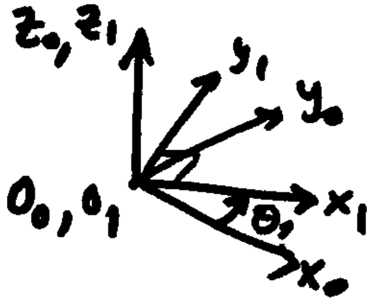
3-10

Base frame: $O_0 x_0 y_0 z_0$ shown in picture.

Frame 1: $O_1 = O_0$; $z_1 = z_0$

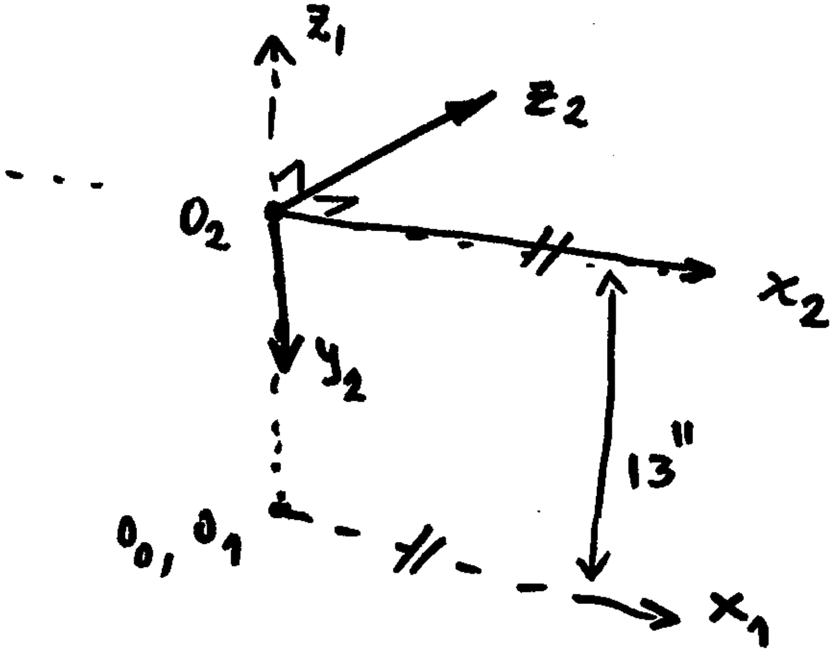


Link 1: $\begin{cases} a_1 = 0 \\ \alpha_1 = 0 \\ d_1 = 0 \\ \theta_1 = \theta_1^* \end{cases}$

$$\boxed{A_1^0 = Rot_{z,\theta_1}}$$

Frame 2:

z_2 attached to shoulder joint; $O_2^0 = \begin{bmatrix} 0 \\ 0 \\ 13 \end{bmatrix}$ "

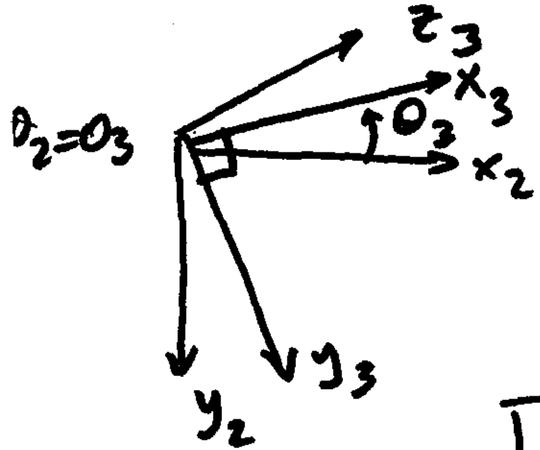


Link 2: $\begin{cases} a_2 = 0 \\ \alpha_2 = -90° \\ d_2 = 13 \\ \theta_2 = 0 \end{cases}$

$$\boxed{A_2^1 = Trans_{z,13} \cdot Rot_{x,-90}}$$

Note: This frame does not involve a joint variable, it's only auxiliary.

Frame 3: $O_3 = O_2$; $z_3 = z_2$

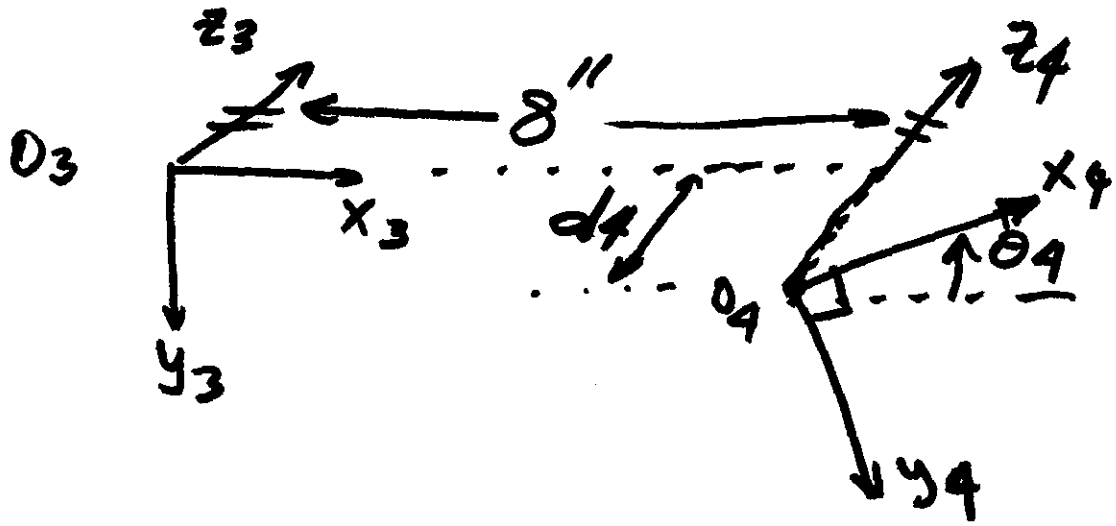


Link 3 :

$$\begin{cases} a_3 = 0 \\ \alpha_3 = 0 \\ d_3 = 0 \\ \theta_3 = \theta_3^* \end{cases}$$

$$\boxed{A_3^2 = Rot_{z,\theta_3}}$$

Frame 4 :

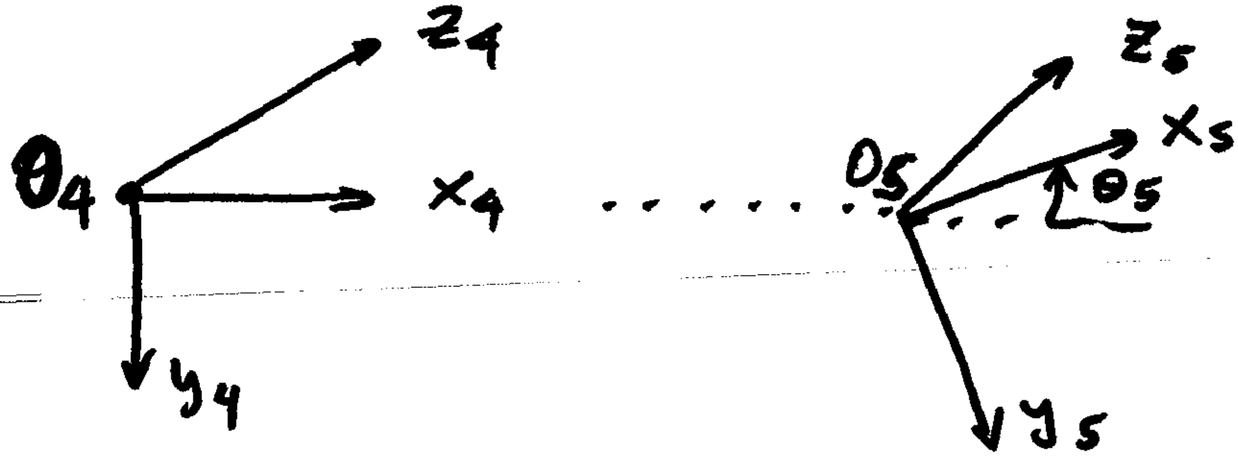


Link 4 :

$$\begin{cases} a_4 = 8 \\ \alpha_4 = 0 \\ d_4 = d_4 \text{ (negative number)} \\ \theta_4 = \theta_4^* \end{cases}$$

$$A_4^3 = Rot_{z,\theta_4} \cdot Trans_{z,d_4} \cdot Trans_{x,8}$$

Frame 5: (to wrist rotation)

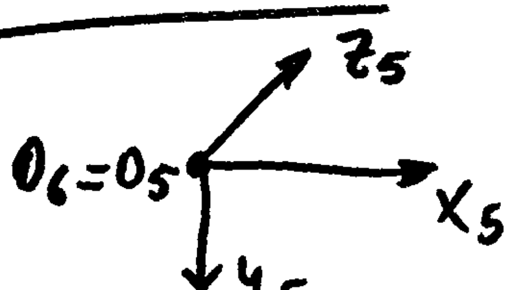


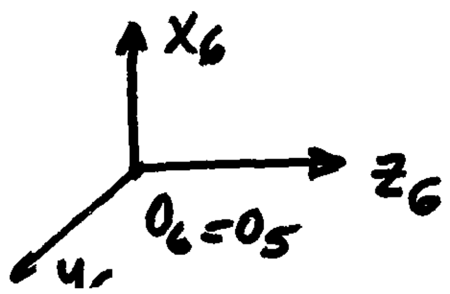
Link 5

$$\begin{cases} a_5 = 8 \\ \alpha_5 = 0 \\ d_5 = 0 \\ \theta_5 = \theta_5^* \end{cases}$$

$$A_5^4 = Rot_{z,\theta_5} \, Trans_{x,8}$$

Frame 6 (to wrist twist) $O_6 = O_5$





) auxiliary frame

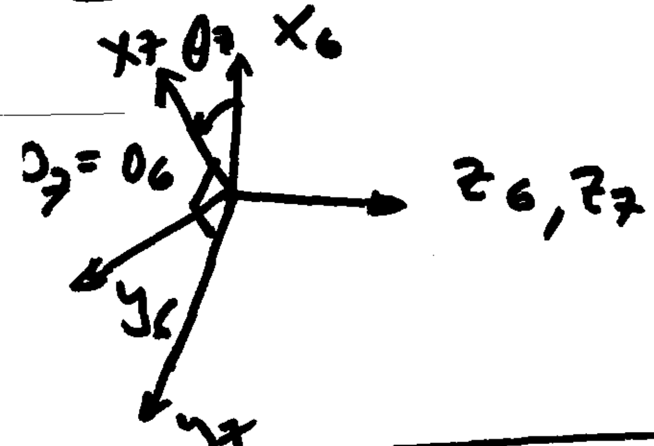
Link 6:

$$\begin{cases} a_6 = 0 \\ \alpha_6 = -90^\circ \\ d_6 = 0 \\ \theta_6 = -90^\circ \end{cases}$$

$$\boxed{A_6^5 = Rot_{z,-90}\, Rot_{x,-90}}$$

Frame 7 (to wrist twist)

$o_7 = o_6$

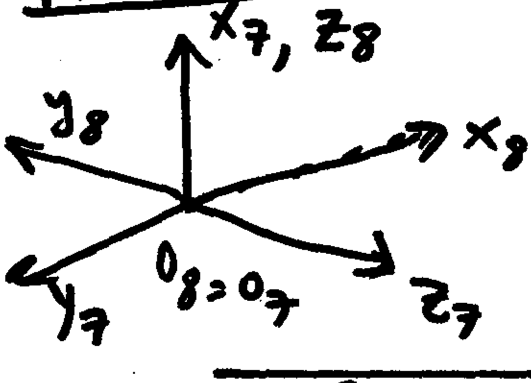


Link 7:

$$\begin{cases} a_7 = 0 \\ \alpha_7 = 0 \\ d_7 = 0 \\ \theta_7 = \theta_7^* \end{cases}$$

$$\boxed{A_7^6 = Rot_{z,\theta_7}}$$

Frame 8: auxiliary (to meet DH2)

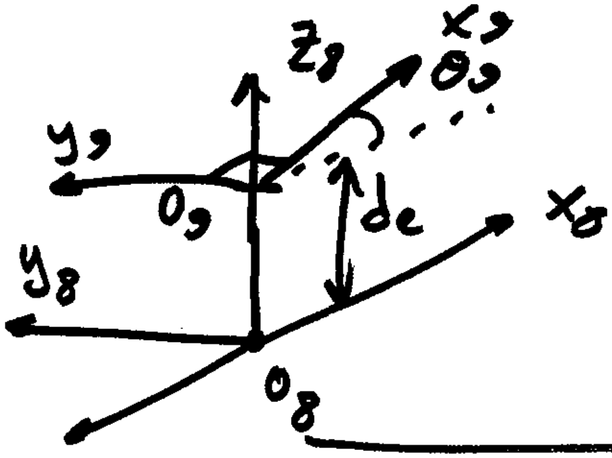


Link 8:

$$\begin{cases} a_8 = 0 \\ \alpha_8 = -90 \\ d_8 = 0 \\ \theta_8 = -90 \end{cases}$$

$$\boxed{A_8^7 = Rot_{z,-90}\, Rot_{x,-90}}$$

Frame 9 (end frame to flange)



Link 9 : $\begin{cases} a_9 = 0 \\ \alpha_9 = 0 \\ d_9 = d_e \\ \theta_9 = \theta_9^* \end{cases}$

$$A_9^8 = Rot_{z,\theta_9} \cdot Trans_{z,d_e}$$

See ~~Maple worksheet~~ Matlab program for computation of

$$T_9^0 = \prod_{j=1}^{9} A_j^{j-1}$$

```
%Matlab program to verify Prob 3-10 in SHV
%by Hanz Richter

syms th1 th3 th4 th5 th7 th9 de d4
A10=[cos(th1) -sin(th1) 0 0;sin(th1) cos(th1) 0 0;0 0 1 0;0 0 0 1];
A21=[eye(3) [0;0;13];0 0 0 1]*[1 0 0 0;0 0 1 0;0 -1 0 0;0 0 0 1];
A32=[cos(th3) -sin(th3) 0 0;sin(th3) cos(th3) 0 0;0 0 1 0;0 0 0 1];
A43=[cos(th4) -sin(th4) 0 0;sin(th4) cos(th4) 0 0;0 0 1 0;0 0 0 1]*[eye(3) [8;0;d4];0 0 0 1];
A54=[cos(th5) -sin(th5) 0 0;sin(th5) cos(th5) 0 0;0 0 1 0;0 0 0 1]*[eye(3) [8;0;0];0 0 0 1];
A65=[0 1 0 0;-1 0 0 0;0 0 1 0;0 0 0 1]*[1 0 0 0;0 0 1 0;0 -1 0 0;0 0 0 1];
A76=[cos(th7) -sin(th7) 0 0;sin(th7) cos(th7) 0 0;0 0 1 0;0 0 0 1];
A87=A65;
A98=[cos(th9) -sin(th9) 0 0;sin(th9) cos(th9) 0 0;0 0 1 0;0 0 0 1]*[eye(3) [0;0;de];0 0 0 1];

T90=A10*A21*A32*A43*A54*A65*A76*A87*A98;

%To check validity, we know that when all joint angles are zero,
%o_9^0=[16;d4;13+de]    %d4<0

o_99=[0;0;0;1];

th1=0;
th3=0;
th4=0;
th5=0;
th7=0;
th9=0;

o_90=eval(T90*o_99)  %Works!
```