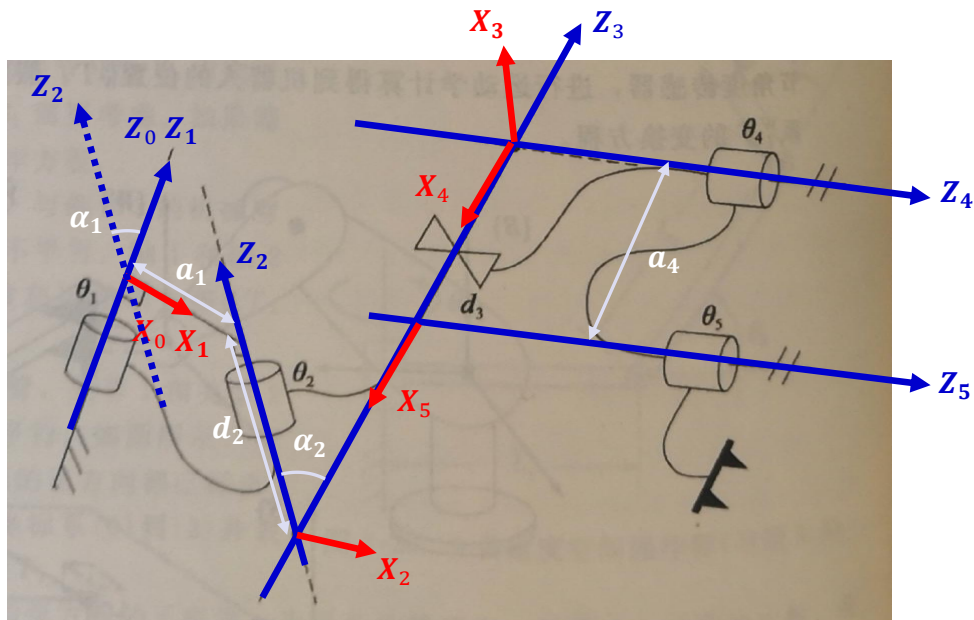


3.13



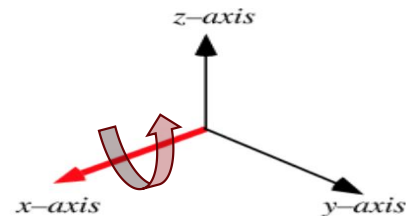
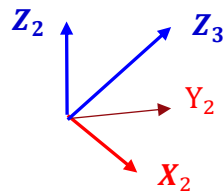
DH参数表

关节	α_{i-1}	\vec{a}_{i-1}	d_i	θ_i
1	0	0	0	θ_1
2	α_1	a_1	$-d_2$	θ_2
3	$-\alpha_2$	0	d_3	$-\theta_3^*$
4	$-\alpha_3$	0	0	θ_4
5	0	a_4	0	θ_5

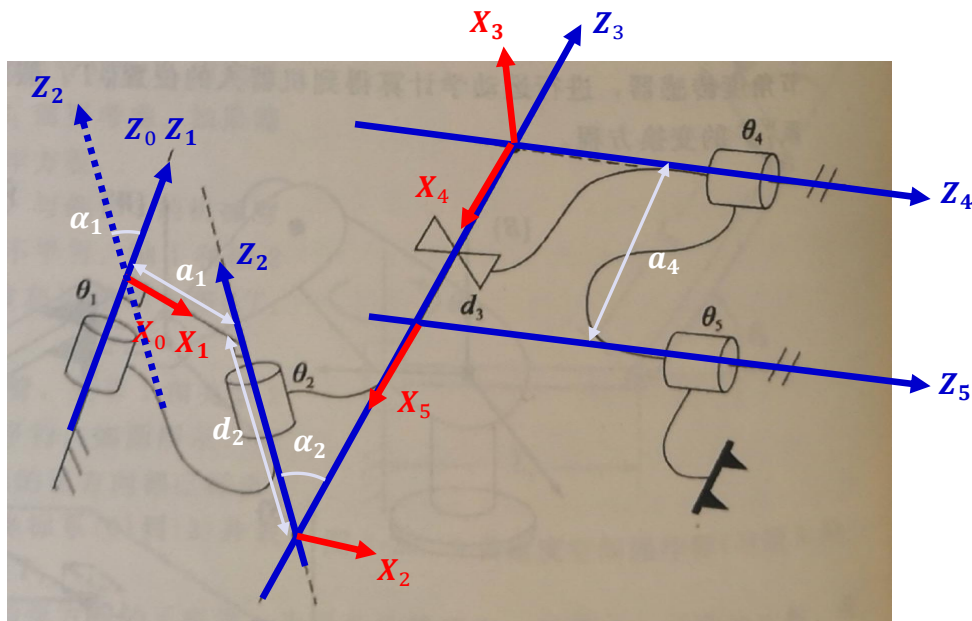
问题1:

第3个关节 α_{i-1} : 绕 X_2 轴, 从 Z_2 旋转到 Z_3

$-\alpha_2$

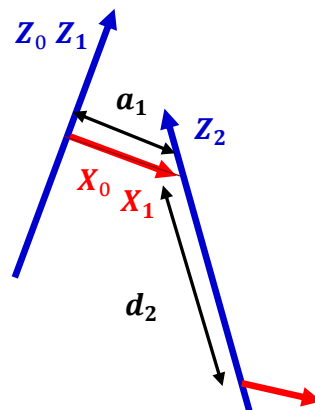


3.13



DH参数表

关节	α_{i-1}	\vec{a}_{i-1}	d_i	θ_i
1	0	0	0	θ_1
2	α_1	a_1	$-d_2$	θ_2
3	$-\alpha_2$	0	d_3	$-\theta_3^*$
4	$-\alpha_3$	0	0	θ_4
5	0	a_4	0	θ_5

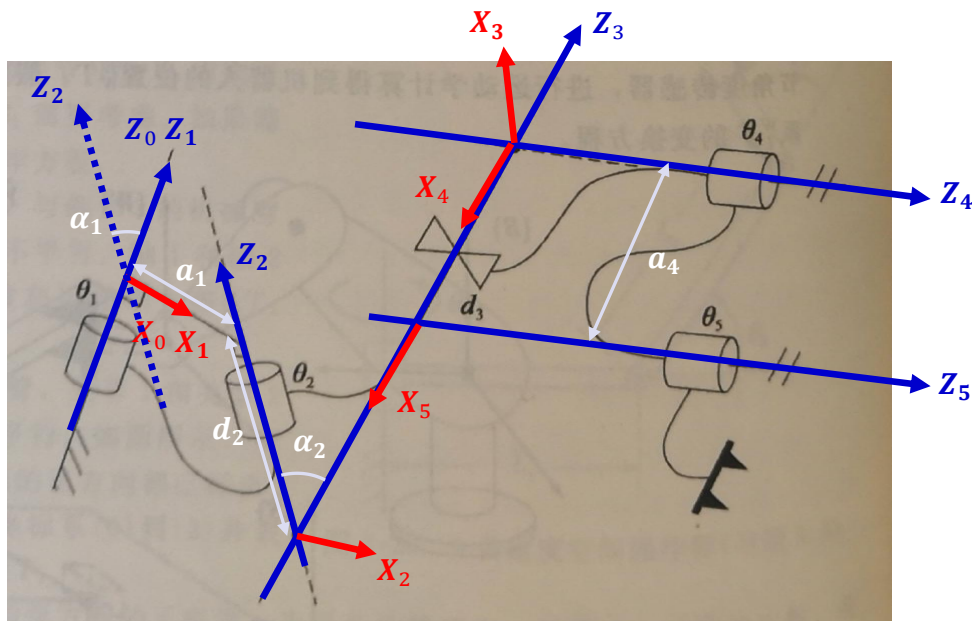


问题2:

第2个关节 d_i : 绕 Z_2 轴, 从 X_1 移动到 X_2

$-d_2$

3.13



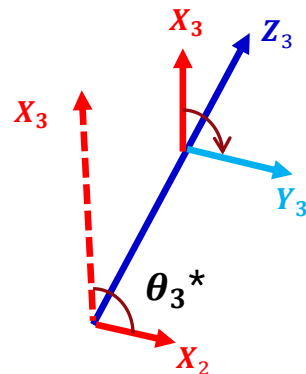
第3个关节是平动关节, d_3 是变量
第3个关节 θ_3 : 绕 Z_3 轴, 从 X_2 旋转到 X_3

问题3:

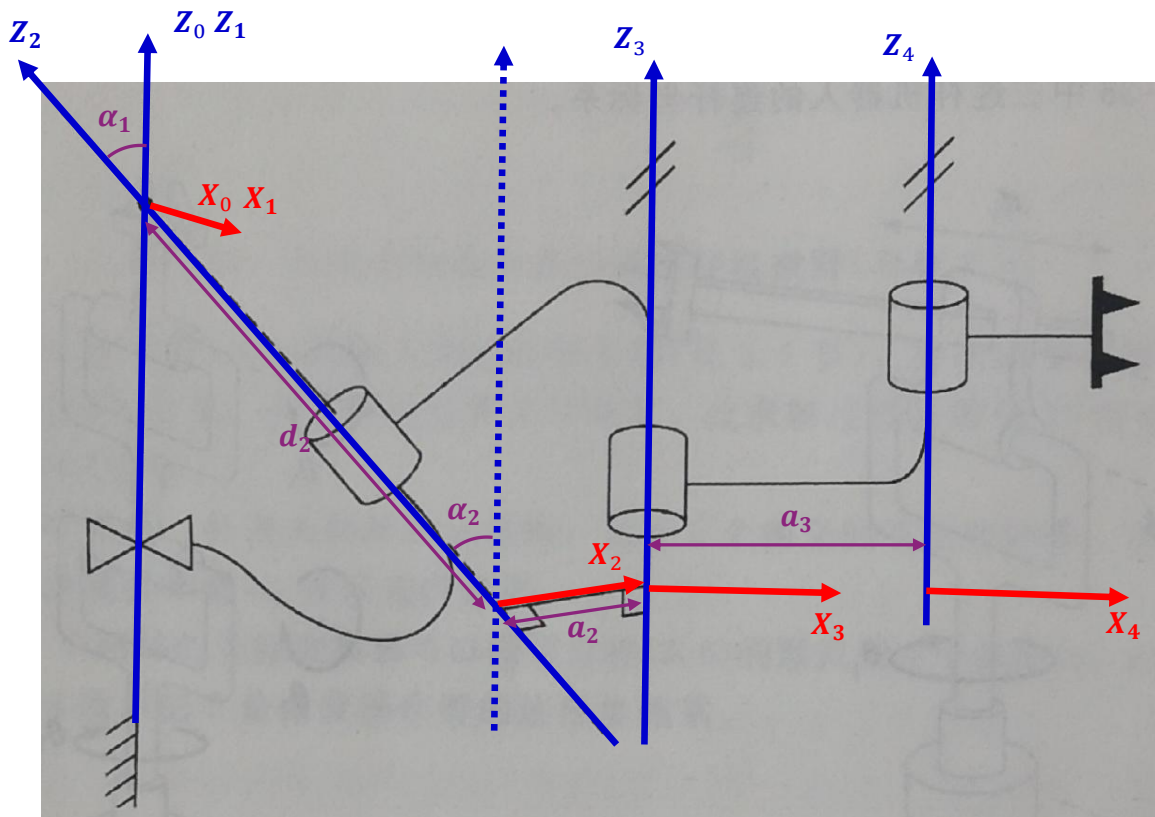
定值 $-\theta_3^*$

DH参数表

关节	α_{i-1}	\vec{a}_{i-1}	d_i	θ_i
1	0	0	0	θ_1
2	α_1	a_1	$-d_2$	θ_2
3	$-\alpha_2$	0	d_3	$-\theta_3^*$
4	$-\alpha_3$	0	0	θ_4
5	0	a_4	0	θ_5



3.22



DH参数表

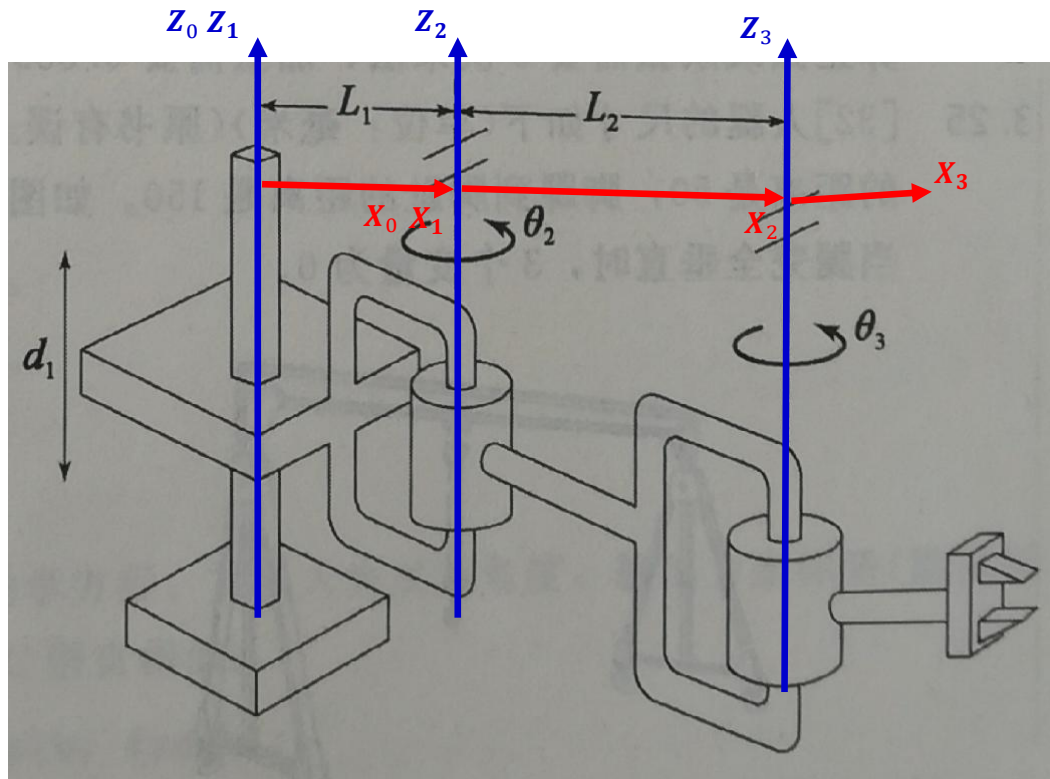
关节	α_{i-1}	\vec{a}_{i-1}	d_i	θ_i
1	0	0	d_1	0
2	α_1	0	$-d_2$	θ_2
3	α_2	a_2	0	θ_3
4	0	a_3	0	θ_4

第2个关节 d_i : 绕 Z_2 轴, 从 X_1 移动到 X_2

问题:

$-d_2$

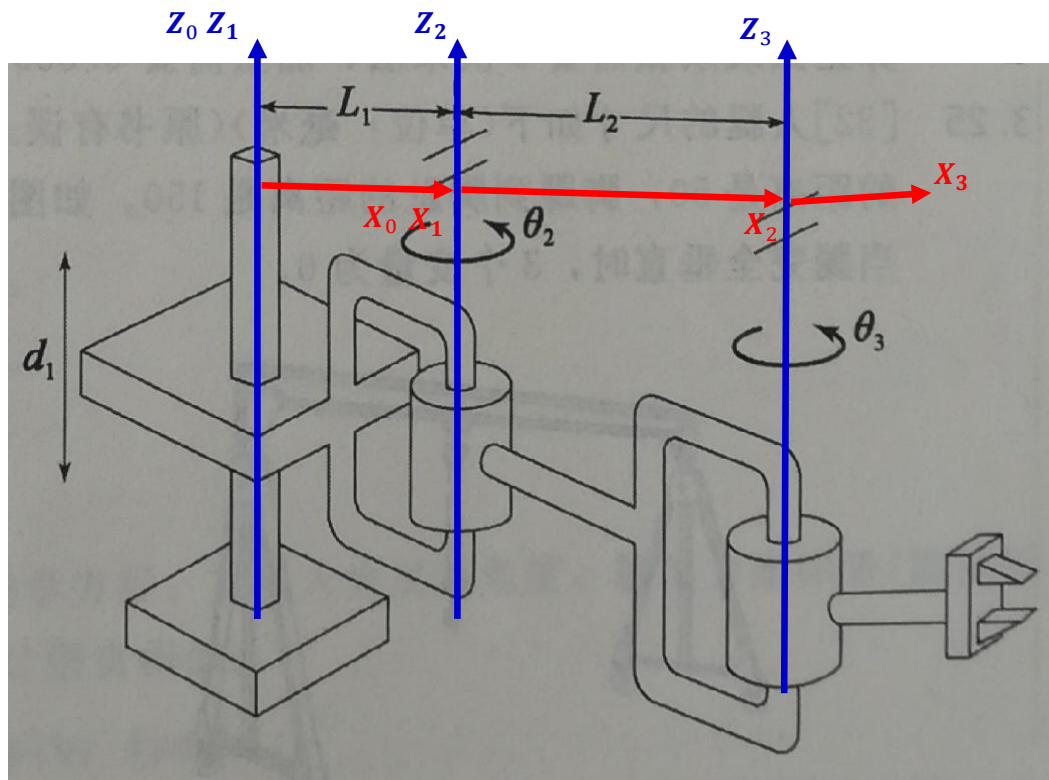
3.17



DH参数表

关节	α_{i-1}	\vec{a}_{i-1}	d_i	θ_i
1	0	0	d_1	0
2	0	L_1	0	θ_2
3	0	L_2	0	θ_3

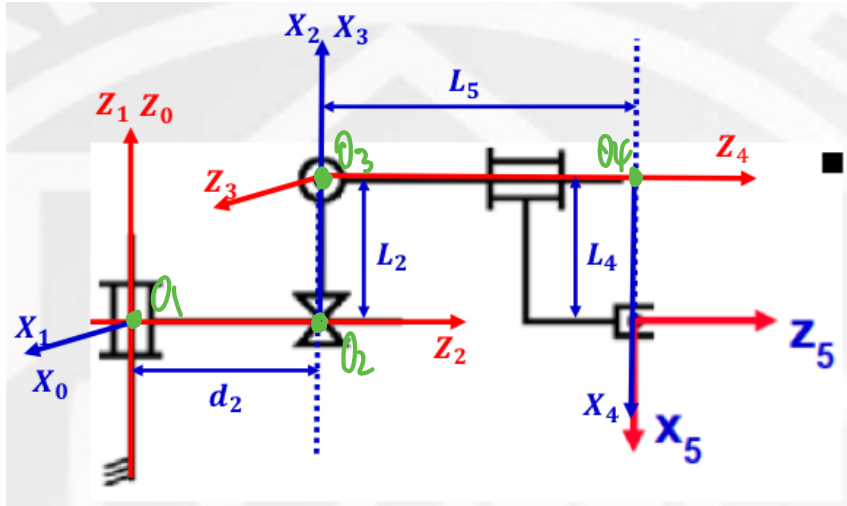
3.20



DH参数表

关节	α_{i-1}	\vec{a}_{i-1}	d_i	θ_i
1	0	0	d_1	0
2	0	L_1	0	θ_2
3	0	L_2	0	θ_3

例2 空间RP2R四关节机器人正运动学



Handwritten notes above table: 20.21, 20.21, 0.0, 0.0, 0.0, 0.0

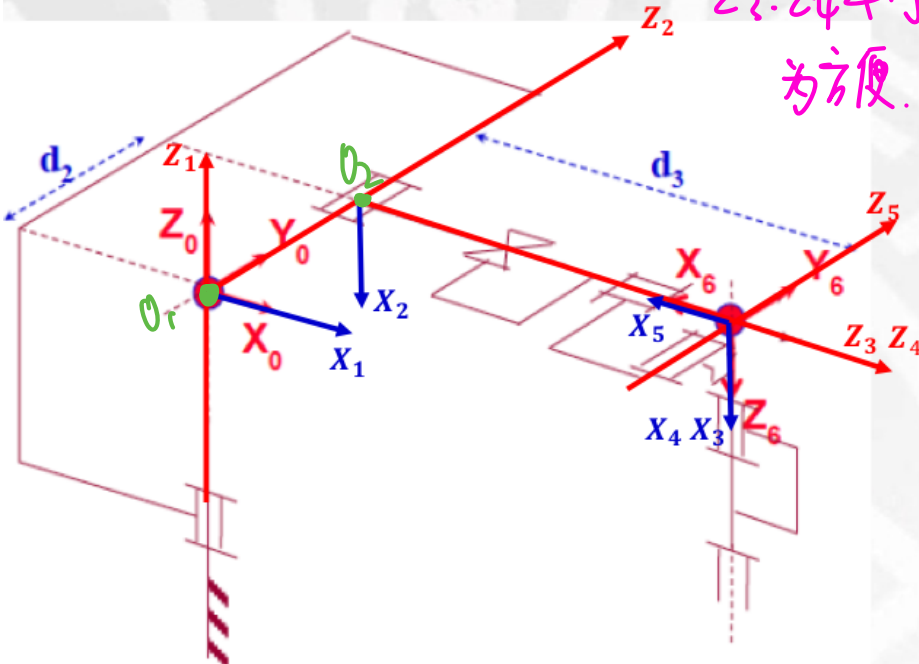
Handwritten note: 为何要给末端执行器编号? (Why number the end effector?)

Handwritten note: 05=0 表示末端执行器不转 (05=0 indicates the end effector does not rotate)

关节	α_{i-1}	\bar{a}_{i-1}	d_i	θ_i
0-1	0	0	0	θ_1
1-2	-90°	0	d_2	-90°
2-3	-90°	L_2	0	θ_3
3-4	90°	0	L_5	θ_4
4-5	0	L_4	0	0

Handwritten values for the last row (4-5): 0, 0, 0, 0, 0

例3 Stanford Scheinman机器人正运动学



Handwritten notes: z_2, z_4 平行, 公垂线任意: 原点随便选 (parallel, common normal arbitrary: origin can be chosen arbitrarily)

根据关节类型, 先填入变量 (According to joint type, fill in variables first)

为方便, 后3个原点重合 (For convenience, the last 3 origins coincide)

Handwritten note: 变量 (variable)

关节	α_{i-1}	\bar{a}_{i-1}	d_i	θ_i
1	0	0	0	θ_1
2	-90°	0	d_2	θ_2
3	90°	0	d_3	0
4	0	0	0	θ_4
5	-90°	0	0	θ_5
6	90°	0	0	θ_6

注意: 各个关节的零点位置 (Note: Zero position of each joint)

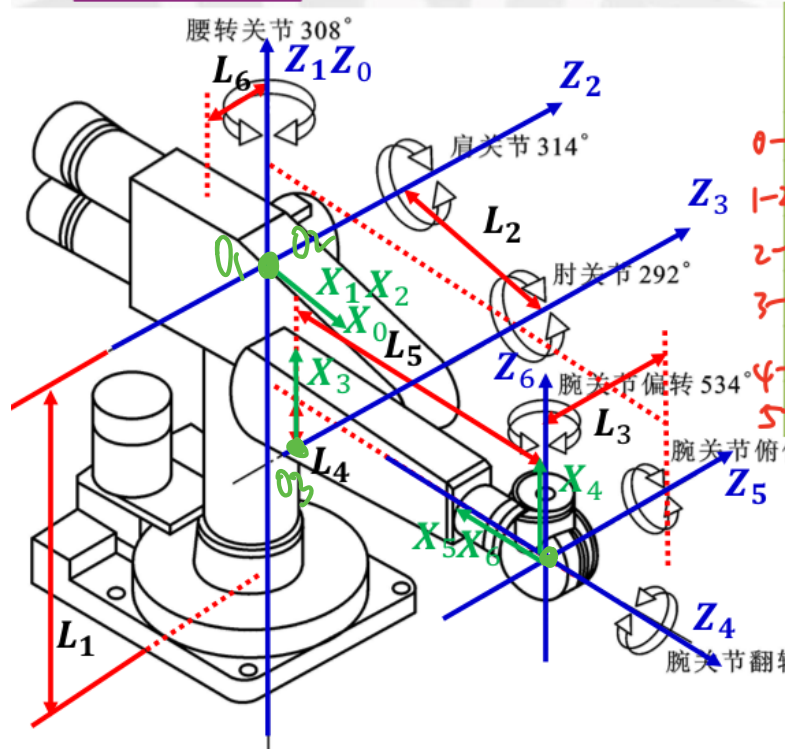
Stanford Scheinman机器人: 空间2R3P机器人

Handwritten notes: 由于 z_3, z_4 重合, x_3 也随意, 先放下. (Since z_3, z_4 coincide, x_3 is also arbitrary, put it down first.)

确定 x_4 后, 为方便, 令 x_3 与 x_4 重合 (After determining x_4 , for convenience, let x_3 coincide with x_4)

3.5 PUMA机器人正运动学建模

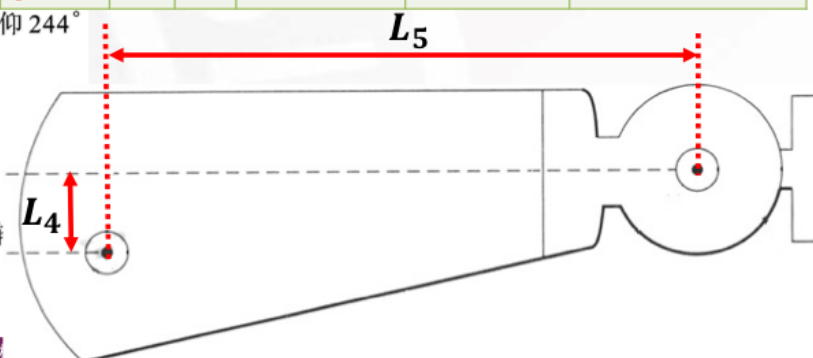
L3不如. 偏移规则奇并点



PUMA robot arm link coordinate parameters					
Joint i	θ_i	α_{i-1}	a_{i-1}	d_i	Joint range
0-1	θ_1	0	0	0	-160 to 160
1-2	θ_2	-90	0	0	-225 to 45
2-3	θ_3	0	L_2	L_3	-45+180 to 225+180
3-4	θ_4	-90	L_4	L_5	-110 to 170
4-5	θ_5	90	0	0	-100 to 100
5-6	θ_6	-90	0	0	-266 to 266

0-1
1-2
2-3
3-4
4-5
5-6

肘关节与X1轴相反



z2 z3平行. o2也随意. 无法与o3重合 因此与o1重合

第三章

3.5 举例：3DOF 圆柱机械臂

《机器人学导论》

Link parameters for 3-link cylindrical manipulator

Link	a_i	α_i	d_i	θ_i
1	0	0	d_1	θ_1^*
2	0	-90	d_2^*	0
3	0	0	d_3^*	0

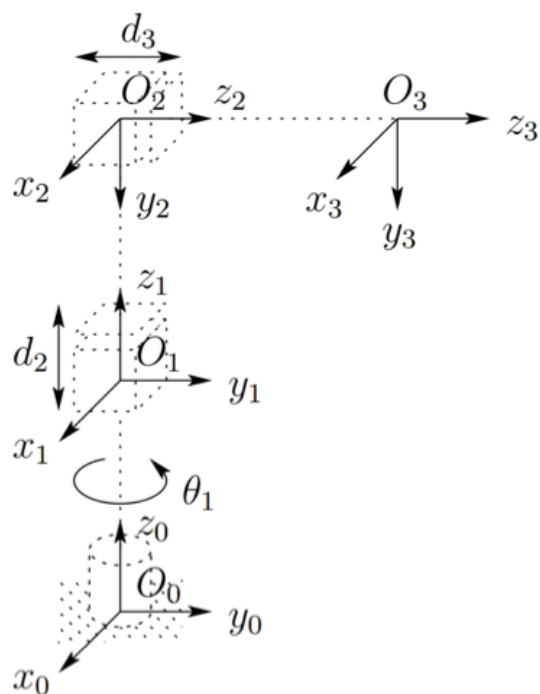
* variable

$$A_1 = \begin{bmatrix} c_1 & -s_1 & 0 & 0 \\ s_1 & c_1 & 0 & 0 \\ 0 & 0 & 1 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_2 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

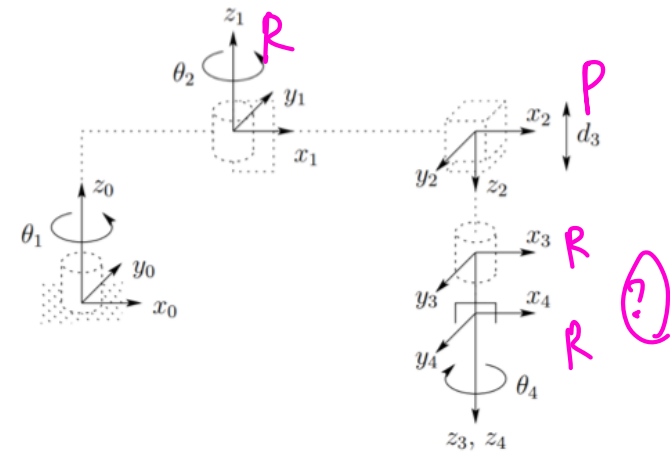
$$A_3 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_3^0 = A_1 A_2 A_3 = \begin{bmatrix} c_1 & 0 & -s_1 & -s_1 d_3 \\ s_1 & 0 & c_1 & c_1 d_3 \\ 0 & -1 & 0 & d_1 + d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$



Three-link cylindrical manipulator

3.5 举例：SCARA机械臂



DH coordinate frame assignment for the SCARA manipulator

Joint parameters for SCARA.

Link	a_i	α_i	d_i	θ_i
1	a_1	0	0	*
2	a_2	180	0	*
3	0	0	*	0
4	0	0	d_4	*

* joint variable

$$A_1 = \begin{bmatrix} c_1 & -s_1 & 0 & a_1 c_1 \\ s_1 & c_1 & 0 & a_1 s_1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_2 = \begin{bmatrix} c_2 & s_2 & 0 & a_2 c_2 \\ s_2 & -c_2 & 0 & a_2 s_2 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_3 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_4 = \begin{bmatrix} c_4 & -s_4 & 0 & 0 \\ s_4 & c_4 & 0 & 0 \\ 0 & 0 & 1 & d_4 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_4^0 = A_1 \cdots A_4 = \begin{bmatrix} c_{12}c_4 + s_{12}s_4 & -c_{12}s_4 + s_{12}c_4 & 0 & a_1c_1 + a_2c_{12} \\ s_{12}c_4 - c_{12}s_4 & -s_{12}s_4 - c_{12}c_4 & 0 & a_1s_1 + a_2s_{12} \\ 0 & 0 & -1 & -d_3 - d_4 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$