Matlab 相机标定工具箱实验

（Camera Calibration Toolbox for Matlab）

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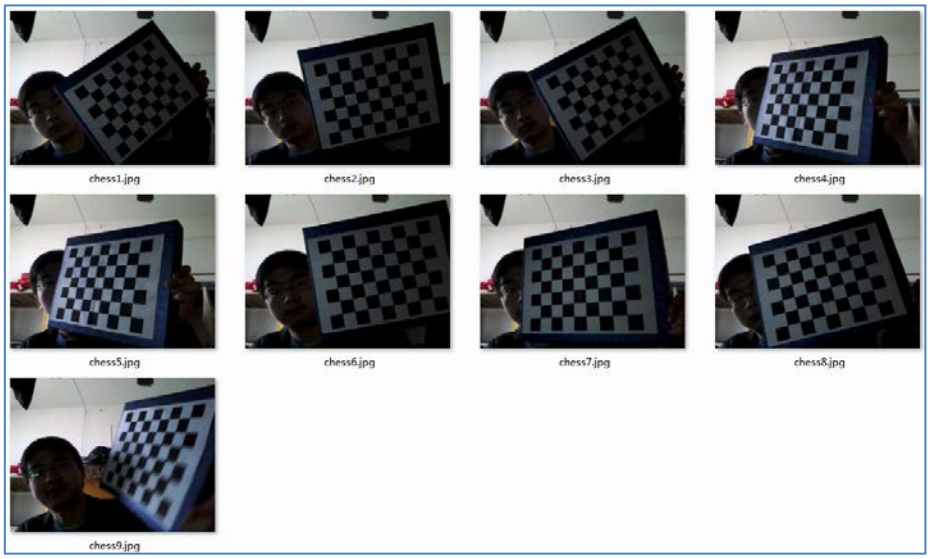
一、原始数据

image 文件夹下的 9 张影像（以前做相机标定时用笔记本摄像头采集的数据）
1600pixel*1200pixel

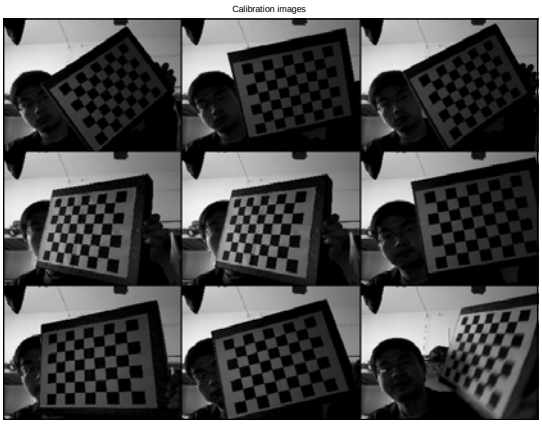


二、实验过程

1、安装工具箱

下载相机标定工具箱（Camera Calibration Toolbox for Matlab），并加载到系统路径。
http://www.vision.caltech.edu/bouguetj/calib_doc/#start

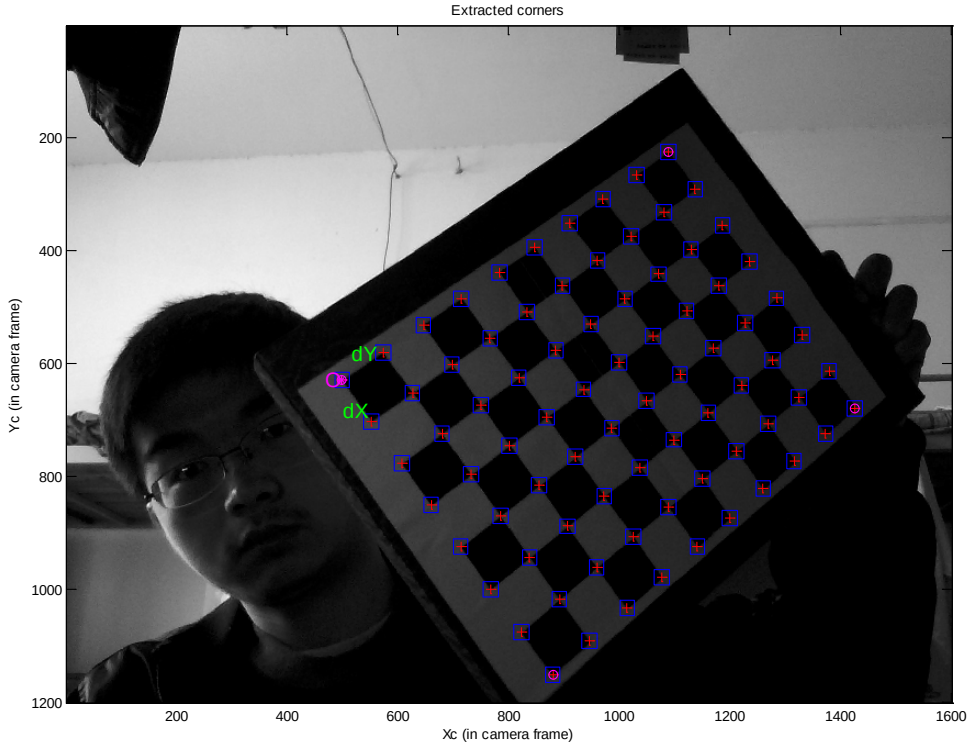
2、读入影像

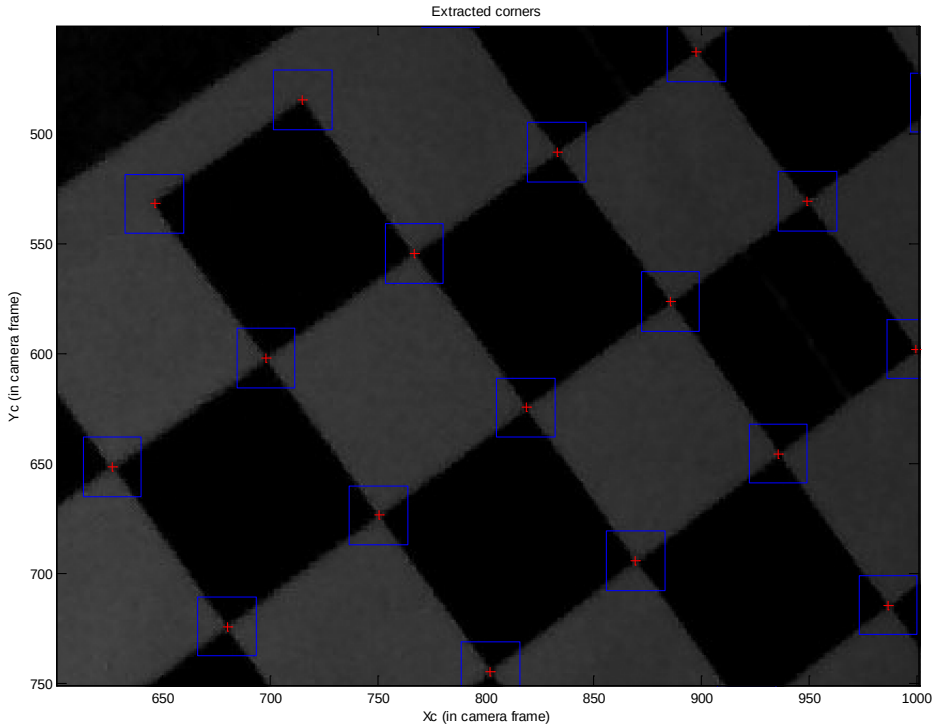


因为第 9 张影像呈现模糊，后面就舍弃了（工具箱的文档说最好用 20~25 张影像）。

3、提取角点

通过简单手动交互，从 Chess1.jpg 提取的角点如下：





按文档的说法，角点提取的精度能达到 0.1 pixel。提取角点过程中可以通过设置初始畸变参数对自动检测到的角点进行调整（可以反复进行），直到对提取到的角点比较满意。

如果镜头畸变太大（如鱼眼相机），可能无法精确提取到角点，只能手动完成角点提取（即一个一个点击，这是非常耗时的，也是最后的无奈之举！）

4、标定

标定包括两步：初始化、非线性优化。

初始化是在不考虑镜头畸变的情况下计算相机参数，非线性优化过程是基于最小二乘准则使得像点的反投影误差最小。

结果如下：

Calibration parameters after initialization:

Focal Length: fc = [1568.55714 1568.55714]

Principal point: cc = [799.50000 599.50000]

Skew: alpha_c = [0.00000] => angle of pixel = 90.00000 degrees

Distortion: kc = [0.00000 0.00000 0.00000 0.00000 0.00000]尚未考虑畸变差！

Main calibration optimization procedure - Number of images: 8

Gradient descent iterations（梯度下降迭代）: 1...2...3...4...5...6...7...8...9...10...11...12...13...14...15...16...17...18...19...20...done

Estimation of uncertainties...done

Calibration results after optimization (with uncertainties):

Focal Length: fc = [1582.65925 1583.72173] ± [28.56101 27.73260]

Principal point: cc = [784.75027 621.28086] ± [21.57134 18.70249]

Skew: alpha_c = [0.00000] ± [0.00000] => angle of pixel axes = 90.00000 ± 0.00000 degrees

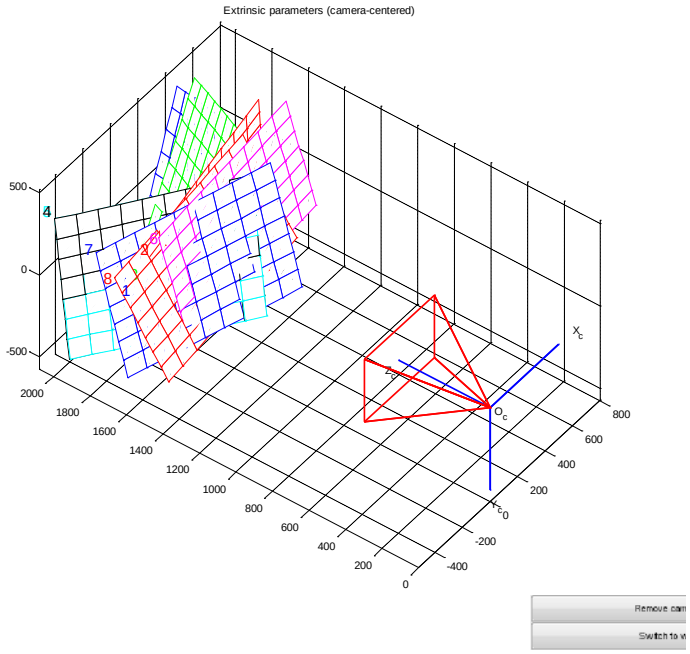
Distortion: kc = [0.06559 -0.25891 0.00055 0.00569 0.00000] ± [0.03454 0.13605 0.00395 0.00507 0.00000]

Pixel error: err = [1.82640 0.86523] **（可以与后面二次标定的结果比较！）**

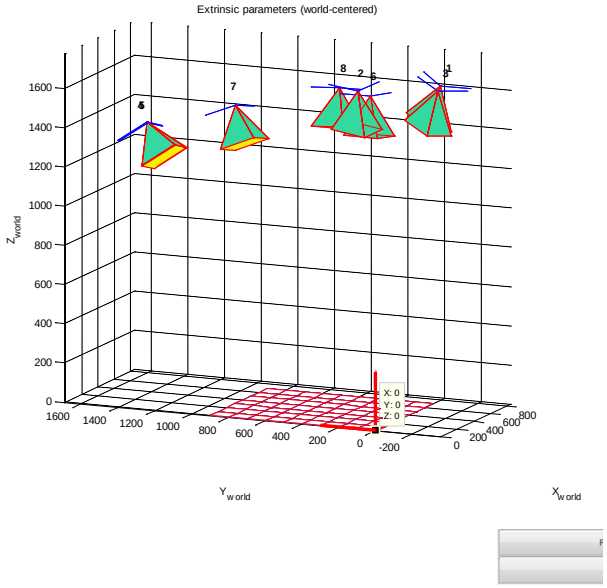
Note: The numerical errors are approximately three times the standard deviations (for reference).

5、相机的外参数

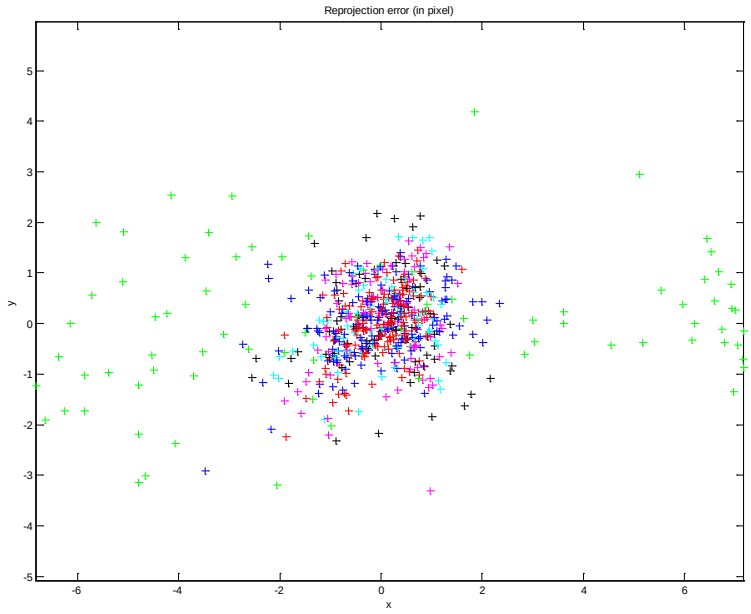
相机坐标系下的视图：



世界坐标系下的视图：

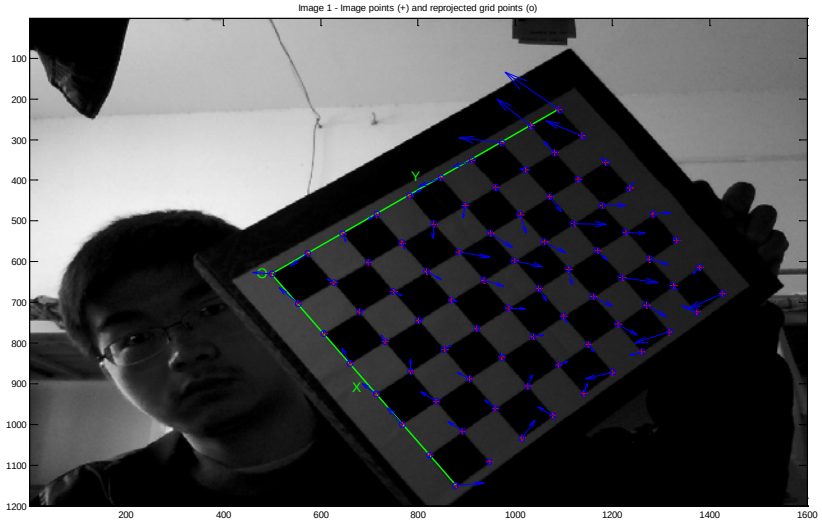


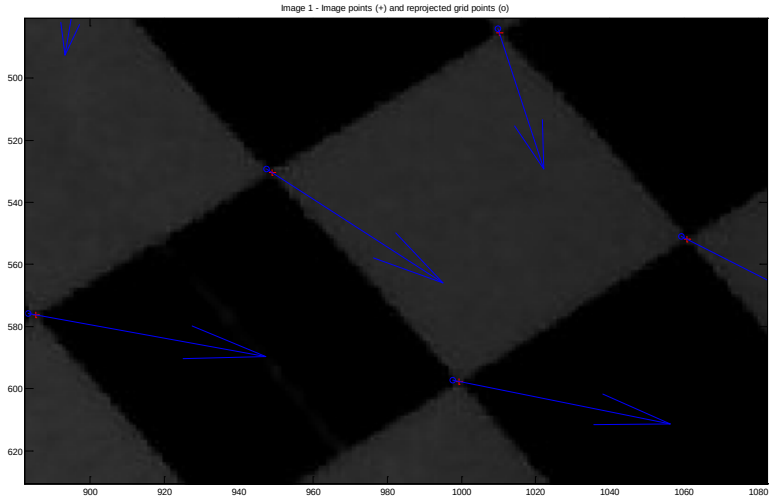
6、投影误差分析



各角点的投影误差区间是 x:（-6.5 , 7）,y:（-3.2 , 4.2）**（可以与后面二次标定的结果比较！）**

上图共有 8 中色彩，表示的是每张影像的投影差，如蓝色表示的是 chess1.jpg 上各个角点的反投影误差，详情如下图。





可以看出 chess1.jpg 上各个角点的投影误差方向有一定的规律性。

误差分析：

Pixel error: err = [1.82640 0.86523] (all active images)

用鼠标选择误差分布图上的某个点，结果如下：

Selected image: 1 # 第一张影像

Selected point index: 22 # 第 22 个角点

Pattern coordinates (in units of (dX,dY)): (X,Y)=(5,7) # 在模板上的坐标

Image coordinates (in pixel): (1219.53,638.01) # 在图像上的坐标

Pixel error = (2.34570,0.40206) # 投影误差

Window size: (wintx,winty) = (13,13)

Selected image: 2

Selected point index: 29

Pattern coordinates (in units of (dX,dY)): (X,Y)=(4,6)
Image coordinates (in pixel): (1147.60,669.70)
Pixel error = (-0.29877,0.07599)
Window size: (wintx,winty) = (13,13)

.....

Selected image: 5
Selected point index: 29
Pattern coordinates (in units of (dX,dY)): (X,Y)=(4,6)
Image coordinates (in pixel): (801.63,740.93)
Pixel error = (0.29962,-0.24884)
Window size: (wintx,winty) = (13,13)

Selected image: 6
Selected point index: 8
Pattern coordinates (in units of (dX,dY)): (X,Y)=(7,9)
Image coordinates (in pixel): (1594.26,890.54)
Pixel error = (0.97464,-3.30900)
Window size: (wintx,winty) = (13,13)

7、考虑畸变系数后重新标定

Aspect ratio optimized (est_aspect_ratio = 1) -> both components of fc are estimated (DEFAULT).
Principal point optimized (center_optim=1) - (DEFAULT). To reject principal point, set center_optim=0
Skew not optimized (est_alpha=0) - (DEFAULT)
Distortion not fully estimated (defined by the variable est_dist):
Sixth order distortion not estimated (est_dist(5)=0) - (DEFAULT) .

Main calibration optimization procedure - Number of images: 8
Gradient descent iterations: 1...2...3...4...5...6...7...8...9...10...11...12...13...14...15...16...17...18...19...20...done
Estimation of uncertainties...done
上述过程显示并没有进行初始化，因为是从在上次标定的结果的基础上进行优化。

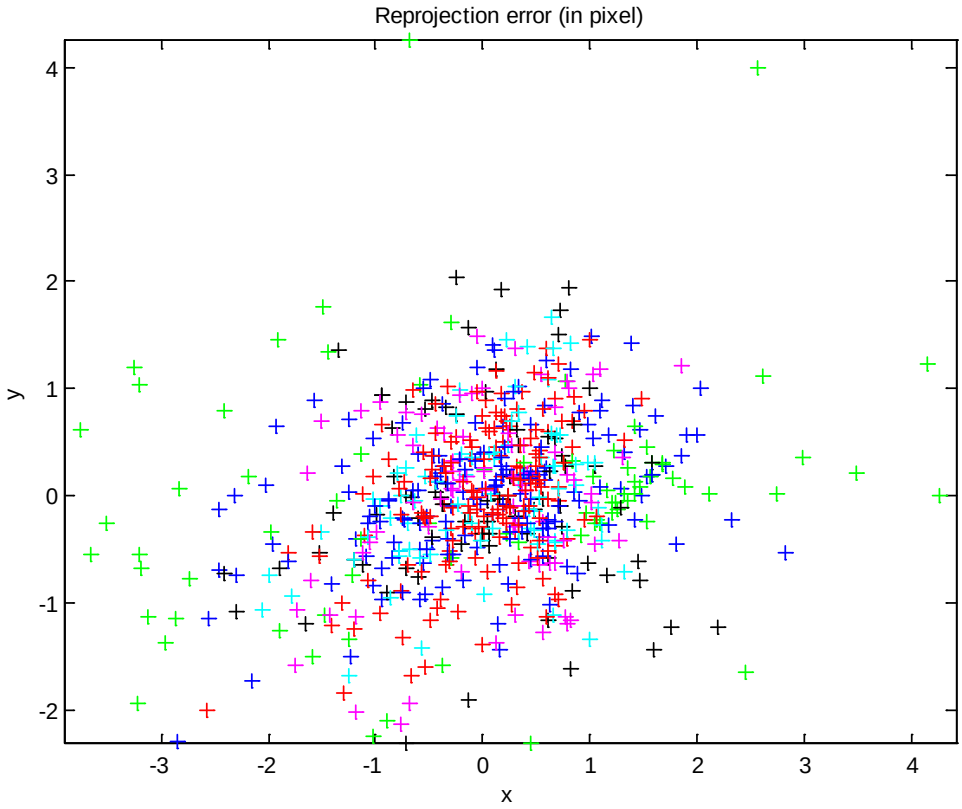
Calibration results after optimization (with uncertainties): 注：下面的?其实都是±。

Focal Length: fc = [1593.11040 1596.07192] ? [18.08120 17.61336]
Principal point: cc = [781.57083 623.99733] ? [13.63710 11.75612]
Skew: alpha_c = [0.00000] ? [0.00000] => angle of pixel axes = 90.00000 ? 0.00000 degrees
Distortion: kc = [0.07159 -0.30191 0.00128 0.00712 0.00000] ? [0.02198 0.08808 0.00248 0.00321 0.00000]

Pixel error: err = [1.01103 0.76628]第二次标定的结果显示，x 和 y 方向的标准差都明显减小。

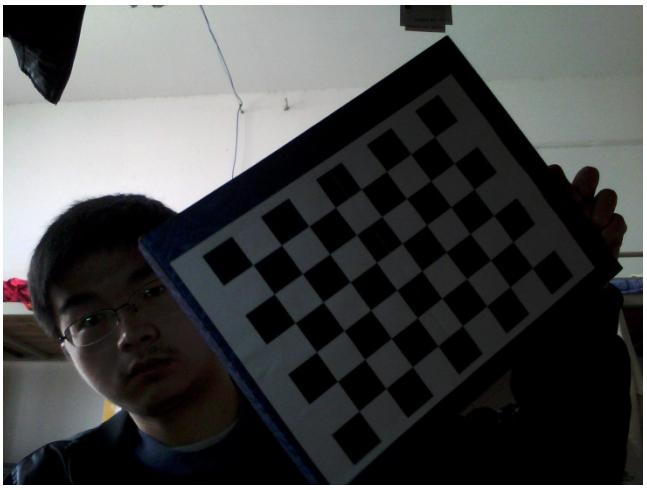
Note: The numerical errors are approximately three times the standard deviations (for reference).

8、重标定后的投影误差再分析



误差区间：x:（-4 , 4.5）,y:（-2.5 , 2）。**（可以与前面第一次标定的结果比较！）**

9、对影像进行纠正



Chess1.jpg

chess_rect1.bmp**（纠正后，注意边缘！）**

三、结果

标定的中间数据存于 calib_data.mat。

计算结果存于 Calib_Results.m 和 Calib_Results.mat 中，包括内参数和外参数。