

Report

1. Intrinsic Camera Parameters:

Focal lengths : $(f_x, f_y) = (1190.7, 1192.35)$

Skew parameter : 0 (usually its value is zero)

Principal point : $(C_x, C_y) = (598.53, 791.15)$

2. Extrinsic Camera Parameters:

Rotation Matrix image1:

```
[[-0.06261427  0.87442705  0.48109955]
 [-0.90875091  0.14933886 -0.38970461]
 [-0.41261511 -0.46160073  0.78528564]]
```

translation vector image1:

```
[[-4.09432471]
 [ 1.28771818]
 [14.83373467]]
```

Rotation Matrix image2:

```
[[ 0.03281847  0.9990212  0.02965788]
 [-0.9981893  0.03126563  0.05138666]
 [ 0.05040909 -0.03129061  0.99823836]]
```

translation vector image2:

```
[[-3.98907717]
 [ 2.76974378]
 [12.11914878]]
```

Rotation Matrix image3:

```
[[-0.00277006  0.99354099  0.11343994]
 [-0.79539708  0.06656539 -0.60242222]
 [-0.60608235 -0.09189854  0.79007522]]
```

translation vector image3:

```
[[-4.25834318]
 [ 2.55620445]
 [15.9177424 ]]
```

Rotation Matrix image4:

```
[[ 0.07796071  0.98570661  0.1493473 ]
 [-0.95199764  0.02912613  0.30471652]
 [ 0.29601118 -0.16593419  0.94066106]]
```

translation vector image4:

```
[[ -4.08198816]
 [-0.4557984 ]
 [13.04861431]]
```

Rotation Matrix image5:

```
[[ -0.00554839  0.97600874  0.21766066]
 [-0.99994387 -0.00345053 -0.01001713]
 [-0.00902576 -0.21770402  0.9759731 ]]
```

translation vector image5:

```
[[ -4.2000856 ]
 [ 3.5742766 ]
 [13.06809992]]
```

Rotation Matrix image6:

```
[[ 0.04656186  0.99839502  0.03223943]
 [-0.919723    0.05544231 -0.38863319]
 [-0.38979686 -0.01155586  0.92082836]]
```

translation vector image6:

```
[[ -3.97797504]
 [ 0.89131155]
 [14.69225337]]
```

Rotation Matrix image7:

```
[[ 0.03590642  0.97609841 -0.2143423 ]
 [-0.99934555  0.03601098 -0.0034182 ]
 [ 0.00438217  0.21432476  0.97675263]]
```

translation vector image7:

```
[[ -3.62618965]
 [ 3.71941063]
 [11.13519754]]
```

Rotation Matrix image8:

```
[[ 0.03478814  0.99908717  0.02479133]
```

```
[-0.95247252  0.02563289  0.30354416]
[ 0.30263161 -0.03417279  0.95249479]]
```

translation vector image8:

```
[[ -4.02995218]
 [  1.11447572]
 [12.71433596]]
```

Rotation Matrix image9:

```
[[ -0.00915261  0.99994829 -0.00443262]
 [ -0.99992392 -0.00918887 -0.00822913]
 [ -0.00826943  0.00435696  0.99995632]]
```

translation vector image9:

```
[[ -3.63512343]
 [  0.98448922]
 [13.19749989]]
```

Rotation Matrix image10:

```
[[ -0.01659115  0.99968692 -0.01872978]
 [ -0.98908069 -0.01915287 -0.14612513]
 [ -0.14643811  0.01610088  0.98908879]]
```

translation vector image10:

```
[[ -3.78884412]
 [  1.63810867]
 [12.86358576]]
```

Rotation Matrix image11:

```
[[  0.01091044  0.99759232 -0.06848737]
 [ -0.82241358 -0.0300069  -0.56809814]
 [ -0.56878544  0.06252314  0.82010608]]
```

translation vector image11:

```
[[ -3.78746887]
 [  1.47020218]
 [14.58179263]]
```

Rotation Matrix image12:

```
[[  0.04752825  0.95172567  0.30324795]
 [ -0.99798777  0.03248895  0.05445065]
 [  0.04196987 -0.30522569  0.95135472]]
```

translation vector image12:

```
[[ -4.17816211]
 [  0.8861415 ]
 [14.59110461]]
```

Rotation Matrix image13:

```
[[ 0.00637919  0.72698699 -0.6866216 ]
 [-0.88426955 -0.31651847 -0.34334156]
 [-0.46693326  0.60934881  0.64083332]]
```

translation vector image13:

```
[[ -1.21090623]
 [  3.68084038]
 [  9.40219189]]
```

Rotation Matrix image14:

```
[[ -0.02799819  0.99231141 -0.12055771]
 [-0.87013945 -0.08355607 -0.48567039]
 [-0.4920096   0.09130413  0.86578872]]
```

translation vector image14:

```
[[ -3.3014036]
 [  3.6683297]
 [14.5586098]]
```

Rotation Matrix image15:

```
[[ 0.07276769  0.93086817 -0.35803536]
 [-0.98371004  0.12615405  0.12806133]
 [ 0.16437583  0.34288425  0.92488431]]
```

translation vector image15:

```
[[ -2.88572785]
 [  0.8333922 ]
 [10.41682229]]
```

Rotation Matrix image16:

```
[[ 0.07451531  0.85005188  0.52140126]
 [-0.79965814  0.36332741 -0.47805863]
 [-0.59581401 -0.38132008  0.70682436]]
```

translation vector image16:

```
[[ -4.66586649]
 [  1.16587513]]
```

[15.69017653]]

Rotation Matrix image17:

```
[[ 0.08978605  0.97415074  0.20728918]
 [-0.97247867  0.04082052  0.22938814]
 [ 0.21499698 -0.22218016  0.95100593]]
```

translation vector image17:

```
[[ -4.46298615]
 [-0.20819022]
 [13.22817183]]
```

Rotation Matrix image18:

```
[[ -0.00113467  0.89849146  0.43898953]
 [-0.99378797 -0.04986582  0.09949303]
 [ 0.11128421 -0.43614963  0.89296659]]
```

translation vector image18:

```
[[ -4.17452737]
 [ 3.46635775]
 [13.14542173]]
```

Rotation Matrix image19:

```
[[ -0.01911226  0.99757253 -0.06696088]
 [-0.91149477  0.01013731  0.41118673]
 [ 0.41086739  0.0688932   0.9090884  ]]
```

translation vector image19:

```
[[ -3.53700039]
 [ 0.6953889 ]
 [11.32070417]]
```

Rotation Matrix image20:

```
[[ 0.02327836  0.97200948 -0.23378557]
 [-0.99954664  0.02709538  0.01312809]
 [ 0.01909514  0.23337399  0.97219955]]
```

translation vector image20:

```
[[ -3.08563342]
 [ 2.82513744]
 [10.69792799]]
```

Rotation Matrix image21:
[[0.14716208 0.96686331 0.20861128]
[-0.94059353 0.07155044 0.33191015]
[0.30598551 -0.24506301 0.91995488]]

translation vector image21:
[[-4.77009435]
[0.70111263]
[13.09596146]]

Rotation Matrix image22:
[[-0.03639924 0.82330084 -0.56643695]
[-0.98970578 -0.1082034 -0.09367222]
[-0.13841082 0.55719633 0.81876413]]

translation vector image22:
[[-1.35300971]
[3.68609087]
[9.07536656]]

Rotation Matrix image23:
[[0.0484388 0.9890699 -0.13926381]
[-0.79071005 -0.0472171 -0.61036723]
[-0.61027149 0.13968275 0.77978038]]

translation vector image23:
[[-3.73655259]
[3.42569244]
[14.77401561]]

Rotation Matrix image24:
[[-0.0246971 0.93148977 0.36292818]
[-0.98992866 0.02783438 -0.13880379]
[-0.13939619 -0.36270106 0.92142099]]

translation vector image24:
[[-4.9690662]
[2.79722617]
[17.29092023]]

Rotation Matrix image25:
[[-0.0228057 0.99945041 0.02405791]
[-0.99634868 -0.02074136 -0.08281971]

```
[-0.0822752 -0.02585883 0.99627411]]
```

translation vector image25:

```
[-3.94810656]  
[ 2.95765689]  
[14.96629396]]
```

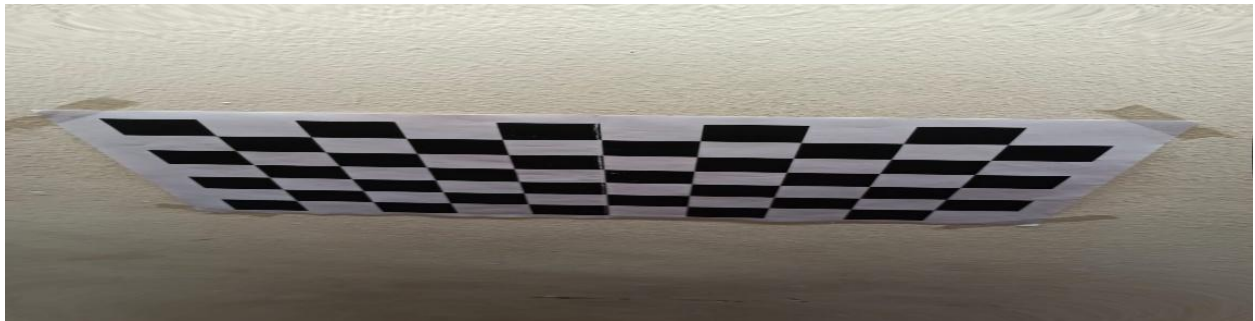
3. Radial distortion Coefficient:

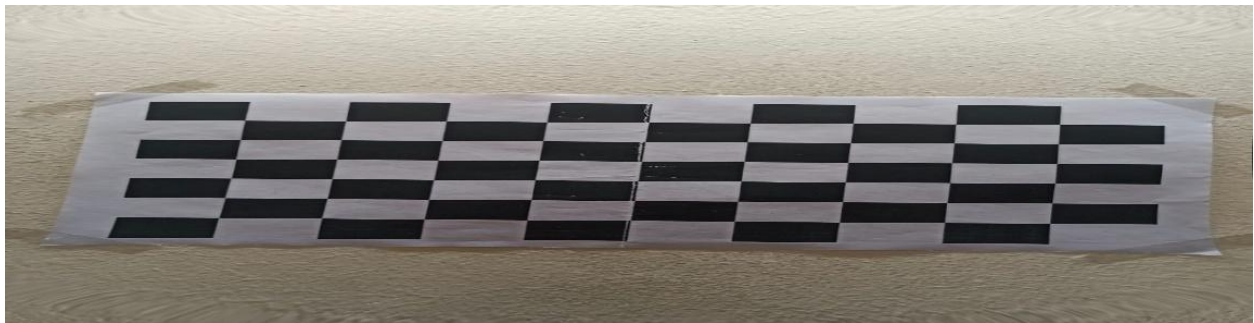
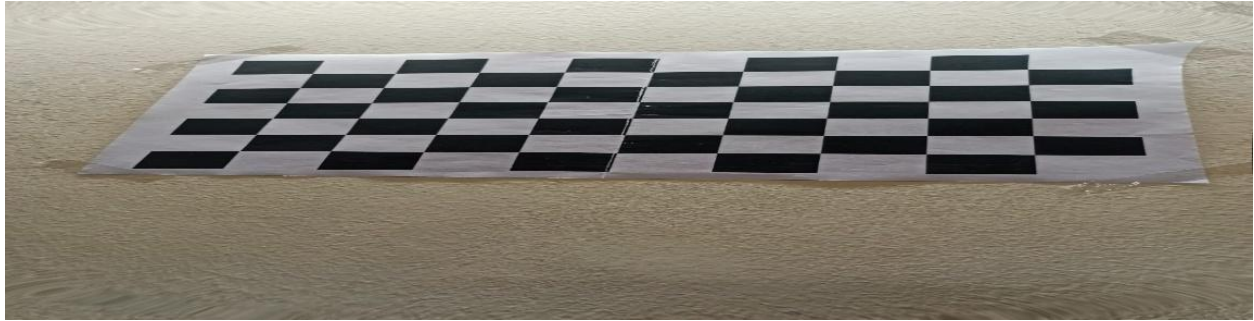
Distortion Coeffs:

(k1, k2, p1, p2, k3) = (0.1054, -0.0292, -0.0029, 0.0035, -1.0968)

When we apply radial distortion on the image, straight lines at the corner of the image will appear tilted. In order to remove that tiltedness we will do undistortion of the image.

Undistorted images:





4. Re-projection error:

re-projection error:
image1: 0.14

re-projection error:
image2: 0.12

re-projection error:
image3: 0.13

re-projection error:
image4: 0.12

re-projection error:
image5: 0.12

re-projection error:
image6: 0.1

re-projection error:
image7: 0.13

re-projection error:
image8: 0.11

re-projection error:
image9: 0.09

re-projection error:
image10: 0.1

re-projection error:
image11: 0.13

re-projection error:
image12: 0.09

re-projection error:
image13: 0.25

re-projection error:
image14: 0.14

re-projection error:
image15: 0.15

re-projection error:
image16: 0.17

re-projection error:
image17: 0.11

re-projection error:
image18: 0.12

re-projection error:
image19: 0.15

re-projection error:
image20: 0.14

re-projection error:
image21: 0.12

re-projection error:
image22: 0.21

re-projection error:
image23: 0.16

re-projection error:
image24: 0.1

re-projection error:
image25: 0.09

Plot : error vs image:



Mean of the re-projection error: 0.13

Std deviation of the re-projection error: 0.04

5. Firstly, we apply camera calibration on a data set of 25 raw images of checkerboard, then find the checkerboard corners and refine for each image using function **cv2.cornerSubpix**. We used 3D corners from calibration to projected in 2D image plane by using opencv function **cv2.projectPoints**, and both the checkerboard and reprojected corners were drawn on the image with help of **cv2.drawChessboardCorners**. After that the reprojection error was computed and displayed for each of 25 images.

6. Checkerboard plane normals for each of the 25 images:

```
image1: n1 = [0.48, -0.39, 0.79]
image2: n2 = [0.03, 0.05, 1.0]
image3: n3 = [0.11, -0.6, 0.79]
image4: n4 = [0.15, 0.3, 0.94]
image5: n5 = [0.22, -0.01, 0.98]
image6: n6 = [0.03, -0.39, 0.92]
image7: n7 = [-0.21, -0.0, 0.98]
image8: n8 = [0.02, 0.3, 0.95]
image9: n9 = [-0.0, -0.01, 1.0]
image10: n10 = [-0.02, -0.15, 0.99]
image11: n11 = [-0.07, -0.57, 0.82]
image12: n12 = [0.3, 0.05, 0.95]
image13: n13 = [-0.69, -0.34, 0.64]
image14: n14 = [-0.12, -0.49, 0.87]
image15: n15 = [-0.36, 0.13, 0.92]
image16: n16 = [0.52, -0.48, 0.71]
image17: n17 = [0.21, 0.23, 0.95]
image18: n18 = [0.44, 0.1, 0.89]
image19: n19 = [-0.07, 0.41, 0.91]
image20: n20 = [-0.23, 0.01, 0.97]
image21: n21 = [0.21, 0.33, 0.92]
image22: n22 = [-0.57, -0.09, 0.82]
image23: n23 = [-0.14, -0.61, 0.78]
image24: n24 = [0.36, -0.14, 0.92]
image25: n25 = [0.02, -0.08, 1.0]
```