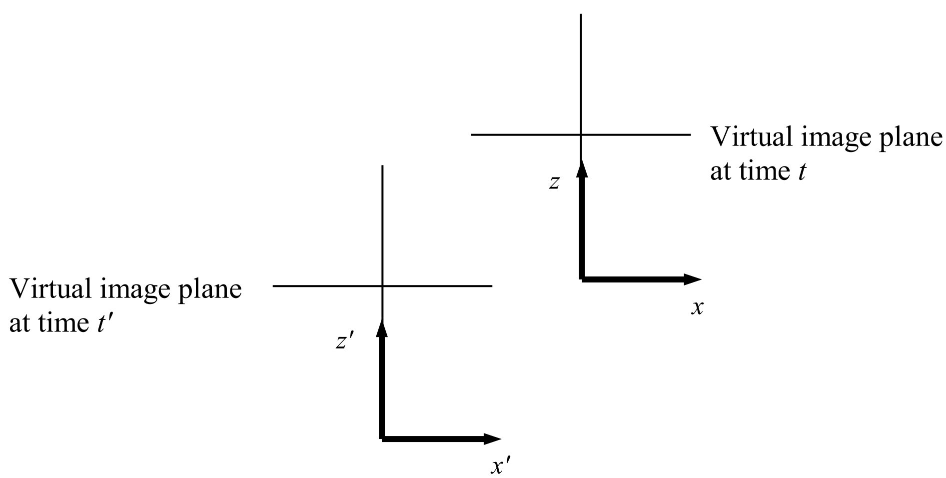
ECE 4554 / 5554: Computer Vision: Homework 4

Fall 2022

Instructions

- The assignment is due at Canvas on Oct. 12 before 11:59 PM. Late submissions are allowed at the cost of 1 token per 24-hour period. A submission received only a minute after midnight will cost an additional token. Be careful that you do not let your token count drop below zero.
- Please review the Honor Code statement in the syllabus. This is an "individual" assignment, not a "team" assignment. The work that you submit for a grade must be your own.
- Concerning the Honor Code, a *new requirement* is that if you borrow Python code from ANY source except the instructor, you must provide comment lines in your programs to state where you obtained that code. Failure to cite sources of code that you borrowed (even if you made modifications) will be considered a violation of the Honor Code.
- The assignment consists of 4 analytical problems, which are presented here, and 2 "machine problems", which require work using Colab. Notice that one of the analytical problems is required for 5554 students, but is optional (extra credit) for 4554 students.
- For the analytical problems, prepare an answer sheet that contains all of your written answers in a single file named `Homework4_Problems1-4_USERNAME.pdf`. (Use your own VT Username.) Show your work. Handwritten solutions are allowed, but they must be easily legible to the grader.
- Your solutions to the machine problems should be submitted together as one Jupyter notebook file. Details are provided at the end of this assignment. For any coding problem, the notebook file that you submit must be compatible with Google Colab. Your code should execute after the grader makes only one change to your file, which is the location of the working directory. If the notebook file does not execute, then the grader will be tempted to assign a grade of zero for the coding problems.
- After you have submitted to Canvas, please download the files that you submitted and verify that they are correct and complete. *The files that you submit to Canvas are the files that will be graded.*

Problem 1. (10 points.) Assume that 2 images have been captured using a single camera at 2 different time instants, t' and t. Between these 2 points in time, the camera has translated (but not rotated) as illustrated in the birds-eye view that appears below: in the direction x' by the distance f (the focal length), and also in the direction z' by the distance f. There is no translation in the direction y'.



a) Find the essential matrix that relates these two camera positions.

b) Solve for the epipole in the image at time t. Clearly explain your choice of image coordinates.

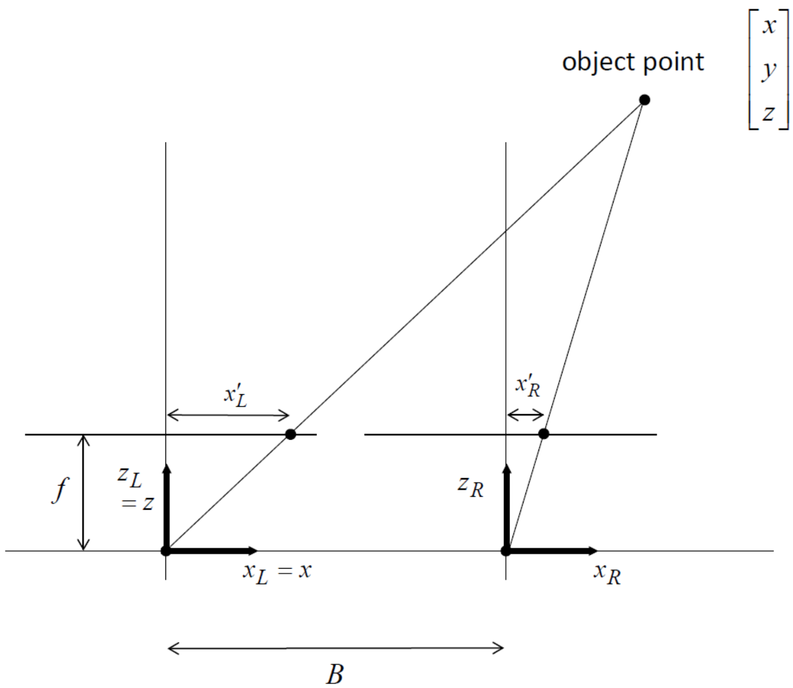
Problem 2. (10 points.) Consider a calibrated stereo camera arrangement, and assume that you have been given the translation vector t and rotation matrix R that relates the two cameras:

$$t = \begin{bmatrix} 3 \\ 2 \\ 1 \end{bmatrix} \qquad R = \begin{bmatrix} \cos(45°) & -\sin(45°) & 0 \\ \sin(45°) & \cos(45°) & 0 \\ 0 & 0 & 1 \end{bmatrix}.$$

a) Solve for the essential matrix.

b) Compute the rank of your answer to part (a) using singular value decomposition, SVD. If you use computational tools, cut-and-paste your code as part of your answer. (If you encounter very small values such as 10^{-15} in your calculations, consider those values to be zero.)

Problem 3. (10 points.) Consider the simple stereo imaging geometry that was introduced in class, as shown below. Both optical axes are parallel, and both cameras have the same focal length. In this view from above, the overall coordinate reference frame (x, y, z) is centered at the left camera.



Assume that all distances are given in units of meters. Let $f = 0.025$ and $B = 0.15$. Suppose that you are given the following corresponding pair of points from the two images:

$$(x'_L, y'_L) = (0.005, 0.0) \quad \text{and} \quad (x'_R, y'_R) = (0.003, 0.0).$$

a) Solve for the 3D point (x, y, z) that is associated with these two image points.

b) Suppose that the system designer is considering a slightly larger baseline distance of $B+\Delta B$. Give a clear argument explaining why (or why not) the designer might expect that computed values of z will be higher in accuracy.

Problem 4. (10 points. For 5554 students, this problem is required. For 4554 students, this problem is optional and can be submitted for extra credit.) Suppose that an automobile has been equipped with a single forward-looking camera. The intrinsic parameters of the camera are known, including the focal length *f*. Also suppose that designers have developed a good technique for detecting highway lane lines using this camera. Intuitively, the detected lane lines are indicated in green in the figure below.

[Source: https://www.analyticsvidhya.com/blog/2020/05/tutorial-real-time-lane-detection-opencv]

Suppose that 2 lane lines have been detected as follows, where u and v represent the image coordinate system:

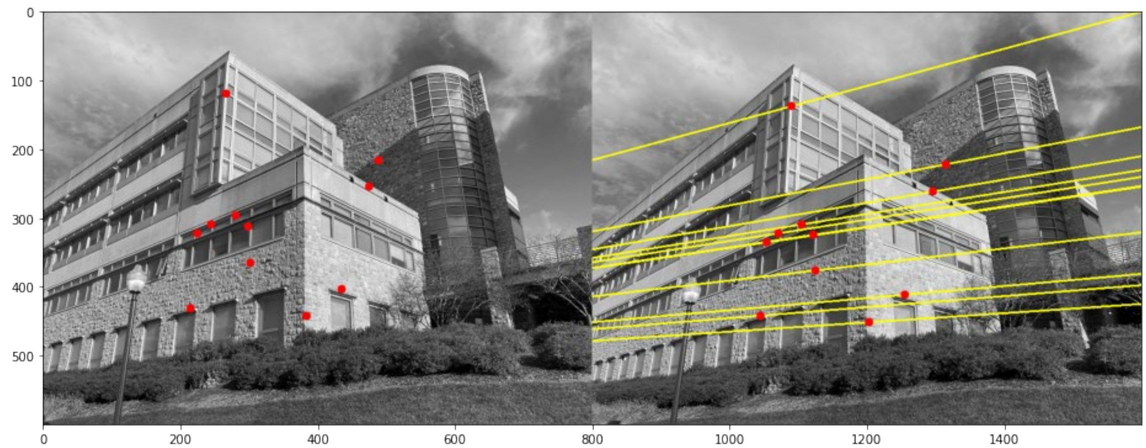
Line 1: $a_1u + b_1v + c_1 = 0$
Line 2: $a_2u + b_2v + c_2 = 0$

Explain why it is possible (or why it is *not* possible) to estimate the 3D pose (position and orientation) of the camera relative to the road from knowledge of the parameters a_i, b_i, and c_i. If needed, you may assume that the road is locally flat and straight, and that the camera is mounted with its optical axis parallel to the road.

Machine Problems.
You have been given a Jupyter notebook file `Homework4_USERNAME.ipynb` and several image files. Replace "`USERNAME`" with your Virginia Tech Username. Then upload these files to Google Drive. Open the `ipynb` file in Google Colab. Follow the instructions that you will find inside the notebook file.

Here are a few more comments concerning the machine problems.

- Several image pairs have been provided. You are required to use some of them (Durham*.png, operahouse*.png), and you are not required to use the other images. They have been provided so that you have the option to try your code using different images.
- For reference, the example below shows the type of output that you should try to generate for Machine Problem 1, part (c). (This case is slightly different from an example that I showed during a lecture.) It is a good idea also to draw epipolar lines in the image at the left, but you are not required to draw epipolar lines in both images.



- Remember that the 8-point algorithm also works for <u>more</u> than 8 pairs of corresponding points. As discussed in class, the algorithm provides a least-squares solution for 8 <u>or more</u> correspondences.
- You are asked to write a function to compute a fundamental matrix, and a scale factor is passed as a parameter. The reason for the scale factor is that better results are usually obtained if coordinate values are normalized to the range [0, 1]. You can perform the normalization by dividing each coordinate by the largest image dimension. After computing F, you will need to "unscale" your result. As a hint, if $x_{normalized} = Tx$, where x is an image location and T is a diagonal 3×3 matrix, then $F_{unnormalized} = T^{\mathrm{T}} F\, T$. You must enforce the singularity condition of your computed F before unscaling.

What to hand in: After you have finished, you will have created the following 3 files. Upload these 3 files to Canvas before the deadline. Do not combine them in a single ZIP file.

`Homework4_Problems1-4_USERNAME.pdf` ← Your solutions to problems 1 through 4

`Homework4_Code_USERNAME.zip` ← Your zipped Jupyter notebook file

`Homework4_Notebook_USERNAME.pdf` ← A PDF version of your Colab session
