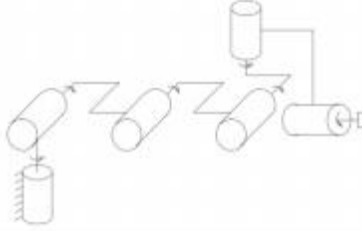


# Homework 4

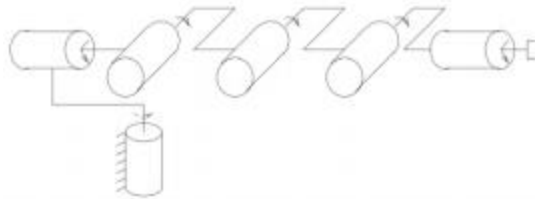
(Due time: 10:00, Apr. 26, 2024)

1. For each of the manipulators shown schematically in Figure 1:

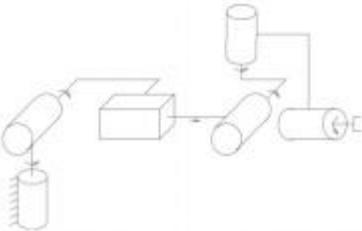
- (a) Derive the spatial and body Jacobians.
- (b) Give a geometric description of the singular configurations.



(i) Elbow manipulator



(ii) Inverse elbow manipulator



(iii) Stanford manipulator

Fig 1. Sample manipulators. Revolute joints are represented by cylinders; prismatic joints are represented by rectangular boxes.

2. Euler angles can be used to represent rotations via the product of exponentials formula. If we think of  $(\alpha, \beta, \gamma)$  as joints angles of a robot manipulator, then we can find the singularities of an Euler angle parameterization by calculating the Jacobian of the “forward kinematics”, where we are concerned only with the rotation portion of the forward kinematics map. Use this point of view to find singularities for the following classes of Euler angles:
- (a) ZYZ Euler angles
  - (b) ZYX Euler angles