Computer Processing of Pictorial Information Homework 1

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I. Introduction

This homework aims to estimate the intrinsic and extrinsic parameters for a camera. In this homework, we assume there is no skew s parameter and a two parameters distortion model. The whole pipeline follows [1]. Final estimated camera poses are shown in the result.

II. AutoCalib!

In this section, we describe the pipeline of our camera calibration. We are given a set of images contains different view calibration board, as shown in Fig.1. X axis has even number of squares when Y axis has odd number. The size of each square is 21.5mm which is hand measured in the world co-ordinate.

A. Initial parameter Estimation

Before we run a non-linear optimizer, we need an appropriate initial guess of parameters. Given X in 3D world coordinate and x on image plane, we have the following equation

$$\begin{bmatrix} x_1 \\ x_2 \\ 1 \end{bmatrix} = A \begin{bmatrix} R & T \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ 1 \end{bmatrix} \tag{1}$$

where A is camera intrinsic matrix, R and T is the rotation and translation of the camera in the world frame. Following the procedure in Sec. 3.1 and Appendix B in [1], we can get an initial estimated camera intrinsic matrix A by taking the eigenvector with the smallest eigenvalue.

B. Estimate appropriate R and T

With camera intrinsic matrix A, we can easily derive rotation and translation matrix by

$$\begin{aligned} r_1 &= \lambda A^{-1} h_1 \\ r_2 &= \lambda A^{-1} h_2 \\ r_3 &= r_1 \times r_2 \\ T &= \lambda A^{-1} h_3 \end{aligned} \tag{2}$$

where $\lambda = 1/\left\|A^{-1}h_1\right\| = 1/\left\|A^{-1}h_2\right\|$, $R = [r_1 r_2 r_3]$, and h_i is the ith column of homography.

One should notice that R estimated here does not in general satisfy the property of rotation matrix because of the noise in data. We can follow Appendix C in [1] to get the best rotation R_{best}.

C. Non-linear Geometric Error Minimization

Once we have an initial estimation of K, R and T, we set initial distortion $k_s = [0, 0]$ and try to minimize the following error

$$\sum_{i=1}^{N} \sum_{j=1}^{M} \| x_{i,j} - \hat{x}_{i,j}(K, R_i, T_i, X_j, k_s) \| \tag{3}$$

where N is the number of images, M is the number of corresponding points, $x_{i,j}$ is the jth corresponding point on the ith image, and $\hat{x}_{i,j}$ is the projection of the jth corresponding point on image i using estimated intrinsic and extrinsic parameters. We minimized the geometric error by using Levenberg-Marquardt solver[2].

III. Result

The estimated camera poses for each image are shown in Fig.2 and accumulative error are shown in Fig.3. As discussing in Sec.II-B, if we use the best rotation matrix R_{best} as initial R, the initial error will be larger since we enforce the R, which minimizes the error, to satisfy the property of rotation matrix. However, from Fig.2 and Fig.3, we can observe that the result after non-linear minimization are the same.

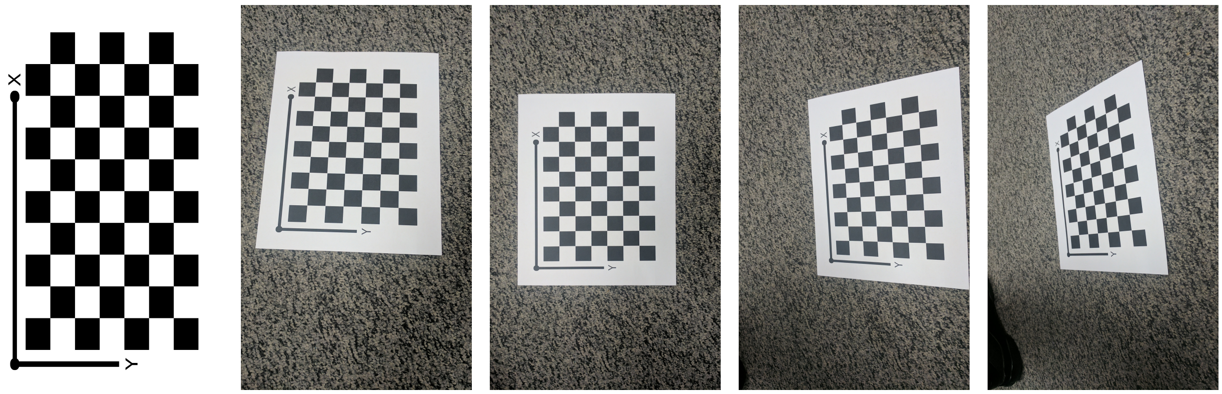
IV. Acknowledgement

Special thanks Wei-An Lin for discussion.

References

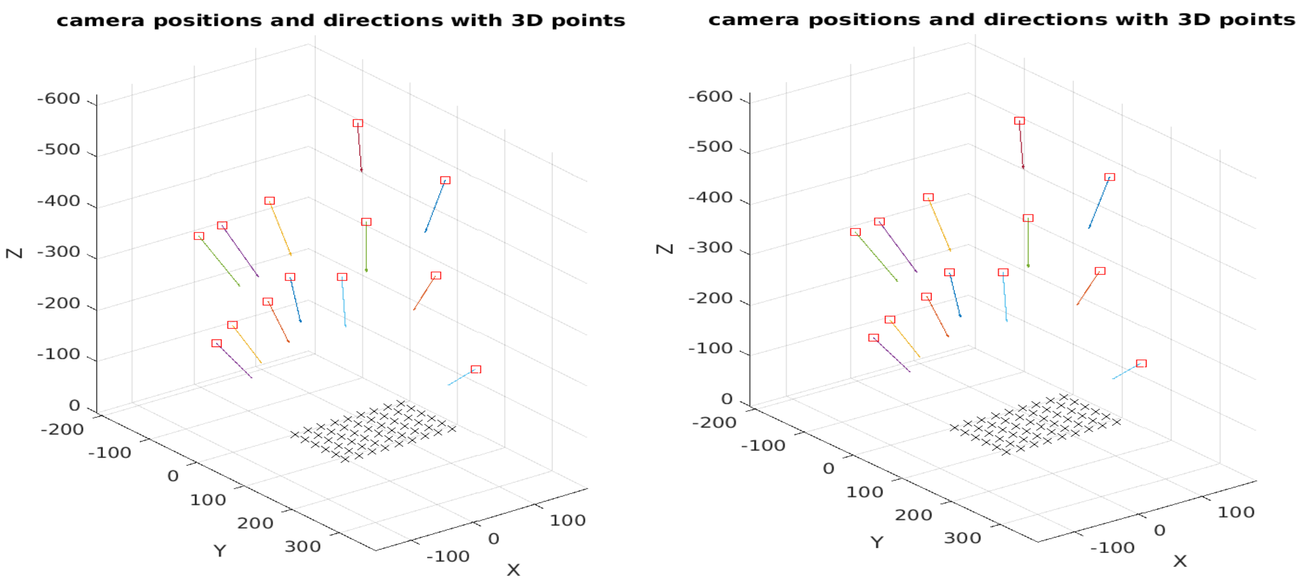
[1] *Flexible Camera Calibration By Viewing a Plane From Unknown Orientations*. IEEE, September 1999.

[2] Donald W. Marquardt. An algorithm for least-squares estimation of nonlinear parameters. *SIAM Journal on Applied Mathematics*, 1963.



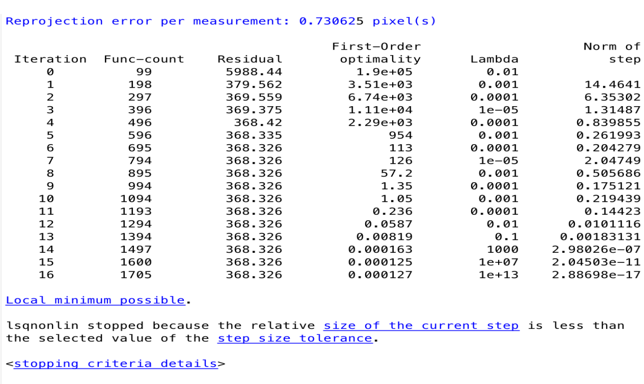
(a) Calibration pattern (b) View1 (c) View2 (d) View3 (e) View4

Fig. 1: Calibration Pattern and different view.



(a) R (b) R_{best}

Fig. 2: Estimated camera pose.



Reprojection error per measurement: 0.730625 pixel(s)

Iteration	Func-count	Residual	First-Order optimality	Lambda	Norm of step
0	99	5988.44	1.9e+05	0.01	
1	198	379.562	3.51e+03	0.001	14.4641
2	297	369.559	6.74e+03	0.0001	6.35302
3	396	369.375	1.11e+04	1e-05	1.31487
4	496	368.42	2.29e+03	0.0001	0.839855
5	596	368.335	954	0.001	0.261993
6	695	368.326	113	0.0001	0.204279
7	794	368.326	126	1e-05	2.04749
8	895	368.326	57.2	0.001	0.505686
9	994	368.326	1.35	0.0001	0.175121
10	1094	368.326	1.05	0.001	0.219439
11	1193	368.326	0.236	0.0001	0.14423
12	1294	368.326	0.0587	0.01	0.0101116
13	1394	368.326	0.00819	0.1	0.00183131
14	1497	368.326	0.000163	1000	2.98026e-07
15	1600	368.326	0.000125	1e+07	2.04503e-11
16	1705	368.326	0.000127	1e+13	2.88698e-17

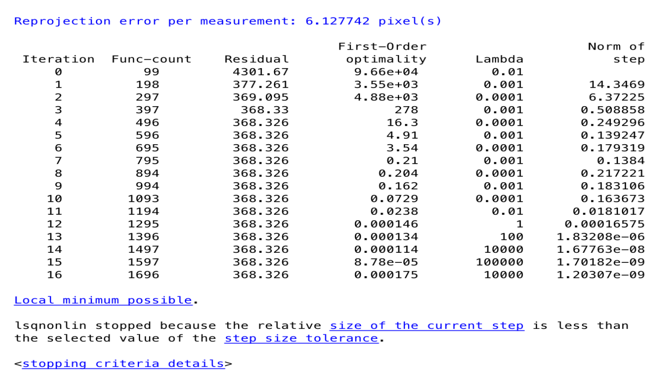
Local minimum possible.

lsqnonlin stopped because the relative size of the current step is less than the selected value of the step size tolerance.

<stopping criteria details>

Reprojection error per measurement: 0.524681 pixel(s)

(a) R



Reprojection error per measurement: 6.127742 pixel(s)

Iteration	Func-count	Residual	First-Order optimality	Lambda	Norm of step
0	99	4301.67	9.66e+04	0.01	
1	198	377.261	3.55e+03	0.001	14.3469
2	297	369.095	4.88e+03	0.0001	6.37225
3	397	368.33	278	0.001	0.508858
4	496	368.326	16.3	0.0001	0.249296
5	596	368.326	4.91	0.001	0.139247
6	695	368.326	3.54	0.0001	0.179319
7	795	368.326	0.21	0.001	0.1384
8	894	368.326	0.204	0.0001	0.217221
9	994	368.326	0.162	0.001	0.183106
10	1093	368.326	0.0729	0.0001	0.163673
11	1194	368.326	0.0238	0.01	0.0181017
12	1295	368.326	0.000146	1	0.00016575
13	1396	368.326	0.000134	100	1.83208e-06
14	1497	368.326	0.000114	10000	1.67763e-08
15	1597	368.326	8.78e-05	100000	1.70182e-09
16	1696	368.326	0.000175	10000	1.20307e-09

Local minimum possible.

lsqnonlin stopped because the relative size of the current step is less than the selected value of the step size tolerance.

<stopping criteria details>

Reprojection error per measurement: 0.524681 pixel(s)

(b) R_{best}

Fig. 3: Estimated camera pose.