FINAL EXAM

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1. 1) Hard automation: specialised machines for high-volume manufacturing (i.e, assembly line)

2) Flexible automation: robots in place of specialised machines used in hard automation.

3) Planar robot: robot whose end-effector's motion is limited to a single plane

4) Dextrous workspace: volume of space the end-effector can reach with any desired orientation

2. 1) ${}^{C}T_{D}$, ${}^{A}T_{B}$, ${}^{A}T_{E}$, ${}^{E}T_{D}$ $\rightarrow$ ${}^{B}T_{C} = ?$

$${}^{B}T_{C} = ({}^{A}T_{B})^{-1} * {}^{A}T_{E} * {}^{E}T_{D} * ({}^{C}T_{D})^{-1}$$

2) Lap 1, $M = \begin{bmatrix} 0 & -1 & 0 \\ -1 & 5 & -1 \\ 0 & -1 & 0 \end{bmatrix}$ $\quad s = -1(4) + 5 = 1$

$$f_{85} = \frac{1}{1} \left| (75(0) + 75(-1) + 75(0) + 130(-1) + 5(75) + 130(-1) + 75(0) + 75(-1) + 75(0)) \right|$$

$$f_{85} = |-35| = 35$$

3) $A = Trans(3,3,2) * Rot(z, \sim 39.7°)$ $\therefore$ it is a valid representation of a frame. the others do not match the transformation matrices.

C not valid b/c $trans(3, 0.5, 15) * Rot(z, -90) * Rot(x, 30) = \begin{bmatrix} 0 & \sqrt{3}/2 & -1/2 & 3 \\ -1 & 0 & 0 & 0.5 \\ 0 & \frac{1}{2} & +\sqrt{3}/2 & 15 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

B not valid b/c $(Rot(z,-90)^{-1} * (Trans(3, 0.5, 2)^{-1}) * B$

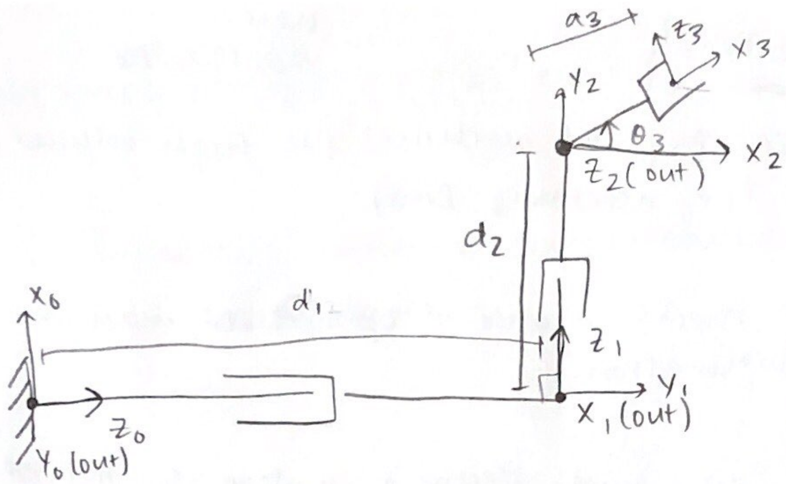
= → see next pg

3) $(Rot(z,-90)^{-1}) * Trans(3, 0.5, 2)^{-1} * B = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \sqrt{3}/2 & 0 & 0 \\ 0 & 0.5 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

$\hookrightarrow$ doesn't match a translation/rotation matrix

$\therefore$ invalid

3, a)



b)

i	θ_i	d_i	a_i	α_i
1	90°	d_1^*	0	90°
2	90°	d_2^*	0	90°
3	θ_3^*	0	a_3	-90°

joint variables are starred w *

c) See diagram in a

d) by the formula to calculate A matrices from DH parameters:

$$A1 = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & d_1 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$A2 = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & d_2 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$A3 = \begin{bmatrix} C\theta_3 & 0 & -S\theta_3 & a_3 C\theta_3 \\ S\theta_3 & 0 & C\theta_3 & a_3 S\theta_3 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$T = A1 * A2 * A3$

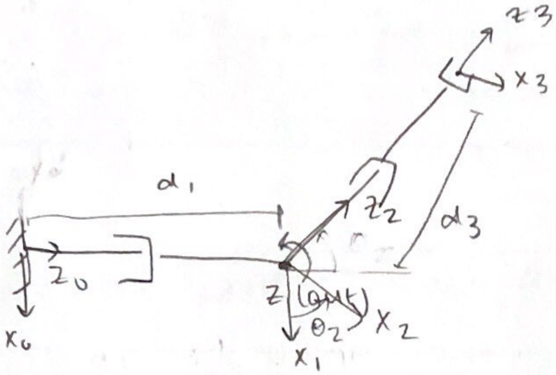
$$T = \begin{bmatrix} S\theta_3 & 0 & C\theta_3 & d_2 + a_3 S\theta_3 \\ 0 & -1 & 0 & 0 \\ C\theta_3 & 0 & S\theta_3 & d_1 + a_3 C\theta_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

3.e) $\phi = \theta_3$

$$P_z = d_1 + C\theta_3 \rightarrow d_1 = P_z - a_3 C\phi$$

$$P_x = d_2 + S\theta_3 \rightarrow d_2 = P_x - a_3 S\phi$$

4.a)



θ_i	d_i	a_i	α_i
0	d_1	0	90°
θ_2	0	0	-90°
0	d_3	0	0°

say the robot operates in the xy plane $\overset{y}{\uparrow}\!\rightarrow x$

$$P_y = d_3 S\theta_2$$

$$P_x = d_1 + d_3 C\theta_2$$

$$P_z = 0$$

by the formula:

$$T = \begin{bmatrix} C\theta_2 & 0 & -S\theta_2 & -d_3 S\theta_2 \\ 0 & 1 & 0 & 0 \\ S\theta_2 & 0 & C\theta_2 & d_1 + d_3 C\theta_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$J(q) = \begin{bmatrix} \frac{\partial p_x}{\partial d_1} & \frac{\partial p_x}{\partial \theta_2} & \frac{\partial p_x}{\partial d_3} \\ \frac{\partial p_y}{\partial d_1} & \frac{\partial p_y}{\partial \theta_2} & \frac{\partial p_y}{\partial d_3} \\ \zeta_1 z_0 & \zeta_2 z_1 & \zeta_3 z_2 \end{bmatrix} = \begin{bmatrix} 1 & -d_3 S\theta_2 & C\theta_2 \\ 0 & d_3 C\theta_2 & S\theta_2 \\ 0 & 1 & 0 \end{bmatrix}$$

$\zeta_1 = \zeta_3 = 0$ b/c prismatic

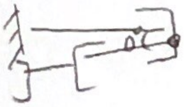
$\zeta_2 = 1$ b/c revolute

$$\hookrightarrow \begin{bmatrix} v_x \\ v_y \\ \omega_z \end{bmatrix} = J(q) \begin{bmatrix} \dot{d}_1 \\ \dot{\theta}_2 \\ \dot{d}_3 \end{bmatrix}$$

b) $|J(q)| = -\sin(\theta_2)$

$-\sin(\theta_2) = 0$ when $\theta_2 = 0, 180°$

4. c)



OR

translation in the y-axis &
and rotation in z are
the two lost DOF

5. horizontal plane → assume $G(q) = 0$.

a) $P_x = 0.3\,C\theta_{12} + 0.4\,C\theta_1$
$P_y = 0.3\,S\theta_{12} + 0.4\,S\theta_1$

$$J(q) = \begin{bmatrix} \frac{\partial P_x}{\partial \theta_1} & \frac{\partial P_x}{\partial \theta_2} \\ \frac{\partial P_y}{\partial \theta_1} & \frac{\partial P_y}{\partial \theta_2} \\ 3_1 z_0 & 3_2 z_1 \end{bmatrix}$$

$a_1 = 0.4\,m \quad \theta_1 = 35°$
$a_2 = 0.3\,m \quad \theta_2 = -75°$

$$J(\theta_1, \theta_2) = \begin{bmatrix} -0.3\,S(35-75) - 0.4\,S(35) & -0.3\,S(35-75) \\ 0.3\,C(35-75) + 0.4\,C(35) & 0.3\,C(35-75) \\ 1 & 1 \end{bmatrix} = \begin{bmatrix} -0.0366 & 0.1928 \\ 0.5575 & 0.2298 \\ 1 & 1 \end{bmatrix}$$

$$F = \begin{bmatrix} 20 \\ -15 \end{bmatrix} \qquad \tau = (J(\theta_1, \theta_2))^T F = \begin{bmatrix} -0.0366 & 0.5575 \\ 0.1928 & 0.2298 \end{bmatrix} \begin{bmatrix} 20 \\ -15 \end{bmatrix} = \boxed{\begin{bmatrix} -9.10 \\ 0.41 \end{bmatrix} \text{Nm}}$$

b) $F = (J(q)^{-1})^T (\tau - \cancel{g(q)}^{\,0}) \qquad \tau = [10 \quad 5]^T$

$$F = [J(\theta_1, \theta_2)^{-1}]^T \tau = \begin{bmatrix} -1.9827 & 4.8095 \\ 1.6637 & 0.3157 \end{bmatrix} \begin{bmatrix} 10 \\ 5 \end{bmatrix} = \boxed{\begin{bmatrix} 4.22 \\ 18.22 \end{bmatrix} \text{N}}$$

$$J^{-1}(q) = \frac{1}{(0.3)(0.4)(S(-75))} \begin{bmatrix} 0.2298 & -0.1928 \\ -0.5575 & -0.0366 \end{bmatrix} = \begin{bmatrix} -1.9827 & 1.6637 \\ 4.8095 & 0.3157 \end{bmatrix}$$