CS 6320, 3D Computer Vision
Spring 2015, Prof. Guido Gerig

Assignment 1: Geometric Camera Models & Calibration

Out:	Wed Jan-28-2015
Due:	Wed Feb-11-2015, midnight (theoretical and practical parts)
TA:	Padmashree Teeka
Office hours	TA MEB 3115: Tue 3-5pm, Thu 11am to 1pm, Instructor Mo/Wed 3pm-5pm

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://www.sci.utah.edu/~gerig/CS6320-S2015/CS6320_3D_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 School of Computing misconduct information.

I. Theoretical Problems

Write a report on your solutions for the theoretical problems. This report can be handed in on paper during the class lecture on the day of the deadline or can be added to the electronic pdf/Word report of the theoretical part (submitted via the CANVAS 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

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 $\mathcal{MO} = 0$. (Hint: Think about the coordinates of the optical center in the world coordinate system and plug this into the projection equation.)

Problem 4: Depth of Field

a) An interesting and desirable property of the pinhole camera is the infinite depth of focus. Give an intuitive explanation.

b) Consider a camera equipped with a thin lens, with its image plane at position z' and the plane of scene points in focus at position z. What is the size of the blur circle b obtained by imaging a point located at position $z + \delta z$ on the optical axis?

c) Use this result to derive the equation for $\triangle Z_0^+$ similarly to the way $\triangle Z_0^-$ is derived in the chapter 2 slides on "Lenses", using the thin lens assumption. Discuss the relationship of lens diameter d and object distance Z_0 to the depth-of-field $\triangle Z_0^+$. (Hint: Z_0^+ and Z_0^- are the two distances farther and closer than Z_0 to the lens, at points P_0^+ and P_0^+.)

I. Practical Problem

Problem 6: 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.
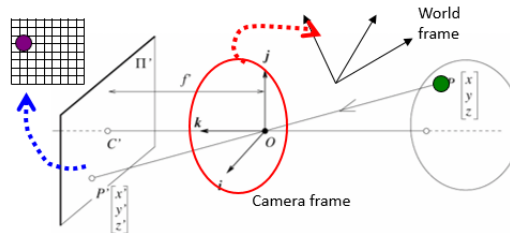

Figure 1: Calibration setup: Take picture from object in world space and calculate world to camera (extrinsic) and camera to pixel raster transformations (intrinsic).

Assignment Requirements:

1. Calibrate your own camera with a fixed focal length with two orthogonal checkerboard planes (see Fig. 2). Real world coordinates are measured via a tape measure or ruler relative to a world coordinate origin of your choice and stored in a file. 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., the iphone has 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 up 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.

8. What you should turn in via the canvas hand-in:

a) An electronic copy of the theoretical questions (scan or well readable good contrast picture).

b) A report in a printable pdf format including descriptions of how you coded it, images, graphs and tables.

c) Matlab (or other) code that you used to calculate the calibration parameters.
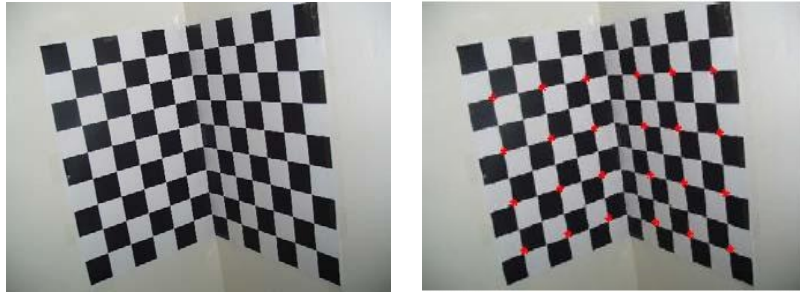

Figure 2: Checkerboard mounted on wall corner (left) and manually defined points in the camera image (right).

Instructions:

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