Camera Calibration Project Report

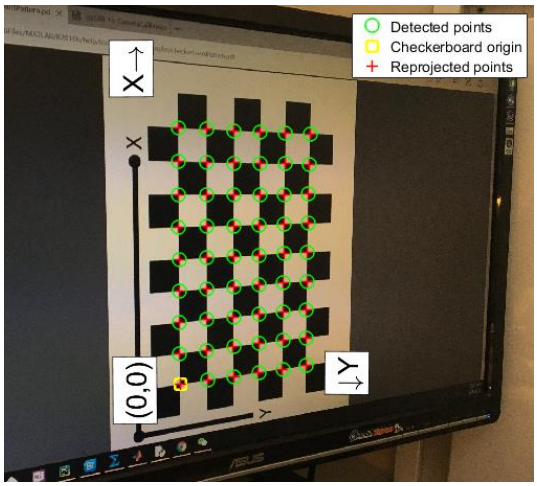
Haoyuan Zhang | Robotics | GRASP Lab, UPenn

1. Introduction

This work shows the estimated result for the hand-handled camera, also includes the result obtained from Matlab built-in calibration function for comparison, and some algorithm and results analyses.

2. Estimated Result

The coordinate system in the 3D world shows below, and Z axis points inside the screen.



In the sheet table, the first column shows the result obtained from built calibration function while the second column is my estimated result.

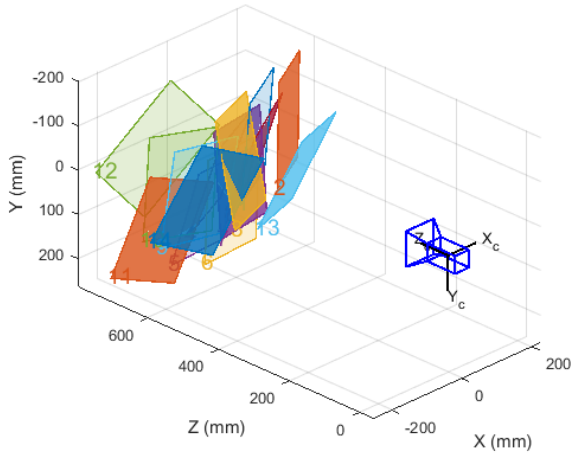
	Matlab Toolbox Estimation	**Own Estimation**
Radial Distortion	[0.1446, -0.3113]	[0.14493534, -0.3133529]
Intrinsic Matrix	$\begin{bmatrix} 3378.073744 & 0 & 2010.179563 \\ 0 & 3378.20692 & 1513.85514 \\ 0 & 0 & 1 \end{bmatrix}$	$\begin{bmatrix} 3376.322772 & 1.349 & 2009.818788 \\ 0 & 3376.514762 & 1512.787573 \\ 0 & 0 & 1 \end{bmatrix}$
Mean Reprojection Error	0.3334	0.3327
Focal Length Error	[3.62944167, 3.5981654]	[3.629441674, 3.5981654]
Principle Point Error	[1.451657, 0.93502]	[1.451657, 0.93502]
Radial Distortion Error	[0.0017077, 0.00758586]	[0.0017077, 0.007585859]

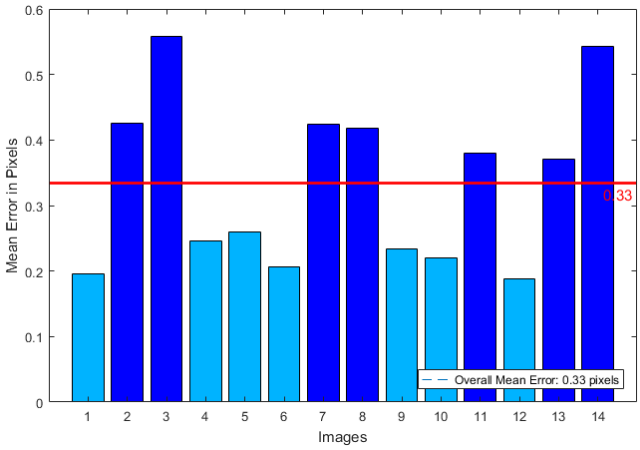
According to the table above, two result sets are pretty similar. One significant difference is, my estimation's skew factor equals to 1.349 instead of 0, except that, all other estimated parameters are pretty close, such as focal length, principle points and the mean error.

I find the actual camera focal length is almost 4mm with CCD size 4.80 x 3.60 mm, so the estimated focal length in pixel unit is about 4032 * 4 / 4.8 = 3360 pixels. Therefore, my estimated result 3376.322 is close to the actual one. What's more, for the principle point, since the image size is 4032 x 3024, the ideal center point should locate at around (2016, 1512), while my estimation result is about (2009.8, 1512.787), also close to the practical result.

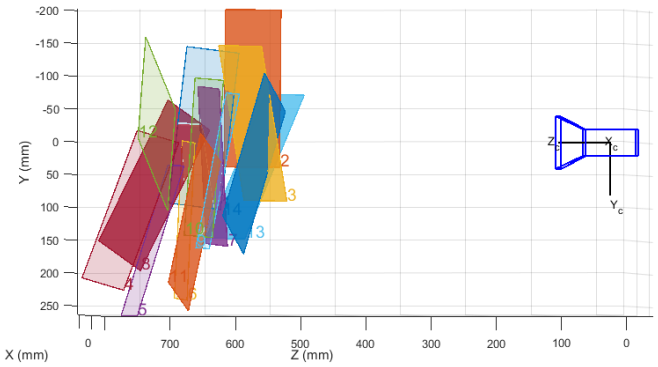
Besides checking the accuracy via the data above, I also plot some figures to verify my estimation.

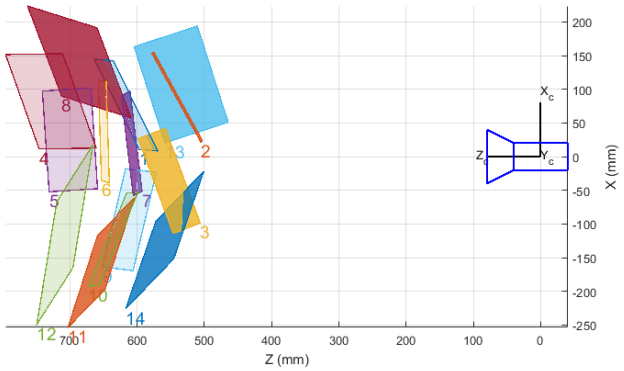
I use total 18 images for calibration, and total 14 images are detected. Below figure shows the true pose of cameras in the global frame with respected to the checkerboard plane frame. And the histogram on right side shows the reprojection error obtained from each camera.

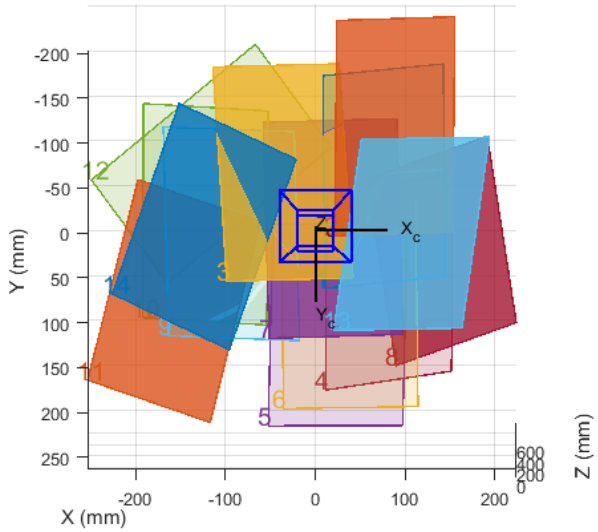




In order to get a much clearer global figure, I also plot corresponding relative positions in three 2D view.



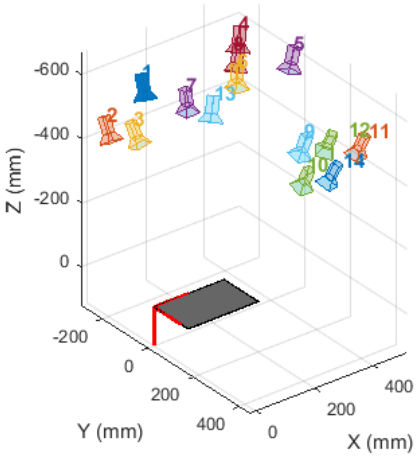
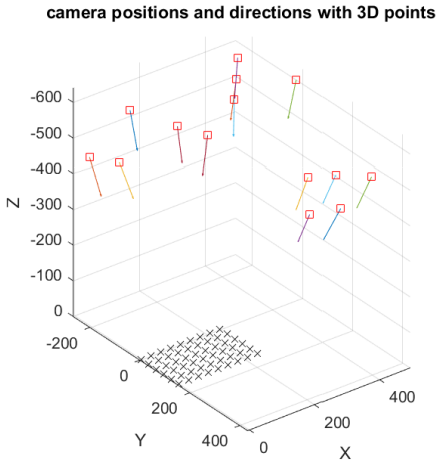
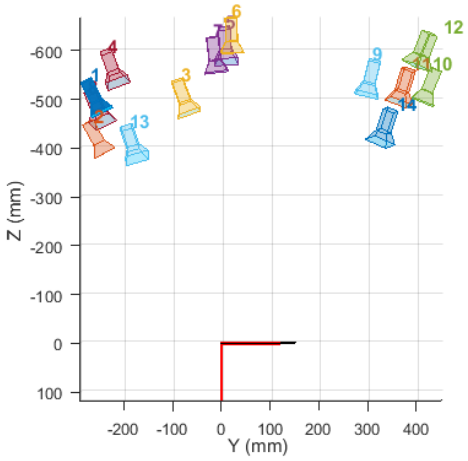
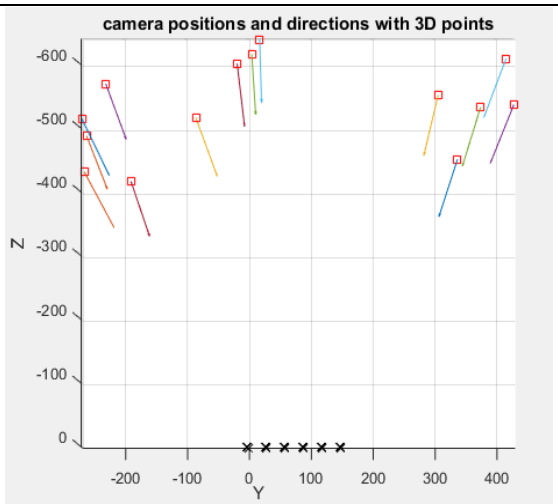
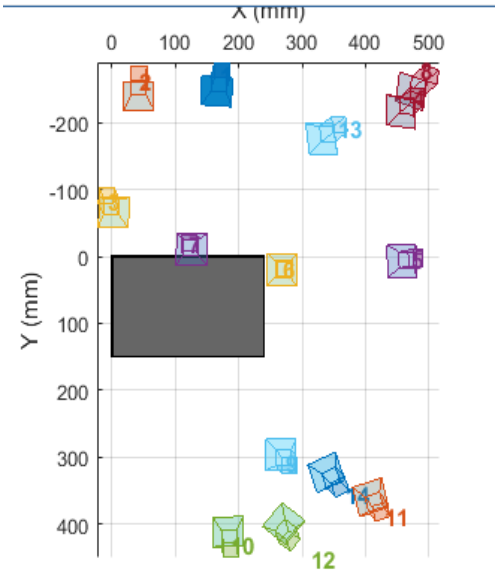
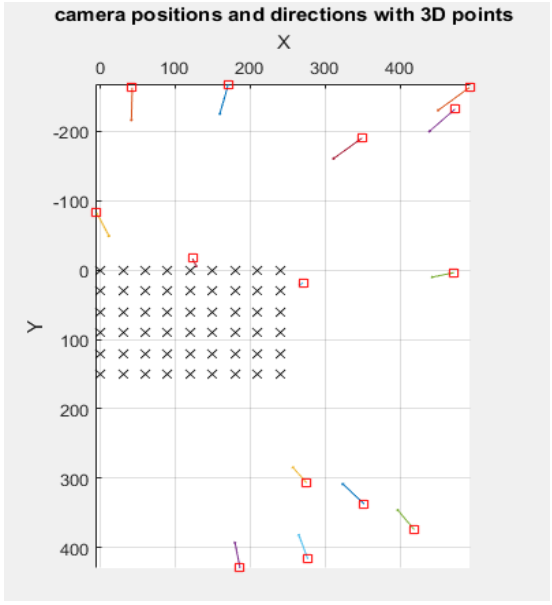


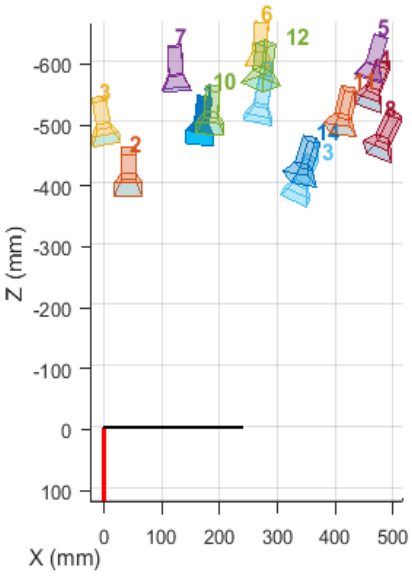
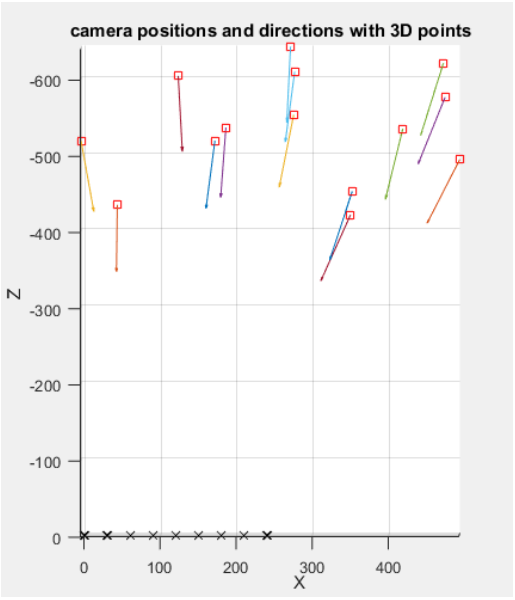


I use the toolbox function to verify my accuracy of data collection. The first one shows the view from X axis to YZ plane, second one is from Y axis to ZX and third one represents the figure from Z to YZ plane.

It's pretty obvious to get an idea of the rotation and translation of each camera with respected to the checkerboard plane.

Then below table shows the comparison between the result obtained from toolbox and my own estimation to verify the accuracy of code in a much clearer view.

	Matlab Toolbox Estimation	Own Estimation
3D View		
ZY View		
YX View		

XZ View		

According to the figure above, it's obvious that two results are pretty similar, including rotation and translation which can strengthen the confidence of the accuracy of my estimation.

Below data shows the reprojection error in each iteration times. You can find that the error decreases with iterations which means the algorithm is converging correctly.

Three reprojection error

* Reprojection error per measurement: 1.154746 pixel(s)
* Reprojection error per measurement: 1.149983 pixel(s)
* Reprojection error per measurement: 0.172645 pixel(s)

Iteration Process (You can run demo to see the whole process of iteration)

Iteration	Func-count	Residual	First-Order optimality	Lambda	Norm of step
0	106	19806.8	3.9e+05	0.01	
1	212	433.999	3.21e+04	0.001	71.5777
2	318	161.283	2.24e+04	0.0001	166.511
3	425	131.843	2.66e+03	0.001	44.4531
4	531	130.739	2.35e+03	0.0001	11.7575
5	638	130.536	1.52e+03	0.001	3.13435
			.....		
20	2238	130.52	0.801	1	0.000880785
21	2344	130.52	0.81	0.1	0.000865637
22	2451	130.52	0.768	1	0.000815123
23	2557	130.52	0.882	0.1	0.00088862
24	2664	130.52	0.819	1	0.000880683
25	2770	130.52	0.931	0.1	0.00089538
26	2877	130.52	1.07	1	0.00099766
			.....		
44	4794	130.52	0.209	1	0.000120534
45	4901	130.52	0.216	10	0.000129078
46	5007	130.52	0.194	1	0.000113854
47	5114	130.52	0.183	10	0.000109177
48	5220	130.52	0.219	1	0.000128309
49	5327	130.52	0.233	10	0.00013291
50	5433	130.52	0.221	1	0.000125802
51	5546	130.52	0.000901	1e+07	1.27137e-10
52	5657	130.52	0.000863	1e+12	1.54797e-15
53	5765	130.52	0.000899	1e+14	1.53064e-17