

- Please include a little grid like this at the top of your first page of homework:

1	2	3	Total

1. Assume that for a given manipulator, frames have been assigned to the links following the standard conventions. Given the transformation matrix from  $\{i\}$  to  $\{i - 1\}$

$${}^i{}_{i-1}T = \begin{bmatrix} t_{11} & t_{12} & t_{13} & t_{14} \\ t_{21} & t_{22} & t_{23} & t_{24} \\ t_{31} & t_{32} & t_{33} & t_{34} \\ t_{41} & t_{42} & t_{43} & t_{44} \end{bmatrix}$$

use equation (2.7) to determine the D-H parameters  $a_{i-1}$ ,  $\alpha_{i-1}$ ,  $d_i$ ,  $\theta_i$  in terms of the  $t_{jk}$ 's.

2. Consider the planar PR manipulator shown here:

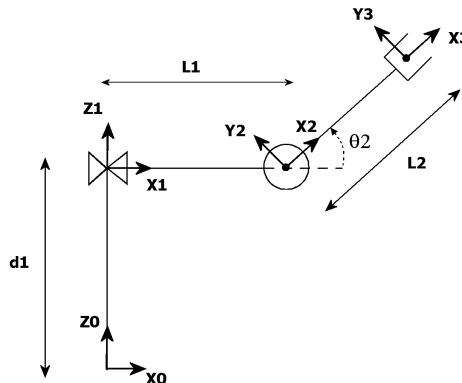


Figure 1: PR Manipulator

- (a) Find the origin of frame  $\{3\}$  expressed in terms of frame  $\{0\}$ , that is  ${}^0P_{3org}$ .  
*Tip: you can derive this geometrically, if you want to avoid going through DH parameters.*
  - (b) Give the  $2 \times 2$  Jacobian that relates the joint velocities to the linear velocity of  ${}^0P_{3org}$ .
  - (c) For what joint values is the manipulator at a singularity? What motion is restricted at this singularity?
3. Consider the RRR manipulator shown in Figure 2.
    - (a) Assuming that the joint limits of this manipulator are  $0 \leq \theta_2 \leq 180^\circ$  and  $-90^\circ \leq \theta_3 \leq 90^\circ$ , sketch the workspace of this manipulator. Be sure to include a cross section with dimensions included.

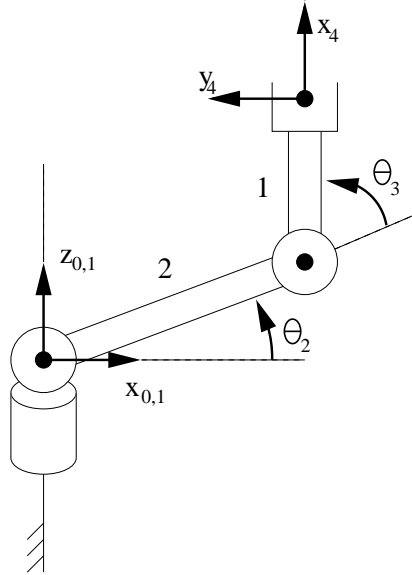


Figure 2: An RRR manipulator.

- (b) Find the DH parameters for this manipulator. Remember to assign the interior frames of this manipulator using the conventions discussed in class.
- (c) Derive the forward kinematics,  ${}^0_4T$ , of this manipulator.
- (d) Find the basic Jacobian,  $J_0$ , for this manipulator.
- (e) Find  ${}^1J_v$ , the position Jacobian matrix expressed in frame  $\{1\}$ .
- (f) Use the matrix that you found in (e) to find the singularities (with respect to linear velocity) of this manipulator.
- (g) For each type of singularity that you found in part (f), explain the physical interpretation of the singularity, by sketching the arm in a singular configuration and describing the resulting limitation on its movement.