CS 6968, 3D Computer Vision
Fall 2009, Prof. Guido Gerig

Assignment 1: Geometric Camera Models & Calibration

Out:	Thursday Sept-10-2009
Due:	Thursday Sept-24-2009 (theoretical and practical parts)
TA:	Evrard Ohou (eohou@cs.utah.edu)
Office hours:	Tue/Thu 2pm to 3pm

Required Readings: Computer Vision, Forsyth & Ponce, Chapters 1 to 3
Slides to chapters provided on WebCT

Grading

Theoretical problems: These serve as your own study of the material using the textbook and all materials provided on WebCT. The theoretical questions will not be graded in details but just listed as completed. 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.

I. Theoretical Problems

Problem 1: 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 (problem 1.2 F&P book).

b) Prove the same result algebraically using the perspective projection Eq. (1.1). You can assume for simplicity that the plane $\prod$ is orthogonal to the image plane (problem 1.3 F&P book).

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 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 1 slides, 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^+.)

Problem 4: Properties of transformations

Show that the set of matrices associated with rigid transformations and equipped with the matrix product forms a group (problem 2.3 F&P book).
(Hint: See definitions groups and rigid transformations pages 26/27 of F&P book.)

Problem 5: Perspective projection equation: Position of camera's 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 $\mathcal{M}\mathcal{O} = 0$ (problem 2.9 F&P book).

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 and stored in a file. Corresponding counterparts 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`.

3. Implement the LSE algorithm (chapter 3, ignore radial distortion) to calibrate the dataset, best is to use appropriate Matlab functions to solve the homogeneous overconstrained equation system.

4. Extract the intrinsic and extrinsic parameters from the calibration matrix following the instructions from the textbook, slides and handouts.

5. Try to reconstruct the image coordinates p from the world coordinates P using the calibration matrix. Compare the calculated pixel locations to the measured locations and list 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:

   a) A report in a printable pdf/Word/html 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.

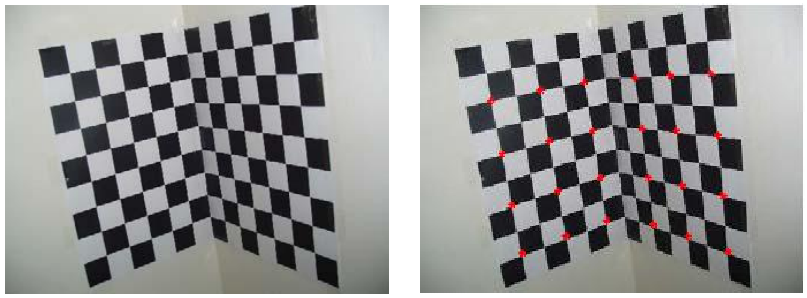

Figure 1: Checkerboard mounted on wall corner (left) and manually defined points in the camera image (right).

Instructions:

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

Problem 7: Optional, only for those who want to compare to existing 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.