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Airborne Data Acquisition Lab2

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Task 1. Manual measurement of ground control points (GCP) and check points (CHP)

1.1 Perform manual measurement of image points. Open the project from lab1, which is shown as Fig1. Select Georeferencing->MATCH-AT->Multi Photo Measurement, show 'GCP&CheckOnly' points and manually measure all the control points.

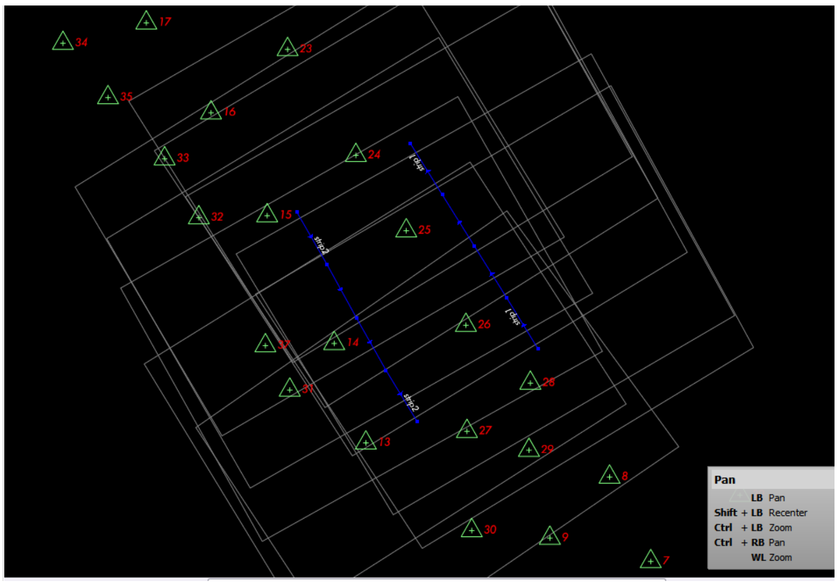
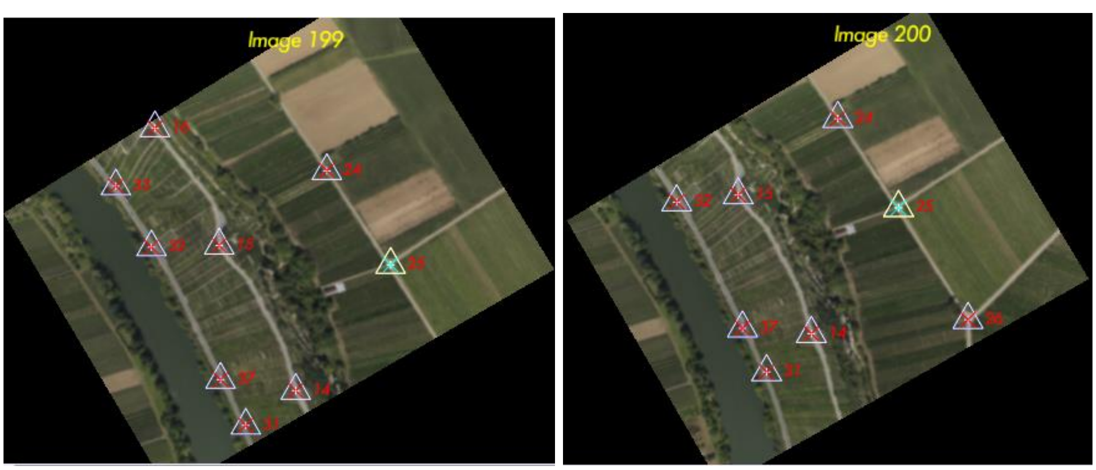


Fig1-1. Processing Block

1.2 Fig2 shows the distribution of the control points in the 10 images, from which we can see that control points in image 199-203 cover distribute uniformly, while control points in image 204, 245-248 are almost gathered in the left part.



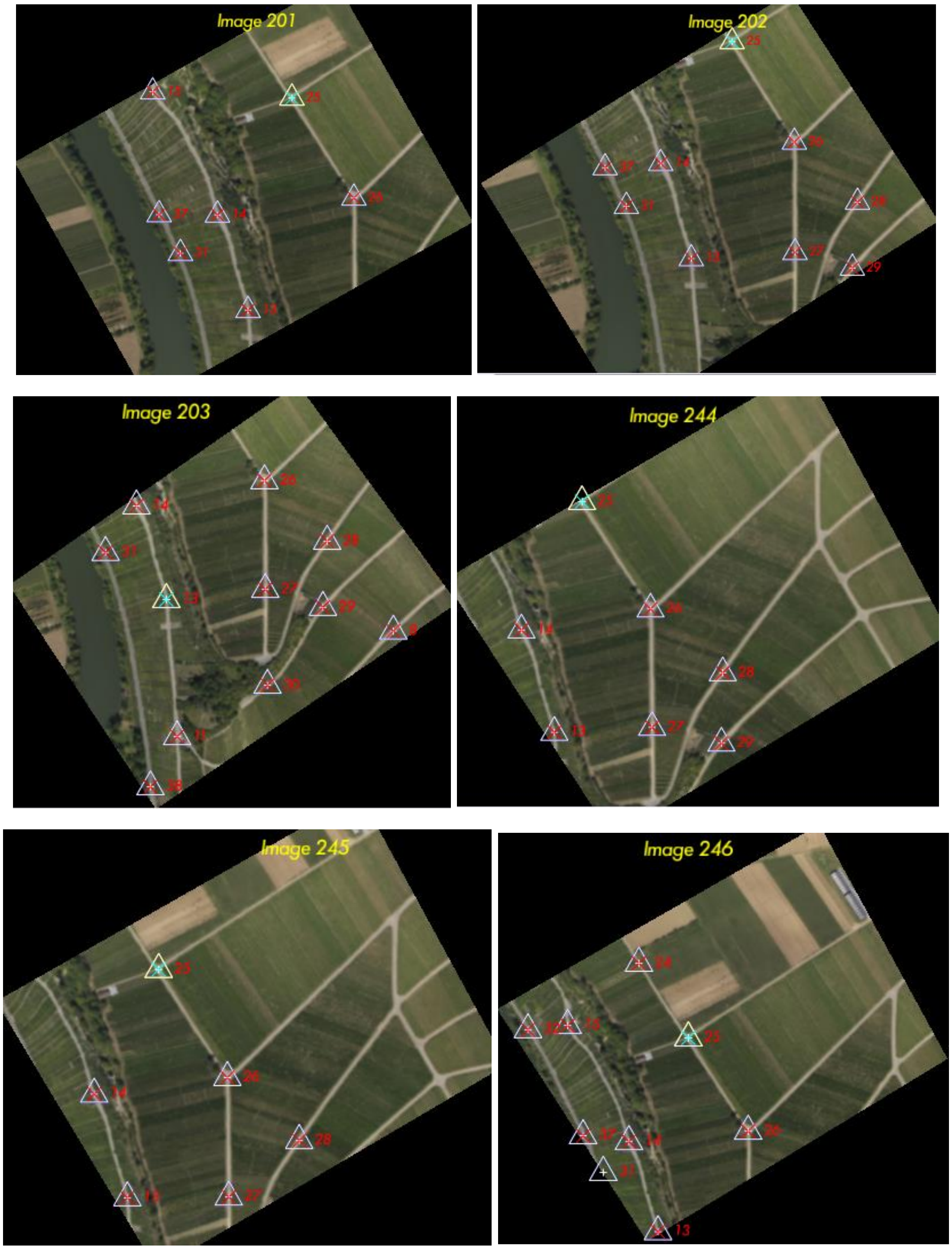


Image 201
Image 202
Image 203
Image 244
Image 245
Image 246

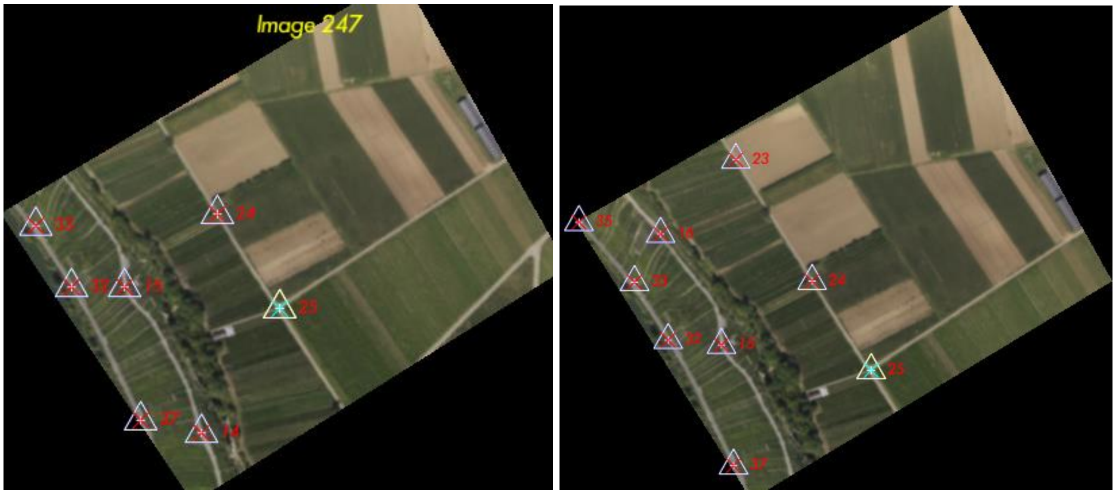


Fig1-2. Distributions of control points

Table 1 shows the number of control points per image.

Table 1. Number of GCPs per image

image	199	200	201	202	203	244	245	246	247	248
Number of GCPs	9	8	7	9	11	7	6	9	7	9

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Task 2. Automatic tie point measurement and transfer

2.1 Select Georeferencing->MATCH-AT->Aerial Frame Triangulation->Automatic tie point extraction with adjustment of block, select edit->strategy, and set the image pyramids. Here we choose default point density and 4*4 TPC pattern. Run the program and then we can get the AAT file and output report.

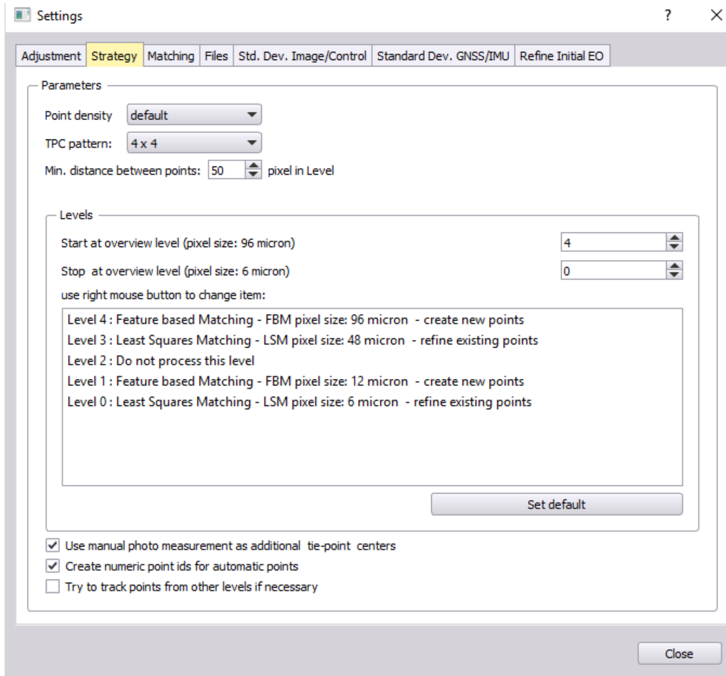


Fig2-1. Automatic tie point measurement pyramids

2.2 Knowing from the AAT file, there are totally 2677 points which have been automatically measured (Fig2-2).

```
created   318 observations for photo          200
created   281 observations for photo          201
created   253 observations for photo          202
created   177 observations for photo          203
created   249 observations for photo          244
created   308 observations for photo          245
created   340 observations for photo          246
created   280 observations for photo          247
created   227 observations for photo          248
created   244 observations for photo          199
```

Fig2-2. Number of automatically measured points

2.3 Fig2-3 shows the distribution of automatically matched points by using the Analyzer Tool. From the figure we can see that in the middle area of the block, the density of points is much lower than other areas. The reason comes from the characteristic of the image, as this area is mostly farming field, which does not have apparent feature. Therefore, the program does not see it as a sound source for point extracting.

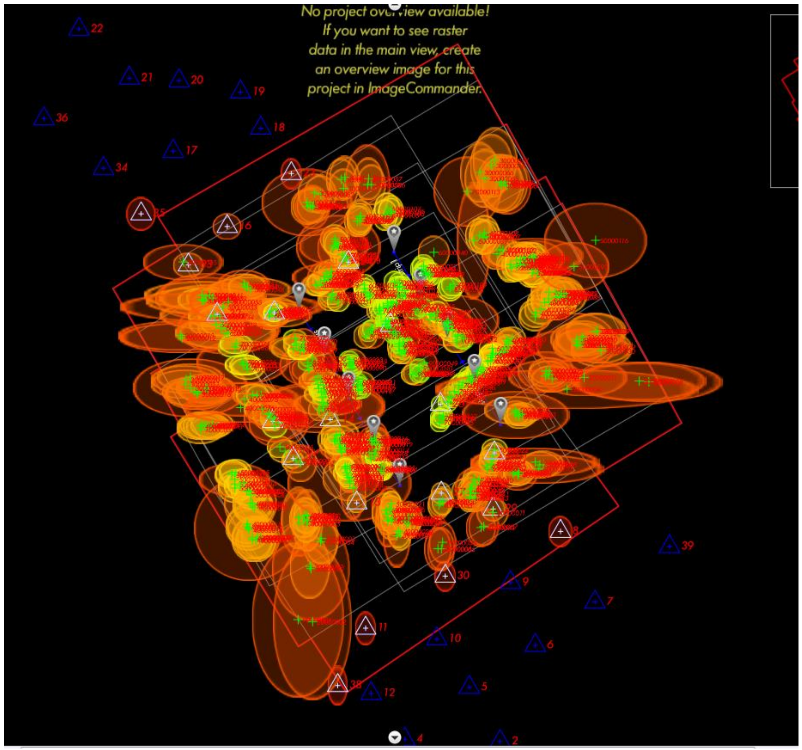


Fig2-3. Distribution of automatically matched points

Task 3. AT with all Ground Control Points (GCP) only

The first adjustment is based on all GCPs, this does not allow to perform external accuracy evaluation because of the lack of check points. Thus only precision of the AT is analysed here.

Sigma naught

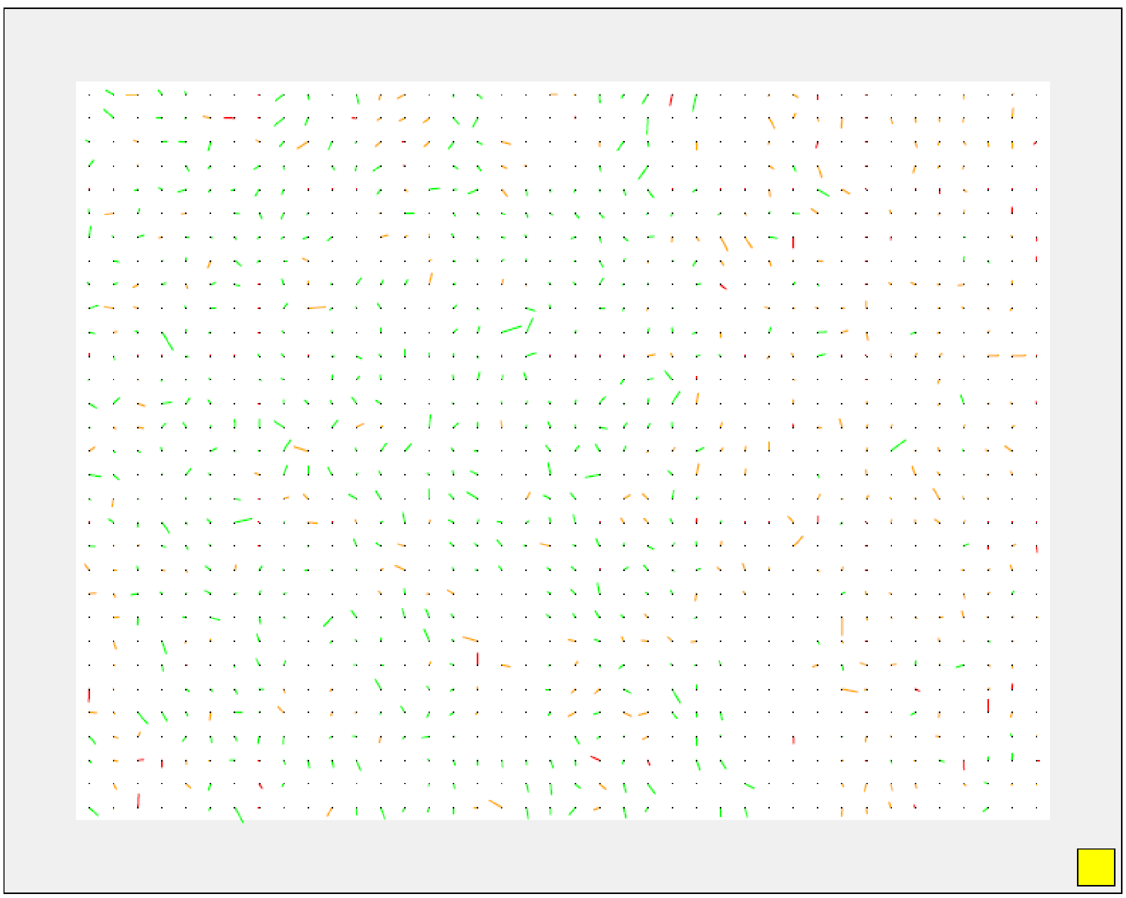
Sigma naught [micron]	1.0457

Figure 3-1 sigma naught of AT with GCP

The final sigma naught is 1.0457 [micron] = 0.2 [pixel in level 0]. And the pixel size(x/y) is 6[micron]. Sigma naught value divided by original pixel size of image equal to 1/6 which is sufficient the requirement.

Image measurement residuals

Image residuals (Camera: camera1)

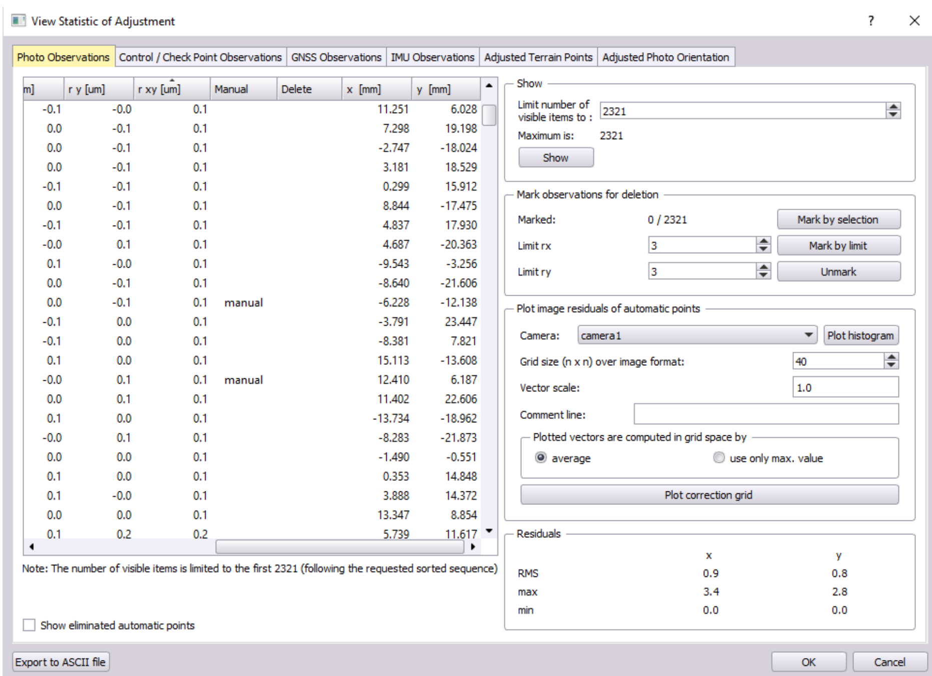


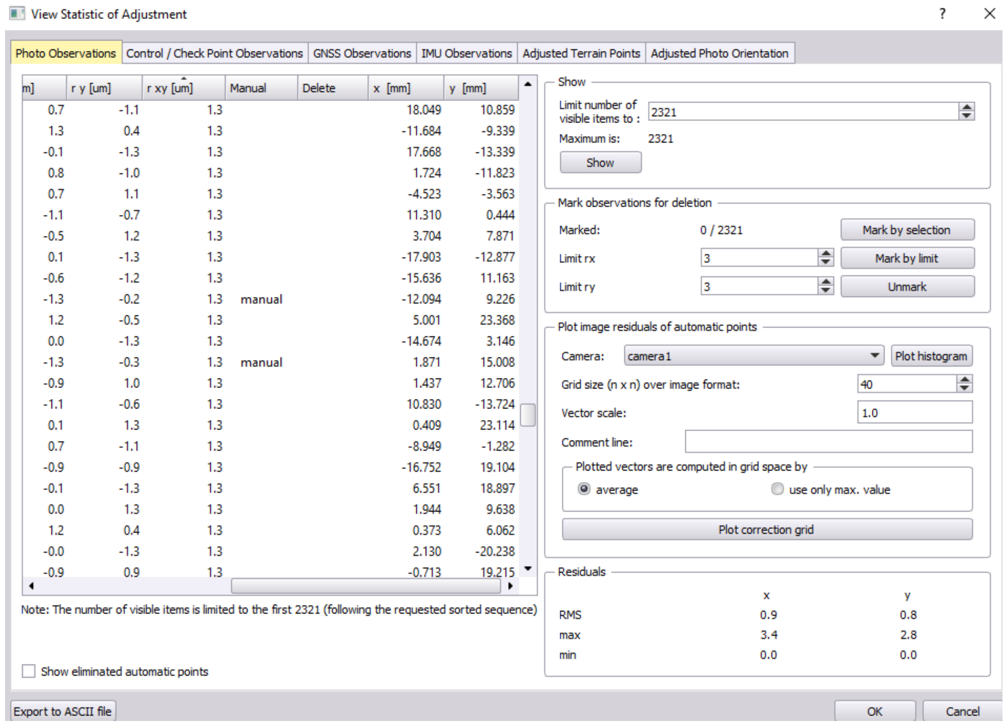
```
RMS automatic points in photo (number: 2240)
        x           0.8 micron
        y           0.8 micron

RMS  control and manual points in photo (number: 81)
        x           1.0 micron
        y           1.1 micron
```

Figure 3-2 Image measurement residuals

According to the RMS for all automatic points and manual points, 0we can find automatic points' RMS is better than manual's. We can get more detail from below figures:





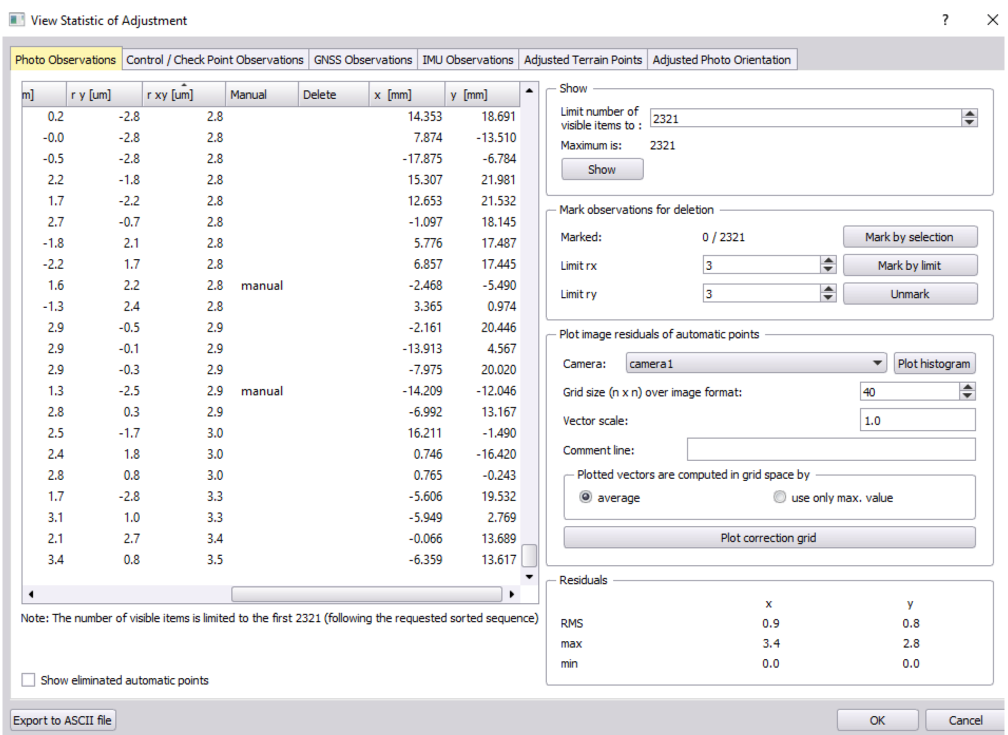


Figure 3-3 Distribution of residuals

From above figures we can know manual RMS evenly distributed from tiny to large. This two results may because operational errors influence the accuracy of control points. And the distribution of manual points indicate that we can get the right point position when zoom in the image to enough scale.

Control points residuals

residuals horizontal control points in [meter]

control point ID	rx	ry
8	-0.008	-0.021
11	0.004	-0.021
13	0.029	0.027
14	0.024	0.010
15	0.030	0.006
16	0.010	0.009
23	-0.017	-0.024
24	-0.004	-0.024
25	-0.020	-0.019
26	-0.030	0.005
27	0.001	0.017
28	-0.024	0.011
29	-0.003	0.004
30	0.003	-0.005
31	0.018	-0.001
32	-0.023	0.005
33	-0.008	0.017
35	-0.007	0.025
37	0.020	0.001
38	0.004	-0.021

residuals vertical control points in [meter]

control point ID	rz
8	-0.001
11	0.009
13	0.001
14	0.007
15	0.007
16	-0.017
23	-0.001
24	0.023
25	0.014
26	-0.018
27	-0.003
28	-0.005
29	-0.019
30	0.002
31	-0.005
32	-0.005
33	-0.011
35	0.007
37	0.004
38	0.011

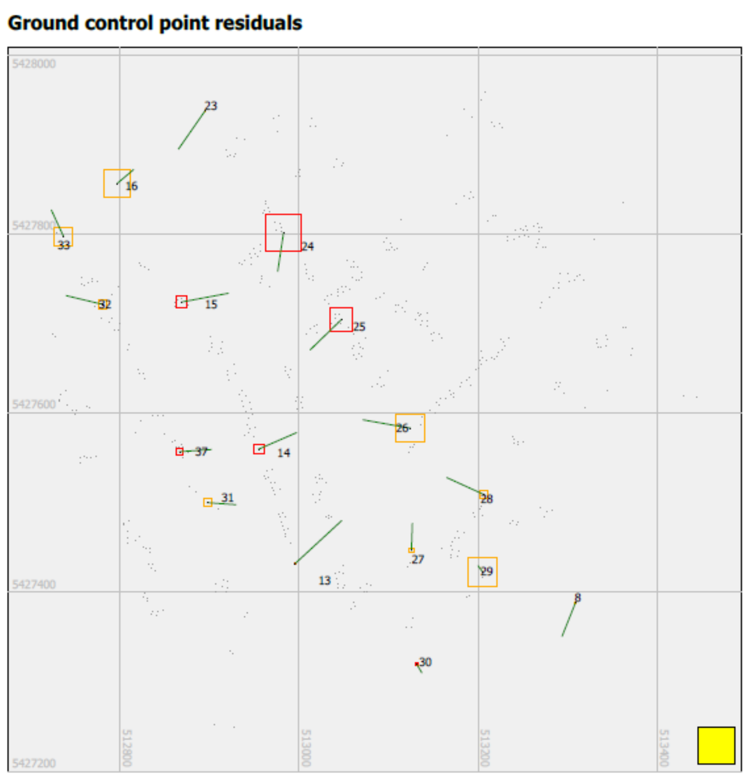


Figure 3-4 Control Point Residuals

From above figure we can find all residuals are smaller than requirement(7cm) which means there is no measurement error.

Precision of adjusted terrain points

Mean standard deviation of terrain points

X [m]	Y [m]	Z [m]	Total [m]
0.0148	0.0123	0.0399	0.0443

Figure 3-5 Precision of adjusted terrain points

Precision of adjusted terrain points are shown above. And accuracy of expectation is a half of ground sampling distance. And that value is 0.0311m(x/y direction). So this accuracy matching our expectation.

Precision of adjusted exterior orientation elements

Mean standard deviation of translations

X [m]	Y [m]	Z [m]	Total [m]
0.0285	0.0278	0.0138	0.0421

Mean standard deviation of rotations

Omega [deg/1000]	Phi [deg/1000]	Kappa [deg/1000]
3.7434	3.0228	1.3960

Figure 3-6 precision of adjusted exterior orientation elements

From the above result, we can get the precision of x,y direction are less than z direction. Corresponding to position elements, the precision of omega and phi are also less than kappa. Theoretically, precise of kappa should larger than omega and phi but wind or fly condition will influence the Z-orientation. Because of this tilt , we can distinguish error of focal length and object coordinates for camera in z-orientation.

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Task 4. AT with additional Check Points(CHP)

Introduce additional check points by changing the status from control to check point. Then redo the Adjustment.

So we change some control points status to check points, the control points remained are 14, 16, 24, 25, 27, 31, 32, 33, 37 and 8(as figure below). Other points are changed to check points. The remained control points are sufficient requirement below: Each image have at least 3 control points. These control are best located on the edge of images in different sides. After change the status of some points,we redo the adjustment and get a new result.

Trimble MATCH-AT

Ground control points

Ground control point errors

#	ID	Fold	X [m]	Y [m]	Z [m]	Total [m]	Remark
1	**14**	9	-0.0262	-0.0149	-0.0060	0.0308	
2	**16**	2	-0.0104	-0.0071	0.0162	0.0205	
3	**24**	5	-0.0013	0.0248	-0.0180	0.0306	
4	**25**	9	0.0153	0.0158	-0.0031	0.0222	
5	**27**	4	-0.0046	-0.0291	0.0096	0.0310	
6	**31**	5	-0.0149	-0.0002	0.0029	0.0152	
7	**32**	5	0.0290	-0.0032	0.0001	0.0292	
8	**33**	3	0.0152	-0.0135	0.0062	0.0213	
9	**37**	7	-0.0164	-0.0018	-0.0080	0.0183	
10	**8**	1	0.0187	0.0107	0.0076	0.0228	
	Maximum		0.0290	-0.0291	-0.0180		
	Mean		0.0004	-0.0018	0.0007		
	Sigma		0.0182	0.0159	0.0099		
	RMSE(x,y,z)		0.0165	0.0155	0.0093		
	RMSEr		0.0226	SQRT(RMSEx * RMSEx + RMSEy * RMSEy)			
	ACCr (at 95% Confidence Level)		0.0391	RMSEr * 1.7308			
	ACCz (at 95% Confidence Level)		0.0182	RMSEz * 1.9600			

Figure 4-1 Remain Control Points

Compare the result with task3 result

Block adjustment results

Accuracy

Sigma naught [micron]	1.0431

Mean standard deviation of translations

X [m]	Y [m]	Z [m]	Total [m]
0.0379	0.0373	0.0189	0.0564

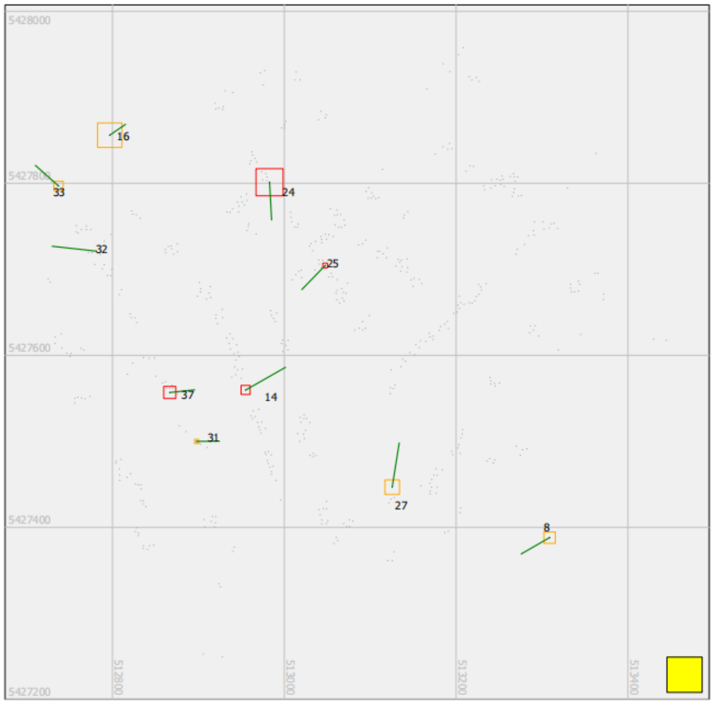
Mean standard deviation of rotations

Omega [deg/1000]	Phi [deg/1000]	Kappa [deg/1000]
5.0223	3.9297	1.9233

Mean standard deviation of terrain points

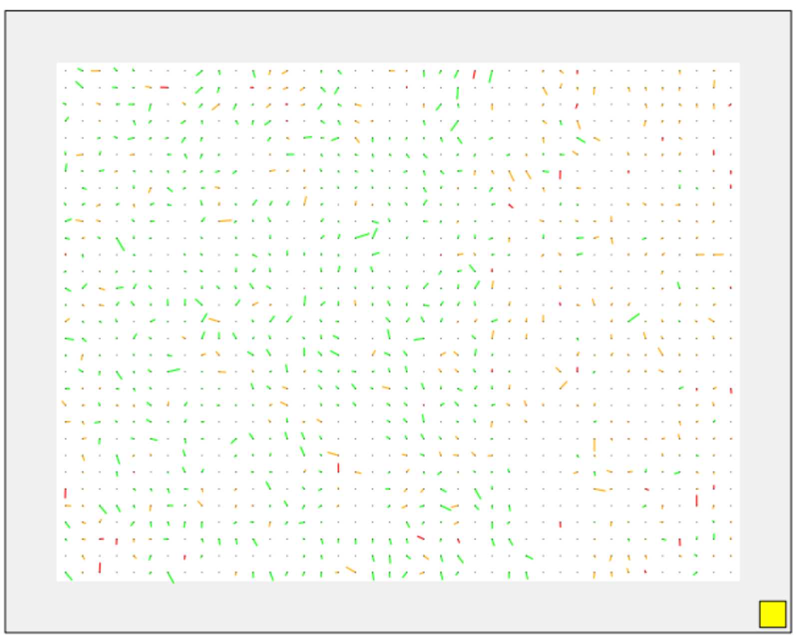
X [m]	Y [m]	Z [m]	Total [m]
0.0148	0.0123	0.0399	0.0443

Ground control point residuals



Graphic with 10 ground control points from the project. The points are shown with its residuals for XYZ from the adjustment. The area has a planimetric extent of about: 820 x 808 [m].

Image residuals (Camera: camera1)



Average image residual vectors (min=0.001, avg=0.168, max=0.583 [pixel]) for image matrix elements. An image matrix element is defined with about (200 x 200) pixels.

Figure 4-2 AT with additional check point result

From the result above we can find after we decrease the control points, deviation of translation, rotation and terrian points get larger. And the rotation elements increase more than translation elements. That may because of rotation elements will be influence by translation elements according to error propagation.

And sigma naught get a little bit smaller, I think it's because some control points which we decrease may have lower quality, so sigma naught change a little smaller.

Compare residuals from check points analysis to terrian points

control point ID	rx	ry	
8	-0.019	-0.011	
11	0.004	-0.018	
13	0.038	0.042	check point
14	0.026	0.015	
15	0.041	0.005	check point
16	0.010	0.007	
24	0.001	-0.025	
25	-0.015	-0.016	
26	-0.027	0.014	check point
27	0.005	0.029	
28	-0.025	0.022	check point
29	0.009	0.006	check point
31	0.015	0.000	
32	-0.029	0.003	
33	-0.015	0.014	
37	0.016	0.002	

control point ID	rz	
8	-0.008	
11	0.007	
13	0.021	check point
14	0.006	
15	0.035	check point
16	-0.016	
24	0.018	
25	0.003	
26	-0.050	check point
27	-0.010	
28	-0.032	check point
29	-0.097	check point
31	-0.003	
32	-0.000	
33	-0.006	
37	0.008	

Figure 4-3 Residual from Control Point and Check Point

According to figures above, we can find check points' residuals are much larger than control points. For the whole adjustment processing, we first use the control points(manual points, error mainly because of operating error) calculate exterior orientation elements. Then we can get other points' coordinates by using this elements. Check points' residuals are the coordinate difference between new calculate points and true points. And control points residuals are the coordinate difference between manual points and true points. That is also the reason that terrian point's residuals is smaller than the check points'.

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Task 5. GNSS-supported AT (with CHP)

Within first run, we use GNSS perspective center coordinates with a standard deviation as 5m, which means the observation can hardly influence the adjustment. While we edit the settings, we turn on the drift/offset adjust. The result shows below.

Accuracy

Sigma naught [micron]	1.0401

Mean standard deviation of translations

X [m]	Y [m]	Z [m]	Total [m]
0.0378	0.0372	0.0188	0.0563

Mean standard deviation of rotations

Omega [deg/1000]	Phi [deg/1000]	Kappa [deg/1000]
5.0076	3.9182	1.9176

Mean standard deviation of terrain points

X [m]	Y [m]	Z [m]	Total [m]
0.0147	0.0123	0.0398	0.0442

Figure 5- 1 Overview (5m)

Ground control points

Ground control point errors

#	ID	Fold	X [m]	Y [m]	Z [m]	Total [m]	Remark
1	**14**	9	-0.0262	-0.0149	-0.0060	0.0308	
2	**16**	2	-0.0104	-0.0071	0.0162	0.0205	
3	**24**	5	-0.0013	0.0248	-0.0180	0.0306	
4	**25**	9	0.0153	0.0158	-0.0031	0.0222	
5	**27**	4	-0.0046	-0.0291	0.0096	0.0310	
6	**31**	5	-0.0149	-0.0002	0.0029	0.0152	
7	**32**	5	0.0290	-0.0032	0.0001	0.0292	
8	**33**	3	0.0152	-0.0135	0.0062	0.0213	
9	**37**	7	-0.0164	-0.0018	-0.0080	0.0183	
10	**8**	1	0.0187	0.0107	0.0076	0.0228	
	Maximum		0.0290	-0.0291	-0.0180		
	Mean		0.0004	-0.0018	0.0007		
	Sigma		0.0182	0.0159	0.0099		
	RMSE(x,y,z)		0.0165	0.0155	0.0093		
	RMSEr		0.0226	SQRT(RMSEx * RMSEx + RMSEy * RMSEy)			
	ACCr (at 95% Confidence Level)		0.0391	RMSEr * 1.7308			
	ACCz (at 95% Confidence Level)		0.0182	RMSEz * 1.9600			

Figure 5- 2 Residual of GCPs (5m)

Check points

Check point errors

#	ID	Fold	X [m]	Y [m]	Z [m]	Total [m]	Remark
1	**13**	6	-0.0378	-0.0422	-0.0213	0.0606	
2	**15**	6	-0.0408	-0.0051	-0.0352	0.0542	
3	**26**	7	0.0270	-0.0137	0.0496	0.0582	
4	**28**	4	0.0255	-0.0222	0.0315	0.0462	
5	**29**	3	-0.0094	-0.0059	0.0974	0.0980	
	Maximum		-0.0408	-0.0422	0.0974		
	Mean		-0.0071	-0.0178	0.0244		
	Sigma		0.0328	0.0153	0.0540		
	RMSE(x,y,z)		0.0302	0.0225	0.0541		
	RMSEr		0.0376	SQRT(RMSEx * RMSEx + RMSEy * RMSEy)			
	ACCr (at 95% Confidence Level)		0.0652	RMSEr * 1.7308			
	ACCz (at 95% Confidence Level)		0.1060	RMSEz * 1.9600			

Figure 5- 3 Residual of Check points (5m)

Then comes the second run with all the conditions the same but the standard deviation as 0.1m, which is a more realistic data and will influence the adjusted strongly since the smaller the standard deviation is, the more weight the coordinates get. The result shows below.

Block adjustment results

Accuracy

Sigma naught [micron]	0.8640

Mean standard deviation of translations

X [m]	Y [m]	Z [m]	Total [m]
0.0429	**0.0412**	**0.0234**	**0.0639**

Mean standard deviation of rotations

Omega [deg/1000]	Phi [deg/1000]	Kappa [deg/1000]
5.9781	4.3906	1.9742

Mean standard deviation of terrain points

X [m]	Y [m]	Z [m]	Total [m]
0.0138	0.0118	0.0367	0.0410

Figure 5- 4 Overview (0.1m)

Ground control points

Ground control point errors

#	ID	Fold	X [m]	Y [m]	Z [m]	Total [m]	Remark
1	**14**	9	-0.0071	-0.0031	-0.0018	0.0080	
2	**16**	2	-0.0174	-0.0028	0.0114	0.0209	
3	**24**	5	0.0067	-0.0109	-0.0121	0.0176	
4	**25**	9	0.0087	-0.0030	-0.0070	0.0115	
5	**27**	4	-0.0102	0.0034	0.0140	0.0177	
6	**31**	5	0.0038	0.0014	0.0051	0.0064	
7	**32**	5	0.0191	0.0085	-0.0075	0.0222	
8	**33**	3	-0.0115	0.0066	0.0056	0.0144	
9	**37**	7	-0.0038	0.0035	-0.0052	0.0073	
10	**8**	1	-0.0017	-0.0064	0.0001	0.0067	
	Maximum		0.0191	-0.0109	0.0140		
	Mean		-0.0013	-0.0003	0.0003		
	Sigma		0.0110	0.0060	0.0086		
	RMSE(x,y,z)		0.0108	0.0055	0.0078		
	RMSEr		0.0122	SQRT(RMSEx * RMSEx + RMSEy * RMSEy)			
	ACCr (at 95% Confidence Level)		0.0210	RMSEr * 1.7308			
	ACCz (at 95% Confidence Level)		0.0153	RMSEz * 1.9600			

Figure 5- 5 Residual of GCPs (0.1m)

Check points

Check point errors

#	ID	Fold	X [m]	Y [m]	Z [m]	Total [m]	Remark
1	**13**	6	-0.0071	-0.0067	0.0520	0.0529	
2	**15**	6	-0.0228	-0.0078	-0.0304	0.0388	
3	**26**	7	0.0010	-0.0101	0.0391	0.0404	
4	**28**	4	-0.0134	-0.0102	0.0224	0.0280	
5	**29**	3	-0.0279	0.0074	0.0659	0.0720	
	Maximum		-0.0279	-0.0102	0.0659		
	Mean		-0.0140	-0.0055	0.0298		
	Sigma		0.0117	0.0074	0.0373		
	RMSE(x,y,z)		0.0175	0.0086	0.0447		
	RMSEr		0.0195	SQRT(RMSEx * RMSEx + RMSEy * RMSEy)			
	ACCr (at 95% Confidence Level)		0.0337	RMSEr * 1.7308			
	ACCz (at 95% Confidence Level)		0.0877	RMSEz * 1.9600			

Figure 5- 6 Residual of Check points (0.1m)

In GNSS-supported AT, the image perspective centers can be determined by GNSS measurements and they can play a role as the control points in the air. In this case, the precision of perspective centers measurements will determine the weight their coordinates have, and finally improve the adjustment in some degree.

As we can tell easily from the figures above, after we use a more 'accuracy' measurement, the σ_0 is smaller and all the residual of check points and GCPs are smaller significantly.

The additional drift and offset corrections are the used to correct the difference between the antenna and the actual center of camera. So if we remove the additional drift and offset corrections, the result will be worse and standard deviation gets larger.

Block adjustment results

Accuracy

Sigma naught [micron]	0.8677

Mean standard deviation of translations

X [m]	Y [m]	Z [m]	Total [m]
0.0245	0.0248	0.0144	0.0377

Mean standard deviation of rotations

Omega [deg/1000]	Phi [deg/1000]	Kappa [deg/1000]
3.2060	2.9505	1.9417

Mean standard deviation of terrain points

X [m]	Y [m]	Z [m]	Total [m]
0.0127	0.0109	0.0334	0.0374

Figure 5- 7 Overview (no drift)

Ground control points

Ground control point errors

#	ID	Fold	X [m]	Y [m]	Z [m]	Total [m]	Remark
1	**14**	9	-0.0155	-0.0032	0.0057	0.0169	
2	**16**	2	-0.0178	-0.0009	0.0073	0.0192	
3	**24**	5	0.0054	0.0060	-0.0167	0.0185	
4	**25**	9	0.0129	0.0107	-0.0057	0.0177	
5	**27**	4	-0.0038	-0.0025	0.0172	0.0178	
6	**31**	5	-0.0036	-0.0004	0.0106	0.0112	
7	**32**	5	0.0182	0.0074	-0.0089	0.0216	
8	**33**	3	-0.0046	0.0034	-0.0002	0.0057	
9	**37**	7	-0.0112	0.0021	0.0022	0.0116	
10	**8**	1	0.0126	-0.0060	0.0070	0.0156	
	Maximum		0.0182	0.0107	0.0172		
	Mean		-0.0008	0.0017	0.0018		
	Sigma		0.0125	0.0053	0.0100		
	RMSE(x,y,z)		0.0114	0.0050	0.0092		
	RMSEr		0.0125	SQRT(RMSEx * RMSEx + RMSEy * RMSEy)			
	ACCr (at 95% Confidence Level)		0.0216	RMSEr * 1.7308			
	ACCz (at 95% Confidence Level)		0.0181	RMSEz * 1.9600			

Figure 5- 8 Residual of GCPs (no drift)

Check points

Check point errors

#	ID	Fold	X [m]	Y [m]	Z [m]	Total [m]	Remark
1	**13**	6	-0.0153	-0.0118	0.0607	0.0637	
2	**15**	6	-0.0344	-0.0019	-0.0399	0.0527	
3	**26**	7	0.0131	-0.0046	0.0505	0.0524	
4	**28**	4	0.0071	-0.0087	0.0313	0.0333	
5	**29**	3	-0.0120	0.0042	0.0775	0.0785	
	Maximum		-0.0344	-0.0118	0.0775		
	Mean		-0.0083	-0.0045	0.0360		
	Sigma		0.0190	0.0062	0.0456		
	RMSE(x,y,z)		0.0189	0.0072	0.0544		
	RMSEr		0.0202	SQRT(RMSEx * RMSEx + RMSEy * RMSEy)			
	ACCr (at 95% Confidence Level)		0.0350	RMSEr * 1.7308			
	ACCz (at 95% Confidence Level)		0.1067	RMSEz * 1.9600			

Figure 5- 9 Residual of Check points (no drift)

Finally, we need to see what will happen if we only use one GCP for adjust. We chose the GCP in the center of the block and run the adjust to see the result. It turns out to be the worst adjust with no accident. But it is not that bad since the GNSS data still provides some accuracy insurance.

Block adjustment results

Accuracy

Sigma naught [micron]	1.0380

Mean standard deviation of translations

X [m]	Y [m]	Z [m]	Total [m]
19.9214	22.1003	16.5980	34.0702

Mean standard deviation of rotations

Omega [deg/1000]	Phi [deg/1000]	Kappa [deg/1000]
2364.3289	3118.2727	4172.2215

Mean standard deviation of terrain points

X [m]	Y [m]	Z [m]	Total [m]
8.9255	9.0203	8.2894	15.1573

Figure 5- 10 Overview (1 GCP)

Ground control points

Ground control point errors

#	ID	Fold	X [m]	Y [m]	Z [m]	Total [m]	Remark
1	**25**	9	0.0000	0.0000	0.0000	0.0000	
	Maximum		0.0000	0.0000	0.0000		
	Mean		0.0000	0.0000	0.0000		
	Sigma		0.0000	0.0000	0.0000		
	RMSE(x,y,z)		0.0000	0.0000	0.0000		
	RMSEr		0.0000	SQRT(RMSEx * RMSEx + RMSEy * RMSEy)			
	ACCr (at 95% Confidence Level)		0.0000	RMSEr * 1.7308			
	ACCz (at 95% Confidence Level)		0.0000	RMSEz * 1.9600			

Figure 5- 11 Residual of GCPs (1 GCP)

Check points

Check point errors

#	ID	Fold	X [m]	Y [m]	Z [m]	Total [m]	Remark
1	**13**	6	0.0977	2.4329	-2.3876	3.4102	
2	**14**	9	0.7050	1.6317	-1.7176	2.4717	
3	**15**	6	1.7119	0.6717	-1.1954	2.1934	
4	**16**	2	2.6216	-0.1256	-0.6193	2.6967	
5	**24**	5	0.7204	-0.4884	0.1771	0.8881	
6	**26**	7	-0.7851	0.6983	-0.1849	1.0669	
7	**27**	4	-1.1401	1.6812	-1.3067	2.4153	
8	**28**	4	-1.4390	1.1274	0.0573	1.8289	
9	**29**	3	-1.5593	1.8706	-0.5138	2.4889	
10	**31**	5	1.4501	2.6355	-2.3569	3.8215	
11	**32**	5	2.9109	1.3381	-1.5794	3.5719	
12	**33**	3	3.4381	0.8839	-1.2893	3.7768	
13	**37**	7	1.8136	2.3022	-2.2080	3.6694	
	Maximum		3.4381	2.6355	-2.3876		
	Mean		0.8112	1.2815	-1.1634		
	Sigma		1.6926	0.9504	0.8895		
	RMSE(x,y,z)		1.8173	1.5736	1.4436		
	RMSEr		2.4039	SQRT(RMSEx * RMSEx + RMSEy * RMSEy)			
	ACCr (at 95% Confidence Level)		4.1606	RMSEr * 1.7308			
	ACCz (at 95% Confidence Level)		2.8294	RMSEz * 1.9600			

Figure 5- 12 Residual of Check points (1 GCP)

Task 6. AT with additional parameters for camera self-calibration

As the final run, we would like to add additional self-calibration parameters into the bundle adjustment process. Here we choose 12 parameters first and then choose 44 parameters and compare the results with the first run with only GCPs.

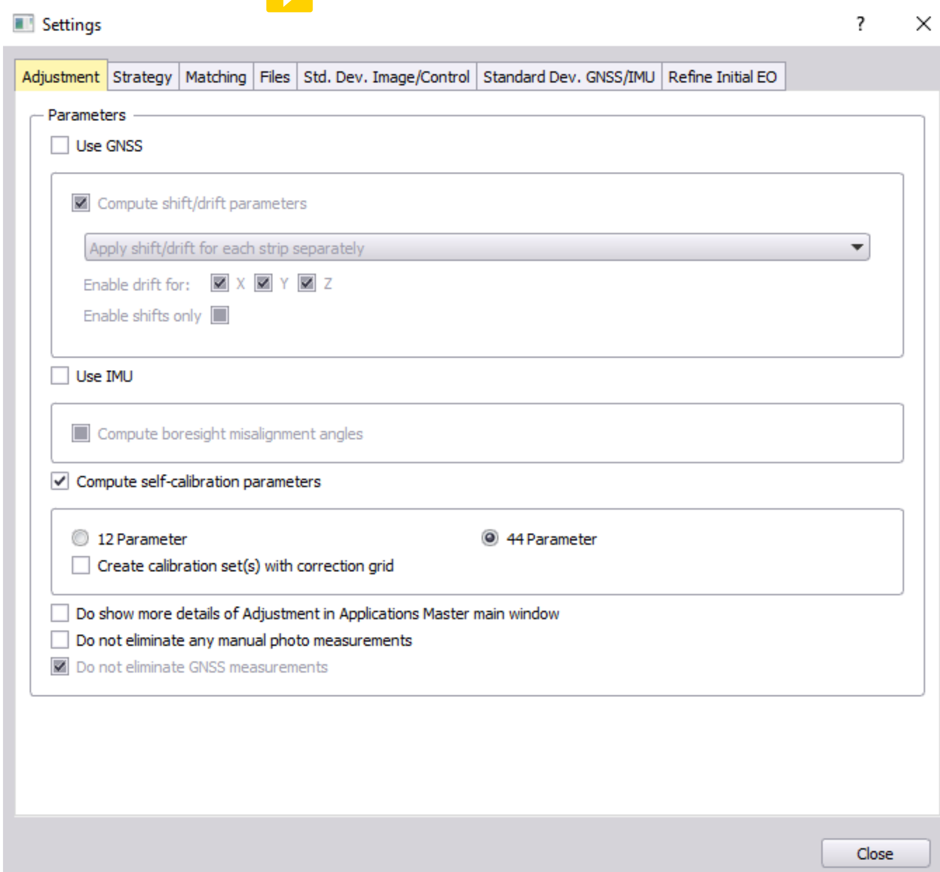

Figure 6- 1 Step

- 12 parameters: $\sigma_0 = 0.8799$
- 44 parameters: $\sigma_0 = 0.8665$
- GCPs only: $\sigma_0 = 1.0431$

As we can tell from the data, when we consider the self-calibration the σ_0 is getting smaller. The more parameters are considered, the more accuracy the adjustment becomes. The residual images are shown below.

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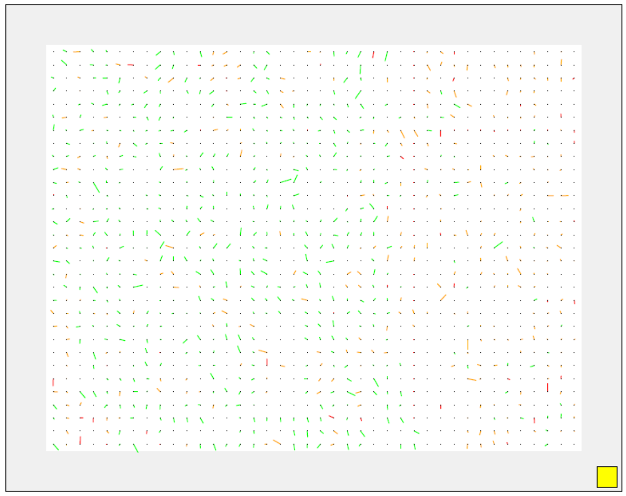

Figure 6- 2 GCPs only

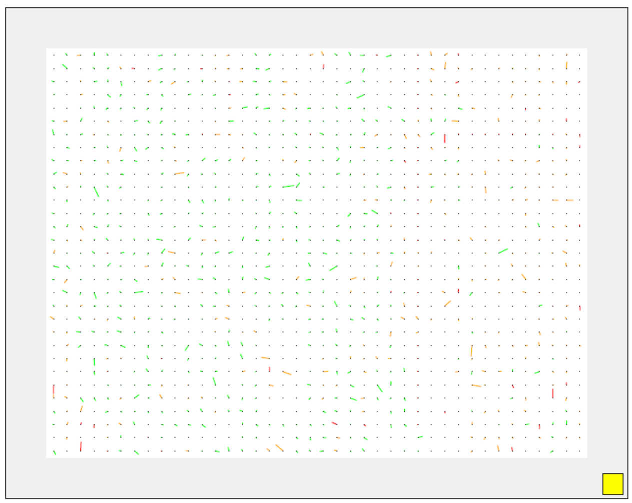

Figure 6- 3 12 parameters

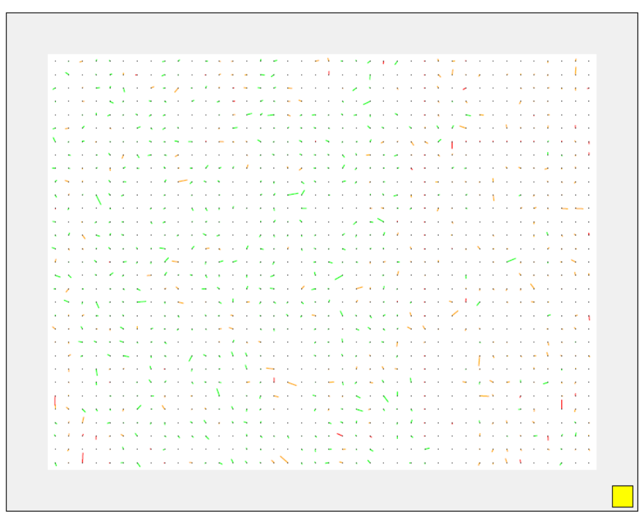

Figure 6- 4 44 parameters