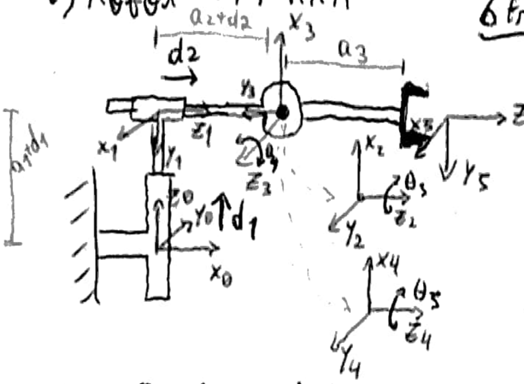
i) Robot → PPRRR



6 Frames

	θ	d	a	α	θ_{off}
$0 \to 1$	θ^*	a_1+d_1	0	$-\pi/2$	$-\pi/2$ *
$1 \to 2$	θ^*	a_2+d_2	0	0	$-\pi/2$ *
$2 \to 3$	θ_3	0	0	$-\pi/2$	0
$3 \to 4$	θ_4	0	0	$\pi/2$	0
$4 \to 5$	θ_5	a_3	0	0	$\pi/2$

} offset das juntas i somado a θ na nossa Função

$$ {}^{0}_{EE}T = \underbrace{{}^{0}_{1}T \cdot {}^{1}_{2}T}_{PP} \cdot \underbrace{{}^{2}_{3}T \cdot {}^{3}_{4}T \cdot {}^{4}_{5}T}_{RRR} = \begin{array}{cccc} m & s & a & t \\ \left[\begin{matrix} -S_4 \times S_5 \\ C_3\times C_5 - C_4\times S_3\times S_5 \\ -C_5\times S_3 - C_3\times C_4\times S_5 \\ 0 \end{matrix}\right. & \begin{matrix} -C_5\times S_4 \\ -C_3\times S_5 - C_4\times C_5\times S_3 \\ S_3\times S_5 - C_3\times C_4\times C_5 \\ 0 \end{matrix} & \begin{matrix} \boxed{-C_4}\, a_x \\ \boxed{S_3\times S_4}\, a_y \\ \boxed{+C_3\times S_4}\, a_z \\ 0 \end{matrix} & \left.\begin{matrix} -a_2 - d_2 - a_3\times C_4 \\ a_3\times S_3\times S_4 \\ a_1+d_1+a_3\times C_3\times S_4 \\ 1 \end{matrix}\right] \end{array} $$

• Cinemática Inversa → d_1: translação segundo z_0

d_2: translação segundo x_0

• Do PP

$$ {}^{0}T = \left[\begin{array}{ccc|c} 0 & 0 & 1 & a_2+d_2 \\ 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & a_1+d_1 \end{array}\right] \longrightarrow \left| \begin{array}{l} t_x = a_2+d_2 \\ t_y = 0 \\ t_z = a_1+d_1 \end{array} \right. $$

$$ \left| \begin{array}{l} a_x = -C_4 \\ a_z = C_3 \times S_4 \end{array} \right. $$

$$ \left| \begin{array}{l} t_x = -a_2 - d_2 - a_3\times C_4 \\ t_z = a_1 + d_1 + a_3 \times C_3 \times S_4 \end{array} \right. \quad \left| \begin{array}{l} t_x = -a_2 - d_2 + a_3 \times a_x \\ t_z = a_1 + d_1 + a_3 \times a_z \end{array} \right. \Leftrightarrow \left| \begin{array}{l} d_2 = -a_2 + a_3\times a_x - t_x \\ d_1 = -a_1 - a_3 a_z + t_z \end{array} \right. $$

• Do PRR

$$ {}^{2}_{EE}T = {}^{2}_{0}T \times {}^{0}_{EE}T = \left({}^{0}_{2}T\right)^{-1} \cdot {}^{0}_{EE}T = \begin{bmatrix} 0 & 0 & 1 & -a_1-d_1 \\ 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & -a_2-d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} m_x & s_x & a_x \\ m_y & s_y & a_y \\ m_z & s_z & a_z \\ 0 & 0 & 0 \end{bmatrix} $$

$$ = \begin{bmatrix} m_z & s_z & a_z & t_z - d_1 - a_1 \\ -m_y & -s_y & -a_y & -t_y \\ m_x & s_x & a_x & t_x - d_2 - a_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$
{}^{2}_{EE}T = \begin{bmatrix} -c_5 \times s_3 - c_3 \times c_4 \times s_5 & s_3 \times s_5 - c_3 \times c_4 \times c_5 & \boxed{c_3 \times s_4}\ a_z & a_3 \times c_3 \times s_4 \\ c_4 \times s_3 \times s_5 - c_3 \times c_5 & c_3 \times s_5 + c_4 \times c_5 \times s_3 & \boxed{-s_3 \times s_4}\ -a_y & -a_3 \times s_3 \times s_4 \\ \boxed{-s_4 \times s_5}\ m_x & \boxed{-c_5 \times s_4}\ s_x & \boxed{-c_4}\ a_x & -2 \times a_2 - 2 \times d_2 - a_3 \times c_4 \\ 0 & 0 & 0 & 1 \end{bmatrix}
$$

$$\boxed{tg\,\theta = \frac{sen\,\theta}{cos\,\theta}}$$

$$\frac{-s_3 \times \cancel{s_4}}{c_3 \times \cancel{s_4}} = \frac{a_y}{a_z} \Leftrightarrow \theta_3 = tg^{-1}(a_y, a_z)$$

$$\frac{-\cancel{s_4} \times s_5}{-c_5 \times \cancel{s_4}} = \frac{-m_x}{-s_x} \Leftrightarrow \theta_5 = tg^{-1}(-m_x, -s_x)$$

multiplicar cos e sen

$$\begin{cases} c_3 \times s_4 = a_z \\ -s_3 \times s_4 = -a_y \end{cases} \Leftrightarrow \begin{cases} c_3^2\, s_4 = c_3\, a_z \\ +s_3^2\, s_4 = +s_3\, a_y \end{cases}$$

• Sabendo que $cos^2 + sen^2 = 1$

$$s_4 (c_3^2 + s_3^2) = c_3\, a_z + s_3\, a_y$$

$$\Leftrightarrow s_4 = c_3\, a_z + s_3\, a_y$$

Por inspecção $\rightarrow -c_4 = a_x$

$$tg\,\theta = \frac{sen\,\theta}{cos\,\theta} = \frac{c_3\, a_z + s_3\, a_y}{-a_x}$$

$$\Leftrightarrow \theta_4 = tg^{-1}(c_3\, a_z + s_3\, a_y, -a_x)$$

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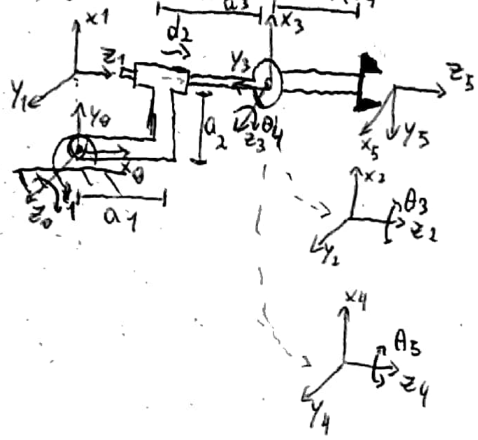
ii) Robot → RP RRR



	θ	d	a	α	off
$0 \to 1$	θ_1	0	a_2	$\pi/2$	$\pi/2$
$1 \to 2$	0	$d_2+a_1+a_3$	0	0	0
$2 \to 3$	θ_3	0	0	$-\pi/2$	0
$3 \to 4$	θ_4	0	0	$\pi/2$	0
$4 \to 5$	θ_5	a_4	0	0	$\pi/2$

$l_1 = a_1 + a_3$

$${}^{0}_{EE}T = {}^{0}_{1}T \cdot {}^{1}_{2}T \cdot {}^{2}_{3}T\, {}^{3}_{4}T\, {}^{4}_{5}T = [\, c5 \times s1 \times s3 + c1 \times s4 \times s5 +$$

$$= \begin{bmatrix} c5 \times s1 \times s3 + c1 \times s4 \times s5 + c3 \times c4 \times s1 \times s5 & c1 \times c5 \times s4 - s1 \times s3 \times s5 + c3 \times c4 \times c5 \times s1 & \overbrace{c1 \times c4 - c3 \times s1 \times s4}^{a \quad ax} & \overbrace{d2 \times c1 + l1 \times c1 - a2 \times s1 + a4 \times c1 \times c4 - a4.c3.s3.s4}^{t \qquad ax} \\ s1 \times s4 \times s5 - c1 \times c5 \times s3 - c1 \times c3 \times c4 \times s5 & c1 \times s3 \times s5 + c5 \times s1 \times s4 - c1 \times c3 \times c4 \times c5 & c4 \times s1 + c1 \times c3 \times s4 & a2.c1 + d2.s1 + l1.s1 + a4.c4.s1 + a4.c1 \times c3.s4 \quad ay \\ c3 \times c5 - c4 \times s3 \times s5 & -c3 \times s5 - c4 \times c5 \times s3 & s3 \times s4 & \underbrace{a4.s3 \times s4}_{a_z} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

- Cinemática Inversa θ_1:
  - Do RP d_2

$$\begin{cases} t_x = d_2 \times c_1 + l_1 \times c_1 - a_2 \times s_1 + a_4\, a_x \\ t_y = a_2.c_1 + d_2.s_1 + l_1.s_1 + a_4.a_y \\ t_z = a_4 \times a_z \end{cases} \Leftrightarrow \begin{cases} t_x = c_1(d_2+l_1) - a_2 s_1 + a_4 a_x \\ t_y = a_2 c_1 + s_1(d_2+l_1) + l_1 s_1 + a_4 a_y \\ t_z = a_4 a_z \end{cases}$$

$${}^{0}_{2}T = \begin{bmatrix} -s1 & 0 & c1 & a1.c1 + a3.c1 + d2.c1 - a2.s1 \\ c1 & 0 & s1 & a2.c1 + a1.s1 + a3.s1 + d2.s1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \rightarrow \begin{cases} t_x = c_1(a_1+a_3+d_2) - a_2.s_1 \\ t_y = s_1(a_1+a_3+d_2) + a_2.c_1 \\ t_z = 0 \end{cases}$$

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