RBE/CS549 Computer Vision

Homework 1 - AutoCalib

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Using 1 late day

***Abstract*—The assignment details the implementation of Camera Calibration as described in ”A Flexible New Technique for Camera Calibration” by Zhengyou Zhang.**

***Index Terms*—Intrinsic parameters, Extrinsic parameters.**

I. Introduction

Camera calibration is the process of estimating the characteristics of a camera. That is, we have all of the camera's information, such as parameters or coefficients, that are required to determine an accurate relationship between a 3D point in the real world and its corresponding 2D projection in the image acquired by that calibrated camera.

A. Estimating Homography matrix

The first step is to find the pixel coordinates of the chessboard corners in each image. Points are found using the cv2.findChessboardCorners function. The pattern size parameter is (9,6) which is the number of inner corners that are to be detected. A total of 54 corner points are found for each image. From these points, we calculate the Homography matrix using cv2.findHomography. After this step, we will get a total of thirteen H matrices. The intrinsic parameters are then calculated by using the Homography matrix calculated.

B. Estimating Intrinsic parameters

For calculating the intrinsic parameters, we calculate the v matrix, using the below-given equation for v_{ij}. Solving for v we get B from equation (1). This B is then used for the calculation of alpha, beta, gamma, u0, and v0 (Eq, 2, 3, 4, 5, 6, 7). From this, we calculate the intrinsic parameter matrix A. The initial estimates of k1 and k2 are considered to be 0 (which will later be optimized).

$$\begin{aligned} v_{ij} = [&h_{i1}h_{j1}, h_{i1}h_{j2} + h_{i2}h_{j1}, \\ &h_{i2}h_{j2}, h_{i3}h_{j1} + h_{i1}h_{j3}, h_{i3}h_{j2} + h_{i2}h_{j3}, h_{i3}h_{j3}] \end{aligned} \tag{1}$$

$$\begin{bmatrix} v_{12} \\ (v_{11} - v_{22})^T \end{bmatrix} b = 0$$

$$Vb = 0 \tag{2}$$

$$v_0 = (B_{12}B_{13} - B_{11}B_{23})/(B_{11}B_{22} - B_{12}^2) \tag{3}$$

$$\lambda = B_{33} - [B_{13}^2 + v_0(B_{12}B_{13} - B_{11}B_{23})]/B_{11} \tag{4}$$

$$\alpha = \sqrt{\lambda/B_{11}} \tag{5}$$

$$\beta = \sqrt{\lambda B_{11}/(B_{11}B_{22} - B_{12}^2)} \tag{6}$$

$$\gamma = -B_{12}\alpha^2\beta/\lambda \tag{7}$$

$$u_0 = \gamma v_0/\beta - B_{13}\alpha^2/\lambda \tag{8}$$

C. Estimating Extrinsic parameters

Now we calculate extrinsic parameters using equations (8, 9, 10, 11) for each homography and then append all these values in the extrinsic matrix.

$$r_1 = \lambda A^{-1}h_1 \tag{9}$$

$$r_2 = \lambda A^{-1}h_2 \tag{10}$$

$$r_3 = r_1 \times r_2 \tag{11}$$

$$t = \lambda A^{-1}h_3 \tag{12}$$

D. Optimization, Loss and Reprojection error

Once we get the initial estimates for the parameters, we try to minimize the re-projection error using the equation (12). Here, m_{ij}(u, v, 1) are from real image points, M_{ij} (has $\check{u}$, $\check{v}$, 1) are the world reference points. The $\check{u}$ and $\check{v}$ are calculated using the equation (13, 14). This calculated error is passed on to the least squares function as the loss function. After calculating the optimized parameters, we then calculate the re-projected points and average reprojected error.

$$\sum_{i=1}^{n}\sum_{i=1}^{m} ||m_{ij} - \hat{m}(A, R_i, t_i, M_j)||^2 \tag{13}$$

$$\check{u} = u + (u - u_0)[k_1(x^2 + y^2) + k_2(x^2 + y^2)^2] \tag{14}$$

$$\check{v} = v + (v - v_0)[k_1(x^2 + y^2) + k_2(x^2 + y^2)^2] \tag{15}$$

$$\sum_{i=1}^{n}\sum_{i=1}^{m} ||m_{ij} - \hat{m}(A, k_1, k_2, R_i, t_i, M_j)||^2 \tag{16}$$

II. Conclusion

Before the optimization, K matrix is given by

$$K = \begin{bmatrix} 2.06525742e+03 & -2.93992715e+00 & 7.64675572e+02 \\ 0.00000000e+00 & 2.05348445e+03 & 1.36276871e+03 \\ 0.00000000e+00 & 0.00000000e+00 & 1.00000000e+00 \end{bmatrix} \tag{17}$$

[

After the optimization, the projection error comes out to be 0.8122016093784894. The optimized K matrix is given by

$$K = \begin{bmatrix} 2.0652573e+03 & -2.9399271e+00 & 7.6467560e+02 \\ 0.0000000e+00 & 2.0534844e+03 & 1.3627687e+03 \\ 0.0000000e+00 & 0.0000000e+00 & 1.0000000e+00 \end{bmatrix} \tag{18}$$

The distortion k is given by,

$$k = \begin{bmatrix} -0.00036316 & -0.00031808 \end{bmatrix} \tag{19}$$

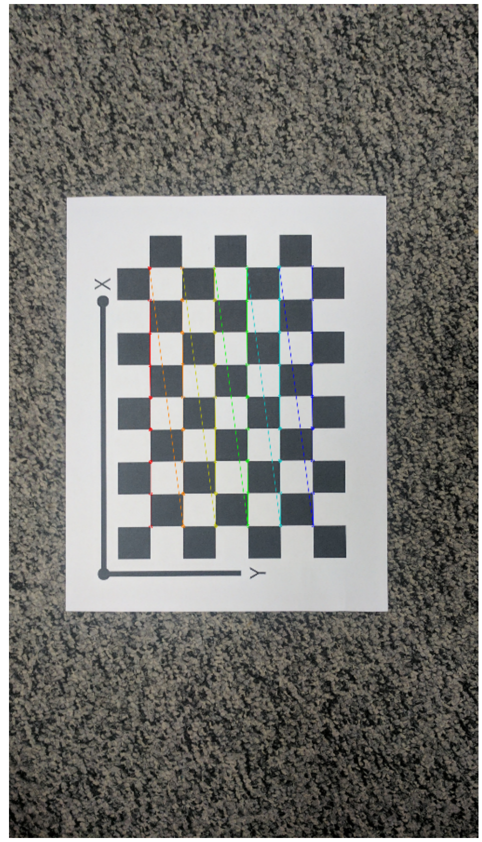

Fig. 1: Corners

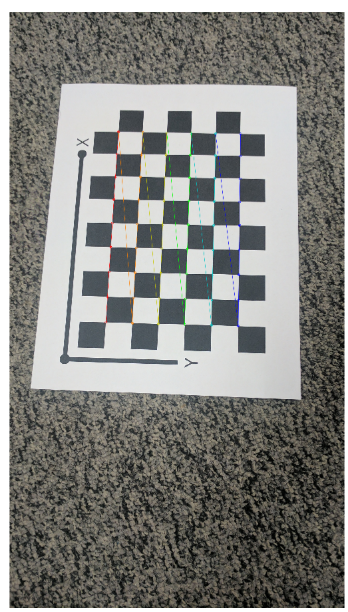

Fig. 2: Corners

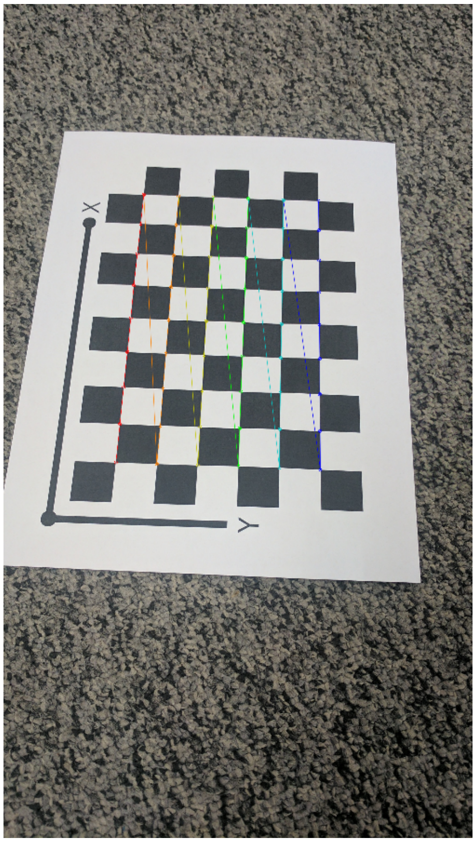

Fig. 3: Corners

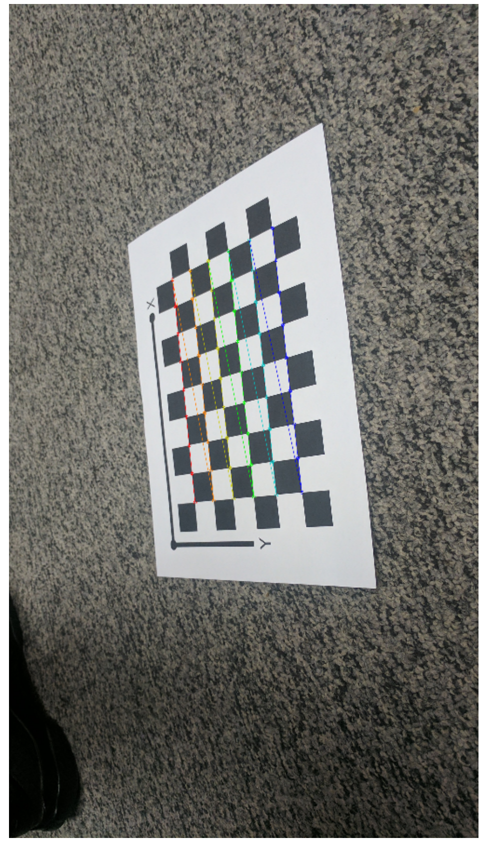

Fig. 5: Corners

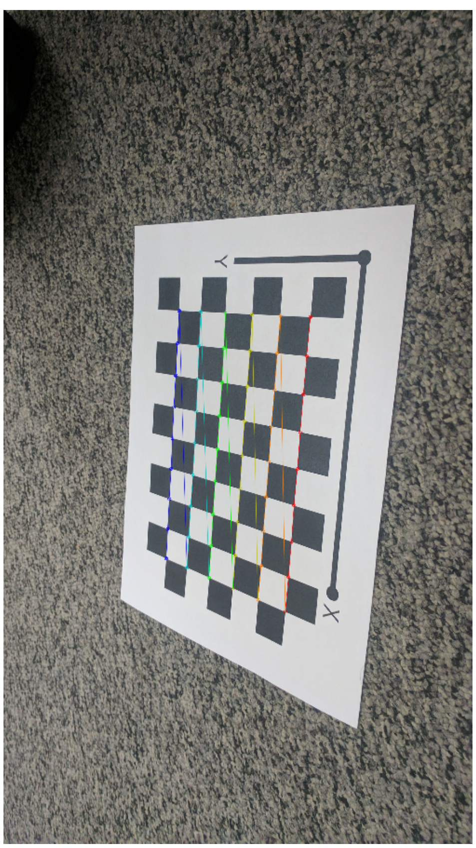

Fig. 4: Corners

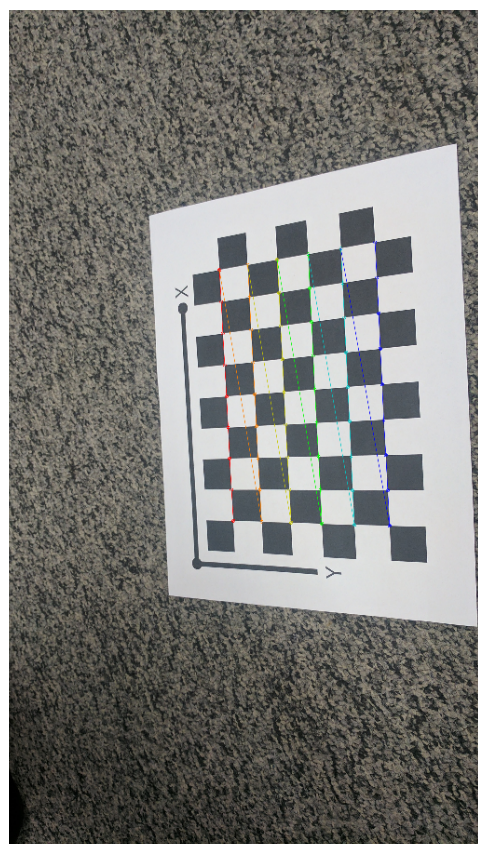

Fig. 6: Corners

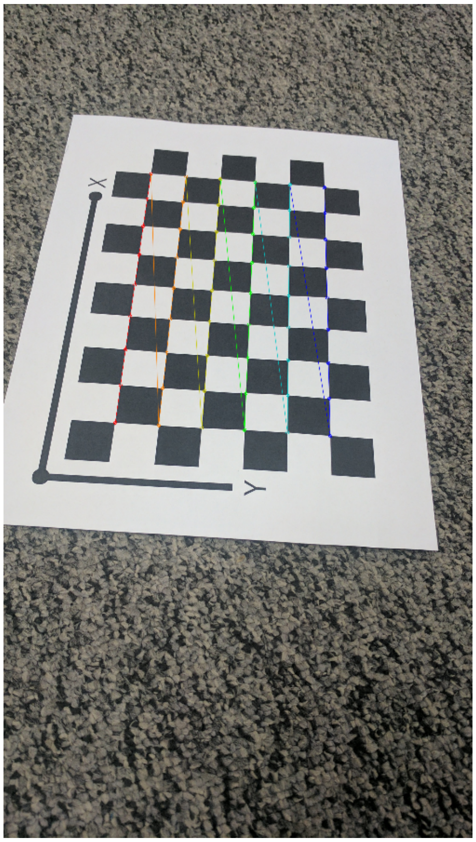

Fig. 7: Corners

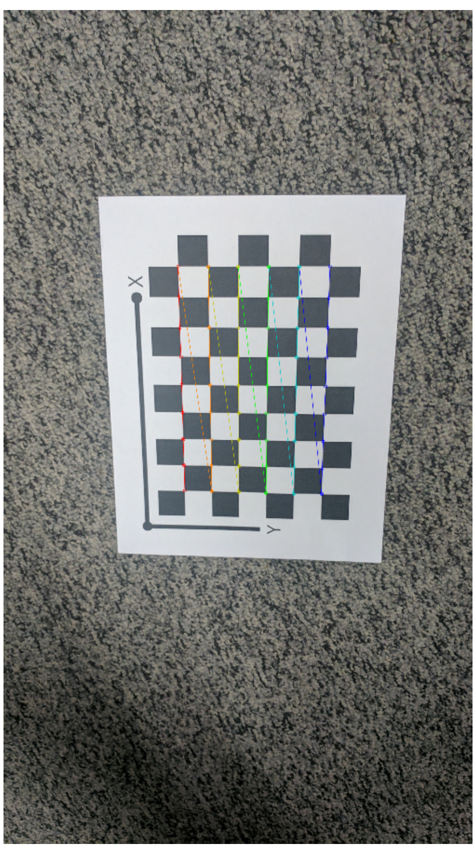

Fig. 8: Corners

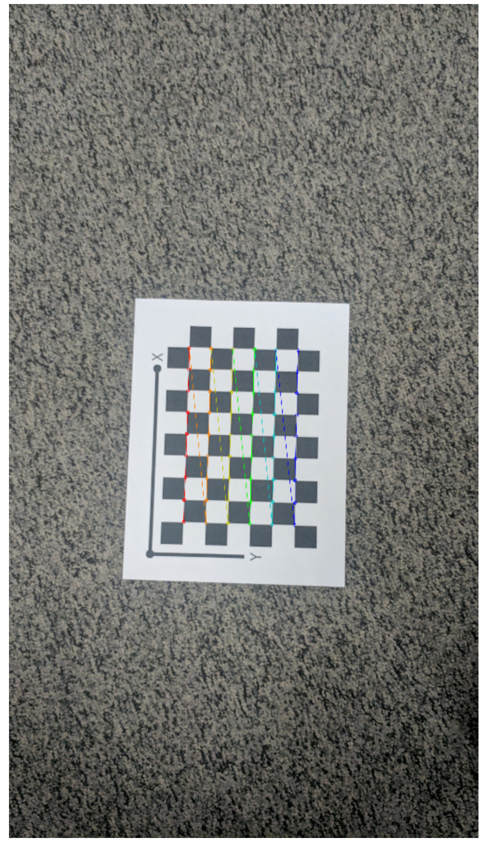

Fig. 9: Corners

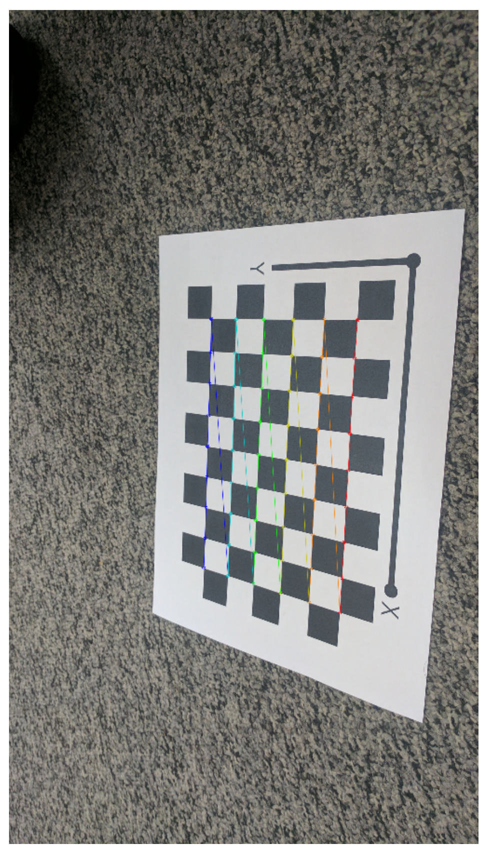

Fig. 10: Corners

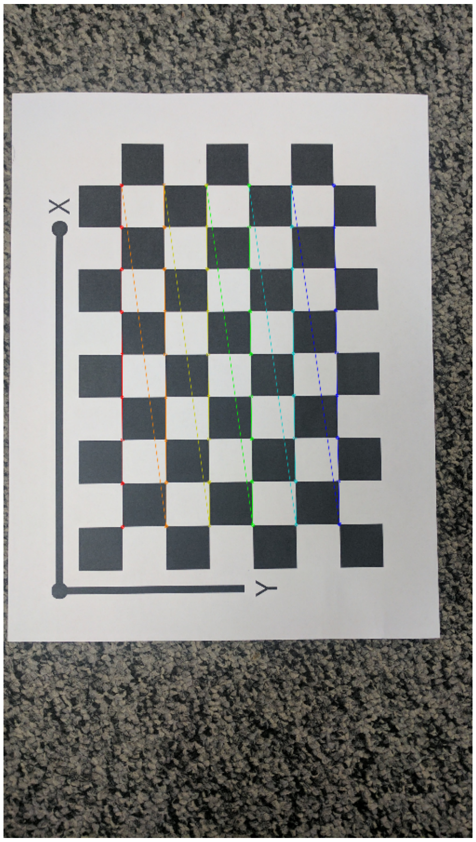

Fig. 11: Corners

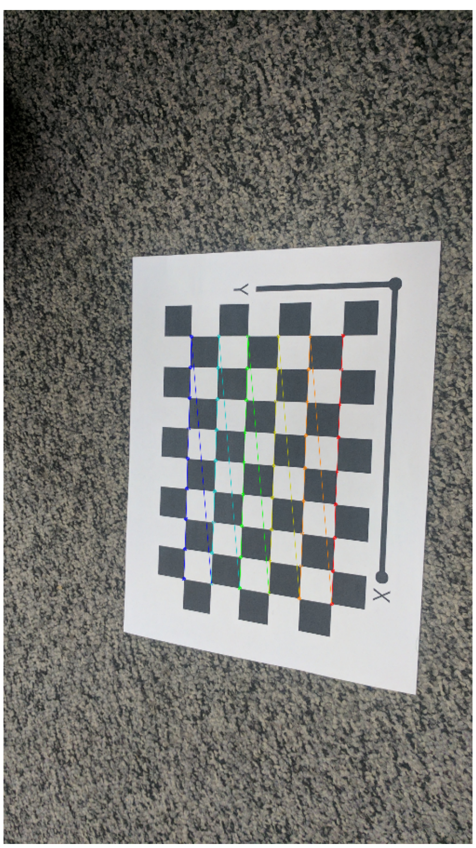

Fig. 12: Corners

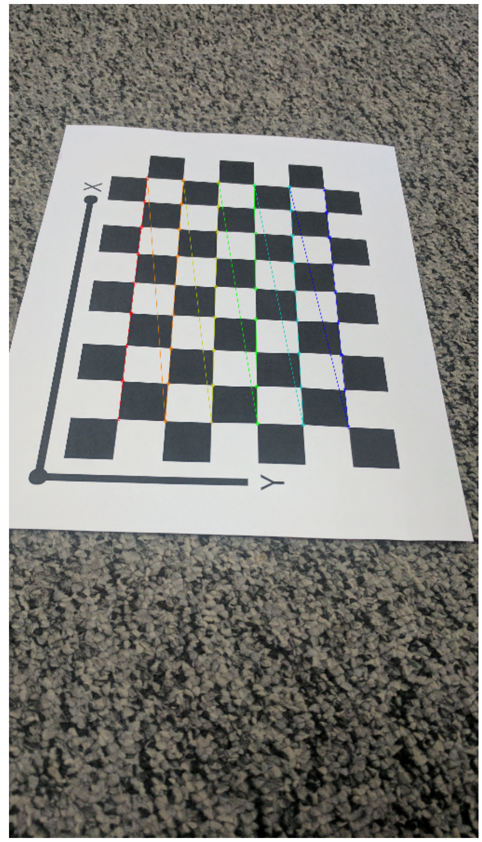

Fig. 13: Corners

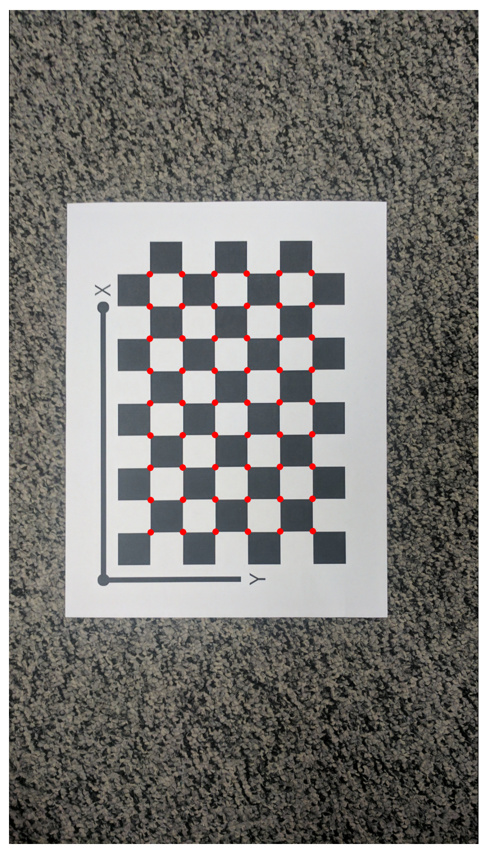

Fig. 14: Corners

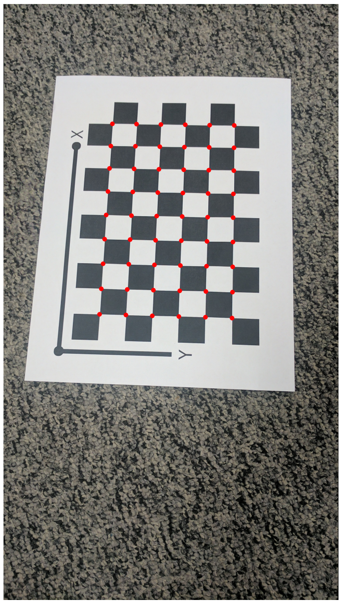

Fig. 15: Corners

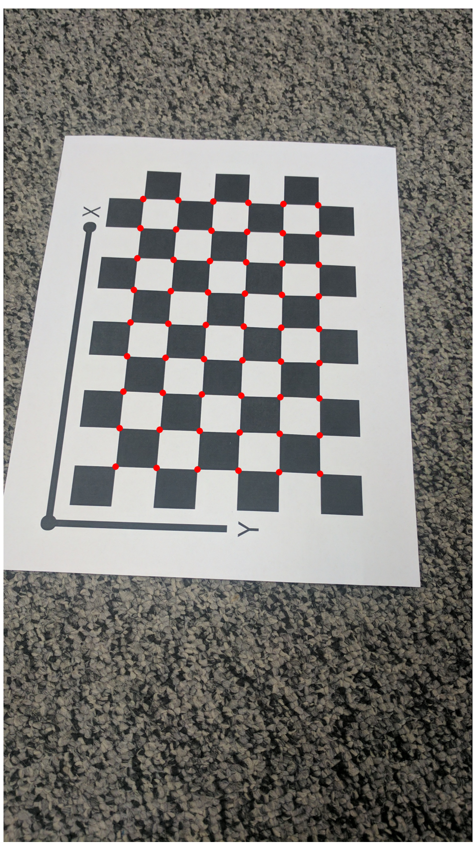

Fig. 16: Corners

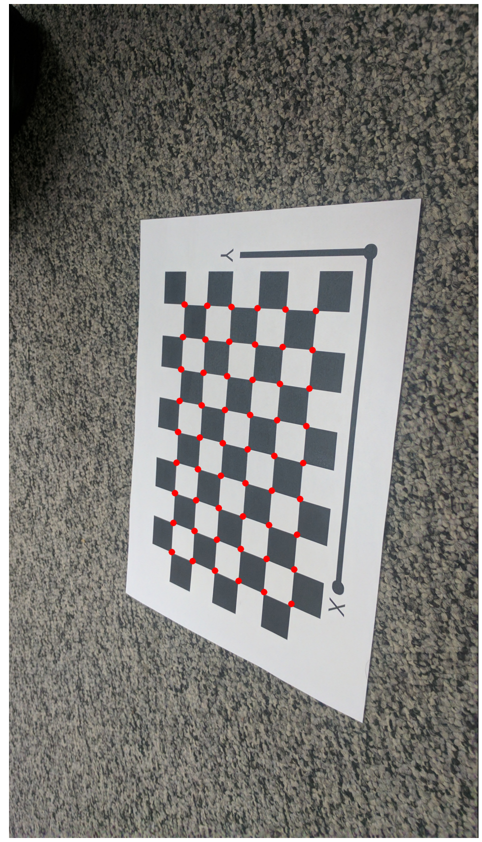

Fig. 17: Corners

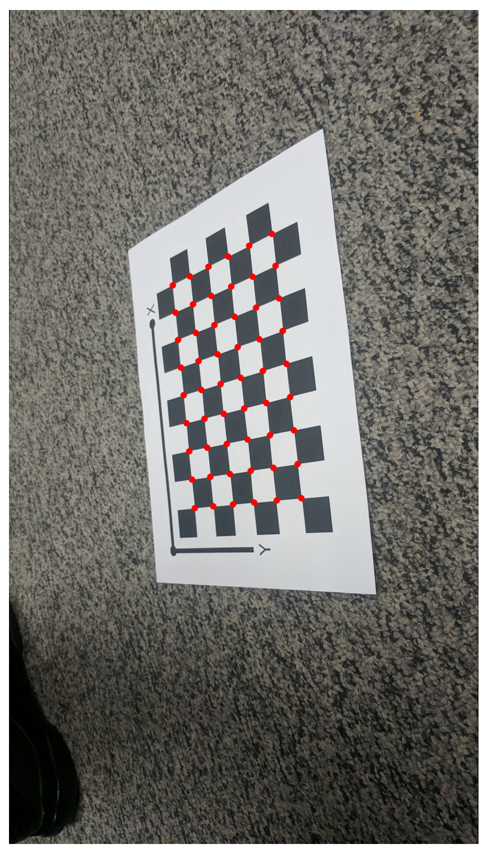

Fig. 18: Corners

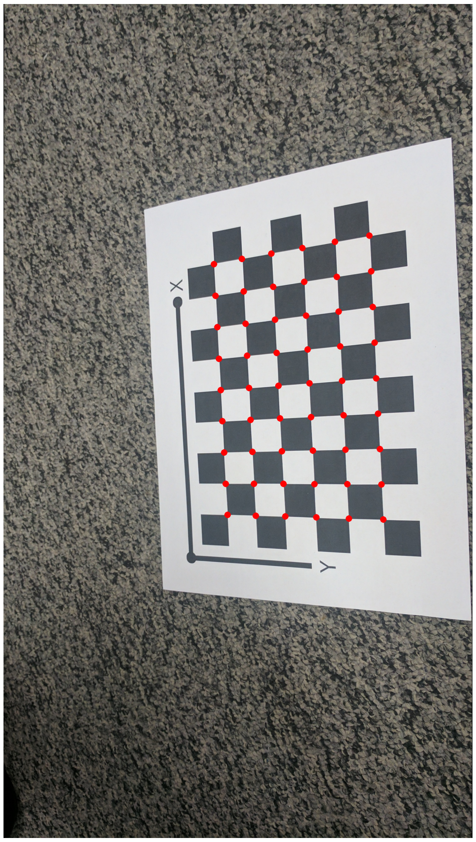

Fig. 19: Corners

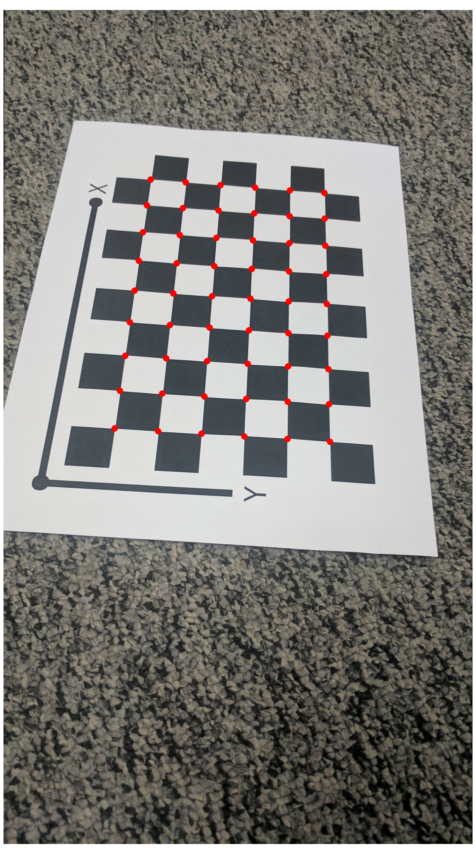

Fig. 20: Corners

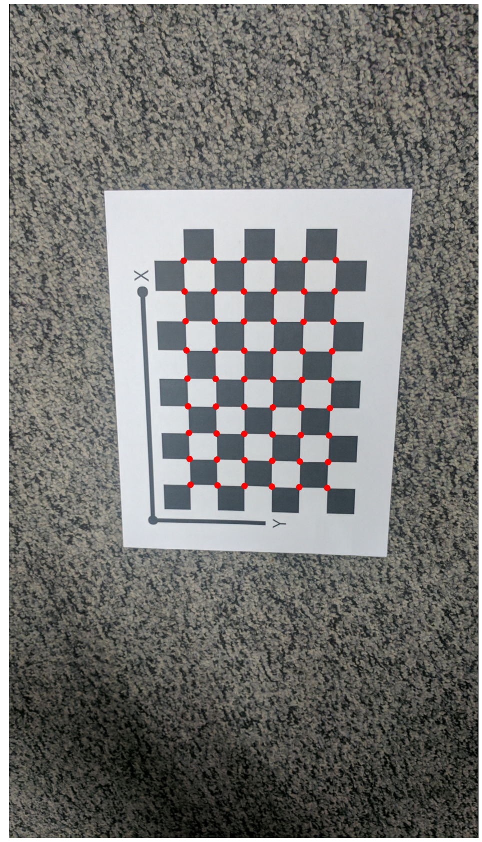

Fig. 21: Corners

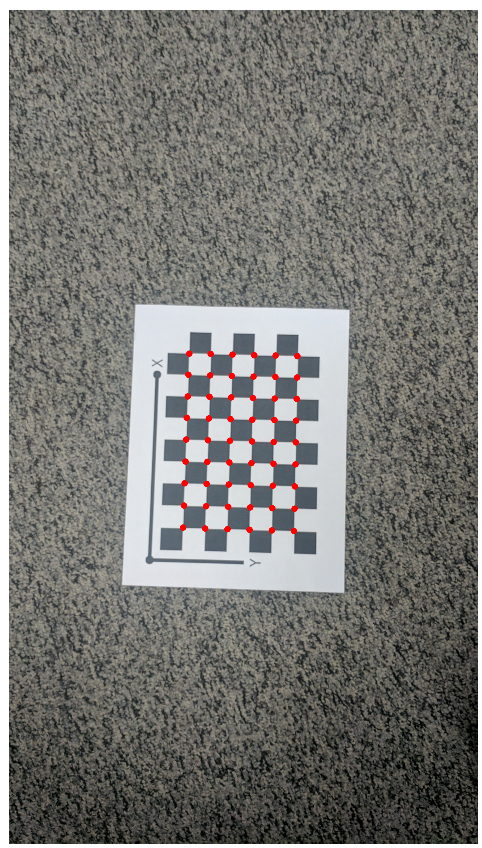

Fig. 22: Corners

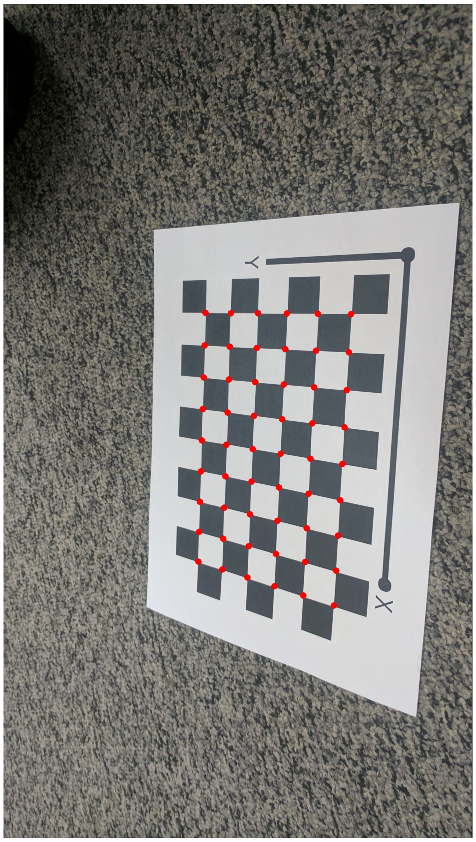

Fig. 23: Corners

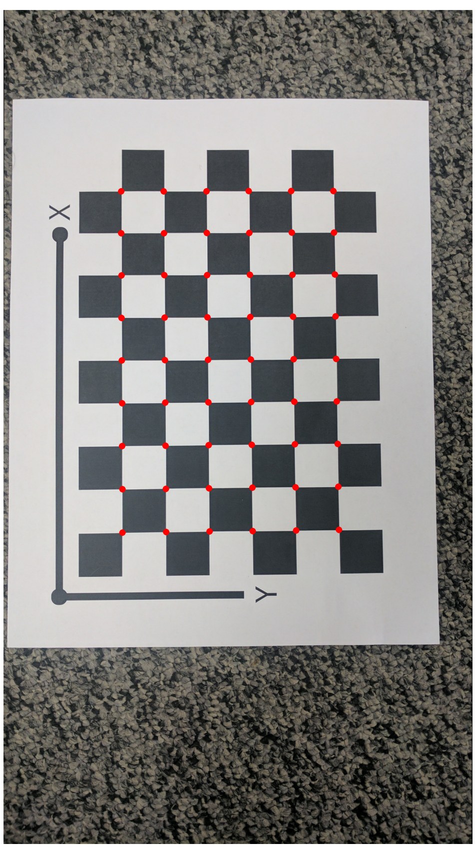

Fig. 24: Corners

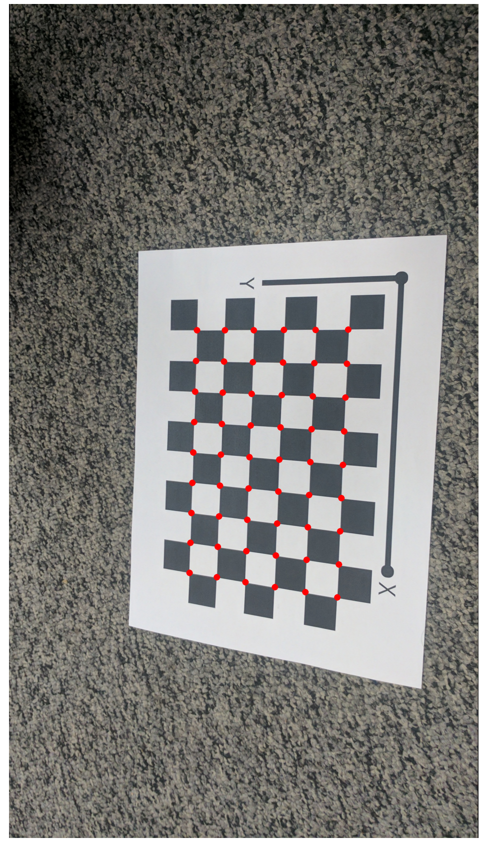

Fig. 25: Corners

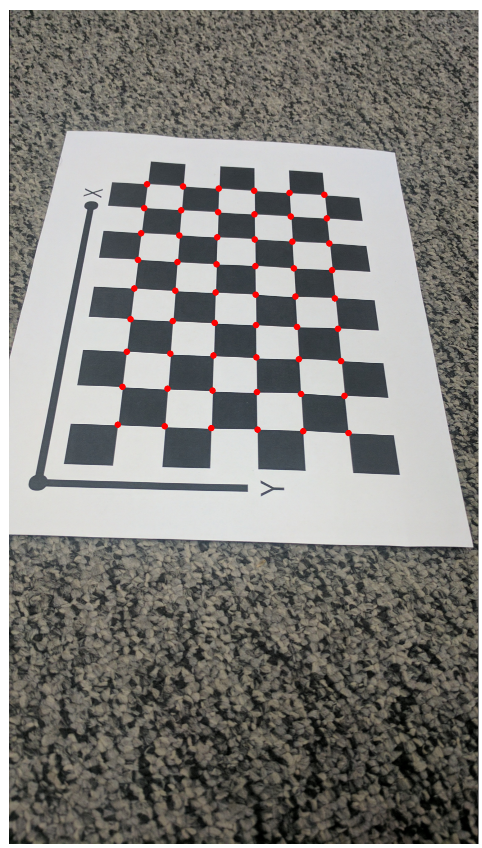

Fig. 26: Corners