



Resolução de Problemas I

SEM 0137 - Exercícios Capítulo 3

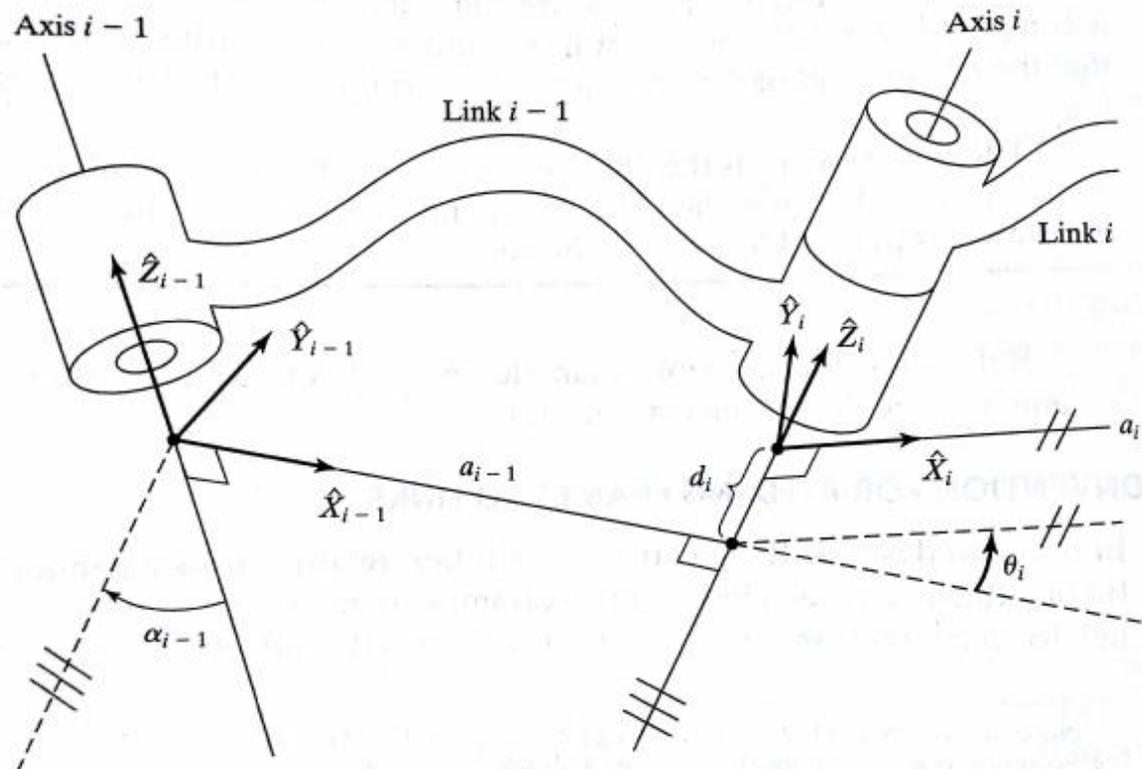
Prof. Assoc. Marcelo Becker
Monitor: Diego Soler

USP - EESC - SEM
LabRoM

Revisão

- Escolher \hat{Z}_i ao longo do eixo da junta
- Escolher \hat{X}_i ao longo da perpendicular common, ou, se os eixos se interceptam, escolha como a normal ao plano formado.

Revisão



Revisão

Matriz Transformação (Forma Geral)

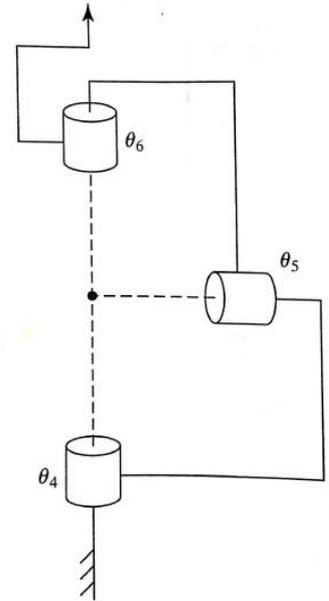
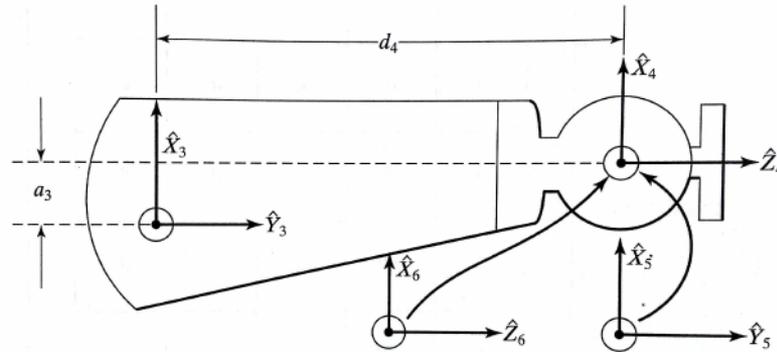
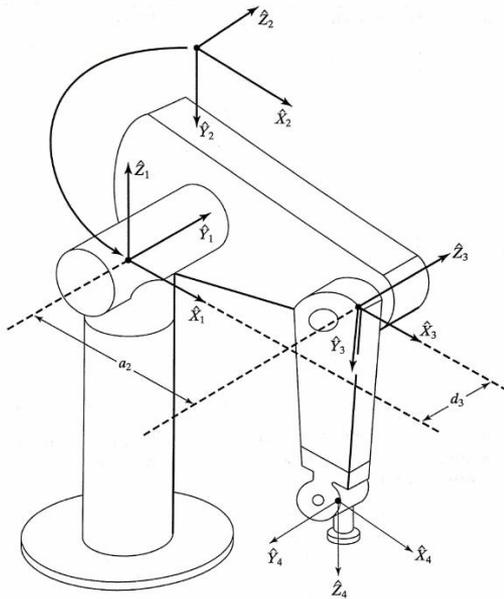
$${}^{i-1}T_i = \begin{bmatrix} c\theta_i & -s\theta_i & 0 & a_{i-1} \\ s\theta_i c\alpha_{i-1} & c\theta_i c\alpha_{i-1} & -s\alpha_{i-1} & -s\alpha_{i-1}d_i \\ s\theta_i s\alpha_{i-1} & c\theta_i s\alpha_{i-1} & c\alpha_{i-1} & c\alpha_{i-1}d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

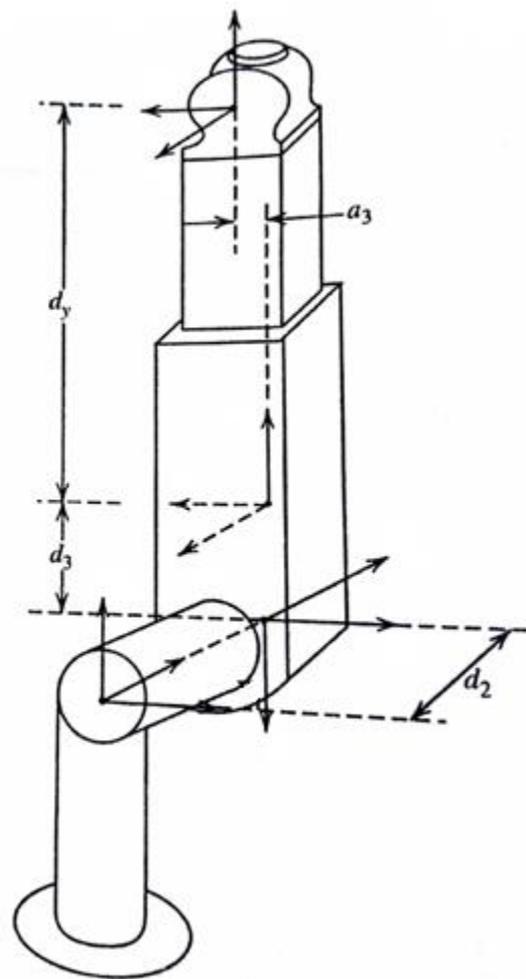
Onde:

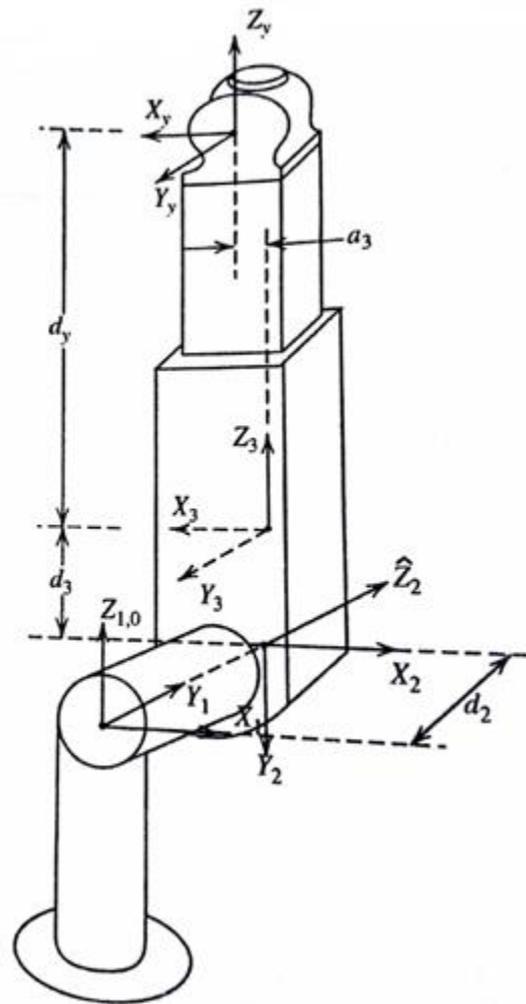
- a_i é a distancia entre \hat{Z}_{i+1} e \hat{Z}_i ao longo de \hat{X}_i ;
- α_i é o ângulo entre \hat{Z}_{i+1} e \hat{Z}_i em \hat{X}_i ;
- d_i é a distancia entre \hat{X}_{i-1} e \hat{X}_i ao longo de \hat{Z}_i ;
- θ_i é o ângulo entre \hat{X}_{i-1} e X_i em \hat{Z}_i ;

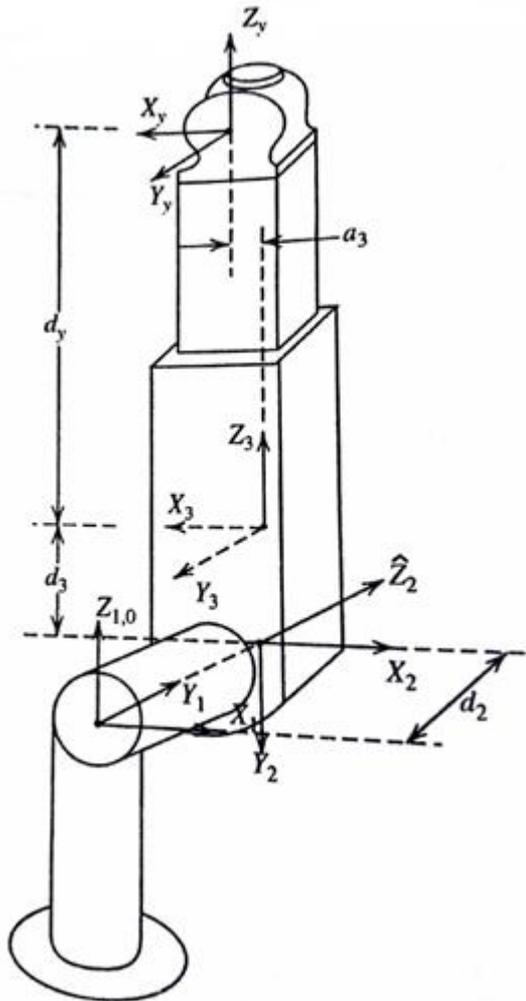
Exercício 3.2

Determine as equações cinemáticas de um braço robótico como o PUMA 560, onde a junta 3 foi substituída por uma junta prismática e também foi adicionado um offset d_3 .

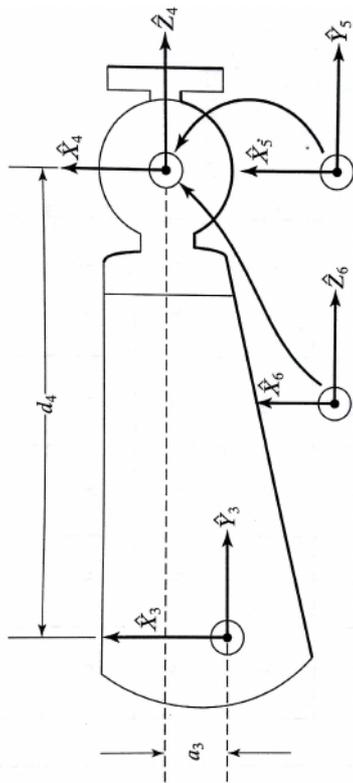




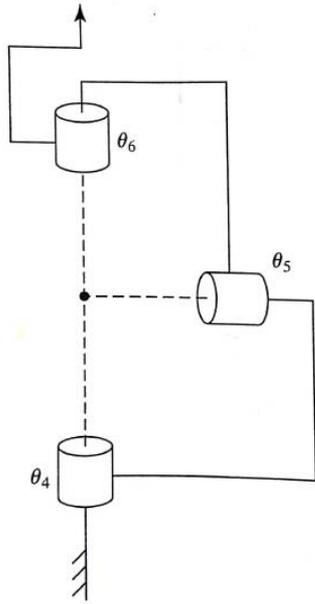




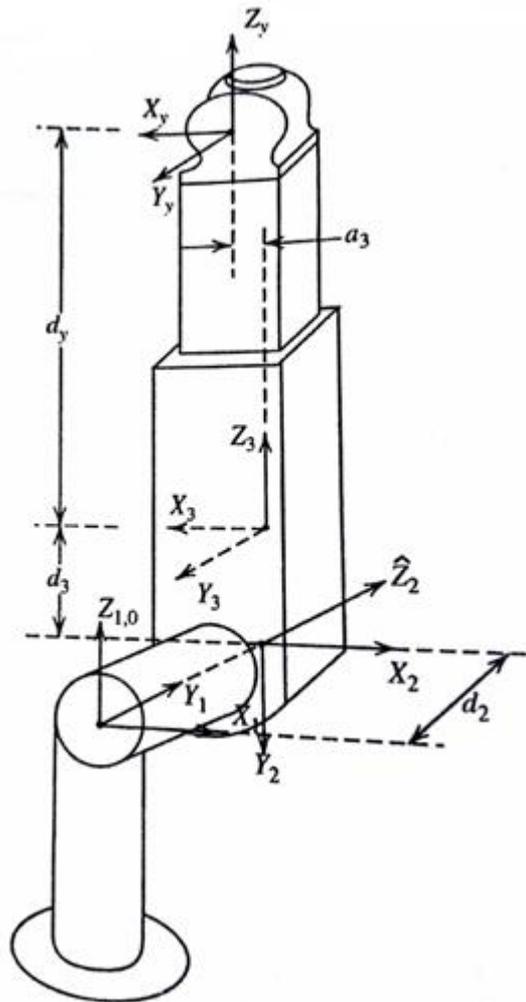
α_i	a_i	d_i	θ_i
0	0	0	θ_1
-90	0	d_2	θ_2
90	0	d_3	180



α_i	a_i	d_i	θ_i
0	0	0	θ_1
-90	0	d_2	θ_2
90	0	d_3	180
0	a_3	d_4	θ_4



α_i	a_i	d_i	θ_i
0	0	0	θ_1
-90	0	d_2	θ_2
90	0	d_3	180
0	a_3	d_4	θ_4



α_i	a_i	d_i	θ_i
0	0	0	θ_1
-90	0	d_2	θ_2
90	0	d_3	180
0	a_3	d_4	θ_4
90	0	0	θ_5
-90	0	0	θ_6

α_i	a_i	d_i	θ_i
0	0	0	θ_1
-90	0	d_2	θ_2
90	0	d_3	180
0	a_3	d_4	θ_4
90	0	0	θ_5
-90	0	0	θ_6

$${}^{i-1}T_i = \begin{bmatrix} c\theta_i & -s\theta_i & 0 & a_{i-1} \\ s\theta_i c\alpha_{i-1} & c\theta_i c\alpha_{i-1} & -s\alpha_{i-1} & -s\alpha_{i-1}d_i \\ s\theta_i s\alpha_{i-1} & c\theta_i s\alpha_{i-1} & c\alpha_{i-1} & c\alpha_{i-1}d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$${}^0T_1 = \begin{bmatrix} C_1 & -S_1 & 0 & 0 \\ S_1 & C_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$${}^5T_6 = \begin{bmatrix} C_6 & -S_6 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -S_6 & -C_6 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$${}^1T_2 = \begin{bmatrix} C_2 & -S_2 & 0 & 0 \\ 0 & 0 & 1 & d_2 \\ -S_2 & -C_2 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$${}^2T_3 = \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & -1 & -d_3 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$${}^3T_4 = \begin{bmatrix} C_4 & -S_4 & 0 & a_3 \\ S_4 & C_4 & 0 & 0 \\ 0 & 0 & 1 & d_4 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$${}^4T_5 = \begin{bmatrix} C_5 & -S_5 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ S_5 & C_5 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Transformação da base ao punho (Base to Wrist frame)

$${}^0_3T = {}^0_1T {}^1_2T {}^2_3T = \begin{bmatrix} -C_1 C_2 & S_1 & C_1 S_2 & -d_2 S_1 + d_3 C_1 S_2 \\ -S_1 C_2 & -C_1 & S_1 S_2 & d_2 C_1 + d_3 S_1 S_2 \\ S_2 & 0 & C_2 & d_3 C_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Transformação do punho até o goal (Wrist to Goal frame)

$${}^3_6T = {}^3_4T {}^4_5T {}^5_6T = \begin{bmatrix} C_4 C_5 C_6 - S_4 S_6 & -(C_4 C_5 S_6 + S_4 C_6) & -C_4 S_5 & a_3 \\ (S_4 C_5 C_6 + C_4 S_6) & -S_4 C_5 S_6 + C_4 C_6 & -S_4 S_5 & 0 \\ S_5 C_6 & -S_5 S_6 & C_5 & d_4 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$${}^0_6T = {}^0_3T {}^3_6T = \begin{bmatrix} R_{11} & R_{12} & R_{13} & P_x \\ R_{21} & R_{22} & R_{23} & P_y \\ R_{31} & R_{32} & R_{33} & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$R_{11} = -C_1 C_2 C_4 C_5 C_6 + C_1 C_2 S_4 S_6 + S_1 S_4 C_5 C_6 + S_1 C_4 S_6 + C_1 S_2 S_5 S_6$$

$$R_{12} = C_1 C_2 C_4 C_5 S_6 + C_1 C_2 S_4 C_6 - S_1 S_4 C_5 S_6 + S_1 C_4 C_6 - S_1 S_2 S_5 S_6$$

$$R_{13} = C_1 C_2 C_4 S_5 - S_1 S_4 S_5 + C_1 S_2 C_5$$

$$R_{21} = -S_1 C_2 C_4 C_5 C_6 + S_1 C_2 S_4 S_6 - C_1 S_4 C_5 C_6 - C_1 C_4 S_6 + S_1 S_2 S_5 C_6$$

$$R_{22} = S_1 C_2 C_4 C_5 S_6 + S_1 C_2 S_4 C_6 + C_1 S_4 C_5 S_6 - C_1 C_4 C_6 - S_1 S_2 S_5 S_6$$

$$R_{23} = S_1 C_2 C_4 S_5 + C_1 S_4 S_5 + S_1 S_2 C_5$$

$$R_{31} = S_2 C_4 C_5 C_6 - S_2 S_4 S_6 + C_2 S_5 C_6$$

$$R_{32} = -S_2 C_4 C_5 S_6 - S_2 S_4 C_6 - C_2 S_5 S_6$$

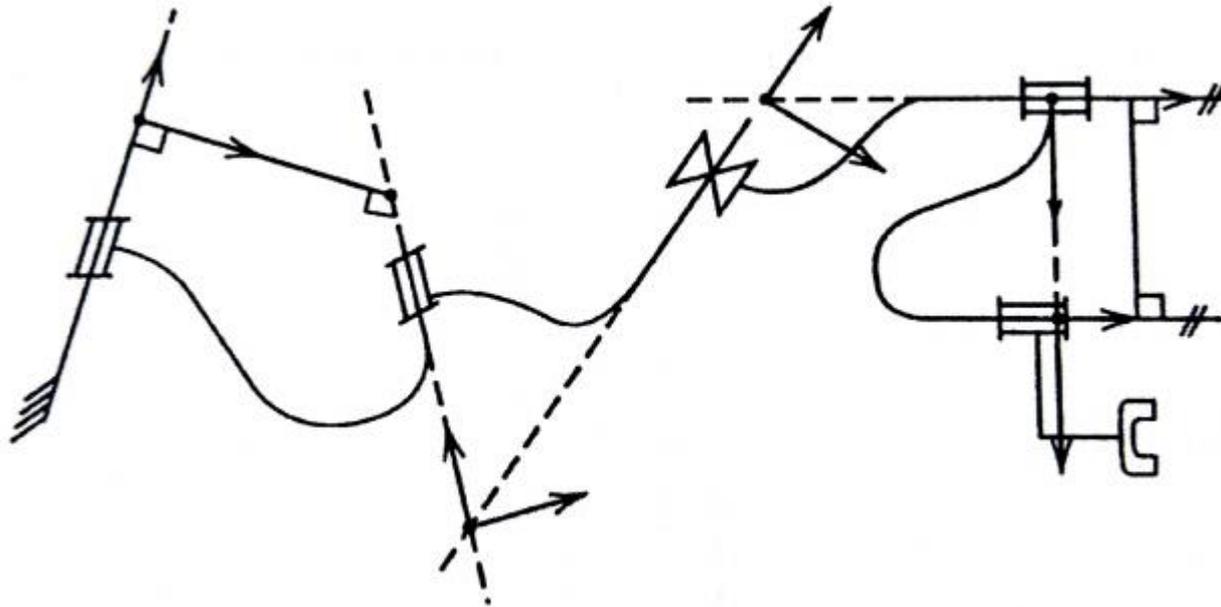
$$R_{33} = -S_2 C_4 C_5 + C_2 C_5$$

$$P_x = -d_2 S_1 + (d_3 + d_4) C_1 S_2 - a_3 C_1 C_2$$

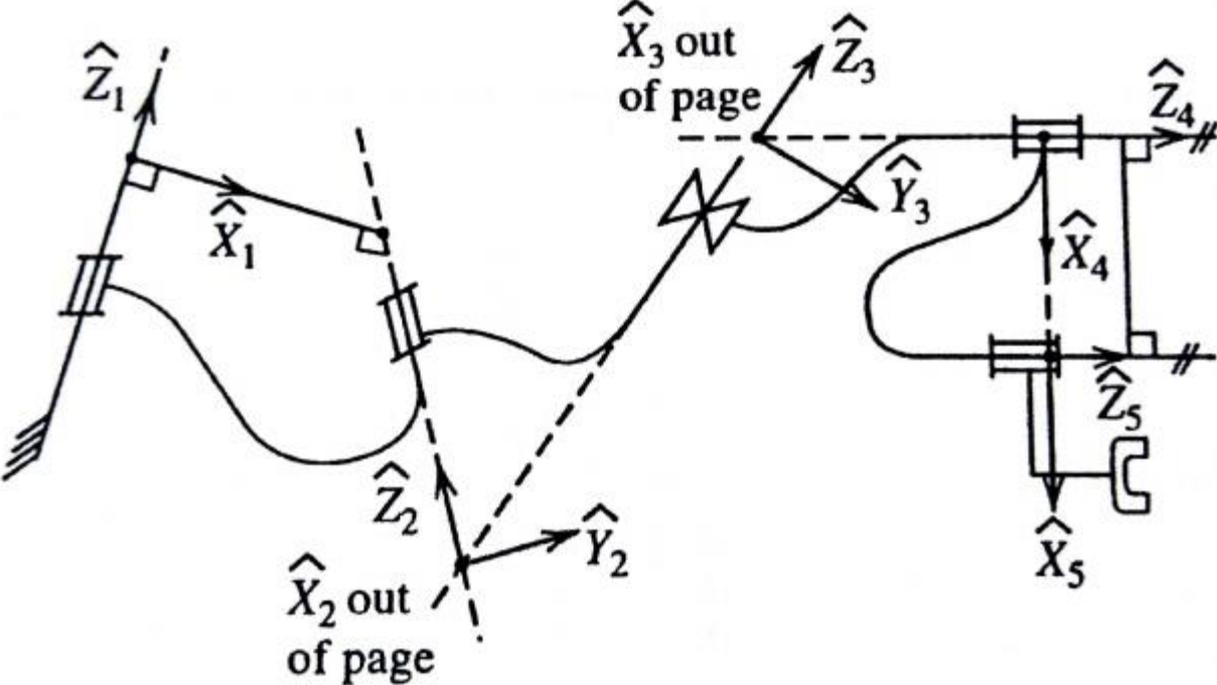
$$P_y = d_2 C_1 + (d_3 + d_4) S_1 S_2 - a_3 S_1 C_2$$

$$P_z = (d_3 + d_4) C_2 + a_3 S_2$$

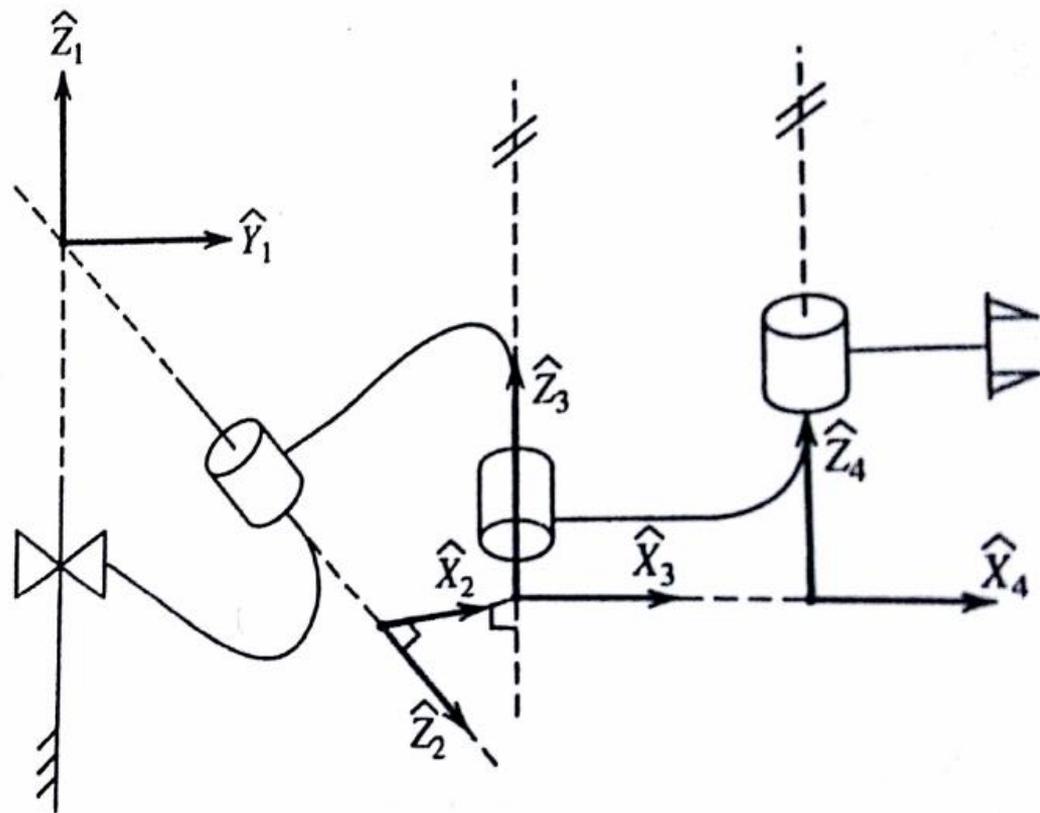
Exercício 3.13



Exercício 3.13



Exercício 3.22



Bibliografia

- Craig, J.C., 2005, Introduction to Robotics: Mechanics and Control, 3rd Edition, Pearson Education Inc., ISBN 0-201-54361-3