

# ECE 417/598: Homework 1

Max marks: 100

Due on Jan 28, 2021, 11:59 PM

You are allowed to use any matrix or linear algebra library (Eigen or xtensor), but no library that implements rotation matrices. You are not allowed to use Eigen/Geometry. You can use the following code for generating random rotation matrices: `random_rotation.cpp`. You can also use the following template to fill in your answers: `hw1.cpp`

## 1 Jan 24 Lecture: 3D transformations

**Problem 1** *Degrees of Freedom of a quantity is the number independent scalar variables needed to represent that quantity. What is degrees of freedom required to*

1. Position and orientation in 1-D
2. Position and orientation in 2-D
3. Position and orientation in 3-D
4. Position and orientation in 4-D

(10 marks. Estimated time: 15 min) Justify your answer.

**Problem 2** *Write a program in C++ that checks if a given 3x3 matrix is a valid Rotation matrix is a valid Rotation matrix (check for orthonormality i.e. orthogonality and determinant = 1). You may use Eigen's matrix multiplication and determinant() function. (10 marks. Used in the following problems. Estimated time: 15 min).*

**Problem 3** *In class, we proved the expression to convert roll ( $\theta$ ), pitch ( $\phi$ ), yaw ( $\psi$ ) from Euler Angles to Rotation matrix,*

$$R(\theta, \phi, \psi) = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix} = R_z(\psi)R_y(\phi)R_x(\theta). \quad (1)$$

*What if we want to do the inverse? Prove that given a proper 3x3 rotation matrix ( $R^T R = I$  and  $\det(R) = 1$ ), the Euler angles are given by*

$$\begin{bmatrix} \theta(R) \\ \phi(R) \\ \psi(R) \end{bmatrix} = \begin{bmatrix} \arctan2(r_{32}, r_{33}) \\ -\arcsin(r_{31}) \\ \arctan2(r_{21}, r_{11}) \end{bmatrix} \quad (2)$$

*where  $r_{ij}$  is the element in  $i$ th row and  $j$ th column of the rotation matrix  $R$ . (10 marks. Used in the following problems. Estimated time: 15 min).*

**Problem 4** *Write a pair of functions in C++ that converts rotation matrix from XYZ Euler angles (roll, pitch, yaw) and vice versa. Test the pair of functions with randomly generated Euler angles. And check if the converted rotation matrix is orthonormal. What happens when pitch =  $\pi/2$ , are you able to convert from rotation matrix to Euler angle? Why or why not? (50 marks. Estimated time: 30 min)*

**Problem 5** *Write a function in C++ that generates a 4x4 transformation matrix given XYZ Euler angles (roll, pitch, yaw) and translation. You can use the function that you wrote in Prob 4 (20 marks. Estimated time: 15 min).*