ECE4580 Homework #5

Due: Feb. 16, 2017

Problem 1 [35 pts] Now that you have practice with simple calibration using the singular value decomposition (SVD), it's time to calibrate a stereo rig that exists in your little vision lab (depicted in Figure 1). Since you bought two of the exact same model of camera, you've found that the intrinsic camera matrix for the left and right camera is the same:

$$\Psi = \begin{bmatrix} 500.000 & 0.000 & 320.000 \\ 0.000 & -500.000 & 240.000 \\ 0.000 & 0.000 & 1.000 \end{bmatrix}$$

and you know that the following world points

$$\left\{ \begin{matrix} 2.0 \\ 7.0 \\ 5.0 \end{matrix} \right\}, \quad \left\{ \begin{matrix} 8.0 \\ 6.0 \\ 4.0 \end{matrix} \right\}, \quad \left\{ \begin{matrix} 3.0 \\ 2.0 \\ 4.0 \end{matrix} \right\}, \quad \left\{ \begin{matrix} 4.0 \\ 8.0 \\ 4.0 \end{matrix} \right\}, \quad \left\{ \begin{matrix} 6.0 \\ 8.0 \\ 2.0 \end{matrix} \right\}, \quad \left\{ \begin{matrix} 5.0 \\ 5.0 \\ 2.0 \end{matrix} \right\}, \quad \text{and} \quad \left\{ \begin{matrix} 5.0 \\ 4.0 \\ 2.0 \end{matrix} \right\}.$$

project to the following image plane points

$$\left\{ \begin{matrix} 384.0 \\ 137.0 \end{matrix} \right\}, \quad \left\{ \begin{matrix} 189.0 \\ 169.0 \end{matrix} \right\}, \quad \left\{ \begin{matrix} 22.0 \\ 287.0 \end{matrix} \right\}, \quad \left\{ \begin{matrix} 358.0 \\ 172.0 \end{matrix} \right\}, \quad \left\{ \begin{matrix} 313.0 \\ 243.0 \end{matrix} \right\}, \quad \left\{ \begin{matrix} 215.0 \\ 298.0 \end{matrix} \right\}, \quad \text{and} \quad \left\{ \begin{matrix} 165.0 \\ 316.0 \end{matrix} \right\}.$$

for the first camera, and to the following image plane points

$$\left\{ \begin{matrix} 579.0 \\ 178.0 \end{matrix} \right\}, \quad \left\{ \begin{matrix} 433.0 \\ 250.0 \end{matrix} \right\}, \quad \left\{ \begin{matrix} 253.0 \\ 375.0 \end{matrix} \right\}, \quad \left\{ \begin{matrix} 597.0 \\ 220.0 \end{matrix} \right\}, \quad \left\{ \begin{matrix} 580.0 \\ 309.0 \end{matrix} \right\}, \quad \left\{ \begin{matrix} 457.0 \\ 379.0 \end{matrix} \right\}, \quad \text{and} \quad \left\{ \begin{matrix} 408.0 \\ 399.0 \end{matrix} \right\}.$$

for the second camera, as best as you can tell (there should be a file called `stereo_prob.mat` with this data). Note that the intrinsic camera matrix has a negative focal length in the second row. This is because of the fact that Matlab uses a reverse orientation for the matrices. It is normal and OK since the image coordinate are given in Matlab's matrix coordinate system, which Matlab calls ij-coordinates versus xy-coordinates. You can plot points in ij-coordinates by typing "`axis ij`" and in xy-coordinates by typing "`axis xy`" (this is the default view mode for plotting points).

Your job is to identify what the positions and orientations are of the two cameras. In your lab setup, knowing these transformation parameters will help you use triangulation to compute the distance of a point seen in both cameras. What are the (R, T) pairs for each camera, with respect to the world frame? Also what is the (R, T) pair for the right camera relative to the left camera?

Note: *Recall that if you solve using what was discussed in class, you will solve for the world frame relative to the camera frame, which is the inverse of what's really asked for. This was discussed a bit in the earlier extrinsic parameters problem. Sometimes it is easier to solve for the inversed R and T, then build the full g matrix and invert it to get the answer in the wrold coordinate frame.*

Testing: *You can always test your solution by seeing if the world points project properly onto the image coordinates for both cameras.*

Code Stub: *There should be a code stub called* `extrinsicCalib.m` *that you can use. Some of the code from the earlier SVD problem can be recycled.*

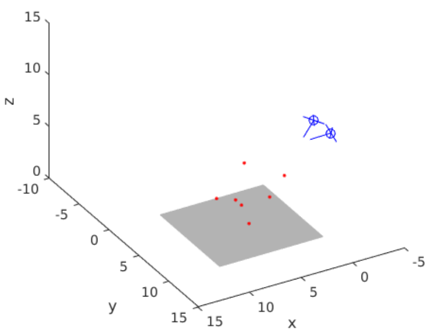
Problem 2. [20 pts] (*Surveillance Setup*) Recall the earlier problem where you had a surveillance camera setup. You had calibrated it for use in some code you have. However the earlier calibration work was incomplete because it did not extract the intrinsic from the extrinsic parameters. Use the data that you had before, plus the QR decomposition to decompose the camera projection matrix M into its different components.

Recall that your measurements were as follows. The world coordinates

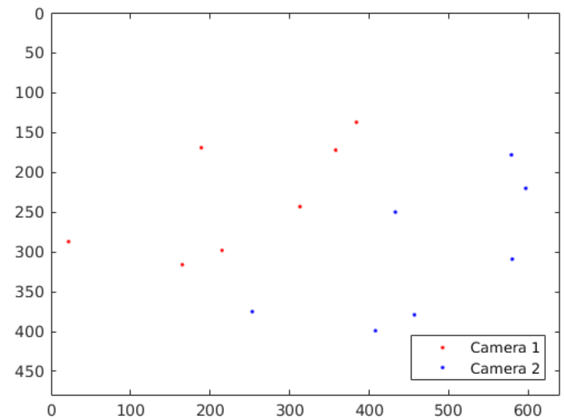
$$p_1^W = \left\{ \begin{matrix} 13.18 \\ -3.362 \\ 12.48 \end{matrix} \right\}, p_2^W = \left\{ \begin{matrix} 24.75 \\ -11.790 \\ 15.57 \end{matrix} \right\}, p_3^W = \left\{ \begin{matrix} 14.47 \\ -9.918 \\ 5.456 \end{matrix} \right\}, p_4^W = \left\{ \begin{matrix} 15.83 \\ -11.390 \\ 15.78 \end{matrix} \right\}, p_5^W = \left\{ \begin{matrix} 22.51 \\ -1.419 \\ 15.30 \end{matrix} \right\}, p_6^W = \left\{ \begin{matrix} 12.55 \\ -5.846 \\ 12.21 \end{matrix} \right\}.$$

led to the following image coordinates,

$$r_1 = \left\{ \begin{matrix} 157.0000 \\ 376.0000 \end{matrix} \right\}, r_2 = \left\{ \begin{matrix} 92.0000 \\ 139.0000 \end{matrix} \right\}, r_3 = \left\{ \begin{matrix} 416.0000 \\ 97.0000 \end{matrix} \right\}, r_4 = \left\{ \begin{matrix} 3.0000 \\ 26.0000 \end{matrix} \right\}, r_5 = \left\{ \begin{matrix} 91.0000 \\ 387.0000 \end{matrix} \right\}, r_6 = \left\{ \begin{matrix} 167.0000 \\ 238.0000 \end{matrix} \right\}.$$



(a) Stereo camera setup with test points.



(b) Image coordinate projections of the test points.

Figure 1: Depictions of the setup for Problem 1.

Complete the full camera calibration and provide both the Ψ matrix plus the $D = [R \mid T]$ matrix.

Note: To avoid having to enter the world points and the image coordinates, recycle the earlier Matlab file `calib01.mat`*. Also, to make your life easier, you may want to consider using the code stub* `calibrateFull.m` *(uploaded). Some part of it can be recycled from last week's homework.*

Problem 3. [10 pts] (*Stereo Sequence*) Let's investigate this epipolar line stuff given two cameras, let's call them left and right. Recall that the epipolar line for the right image is generated by projecting onto the right camera the back-projected ray associated to an image point in the first camera. What we will do is generate a few back-projected points and see if they really generate a line. From our earlier stereo problem (please use those transformations and world coordinates), we found out that the third of the three points actually projected onto the image plane.

Let the intrinsic parameters for both cameras be:

$$\Psi = \begin{bmatrix} 400 & 0 & 360 \\ 0 & -400 & 240 \\ 0 & 0 & 1 \end{bmatrix},$$

and that the image dimensions for both cameras are $720x480$ (width x height).

Consider the visible point, whose coordinates in the camera frame were

$$p^L = \left\{ \begin{matrix} 16.596 \\ -15.538 \\ 63.748 \end{matrix} \right\}$$

and whose coordinates in the world frame were

$$p^W = \left\{ \begin{matrix} 33.100 \\ -39.100 \\ 38.500 \end{matrix} \right\}.$$

What you should do is take the point in the (left) camera frame and multiply it by several scalar factors. The easiest would be to use `linspace` to generate some scalar factors going from 0.5 up to say 100, evenly spaced by 1 or 2. (You could also generate a linspace from -1 to 8 in increments of 0.20 and then take 2 to the power of this vector in order to get them evenly spaced as muliplicative factors). Multiply the point p^L by these factors to get a bunch of points along the ray (all of these points would project to the same image coordinates in the left camera).

Take these points given in the left camera frame and then project them to the right camera frame. Plot only the ones that are visible (based on the image dimensions). You should see them generate a line. This line is the epipolar line.

Note: You should be able to use both the Matlab file `stereo01.mat` *from your earlier homework, plus your (or my) solution to get this problem going.*

Problem 4. [20 pts] Now that you've done the first week of the learning module, go through the second week. Stick with your partner if you elected to have one. The group submission should reflect the work of the group, and should also be submitted individually with the name of your partner in the document. If submitting video or links to video for the pair, then only one member need to do so, while the other member should just note as much.

The expectation for deliverables should remain the same:
The submission can be published in with the main homework document, or submitted separately. Whatever makes most sense for the particular topic. For these submissions though, the expectation is that what gets turned in will be a little more extensive than the normal homework in terms of documentation of outcomes. You should roughly reiterate the activity, discuss how it was accomplished, demonstrate through images (if possible) the functionality, then briefly note any observations (including cases where it may not work so faithfully, or what is needed to work very well). In many cases, for discussing the how, including some kind of English-styled algorithm or pseudocode would be appropriate.

Make sure to add a brief video if there is video processing; only one of you needs to upload the video or have a link to some online video (past submissions have used youtube). For those using Matlab, you can use their video writer to save the image sequences being output to a figure. For others, there are usually ways to record the desktop.

If the particular activity specifies to demo, the make sure to demo during inquiry hours, or schedule a convenient time to do so otherwise. In some cases, video demonstration will be sufficient, but you are advised to e-mail to confirm so.