 (11)
GCP1	0.0669706	0.0717255	-0.0797515	0.126451	0.618 (10)
GCP2	0.0138501	-0.00638408	0.0126768	0.0198314	0.481 (10)
GCP6	-0.0376134	0.0400638	-0.038613	0.0671628	0.371 (10)
901	0.029007	0.08618	-0.0123504	0.0917657	0.342 (10)
Total	**0.0366306**	**0.0496243**	**0.0452339**	**0.0764884**	**0.422**

Table 6. Control points.
X - Longitude, Y - Latitude, Z - Altitude.

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
904	-0.0190787	-0.0147285	-0.0360126	0.043334	0.309 (10)
GCP3	-0.144625	-0.140111	0.0163324	0.202025	0.412 (9)
GCP4	-0.162747	-0.0898769	0.0974656	0.209914	0.415 (12)
GCP5	-0.0540902	0.0306264	0.0766893	0.0987167	0.248 (10)
Total	**0.112575**	**0.0849468**	**0.0650854**	**0.155323**	**0.355**

Table 7. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

Reprocess constraining GCP to 0.0005’ to force model to fit vertical with optimize.

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
902	-0.00603326	0.00608013	-0.00735321	0.0112888	0.349 (12)
903	-0.00379298	-0.00229944	-0.000685026	0.00448813	0.345 (11)
GCP1	0.00890218	-0.00496162	-0.00703265	0.0123824	0.669 (10)
GCP2	0.0138108	-0.0048188	0.0130613	0.0196101	0.455 (10)
GCP6	-0.00419615	0.000978973	-0.000213845	0.00431413	0.385 (10)
901	-0.00643	0.00584299	0.00423032	0.00966338	0.363 (10)
Total	**0.00795535**	**0.00456787**	**0.00698255**	**0.0115286**	**0.439**

Table 6. Control points.
X - Longitude, Y - Latitude, Z - Altitude.

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
904	-0.0064642	-0.00294922	-0.0255952	0.0265631	0.310 (10)
GCP3	-0.13794	-0.130671	0.0177455	0.190833	0.412 (9)
GCP4	-0.156834	-0.0801048	0.0941027	0.199673	0.416 (12)
GCP5	-0.0304191	0.0338547	0.0892273	0.100165	0.249 (10)
Total	**0.105584**	**0.0784959**	**0.0666837**	**0.1475**	**0.355**

Table 7. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

Flight 2 – (20190321)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
902	-0.0108762	0.0412293	0.0754	0.0866216	0.282 (10)
903	-0.00215867	0.028032	0.0864983	0.0909528	0.403 (14)
GCP1	0.00497533	0.016648	0.0972172	0.0987577	0.321 (13)
GCP2	0.00593046	0.0263758	0.0905455	0.0944952	0.338 (11)
GCP6	0.00971537	0.0180198	0.0788829	0.0814961	0.338 (13)
901	0.00316346	0.0020441	0.0586116	0.0587325	0.241 (10)
Total	**0.00691943**	**0.0251243**	**0.0821326**	**0.0861677**	**0.330**

Table 6. Control points.
X - Longitude, Y - Latitude, Z - Altitude.

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
904	-0.00320154	0.0372885	0.197183	0.200703	0.214 (7)
GCP3	-0.000969356	0.0889071	0.220632	0.237873	0.271 (8)
GCP4	0.00942472	0.0955885	0.199673	0.221575	0.391 (9)
GCP5	-0.00557977	0.0178326	0.154669	0.155794	0.134 (7)
Total	**0.00572601**	**0.0684654**	**0.194519**	**0.206296**	**0.279**

Table 7. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

Reprocess constraining GCP to 0.0005’ to force model to fit vertical and optimize.

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
902	-0.00236748	0.00404543	-0.00113002	0.00482155	0.272 (10)
903	-0.00056161	-0.000414865	0.0048506	0.00490059	0.403 (14)
GCP1	-0.000886991	0.00256945	0.00690648	0.00742215	0.327 (13)
GCP2	0.00380234	-0.00307859	0.0118323	0.0128039	0.338 (11)
GCP6	0.000867492	0.000661212	0.00405121	0.00419548	0.344 (13)
901	0.001669	-0.0012406	-0.00360587	0.00416257	0.244 (10)
Total	**0.00202908**	**0.00240117**	**0.00634985**	**0.00708543**	**0.331**

Table 6. Control points.
X - Longitude, Y - Latitude, Z - Altitude.

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
904	-0.00862753	0.024599	0.20301	0.204677	0.216 (7)
GCP3	-0.00853975	0.084473	0.218341	0.234268	0.271 (8)
GCP4	0.0018632	0.0907534	0.201303	0.220822	0.391 (9)
GCP5	-0.00234273	-0.00811805	0.144776	0.145023	0.135 (7)
Total	**0.00625143**	**0.0633303**	**0.193887**	**0.204064**	**0.279**

Table 7. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

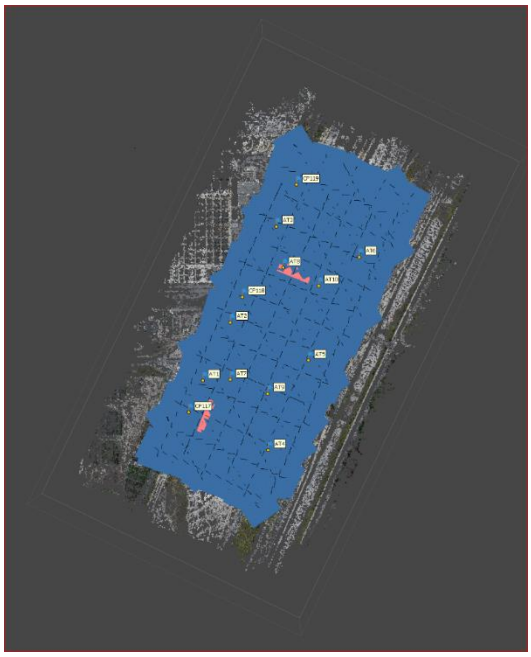
Flight 3 – (20190417)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
901	0.0124597	-0.0160983	-0.0118228	0.023541	0.290 (10)
902	-0.00387063	0.0154539	0.00908138	0.0183378	0.194 (10)
903	-0.00390473	0.0182908	-0.0232611	0.0298477	0.201 (10)
GCP1	0.0349769	-0.0274329	0.0199511	0.0487237	0.681 (10)
GCP2	0.00880746	0.00939815	0.0658569	0.0671046	0.287 (10)
GCP6	0.0159926	0.00170129	0.0614524	0.0635221	0.156 (10)
Total	**0.0170401**	**0.0167148**	**0.0393169**	**0.0459953**	**0.349**

Table 5. Control points.
X - Longitude, Y - Latitude, Z - Altitude.

OC Survey – sUAV Testing (Camera) - Equipment and Procedures

Santa Ana River



Distance from FVPK – 1.8 miles (2.9km)

https://www.ocgis.com/potree/1.6/SAR_Field_Services_Tests.html

Field Control: GCPs based on existing control stations. Horizontal and vertical conventionally established.

Flight 1 – (20190416)

NADIR - 150' AGL, forward 80%, side 65%, Flight time = 6min 52s, 142 Photos

GRID - 175' AGL, forward 80%, side 70%, camera angle 70, Flight time = 14min 47s, 299 Photos

45 DEGREE ANGLE - 100' AGL, forward 80%, side 60%, camera angle 75, Flight time = 6min 53s, 159 Photos

Flight 2 – (20190426)

NADIR - 150' AGL, forward 80%, side 65%, Flight time = 6min 52s, 142 Photos

45 DEGREE ANGLE - 100' AGL, forward 80%, side 60%, camera angle 75, Flight time = 6min 53s, 159 Photos

-45 DEGREE ANGLE - 100' AGL, forward 80%, side 60%, camera angle 75, Flight time = 6min 53s, 159 Photos

Flight 3 – (20190430)

NADIR - 150' AGL, forward 80%, side 65%, Flight time = 6min 52s, 141 Photos

45 DEGREE ANGLE - 100' AGL, forward 80%, side 60%, camera angle 75, Flight time = 6min 53s, 149 Photos

-45 DEGREE ANGLE - 100' AGL, forward 80%, side 60%, camera angle 75, Flight time = 6min 53s, 153 Photos

OC Survey – sUAV Testing (Camera) - Equipment and Procedures

SANTA ANA RIVER - LOKI & AIRGON CALIBRATION

Flight 1 – (20190416)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
AT1	0.0153174	0.00219915	-0.0795066	0.0809985	0.665 (10)
AT2	0.0242012	0.000943722	-0.0473115	0.0531504	0.453 (10)
AT3	0.0674735	0.0283654	-0.095023	0.119944	0.429 (10)
AT4	0.000977195	0.019768	-0.0241218	0.0312025	0.699 (10)
AT5	0.024675	-0.00208641	-0.042552	0.0492329	0.374 (10)
AT6	0.0837422	0.0287144	0.0183599	0.0904121	0.689 (10)
AT7	0.0267237	-0.000410915	-0.115551	0.118601	0.313 (11)
AT8	0.0384353	0.039615	-0.0887823	0.104541	0.570 (10)
AT9	0.0189161	-0.00663686	-0.127606	0.129171	0.440 (10)
AT10	0.0587512	0.0077458	-0.0851937	0.103777	0.350 (10)
Total	**0.043585**	**0.0192446**	**0.0806809**	**0.0936985**	**0.515**

Table 6. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

Flight 2 – (20190426)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
AT1	0.0595534	-0.030627	-0.0801841	0.104471	0.467 (10)
AT2	0.020709	-0.0362003	-0.0607998	0.0737288	0.590 (10)
AT4	0.020843	-0.0109298	-0.0747556	0.0783727	0.374 (10)
AT5	0.0239681	-0.0210996	-0.0352779	0.0475836	0.639 (10)
AT6	0.00498156	-0.0431143	-0.0191269	0.0474289	0.615 (10)
AT7	0.0690111	-0.0479829	-0.0480068	0.0967964	0.464 (10)
AT9	0.0210056	-0.0793895	-0.0145133	0.083394	0.683 (10)
AT10	0.0369015	-0.0620129	0.0375603	0.0813517	0.485 (10)
CP118	0.0215923	-0.0649611	-0.0426622	0.0806612	0.472 (10)
Total	**0.036577**	**0.048697**	**0.0506305**	**0.0792005**	**0.541**

Table 6. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

Flight 3 – (20190430)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
AT1	0.0187579	-0.0489086	-0.122473	0.133205	0.243 (10)
AT2	-0.0144169	-0.0790346	-0.0833667	0.115777	0.304 (10)
AT4	0.00929421	0.00690907	-0.124159	0.124698	0.608 (10)
AT5	-0.00878426	-0.0385928	-0.115279	0.121884	0.495 (10)
AT6	-0.00120845	-0.0392323	-0.054156	0.0668843	0.536 (10)
AT7	0.0364843	-0.0695524	-0.0763688	0.109548	0.517 (10)
AT9	-0.00521917	-0.0712053	-0.162816	0.177782	0.471 (10)
AT10	-0.00351236	-0.02609	-0.0607881	0.0662436	0.511 (10)
Total	**0.0161841**	**0.0528006**	**0.105844**	**0.119385**	**0.475**

Table 6. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

OC Survey – sUAV Testing (Camera) - Equipment and Procedures

SANTA ANA RIVER - GCPs

Flight 1 – (20190416)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
AT1	-0.00157212	0.00841712	-0.000586587	0.00858274	0.148 (10)
AT3	0.00811554	-0.0209289	-0.0249617	0.0335703	0.134 (10)
AT4	-0.00313769	0.0156319	-0.0283749	0.0325475	0.230 (10)
AT6	0.0144437	0.0259462	-0.000668387	0.0297031	0.241 (10)
AT8	-0.015417	-0.00884833	0.0145561	0.0229752	0.196 (10)
AT9	-0.00369049	-0.0204759	0.024253	0.0319545	0.304 (10)
CP117					
CP118					
CP119					
Total	**0.00947017**	**0.0179071**	**0.0192748**	**0.0279618**	**0.217**

Table 7. Control points.
X - Longitude, Y - Latitude, Z - Altitude.

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
AT2	0.00873206	-0.000475756	0.0656939	0.0662734	0.102 (10)
AT5	0.00318369	0.00646692	0.019829	0.0210985	0.220 (10)
AT7	0.00548412	0.0149948	-0.0236746	0.0285553	0.096 (10)
AT10	-0.00785935	0.00621411	-0.0416993	0.0428861	0.229 (10)
Total	**0.00667514**	**0.00873937**	**0.0418575**	**0.043278**	**0.174**

Table 8. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

Flight 2 – (20190426)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
AT1	0.0202064	0.0123088	-0.0568155	0.0615452	0.177 (12)
AT3					
AT4	-0.00939584	0.0157939	-0.0237833	0.0300562	0.185 (10)
AT6	0.0053188	0.0136427	-0.0316934	0.0349125	0.187 (10)
AT8					
AT9	-0.00801627	-0.0340426	0.0704774	0.078678	0.378 (10)
CP117					
CP118	-0.00905401	-0.00640548	0.0337392	0.0355154	0.187 (10)
CP119					
Total	**0.0115854**	**0.0189051**	**0.046698**	**0.0516945**	**0.234**

Table 7. Control points.
X - Longitude, Y - Latitude, Z - Altitude.

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
AT2	-0.000389936	0.0177693	0.0115055	0.0211726	0.209 (10)
AT5	0.00116422	0.00846644	0.118844	0.119151	0.558 (10)
AT7	0.0494859	-0.00882921	0.124667	0.134419	0.597 (10)
AT10	0.00680761	-0.0266717	0.134633	0.137418	0.662 (10)
Total	**0.0249835**	**0.017152**	**0.109458**	**0.113575**	**0.536**

Table 8. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

Flight 3 – (20190430)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
AT1	0.00192822	0.00199204	-0.0639851	0.0640452	0.132 (10)
AT2	-0.00997104	-0.0109141	-0.00297496	0.0150794	0.159 (10)
AT4	-0.016736	0.00539659	-0.0130357	0.0218894	0.235 (10)
AT6	0.00352307	0.0127385	-0.0525792	0.0542149	0.201 (10)
AT7	0.0159962	-0.00566222	0.0652375	0.0674083	0.362 (10)
AT10	0.00412656	-0.00382248	0.0566821	0.0569605	0.246 (10)
Total	**0.0105558**	**0.00775834**	**0.0491702**	**0.0508854**	**0.234**

Table 6. Control points.
X - Longitude, Y - Latitude, Z - Altitude.

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
AT5	-0.00485863	0.00860961	0.115434	0.115856	0.307 (10)
AT9	0.00584758	-0.0491534	0.139197	0.147737	0.760 (10)
Total	**0.00537589**	**0.0352859**	**0.127869**	**0.132757**	**0.580**

Table 7. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

OC Survey – sUAV Testing (Camera) - Equipment and Procedures

SANTA ANA RIVER - LOKI & GCPs

Flight 1 – (20190416)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
AT1	0.0097817	0.00933972	-0.0420629	0.0441837	0.249 (10)
AT2	0.00683831	-0.00325576	-0.0186116	0.0200936	0.124 (10)
AT4	-0.0112936	0.0315442	-0.0121566	0.0356422	0.270 (10)
AT6	0.0568953	0.0231626	0.0137698	0.0629539	0.273 (10)
AT7	0.0152158	0.00495469	-0.0769082	0.0785553	0.128 (11)
AT10	0.0309665	0.00438499	-0.0672922	0.074205	0.166 (10)
Total	**0.0279807**	**0.016699**	**0.0463612**	**0.0566669**	**0.211**

Table 6. Control points.
X - Longitude, Y - Latitude, Z - Altitude.

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
AT3	0.0390197	0.0226129	-0.0922527	0.102686	0.109 (10)
AT5	0.00330812	6.68512e-005	-0.0345514	0.0347094	0.141 (10)
AT8	0.0140393	0.0323577	-0.0754695	0.0833053	0.207 (10)
AT9	0.000793528	-0.00106586	-0.105206	0.105215	0.220 (10)
Total	**0.0208039**	**0.0197453**	**0.0813456**	**0.0862542**	**0.175**

Table 7. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

Flight 2 – (20190426)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
AT1	0.0409463	-0.0177466	-0.0487352	0.0660807	0.229 (10)
AT2	0.00285631	-0.0201129	-0.0191244	0.0279004	0.179 (10)
AT4	-0.00223005	0.0029598	-0.0668069	0.0669097	0.153 (10)
AT6	-0.00403534	-0.0316822	-0.0223188	0.0389638	0.272 (10)
AT7	0.0447021	-0.0374999	-0.0335636	0.067313	0.263 (10)
AT10	0.0188057	-0.0495742	0.0302117	0.0610247	0.302 (10)
Total	**0.0260062**	**0.0305392**	**0.0402936**	**0.0568554**	**0.239**

Table 6. Control points.
X - Longitude, Y - Latitude, Z - Altitude.

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
AT5	0.00250015	-0.00931061	-0.0357013	0.03698	0.258 (10)
AT9	-0.00653123	-0.0666963	-0.013711	0.0684035	0.412 (10)
CP118	-0.000517281	-0.0533655	-0.021748	0.0576292	0.200 (10)
Total	**0.00404867**	**0.0496083**	**0.0254005**	**0.0558799**	**0.304**

Table 7. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

Flight 3 – (20190430)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
AT2	-0.00334008	-0.0519938	-0.049654	0.0719724	0.200 (13)
AT4	-0.0141252	0.025236	-0.0912342	0.0957081	0.364 (10)
AT6	-0.0283043	-0.0212532	-0.0359142	0.0504248	0.341 (10)
AT7	0.0339946	-0.0520948	-0.057574	0.08476	0.241 (10)
AT10	-0.0271482	-0.0131701	-0.0417074	0.051478	0.239 (13)
AT1	0.0263524	-0.0314454	-0.0578582	0.0709284	0.200 (12)
Total	**0.0244912**	**0.0357492**	**0.058425**	**0.0727413**	**0.266**

Table 6. Control points.
X - Longitude, Y - Latitude, Z - Altitude.

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
AT5	-0.0276646	-0.0240496	-0.0904585	0.0976036	0.229 (10)
AT9	-0.0183841	-0.0503001	-0.236979	0.242955	0.390 (15)
Total	**0.0234873**	**0.0394239**	**0.179363**	**0.18514**	**0.335**

Table 7. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

Reprocess constraining GCP to 0.0005’ to force model to fit vertical and optimize.

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
AT2	-0.00107625	0.00118803	-0.00142148	0.0021425	0.186 (13)
AT4	-0.00199245	0.0013512	-0.000739703	0.00251848	0.348 (10)
AT6	-0.000186756	-0.00164393	-0.00121719	0.00205401	0.343 (10)
AT7	0.00778463	-0.0107488	-0.00441232	0.0139859	0.264 (10)
AT10	-0.000457572	0.00335992	0.002878	0.00444762	0.230 (13)
AT1	-0.00206069	0.00396395	0.00151056	0.00471605	0.214 (12)
Total	**0.003421**	**0.00497459**	**0.00238336**	**0.00649078**	**0.265**

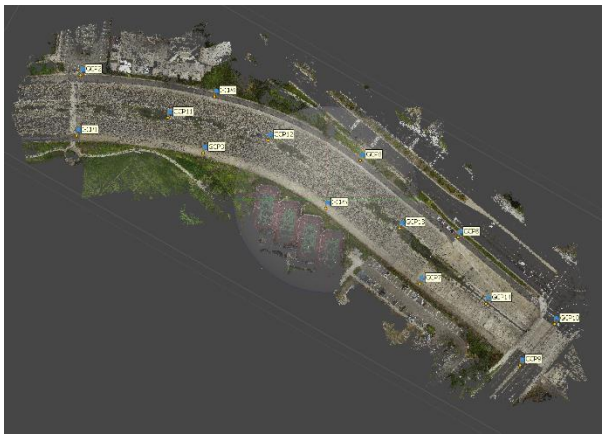
Table 4. Control points.
X - Longitude, Y - Latitude, Z - Altitude.

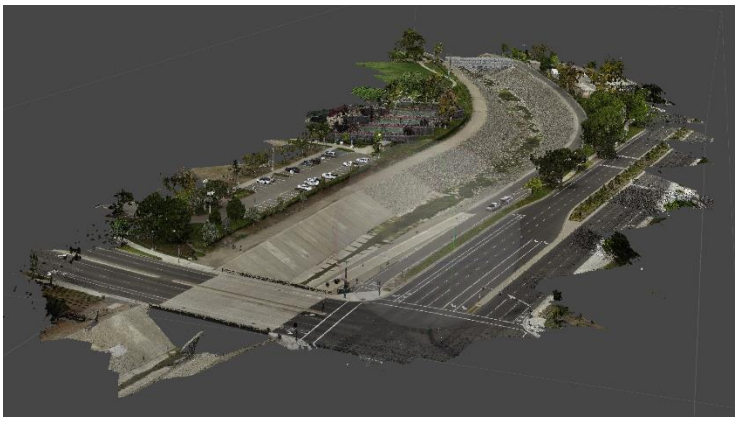
Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
AT5	-0.0133934	0.00294835	-0.0097098	0.0168034	0.235 (10)
AT9	-0.0156613	-0.0315463	-0.15753	0.16142	0.397 (15)
Total	**0.0145715**	**0.0224038**	**0.111602**	**0.114758**	**0.341**

Table 5. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

OC Survey – sUAV Testing (Camera) - Equipment and Procedures

San Diego Creek Reach 2





Distance from TRAK – 4.9 miles (7.9km)

https://www.ocgis.com/potree/1.6/SAR_Field_Services_Tests.html

Field Control: GCPs based on existing control stations. Horizontal and vertical conventionally established.

Flight 1 – (20190924)

NADIR - 125' AGL, forward 80%, side 80%, Flight time = 15min 3s, 371 Photos

GRID - 105' AGL, forward 60%, side 60%, camera angle 70, Flight time = 5min 47s, 282 Photos

Flight 2 – (20190926)

NADIR - 125' AGL, forward 80%, side 80%, Flight time = 15min 3s, 371 Photos

GRID - 125' AGL, forward 70%, side 70%, camera angle 70, Flight time = 7min 9s, 343 Photos

Flight 3 – (20190930)

NADIR - 125' AGL, forward 80%, side 80%, Flight time = 15min 3s, 371 Photos

GRID - 125' AGL, forward 70%, side 70%, camera angle 70, Flight time = 7min 9s, 343 Photos

SANTA ANA RIVER - LOKI & AIRGON CALIBRATION

Not performed due to difference in epoch positions; CGPS = 2017.50, GCP = 1990 adj.

OC Survey – sUAV Testing (Camera) - Equipment and Procedures

SAN DIEGO CREEK REACH 2 - LOKI

Flight 1 – (20190923)

LOKI NADIR & LOKI GRID

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
GCP1	-2.01648	2.92486	1.91954	4.03803	0.366 (10)
GCP10	-1.96039	2.80761	1.89851	3.91537	0.385 (10)
GCP11	-2.05741	2.73832	1.98353	3.958	0.451 (10)
GCP12	-2.09727	2.65245	2.00032	3.92878	0.488 (10)
GCP13	-2.15797	2.6855	1.95966	3.96346	0.459 (10)
GCP14	-2.06556	2.71456	1.88234	3.89596	0.436 (10)
GCP2	-1.8704	2.84396	2.08735	3.99294	0.458 (10)
GCP3	-2.06416	2.71177	2.01249	3.95785	0.478 (10)
GCP4	-2.0473	2.68301	1.99349	3.9197	0.412 (10)
GCP5	-2.13711	2.69765	2.01463	3.9879	0.751 (10)
GCP6	-2.14569	2.66646	1.9684	3.94824	0.502 (10)
GCP7	-2.14299	2.6999	1.97179	3.97112	0.509 (10)
GCP8	-2.17462	2.70555	1.97406	3.99323	0.493 (10)
GCP9	-1.93506	2.65581	1.80682	3.74999	0.464 (10)
Total	**2.06418**	**2.72872**	**1.96345**	**3.94486**	**0.483**

Table 4. Control points.
X - Longitude, Y - Latitude, Z - Altitude.

LOKI NADIR & GRID

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
GCP1	-2.03855	2.89162	1.96438	4.04672	0.453 (10)
GCP10	-1.92386	2.81492	1.81615	3.86308	0.248 (10)
GCP11	-2.09443	2.69407	1.96862	3.93956	0.471 (11)
GCP12	-2.14796	2.62296	1.92793	3.90007	0.384 (10)
GCP13	-2.17064	2.67345	1.83005	3.89975	0.553 (10)
GCP14	-2.04582	2.70828	1.76673	3.82642	0.508 (10)
GCP2	-1.90297	2.80451	2.01799	3.94447	0.549 (10)
GCP3	-2.11031	2.68105	1.94843	3.9291	0.502 (10)
GCP4	-2.08948	2.6392	1.95183	3.89114	0.399 (10)
GCP5	-2.1607	2.67915	1.93721	3.94959	0.740 (11)
GCP6	-2.18518	2.66161	1.88606	3.92637	0.451 (11)
GCP7	-2.14407	2.68251	1.83408	3.89317	0.323 (10)
GCP8	-2.17297	2.70663	1.85183	3.93407	0.472 (10)
GCP9	-1.89973	2.64865	1.6995	3.67595	0.417 (10)
Total	**2.07995**	**2.70876**	**1.88774**	**3.90219**	**0.478**

Table 4. Control points.
X - Longitude, Y - Latitude, Z - Altitude.

Flight 2 – (20190926)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
GCP1	-2.02462	2.83307	2.03673	4.03406	0.625 (10)
GCP10	-2.08513	2.74121	1.97628	3.97085	0.630 (10)
GCP11	-2.07204	2.78569	1.93437	3.97432	0.885 (10)
GCP12	-2.044	2.73956	1.9541	3.93721	0.613 (10)
GCP13	-2.06513	2.72761	1.97163	3.94867	0.573 (10)
GCP14	-2.07526	2.73214	2.01165	3.97719	0.758 (10)
GCP2	-2.02135	2.80555	1.98406	3.98666	0.391 (10)
GCP3	-2.04918	2.77011	1.9442	3.95633	0.549 (10)
GCP4	-2.04988	2.76483	1.96669	3.96411	0.782 (10)
GCP5	-2.0594	2.75389	1.95862	3.95743	0.684 (10)
GCP6	-2.03991	2.74492	1.96107	3.94228	0.668 (10)
GCP7	-2.06995	2.74461	1.95922	3.95678	0.736 (10)
GCP8	-2.08871	2.7163	2.03529	3.9854	0.512 (10)
GCP9	-2.10136	2.75301	1.98638	3.99256	0.655 (10)
Total	**2.06055**	**2.75821**	**1.9774**	**3.97035**	**0.658**

Table 4. Control points.
X - Longitude, Y - Latitude, Z - Altitude.

Flight 3 – (20190930)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
GCP1	-1.95201	2.75823	1.98406	3.9185	0.511 (10)
GCP10	-2.15928	2.77719	1.91718	4.00635	0.456 (10)
GCP11	-1.99643	2.71718	2.12287	3.98439	0.595 (10)
GCP12	-2.02559	2.698	1.94308	3.8933	0.843 (10)
GCP13	-2.10429	2.73527	2.09745	4.03845	0.468 (10)
GCP14	-2.124	2.75794	2.10175	4.06632	1.239 (10)
GCP2	-1.95826	2.72746	1.85111	3.83412	0.319 (10)
GCP3	-2.00413	2.73314	2.11107	3.99289	0.538 (10)
GCP4	-2.00501	2.70482	1.97482	3.90333	0.482 (10)
GCP5	-2.05696	2.75552	2.1405	4.05039	0.765 (10)
GCP6	-2.05202	2.70983	2.0102	3.94903	0.447 (10)
GCP7	-2.10632	2.77386	2.06503	4.04911	0.523 (11)
GCP8	-2.12322	2.72047	1.99228	3.98475	0.316 (10)
GCP9	-2.11701	2.76731	1.84272	3.94149	0.976 (10)
Total	**2.05705**	**2.73842**	**2.01327**	**3.97287**	**0.655**

Table 4. Control points.
X - Longitude, Y - Latitude, Z - Altitude.

OC Survey – sUAV Testing (Camera) - Equipment and Procedures

SAN DIEGO CREEK REACH 2 - GCPs

Flight 1 – (20190923)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
GCP1	0.00732357	0.00157839	0.00601572	0.00960807	0.216 (10)
GCP10	-0.00904013	0.00687223	-0.0197301	0.0227646	0.191 (10)
GCP12	-0.00255886	-0.00354075	-0.00264394	0.00510638	0.210 (10)
GCP13	-0.00342828	-0.00864277	0.0206145	0.0226143	0.183 (10)
GCP2	-0.0102538	-0.00220057	-0.0244828	0.0266344	0.209 (10)
GCP5	0.00523673	0.0113072	0.0180037	0.0218954	0.301 (10)
GCP6	0.00916897	0.00216277	-0.00309466	0.00991588	0.189 (10)
GCP9	0.00319437	-0.00668502	-0.00815426	0.0110175	0.166 (12)
Total	**0.00689654**	**0.00631482**	**0.0152357**	**0.0178764**	**0.211**

Table 6. Control points.
X - Longitude, Y - Latitude, Z - Altitude.

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
GCP11	-0.0241834	0.00407395	0.00944869	0.0262814	0.266 (10)
GCP14	0.0030057	-0.0054309	-0.00979829	0.0115989	0.236 (10)
GCP3	0.00462011	0.0108755	0.00550853	0.0130371	0.213 (10)
GCP4	-0.00686184	0.00678986	-0.0133809	0.0164996	0.191 (10)
GCP7	-0.0154495	0.00761787	0.0395871	0.0431724	0.177 (10)
GCP8	-0.0277804	-0.0233792	0.00100466	0.0363228	0.180 (10)
Total	**0.016697**	**0.0116554**	**0.0180869**	**0.0272355**	**0.213**

Table 7. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

Flight 2 – (20190926)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
GCP1	-0.00995246	0.0112853	0.000925044	0.0150754	0.235 (10)
GCP10	0.00441756	0.00936435	-0.0613047	0.0621729	0.234 (10)
GCP12	0.00491696	-0.0138063	0.0360888	0.0389511	0.289 (10)
GCP13	-0.000872522	-0.00352427	-0.00784473	0.00864416	0.354 (10)
GCP2	-0.00446884	-0.00311185	-0.044191	0.0445253	0.206 (10)
GCP5	0.010912	-0.0109497	0.0327355	0.036202	0.285 (10)
GCP6	0.009592	0.00933691	0.0148897	0.0200222	0.297 (10)
GCP9	-0.014626	0.00164551	0.0286302	0.0321919	0.223 (10)
Total	**0.00857667**	**0.00892713**	**0.0338912**	**0.0360814**	**0.270**

Table 6. Control points.
X - Longitude, Y - Latitude, Z - Altitude.

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
GCP11	-0.0248136	-0.00299322	-0.0157376	0.0295355	0.394 (10)
GCP14	-0.00408512	-0.0080054	0.0085691	0.0124179	0.315 (10)
GCP3	-0.00231096	-0.00286147	0.0192527	0.0196009	0.321 (10)
GCP4	-0.00279192	0.00344748	-0.0125694	0.0133293	0.190 (10)
GCP7	-0.0173008	0.027634	0.0376185	0.0497806	0.193 (10)
GCP8	-0.0186997	0.00450623	0.0205208	0.0281263	0.240 (10)
Total	**0.0146886**	**0.0120904**	**0.0211582**	**0.0284535**	**0.285**

Table 7. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

Flight 3 – (20190930)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
GCP1	0.0016616	0.0119268	0.0168979	0.0207497	0.280 (12)
GCP10	-0.0189774	0.0083782	0.0439823	0.048629	0.423 (10)
GCP12	0.000578891	-0.0102811	-0.0447196	0.0458898	0.386 (10)
GCP13	-0.00238212	-0.00185071	0.0271247	0.0272919	0.326 (10)
GCP2	-0.00673416	-0.00334439	-0.0235298	0.0247019	0.157 (10)
GCP5	-0.00505945	0.0109205	0.0822759	0.0831516	0.553 (10)
GCP6	0.0114178	-0.0114647	-0.0316057	0.0355067	0.208 (10)
GCP9	0.0198208	-0.00428294	-0.0799891	0.0825195	0.312 (10)
Total	**0.0109721**	**0.00867321**	**0.049593**	**0.0515274**	**0.349**

Table 6. Control points.
X - Longitude, Y - Latitude, Z - Altitude.

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
GCP11	0.0122104	-0.0122356	0.0851019	0.0868397	0.804 (10)
GCP14	0.0239081	-0.0174076	0.0882824	0.0931043	0.545 (10)
GCP3	0.00990995	-0.00451217	0.0321748	0.0339674	0.432 (10)
GCP4	0.00847848	-0.0121845	-0.0283089	0.0319647	0.256 (10)
GCP7	-0.00394306	0.0196248	-0.00213961	0.020131	0.490 (10)
GCP8	-0.0120336	-0.0190901	-0.0488628	0.0538221	0.213 (10)
Total	**0.0132359**	**0.0151169**	**0.056664**	**0.0601209**	**0.497**

Table 7. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

OC Survey – sUAV Testing (Camera) - Equipment and Procedures

SAN DIEGO CREEK REACH 2 – LOKI & GCPs

Flight 1 – (20190923)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
GCP1	-0.00213779	0.147505	0.00101394	0.147524	0.244 (10)
GCP10	0.0982794	0.143881	-0.0285173	0.176561	0.227 (10)
GCP12	-0.059096	-0.140566	0.0112263	0.152896	0.315 (10)
GCP13	-0.118124	-0.0540519	0.0391942	0.135687	0.293 (10)
GCP2	0.141619	0.0736447	-0.0549432	0.168814	0.124 (10)
GCP5	-0.0895185	-0.062641	0.0659416	0.127616	0.361 (10)
GCP6	-0.120704	-0.0947265	0.00110797	0.15344	0.300 (10)
GCP9	0.150625	-0.0130908	-0.0393713	0.156235	0.288 (10)
Total	**0.107492**	**0.102245**	**0.0377407**	**0.153078**	**0.277**

Table 4. Control points.
X - Longitude, Y - Latitude, Z - Altitude.

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
GCP11	-0.0204562	-0.0763435	-0.0259349	0.083183	0.308 (10)
GCP14	-0.013828	0.0158695	-0.00199607	0.0211433	0.307 (10)
GCP3	-0.013151	-0.0776313	0.0582027	0.0979138	0.277 (10)
GCP4	-0.00990792	-0.116091	-0.0366109	0.12213	0.200 (10)
GCP7	-0.0897342	-0.0179289	0.0906237	0.128788	0.313 (10)
GCP8	-0.144694	-0.00777991	0.043159	0.151194	0.280 (10)
Total	**0.0705567**	**0.0657849**	**0.0507935**	**0.109022**	**0.284**

Table 5. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

Flight 2 – (20190926)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
GCP1	0.0064547	0.020705	0.0178044	0.0280599	0.299 (10)
GCP10	0.0124026	0.000790044	-0.0477011	0.0492934	0.224 (10)
GCP12	-0.00243492	-0.017001	0.0182745	0.0250783	0.395 (10)
GCP13	-0.00788809	-0.013943	0.0197074	0.0253971	0.372 (10)
GCP2	-0.00648342	-0.0102098	-0.0551218	0.056433	0.205 (10)
GCP5	-0.00770408	0.00738339	0.0275484	0.0295429	0.388 (10)
GCP6	0.00819415	0.00596079	0.0153061	0.0183562	0.379 (10)
GCP9	-0.00244147	0.00643627	0.00464631	0.00830509	0.321 (10)
Total	**0.00740044**	**0.0119816**	**0.0303478**	**0.0334562**	**0.331**

Table 4. Control points.
X - Longitude, Y - Latitude, Z - Altitude.

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
GCP11	-0.0334665	-0.00255508	-0.0296338	0.0447738	0.531 (10)
GCP14	0.0010217	-0.0111228	0.0251097	0.0274819	0.492 (10)
GCP3	-0.00189122	0.000102242	0.0145413	0.0146641	0.277 (10)
GCP4	-0.0204445	-0.000606728	0.00937071	0.0224979	0.343 (10)
GCP7	-0.00647772	0.00214275	0.0336119	0.0342975	0.335 (10)
GCP8	-0.0222918	-0.0162132	0.0689575	0.0742626	0.245 (10)
Total	**0.0186256**	**0.00814539**	**0.0358069**	**0.0411752**	**0.385**

Table 5. Check points.
X - Longitude, Y - Latitude, Z - Altitude.

Flight 3 – (20190930)

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
GCP1	0.0046342	0.0182587	0.0553079	0.0584279	0.332 (10)
GCP10	-0.0103157	0.0194389	-0.0454997	0.0505421	0.245 (10)
GCP12	-0.00220115	-0.0307062	-0.0597942	0.0672537	0.681 (10)
GCP13	-0.020668	-0.0100316	0.11188	0.114214	0.388 (10)
GCP2	-0.00811443	0.00766996	-0.118566	0.11909	0.179 (10)
GCP5	-0.00103851	0.0127761	0.161308	0.161817	0.527 (10)
GCP6	0.0113372	-0.0100844	-0.00287053	0.0154424	0.317 (10)
GCP9	0.0289569	-0.00948188	-0.0931774	0.0980328	0.494 (10)
Total	**0.014115**	**0.0164636**	**0.0935347**	**0.0960158**	**0.424**

Table 4. Control points.
X - Longitude, Y - Latitude, Z - Altitude.

Label	X error (ft)	Y error (ft)	Z error (ft)	Total (ft)	Image (pix)
GCP11	-0.0134532	-0.0142493	0.139644	0.141012	0.472 (10)
GCP14	-0.00146167	-0.00402572	0.133021	0.13309	0.782 (10)
GCP3	-0.000749765	-0.00220668	0.144539	0.144557	0.402 (10)
GCP4	-0.00300366	-0.00772788	-0.0297982	0.0309301	0.322 (10)
GCP7	-0.00810444	0.0175492	0.110565	0.112242	0.330 (11)
GCP8	-0.0172292	-0.0156809	-0.00466713	0.0237596	0.213 (10)
Total	**0.00961974**	**0.011816**	**0.10895**	**0.11001**	**0.455**

Table 5. Check points.
X - Longitude, Y - Latitude, Z - Altitude.