

Assignment 2 (Due: Dec. 17, 2023)

1. **(Math)** In the augmented Euclidean plane, there is a line $x - 3y + 4 = 0$, what is the homogeneous coordinate of the infinity point of this line?
2. **(Math)** On the normalized retinal plane, suppose that \mathbf{p}_n is an ideal point of projection without considering distortion. If distortion is considered, $\mathbf{p}_n = (x, y)^T$ is mapped to $\mathbf{p}_d = (x_d, y_d)^T$ which is also on the normalized retinal plane. Their relationship is,

$$\begin{cases} x_d = x(1 + k_1 r^2 + k_2 r^4) + 2\rho_1 xy + \rho_2(r^2 + 2x^2) + xk_3 r^6 \\ y_d = y(1 + k_1 r^2 + k_2 r^4) + 2\rho_2 xy + \rho_1(r^2 + 2y^2) + yk_3 r^6 \end{cases}$$

where $r^2 = x^2 + y^2$

For performing nonlinear optimization in the pipeline of camera calibration, we need to compute the Jacobian matrix of \mathbf{p}_d w.r.t \mathbf{p}_n , i.e.,

$$\frac{d\mathbf{p}_d}{d\mathbf{p}_n^T}$$

It should be noted that in this question \mathbf{p}_d is the function of \mathbf{p}_n and all the other parameters can be regarded as constants.

3. **(Math)** In our lecture, we mentioned that for performing nonlinear optimization in the pipeline of camera calibration, we need to compute the Jacobian of the rotation matrix (represented in a vector) w.r.t its axis-angle representation. In this question, your task is to derive the concrete formula of this Jacobian matrix. Suppose that

$$\mathbf{d} = \theta \mathbf{n} \in \mathbb{R}^{3 \times 1}, \text{ where } \mathbf{n} = \begin{bmatrix} n_1 \\ n_2 \\ n_3 \end{bmatrix} \text{ is a 3D unit vector and } \theta \text{ is a real number denoting the rotation angle.}$$

With Rodrigues formula, \mathbf{d} can be converted to its rotation matrix form,

$$\mathbf{R} = \cos \theta \mathbf{I} + (1 - \cos \theta) \mathbf{n} \mathbf{n}^T + \sin \theta \hat{\mathbf{n}}$$

$$\text{and obviously } \mathbf{R} \triangleq \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix} \text{ is a } 3 \times 3 \text{ matrix.}$$

Denote \mathbf{r} by the vectorized form of \mathbf{R} , i.e.,

$$\mathbf{r} \triangleq (r_{11}, r_{12}, r_{13}, r_{21}, r_{22}, r_{23}, r_{31}, r_{32}, r_{33})^T$$

Please give the concrete form of Jacobian matrix of \mathbf{r} w.r.t \mathbf{d} , i.e., $\frac{d\mathbf{r}}{d\mathbf{d}^T} \in \mathbb{R}^{9 \times 3}$.

In order to make it easy to check your result, please follow the following notation requirements,

$$\alpha \triangleq \sin \theta, \beta \triangleq \cos \theta, \gamma \triangleq 1 - \cos \theta$$

In other words, the ingredients appearing in your formula are restricted to $\alpha, \beta, \gamma, \theta, n_1, n_2, n_3$.

4. **(Programming)** Bird's-eye-view generation. The geometric transform between the physical plane and its bird's-eye-view image can be simply described by a **similarity transformation** matrix. Bird's-eye-view is very useful in autonomous industrial inspection, ADAS, etc. In this question, your task is to create the bird's-eye-view image of a physical plane, e.g., the wall of your room. For this purpose, you may need to,
 - 1) make a calibration board with chessboard patterns;
 - 2) calibrate your camera (the camera mounted on your laptop or the camera of your mobile phone with fixed focal length) to get its intrinsics;
 - 3) attach regular patterns (e.g., chessboard patterns) to the wall, determine the 2D coordinate system C_W of the wall, and determine the coordinates $\{\mathbf{x}_{Wi}\}_{i=1}^N$ of the feature points of the regular patterns with

- respect to C_W ;
- 4) take the image I_d of the wall with regular patterns;
 - 5) undistort image I_d with the camera's intrinsics to get the undistorted image I ;
 - 6) For each \mathbf{x}_{Wi} , determine its image \mathbf{x}_{Ii} on I ;
 - 7) solve the homography matrix $P_{W \rightarrow I}$ between the wall and the image I wall using $\{\mathbf{x}_{Wi} \leftrightarrow \mathbf{x}_{Ii}\}_{i=1}^N$;
 - 8) generate the final bird's-eye-view image of the wall using the technique introduced in our lecture.

For submission, you **only** need to submit the following items to TA:

- 1) the intrinsic parameters of your camera;
- 2) the original image of the wall (or other physical planes) taken by your camera; make sure that your name is painted or attached on the wall (or the plane); (maybe similar to following image I provide to you)
- 3) the generated bird's-eye-view image of the wall (or other physical planes).

