

CS 6320, 3D Computer Vision

Spring 2012, Prof. Guido Gerig

Assignment 1: Geometric Camera Models & Calibration

Out: Monday Jan-30-2012
Due: Monday Feb-13-2012, midnight (theoretical and practical parts)
TA: Kathlea Quebbeman
Office hours (TA and Instructor): Mo/Tue 3pm to 5pm

Required Readings: Computer Vision, Richard Szelisky, Chapter 2
Slides to chapters as provided on course web-page
(http://www.sci.utah.edu/~gerig/CS6320-S2012/CS6320_3D_Computer_Vision.html)

Grading

Theoretical problems: These serve as your own study 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 and acknowledge that you understood by signing the form (see class web-page). Bring the signed form to class, latest on February 13. The assignment will not be graded without this document with your personal signature.

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 Monday February 13 or can be added to the electronic pdf/Word report of the theoretical part (submitted to the CADE handin system, deadline Monday Feb. 13 midnight).

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 Π appear to converge on a horizon line H formed by the intersection of the image plane with the plane parallel to Π and passing through the pinhole.
- b) Prove the same result algebraically using the perspective projection equation. You can assume for simplicity that the plane Π is orthogonal to the image plane (as you might see in an image of railway tracks, e.g.).

Problem 3: 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 ΔZ_0^+ similarly to the way ΔZ_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 ΔZ_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^- .)

Problem 4: 3D Rotation

- a) Show that 3D Rotations expressed as Rz.Ry.Rz are not commutative (i.e. the order of transformations does matter).
- b) Given very small angles of rotation which is often found as misalignment, where $\cos(\text{angle}) \rightarrow 1$ and $\sin(\text{angle}) \rightarrow \varepsilon$. Would that have an effect on the commutativity?

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.

Assignment Requirements:

1. Calibrate your own camera with a fixed focal length with two orthogonal checkerboard planes (see Fig. 1). 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. 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.
3. 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).
4. Extract the intrinsic and extrinsic parameters from the calibration matrix following the instructions from the slides and handouts. 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.
5. 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 and/or plot the differences.
6. Write up a report including the following:
 - a) Brief description about your experimental procedure: data capturing and methods used, setup of LSE, solution strategy.
 - b) Intrinsic parameters.
 - c) Extrinsic parameters.
 - d) Discussion of results: How plausible is each parameter?
7. What you should turn in (CADE lab handin):
 - a) A report in a printable pdf/Word format including descriptions, images, graphs and tables, and including also a print of the Matlab (or other) code.
 - b) Matlab (or other) code that you used to calculate the calibration parameters.

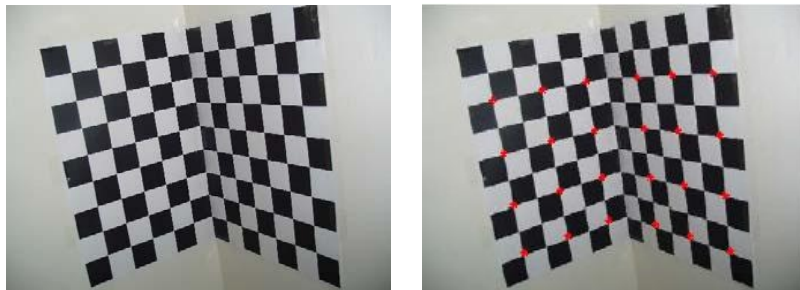


Figure 1: Checkerboard mounted on wall corner (left) and manually defined points in the camera image (right).

Instructions:

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

Bonus Problem 7: Optional bonus question, for those who want to compare own results to existing calibration software.

You can compare your LSE solution with the results of an existing software package:
For calibration software, you can either:

- Download the Bouguet MATLAB camera calibration toolbox from http://www.vision.caltech.edu/bouguetj/calib_doc/index.html,
- Install the Intel OpenCV Library from <http://sourceforge.net/projects/opencvlibrary/> on your MS Windows computer. Although working with the Linux version is possible, experience shows that getting a webcam to work in Linux and OpenCV is a lot more work and therefore we do not recommend it in the beginning.