RBE/CS549: Homework 1

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Using 1 late day

***Abstract*—Homework 1 is a Camera calibration technique based on Zhengyou Zhang Paper. The paper gives us a way of camera calibration with minimal setup and photo using general camera. The process of camera calibration involves the estimation of essential camera parameters, including focal length, distortion coefficients, and principle point. This step is of great significance in 3D geometry-based computer vision research, albeit being time-consuming. The primary objective of this study is to undertake the calibration of a camera from the ground up, utilizing the methodology proposed by Zhang in their previous work [1].**

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

I. INTRODUCTION

The objective of this task is to develop an automated camera calibration technique based on the method proposed by Zhengyou Zhang of Microsoft. A checkerboard pattern, illustrated in Figure 1, is utilized as the calibration target, which was printed on an A4 paper and consisted of squares measuring 21.5 mm in size.

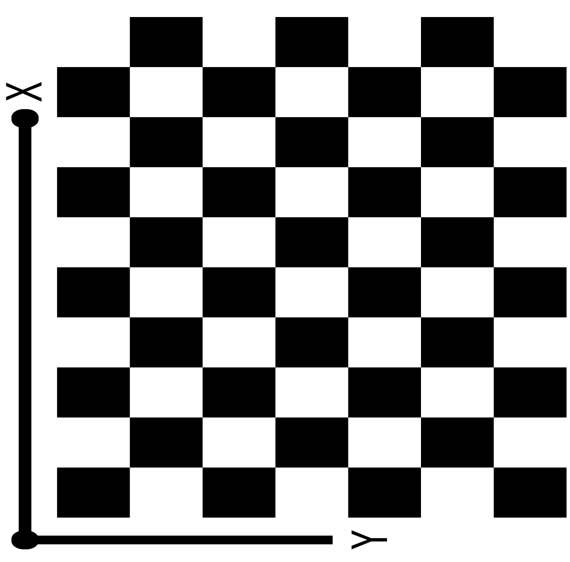

Fig. 1: Calibration Target .

The Camera Calibration consists of the following steps:

- For given set of images get corners using cv2.findChessBoardCorners
- Calculating the Homography between the image coordinates and the world coordinates
- Calculating the intrinsic and Extrinsic parameters.
- optimising the values using the Optimiser and a loss function
- Optimise the values and use it get the undistorted image using cv2.undistort

II. CAMERA CALIBRATION

In this work, an automated camera calibration technique is implemented based on the method proposed by Zhengyou Zhang of Microsoft. The calibration target employed is a 9 x 6 checkerboard pattern, with the corner points detected through the use of the "cv2.findChessboardCorners" function within the OpenCV library. By generating a mesh grid of 9 x 6 points and multiplying it by 21.5 mm, another set of ideal real points, referred to as scaled points, is computed. Subsequently, the homography between the image's corner points and their corresponding ideal real points is calculated and saved as a list. The extracted corner points are illustrated in Figure 2.

$$K = \begin{bmatrix} f_x & s & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \tag{1}$$

$$B = \begin{bmatrix} B11 & B12 & B13 \\ B12 & B22 & B23 \\ B13 & B23 & B33 \end{bmatrix} \tag{2}$$

$$b = \begin{bmatrix} B_{11} \\ B_{12} \\ B_{22} \\ B_{13} \\ B_{23} \\ B_{33} \end{bmatrix} \tag{3}$$

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

$$\lambda = B_{33} - \frac{\left[B_{13}^2 + v_0\left(B_{12}B_{13} - B_{11}B_{23}\right)\right]}{B_{11}}$$

$$\alpha = \sqrt{\frac{\lambda}{B_{11}}}$$

$$\beta = \sqrt{\frac{\lambda B_{11}}{B_{11}B_{12} - B_{12}^2}}$$

$$\gamma = -\frac{B_{12}\alpha^2\beta}{\lambda}$$
$$u_0 = \frac{\gamma v_0}{\beta} - \frac{B_{13}\alpha^2}{\lambda}$$

The initial estimation of the camera intrinsic matrix (K) based on the values calculated above is

$$K_{\text{initiol}} = \begin{bmatrix} 2.065e+03 & -2.939e+00 & 7.646e+02 \\ 0.000e+00 & 2.053e+03 & 1.362e+03 \\ 0.000e+00 & 0.000e+00 & 1.000e+00 \end{bmatrix}$$

C. Estimation of Camera Extrinsics (R & t)

After cormputing the homography $\mathbf{H}$ and the Camera Intrinsic.

Matrix (K), we can calculate the extrinsic parameters Rotation Matr R and translation vector t by using the formula given below:

$$\mathbf{r}1 = \lambda K^{-1}\mathbf{h}1$$
$$\mathbf{r}2 = \lambda K^{-1}\mathbf{h}1$$
$$\mathrm{r}3 = r1 \times r2$$
$$\mathrm{t} = \lambda K^{-1}\ \mathrm{h}3$$

Here $r1, r2$ and $r3$ are the column vectors of the rotation matrix R and t is the translation vector. The values of λ is given by

$$\lambda = \frac{1}{\|K^{-1} \cdot \mathbf{h1}\|} = \frac{1}{\|K^{-1} \cdot \mathbf{h}2\|}$$

Therefore for the value of λ to be substituted in the calculation of extrinsic parameters, I have considered the mean of both the calculation.

$$\lambda = \frac{\frac{1}{\|k^{-1} \cdot h1} + \frac{1}{\|k^{-1}\hbar 2\|}}{2}$$

A. Error Rectification

The reprojection error, defined as the distance between the observed corners' coordinates and the corresponding corners' coordinates reprojected using the estimated parameters, was chosen as the objective function to be minimized in this camera calibration process. In order to perform non-linear minimization of this reprojection error, all the parameters to be optimized were consolidated into a single vector and provided as input to the optimization function from the scipy library.

During the optimization process, we also accounted for the radial distortion error. To do so, we computed the corrected coordinates of the corner points using the following approach:

$$\hat{u} = u + (u - u_0)\left[k_1\left(x^2 + y^2\right) + k_2\left(x^2 + y^2\right)^2\right]$$
$$\hat{v} = v + (v - v_0)\left[k_1\left(x^2 + y^2\right) + k_2\left(x^2 + y^2\right)^2\right]$$

To consider the radial distortion error, we calculated the corrected coordinates of the corner points during the optimization process. Specifically, we obtained the corrected pixel coordinates (u, v) and the corresponding ideal normalized image coordinates (x, y) without distortion. We formulated a non-linear minimization problem and employed the Levenberg−Marquardt Algorithm, as implemented in Minpack, to solve it. The optimization was performed using the leastsquares function from the scipy.optimize module.

$$K_{\text{final}} = \begin{bmatrix} 2.052e+03 & -2.942e+00 & 7.650e+02 \\ 0 & 2.057e+03 & 1.357e+03] \\ 0.000e+00 & 0.000e+00 & 1.000e+00 \end{bmatrix}$$

III. Reference

Z. Zhang, "A flexible new technique for camera calibration," in *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 22, no. 11, pp. 1330-1334, Nov. 2000, doi: 10.1109/34.888718.

IV. Result

A. Corner Images using cv2.findChessboardCorners

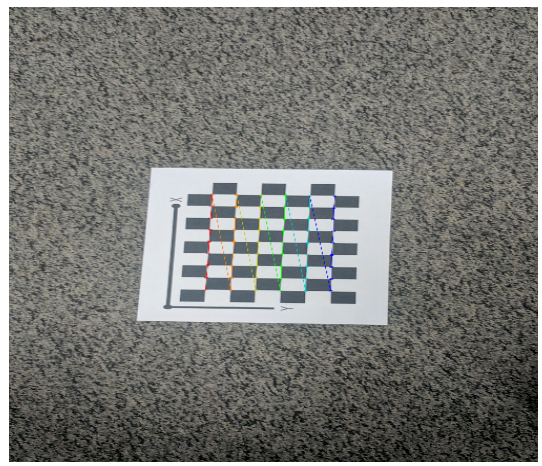

Fig. 2: image 1

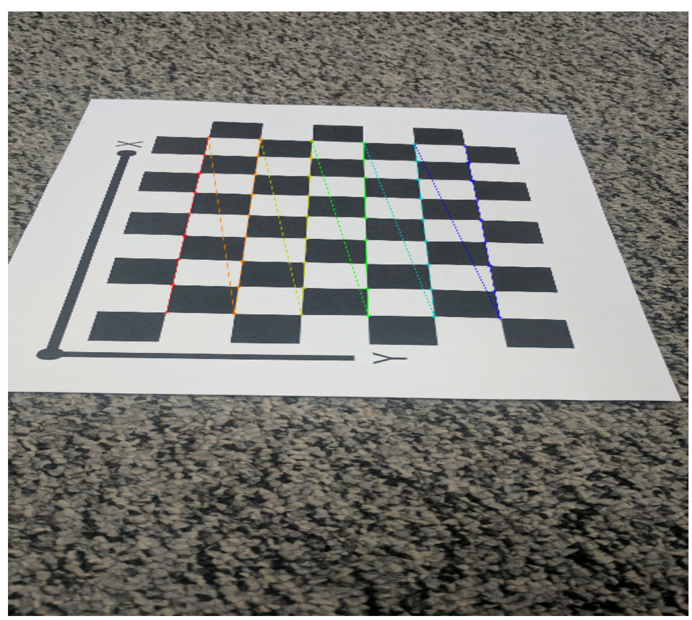

Fig. 3: image 2

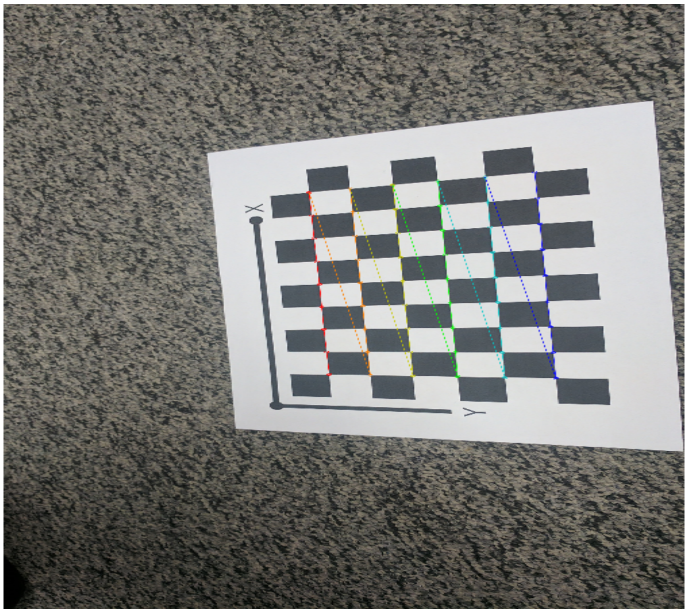

Fig. 4: image 3

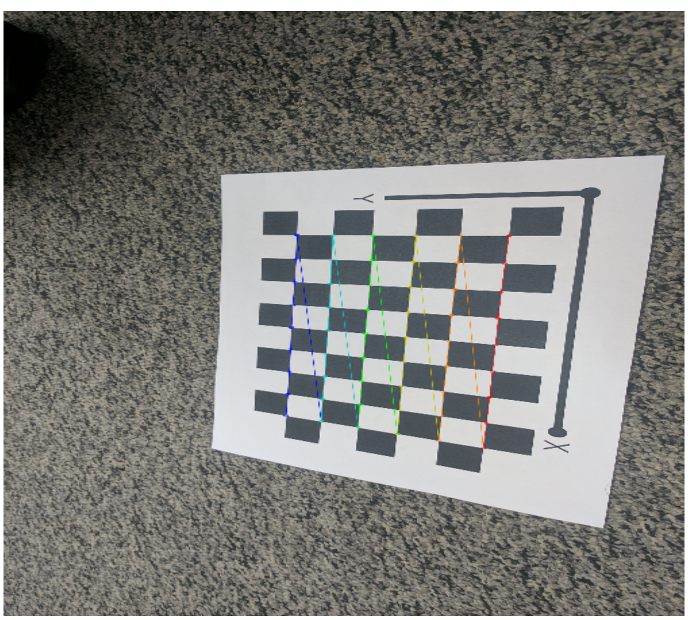

Fig. 5: image 4

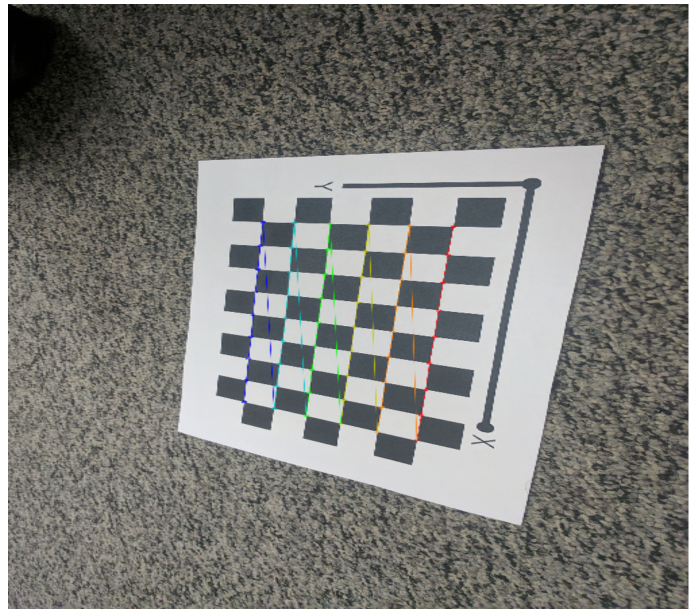

Fig. 6: image 5

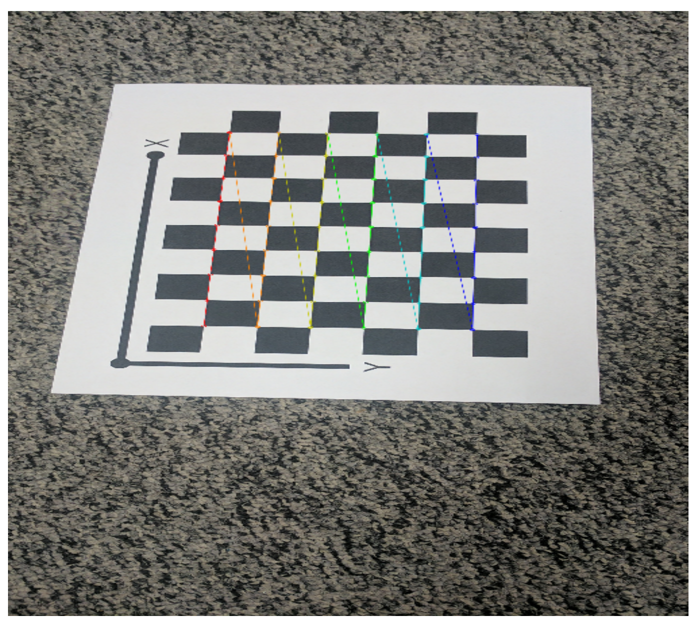

Fig. 7: image 6

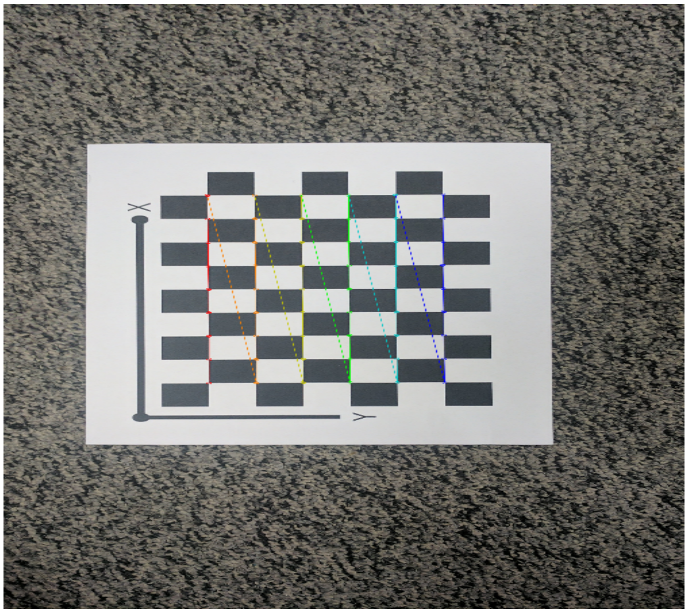

Fig. 8: image 7

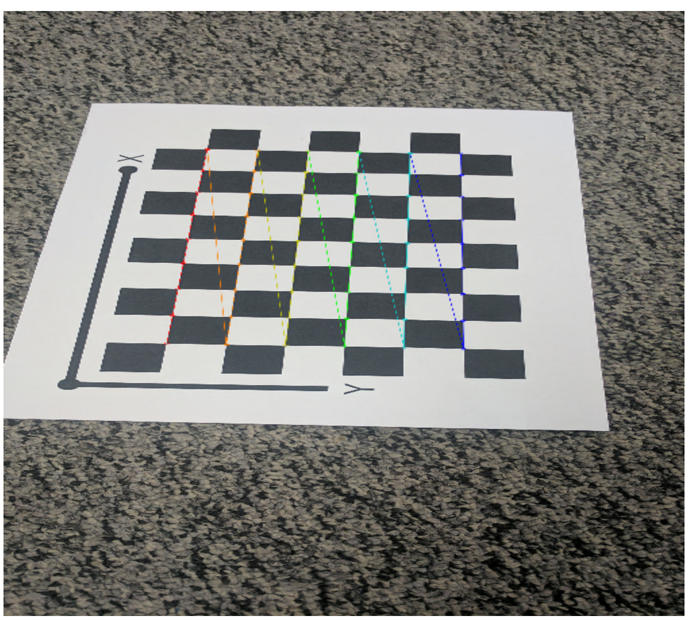

Fig. 9: image 8

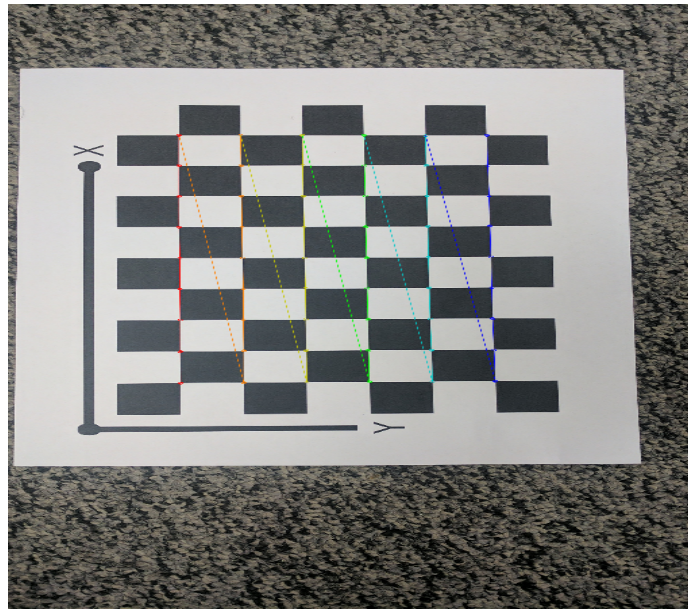

Fig. 10: image 9

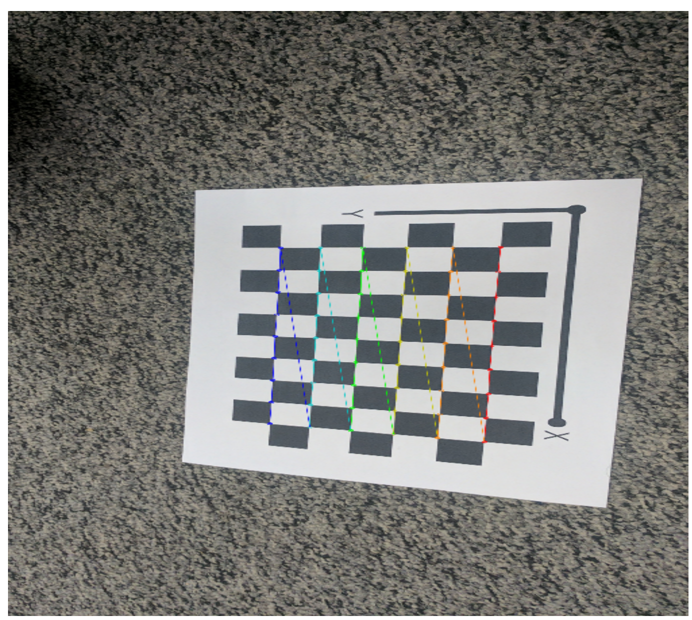

Fig. 11: image 10

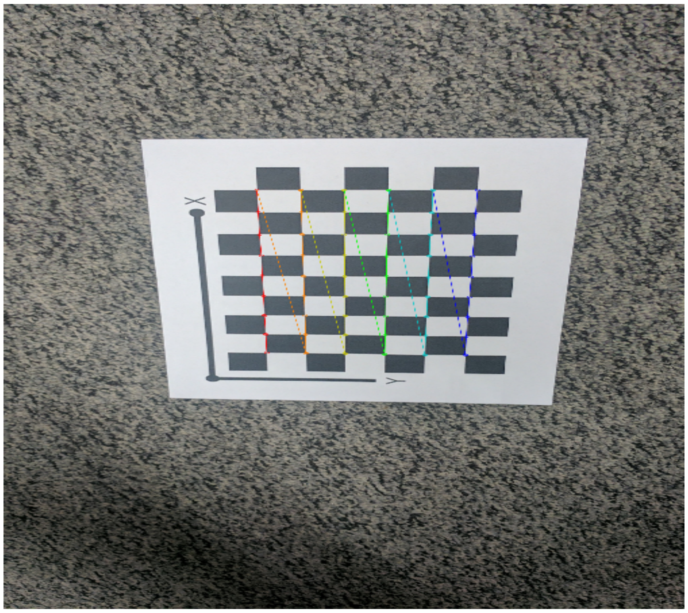

Fig. 12: image 11

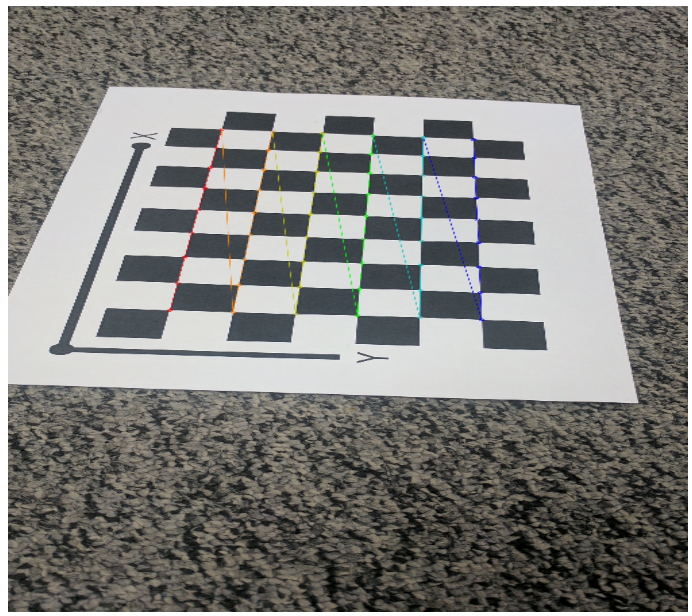

Fig. 14: image 13

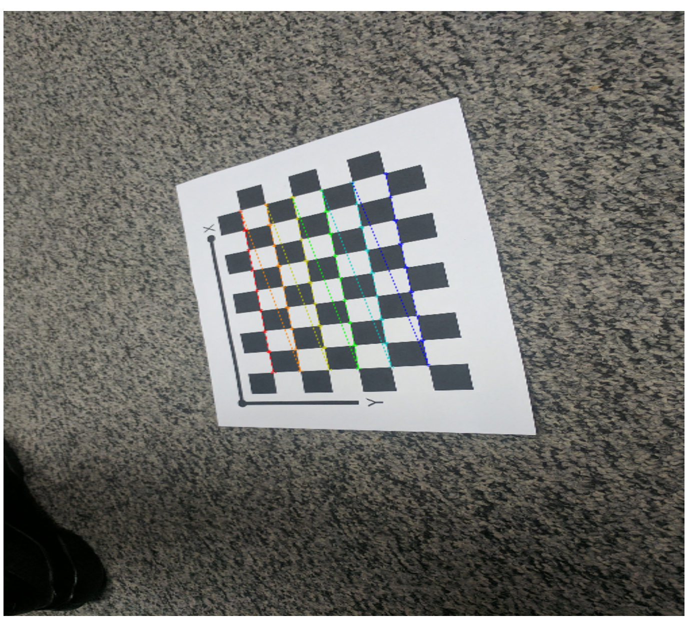

Fig. 13: image 12

B. Reprojected Images

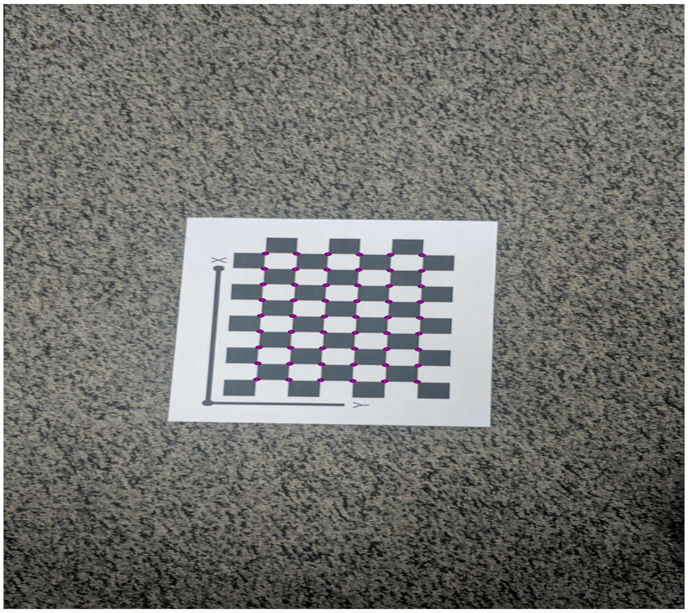

Fig. 15: image 1

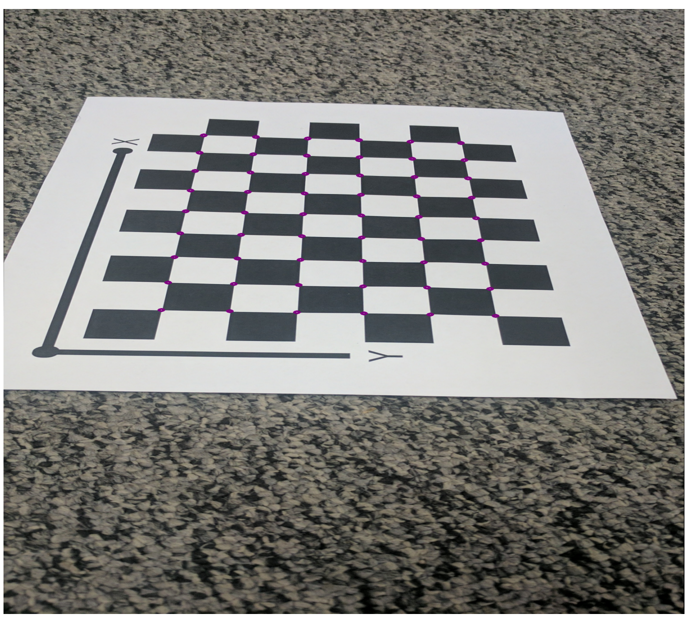

Fig. 16: image 2

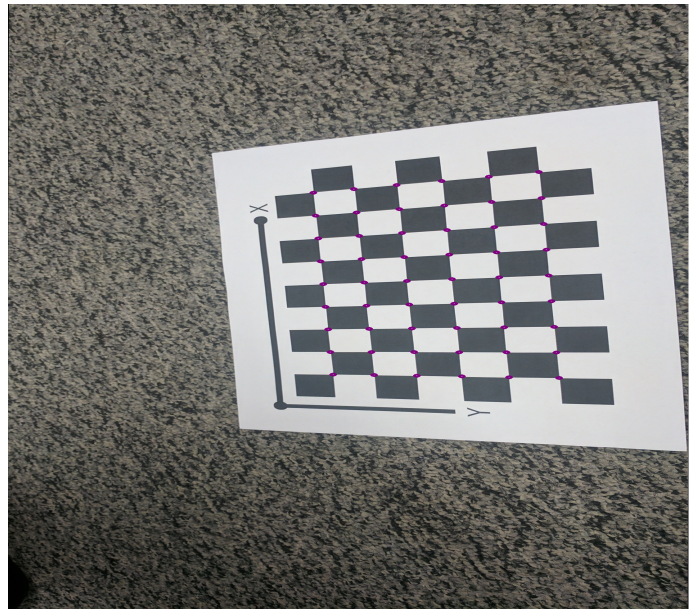

Fig. 17: image 3

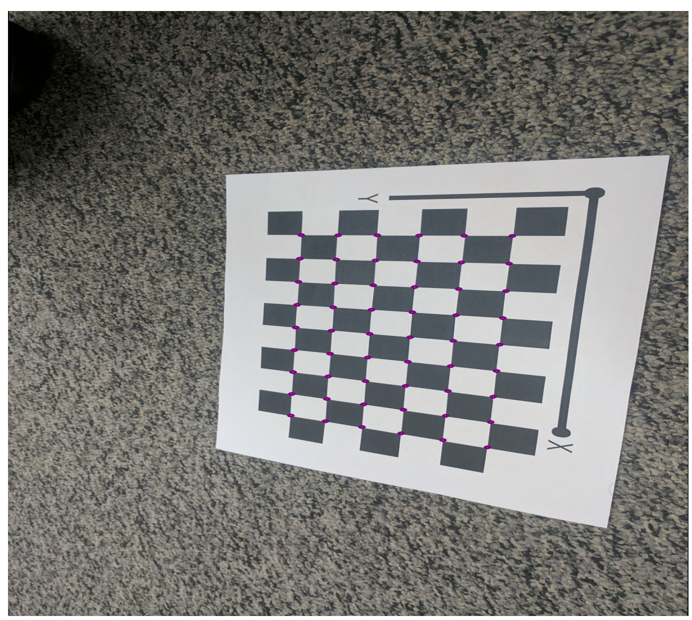

Fig. 18: image 4

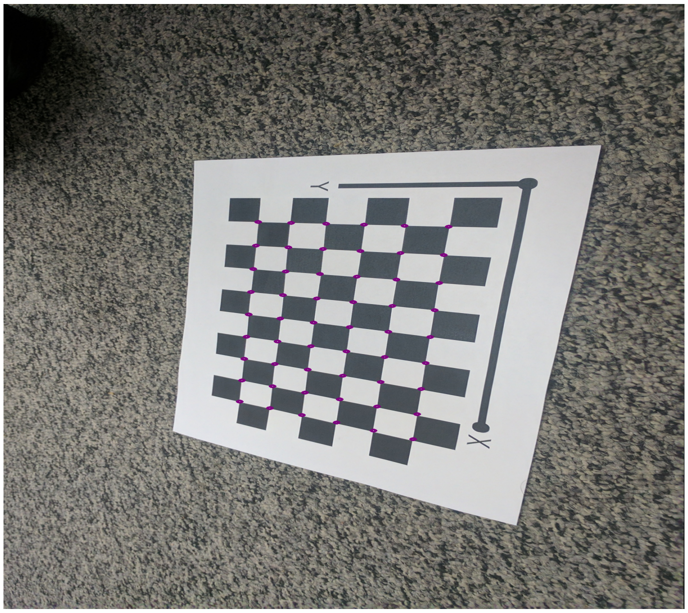

Fig. 19: image 5

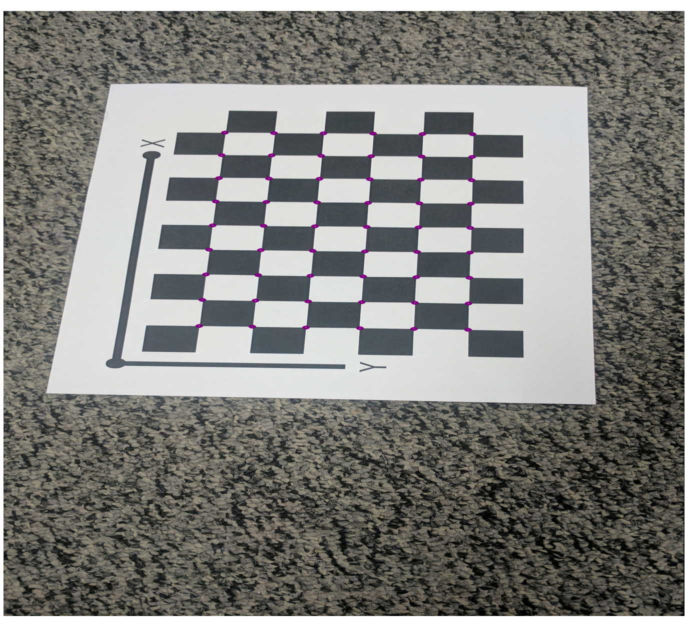

Fig. 20: image 6

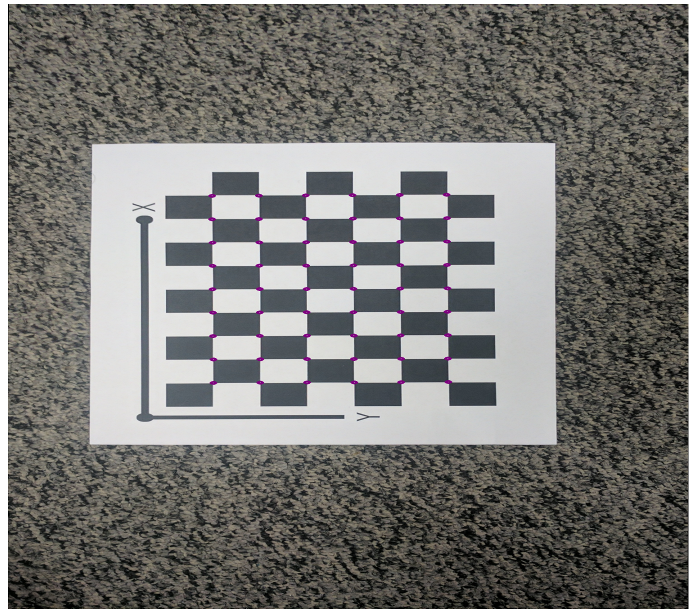

Fig. 21: image 7

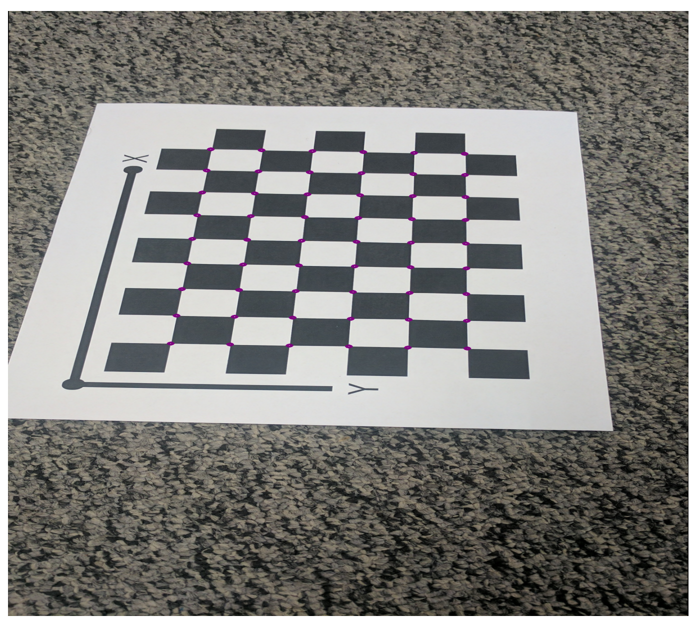

Fig. 22: image 8

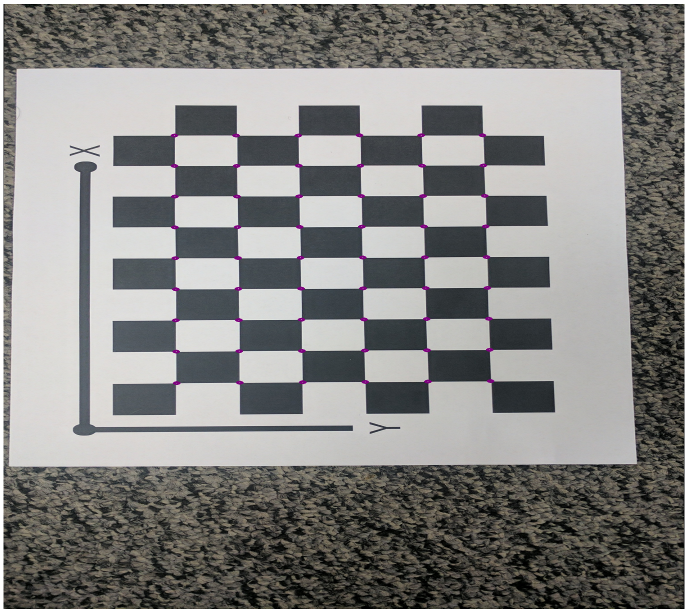

Fig. 23: image 9

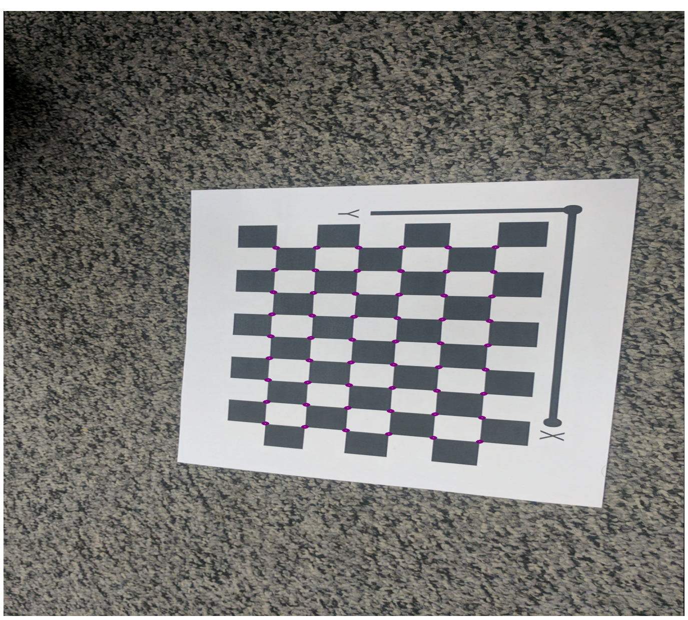

Fig. 24: image 10

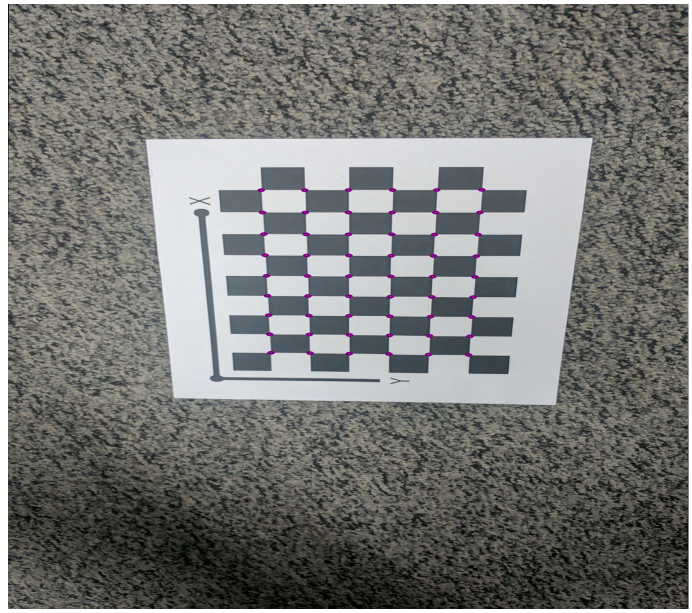

Fig. 25: image 11

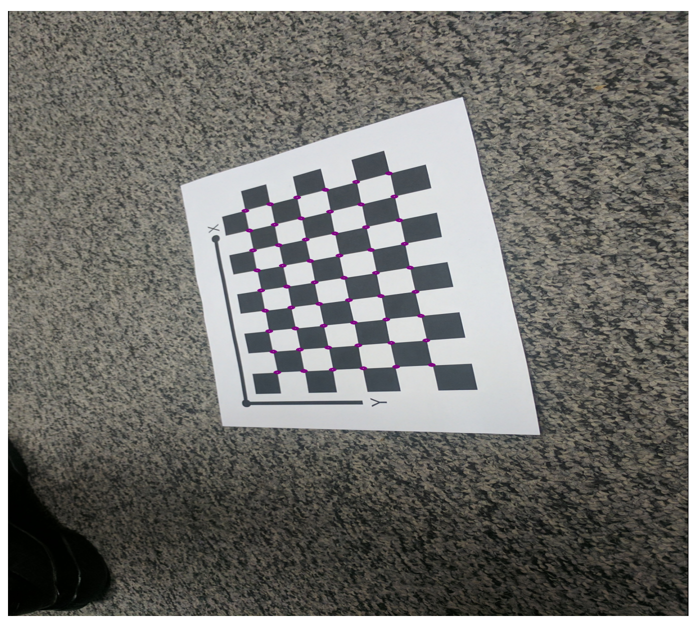

Fig. 26: image 12

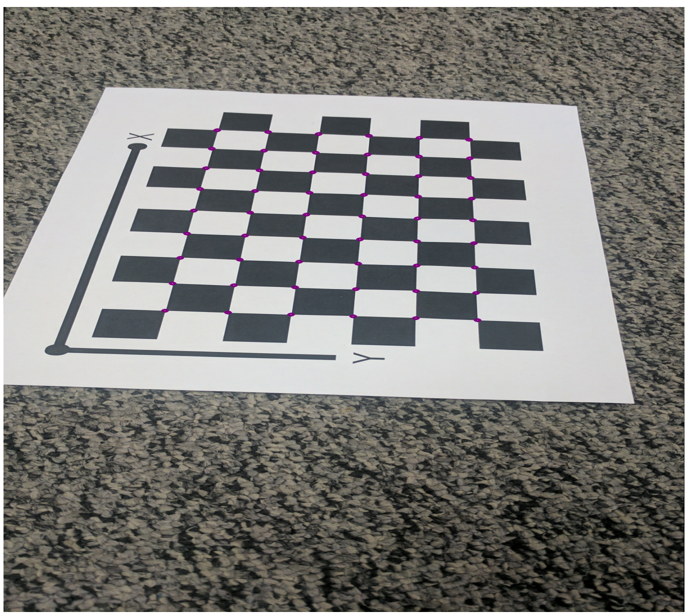

Fig. 27: image 13