NYU CS-GY 6643, Computer Vision
Spring 2017, Prof. Guido Gerig

Assignment 1: Geometric Camera Models & Calibration

Out:	Tue Feb-07-2017
Due:	Wed Feb-22-2017, midnight (theoretical and practical parts)
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Office hours	TA: Tue 3-5pm Rupanta Dutta, Thu 2-4pm Guangqi Chen, MetroTech Center, 10th floor,
	Instructor Mo 3pm-5pm, 2 MetroTech Center, 10.094

Required Readings:	Computer Vision, Texbook old version sections 1-3, new version 1.1-1.3
	Slides to chapters as provided on course web-page
	`http://engineering.nyu.edu/~gerig/CS-GY-6643-S2017/CS-GY_6643_Computer_Vision.html`

Grading

Theoretical problems: These serve for improved understanding of the material using the textbook and all materials provided on our course homepage. Detailed solutions will be provided.

Practical problem: Grading will primarily concern your solution strategy and solution of the camera calibration, and the report that describes your project, your development of the methodology, results, and critical assessments of the results.

Late submissions: Late submissions result in 10% deduction for each day. The assignment will no longer be accepted 3 days after the deadline.

Honor Code, Misconduct: Please read the NYU and School of Engineering misconduct information.

I. Theoretical Problems: Total 10 points

Write a report on your solutions for the theoretical problems. This report can be handed in on paper during the class before the due date, or can be added to the electronic pdf/Word report of the theoretical part (submitted via the NYUClasses handin system).

Problem 1: Pinhole Camera

a "A straight line in the world space is projected onto a straight line at the image plane". Prove by geometric consideration (qualitative explanation via reasoning). Assume perspective projection.

b Show that, in the pinhole camera model, three collinear points in 3-D space are imaged into three collinear points on the image plane (show via a formal solution).

Problem 2: Perspective Projection

See Fig. 1.4 from textbook on page 6 (pdf handouts) for reference.

a) Prove geometrically that the projections of two parallel lines lying in some plane $\prod$ appear to converge on a horizon line H formed by the intersection of the image plane with the plane parallel to $\prod$ and passing through the pinhole.

b) Prove the same result algebraically using the perspective projection equation. You can assume for simplicity that the plane $\prod$ is orthogonal to the image plane (as you might see in an image of railway tracks, e.g.).

Problem 3: Coordinates of Optical Center

Let $\mathcal{O}$ denote the homogeneous coordinate vector of the optical center of a camera in some reference frame, and let $\mathcal{M}$ denote the corresponding perspective projection matrix. Show that $\mathcal{M}\mathcal{O} = 0$. (Hint: Think about the coordinates of the optical center in the world coordinate system, use the notion of transformations between world and camera, and plug this into the projection equation.)

I. Practical Problem: Total 30 points

Problem 4: Camera Calibration

This objective of this assignment is to calibrate a (digital) camera so as to be able to capture images of objects from known locations and with a known camera model.

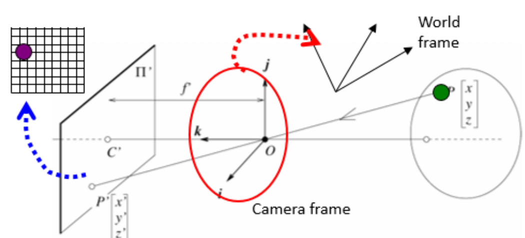

Figure 1: Calibration setup: Take picture from object in world space and calculate world to camera (extrinsic) and camera to pixel raster transformations (intrinsic).

Assignment Requirements:

1. Calibrate your own camera with a fixed focal length with two orthogonal checkerboard planes (see Fig. 2). Real world coordinates (X,Y,Z) are measured via a tape measure or ruler relative to a world coordinate origin of your choice and stored in a file (e.g., tape checkerboard prints to a wall corner or a box, and choose an origin). Corresponding pixel locations are obtained in the image, e.g. by using MATLAB function ginput() to acquire image positions with mouse clicking, and show clicked position with function plot(). This gives us the list of points in world space $P_i = (x, y, c)^T$ and associated points in image space $p_i = (u, v)^T$.

2. Collect a measurement of the distance of the optical center to the world coordinate origin as it will help to discuss the parameters which you estimate. Make sure you don't flip the coordinate systems, i.e. best is to use world coordinates similarly to the camera coordinates that point towards the camera.

3. A calibration pattern can be downloaded at `http://www.vision.caltech.edu/bouguetj/calib_doc/htmls/pattern.pdf`. Best is to use two copies of the pattern and mount it into a straight corner of a wall as shown in the image.

4. Implement the LSE algorithm (discussed in class, ignore radial distortion) to calibrate the dataset, best is to use appropriate Matlab functions to solve the homogeneous overconstrained equation system (SVD).

5. Extract the intrinsic and extrinsic parameters from the calibration matrix following the instructions from the slides, handouts and additional document S.M. Abdullah. Hint: For simple cameras or cell phone cameras, you will need to search for the focal length in the manufacturer's instructions. E.g., a smartphone may have 3.85 mm fixed at aperture f/2.8. Please note that using a camera's optical zooming option results in an unknown focal length, whereas a digital zoom simply reduces image quality by pixel replication. Best is to avoid using any zoom but placing the camera close enough so that the calibration pattern fills a major part of the image.

6. Reconstruct the image coordinates p from the world coordinates P using your estimate of the calibration matrix. Compare the calculated pixel locations to the measured locations and list (e.g. by percentage differences) and/or plot the differences.

7. Write a report including the following:

   a) Brief description about your experimental procedure: data capturing and methods used, type of camera, type of sensor, setup of LSE, solution strategy.

   b) Intrinsic parameters.

   c) Extrinsic parameters.

   d) Discussion and critical assessment of your results: How plausible is each parameter?

   e) Would we want compare the pixel density estimates α and β in terms of sensor size, number of pixels per axis and focal length, we may have to look up those parameters from manufacturer's resources. A good web-site for sensor sizes is `http://www.dpreview.com/articles/8095816568/sensorsizes`, e.g.

Optional bonus question 5

You may take two pictures of the checkerboard calibration pattern, with slighly different camera locations. Rerun the calibration for the second image and compare the intrinsic parameters (extrinsic will differ since you changed your position).

Instructions:

Hardware Preparation/Software Installation: Calibration Pattern can be downloaded at `http://www.vision.caltech.edu/bouguetj/calib_doc/htmls/pattern.pdf`.

1. What you should turn in via NYUClasses hand-in:

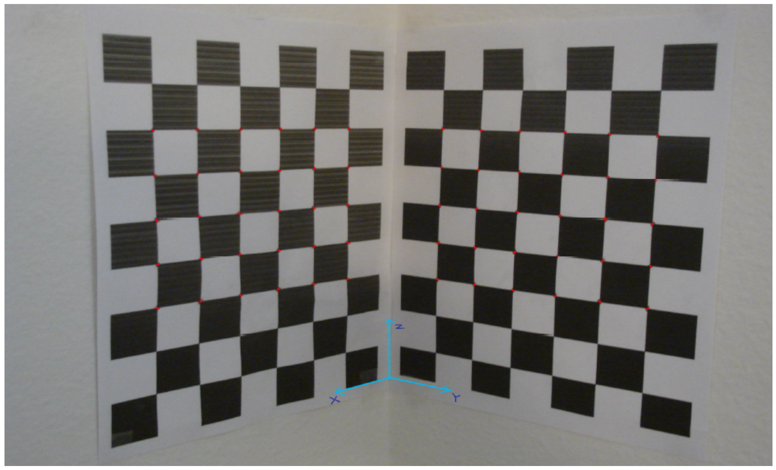

Figure 2: Checkerboard mounted on wall corner with world coordinate system (green) and sample points (red).

- **a)** An electronic copy of the theoretical questions (scan or well readable good contrast picture, use jpg or other compressed format).
- **b)** A report in a printable pdf format including descriptions of how you coded it, images, graphs and tables.
- **c)** Matlab, Octave (or other) code that you used to calculate the calibration parameters, including input images and input lists of points, e.g..