Computer Vision

EECE 4354/5354 Spring 2019

Homework 3: Camera Calibration and Stereopsis

Due Wednesday 3 April 23:59

The goal of this homework is to

1. Learn how to calibrate a camera and use the calibration data.
2. Test a block matching stereopsis procedure.
3. Code and test an epipolar stereopsis program that uses matched points.
4. Code and test a single point stereopsis program.
5. Grad Students: read three designated papers and write synopses of them.

With the exception of the grad student problem, you may work on this assignment with a partner (or alone if you prefer). If you do work with a partner, you may develop solutions together, and share code, but each of you must write your own reports on the results. Also name your partner in the report.

A partner is especially helpful in calibrating your camera. Each of you must calibrate your own cameras. You may use both cameras to capture stereo image pairs if you like.

If you use code that you did not write, cite its source including the URL from which you downloaded it. It is highly likely that you will have to modify any such code, at least a little. Comment out any original lines that you did not use or that you modified. Substitute yours with a comment indicating that you made the modification. The comment can be as simple as *e.g.* "# The next three lines were modified by Alan Peters". If you add a big block of code put a comment at the beginning of the block *e.g.* "# The following code was added by Alan Peters" and at the end of the block, "# End of code by Alan Peters". Please note that you must provide a detailed description of what the program does section by section, whether you wrote it or not. I need to be able to ascertain that you know exactly what the program does. That will count for a substantial part of the grade.

1. **Camera calibration**

   Download and print out a calibration "chessboard." (The file, "pattern.pdf" contains one.) Take 30 pictures of the board being sure to cover the entire visual field of the camera. (Not every image need cover the field, but over the thirty, it should be covered). The following page on stackoverflow.com has an excellent description of a good way to do this:

   "https://stackoverflow.com/questions/12794876/... ...how-to-verify-the-correctness-of-calibration-of-a-webcam/12821056#12821056"

   (There is a direct link on the Brightspace content page.) Use either the OpenCV cameraCalibration.py, the CalTech package for MATLAB , or MATLAB 's Camera Calibrator app. Both the OpenCV program and the MATLAB app will reject any images for which it cannot find corners. You need at least 20 good images. Make a 5-by-4 montage of thumbnails of 20 of your calibration images an include it in your report.

   Include the camera parameters in your report with a description of what each one is and why it is needed.

2. **Block matching stereopsis**

   (a) Make a stereo pair of images from the camera(s) you just calibrated. View them using cross-eyed stereo to verify that they are in fact a good stereo pair with a wide range of depths.. You may also make a red-cyan anaglyph from them and use red-cyan glasses to make sure there is a good range of depths represented in the pair. Include the images in your report.

(b) Use a simple block matching program (such as OpenCV's "StereoBM") to compute a disparity map from your image pair. Experiment with the block size and the range of disparities to get as good a map as you can. Experiment with blurring the images first to see if that makes the results better or worse.

Grad students: Generate a gradient magnitude image from each of the originals and see if those work any better.

3. **Epipolar stereopsis**

This part of the assignment is to be done in Python using OpenCV.

(a) Use one of the programs that you wrote for Assignment 2 to generate a set of matched key-points in your stereo pair. Display a subset of the matched points superimposed over the image pair (in one image that contains the pair side-by-side) with lines connecting them.

(b) Use the camera matrix and distortion coefficients that you derived for your camera in problem 1 to undistort both the key-points and the images Display the undistorted images.

(c) Generate a fundamental matrix (FM) from the undistorted key-points include the matrix (its values) in your report. Include left and right images that show the epipolar lines for a subset of the key-points

(d) Generate camera projection matrices for each of the cameras.

(e) Use triangulation to estimate the 3D positions of the key-points in the scene. Then use the camera projection matrices to project the 3-D points back onto the the right and left images. For both images compute the norm of the error between each original key-point location and the reprojected 3D points. Compute the average of the reprojection errors for each image and include them in the report. If you have done everything correctly that error should be less than one pixel.

(f) Generate left and right homography matrices and include them in your report.

(g) Rectify the left and right images using the homography matrices. Include the rectified images in your report. Display them side-by-side in one image. Draw 10-15 horizontal lines across the image pair to demonstrate that the rectification is correct – that the scan lines match. If they do not, you may have to adjust the homography matrix for one of the images to shift it up or down. Do that, if necessary and display the resulting images as before

(h) Using the rectified images, generate a disparity map of the scene. Grad students: use the disparity map to generate a point cloud. Show the point cloud from 3 or more different perspectives. Comment on its accuracy in conveying the 3d structure of the scene.

4. **Point-based stereopsis** Extract the rotation matrix and translation vector from the right camera projection matrix. Visually select four point pairs that are on objects that are clearly at different distances. Measure their pixel locations in each image. Use the Haralick and Shapiro single point stereopsis method to compute the depth of the each. You will need to write your own program to implement the procedure. Include your code, the point pair pixel locations, and the depths in your report.

5. **Additional problem for graduate students**

Read the three following papers and write short summaries of each. The summary should include what you think are its main ideas and your interpretation of them.

(a) Louong, Quan-Tuan and Olivier Faugeras, "The fundamental matrix: Theory, algorithms, and stability analysis," *International Journal of Computer Vision*, 17, 43-75 (1996).

Read and report on the first three sections – the first 12 pages.

(b) Hartley, Richard I., "In defense of the Eight-Point Algorithm," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 19, No. 6, June 1977.

Try computing your fundamental matrix from problem 3 without normalizing the points and compare the results with those from problem 3. In particular, compare the rotation matrices, the translation vectors, and the residual camera matrices. Comment on the results.

(c) Loop, Charles and Zhang, Zhengyou, "Computing rectifying homographies for stereo vision," Technical Report MSR-TR-99-21, Microsoft Research, Microsoft Corporation, One Microsoft Way, Redmond, WA 98052 (1999)

Compute the rectifying homographies from the fundamental matrix in problem 3 using the method of this paper and compare the results with those computed by OpenCV.

Rules for homework assignments

1. Perform all the tasks listed in the instructions.
2. Explain the tasks you performed in detail.
3. Answer in writing in your report all the questions asked in the instructions.
4. Include in the report the original images you used and those resultant images that were specified in the instructions.
5. Include all computer code **that you wrote** and used, clearly documented, in an appendix.
6. Write your results in a clear homework report format using MS Word, Google Docs, LaTeX, or any other word processor with which you can embed images in text. I prefer that the reports be submitted in .pdf format, but that is not required.
7. Assignments are due at midnight on the day specified in the instructions or in class. The grade on a homework report will be reduced by 10 points (out of 100) for every day (24 hours) that it is late. See the syllabus for an exact breakdown of the penalties.