Auto Calibration

Irakli Grigolia

Computer Science
Worcester Polytechnic Institute
Worcester, Massachusetts 01609
Email: igrigolia@wpi.edu
Telephone: (508) 373-3402

***Abstract*—In this project we follow steps described in "A Flexible New Technique for Camera Calibration" by Zhengyou Zhang and implement camera calibration system.**

I. Introduction

The aim of camera calibration is to determine the accurate mapping between a three-dimensional point in the physical world and its corresponding two-dimensional representation in the image captured by a specific camera. This is accomplished by estimating the unique characteristics or coefficients of the camera, known as its parameters.

A. Homography Matrix

The initial step involves determining the pixel locations of the chessboard corners in each photo. This can be achieved using the cv2.findChessboardCorners function and specifying the pattern size as (9,6), representing the number of inner corners to be detected. A total of 54 corners are identified in each image. Subsequently, we employ cv2.findHomography to calculate the Homography matrix, resulting in a total of thirteen H matrices. Finally, the intrinsic parameters are calculated utilizing the calculated Homography matrix.

B. Intrinsic Parameters

To find the intrinsic parameters, we calculate the "v" matrix using the equation provided. By solving for "v", we obtain "B" from equation 1. This "B" is then used to compute "alpha", "beta", "gamma", "u0" and "v0" through equations 2, 3, 4, 5, 6, and 7. The intrinsic parameter matrix "A" is obtained through these values. The initial values assumed for "k1" and "k2" are zero.

$$\mathbf{v}_{ij} = [h_{i1}h_{j1}, h_{i1}h_{j2} + h_{i2}h_{j1}, h_{i2}h_{j2}, h_{i3}h_{j1} + h_{i1}h_{j3}, h_{i3}h_{j2} + h_{i2}h_{j3}, h_{i3}h_{j3}]^T .$$

$$\begin{bmatrix} \mathbf{v}_{12}^T \\ (\mathbf{v}_{11} - \mathbf{v}_{22})^T \end{bmatrix} \mathbf{b} = \mathbf{0} .$$

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

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

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

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

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

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

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

C. Extrinsic parameters

We then determine the extrinsic parameters of the camera by utilizing equations (8), (9), (10), and (11) for every homography and compiling all the results 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. Non-linear Geometric Error Minimization

Initially, we estimate the parameters and then aim to minimize the re-projection error with equation (13). This equation compares the real image points (mij (u, v, 1)) to the world reference points (Mij (u-hat, v-hat, 1)). The u-hat and v-at are determined using equations (14, 15). The resulting error is used as the loss function in a least squares calculation. Upon obtaining the optimized parameters, we calculate the re-projected points and determine the average re-projection error.

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

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

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

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

II. Conclusion

```
Error before optimization = 1.089038256300617
A=[[ 2.03475109e+03 -3.68916418e-11  7.72703920e+02]
 [ 0.00000000e+00  2.01790464e+03  1.36090928e+03]
 [ 0.00000000e+00  0.00000000e+00  1.00000000e+00]]
A_optimized=[[2.03566797e+03 8.17800768e-01 7.72523459e+02]
 [0.00000000e+00 2.01938548e+03 1.36037683e+03]
 [0.00000000e+00 0.00000000e+00 1.00000000e+00]]
k1=-1.4334657177666839e-09 k2=3.048446619979197e-16
Error after optimization = 1.0137103870669237
```

Fig. 1. K matrix, Error before and after Optimization

We can see K matrix or intrinsic matrix "A" in the image before and after optimization as well as error. k vector is [-1.433,3.048]

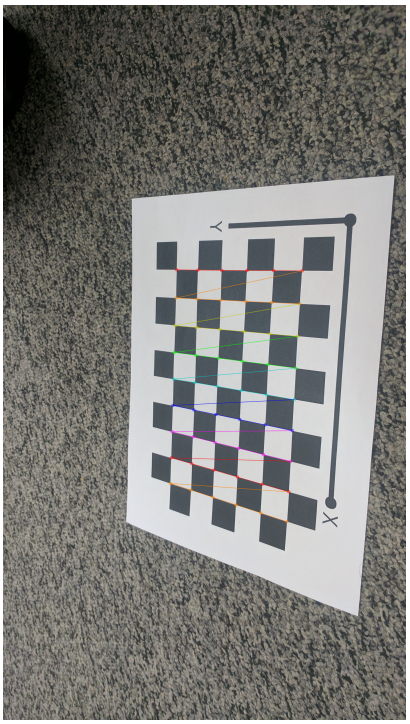

Fig. 2. Corners

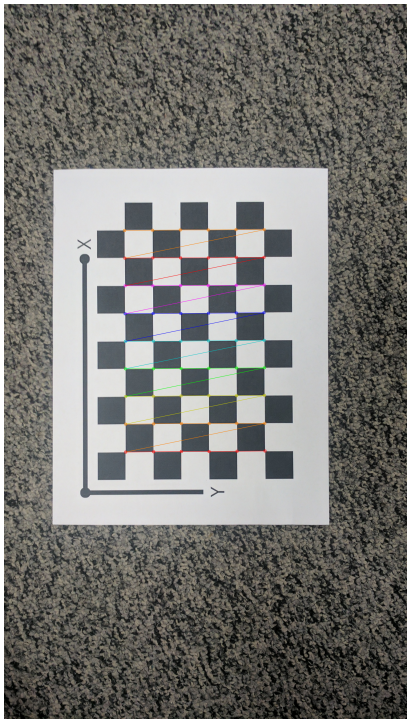

Fig. 3. Corners

References

1 Zhengyou Zhang. A Flexible New Technique for Camera Calibration(1998)

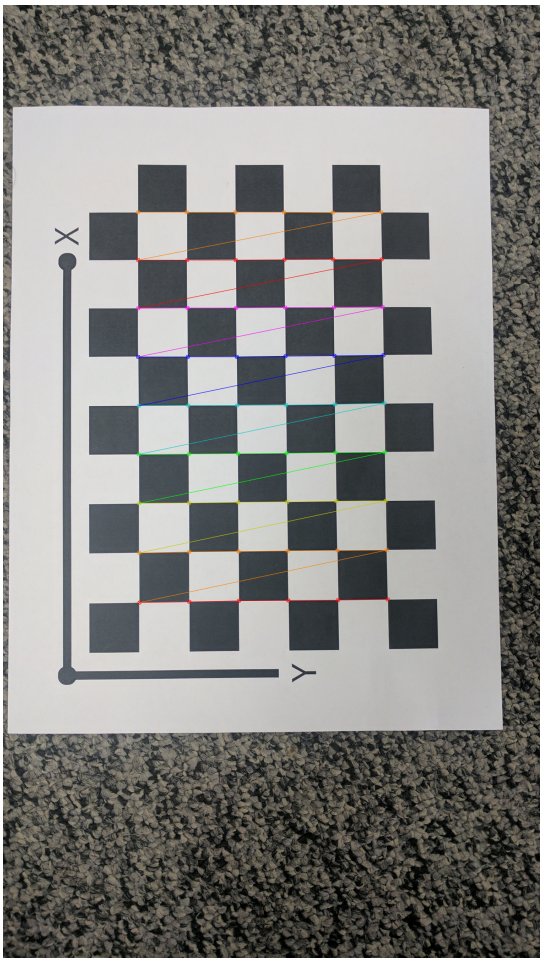

Fig. 4. Corners

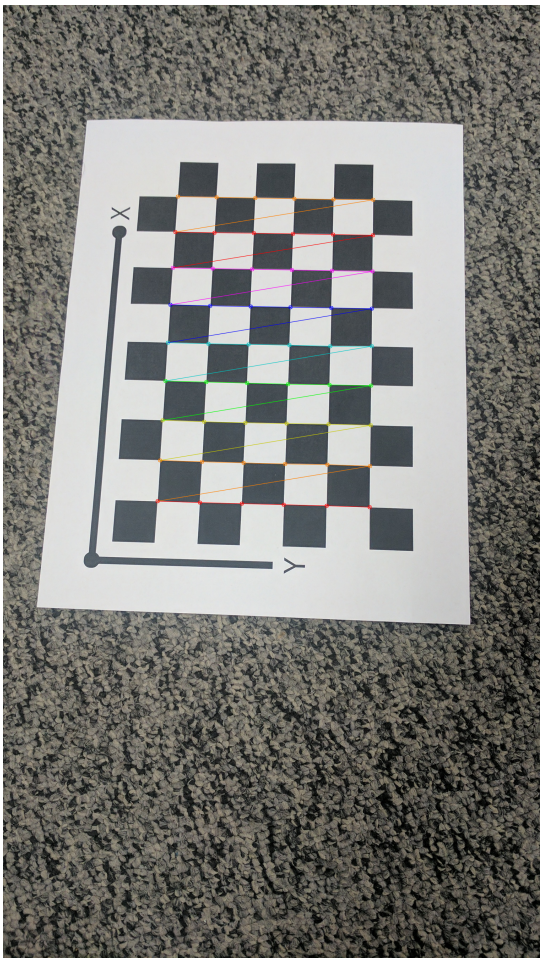

Fig. 5. Corners

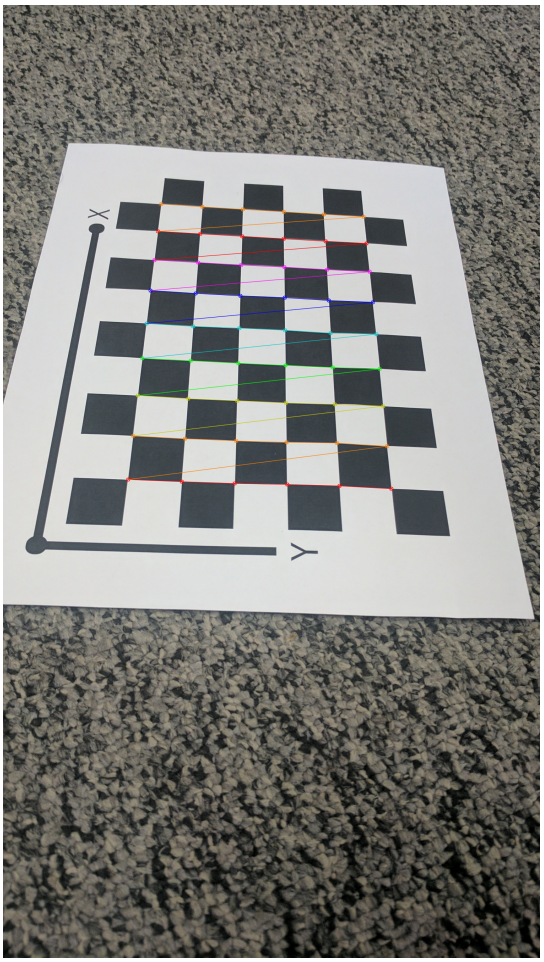

Fig. 6. Corners

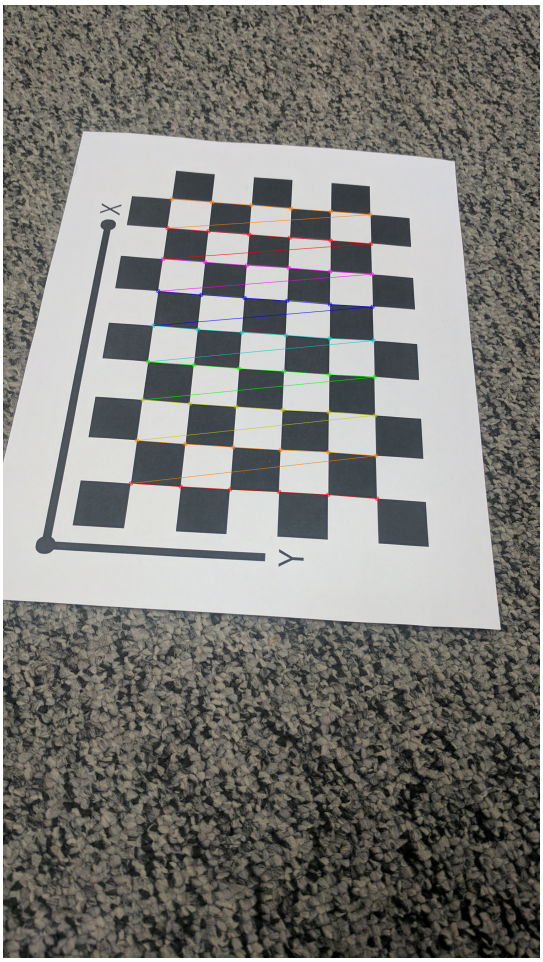

Fig. 7. Corners

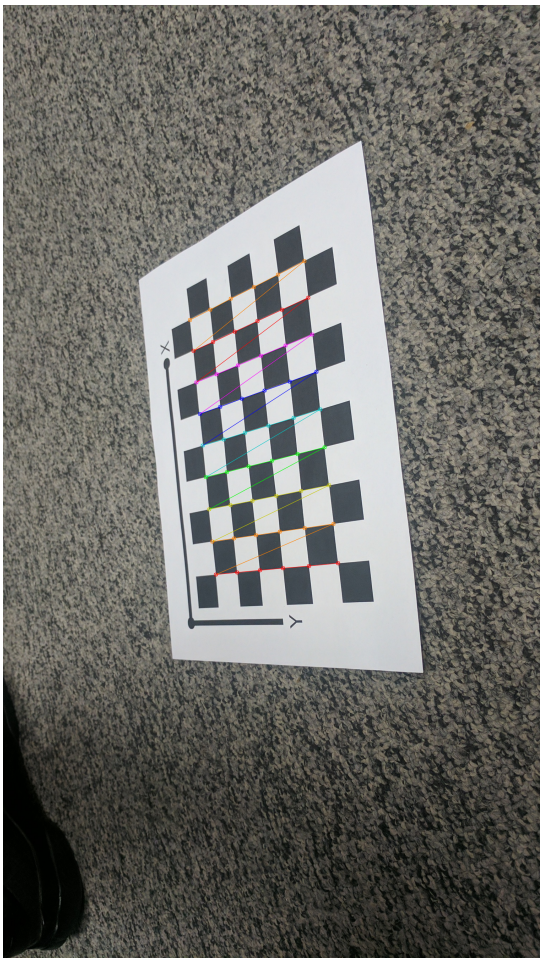

Fig. 8. Corners

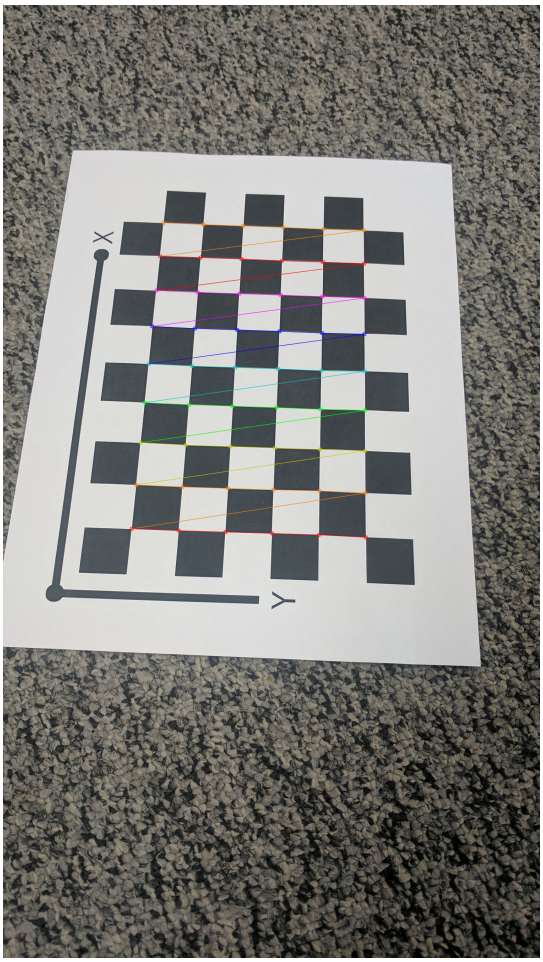

Fig. 9. Corners

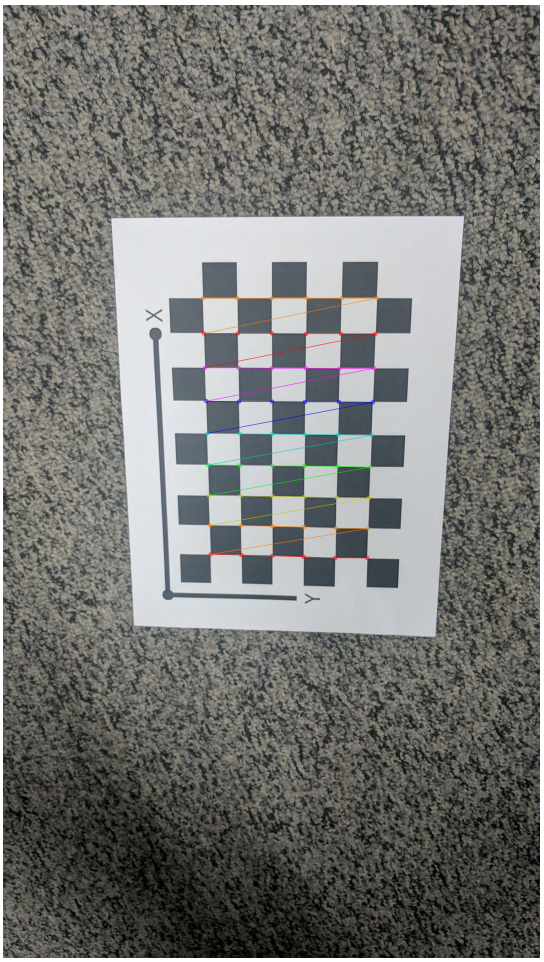

Fig. 10. Corners

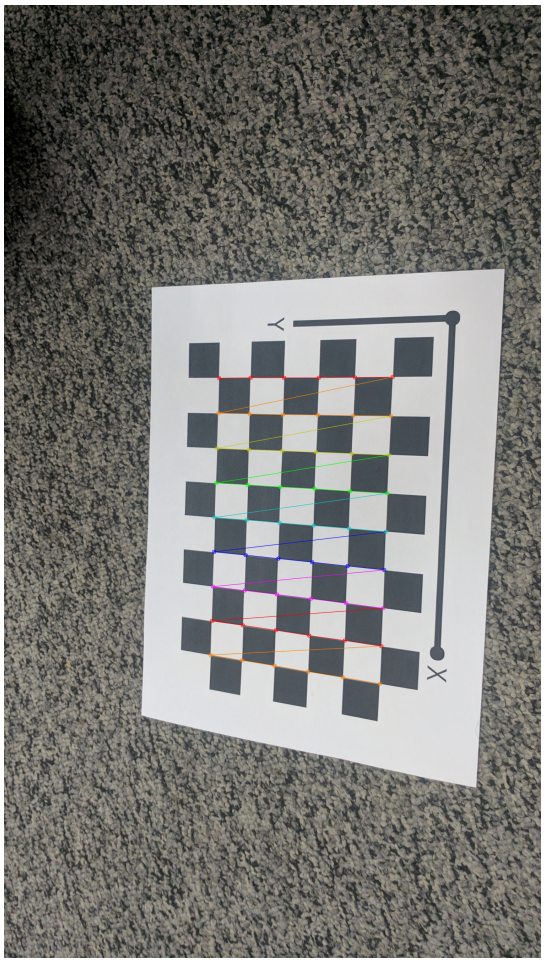

Fig. 11. Corners

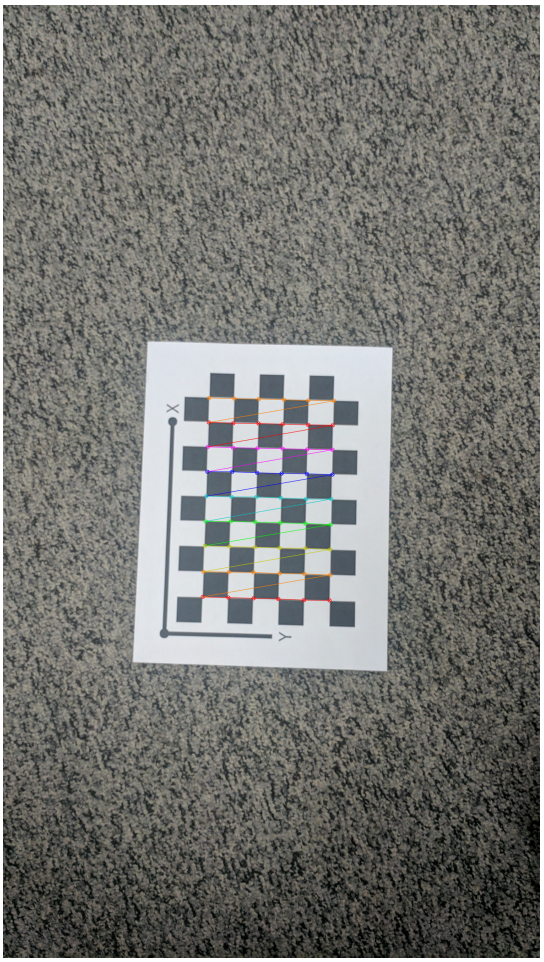

Fig. 12. Corners

Fig. 13. Corners

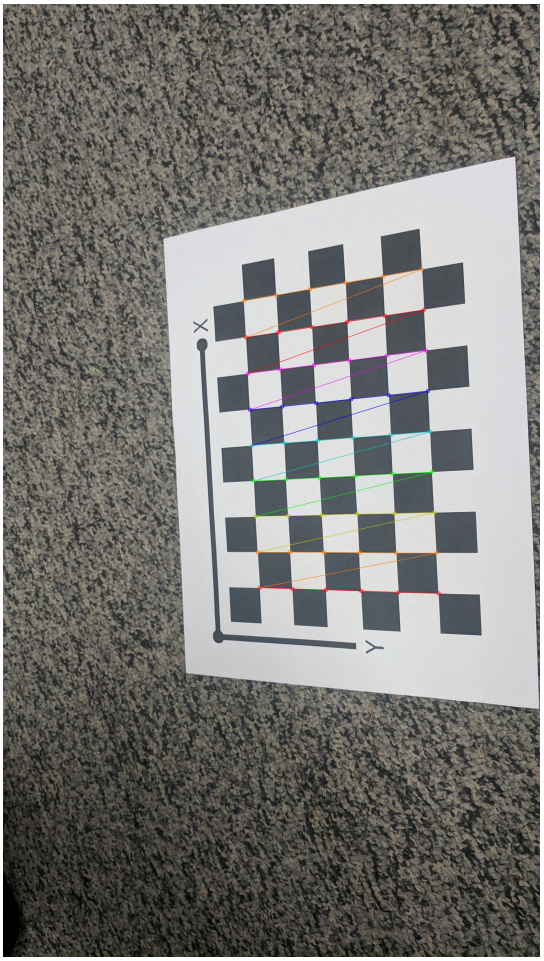

Fig. 14. Corners

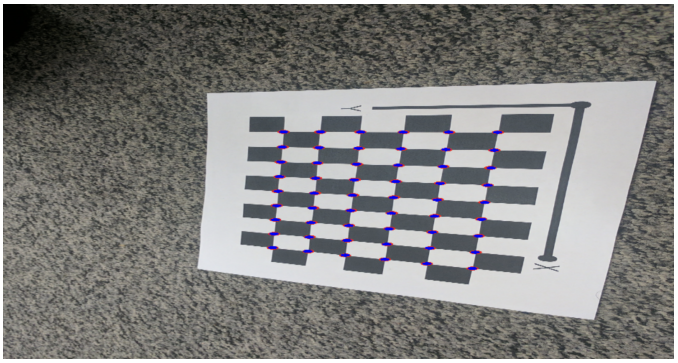

Fig. 15. Predicting Corners

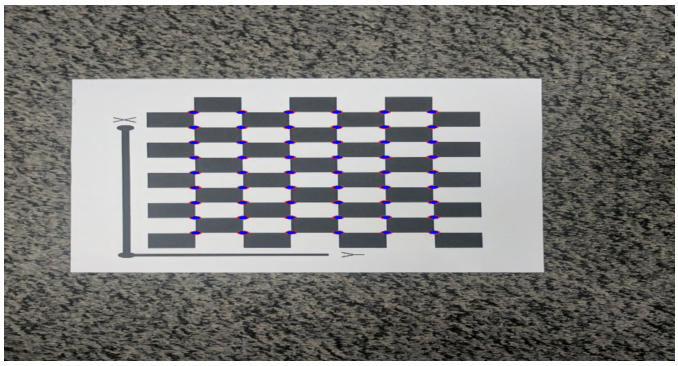

Fig. 16. Predicting Corners

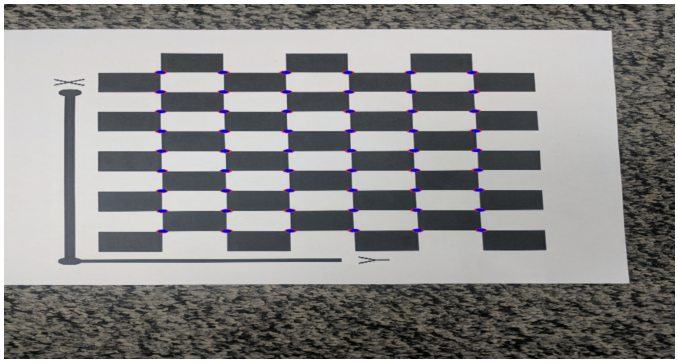

Fig. 17. Predicting Corners

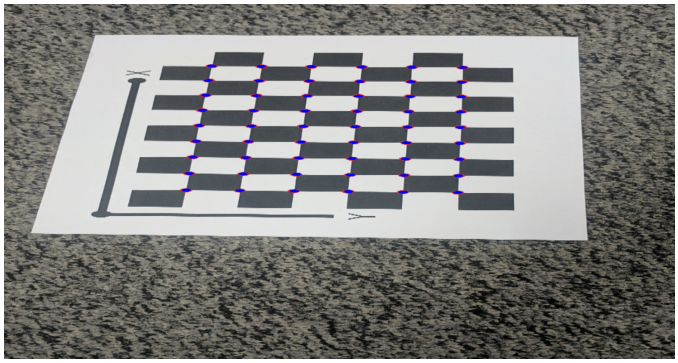

Fig. 18. Predicting Corners

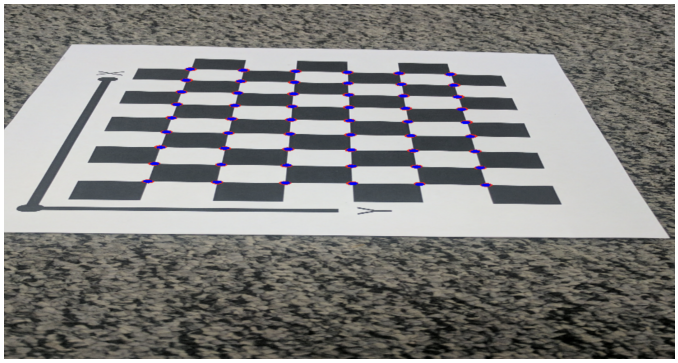

Fig. 19. Predicting Corners

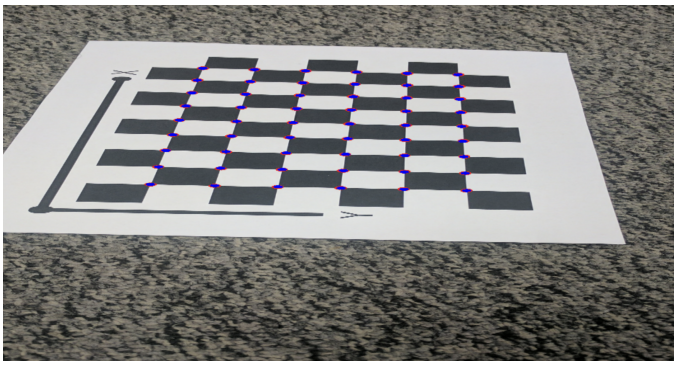

Fig. 20. Predicting Corners

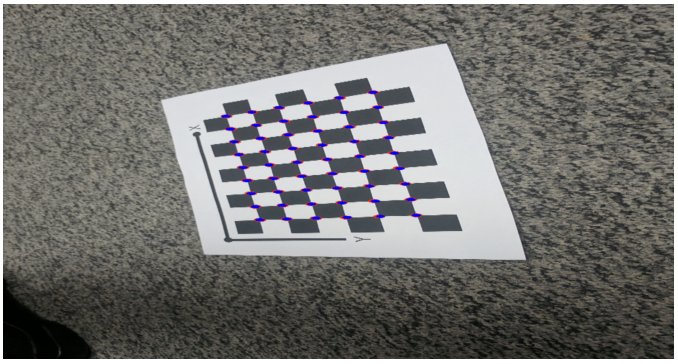

Fig. 21. Predicting Corners

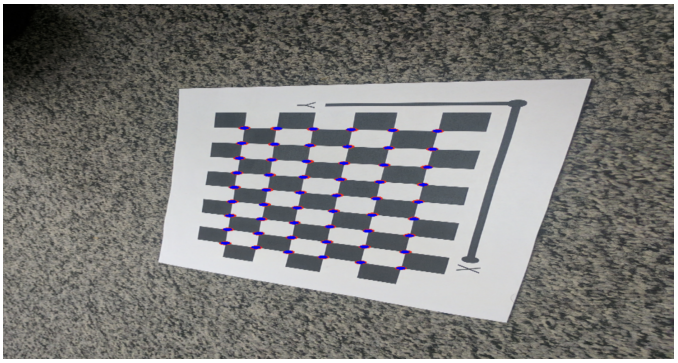

Fig. 22. Predicting Corners

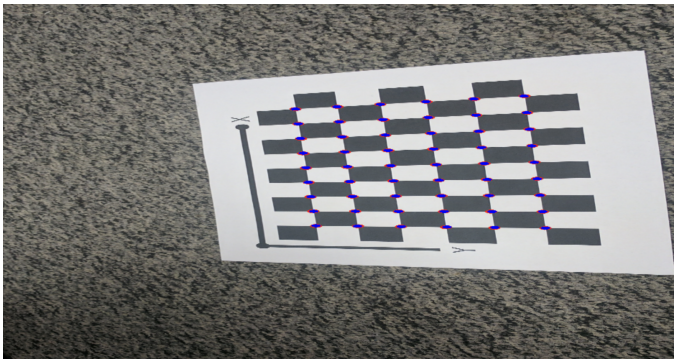

Fig. 23. Predicting Corners

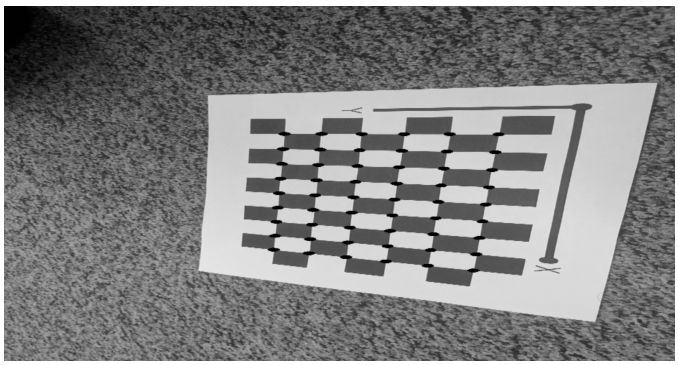

Fig. 24. Rectified Corners

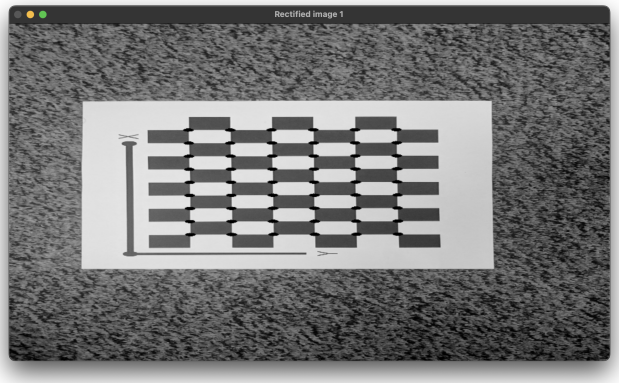

Fig. 25. Rectified Corners

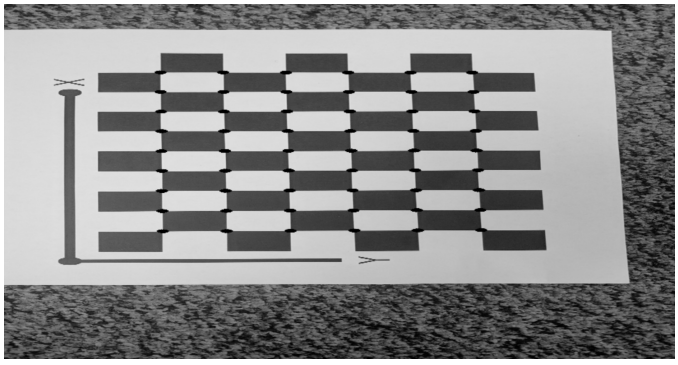

Fig. 26. Rectified Corners

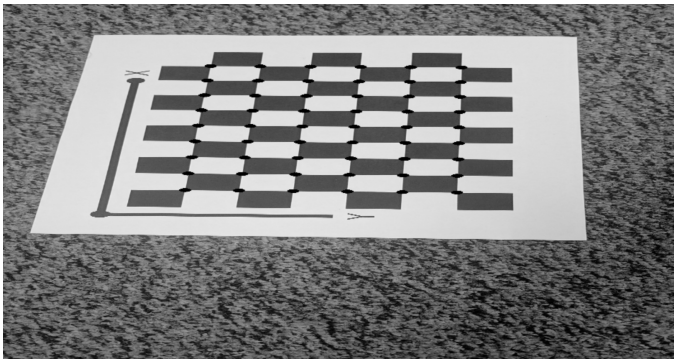

Fig. 27. Rectified Corners

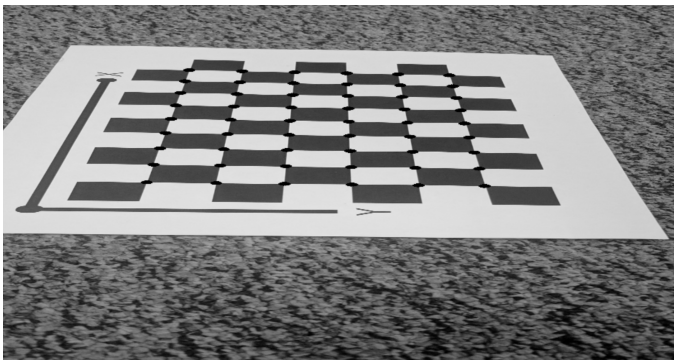

Fig. 28. Rectified Corners

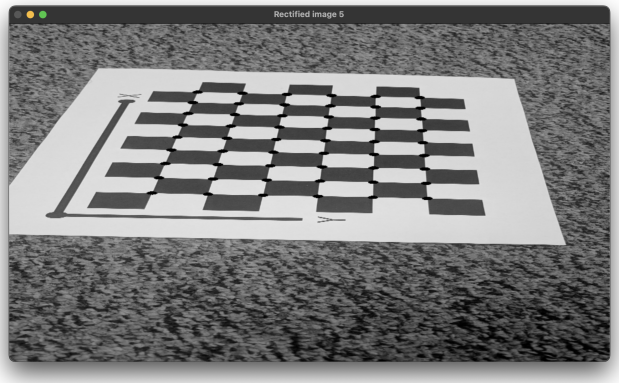

Fig. 29. Rectified Corners

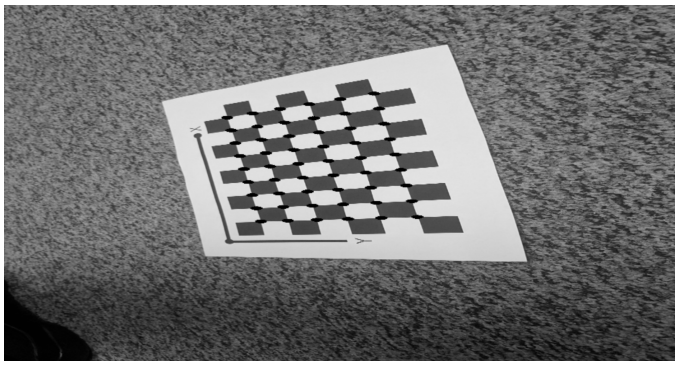

Fig. 30. Rectified Corners

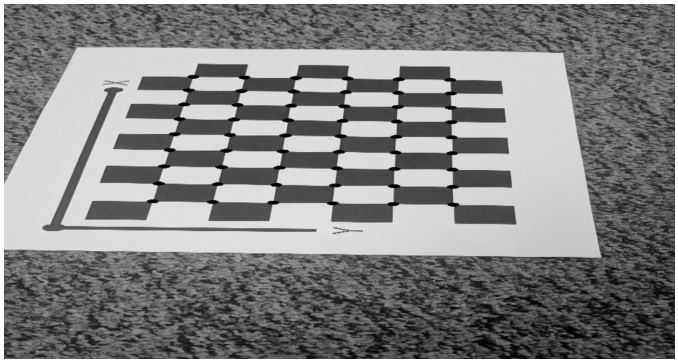

Fig. 31. Rectified Corners

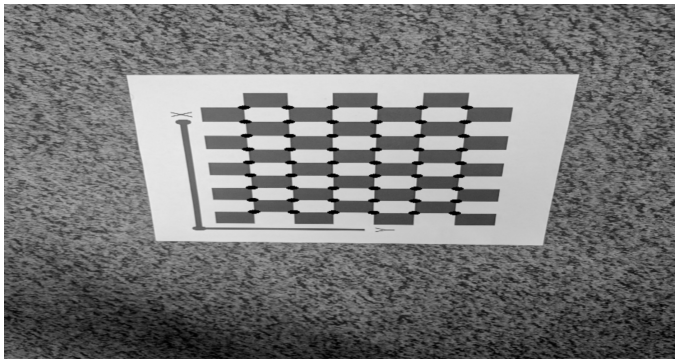

Fig. 32. Rectified Corners

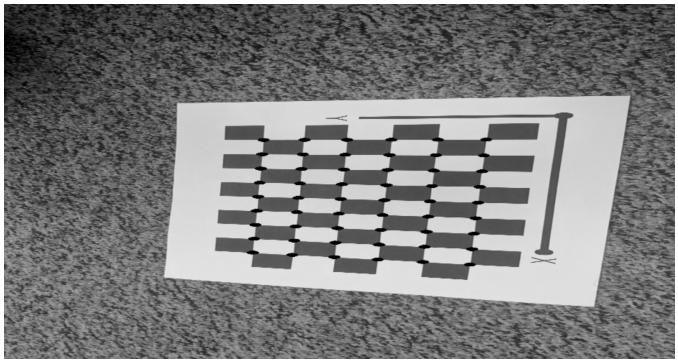

Fig. 33. Rectified Corners

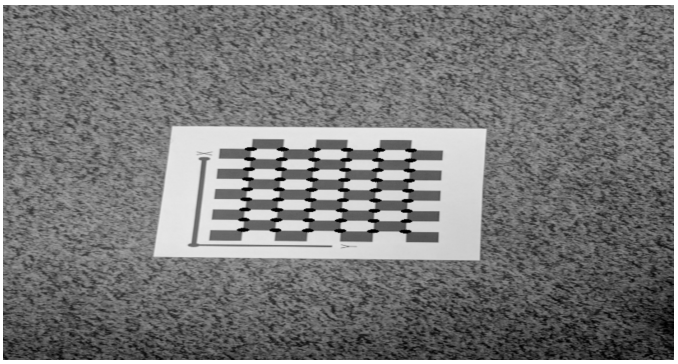

Fig. 34. Rectified Corners

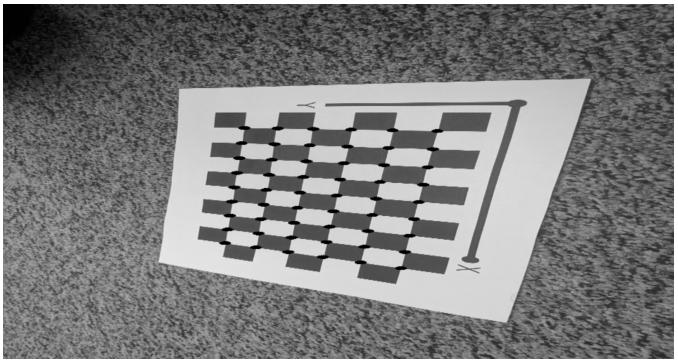

Fig. 35. Rectified Corners

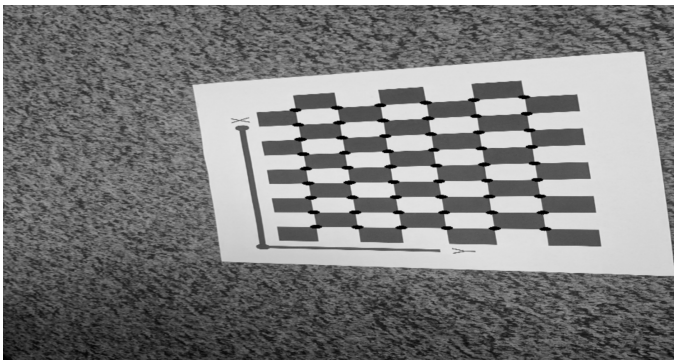

Fig. 36. Rectified Corners