Homework 08: Camera Geometry

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Handout: 2025-10-22

Due: 2025-10-29, 11:59pm, on Canvas

General Instructions:

- You should solve the homework and submit your report **individually**. Identical submissions will receive a grade of zero.
- Getting help from others or checking your answers with other students (not the TAs) is okay and encouraged.
- Ask any questions on **Ed Discussion** (instead of emailing).
- **Before** the homework due date, TAs are strictly prohibited from **pre-grading** your homework. Do not expect the TAs to help you verify if your answers are correct or give you the problem solution.
- **After** the homework due date, if you do not know how to solve a problem, reach out to the TAs. They will walk you through the solution and help you understand it. Note that homework solutions will **not** be posted because some problems will be used in next year's class.
- **Exams** may contain questions related to homework, so make sure you learn how to solve the homework problems correctly.
- The deliverables are outlined for each problem, and you should carefully **follow the instructions**. Failing to follow instructions will result in **points being subtracted**.
- You will submit a **single PDF** file to Canvas as your homework report. The PDF must contain your **answers** and any requested **outputs** (e.g., printouts, snapshots of code, or GUIs). If requested, follow the instructions specified by the problem to provide your **code** (e.g., in a compressed .zip or .tar file) in addition to the PDF file.
- **Grading:** Each homework in this class will contribute **5pts** to your final grade (there will be 12 homework assignments, each 5pts, leading to 60pts for all assignments). A detailed grading **rubric** will be posted on **Canvas** after the homework due date. Any bonus points will be added to your overall course bonus points, which will be added to your final grade.
- **Late submission:** Late or missed submission will not be accepted and will receive a grade a zero. Any excused absence must be documented and disclosed to the instructor (extensions will be granted on a case-by-case basis). Three or more missed homework lead to an INC grade.

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EXERCISE 1 (2.5pts) – Given a 3D point ${}^{W}p$ in the world frame, denoted by W, camera intrinsic matrix K, camera image frame denoted by C,and the homogeneous transformation matrices shown below, use appropriate matrices to answer the following questions.

1) Compute the ***camera matrix***
2) Compute the point's image coordinates in the image frame ***using the camera matrix*** computed above
3) If the image coordinates you obtained are non-integer, how do you obtain integer ***pixel*** coordinates? Compute them.

$$ {}^{W}p = \begin{bmatrix} 10 \\ 20 \\ 30 \end{bmatrix}, \qquad K = \begin{bmatrix} 2 & 0 & 10 \\ 0 & 2 & 20 \\ 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{W}T_{C} = \begin{bmatrix} 0 & -1 & 0 & 2 \\ 1 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \qquad {}^{C}T_{W} = \begin{bmatrix} 0 & 1 & 0 & -1 \\ -1 & 0 & 0 & 2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

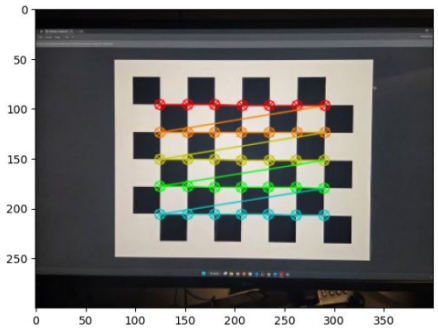
Deliverables:

- Answer to questions 1-3 with ***all steps/computations*** shown and/or explained. Only showing the final answer (without the steps) may result in loss of points.

EXERCISE 2 (2.5pts) – Compute intrinsic matrix of a camera using the camera calibration toolbox in OpenCV. Feel free to use the example provided at https://github.com/ariarobotics/cv/blob/main/code/08_calibration.ipynb
You can optionally write your own code; however, you ***must*** use ***OpenCV*** to become more familiar with it. You can use the calibration board provided at https://github.com/ariarobotics/cv/blob/main/code/data/Calibration%20chessboard%20(US%20Letter).pdf

Explain the calibration process in detail, e.g.,

- What camera did you use (e.g., your phone's camera?)
- What was the ***size*** of the calibration board and the size of each square?
- How many pictures of the calibration board you took? You must have a ***minimum of 5*** images from different viewpoints (but in practice you should use >20 images).
- Show calibration outputs, including images, intrinsic matrix, and distortion parameters



Deliverables:

- Snapshot of entire code and calibration images with detected corners
- Explanation of calibration process as detailed above
- Camera ***intrinsic*** matrix as ***a 3x3 matrix***, and ***radial distortion*** parameters k_1, k_2, k_3, and ***tangential distortion*** parameters p_1, p_2