Camera Calibration Mini Project

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Purposes

- To practise the procedure and tools for camera calibration
- To compare the advantages and disadvantages of different method
- To try and test calibration by using different checker board, including chess board, symmetrical circle and asymmetrical circle

Experiment Environment

- Camera: iPhone 5s rear camera, type: Sony Exmor-RS IMX145 (4.12mm f/2.2)
- Computer: Asus M32BF (CPU AMD A10-7800, 12G Memory), Windows 10
- Calibration Tools:
  - GML Camera Calibration Toolbox v0.72beta (stand along 'exe')
  - MATLAB R2014a Computer Vision System Toolbox
  - OpenCV 3.0, Visual Studio 2013
- Other Toolkit: exiftool v10.9

Methodology

1. Prepare
   - Experiment environment preparation
   - Making checker boards, including:
     i. 8*5 chess board, square size 28mm
     ii. 8*6 chess board, square size 30mm
     iii. 7*6 symmetrical circle, diameter = 11.5mm
     iv. 11*4 asymmetrical circle, diameter = 13.5mm
2. Preliminary Test

In order to determine the feasibility of the experimental plan and confirm the availability of the calibration tools, some quick and dirty tests were made beforehand. There are some findings, which influence our experimental settings:

- GML Camera Calibration Toolbox doesn't support 'even'*'even' and 'odd'*'odd' chess boards, so 8*6 chess board won't work on GML
- Both GML and MATLAB CV support only squared board. Therefore, circle boards calibration can only be performed with OpenCV.

The camera parameters were also retrieved from the third party source. However, it is claimed that the parameters are not accurate. Hence, we won't hold it as the ground truth, but a rough reference. Along with the data those are extracted from picture with exiftool, we can calculate the theoretical focal length in pixel:

As we known, Focal length = 4.12mm; Sensor Size (CCD)[1] = 6mm; Image Width = 3,264 pixels

Hence, focal length in pixel = (image width in pixels) * (focal length in mm) / (CCD width in mm)[2]

= 3,264*4.12/6 = 2,241.28 pixels

3. Detection and Calibration

In accordance with the experiment purposes, four groups of images corresponded to four checker boards need to be taken using the rear camera of my iPhone 5s. Theoretically, the circle boards require fewer images to calibrate. In order to save time, we took 5 pictures for each circle board group, and 10 pictures for each chess board group.

Group	Board Type	Board Size	Block Size	Number of Images
A	Square (Even*Odd)	8x5	28mm	10
B	Square (Even*Even)	8x6	30mm	10
C	Symmetrical Circle	8x5	11.5mm	5
D	Asymmetrical Circle	11*4	13.5mm	5

- Group A

  All of the three calibration tools are applied. The processing speed has no significant difference, though GML and OpenCV seem a little bit faster than MATLAB.

- Group B

  MATLAB and OpenCV are used to detect and calibrate on Group B. The processing times are slightly slower than those on Group A. One possible reason is that the chess board here contains more blocks.

- Group C and Group D

  Only OpenCV can process circle boards. In order to compare the calibration accuracy under smaller number of images, we also picked the first five images of Group, and executed the calibration one more time with three tools repestively.

  Although the processing time for one image is significantly slower than that from Group A and B, considering only five images need to be analyzed, when using the same tool, the overall calibration time is almost the same for all four groups.

During the calibration, we found MATLAB is a bit picky on image. Some images worked well with and OpenCV were rejected by MATLAB. Therefore, we replaced these images to avoid bias. On the other hand, MATLAB CV toolbox provides outstanding visualization features, which help us understand the result easily.

4. Result Evaluation

By examining the overall mean error of the reprojection error for each image, we confirmed that the all results are valid. In other words, the overall mean errors are significantly below 1 pixel.

For each calibration, the undistorted images were checked as to assure the correctness of the result. “Sometimes, if the pattern only covers a small percentage of the image, the calibration achieves low reprojection errors, but the distortion estimation is incorrect.” (MATLAB CV Help)

As also can be seen in all results, the distortion is very small (< 1 pixel). Therefore, we will ignore the distortion at the results reporting section.

All calibration results were stored in files, so that the diagnostic check and comparison can be made afterward.

Results Reporting

Calibration Tools	Group A Square 8x5	Group B Square 8x6	Group C Symmetrical Circle	Group D Asymmetrical Circle
GML	FL=(2740.5, 2743.4) PP=(1641.9, 1191.3) Err=0.51	N/A	N/A	N/A
MATLAB CV	FL=(2752.1, 2745.0) PP=(1670.9, 1244.7) Err=0.59	FL=(4024.4, 4030.7) PP=(1670.4, 1222.7) Err=0.24	N/A	N/A
OpenCV	FL=(2709.1, 2707.5) PP=(1631.5, 1223.5) Err=0.88	FL=(4010.4, 4011.4) PP=(1631.5, 1223.5) Err=0.35	FL=(2752.5, 2752.5) PP=(1631.5, 1223.5) Err=0.35	FL=(2673.7, 2673.7) PP=(1631.5, 1223.5) Err=0.42

FL: Focal length; PP: Principal point; Err: Overall Reprojection Mean Error

Group A	GML	MATLAB CV	OpenCV
First 5 images	FL=(2735.0, 2730.3) PP=(1633.6, 1117.1) Err=0.33	FL=(2737.6, 2727.1) PP=(1678.2, 1205.7) Err=0.59	FL=(2732.6, 2725.7) PP=(1631.5, 1223.5) Err=0.75

As can be observed, OpenCV gets identical principal point at every turn, while the other methods don't.

The values of focal length are close for all calibrations expect the two of Group B (may caused by manual focal adjust during picturing, will repeat this test to confirm later). Unfortunately, the calculated focal lengths are quite different from the theoretical value. We tend to believe the camera parameters got online, e.g. CCD size, are not accurate.

The error data are interesting. If we put Group B aside, it seems that the circle boards have lower error than the chess board. But when we reduced the number of images, the chess board group did not enlarge the error.

Conclusions

1. Tools: Each tool has pros and cons. GML is swift and easy to use, but limited on feature. MATLAB CV is user friendly and well integrated with MATLAB, but it is an expensive black box. And you can do anything with OpenCV as long as you want to roll up sleeves. We can make use of them wisely.
2. Methods: we didn't find significant difference between the three boards. The circle boards perhaps offer a little bit more accuracy, but the cost is the computing time. So we can feel ease to stick to the chess board.
3. Number of images: 10 is the rule of thumb. But as we saw in the experiment, number 5 also works well.

References

[1] Estimating the focal length of a photo from EXIF tags, http://phototour.cs.washington.edu/focal.html

[2] Exmor on WIKIPEDIA, https://en.wikipedia.org/wiki/Exmor