CS-512 – Assignment 4

Camera calibration

Due by: November 24, 2020

Review questions

Answer the following questions. Make sure that your answers are concise. In questions requiring explanations, make sure your explanations are brief.

1. Camera calibration 1

   (a) Given the projection equation $p = MP$ explain the problems of: forward projection, calibration, and reconstruction. Which problem is the easiest? Which is the most difficult?

   (b) Explain what is the necessary input for camera calibration.

   (c) Explain the steps in the non-coplanar calibration algorithm.

   (d) Given a known projection matrix with rows $(1, 2, 3, 4)(1, 0, 3, 4)(1, 1, 1, 1)$ and a world point $P_i = (1, 2, 3)$ what are the 2D image coordinates of P_i after projecting it. Make sure to convert P_i to homogeneous coordinates before projecting it.

   (e) Given the corresponding world-image points: $(1, 2, 3) \leftrightarrow (100, 200)$ write the first two lines of the matrix that needs to be formed for solving for the unknown projection matrix M.

   (f) What is the minimal number of points that is necessary to be able to find a unique solution for M. How is the solution obtained?

   (g) Explain the principal that is used to extract the unknown camera parameters from the projection matrix M.

   (h) Explain how to compute the quality of the projection matrix M estimate.

   (i) Explain the principal of planar camera calibration. How does planar camera calibration differ from non-coplanar one?

   (j) Explain the difference between the homography (2D projective map) H and the projection matrix M. What is the assumption that is used to make sure we deal with homography matrices?

2. Camera calibration 2

   (a) Given a pair of corresponding image and world points $(1, 2)$ $(3, 4, 5)$ respectively, write the first two rows of the matrix that has to be constructed to solve for the unknown coefficients of the projection matrix.

   (b) Given the first two rows in the estimated projection matrix M, $(1, 2, 3, 4)$ and $(2, 3, 4, 5)$ respectively, find the camera parameters u_0 and v_0 (coordinates of principal point) of the camera.

   (c) Given a pair of corresponding image and world points $(1, 2)$ $(3, 4, 5)$ respectively, and estimated projection matrix M, with rows $(1, 2, 3, 4)$, $(2, 3, 4, 5)$, and $(3, 4, 5, 6)$, Find the projection error of the matrix M.

(d) After performing calibration, let the obtained rotation of the world with respect to the camera be given by $I + Q$ where I is a $4x4$ identity matrix and Q is a $4x4$ matrix having in its $(0, 0)$ element the number 5 and zeros elsewhere. Let the obtained translation of the world with respect to the camera be given by the vector $(1, 2, 3)$. Compute the rotation and translation of the camera with respect to the world.

(e) Given a pair of corresponding image and world points $(1, 2)$ $(3, 4, 0)$ respectively, that are used for planar calibration, write the first two rows of the matrix that has to be constructed to solve for the unknown coefficients of the homography matrix.

3. Multiple view geometry 1

   (a) Explain the difference between sparse and dense stereo matching. What are the advantages/disadvantage of each approach?

   (b) Explain how normalized cross correlation (NCC) and sum of square distances (SSD) can be used for point matching. What is the isk in allowing the search space to be the entire image? How can the search space be reduced to a line?

   (c) Given an axis aligned stereo pair with corresponding points $(100, 200)$ and $(103, 200)$ in the left and right images respectively, compute the depth (z-coordinate) of the 3D point that produced this projection. Assume that the focal length of both cameras is 10, that the baseline is 100, and that we are working in camera coordinates.

   (d) Explain the ambiguity problem in stereo matching.

   (e) Given R_l, T_l and R_r, T_r (rotation and translation of left/right cameras with respect to world), Write the expression for the rotation and translation of the right camera with respect to the left camera.

4. Multiple view geometry 2

   (a) Given an axis aligned stereo system with focal length of $10mm$, and baseline $20mm$, compute the depth of a point with disparity of $30mm$.

   (b) Let A and B be the vectors $(1, 2, 3)$, $(2, 3, 4)$, respectively. Write the matrix that if multiplied by B will result in the cross product AxB

   (c) Let F be a fundamental matrix with rows $(1, 2, 3), (2, 3, 4), (3, 4, 5)$. Let $(1, 2)$ and $(2, 3)$ be corresponding left and right points. Compute the value of $p_r^T F p_l$.

   (d) Given corresponding left and right points $(1, 2)(2, 3)$, respectively, write the respective row the in the matrix that has to be formed to solve for the fundamental matrix.

Programming questions

In this assignment you need to implement a camera calibration algorithm under the assumption of noisy data. You need to implement either planar calibration or non-coplanar calibration. Note: you only need to implement one calibration method. Robust estimation through RANSAC should be used to eliminate outliers. The program should satisfy the following specifications:

1. Write a program to extract feature points from the calibration target and show them on the image. You may use the openCV functions to do so (e.g. `cvFindChessboardCorners`, `cvFindCornerSubPix`, `cvDrawChessboardCorners`). Alternatively write a program that allows you to interactively mark the points on the image. Save the image points detected and/or manually entered in a file.

2. Write a second program to compute camera parameters as described below that uses the point files produced by the first program.
   - Program arguments: In the case of non-planar calibration the program argument is the name of a single point correspondence file. In the case of planar calibration the program arguments are the names of 3 point correspondence files specifying correspondence in 3 different views. A point correspondence file is a text file containing in each row a pair of corresponding points (3D-2D) as real numbers separated by space. The first 3 numbers in each row give the x, y, z coordinates of a 3D world point whereas the last 2 numbers give the x, y coordinates of the corresponding 2D image point.
   - After completing the calibration process, the program should display the intrinsic and extrinsic parameters of the camera as determined by the calibration process. The program should compute and display the mean square error between the known and computed position of the image points. The computed position should be obtained by using the estimated camera parameters to project the 3D points onto the image plane. You do not need to address radial lens distortion in your calibration.
   - Write the programs using Python with OpenCV. You may not directly use the openCV calibration function (e.g. `cvCalibrateCamera`). However, you may use this function for verification.
3. Implement the RANSAC algorithm for robust estimation. Your implementation of the RANSAC algorithm should include automatic estimation of the number of draws and of the probability that a data point is an inlier. The final values of these estimates should be displayed by the program. In your estimation of these values, assume a desired probability of 0.99 that at least one of the draws is free from outliers. Set a maximum number of draws that can be performed. When testing the program on noisy data you will note that RANSAC is not handling well one of the provided cases. Explain the reason for RANSAC not being able to handle this case properly. Parameters used in the RANSAC algorithm should be read from a text file named 'RANSAC.config'.
4. Data files for testing the calibration are available on the course website. In addition to testing your program with these files, make sure to test it with real images of a calibration target that you generate. Test files: `http://www.cs.iit.edu/~agam/cs512/data/calibration/index.html`

Submission Instructions

Please follow the submission instruction of assignment 1.