ELL793

Computer Vision

Prof. Brejesh Lall

Assignment 1:

Camera Calibration

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Goal

To find intrinsic and extrinsic camera calibration parameters of a mobile phone camera using a checkerboard object on orthogonal walls.

Setup

- An 8X8 Checkerboard shown in Figure 1 was printed on 2 A4-sized sheets.

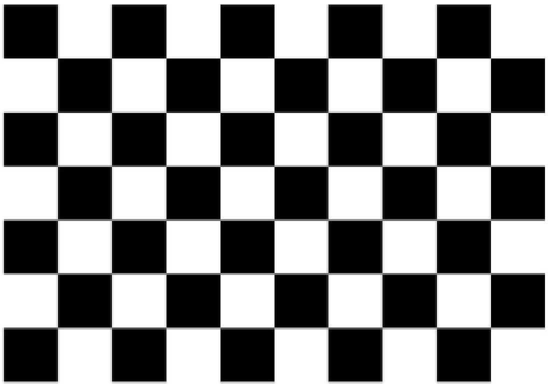

Fig. 1: 8X8 Checkerboard

- The printed checkerboards were pasted on a corner wall, and some points were marked with a red marker, as shown in Figure 2.

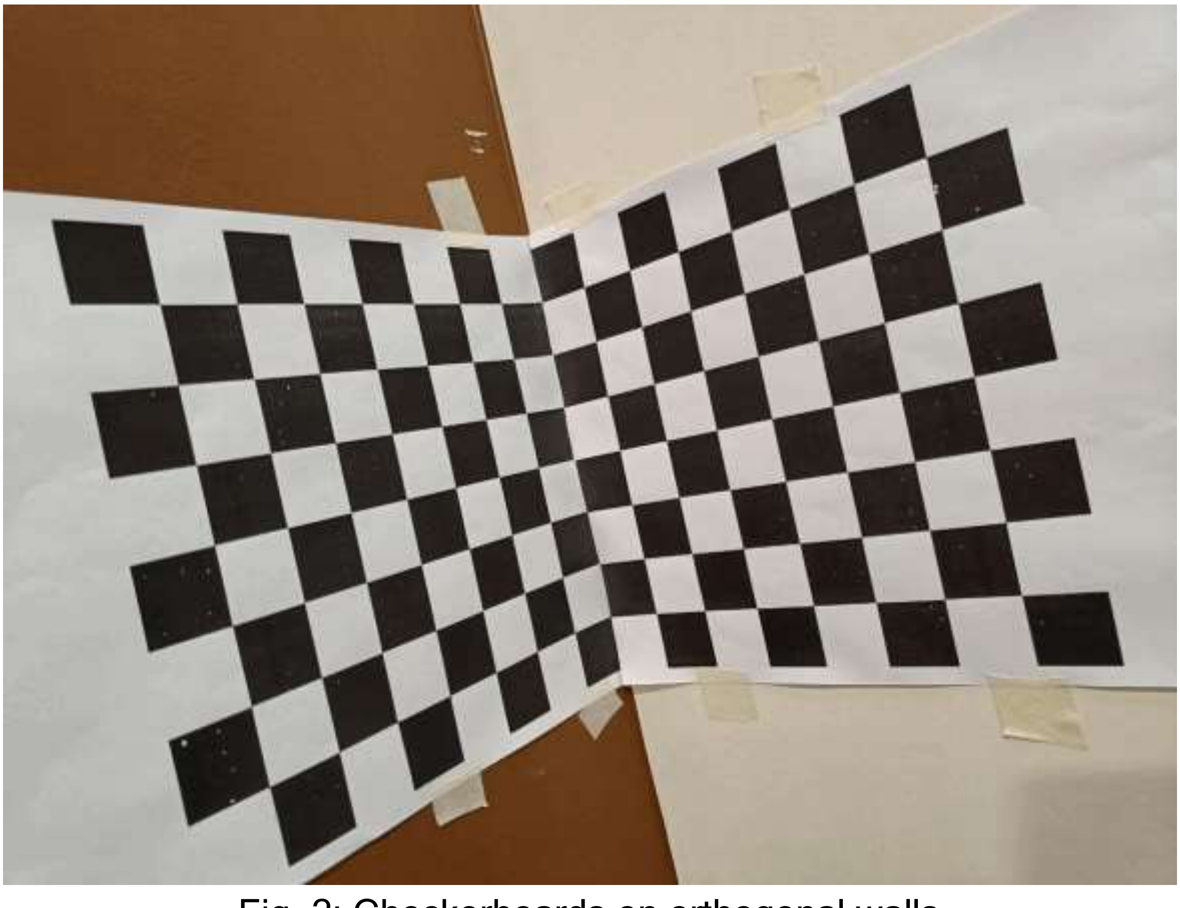

Fig. 2: Checkerboards on orthogonal walls

Dataset Creation

- 3D coordinates were measured using a scale on the checkerboards with the origin marked, as shown in Figure 3.
- The sides of the squares on the board measure 2.54 cm each.
- These measures were then used to calculate the 3D coordinates of each of the points marked.
- 15 instances of the setup were considered for generating 2D coordinates and corresponding calibration exercise.

3D Points			2D Points	
x coordinate	y coordinate	z coordinate	x coordinate	y coordinate
0	2	2	528	458
0	2	1	569	448
0	2	0	612	443
1	2	0	660	431
2	2	0	712	453
0	1	2	544	307
0	1	1	582	509497
0	1	0	621	497
1	1	0	674	491
2	1	0	726	478
0	0	2	553	580
0	0	1	596	566
0	0	0	640	555
1	0	0	684	549
2	0	0	738	541

Table 1: Dataset created : Image 1

Procedure

- These points were normalized by finding T and U matrices such that ^x = Tx and ^X = UX gives the normalized points with centroid at origin and the average distance from origin equal to $\sqrt{2}$ and $\sqrt{3}$ for 2D and 3D points, respectively. The matrices T and U are given as below:

$$T = \begin{bmatrix} \frac{1}{d_{2d}} & 0 & \frac{-x_{centroid}}{d_{2d}} \\ 0 & \frac{1}{d_{2d}} & \frac{-y_{centroid}}{d_{2d}} \\ 0 & 0 & 1 \end{bmatrix}$$

$$U = \begin{bmatrix} \frac{1}{d_{3d}} & 0 & 0 & \frac{-X_{centroid}}{d_{3d}} \\ 0 & \frac{1}{d_{3d}} & 0 & \frac{-Y_{centroid}}{d_{3d}} \\ 0 & 0 & \frac{1}{d_{3d}} & \frac{-Z_{centroid}}{d_{3d}} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$(x_{centroid}, y_{centroid})$ is the centroid of 2D points

$(x_{centroid}, y_{centroid}, z_{centroid})$ is the centroid of 3D points

$$d_{2d} = \frac{Average\ distance\ from\ centroid\ of\ 2D\ points}{\sqrt{2}}$$

$$d_{3d} = \frac{\text{Average distance from centroid of 3D points}}{\sqrt{3}}$$

Why Normalization?

By normalizing the 2D and 3D points, we are reducing the variance in our dataset. Since units of measurement are different for 2D and 3D coordinates, the dataset would have high variance. By reducing variance, the RMSE between the 2D coordinates computed using the projection matrix and the ground truth 2D points would be less.

- After computing the normalized coordinates, we compute the projection matrix by the following equation:

$$\begin{bmatrix} w_i\hat{\mathbf{X}}_i^\top & \mathbf{0}^\top & -x_i\hat{\mathbf{X}}_i^\top \\ \mathbf{0}^\top & -w_i\hat{\mathbf{X}}_i^\top & y_i\hat{\mathbf{X}}_i^\top \end{bmatrix} \begin{pmatrix} \hat{\mathbf{P}}^1 \\ \hat{\mathbf{P}}^2 \\ \hat{\mathbf{P}}^3 \end{pmatrix} = \mathbf{0}$$

The projection matrix P is obtained by finding the eigenvector of $M^T M$ corresponding to the smallest eigenvalue. We then denormalize the projection matrix P using the following equation:

$$P = T^{-1}PU$$

- After computing P we find the intrinsic and extrinsic parameters using the following set of equations:

$$\mathcal{K} = \begin{pmatrix} \alpha & -\alpha\cot\theta & x_0 \\ 0 & \beta/\sin\theta & y_0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$\mathcal{M} = \mathcal{K}\begin{pmatrix}\mathcal{R} & \boldsymbol{t}\end{pmatrix}$$

Results

Using the dataset, the procedure mentioned above results projection matrix P as follows :

The points recovered are plotted on the image below:

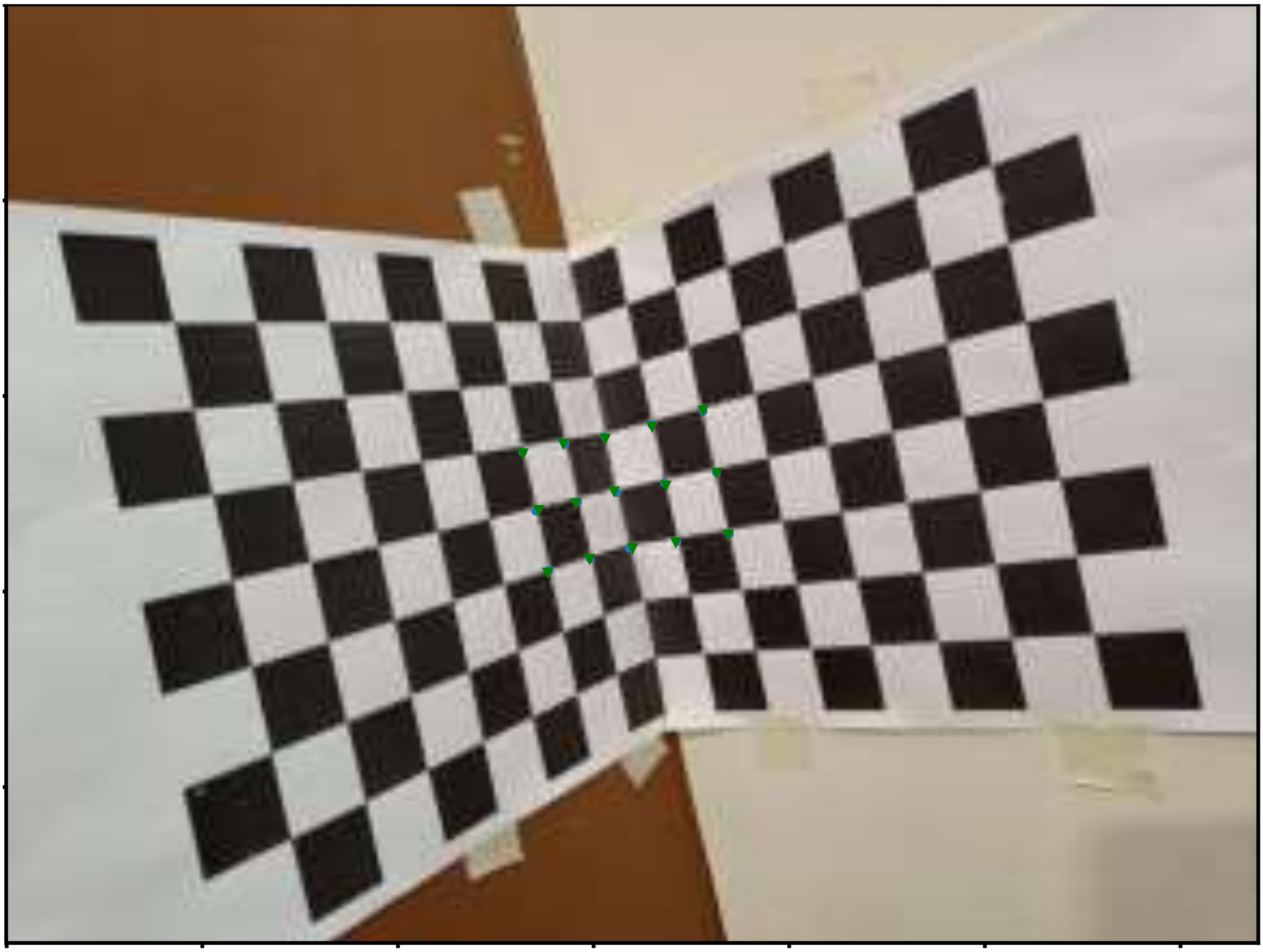

Fig. 4: Recovered Points marked on the image

The blue labels marked here are the estimated points, whereas the green labels marked are the points initially taken.

The Root Mean Squared Error between the points recovered is **1.3948**

Scaling Factor (rho) = 34.821

Intrinsic Parameters

Intrinsic Parameter	Value
α	1261.9658
β	1199.7816
θ	91.45°
x_0	514.5627
y_o	412.9329

```
T: [[   0.01825675    0.           -11.48836417]
 [   0.             0.01825675   -9.09916416]
 [   0.             0.             1.         ]]

U: [[ 1.2874567   0.          0.          -0.77247402]
 [ 0.          1.2874567   0.          -1.2874567 ]
 [ 0.          0.          1.2874567  -0.77247402]
 [ 0.          0.          0.           1.        ]]

P (normalized):
 [[ 0.42782856 -0.11453845 -0.35850043 -0.01020733]
 [-0.08565961 -0.5248217   0.08261887  0.00290837]
 [-0.0228911  -0.0008987  -0.01432784  0.62038465]]


P: [[ 1.16249415e+01 -8.80528171e+00 -3.68890148e+01  4.13792006e+02]
 [-2.07291704e+01 -3.75868291e+01 -3.36747887e+00  3.61403831e+02]
 [-2.94713056e-02 -1.15704351e-03 -1.84464680e-02  6.50292355e-01]]

K: [[3.83838523e+01 2.15028833e-01 1.00052639e+01]
 [0.00000000e+00 3.78095889e+01 2.05971630e+01]
 [0.00000000e+00 0.00000000e+00 3.47874802e-02]]

X0: [12.68389453  1.28437769 14.90775055]
```

Extrinsic Parameters

```
R: [[ 0.52417528 -0.21526337 -0.82395507]
 [-0.08674089 -0.97598946  0.19980137]
 [-0.84718138 -0.03326034 -0.53026169]]

t: [ -5.91121212   0.62483756 -18.69328709]
```