Homework 2: AutoCalib

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***Abstract*—Camera calibration is the process of estimating the parameters of the camera like focal length, distortion coefficients and principle point. It is one of the most time consuming and important part of any computer vision research involving 3D geometry. The aim of this homework is to calibrate a camera from scratch by following the work of Zhang in [1]**

I. Workflow

The procedure consists of a closed-form solution, followed by a nonlinear refinement based on the maximum likelihood criterion. The steps taken include:

1) Print a pattern and attach it to a planar surface
2) Take a few images of the model plane under different orientations by moving either the plane or the camera
3) Detect the feature points in the images
4) Estimate the five intrinsic parameters and all the extrinsic parameters using the closed-form solution as described in Sect.3.1 in [1]
5) Estimate the coefficients of the radial distortion by solving the linear least-squares as described in (13) in Sect.3.3 or simply assume them to be 0
6) Refine all parameters by minimizing (14), the optimization problem in [1].

II. Solving for camera intrinsic matrix, K

The calibration target (checkerboard) is used to estimate camera intrinsic parameters. This was printed on an A4 paper and the size of each square was 21.5mm. Note that the size of the square is not taken into account anywhere in the implementation for the sake of simplicity, i.e, the world coordinates of two adjacent checkerboard corners are unit width apart. This is fair since the homography between the world coordinates and the image coordinates is defined up to scale. Using the homographies from all the calibration images, the homogenous system of linear equations is formulated. The solution to the system can be found using either Eigen decomposition or Singular value decomposition. This solution is the source to our initial estimates of camera intrinsics.

III. Camera extrinsics and radial distortion coefficients

The solution obtained in the previous step is used to get the extrinsics, as explained in section 3.1. The initial estimate of distortion co-efficients is chosen as [0, 0].

IV. Non-linear geometric error minimization

The objective function to be minimised was chosen as the distance between the observed corners' coordinates and the coordinates of the corners reprojected using the estimated parameters, so called the **reprojection error**. For the purpose of the non-linear minimization of this reprojection error, all the different parameters to be optimized were put into a single vector and fed to the optimization function 'minimize()' from the scipy library.

To begin with, the objective function value from the initial estimates was found to be **6499.67** When optimised without considering the distortion coefficients, this value decreased to **680.98**. After considering the distortion coefficients, this value went down further to **363.92**, validating the optimization in the process.

V. Results

For the sake of brevity, only the trends for the camera intrinsics and distortion coefficients are shown below. Since the value of the objective function goes down after optimization we can safely say that the extrinsics for all the calibration images were also optimized appropriately.

A. Camera Intrinsics

1) OpenCV baseline:

$$\begin{bmatrix} 2.042729e+03 & 0.000000e+00 & 7.643600e+02 \\ 0.000000e+00 & 2.035016e+03 & 1.359026e+03 \\ 0.000000e+00 & 0.000000e+00 & 1.000000e+00 \end{bmatrix}$$

2) Initial estimates:

$$\begin{bmatrix} 2.061892e+03 & -2.850592e+00 & 7.760024e+02 \\ 0.000000e+00 & 2.047799e+03 & 1.363240e+03 \\ 0.000000e+00 & 0.000000e+00 & 1.000000e+00 \end{bmatrix}$$

3) Optimization without distortion coefficients:

$$\begin{bmatrix} 2.058478e+03 & -1.454986e+00 & 7.540409e+02 \\ 0.000000e+00 & 2.049441e+03 & 1.354108e+03 \\ 0.000000e+00 & 0.000000e+00 & 1.000000e+00 \end{bmatrix}$$

4) Optimization with distortion coefficients:

$$\begin{bmatrix} 2.048509e+03 & -1.830419e+00 & 7.587442e+02 \\ 0.000000e+00 & 2.040725e+03 & 1.345145e+03 \\ 0.000000e+00 & 0.000000e+00 & 1.000000e+00 \end{bmatrix}$$

B. Distortion Coefficients

1) *OpenCV baseline:* [0.290493410 -2.42737867]
2) *Initial estimate:* [0.0, 0.0]
3) *Post optimization:* [0.17310107 -0.75331797]

Some of the rectified images can be seen in the following figures.

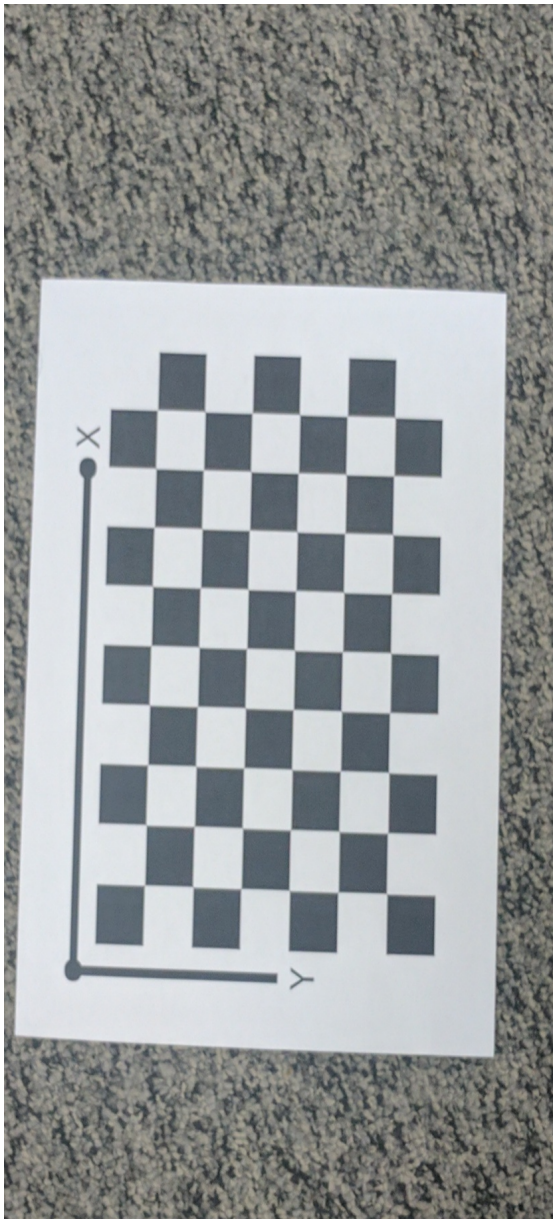

Fig. 1. Rectified image 1

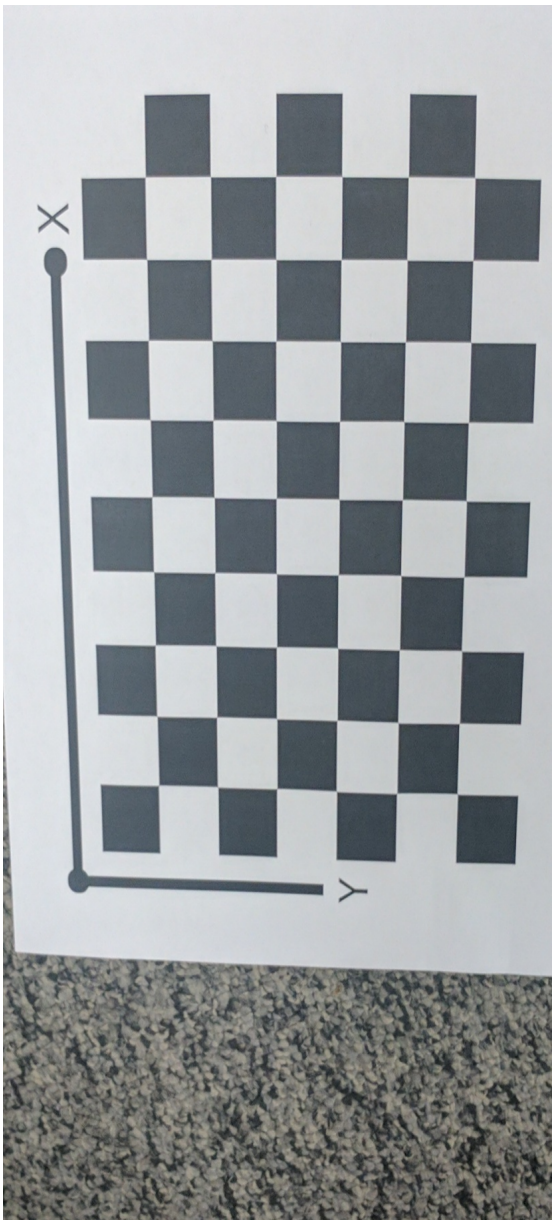

Fig. 2. Rectified image 2

REFERENCES

[1] https://www.microsoft.com/en-us/research/wp-content/uploads/2016/02/tr98-71.pdf

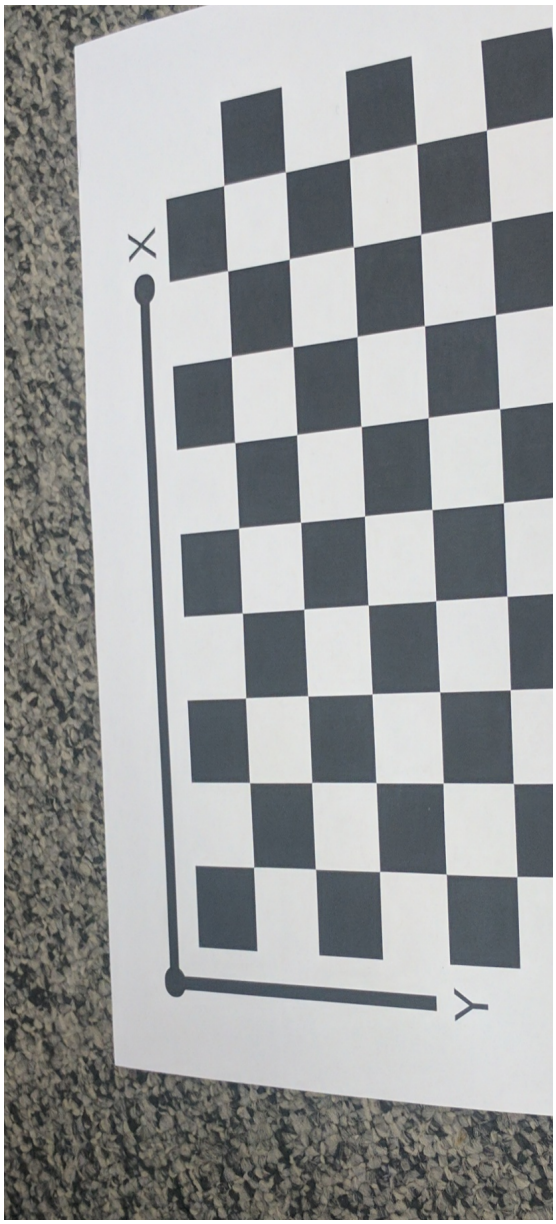

Fig. 3. Rectified image 3

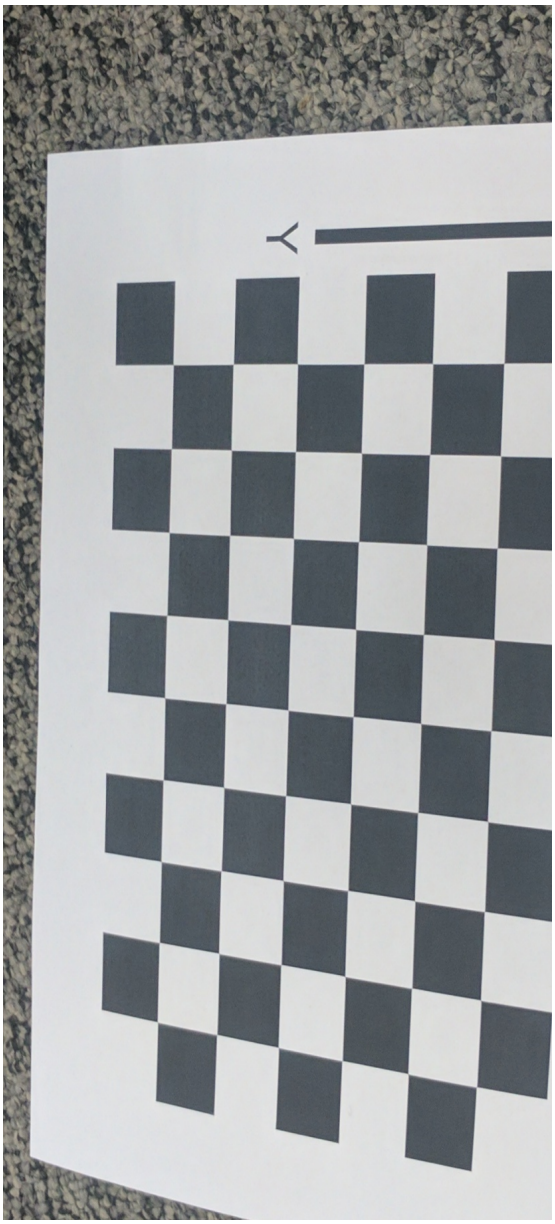

Fig. 4. Rectified image 4