ECE 661: Homework 6
Due November 9th

Problem:

This homework requires you to implement Zhengyou Zhang's camera calibration procedure, which can be downloaded from http://engineering.purdue.edu/ece661/homework/zhang_camera_calibration.pdf

Let's say you want to calibrate a camera at home or in your lab. You'd like to find all five of its intrinsic parameters and also find its six extrinsic parameters with respect to some world reference. Toward that end, download the calibration pattern from http://engineering.purdue.edu/ece661/homework/hw6_calibration_pattern.pdf, print a copy and mount it on a wall somewhere. Then aquire images of the pattern using this procedure:

1. Place the camera at a marked location on a table or a tripod and record an image of the calibration pattern. The extrinsic pose parameters you will calculate will be for this location of the camera.
2. Now remove the camera from tripod and freely more and rotate it so that it assumes different orientations vis-a-vis the calibration pattern. Record an image of the calibration pattern for each position/orientation of the camera. You will need about 20 images in all.

To perform the calibration, we need to establish correspondences between points in the image and the real 3d world coordinates. We will use the corners of the boxes in the calibration pattern as these points. The world coordinates can be obtained by selecting one corner of the pattern to be the origin and then using a ruler to measure the spacing to the other corners (this will give you 2D coordinates, x and y. To get z just set it to 0 for all of the points).

Next we need to identify the corners in the images. Use the following steps:

1. Apply the Canny edge detector to the images (you can use the OpenCV function *Canny*).
2. Use the Hough transform to fit straight lines to the Canny edges (you can use the OpenCV function *HoughLines2*).
3. Group the lines into horizontal and vertical line sets.
4. Sort each set of lines (e.g. top to bottom for horizontal and left to right for vertical).

5. If two or more lines are very close then they probably correspond to the same line in the physical world. In this case you should choose one of them and remove the rest.

6. Define the corners as the intersections of the fitted straight lines. Make sure that the order of the intersections matches the order of the world coordinates.

7. (optional) Use a Harris corner detector to find the strongest nearby corner to each of the intersections from 6 and use this as the true corner location. This step is particularly important if there is a lot of radial distortion.

Once you have correspondences, use section 3.1-2 of Zhengyou Zhang's paper to solve for the camera intrinsic parameters (K in the textbook or A in the paper) and the extrinsic paramters R_i, $\mathbf{t}_i$ for each captured image. For minimizing Equation (10) in the paper you are welcome to use any of the nonlinear least squares solvers you explored in homework 5.

For extra credit, also estimate the radial distrotion parameters in the calibration as described in section 3.3 of the report.

Solution:

You should turn in a report in pdf format of your homework solution using electronic turn-in. The report should include:

1. A writeup of the calibration procedure including any relevant equations.

2. Download the set of 40 images at `http://engineering.purdue.edu/ece661/homework/ECE661_hw6_images.zip` and perform a camera calibration on them.

   (a) Include in your report the intrinsic camera matrix K as well as R and **t** for the first image (*P1010001s.jpg*)

   (b) For at least 4 of the images show the identified corners in green and the reprojected corners (obtained by projecting the world coordinates into the image) in red.

3. Repeat step 2 but with images taken by your own camera. Make sure you use at least 20 images.

4. Your source code.

As always you may look at solutions from previous years but the work you do must be your own. Note that this homework is most similar to homework 8 from 2008.

Some Example Images:

From left to right: input, Canny edges, Hough lines, identified corners, reprojected points