

Interior Orientation and Image Point Refinements

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ENGO 634: Principles of Photogrammetry

Lab-2: Interior Orientation and Image Point Refinements


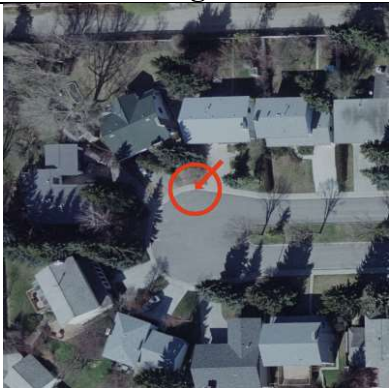


Objectives

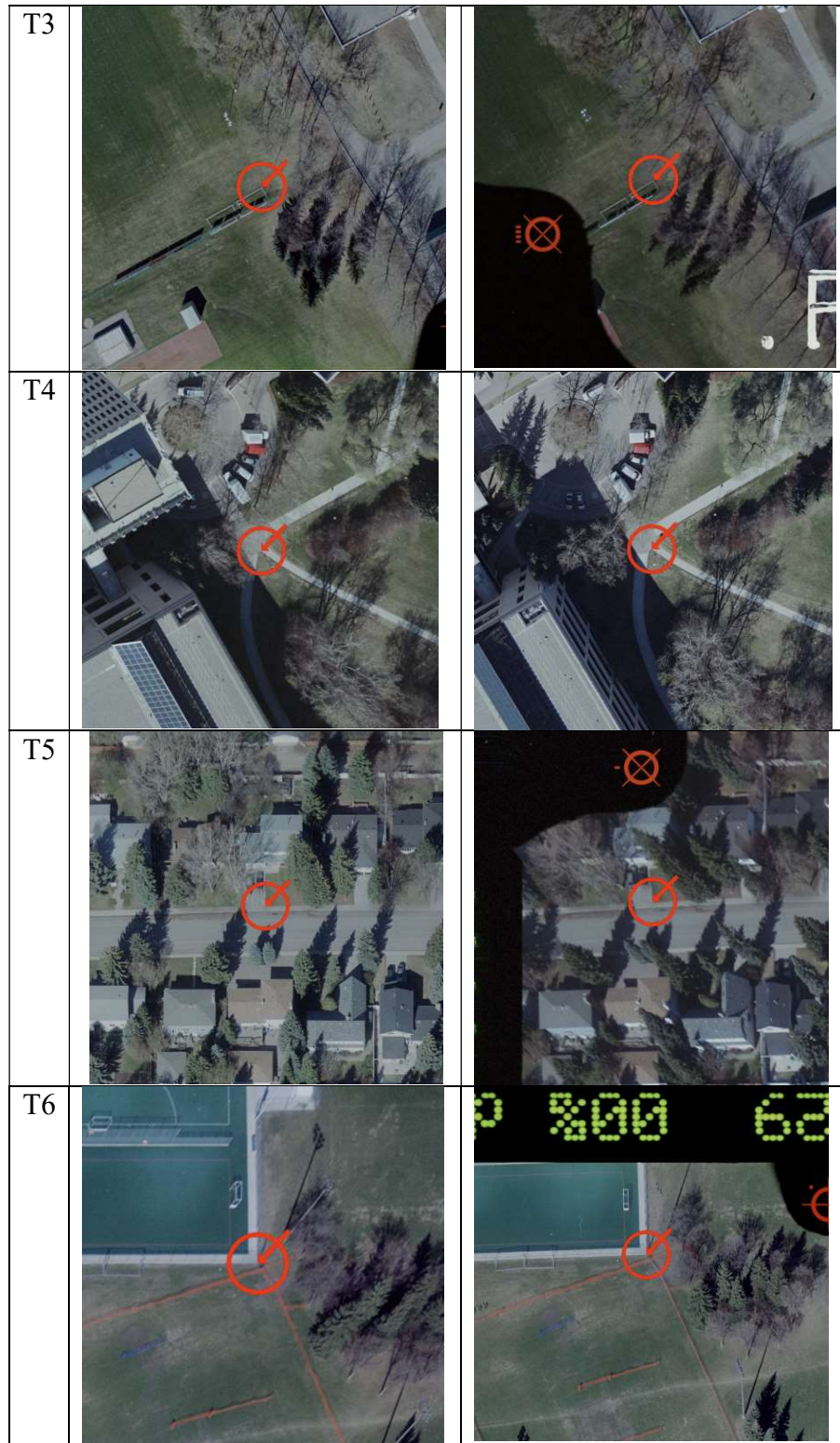
- Perform image point measurement, interior orientation and image point refinement for a pair of images

Problem a:

Object point selection.

Table 1: Selected Tie Point Locations

ID	Image 27	Image 28
T1		
T2		



Selected control points: 102, 104, 105, 200
 Selected check points: 100, 201, 202, 203

Figure 1 and 2 show how these points are distributed across both image 27 and image 28. Xs are tie points, triangles are control points, circles are check points.

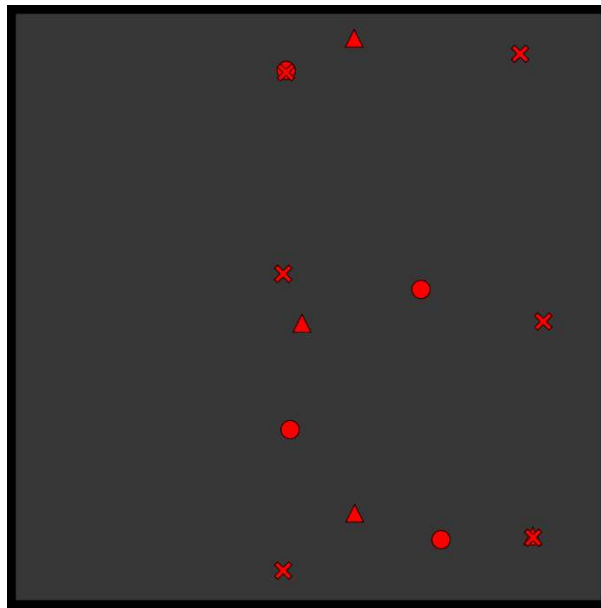


Figure 1: Overall view distribution for image 27

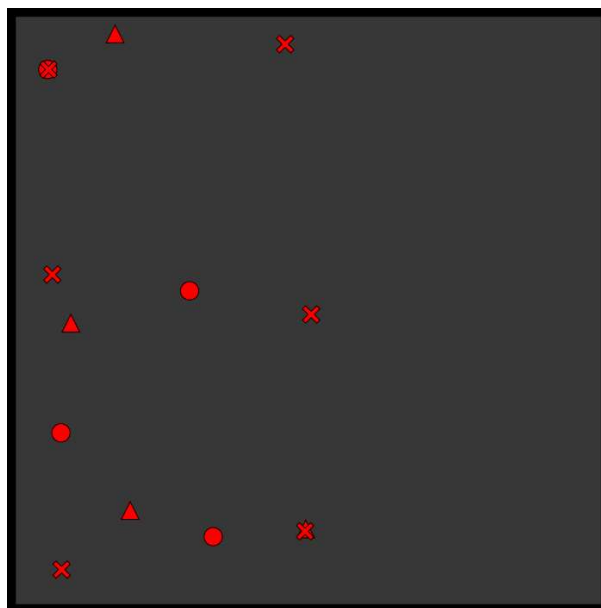


Figure 2: Overall view distribution for image 28

Problem b:

Image coordinate measurement.

Raw Measurements - Left Handed Coordinates:

Table 2: Left handed fiducial marks for image 27

Fiducial Mark Image 27	Meas 1		Meas 2		Meas 3		Meas 4	
	x	y	x	y	x	y	x	y
1	1347	19285	1347	19285	1347	19284	1347	19285
2	19161	1470	19175	1484	19160	1469	19162	1470
3	1345	1471	1358	1473	1345	1471	1346	1472
4	19163	19283	19163	19283	19167	19282	19163	19283
5	843	10379	849	10378	842	10378	843	10379
6	19666	10376	19672	10391	19666	10377	19666	10377
7	10254	966	10267	973	10253	966	10254	967
8	10254	19789	10255	19789	10255	19789	10255	19789

Table 3: Left handed control/check measurments for image 27

Control/Check Image 27	Meas 1		Meas 2		Meas 3		Meas 4	
	x	y	x	y	x	y	x	y
100	9447	2295	9458	2293	9448	2294	9447	2296
102	10053	10883	10056	10883	10048	10880	10052	10883
104	11843	17255	11851	17259	11848	17245	11844	17251
105	17844	18028	17852	18033	17862	18039	17841	18027
200	11782	1172	11781	1172	11781	1172	11781	1174
201	14000	9752	14008	9749	14007	9748	13998	9754
202	9612	14506	9611	14507	9612	14502	9610	14505
203	14684	18207	14676	18211	14685	18205	14685	18205

Table 4: Left handed tie points for image 27

Tie Points Image 27	Meas 1		Meas 2		Meas 3		Meas 4	
	x	y	x	y	x	y	x	y
T1	9406	9117	9405	9118	9407	9117	9406	9117
T2	18185	10723	18186	10722	18187	10722	18185	10723
T3	9350	19175	9350	19176	9350	19177	9350	19176
T4	17824	18055	17824	18056	17825	18056	17824	18056
T5	9459	2291	9458	2291	9458	2291	9459	2291
T6	17434	1693	17435	1694	17435	1695	17434	1694

Table 5: Left handed fiducial marks for image 28

Fiducial Mark Image 28	Meas 1		Meas 2		Meas 3		Meas 4	
	x	y	x	y	x	y	x	y
1	1347	19285	1347	19286	1348	19286	1347	19285
2	19175	1483	19175	1484	19175	1481	19175	1483
3	1358	1472	1358	1472	1358	1472	1358	1472
4	19162	19297	19162	19297	19161	19296	19163	19297

5	849	10379	849	10378	848	10379	849	10379
6	19672	10391	19672	10391	19672	10390	19672	10391
7	10267	972	10268	973	10268	974	10268	973
8	10254	19795	10254	19796	10254	19796	10255	19795

Table 6: Left handed control/check measurments for image 28

Control/Check Image 28	Meas 1		Meas 2		Meas 3		Meas 4	
	x	y	x	y	x	y	x	y
100	1404	2083	1408	2080	1402	2081	1398	2084
102	2269	10787	2272	10787	2270	10787	2268	10786
104	4158	17086	4160	17080	4159	17083	4159	17083
105	10140	17689	10147	17696	10140	17689	10136	17688
200	3727	851	3726	849	3727	852	3727	852
201	6154	9531	6163	9527	6153	9532	6152	9532
202	1948	14420	1958	14415	1947	14419	1948	14419
203	6982	17952	6982	17955	6983	17950	6984	17949

Table 7: Left handed tie points for image 28

Tie Points Image 28	Meas 1		Meas 2		Meas 3		Meas 4	
	x	y	x	y	x	y	x	y
T1	1537	9029	1536	9034	1535	9032	1536	9029
T2	10332	10387	10334	10384	10333	10387	10332	10387
T3	1836	19046	1838	19046	1836	19046	1836	19046
T4	10120	17716	10118	17714	10121	17717	10120	17717
T5	1410	2080	1408	2095	1409	2082	1410	2081
T6	9448	1199	9445	1200	9450	1199	9449	1199

Right Handed Coordinates and Statistics:

Table 8: Right handed fiducial marks for image 27

ID	Meas 1		Meas 2		Meas 3		Meas 4		Mean		Std	
	x	y	x	y	x	y	x	y	x	y	x	y
1	1347	-19285	1347	-19285	1347	-19284	1347	-19285	1347.0	-19284.75	0	0.5
2	19161	-1470	19175	-1484	19160	-1469	19162	-1470	19164.5	-1473.25	7.05	7.18
3	1345	-1471	1358	-1473	1345	-1471	1346	-1472	1348.5	-1471.75	6.35	0.96
4	19163	-19283	19163	-19283	19167	-19282	19163	-19283	19164.0	-19282.75	2	0.5
5	843	-10379	849	-10378	842	-10378	843	-10379	844.25	-10378.5	3.20	0.58
6	19666	-10376	19672	-10391	19666	-10377	19666	-10377	19667.5	-10380.25	3	7.18
7	10254	-966	10267	-973	10253	-966	10254	-967	10257.0	-968.0	6.68	3.37
8	10254	-19789	10255	-19789	10255	-19789	10255	-19789	10254.75	-19789.0	0.5	0

Table 9: Right handed control/check points for image 27

ID	Meas 1		Meas 2		Meas 3		Meas 4		Mean		Std	
	x	y	x	y	x	y	x	y	x	y	x	y
100	9447	-2295	9458	-2293	9448	-2294	9447	-2296	9450.0	-2294.5	5.35	1.29
102	10053	-10883	10056	-10883	10048	-10880	10052	-10883	10052.25	-10882.25	3.3	1.5
104	11843	-17255	11851	-17259	11848	-17245	11844	-17251	11846.5	-17252.5	3.7	5.97
105	17844	-18028	17852	-18033	17862	-18039	17841	-18027	17849.75	-18031.75	9.39	5.5
200	11782	-1172	11781	-1172	11781	-1172	11781	-1174	11781.25	-1172.5	0.5	1.0
201	14000	-9752	14008	-9749	14007	-9748	13998	-9754	14003.25	-9750.75	4.99	2.75
202	9612	-14506	9611	-14507	9612	-14502	9610	-14505	9611.25	-14505.0	0.96	2.16
203	14684	-18207	14676	-18211	14685	-18205	14685	-18205	14682.5	-18207.0	4.36	2.83

Table 10: Right handed tie points for image 27

ID	Meas 1		Meas 2		Meas 3		Meas 4		Mean		Std	
	x	y	x	y	x	y	x	y	x	y	x	y
T1	9447	-2295	9458	-2293	9448	-2294	9447	-2296	9406.0	-9117.25	0.82	0.5
T2	10053	-10883	10056	-10883	10048	-10880	10052	-10883	18185.75	-10722.5	0.96	0.58
T3	11843	-17255	11851	-17259	11848	-17245	11844	-17251	9350.0	-19176.0	0.0	0.82
T4	17844	-18028	17852	-18033	17862	-18039	17841	-18027	17824.25	-18055.75	0.5	0.5
T5	11782	-1172	11781	-1172	11781	-1172	11781	-1174	9458.5	-2291.0	0.58	0.0
T6	14000	-9752	14008	-9749	14007	-9748	13998	-9754	17434.5	-1694.0	0.58	0.82

Table 11: Right handed fiducial marks for image 28

ID	Meas 1		Meas 2		Meas 3		Meas 4		Mean		Std	
	x	y	x	Y	x	y	x	y	x	y	x	y
1	1347	-19285	1347	-19286	1348	-19286	1347	-19285	1347.25	-19285.5	0.5	0.58
2	19175	-1483	19175	-1484	19175	-1481	19175	-1483	19175.0	-1482.75	0.0	1.26
3	1358	-1472	1358	-1472	1358	-1472	1358	-1472	1358.0	-1472.0	0.0	0.0
4	19162	-19297	19162	-19297	19161	-19296	19163	-19297	19162.0	-19296.75	0.82	0.5
5	849	-10379	849	-10378	848	-10379	849	-10379	848.75	-10378.75	0.5	0.5
6	19672	-10391	19672	-10391	19672	-10390	19672	-10391	19672.0	-10390.75	0.0	0.5
7	10267	-972	10268	-973	10268	-974	10268	-973	10267.75	-973.0	0.5	0.82
8	10254	-19795	10254	-19796	10254	-19796	10255	-19795	10254.25	-19795.5	0.5	0.58

Table 12: Right handed control/check points for image 28

ID	Meas 1		Meas 2		Meas 3		Meas 4		Mean		Std	
	x	y	x	y	x	y	x	y	x	y	x	y
100	1404	-2083	1408	-2080	1402	-2081	1398	-2084	1403.0	-2082.0	4.16	1.83
102	2269	-10787	2272	-10787	2270	-10787	2268	-10786	2269.75	-10786.75	1.71	0.5
104	4158	-17086	4160	-17080	4159	-17083	4159	-17083	4159.0	-17083.0	0.82	2.45
105	10140	-17689	10147	-17696	10140	-17689	10136	-17688	10140.75	-17690.5	4.57	3.7
200	3727	-851	3726	-849	3727	-852	3727	-852	3726.75	-851.0	0.5	1.41
201	6154	-9531	6163	-9527	6153	-9532	6152	-9532	6155.5	-9530.5	5.07	2.38
202	1948	-14420	1958	-14415	1947	-14419	1948	-14419	1950.25	-14418.25	5.19	2.22
203	6982	-17952	6982	-17955	6983	-17950	6984	-17949	6982.75	-17951.5	0.96	2.65

Table 13: Right handed tie points for image 28

ID	Meas 1		Meas 2		Meas 3		Meas 4		Mean		Std	
	x	y	x	y	x	y	x	y	x	y	x	y
T1	1537	-9029	1536	-9034	1535	-9032	1536	-9029	1536.0	-9031.0	0.82	2.45
T2	10332	-10387	10334	-10384	10333	-10387	10332	-10387	10332.75	-10386.25	0.96	1.5
T3	1836	-19046	1838	-19046	1836	-19046	1836	-19046	1836.5	-19046.0	1.0	0.0
T4	10120	-17716	10118	-17714	10121	-17717	10120	-17717	10119.75	-17716.0	1.26	1.41
T5	1410	-2080	1408	-2095	1409	-2082	1410	-2081	1409.25	-2084.5	0.96	7.05
T6	9448	-1199	9445	-1200	9450	-1199	9449	-1199	9448.0	-1199.25	2.16	0.5

This process is more precise because since there are multiple measurements you can calculate the standard deviation to get insight into how precise the measurements actually are. Our results show that often the standard deviation is less than 1 pixel but can also be a couple of pixels.

The process also improves the accuracy by allowing us to average the measurements to reduce any biases in the measurements and by allowing us to detect if a measurement differs largely from the other measurements. Each member does have a bias introduced into their measurements by how they use Infraview to measure the pixels, such as how much they zoom in or how they decide where exactly to measure.

Problem c:

Interior orientation – real data

Table 14: Affine transformation parameters

Image	a	b	c	d	dx	dy
27	0.0119	-0.00000108	0.0000000271	0.0119	-0.376	1.655
28	0.0119	-0.00000829	-0.00000741	0.0119	-0.350	1.630

Table 15: Fiducial mark residuals after transformation

Fiducial Mark	Image 27 Residuals		Image 28 Residuals	
	x (mm)	y (mm)	x (mm)	y (mm)
1	-0.004161	-0.007042	0.004864	0.002514
2	0.0007	-0.004617	0.008032	0.002944
3	-0.002541	0.007406	-0.011877	-0.002244
4	0.005976	0.021594	-0.006998	0.000734
5	0.006588	-0.00293	0.001838	-0.003601
6	-0.006074	-0.018656	-0.005782	-0.006828
7	0.001485	0.007684	0.005771	0.004446
8	-0.001972	-0.00344	0.004152	0.002035
RMSE	0.00428	0.0113	0.00676	0.00361

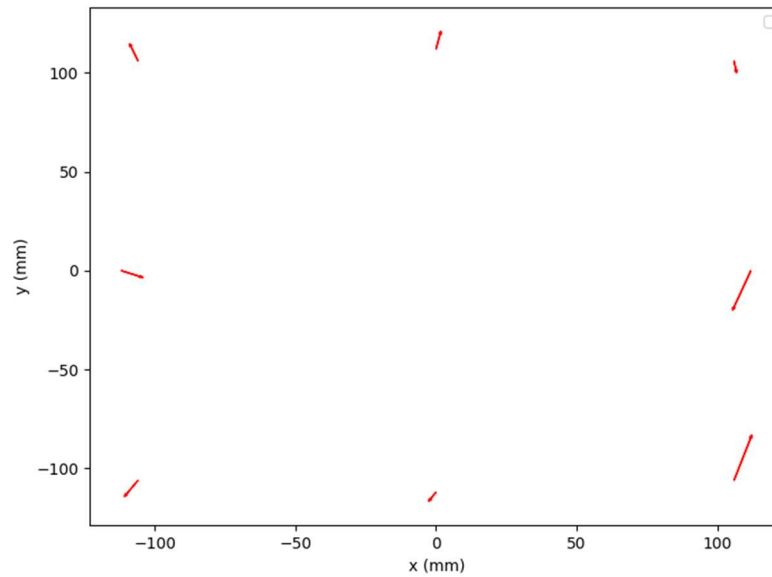


Figure 3: Image 27 Residual Plot (1:1000 residual scale)

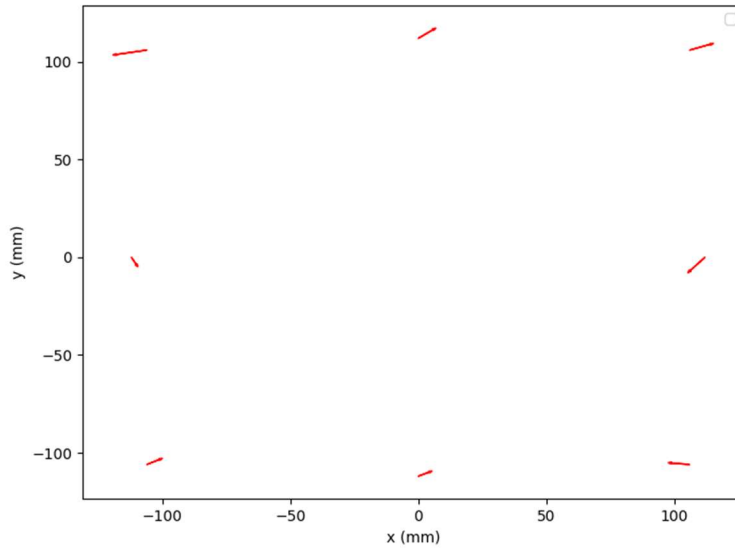


Figure 4: Image 28 Residual Plot (1:1000 residual scale)

Looking at the graphs of the residuals it is difficult to see any bias as the direction of the vectors do not follow any particular pattern. If we use the calculated pixel size of 0.0119mm from Lab 1 then we can see that the RMSE error for x and y for both images is less than the size of a pixel. This means that the solution is of good quality.

The transformation parameters are similar for both images which makes sense as the interior orientation should not change much between images. The translation parameters are relatively large. The scaling parameters will be making the values smaller which makes sense as the pixel values have a larger max than the mm value.

Measured points transformed are included in Table 21 below in Problem e.

Problem d:

Interior orientation – validation

Table 16: Calculated transformation parameters for test data

Transformation	Parameters
a	0.999167
b	-0.011339
c	0.011494
d	0.999157
dx	2.446978
dy	-1.387662

Table 17: Calculated residuals for test data

ID	rx (mm)	ry (mm)
1	-0.0074	-0.0047
2	-0.0066	-0.0029
3	0.0152	-0.0097
4	0.0128	0.005
5	-0.0012	0.0039
6	-0.0039	0.0021
7	-0.0036	-0.0068
8	-0.0106	0.0144
9	0.004	0.0024
10	0.0018	-0.0028
11	0.0015	0.0001
12	-0.0098	0.0098
13	-0.0096	-0.0081
14	0.0016	-0.0058
15	0.0037	0.0053
16	0.0121	-0.0024
RMS	0.00793	0.00646

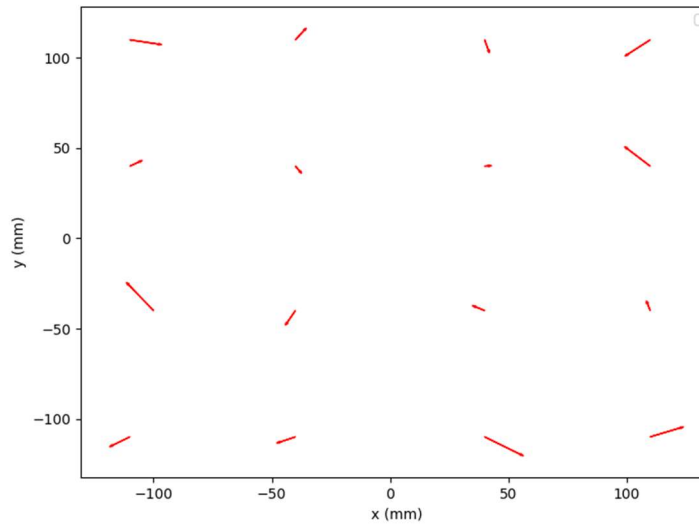


Figure 5: Test Data Residual Plot (1:1000 residual scale)

Our affine transformation function returns the same transformation parameters and residuals for the test comparator and reseau coordinates when we compared with the lecture note. This should mean that the affine transformation function is working correctly.

Problem e:

Image point corrections

Principal Point Offset:

$$\bar{x} = x - x_p$$
$$\bar{y} = y - y_p$$

Radial Lens Correction:

$$K_0 = 0.8878\text{E-}04$$

$$K_1 = -0.1528\text{E-}07$$

$$K_2 = 0.5256\text{E-}12$$

$$K_3 = 0.0000$$

$$r = \sqrt{\bar{x}^2 + \bar{y}^2}$$

Using a balanced distortion profile.

$$\Delta r = k_0 r + k_1 r^3 + k_2 r^5 + k_3 r^7$$

$$\Delta x_{rad} = -\frac{\bar{x}\Delta r}{r}$$

$$\Delta y_{rad} = -\frac{\bar{y}\Delta r}{r}$$

Table 18: Radial lens corrections

ID	Image 27				Image 28			
	r (mm)	dr (mm)	dx (mm)	dy (mm)	r(mm)	dr(mm)	dx (mm)	dy (mm)
1	149.9089	0.0016	0.0011	0.0011	149.8958	0.0016	0.0011	0.0011
2	149.9124	0.0016	-0.0011	-0.0011	149.9229	0.0016	-0.0012	-0.0012
3	149.9116	0.0016	0.0011	-0.0011	149.9113	0.0016	0.0011	-0.0011
4	149.909	0.0016	-0.0011	0.0011	149.9146	0.0016	-0.0012	0.0012
5	111.9874	-0.0023	-0.0023	-0.0	111.9922	-0.0023	-0.0023	-0.0
6	112.0059	-0.0023	0.0023	-0.0	112.0062	-0.0023	0.0023	-0.0
7	112.0087	-0.0023	0.0	0.0023	112.0054	-0.0023	0.0	0.0023
8	112.0074	-0.0023	0.0	-0.0023	112.002	-0.0023	0.0	-0.0023
100	96.6965	-0.0008	-0.0001	0.0008	144.4742	-0.0002	-0.0001	0.0001
102	6.4628	0.0006	0.0002	0.0005	95.2023	-0.0006	-0.0006	-0.0
104	83.9812	0.0006	-0.0001	0.0006	107.8204	-0.0019	-0.0013	-0.0014
105	128.3218	-0.0026	0.0018	-0.0019	86.9617	0.0003	0.0	0.0003

200	111.0682	-0.0022	0.0004	0.0022	137.5425	-0.0017	-0.0009	0.0014
201	45.2235	0.0027	-0.0027	-0.0004	49.8881	0.0027	0.0026	-0.0005
202	49.7083	0.0027	0.0004	0.0027	109.9184	-0.0021	-0.0019	-0.0009
203	107.0444	-0.0019	0.0009	-0.0016	98.1347	-0.0009	-0.0004	-0.0009
T1	18.0967	0.0015	0.0008	-0.0013	105.057	-0.0017	-0.0016	0.0003
T2	94.4624	-0.0005	0.0005	-0.0	0.8686	0.0001	-0.0001	0.0
T3	105.263	-0.0017	-0.0002	-0.0017	143.7777	-0.0004	-0.0002	-0.0003
T4	128.3116	-0.0026	0.0018	-0.0019	87.2695	0.0003	0.0	0.0003
T5	96.728	-0.0008	-0.0001	0.0008	144.3996	-0.0002	-0.0001	0.0001
T6	134.099	-0.0021	0.0014	0.0017	109.7395	-0.0021	-0.0002	0.0021

Decentering Lens Correction:

$$P_1 = 0.1346\text{E-}06$$

$$P_2 = 0.1224\text{E-}07$$

$$\Delta x_{dec} = -[P_1(r^2 + 2\bar{x}^2) + 2P_2\bar{x}\bar{y}]$$

$$\Delta y_{dec} = -[P_2(r^2 + 2\bar{y}^2) + 2P_1\bar{x}\bar{y}]$$

Table 19: Decentering lens corrections

ID	Image 27			Image 28		
	r (mm)	dx (mm)	dy (mm)	r (mm)	dx (mm)	dy (mm)
1	149.9089	-0.0058	0.0025	149.8958	-0.0058	0.0025
2	149.9124	-0.0058	0.0025	149.9229	-0.0058	0.0025
3	149.9116	-0.0063	-0.0036	149.9113	-0.0063	-0.0036
4	149.909	-0.0063	-0.0036	149.9146	-0.0063	-0.0036
5	111.9874	-0.0051	-0.0002	111.9922	-0.0051	-0.0002
6	112.0059	-0.0051	-0.0002	112.0062	-0.0051	-0.0002
7	112.0087	-0.0017	-0.0005	112.0054	-0.0017	-0.0005
8	112.0074	-0.0017	-0.0005	112.002	-0.0017	-0.0005
100	96.6965	-0.0013	-0.0006	144.4742	-0.0061	-0.0033
102	6.4628	-0.0	0.0	95.2023	-0.0036	0.0
104	83.9812	-0.0011	-0.0007	107.8204	-0.0028	0.0013
105	128.3218	-0.0046	-0.0026	86.9617	-0.001	-0.0002
200	111.0682	-0.0017	0.0001	137.5425	-0.0044	-0.0029
201	45.2235	-0.0008	0.0001	49.8881	-0.001	-0.0002
202	49.7083	-0.0003	0.0	109.9184	-0.0041	0.0011
203	107.0444	-0.0024	-0.0017	98.1347	-0.0016	0.0006
T1	18.0967	-0.0001	-0.0001	105.057	-0.0044	-0.0006
T2	94.4624	-0.0036	-0.0002	0.8686	-0.0	-0.0
T3	105.263	-0.0015	-0.0001	143.7777	-0.0052	0.0023
T4	128.3116	-0.0046	-0.0026	87.2695	-0.001	-0.0002
T5	96.728	-0.0013	-0.0006	144.3996	-0.0061	-0.0033
T6	134.099	-0.0042	0.0019	109.7395	-0.0017	-0.0007

Atmospheric Refraction Correction:

$h = 1089.55\text{m}$ (avg terrain height from object point coordinates)

$H = 751.4637599031875$ (from Lab 1) + $1089.55 = 1841.014\text{m}$

$$K = \frac{2410H}{H^2 - 6H + 250} - \frac{2410h}{h^2 - 6h + 250} \left(\frac{h}{H}\right) = 0.00001196 \text{ rad}$$

$c = 153.358\text{mm}$

$$\Delta r = Kr \left(1 + \frac{r^2}{c^2}\right)$$

$$\Delta x_{atm} = -\bar{x}K \left(1 + \frac{r^2}{c^2}\right)$$

$$\Delta y_{atm} = -\bar{y}K \left(1 + \frac{r^2}{c^2}\right)$$

Table 20: Atmospheric refraction corrections

ID	Image 27				Image 28			
	r (mm)	dr (mm)	dx (mm)	dy (mm)	r (mm)	dr (mm)	dx (mm)	dy (mm)
100	96.6965	0.0016	0.0002	-0.0016	144.4742	0.0033	0.0024	-0.0022
102	6.4628	0.0001	0.0	0.0001	95.2023	0.0016	0.0016	0.0001
104	83.9812	0.0013	-0.0003	0.0013	107.8204	0.0019	0.0013	0.0014
105	128.3218	0.0026	-0.0018	0.0019	86.9617	0.0014	0.0	0.0014
200	111.0682	0.002	-0.0003	-0.002	137.5425	0.003	0.0017	-0.0024
201	45.2235	0.0006	-0.0006	-0.0001	49.8881	0.0007	0.0006	-0.0001
202	49.7083	0.0007	0.0001	0.0006	109.9184	0.002	0.0018	0.0009
203	107.0444	0.0019	-0.0009	0.0017	98.1347	0.0017	0.0007	0.0015
T1	18.0967	0.0002	0.0001	-0.0002	105.057	0.0018	0.0018	-0.0003
T2	94.4624	0.0016	-0.0016	0.0001	0.8686	0.0	-0.0	0.0
T3	105.263	0.0019	0.0002	0.0018	143.7777	0.0032	0.0023	0.0023
T4	128.3116	0.0026	-0.0018	0.0019	87.2695	0.0014	0.0	0.0014
T5	96.728	0.0016	0.0002	-0.0016	144.3996	0.0033	0.0024	-0.0022
T6	134.099	0.0028	-0.0018	-0.0022	109.7395	0.002	0.0002	-0.002

Measurment Corrections:

$$x' = \bar{x} + \Delta x_{rad} + \Delta x_{dec} + \Delta x_{atm}$$

$$y' = \bar{y} + \Delta y_{rad} + \Delta y_{dec} + \Delta y_{atm}$$

Principal point offset shown first then each correction step applitted to the pervious value shown in table below.

Table 21: Measurements after each principal point correction (mm)

ID	Transformed		PP corrected	
	Image 27	Image 28	Image 27	Image 28

	x	y	x	y	x	y	x	y
1	-106.001	-106.002	-105.992	-105.992	-105.995	-106.008	-105.986	-105.998
2	106.005	106.003	106.012	106.011	106.011	105.997	106.018	106.005
3	-106.003	106.016	-106.012	106.007	-105.997	106.01	-106.006	106.001
4	106.018	-105.973	106.005	-105.994	106.024	-105.979	106.011	-106.0
5	-111.993	0.004	-111.998	0.003	-111.987	-0.002	-111.992	-0.003
6	112.0	-0.012	112.0	0.0	112.006	-0.018	112.006	-0.006
7	0.006	112.015	0.011	112.011	0.012	112.009	0.017	112.005
8	0.0	-112.001	0.006	-111.996	0.006	-112.007	0.012	-112.002
100	-9.595	96.226	-105.471	98.747	-9.589	96.22	-105.465	98.741
102	-2.419	-5.989	-95.085	-4.842	-2.413	-5.995	-95.079	-4.848
104	18.939	-81.81	-72.55	-79.76	18.945	-81.816	-72.544	-79.766
105	90.377	-91.084	-1.362	-86.945	90.383	-91.09	-1.356	-86.951
200	18.145	109.581	-77.829	113.415	18.151	109.575	-77.823	113.409
201	44.596	7.479	-48.854	10.138	44.602	7.473	-48.848	10.132
202	-7.663	-49.109	-98.857	-48.063	-7.657	-49.115	-98.851	-48.069
203	52.688	-93.171	-38.94	-90.075	52.694	-93.177	-38.934	-90.081
T1	-10.111	15.018	-103.831	16.048	-10.105	15.012	-103.825	16.042
T2	94.368	-4.086	0.862	-0.016	94.374	-4.092	0.868	-0.022
T3	-10.767	-104.705	-100.172	-103.139	-10.761	-104.711	-100.166	-103.145
T4	90.074	-91.369	-1.612	-87.249	90.08	-91.375	-1.606	-87.255
T5	-9.494	96.268	-105.397	98.718	-9.488	96.262	-105.391	98.712
T6	85.418	103.375	-9.742	109.313	85.424	103.369	-9.736	109.307

Table 22: Measurements after radial lens and decentering lens correction (mm)

ID	Radial lens corrected				Decentering lens corrected			
	Image 27		Image 28		Image 27		Image 28	
	x	y	x	y	x	y	x	y
1	-105.994	-106.007	-105.985	-105.997	-106.0	-106.004	-105.991	-105.995
2	106.01	105.996	106.017	106.004	106.004	105.999	106.011	106.006
3	-105.995	106.009	-106.005	106.0	-106.002	106.006	-106.011	105.996
4	106.023	-105.978	106.01	-105.999	106.017	-105.982	106.004	-106.003
5	-111.99	-0.002	-111.994	-0.003	-111.995	-0.002	-111.999	-0.003
6	112.008	-0.018	112.008	-0.006	112.003	-0.018	112.003	-0.006
7	0.012	112.011	0.017	112.008	0.011	112.01	0.015	112.007
8	0.006	-112.01	0.012	-112.004	0.004	-112.01	0.01	-112.005
100	-9.589	96.221	-105.465	98.742	-9.591	96.22	-105.471	98.738
102	-2.413	-5.995	-95.079	-4.848	-2.413	-5.995	-95.083	-4.848
104	18.945	-81.816	-72.546	-79.767	18.944	-81.817	-72.548	-79.766
105	90.385	-91.092	-1.356	-86.951	90.381	-91.094	-1.357	-86.951
200	18.151	109.577	-77.824	113.41	18.15	109.577	-77.828	113.407
201	44.599	7.473	-48.846	10.131	44.598	7.473	-48.847	10.131
202	-7.657	-49.112	-98.853	-48.07	-7.657	-49.112	-98.857	-48.069
203	52.695	-93.178	-38.935	-90.082	52.692	-93.18	-38.936	-90.081
T1	-10.105	15.011	-103.827	16.042	-10.105	15.011	-103.831	16.042

T2	94.374	-4.092	0.868	-0.022	94.371	-4.092	0.868	-0.022
T3	-10.761	-104.713	-100.166	-103.145	-10.763	-104.713	-100.171	-103.143
T4	90.082	-91.377	-1.606	-87.254	90.077	-91.38	-1.607	-87.255
T5	-9.488	96.262	-105.391	98.712	-9.489	96.262	-105.397	98.709
T6	85.426	103.371	-9.737	109.309	85.421	103.373	-9.738	109.308

Table 23: Measurements after atmospheric refraction correction (mm)

ID	Atmospheric refraction corrected / Final coordinates			
	Image 27		Image 28	
	x	y	x	y
1	-106.0	-106.004	-105.991	-105.995
2	106.004	105.999	106.011	106.006
3	-106.002	106.006	-106.011	105.996
4	106.017	-105.982	106.004	-106.003
5	-111.995	-0.002	-111.999	-0.003
6	112.003	-0.018	112.003	-0.006
7	0.011	112.01	0.015	112.007
8	0.004	-112.01	0.01	-112.005
100	-9.59	96.218	-105.469	98.736
102	-2.413	-5.995	-95.081	-4.848
104	18.943	-81.815	-72.547	-79.764
105	90.379	-91.092	-1.357	-86.95
200	18.149	109.575	-77.826	113.405
201	44.598	7.473	-48.846	10.131
202	-7.657	-49.112	-98.855	-48.068
203	52.691	-93.178	-38.936	-90.079
T1	-10.105	15.011	-103.829	16.042
T2	94.369	-4.092	0.868	-0.022
T3	-10.762	-104.711	-100.169	-103.14
T4	90.075	-91.378	-1.607	-87.253
T5	-9.489	96.26	-105.395	98.706
T6	85.42	103.371	-9.738	109.306

If we say the pixel size is 0.0119mm, the corrections are generally not very large with most of them being less than a pixel's worth of measurement error.

All four of the types of points have to the calibrated principal point offset, radial lens distortion, and decentring lens distortion corrections applied because those distortions are caused by properties of the camera meaning they affect all points captured by the camera. But the fiducial marks do not have the atmospheric refraction correction applied because those points do not pass through enough atmosphere to be refracted.

Task Summary:

Name	Summary	Amount of Time
Quinn	Measurements, Code Development, Report Writing	10 hr
Okoye Akachukwu	Measurement, Report writing, Result Analysis	7hrs
Fre Ashal	Measurement, Report Writing, Result Analysis	7hrs
Innocent Chrisantus	Measurement, Report writing, Result Analysis	7hrs

Appendix A: Code

Python script (calc.py) attached in submission