1. Homography estimation:
    a. Describe your solution, including any interesting parameters or implementation choices for feature extraction, putative matching, RANSAC, etc.

        I used SIFT to detect feature points and form the descriptors for these two images. After computing distance between every descriptor, I set my threshold as 30000 to select putative matches. For RANSAC, I set my iteration as 5000, and distance threshold as 300 to calculate my inliers. I choose 4 points randomly to figure out the homography. Here is the summarized table for my parameters.

| | |
|---|---|
| SIFT Matches threshold | 30000 |
| No of samples | 4 |
| RANSAC iteration | 5000 |
| RANSAC distance threshold | 300 |

    b. For the image pair provided, report the number of homography inliers and the average residual for the inliers (squared distance between the point coordinates in one image and the transformed coordinates of the matching point in the other image). Also, display the locations of inlier matches in both images.

        Number of homography inliers: 184

        The average residual: 85.95

        Inlier image:

c. Display the final result of your stitching.
   (1) Keep the overlap.

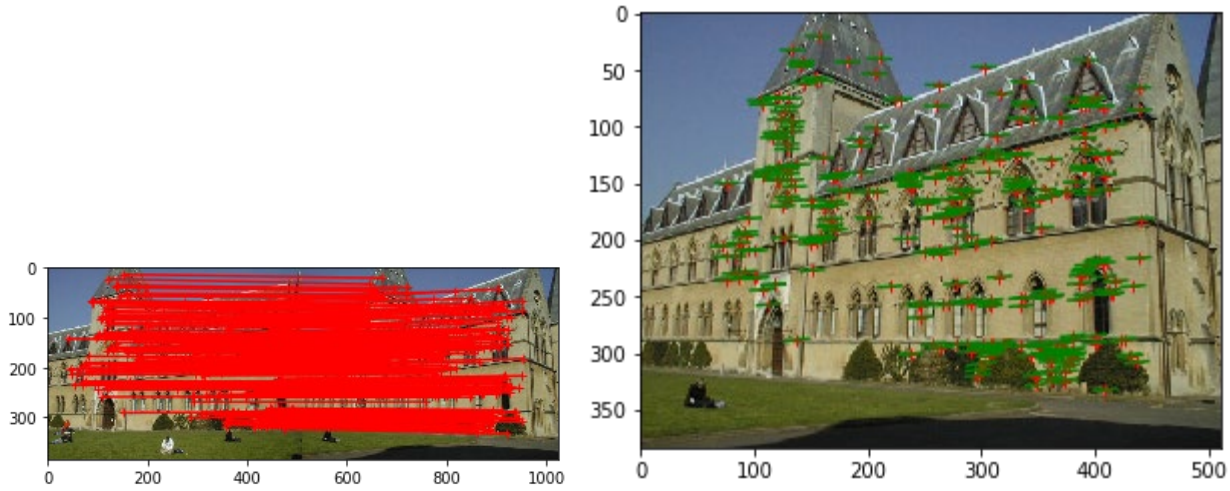
   (2) Remove the shadow and make the left image as overlap.

2. Fundamental matrix estimation, calibration, triangulation:
   a. For both image pairs, for both unnormalized and normalized fundamental matrix estimation, display your result (points and epipolar lines) and report your residual.

Library:

Unnormalized, Homogenous:

Points figure and Epipolar lines:

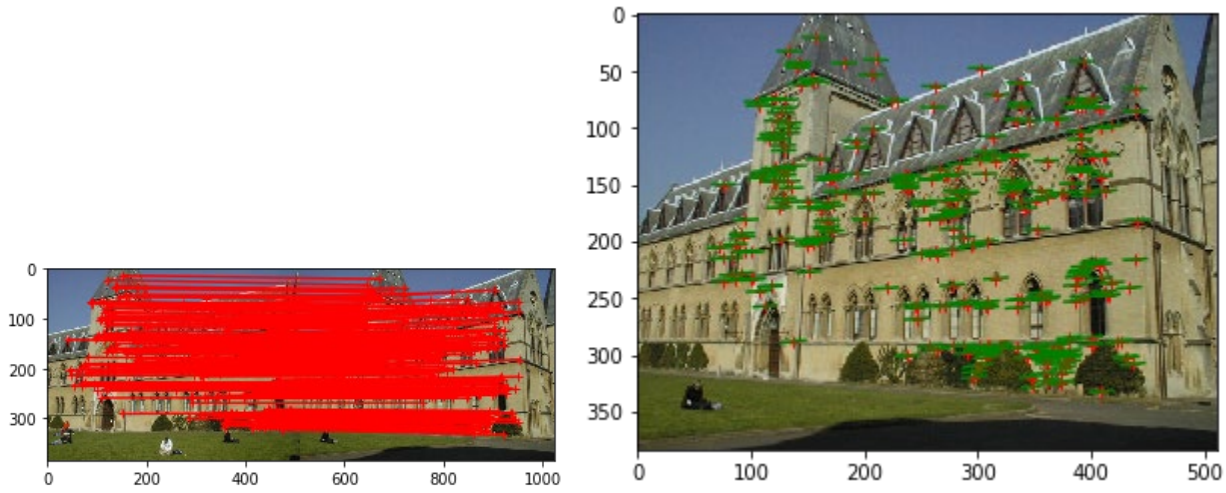



Mean squared distance:

Distance1: [0.1491231] and distance 2 [0.17921337]

Unnormalized, No-homogenous:

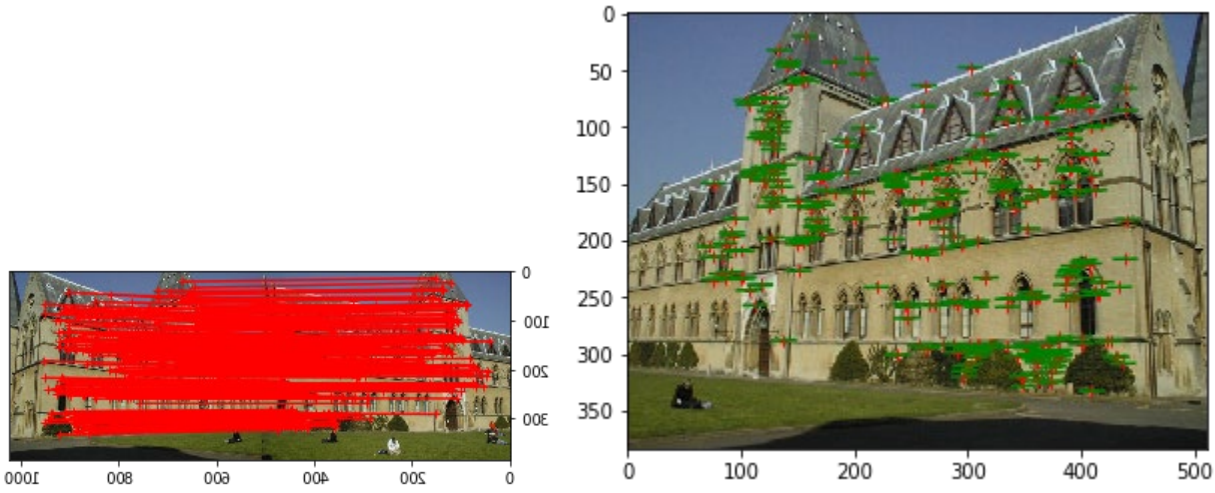
Points and Epipolar lines:




Distance1: [0.14912434] and distance 2 [0.17921562]

Normalized, Homogenous:

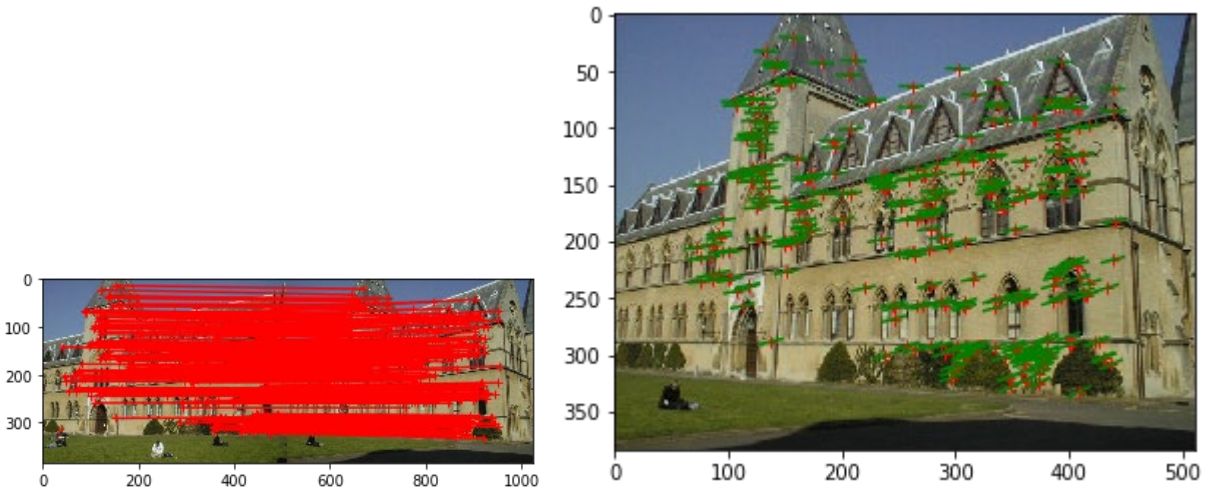
Points and Epipolar lines:



Distance1: [0.05497127] and distance 2 [0.06077737]

Normalized, No-homogenous:

Points and Epipolar lines:

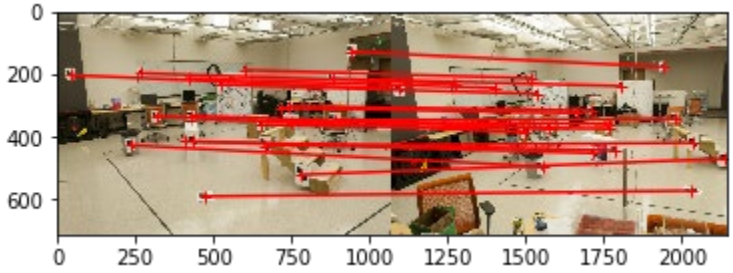


Distance1: [0.11656163] and distance 2 [0.12994752]

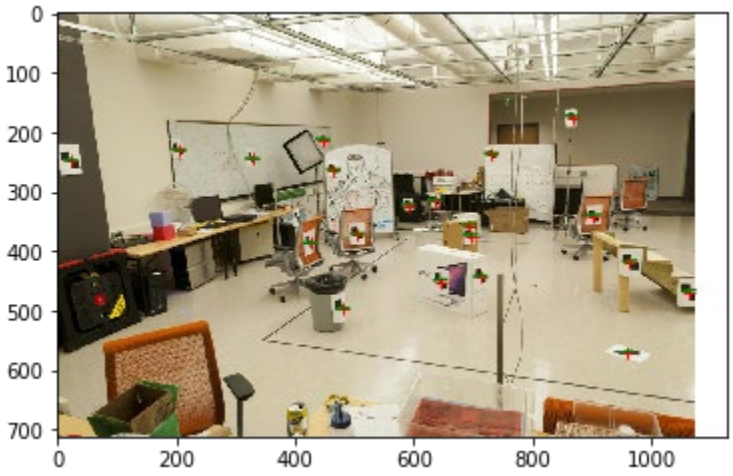
Lab:

Unnormalized, Homogenous:

Points figure:




Epipolar lines:

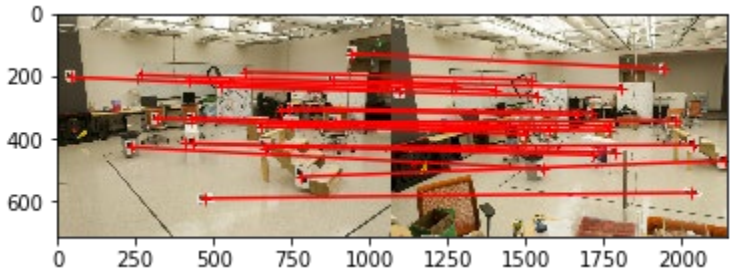



Mean squared distance:

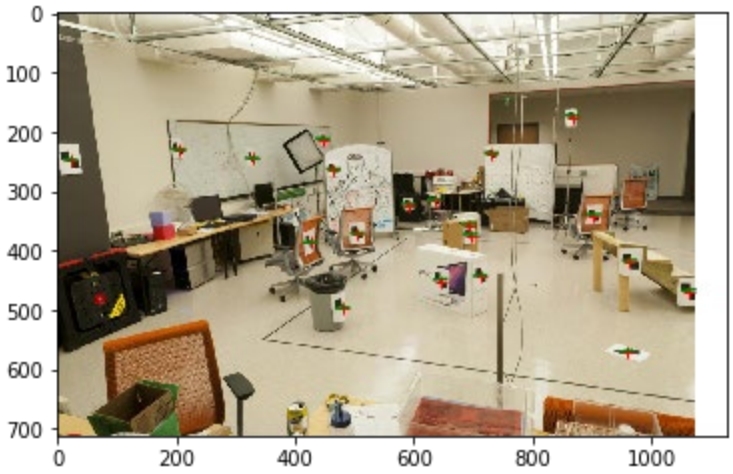
Distance1: [9.76065542] and distance 2 [6.5670915]

Unnormalized, No-homogenous:

Points:



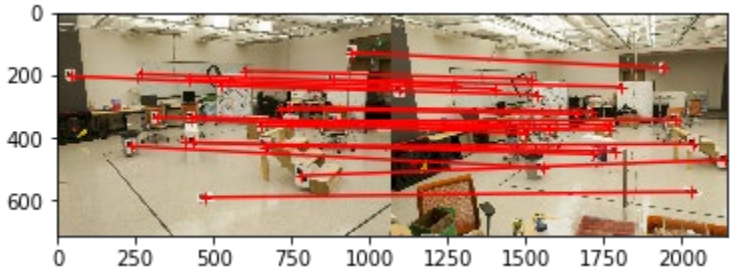

Epipolar lines:



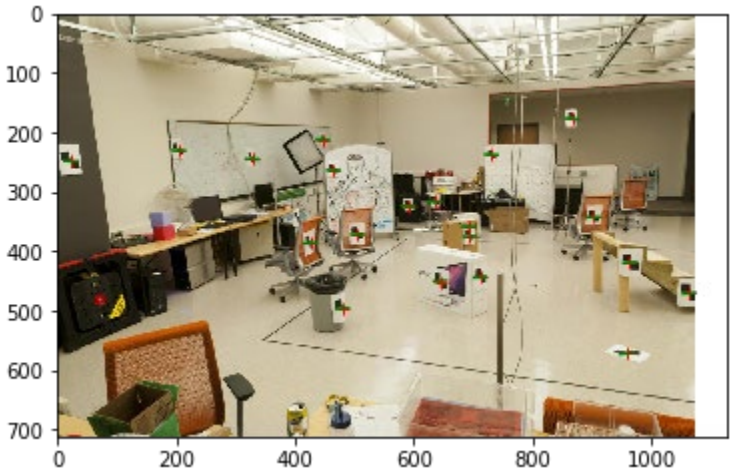

Distance1: [9.81430804] and distance 2 [6.60170276]

Normalized, Homogenous:

Points:



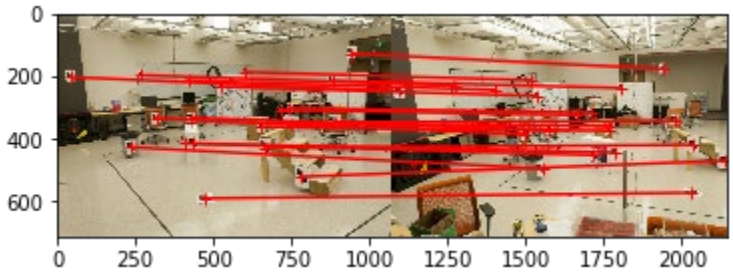

Epipolar lines:



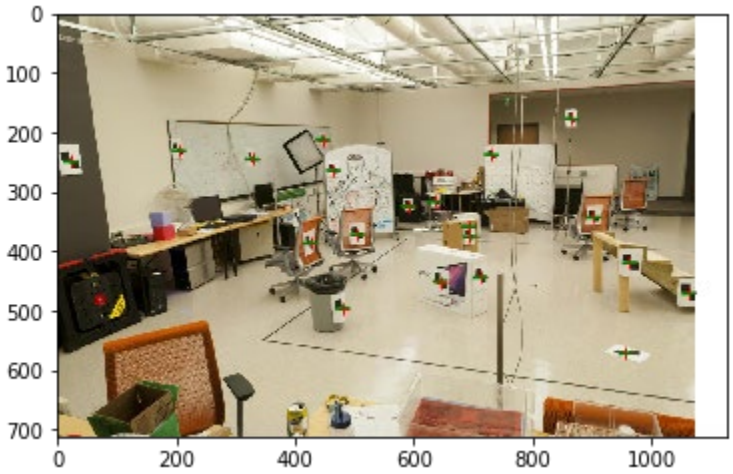
Distance1: [0.56707678] and distance 2 [0.52750546]

Normalized, No-homogenous:

Points:




Epipolar lines:




Distance1: [0.90033358] and distance 2 [0.81499117]

Summarized table:

| | Distance1 | Distance2 |
|---|---|---|
| Library | | |
| Unnormalized-Homogenous | 0.1491231 | 0.17921337 |
| Unnormalized-no homogenous | 0.14912434 | 0.17921562 |
| Normalized-Homogenous | 0.05497127 | 0.06077737 |
| Normalized-No homogenous | 0.11656163 | 0.12994752 |
| Lab | | |
| Unnormalized-Homogenous | 9.76065542 | 6.5670915 |
| Unnormalized-no homogenous | 9.81430804 | 6.60170276 |
| Normalized-Homogenous | 0.56707678 | 0.52750546 |
| Normalized-No homogenous | 0.90033358 | 0.81499117 |

I found normalized plus homogenous have the smallest distance between points and epipolar lines.

b. For the lab image pair, show your estimated 3x4 camera projection matrices. Report the residual between the projected and observed 2D points.

   Lab image1:

   Projection Matrix:

   [[-3.09963993e-03 -1.46204682e-04  4.48498020e-04  9.78930694e-01]

   [-3.07018100e-04 -6.37193577e-04  2.77356184e-03  2.04144330e-01]

   [-1.67933509e-06 -2.74767702e-06  6.83965401e-07  1.32882924e-03]]

   Residual: 13.545776180285374

   Lab image2:

   Projection Matrix:

   [[-6.93154123e-03  4.01683831e-03  1.32603459e-03  8.26700664e-01]

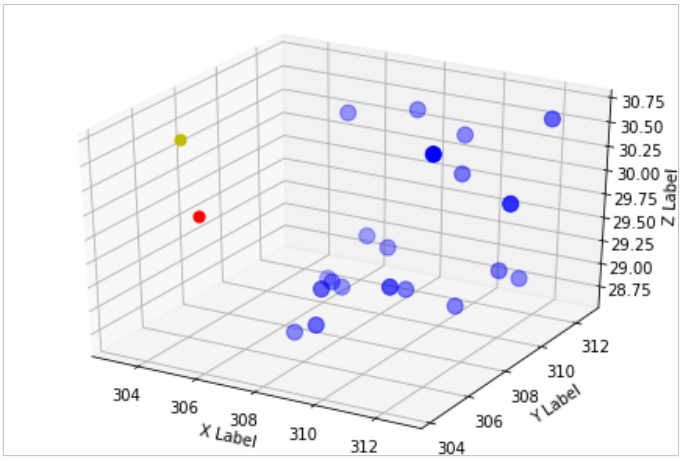
   [-1.54768613e-03 -1.02452781e-03  7.27440289e-03  5.62523094e-01]

   [-7.60945426e-06 -3.70954047e-06  1.90203848e-06  3.38807524e-03]]

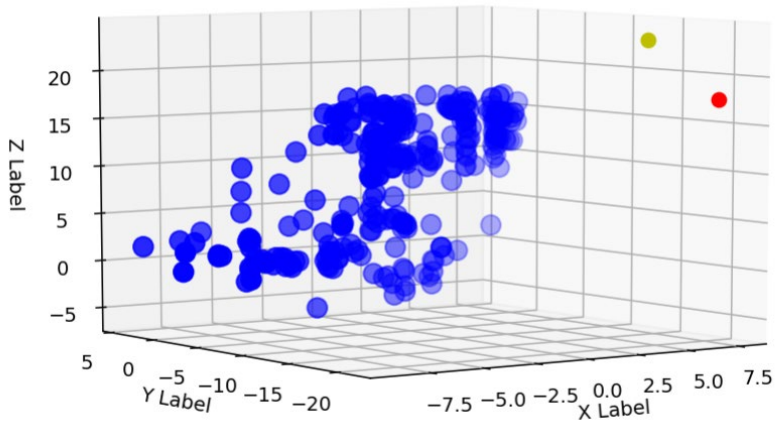
   Residual: 15.5449069211823

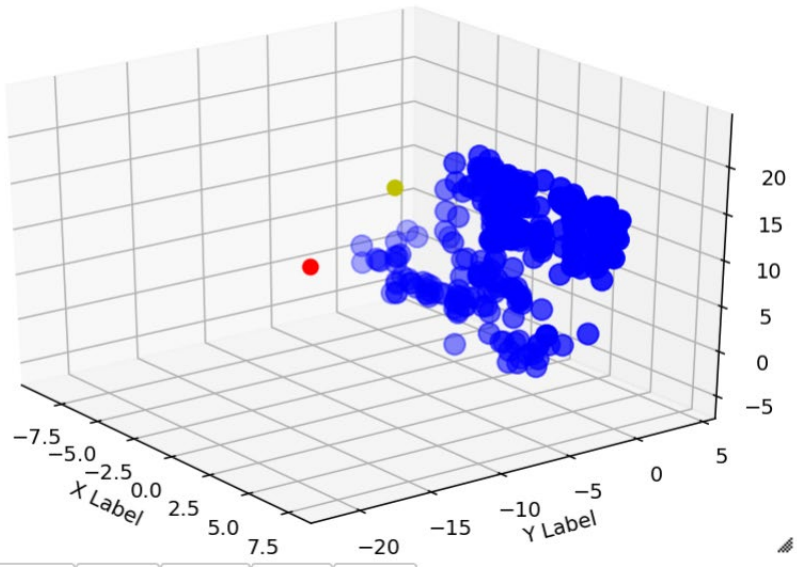
c. For both image pairs, visualize 3D camera centers and triangulated 3D points.

   Lab:


30.75
30.50
30.25
30.00
29.75
29.50
29.25
29.00
28.75
Z Label
304
306
308
310
312
X Label
304
306
308
310
312
Y Label

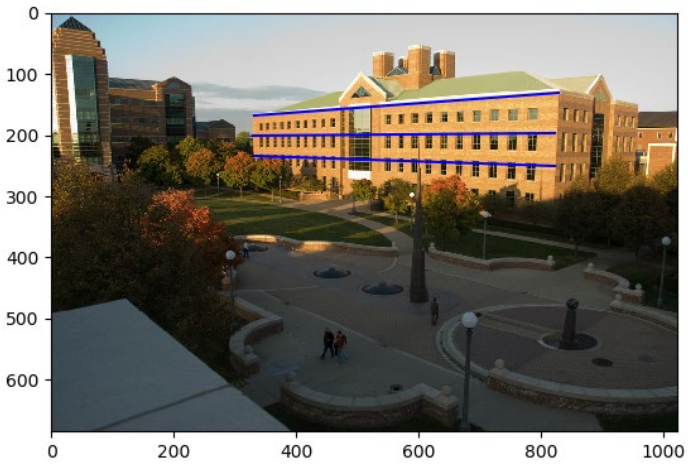
Library:

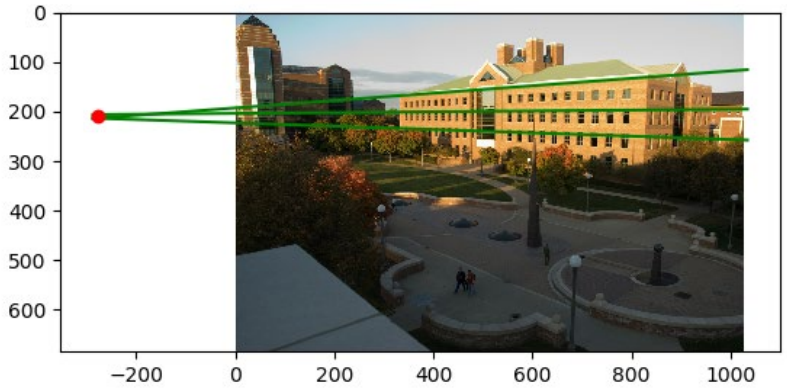

20
15
10
5
0
−5
Z Label
5
0
−5
−10
−15
−20
Y Label
−7.5
−5.0
−2.5
0.0
2.5
5.0
7.5
X Label


20
15
10
5
0
−5
−7.5
−5.0
−2.5
0.0
2.5
5.0
7.5
X Label
5
0
−5
−10
−15
−20
Y Label

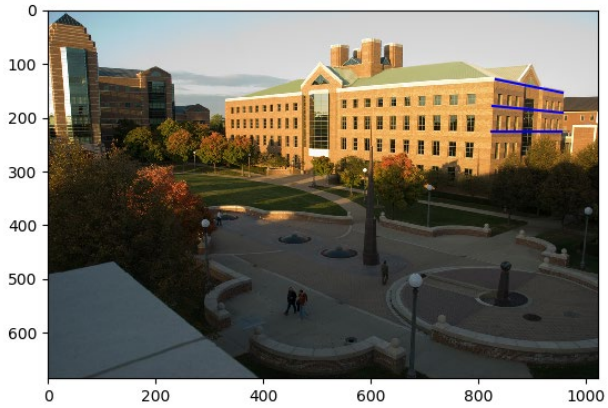
3. Single-view geometry: See items 1-4 in Part 3 above.
    a. Plot the VPs and the lines used to estimate them on the image plane using the provided code.

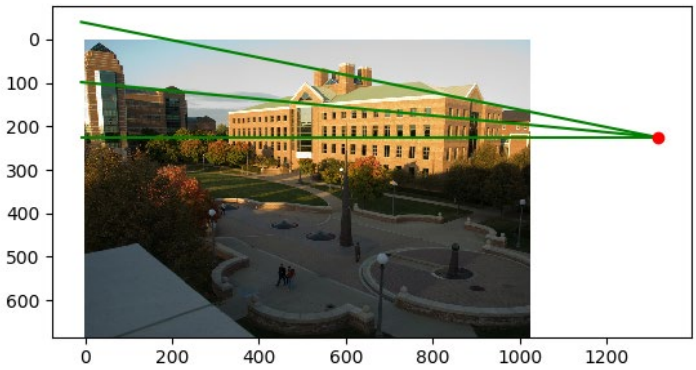
(1)



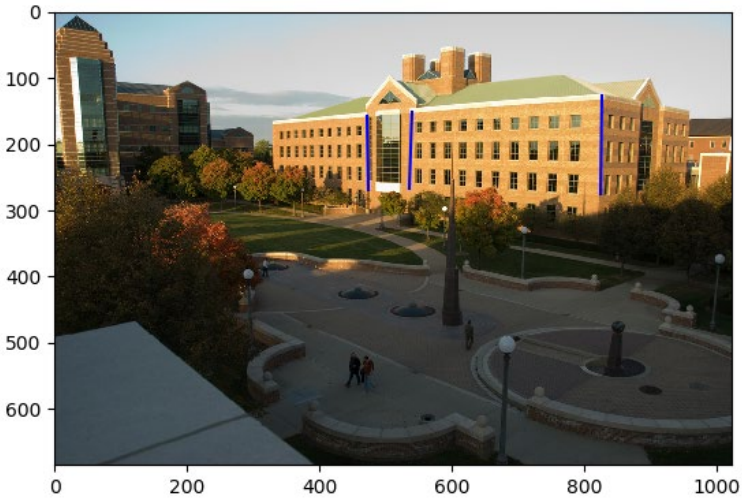



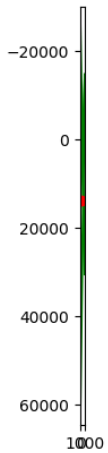

(2)




(3)



b. Specify the VP pixel coordinates.

VP pixel coordinates: (i.e. VP1 is the first column of the following matrix )

[[-4.11195763e+02  1.25913011e+03  5.11391341e+02]

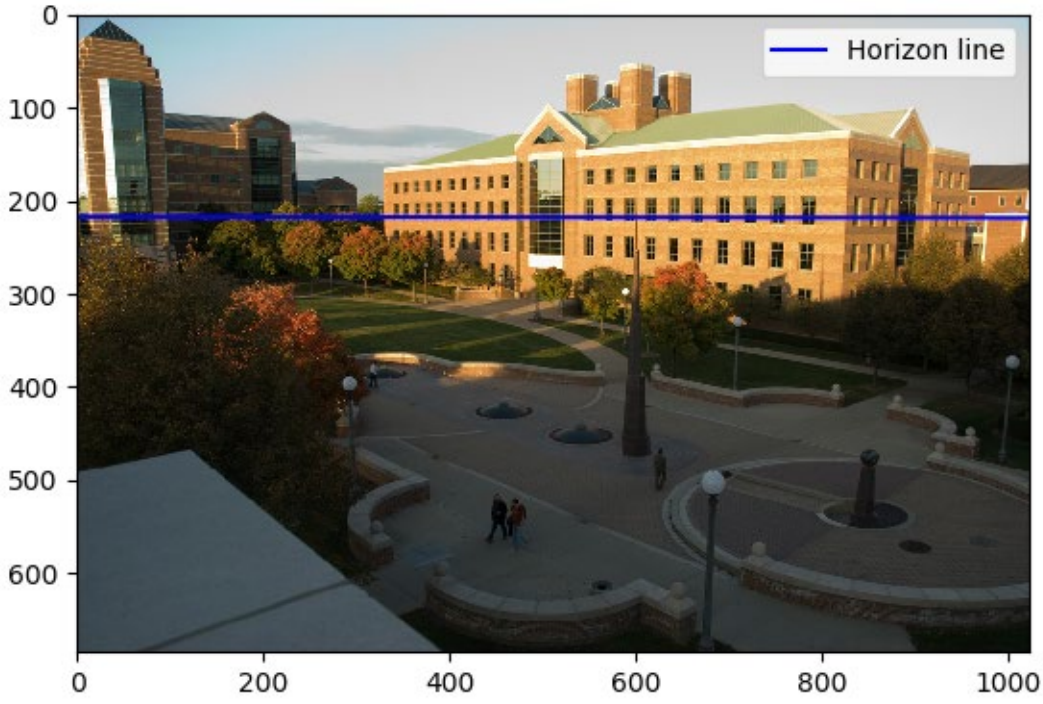
 [ 2.16634189e+02  2.18410961e+02  7.65053922e+03]

 [ 1.00000000e+00  1.00000000e+00  1.00000000e+00]]

c. Plot the ground horizon line and specify its parameters in the form a * x + b * y + c = 0. Normalize the parameters so that: a^2 + b^2 = 1.

Horizon line:

Its parameters: [-1.06372711e-03  9.99999434e-01 -2.17071466e+02]



Using the fact that the vanishing directions are orthogonal, solve for the focal length and optical center (principal point) of the camera. Show all your work.

My calculation process:

```
# work process
px = Symbol('px')
py = Symbol('py')
focal = Symbol('focal')

# K martix
K = Matrix([[focal, 0, px], [0, focal, py], [0, 0, 1]])

eq1 = p1.T * (K.inv().T) * K.inv() * p2
eq2 = p1.T * (K.inv()).T * K.inv() * p3
eq3 = p2.T * (K.inv()).T * K.inv() * p3

answer = solve([eq1[0], eq2[0], eq3[0]], (focal, px, py))
focal, px, py = answer[0]
```

Results: [824.519351935074 519.199420650109 310.240289644354]

Compute the rotation matrix for the camera, setting the vertical vanishing point as the Y-direction, the right-most vanishing point as the X-direction, and the left-most vanishing point as the Z-direction.

Rotation matrix:

[[ 0.50976938 -0.51209818 -0.50716382]

 [ 0.30403346 -0.27169217 -0.30265469]

 [-0.80479738  0.81482441  0.80696034]]

Estimate the heights of (a) the CSL building, (b) the spike statue, and (c) the lamp posts assuming that the person nearest to the spike is 5ft 6in tall. In the report, show all the lines and measurements used to perform the calculation. How do the answers change if you assume the person is 6ft tall?

The person nearest to the spike is 5ft 6in and I transferred it to Metric that is 1.6764m

Estimating height of CSL building: 31.05918487545983 m

Estimating height of the spike statue: 11.71500395144867 m

Estimating height of the lamp posts: 6.540100524274529 m

If I assume the person is 6ft (1.8288), we can get the height.

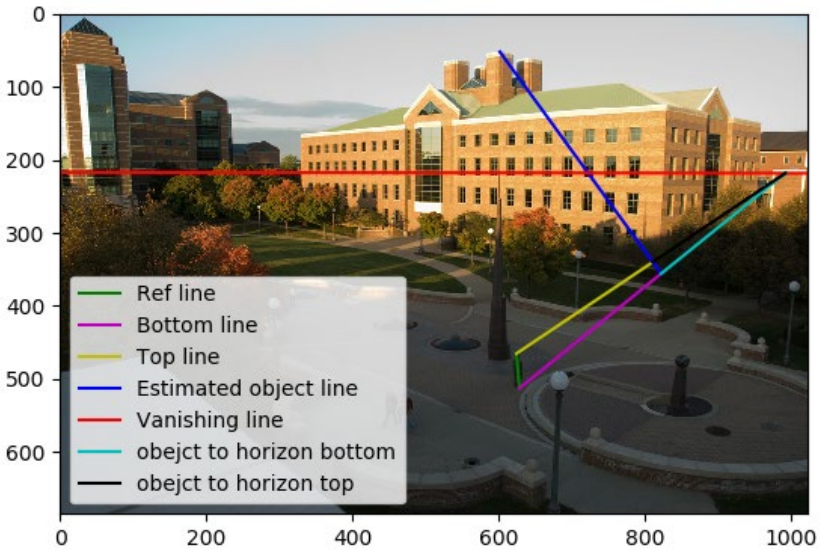
Estimating height of CSL building: 33.88274713686527 m

Estimating height of the spike statue: 12.780004310671277 m

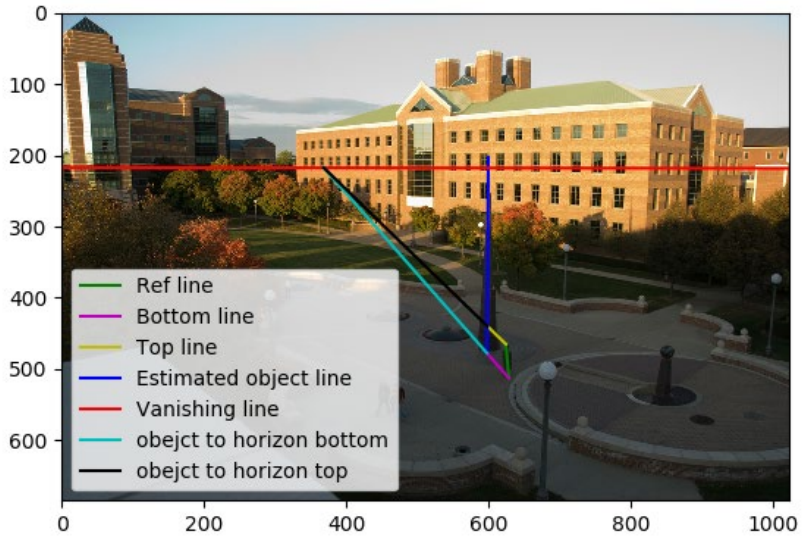
Estimating height of the lamp posts: 7.134655117390396 m

Reference figure:

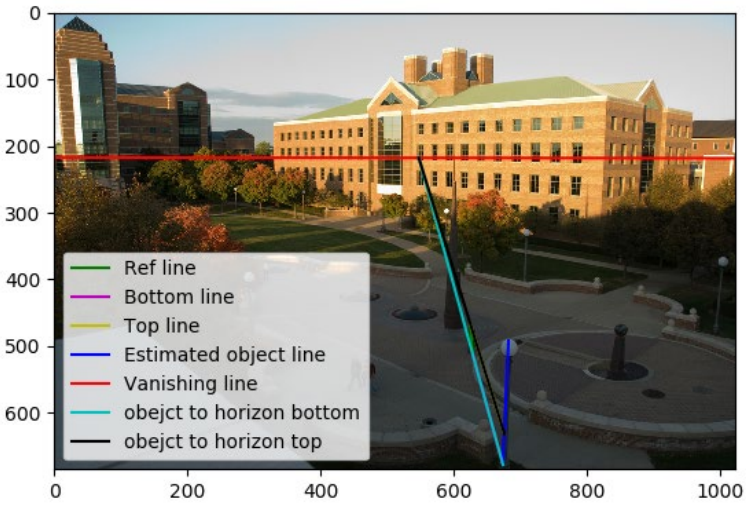
CSL:




Spike statue:


Ref line
Bottom line
Top line
Estimated object line
Vanishing line
obejct to horizon bottom
obejct to horizon top
0
100
200
300
400
500
600
0
200
400
600
800
1000

Lamp posts:


Ref line
Bottom line
Top line
Estimated object line
Vanishing line
obejct to horizon bottom
obejct to horizon top
0
100
200
300
400
500
600
0
200
400
600
800
1000