ME 4K03 Assignment Z

1. a) see diagram

6) n+1	10 nti	duti	anti	duti	d, 02, d3 are
1	900	d,	0	900	joint variables
2	02	0	0	-900	
3	1800	dz	0	00	

c) see diagram

$$A_{1} = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & d_{1} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_{2} = \begin{bmatrix} c\theta_{2} & 0 & -s\theta_{2} & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

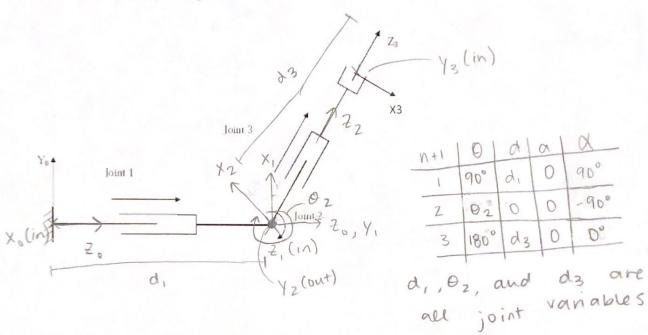
$$A_{3} = \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & d_{3} \end{bmatrix} = {}^{2}T_{3}$$

$${}^{O}T_{3} = A, A_{2}A_{3} = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} C\theta_{2} & 0 & -S\theta_{2} & 0 \\ 0 & 2 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ -C\theta_{2} & 0 & -S\theta_{2} & -S\theta_{2}d_{3} \\ -S\theta_{2} & 0 & C\theta_{2} & d_{1} \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 &$$

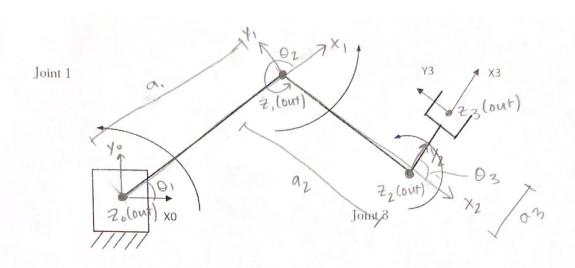
b) N+1 On+1 d N+1 a N+1 where $0., 0., 0., 0.$ 1 O1 O a1 O° joint variables; 2 O2 O a2 O° a1, a2, a3 are fixed 3 O3 O O3 O° parameters c) see oliagram d) $A_1 = \begin{bmatrix} co, -so, 0 a, co, 1 \\ so, co, 0 o a, so, 1 \\ o o o o o o A_3 = \begin{bmatrix} co_3 -so_3 o a_3 co_3 \\ so_3 co_3 o a_3 so_3 \\ o o o o o A_4 = \begin{bmatrix} co_1 -so_2 o a_2 co_3 \\ so_3 co_3 o a_3 so_3 \\ o o o o o A_5 = \begin{bmatrix} co_1 -so_2 o a_2 co_1 + a, co, 1 \\ so_2 co_3 co_3 o O O O O o A_7 = \begin{bmatrix} co_1 -so_1 o a_2 so_1 + a, so_1 so_3 so_3 co_3 \\ o o o o o O O O O O o O O O O O O O O O $	d
2 O_2 O_3 O_4 O_5 O_6 O_7 O_8 $O_$	d
c) see oringram d) $A_1 = \begin{bmatrix} co_1 & -So_1 & 0 & a_1co_1 \end{bmatrix} A_2 = \begin{bmatrix} co_2 & -So_2 & 0 \\ So_1 & Co_1 & 0 & a_1So_1 \end{bmatrix} So_2 Co_2 0$ $\begin{bmatrix} co_1 & co_2 & co_3 & co_3 \\ co_3 & co_3 & co_3 & co_3 \\ co_3 & co_3 & co_3 & co_3 \\ co_4 & co_5 & co_5 & co_5 \\ co_5 & co_5 & co_5 & co_5 \\ co_6 & co_7 & co_7 & co_7 \\ co_7 co_7 & co_7 \\ co_7 & co_7 & co_7 \\ co_7 & co_7$	
d) $A_1 = \begin{bmatrix} co_1 & -So_1 & 0 & a_1 & co_1 \\ So_1 & co_1 & 0 & a_1 & so_1 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} co_2 & -So_2 & 0 \\ So_2 & co_2 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix}$ $A_3 = \begin{bmatrix} co_3 & -So_3 & 0 & a_3 & co_3 \\ So_2 & co_3 & 0 & a_3 & so_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ $A_1 A_2 = \begin{bmatrix} co_{12} & -So_{12} & 0 & a_2 & co_{12} + a_1 & co_1 \\ So_{12} & co_{12} & 0 & a_2 & so_{12} + a_1 & so_1 \end{bmatrix} \begin{bmatrix} co_3 & -so_3 \\ so_1 & co_2 & co_3 \\ so_1 & co_1 & co_1 & co_1 \\ co_1 & co_2 & co_3 \\ co_2 & co_3 & co_3 \\ co_3 & co_3 \\ co_3 & co_3 & co_3 \\ co_3 & co_3 & co_3 \\ co_3 & co$	a.Cu
$A_{3} = \begin{bmatrix} co_{3} & -so_{3} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0$	a. Cu
$A_{3} = \begin{bmatrix} co_{3} & -so_{3} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0$	
$A_{3} = \begin{bmatrix} \cos_{3} & -\cos_{3} & 0 & \alpha_{3} \cos_{3} \\ \cos_{3} & \cos_{3} & 0 & \alpha_{3} \cos_{3} \\ \cos_{3} & \cos_{3} & 0 & \alpha_{3} \cos_{3} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ $A_{1} A_{2} = \begin{bmatrix} \cos_{12} & -\cos_{12} & 0 & \alpha_{2} \cos_{12} + \alpha_{1} \cos_{1} \\ \cos_{12} & \cos_{12} & 0 & \alpha_{2} \cos_{12} + \alpha_{1} \cos_{1} \end{bmatrix} \begin{bmatrix} \cos_{3} & -\cos_{3} \\ \cos_{3} & \cos_{3} & \cos_{3} \\ \cos_{12} & \cos_{12} & 0 & \alpha_{2} \cos_{12} + \alpha_{1} \cos_{1} \end{bmatrix} \begin{bmatrix} \cos_{3} & -\cos_{3} \\ \cos_{3} & \cos_{3} & \cos_{3} \\ \cos_{12} & \cos_{12} & 0 & \alpha_{2} \cos_{12} + \alpha_{1} \cos_{1} \end{bmatrix} \begin{bmatrix} \cos_{3} & -\cos_{3} \\ \cos_{3} & \cos_{3} & \cos_{3} \\ \cos_{3} & \cos_{3} & \cos_{3} \end{bmatrix}$	a, si
$A_{3} = \begin{bmatrix} \cos_{3} & -\cos_{3} & 0 & \alpha_{3} \cos_{3} \\ \cos_{3} & \cos_{3} & 0 & \alpha_{3} \cos_{3} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ $A_{1} A_{2} = \begin{bmatrix} \cos_{12} & -\cos_{12} & 0 & \alpha_{2} \cos_{12} + \alpha_{1} \cos_{1} \\ \cos_{12} & \cos_{12} & 0 & \alpha_{2} \cos_{12} + \alpha_{1} \cos_{1} \end{bmatrix} \begin{bmatrix} \cos_{3} & -\cos_{3} \\ \cos_{3} & \cos_{3} & \cos_{3} \end{bmatrix}$ $SO_{12} CO_{12} O \alpha_{2} SO_{12} + \alpha_{1} SO_{1} SO_{2} CO_{3} O O O O O O O O O $	
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	t
$A_{1}A_{2} = \begin{cases} C\Theta_{12} - S\Theta_{12} & 0 & \alpha_{2}C\Theta_{12} + \alpha_{1}C\Theta_{1} \end{cases} \begin{cases} C\Theta_{3} - S\Theta_{3} \\ S\Theta_{12} & C\Theta_{12} & 0 & \alpha_{2}S\Theta_{12} + \alpha_{1}S\Theta_{1} \end{cases} \begin{cases} S\Theta_{3} & C\Theta_{3} \\ O & O & 1 \end{cases}$	
$A, A_2 = \begin{cases} c\theta_{12} - s\theta_{12} & 0 & \alpha_2 c\theta_{12} + \alpha_1 c\theta_1 \end{cases} \begin{cases} c\theta_3 - s\theta_3 \\ s\theta_{12} & c\theta_{12} & 0 & \alpha_2 s\theta_{12} + \alpha_1 s\theta_1 \end{cases} \begin{cases} s\theta_3 & c\theta_3 \\ 0 & 0 & 1 & 0 \end{cases}$	
$A, A_2 = \begin{cases} c\theta_{12} - s\theta_{12} & 0 & \alpha_2 c\theta_{12} + \alpha_1 c\theta_1 \end{cases} \begin{cases} c\theta_3 - s\theta_3 \\ s\theta_{12} & c\theta_{12} & 0 & \alpha_2 s\theta_{12} + \alpha_1 s\theta_1 \end{cases} \begin{cases} s\theta_3 & c\theta_3 \\ 0 & 0 & 1 & 0 \end{cases}$	
SO12 CO12 O a2SO12+a, SO1 SO3 CO3	
SO12 CO12 O a2SO12+a, SO1 SO3 CO3	0 00
0 0 410 0 0	0 0
0000100	1
	0
A, A, Z A, = (0123 - 50123 0 a, CO, 23 + a, CO, 7	
SO123 CO123 O a3 SO123+ a2 SO12+a, SO,	

Due: 11:59pm 18th Oct, 2021

- 1. For the PRP planar robot shown in Figure below.
- a) Using the predefined YO and Z3 axes, assign the frames using the D-H method.
- b) Determine the D-H parameters and put them in the standard table form. Identify the joint variables.
- c) Draw a diagram of the robot that properly shows the D-H frames, the joint variables, and any d or a parameters that are non-zero. Your drawing should be clear and at least 75 mm X 75 mm in size.
- d) Calculate the A matrices and ${}^{0}T_{3}$.



- 2. For the RRR robot shown in Figure below:
- a) Assign the frames using the D-H method.
- b) Determine the D-H parameters and put them in the standard table form. Identify the joint variables.
- c) Draw a diagram of the robot that properly shows the D-H frames, the joint variables, and any d or a parameters that are non-zero. Your drawing should be clear and at least 75 mm X 75 mm in size.
- d) Calculate the A matrices and "T3



N+1	101	0 d		1 a	
-	0,	0	la,	0	
2	02	10	az	0	
3	10.	3/0) a	30	
				-	

where 0, 02, 03 are joint vanables, a, a2, a3 are fixed parameters