EECE5554 Lab4

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Image naming explanation:
Images whose names start with gray are gray scale images after resizing in .bmp format.
Images whose names end with rect are corresponding gray scale images after rectification in .bmp format.

.mat file naming explanation
lab4_2_final.m is the script for Part 2.
cinder_block.m is the script for cinder block wall mosaicking of Part 3.
graffito.m is the script for graffiti art mosaicking of Part 3.

Part1 - Camera Calibration
First time of calibration:

```
Aspect ratio optimized (est_aspect_ratio = 1) -> both components of fc are estimated (DEFAULT).
Principal point optimized (center_optim=1) - (DEFAULT). To reject principal point, set center_optim=0
Skew not optimized (est_alpha=0) - (DEFAULT)
Distortion not fully estimated (defined by the variable est_dist):
     Sixth order distortion not estimated (est_dist(5)=0) - (DEFAULT) .
Initialization of the principal point at the center of the image.
Initialization of the intrinsic parameters using the vanishing points of planar patterns.

Initialization of the intrinsic parameters - Number of images: 20

Calibration parameters after initialization:

Focal Length:          fc = [ 1167.16730   1167.16730 ]
Principal point:       cc = [ 539.50000   719.50000 ]
Skew:             alpha_c = [ 0.00000 ]   => angle of pixel = 90.00000 degrees
Distortion:            kc = [ 0.00000   0.00000   0.00000   0.00000   0.00000 ]

Main calibration optimization procedure - Number of images: 20
Gradient descent iterations: 1...2...3...4...5...6...7...8...9...10...11...12...13...14...15...16...17...18...19...done
Estimation of uncertainties...done


Calibration results after optimization (with uncertainties):

Focal Length:          fc = [ 1184.04920   1174.89162 ] +/- [ 4.20487   4.05857 ]
Principal point:       cc = [ 525.67064   717.49895 ] +/- [ 2.81990   3.64879 ]
Skew:             alpha_c = [ 0.00000 ] +/- [ 0.00000  ]   => angle of pixel axes = 90.00000 +/- 0.00000 degrees
Distortion:            kc = [ 0.02470   -0.08256   0.00018   -0.00167   0.00000 ] +/- [ 0.01103   0.03673   0.00113   0.00085   0.00000 ]
Pixel error:          err = [ 0.67460   0.58761 ]
```

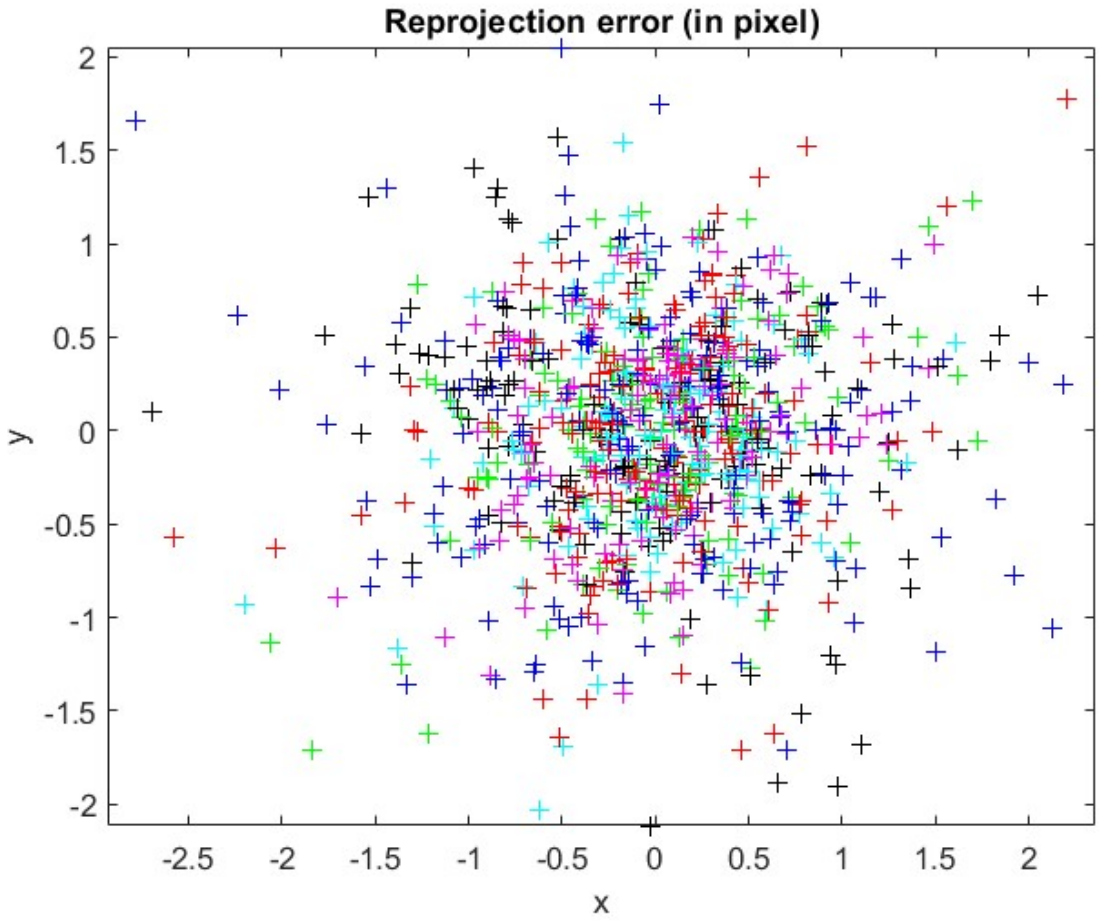


Figure. Reprojection Error

Calibration based on output of first-time calibration

```
Re-extraction of the grid corners on the images (after first calibration)
Window size for corner finder (wintx and winty):
wintx ([] = 5) = 1
winty ([] = 5) = 1
Window size = 3x3
Number(s) of image(s) to process ([] = all images) =
Use the projection of 3D grid or manual click ([]=auto, other=manual):
Processing image 1...2...3...4...5...6...7...8...9...10...11...12...13...14...15...16...17...18...19...20...
done

Aspect ratio optimized (est_aspect_ratio = 1) -> both components of fc are estimated (DEFAULT).
Principal point optimized (center_optim=1) - (DEFAULT). To reject principal point, set center_optim=0
Skew not optimized (est_alpha=0) - (DEFAULT)
Distortion not fully estimated (defined by the variable est_dist):
     Sixth order distortion not estimated (est_dist(5)=0) - (DEFAULT) .

Main calibration optimization procedure - Number of images: 20
Gradient descent iterations: 1...2...3...4...5...6...7...8...9...10...11...12...13...14...15...16...17...done
Estimation of uncertainties...done


Calibration results after optimization (with uncertainties):

Focal Length:          fc = [ 1185.87362   1176.64521 ] +/- [ 1.94984   1.88192 ]
Principal point:       cc = [ 526.11943   718.75647 ] +/- [ 1.30965   1.69679 ]
Skew:             alpha_c = [ 0.00000 ] +/- [ 0.00000  ]   => angle of pixel axes = 90.00000 +/- 0.00000 degrees
Distortion:            kc = [ 0.02331   -0.07869   0.00072   -0.00148   0.00000 ] +/- [ 0.00514   0.01720   0.00052   0.00039   0.00000 ]
Pixel error:          err = [ 0.28813   0.29760 ]
```

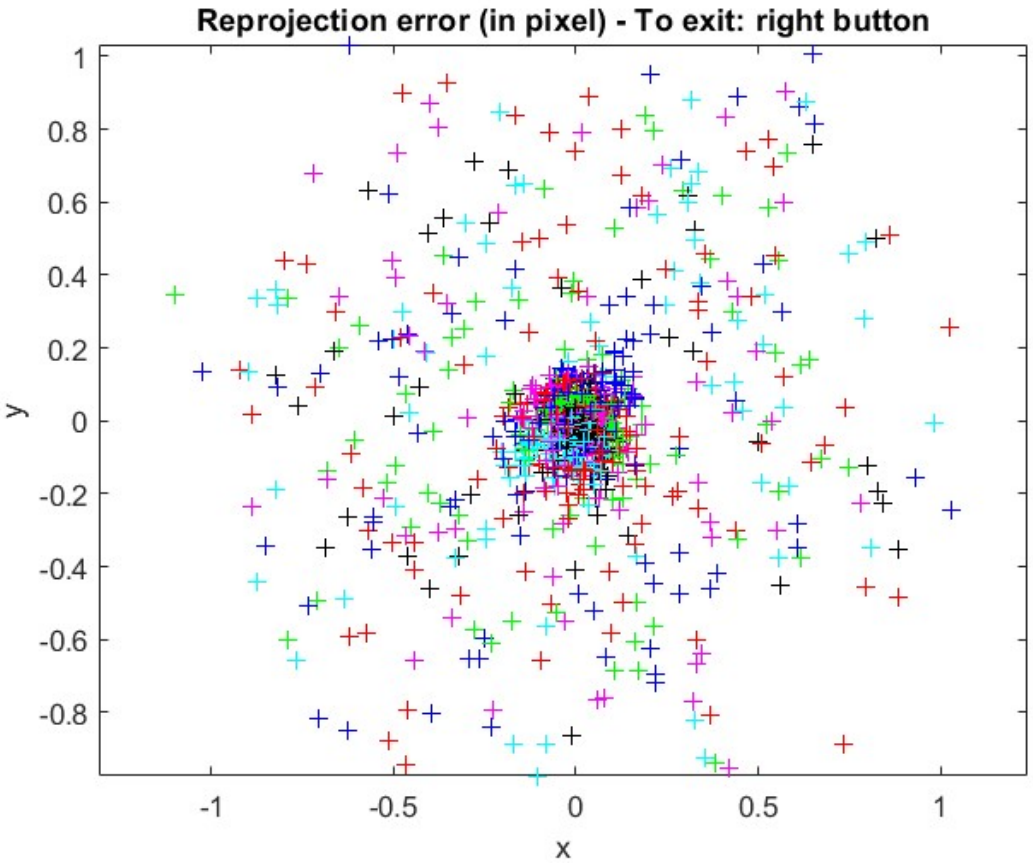


Figure. Reprojection Error

After adding 5 new images and calibration with default window size:

```
Aspect ratio optimized (est_aspect_ratio = 1) -> both components of fc are estimated (DEFAULT).
Principal point optimized (center_optim=1) - (DEFAULT). To reject principal point, set center_optim=0
Skew not optimized (est_alpha=0) - (DEFAULT)
Distortion not fully estimated (defined by the variable est_dist):
     Sixth order distortion not estimated (est_dist(5)=0) - (DEFAULT) .

Main calibration optimization procedure - Number of images: 25
Gradient descent iterations: 1...2...3...4...5...6...7...8...9...10...11...12...13...14...15...16...17...done
Estimation of uncertainties...done


Calibration results after optimization (with uncertainties):

Focal Length:          fc = [ 1184.88603   1175.90945 ] +/- [ 2.22319   2.17148 ]
Principal point:       cc = [ 526.57926   718.14805 ] +/- [ 1.42076   1.79700 ]
Skew:             alpha_c = [ 0.00000 ] +/- [ 0.00000  ]   => angle of pixel axes = 90.00000 +/- 0.00000 degrees
Distortion:            kc = [ 0.02590   -0.08376   0.00046   -0.00136  0.00000 ] +/- [ 0.00553   0.01840   0.00055   0.00042  0.00000 ]
Pixel error:          err = [ 0.33744   0.36274 ]
```

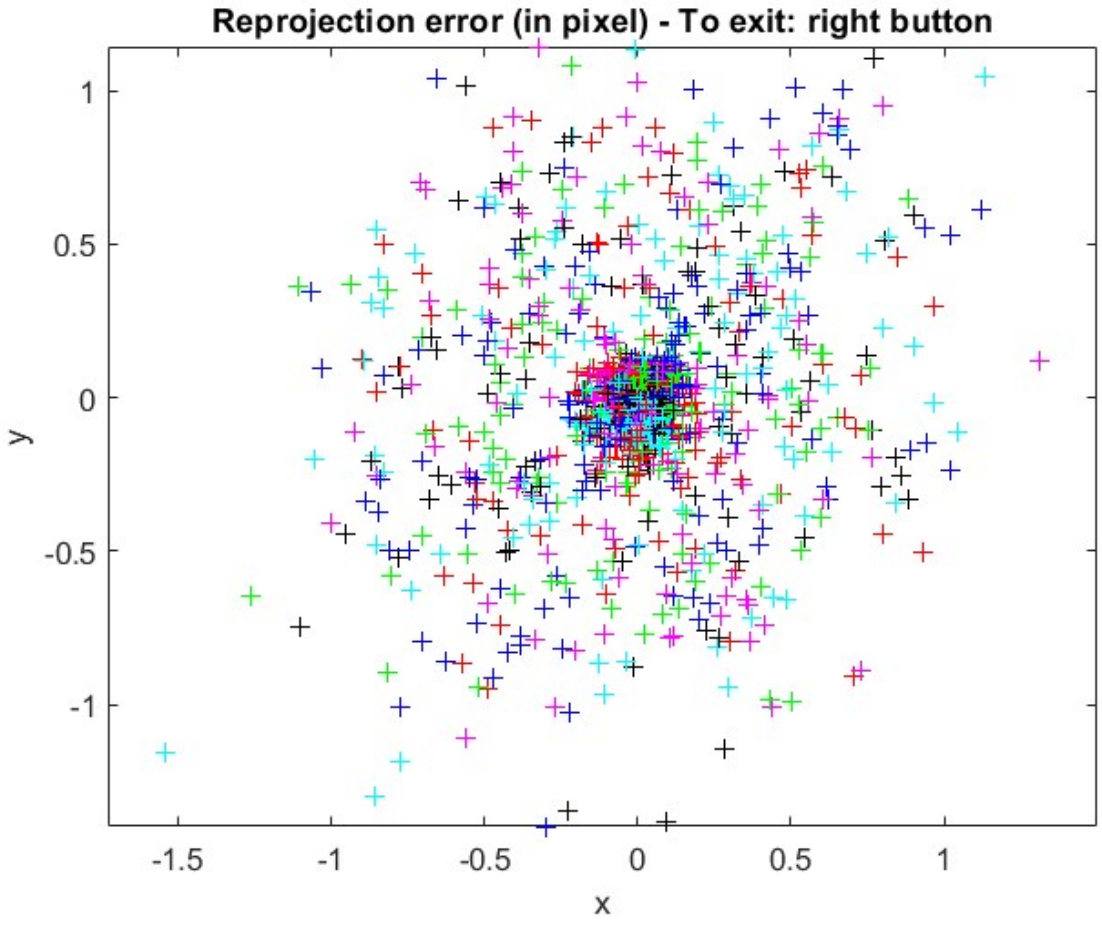


Figure. Reprojection Error

Calibration with different window sizes for last four images:

```
Aspect ratio optimized (est_aspect_ratio = 1) -> both components of fc are estimated (DEFAULT).
Principal point optimized (center_optim=1) - (DEFAULT). To reject principal point, set center_optim=0
Skew not optimized (est_alpha=0) - (DEFAULT)
Distortion not fully estimated (defined by the variable est_dist):
     Sixth order distortion not estimated (est_dist(5)=0) - (DEFAULT) .

Main calibration optimization procedure - Number of images: 25
Gradient descent iterations: 1...2...3...4...5...6...7...8...9...10...11...12...13...14...15...16...17...done
Estimation of uncertainties...done


Calibration results after optimization (with uncertainties):

Focal Length:          fc = [ 1185.36104   1176.12764 ] +/- [ 2.09397   2.04465 ]
Principal point:       cc = [ 526.07011   718.50325 ] +/- [ 1.33879   1.69366 ]
Skew:             alpha_c = [ 0.00000 ] +/- [ 0.00000  ]   => angle of pixel axes = 90.00000 +/- 0.00000 degrees
Distortion:            kc = [ 0.02448   -0.07941   0.00056   -0.00146   0.00000 ] +/- [ 0.00521   0.01734   0.00052   0.00039   0.00000 ]
Pixel error:          err = [ 0.31804   0.34127 ]
```

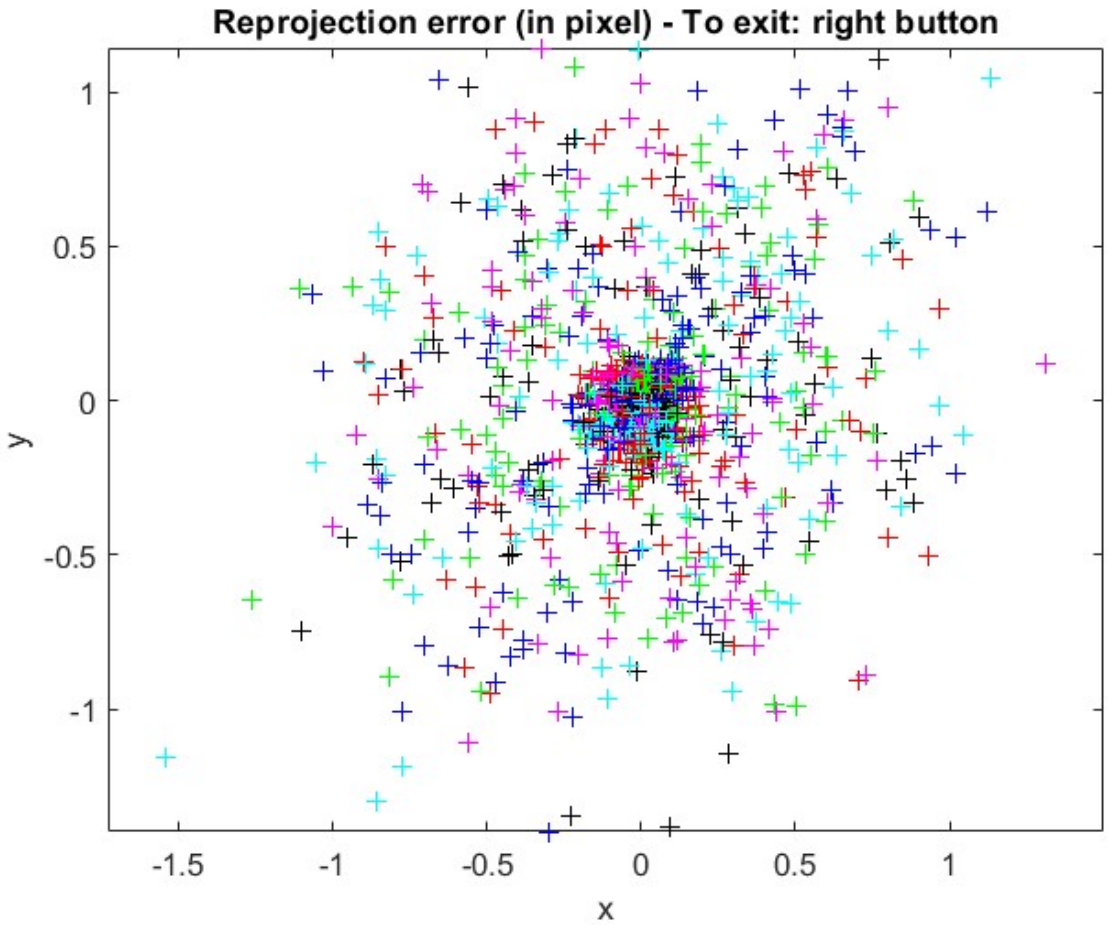


Figure. Reprojection Error

Calibration including the skew factor alpha_c

```
>> est_dist = [1;1;1;1;1];
>> est_alpha = 1;

Aspect ratio optimized (est_aspect_ratio = 1) -> both components of fc are estimated (DEFAULT).
Principal point optimized (center_optim=1) - (DEFAULT). To reject principal point, set center_optim=0
Skew optimized (est_alpha=1). To disable skew estimation, set est_alpha=0.

Main calibration optimization procedure - Number of images: 25
Gradient descent iterations: 1...2...3...4...5...6...7...8...9...10...11...12...13...14...15...16...done
Estimation of uncertainties...done


Calibration results after optimization (with uncertainties):

Focal Length:          fc = [ 1185.20092   1175.97466 ] +/- [ 2.13116   2.07944 ]
Principal point:       cc = [ 526.09520   718.51180 ] +/- [ 1.33933   1.70287 ]
Skew:             alpha_c = [ -0.00004 ] +/- [ 0.00021  ]   => angle of pixel axes = 90.00237 +/- 0.01186 degrees
Distortion:            kc = [ 0.02896   -0.11371   0.00056   -0.00146  0.07534 ] +/- [ 0.01301   0.09272   0.00052   0.00039  0.19972 ]
Pixel error:          err = [ 0.31812   0.34099 ]

Note: The numerical errors are approximately three times the standard deviations (for reference).


Recommendation: The skew coefficient alpha_c is found to be equal to zero (within its uncertainty).
                You may want to reject it from the optimization by setting est_alpha=0 and run Calibration

Recommendation: Some distortion coefficients are found equal to zero (within their uncertainties).
                To reject them from the optimization set est_dist=[1;1;1;1;0] and run Calibration
```

The uncertainty on the 6th order radial distortion coefficient is very large (the uncertainty is much larger than the absolute value of the coefficient), so I disabled its estimation, and did calibration:

```
>> est_dist(5) = 0;

Aspect ratio optimized (est_aspect_ratio = 1) -> both components of fc are estimated (DEFAULT).
Principal point optimized (center_optim=1) - (DEFAULT). To reject principal point, set center_optim=0
Skew optimized (est_alpha=1). To disable skew estimation, set est_alpha=0.
Distortion not fully estimated (defined by the variable est_dist):
     Sixth order distortion not estimated (est_dist(5)=0) - (DEFAULT) .

Main calibration optimization procedure - Number of images: 25
Gradient descent iterations: 1...2...3...4...5...6...7...8...9...10...11...12...13...14...15...16...17...done
Estimation of uncertainties...done


Calibration results after optimization (with uncertainties):

Focal Length:          fc = [ 1185.35053   1176.11767 ] +/- [ 2.09458   2.04519 ]
Principal point:       cc = [ 526.07733   718.53228 ] +/- [ 1.33927   1.70094 ]
Skew:             alpha_c = [ -0.00004 ] +/- [ 0.00021  ]   => angle of pixel axes = 90.00218 +/- 0.01185 degrees
Distortion:            kc = [ 0.02446   -0.07935   0.00057   -0.00146  0.00000 ] +/- [ 0.00521   0.01735   0.00052   0.00039  0.00000 ]
Pixel error:          err = [ 0.31802   0.34125 ]
```

Mean Pixel Error:

```
>> mean(ex, 2)

ans =

   1.0e-09 *

   -0.0435
   -0.1039
```

```
>> fprintf('Mean Pixel Error:          x direciton = %f    y direction = %f (all active images)\n\n',mean(ex,2));
Mean Pixel Error:          x direciton = -0.000000    y direction = -0.000000 (all active images)
```

Mean of absolute value of Pixel Error:

```
>> fprintf('Mean of absolute value of Pixel Error:    x direciton = %f    y direction = %f (all active images)\n\n',mean(abs(ex),2));
Mean of absolute value of Pixel Error:    x direciton = 0.209486    y direction = 0.221871 (all active images)
```

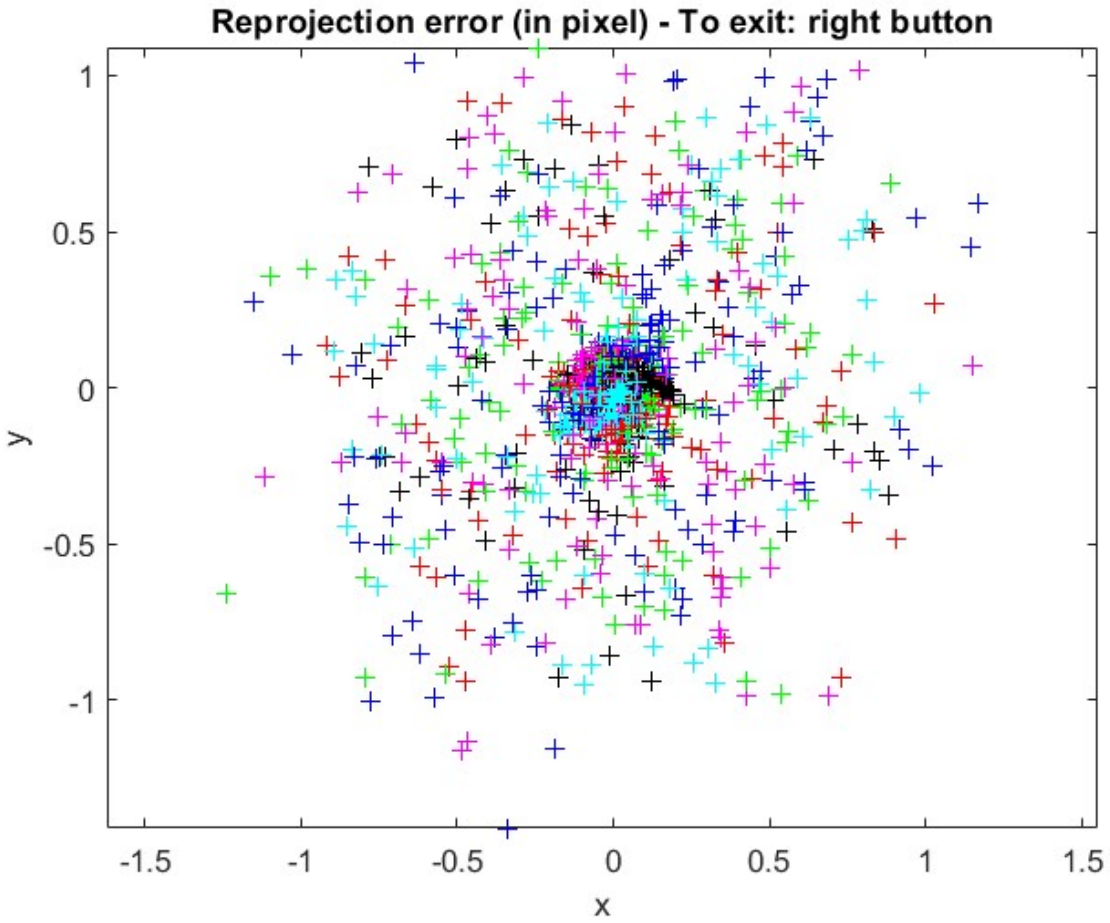
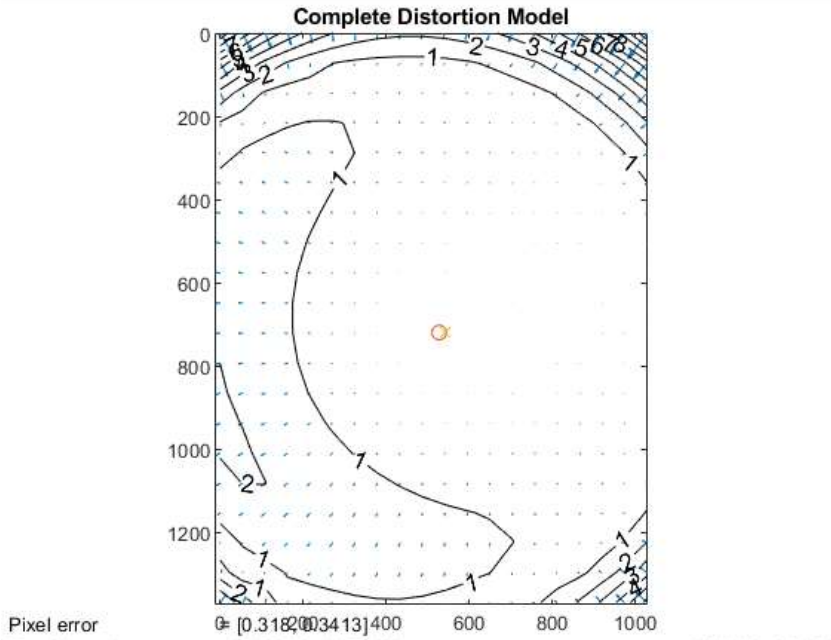
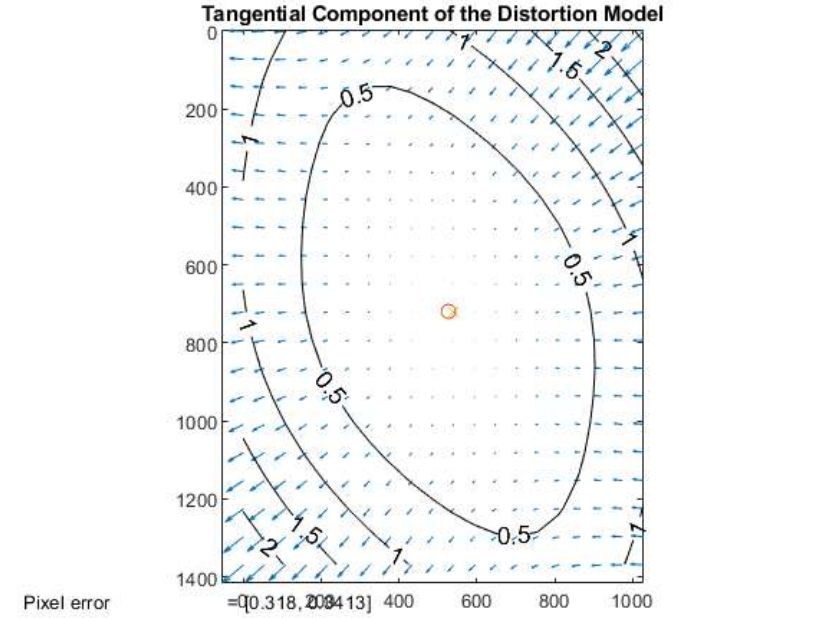


Figure. Final Reprojection Error



Pixel error = [0.318, 0.413]
Focal Length = (1185.35, 1176.12) +/- [2.095, 2.045]
Principal Point = (526.077, 718.532) +/- [1.339, 1.701]
Skew = -3.8e-05 +/- 0.0002069
Radial coefficients = (0.02446, -0.07935, 0) +/- [0.005208, 0.01735, 0]
Tangential coefficients = (0.0005698, -0.001457) +/- [0.0005216, 0.0003938]

Figure. Complete Distortion Model



Pixel error = [0.318, 0.413]
Focal Length = (1185.35, 1176.12) +/- [2.095, 2.045]
Principal Point = (526.077, 718.532) +/- [1.339, 1.701]
Skew = -3.8e-05 +/- 0.0002069
Radial coefficients = (0.02446, -0.07935, 0) +/- [0.005208, 0.01735, 0]
Tangential coefficients = (0.0005698, -0.001457) +/- [0.0005216, 0.0003938]

Figure. Tangential Component of the Distortion Model

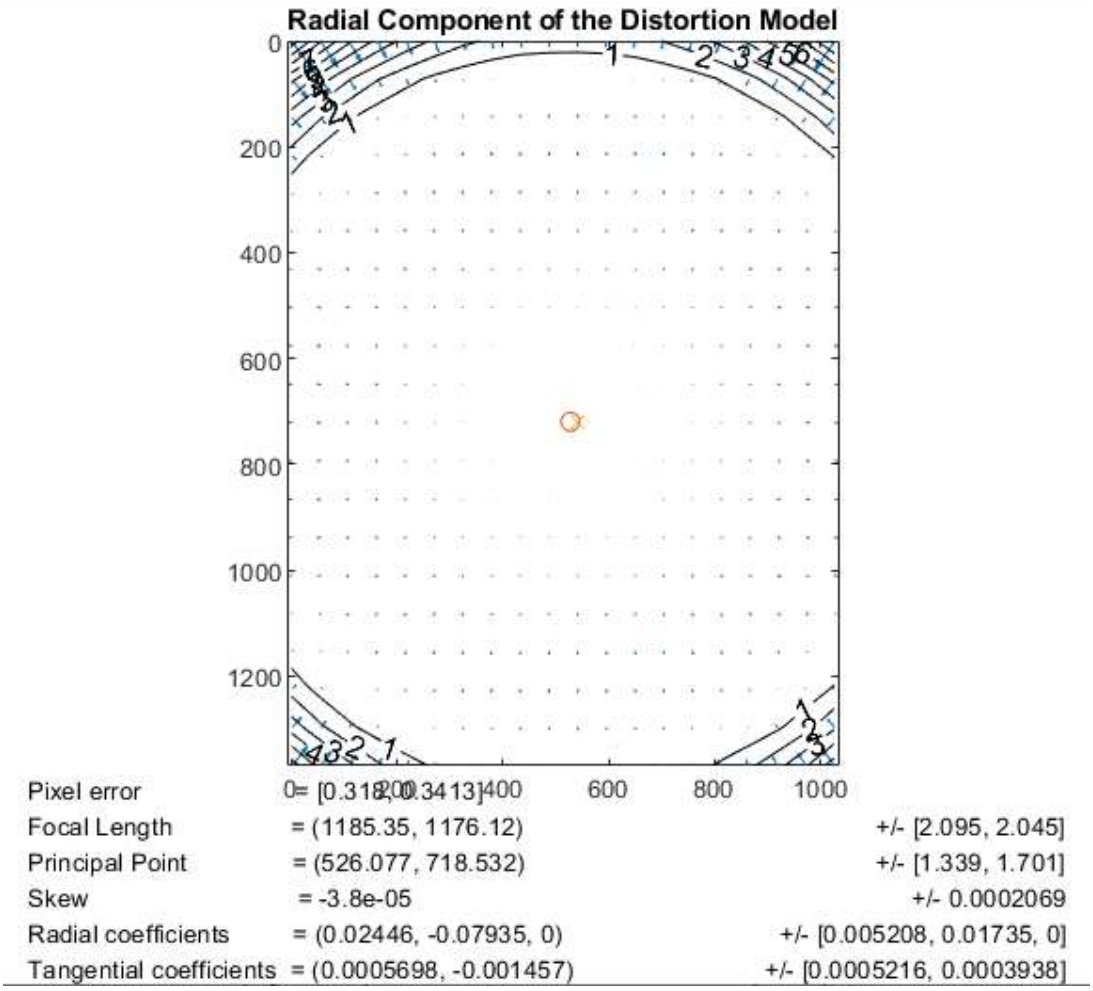


Figure. Radial Component of the Distortion Model

Part2 - Photo Mosaicking:
I think for both part2 and part3, fine-tuning of function parameters is necessary because of the properties of objects I took photos for and varying overlapping ratio.

Undistort images: I can't see much compensation after doing anti-distortion, and I even feel the image is a little bit more distorted after compensation. It will be more obvious if you compare before/after compensation images of cinder block wall.

Figure. A sample before / after image showing the distortion correction

Although I used the same set of parameters, the mosaicking outcome varies between runs. I think this is because of some underlying random process of the Matlab functions. As a result, the script doesn't work well every single time. Results of some runs are as follow:

Figure. Panoramic mosaic 1 of Latino Students Center building

Figure. Panoramic mosaic 2 of Latino Students Center building

Figure. Panoramic mosaic 3 of Latino Students Center building

Figure. Panoramic mosaic 4 of Latino Students Center building

Assuming for every photo, the location of camera with respect to this image is [imageSize(jj,2)/2, imageSize(jj,1)/2, 200], i.e. at the center of that photo but 200 units away from the photo plane. Then I did same homogeneous transformations for camera coordinated as for photos, and the results were coordinates of cameras with respect to panoramic mosaic.

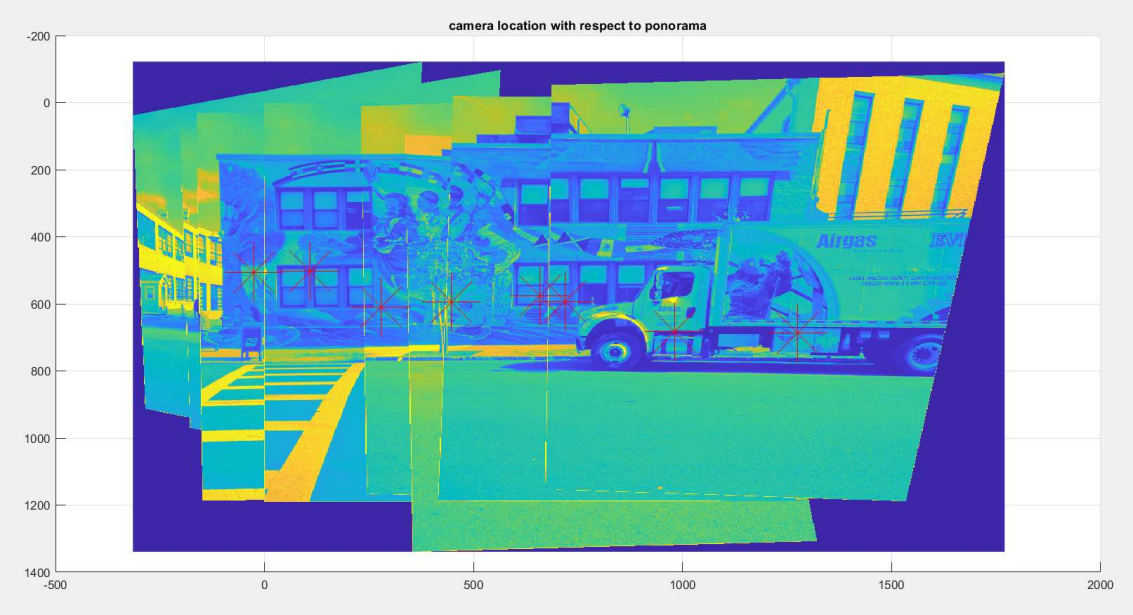


Figure. Camera position estimation with respect to panoramic mosaic

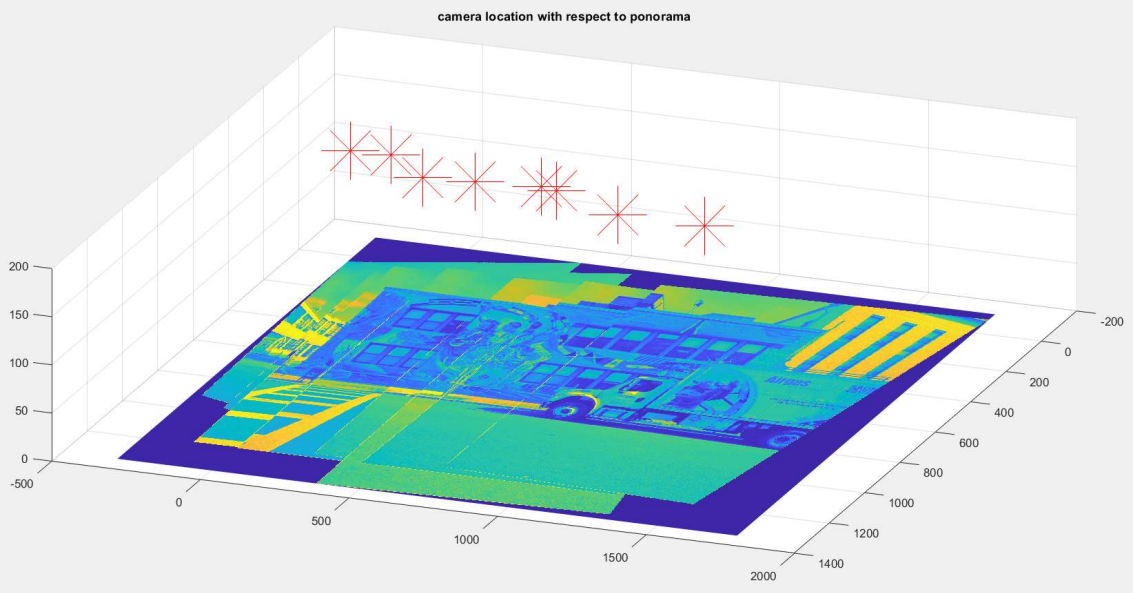


Figure. Camera position estimation with respect to panoramic mosaic

Part3 - Mosaicking with varying overlap

1. For cinder block wall with 50% overlapping between 2 consecutive photos:

In this case, if the whole picture is viewed as 1 region, most corner features will be located at windows and burglar meshes, so I divided each picture into 20*20 regions to ensure there are adequate number of corner features on walls for matching. The theory of camera position estimation is the same as that of part2.

Figure. Panoramic mosaic of cinder block wall

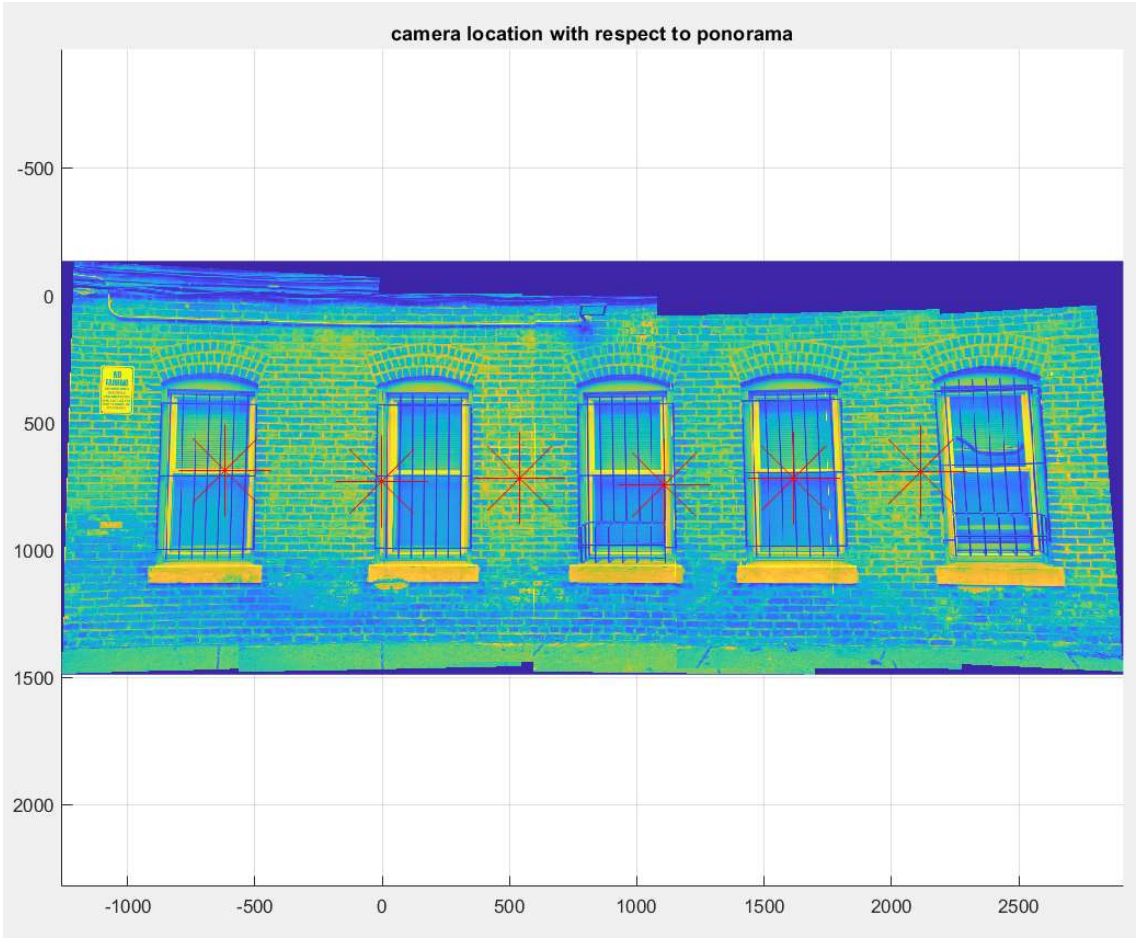


Figure. Camera position estimation with respect to panoramic mosaic

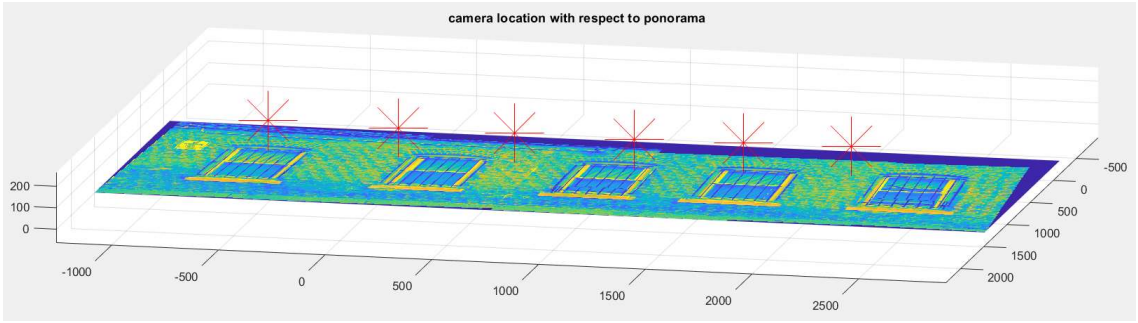


Figure. Camera position estimation with respect to panoramic mosaic

2. For graffiti art with 15% percent overlapping between 2 consecutive photos:
It still works, but with an overlapping of 15% between 2 consecutive images, I divide the image into more regions and increased the maximum number of corners detected by Harris corner detector to ensure there are enough feature points within overlapping regions, for matching purpose. The theory of camera position estimation is the same as that of part2.

Figure. Panoramic mosaic of graffiti art near Boston Symphony Hall

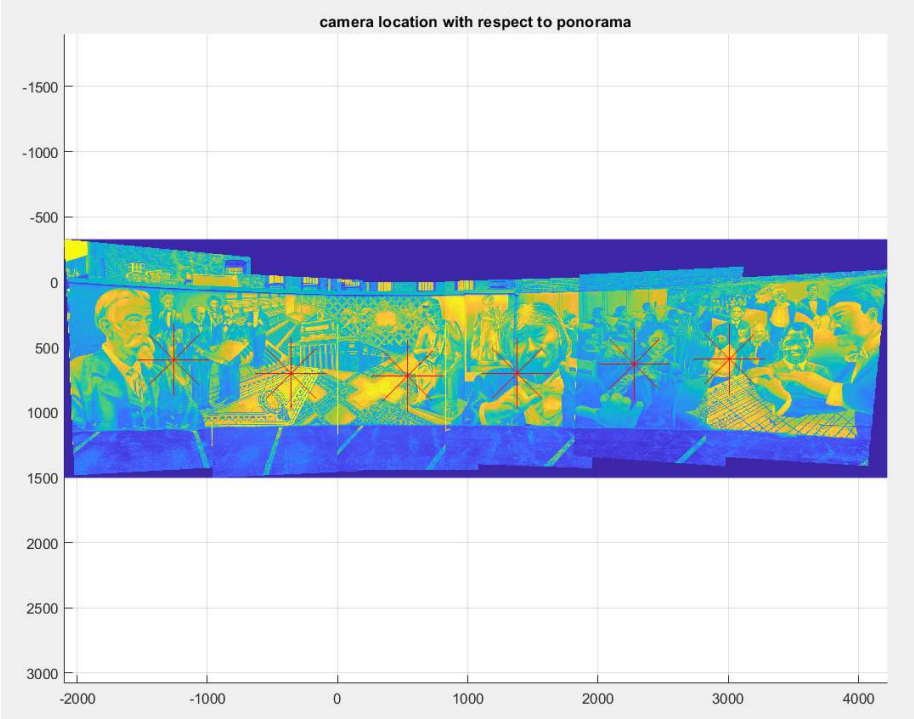


Figure. Camera position estimation with respect to panoramic mosaic

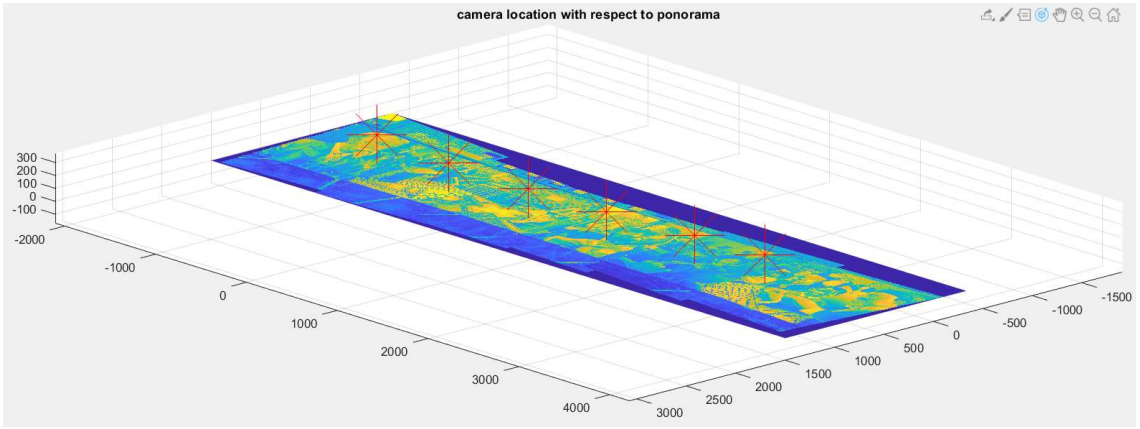


Figure. Camera position estimation with respect to panoramic mosaic