Homework 3 Questions

Instructions

- 2 ethical implications questions, which will be expanded on in discussion sections.
- 5 technical questions.
- Write code where appropriate; feel free to include images or equations.
- Please make this document anonymous.
- This assignment is **fixed length**, and the pages have been assigned for you in Gradescope. As a result, **please do NOT add any new pages**. We will provide ample room for you to answer the questions. If you *really* wish for more space, please add a page *at the end of the document*.
- **We do NOT expect you to fill up each page with your answer.** Some answers will only be a few sentences long, and that is okay.

Q1: One major application of camera calibration is surveillance systems. As of 2020, Brown University had around 800 surveillance cameras in place to ”deter and solve crime”.

One argument in favor of surveillance systems is that surveillance systems improve safety and that if you’re not doing anything wrong, you don’t have anything to worry about. Please respond to this argument and discuss your opinions on surveillance on campus and more broadly. In what circumstances do you believe that the potential benefits of surveillance outweigh potential concerns and why? [6-7 sentences]

A1: Your answer here.

Q2: Another area where surveillance comes up is drones. Drones do not require cameras if they are remotely controlled within line of sight. However, some drones are specifically built for surveillance purposes, and other drones increasingly use sophisticated computer vision strategies like feature matching to enable assisted or even autonomous flying in complex environments, but also raises surveillance concerns.

For your CS1430 final project, you are developing a drone for life-saving organ delivery. You create a successful computer vision algorithm that allows your drone to navigate complex environments autonomously, and are approached by several organizations that want to pay you generously for access to your project.

Please list three organizations that might be interested in acquiring your project for their own purposes. If each of these organizations used your project, who could benefit and how? Who could be harmed and how? [6-7 sentences]

A2: Your answer here.

Q3: Given a stereo pair of cameras:

(a) Briefly describe triangulation (using images might be helpful).

(b) Why is it not possible to find an absolute depth for each point when we don't have calibration information for our cameras?

A3: Your answer here.

A3 (continued): Your answer here.

Q4: In lecture, you've learned that cameras can be represented by intrinsic and extrinsic matrices. These matrices can then be used to calculate the projections of points with 3D world coordinates onto 2D images.

(a) For each of the following camera specifications, fill in its intrinsic and extrinsic matrices. Then perform the multiplications and homogenize to find the 2D coordinates of the projected point on the image.

(i) A camera with focal length in both x and y directions of 1, and no skew, translation, or rotation.

$$\begin{pmatrix} \_\_ & \_\_ & 0 \\ 0 & \_\_ & 0 \\ 0 & 0 & 1 \end{pmatrix} * \begin{pmatrix} \_\_ & \_\_ & \_\_ & \_\_ \\ \_\_ & \_\_ & \_\_ & \_\_ \\ \_\_ & \_\_ & \_\_ & \_\_ \end{pmatrix} * \begin{pmatrix} 30 \\ \text{-20} \\ 10 \\ 1 \end{pmatrix} = \begin{pmatrix} \_\_ \\ \_\_ \\ \_\_ \end{pmatrix} = \_\_ * \begin{pmatrix} \_\_ \\ \_\_ \\ 1 \end{pmatrix} \quad (1)$$

(ii) A camera with focal length in both x and y directions of 2, a translation of 5 along the x-axis, and no skew or rotation.

$$\begin{pmatrix} \_\_ & \_\_ & 0 \\ 0 & \_\_ & 0 \\ 0 & 0 & 1 \end{pmatrix} * \begin{pmatrix} \_\_ & \_\_ & \_\_ & \_\_ \\ \_\_ & \_\_ & \_\_ & \_\_ \\ \_\_ & \_\_ & \_\_ & \_\_ \end{pmatrix} * \begin{pmatrix} 30 \\ \text{-20} \\ 10 \\ 1 \end{pmatrix} = \begin{pmatrix} \_\_ \\ \_\_ \\ \_\_ \end{pmatrix} = \_\_ * \begin{pmatrix} \_\_ \\ \_\_ \\ 1 \end{pmatrix} \quad (2)$$

(b) Compare the two image coordinates you've calculated in parts a and b. Explain how each parameter affects the final image coordinate. (2-3 sentences)

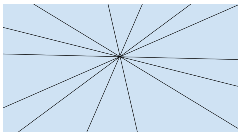
(c) In the questions folder, we've provided stencil code for a camera simulation in camera_simulation.py. Given a projection matrix, the simulator visualizes an image that a camera would produce. Please implement calculate_projection_matrix() by calculating the projection matrix using the parameters given in the code (see stencil for more detail). Paste your code for this function and attach a screenshot of the working demo once you finish. We encourage you to play around with the sliders to see how different parameters affect the projection!

A4: Your answer here.

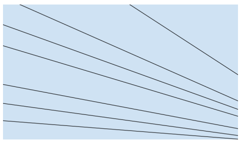
A4 (continued): Your answer here.

Q5: In two-view camera geometry, what do the following epipolar lines say about the cameras' relative positions?:

(a) radiate out of a point on the image plane,

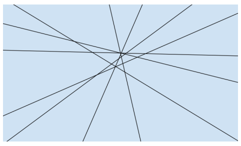


(b) converge to a point outside of the image plane, and



We highly recommend using this interactive demo to explore the different scenarios and get a better feel for epipolar geometry.

(c) What might you need to change about your calculations if you obtained the following epipolar lines? (Hint: check slides from lecture 9)



A5: Your answer here.

Q6: Suppose that we have the following three datasets of an object of unknown geometry:

(a) A video circling the object;

(b) An stereo pair of calibrated cameras capturing two images of the object; and

(c) Two images we take of the object at two different camera poses (position and orientation) using the same camera but with different lens zoom settings.

1. For each of the above setups, decide if we are able to find/calculate the essential matrix, the fundamental matrix, or both.
LaTeX: To fill in boxes, replace '\square' with '\blacksquare' for your answer.

(a)	Essential Matrix	□
	Fundamental Matrix	□
	Both	□
(b)	Essential Matrix	□
	Fundamental Matrix	□
	Both	□
(c)	Essential Matrix	□
	Fundamental Matrix	□
	Both	□

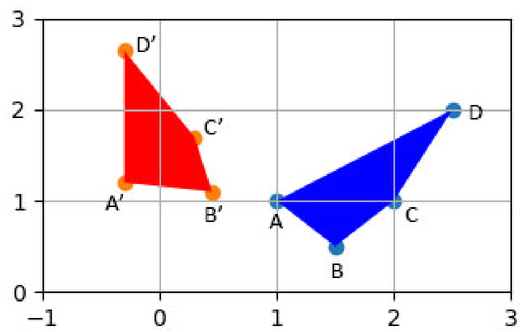
2. State an advantage and disadvantage of using each setup for depth reconstruction; and

3. Name an application scenario for each of the different setups.

A6: Your answer here.

A6 (continued): Your answer here.

Q7 (Linear algebra/numpy question): Suppose we have a quadrilateral $ABCD$ and a transformed version $A'B'C'D'$ as seen in the image below.



$$\begin{aligned} A &= (1,1) & A' &= (-0.3, 1.3) \\ B &= (1.5, 0.5) & B' &= (0.5, 1.1) \\ C &= (2,1) & C' &= (0.3, 1.8) \\ D &= (2.5, 2) & D' &= (-0.3, 2.6) \end{aligned} \tag{3}$$

Let's assume that each point in $ABCD$ was approximately mapped to its corresponding point in $A'B'C'D'$ by a 2×2 transformation matrix M.

e.g. if $A = \begin{pmatrix} x \\ y \end{pmatrix}$ and $A' = \begin{pmatrix} x' \\ y' \end{pmatrix}$, and $\boldsymbol{M} = \begin{pmatrix} m_{1,1} & m_{1,2} \\ m_{2,1} & m_{2,2} \end{pmatrix}$

then $\begin{pmatrix} m_{1,1} & m_{1,2} \\ m_{2,1} & m_{2,2} \end{pmatrix} * \begin{pmatrix} x \\ y \end{pmatrix} \approx \begin{pmatrix} x' \\ y' \end{pmatrix}$

We would like to approximate $\boldsymbol{M}$ using least squares for linear regression.

(a) Rewrite the equation $\boldsymbol{M}x \approx x'$ into a pair of linear equations. We have provided you with a template of what they should look like below.

(b) Use the equations you wrote for part (a) and coordinate values for $ABCD$ and $A'B'C'D'$ to construct a matrix $\boldsymbol{Q}$ and column vector b that satisfy

$$\boldsymbol{Q} * \begin{pmatrix} m_{1,1} \\ m_{1,2} \\ m_{2,1} \\ m_{2,2} \end{pmatrix} = b \tag{4}$$

We have provided you with a template of what they should look like below.

Hint: You have a pair of equations for each x-x' correspondence, giving you 8 rows in $\boldsymbol{Q}$ and b. If you're having trouble, try writing out the equations for each pair of points like in part (a).

Note: Systems of linear equations are typically written in the form $\boldsymbol{A}x = b$, but since we have already defined A and x, we're writing it as $\boldsymbol{Q}m = b$

(c) Our problem is now over-constrained, so we want to find values for $m_{i,j}$ that minimize the squared error between approximated values and real values, or $||\boldsymbol{Q}m - b||_2$. To do this we use singular value decomposition to find the pseudoinverse of $\boldsymbol{Q}$, written as $\boldsymbol{Q}^\dagger$. We then multiply it by both sides, giving us $\boldsymbol{Q}^\dagger\boldsymbol{Q}m = \boldsymbol{Q}^\dagger b \quad \Rightarrow \quad m \approx \boldsymbol{Q}^\dagger b$.

Thankfully, the computer can do all of this for us! `numpy.linalg.lstsq()` takes in our $\boldsymbol{Q}$ matrix and b vector, and returns approximations for m. Plug the values you wrote in part (b) into that function and write the returned $\boldsymbol{M}$ matrix here.

A7: Your answer here.

(a) Replace each of the '__' below with x, y, x', y', or 0.

$$\begin{cases} \_\_ m_{1,1} + \_\_ m_{1,2} + \_\_ m_{2,1} + \_\_ m_{2,2} = \_\_ \\ \_\_ m_{1,1} + \_\_ m_{1,2} + \_\_ m_{2,1} + \_\_ m_{2,2} = \_\_ \end{cases} \tag{5}$$

(b) Replace each of the '__' below with a 0 or a coordinate value from $ABCD$ and $A'B'C'D'$.

$$\begin{pmatrix} \_\_ & \_\_ & \_\_ & \_\_ \\ \_\_ & \_\_ & \_\_ & \_\_ \\ \_\_ & \_\_ & \_\_ & \_\_ \\ \_\_ & \_\_ & \_\_ & \_\_ \\ \_\_ & \_\_ & \_\_ & \_\_ \\ \_\_ & \_\_ & \_\_ & \_\_ \\ \_\_ & \_\_ & \_\_ & \_\_ \\ \_\_ & \_\_ & \_\_ & \_\_ \end{pmatrix} * \begin{pmatrix} m_{1,1} \\ m_{1,2} \\ m_{2,1} \\ m_{2,2} \end{pmatrix} = \begin{pmatrix} \_\_ \\ \_\_ \\ \_\_ \\ \_\_ \\ \_\_ \\ \_\_ \\ \_\_ \\ \_\_ \end{pmatrix} \tag{6}$$

(c) Replace each of the '__' below with the value of $m_{i,j}$.

$$M = \begin{pmatrix} m_{1,1} & m_{1,2} \\ m_{2,1} & m_{2,2} \end{pmatrix} = \begin{pmatrix} \_\_ & \_\_ \\ \_\_ & \_\_ \end{pmatrix} \tag{7}$$

A7 (continued): Your answer here.

Feedback? (Optional)

Please help us make the course better. If you have any feedback for this assignment, we'd love to hear it!