ME EN 537 HW#2 | Jae Lee

2-38, 2-39, 2-40, 2-41, 3-4, 3-6, 3-8

2-38.

$$H_1^0 = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ -1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$R_1^0 = R_{x,\frac{\pi}{2}} R_{z,-\frac{\pi}{2}} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & -1 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & -1 \\ -1 & 0 & 0 \end{bmatrix} \quad d_1^0 = [0\ 0\ 1]^T$$

$$H_2^0 = \begin{bmatrix} 0 & 0 & -1 & 0 \\ -1 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$R_2^0 = R_{z,-\frac{\pi}{2}} R_{x,\frac{\pi}{2}} = \begin{bmatrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & -1 \\ 0 & 1 & 0 \end{bmatrix} = \begin{bmatrix} 0 & 0 & -1 \\ -1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} \quad d_2^0 = [0\ 1\ 0]^T$$

$$H_2^1 = \begin{bmatrix} 0 & -1 & 0 & 1 \\ 0 & 0 & -1 & 0 \\ 1 & 0 & 0 & -1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$R_2^1 = R_{y_1,-\frac{\pi}{2}} R_{x_1,\frac{\pi}{2}} = \begin{bmatrix} 0 & 0 & -1 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & -1 \\ 0 & 1 & 0 \end{bmatrix} = \begin{bmatrix} 0 & -1 & 0 \\ 0 & 0 & -1 \\ 1 & 0 & 0 \end{bmatrix} \quad d_2^1 = \begin{bmatrix} 1 \\ 0 \\ -1 \end{bmatrix}$$

$$H_2^0 = H_1^0 H_2^1 = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ -1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0 & -1 & 0 & 1 \\ 0 & 0 & -1 & 0 \\ 1 & 0 & 0 & -1 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 0 & 0 & -1 & 0 \\ -1 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

2-39. Find H_1^0 H_2^0 H_3^0 H_3^2

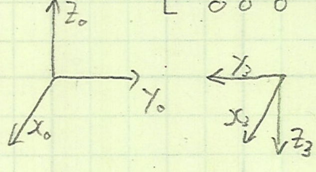
$$H_1^0 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad H_2^0 = \begin{bmatrix} 1 & 0 & 0 & -0.5 \\ 0 & 1 & 0 & 1.5 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$H_3^0 = \begin{bmatrix} 0 & 1 & 0 & -0.5 \\ 1 & 0 & 0 & 1.5 \\ 0 & 0 & -1 & 3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$R_3^0 = R_{z_0,\frac{\pi}{2}} R_{x_0,\pi} = \begin{bmatrix} 0 & -1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & -1 \end{bmatrix} \quad d_3^0 = \begin{bmatrix} -0.5 \\ 1.5 \\ 3 \end{bmatrix}$$

$$H_3^2 = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

2-40.



$$H_3^0 = \begin{bmatrix} 1 & 0 & 0 & -0.5 \\ 0 & -1 & 0 & 1.5 \\ 0 & 0 & -1 & 3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad H_5^2 = \begin{bmatrix} 1 & 0 & 0 & -0.5 \\ 0 & -1 & 0 & 1.5 \\ 0 & 0 & -1 & 3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

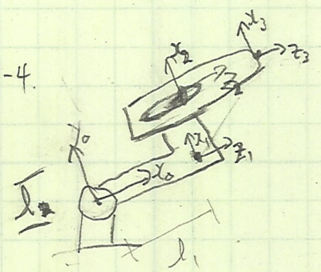
$$R_3^0 = R_{x_0,\pi} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{bmatrix}$$

2-43. $(R_{x,\alpha}, Trans_{x,b})$, $(Trans_{z,d}, R_{z,\theta})$ can commute

because elements in the matrix is not affected by the order of calculation.

$$H = R_{x\alpha} T_{xb} T_{zd} R_{z\theta} = T_{xb} R_{x\alpha} R_{z\theta} T_{zd}$$
$$= T_{xb} R_{x\alpha} T_{zd} R_{z\theta} = R_{x\alpha} T_{xb} R_{z\theta} T_{zd}$$

3-4.



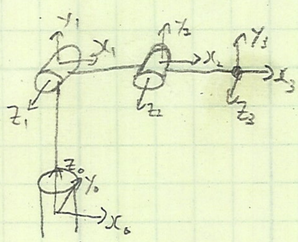
$R = R_{z,\theta} T_{z,d} T_{x,a} R_{x,\alpha}$

link	θ	d	a	α
1	$\theta_1 + \frac{\pi}{2}$	0	l_1	$\frac{\pi}{2}$
2	0	0	l_2	0
3	0	d_1	0	0

$$A_i = \begin{bmatrix} C\theta_i & -S\theta_i C\alpha_i & S\theta_i S\alpha_i & a_i C\theta_i \\ S\theta_i & C\theta_i C\alpha_i & -C\theta_i S\alpha_i & a_i S\theta_i \\ 0 & S\alpha_i & C\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$T = A_1 A_2 A_3$

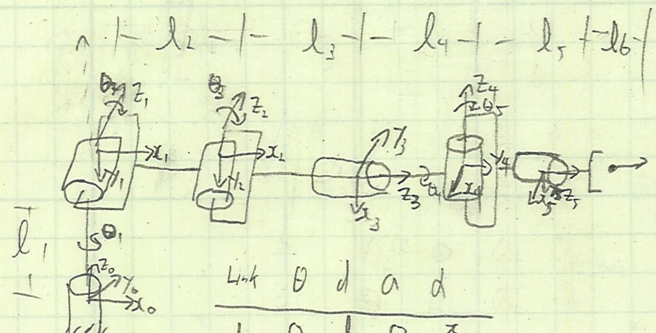
3-6



link	θ	d	a	α
1	θ_1	d_1	0	$\frac{\pi}{2}$
2	θ_2	0	a_2	0
3	θ_3	0	a_3	0

$T = A_1 A_2 A_3$

3-8.



Link	θ	d	a	α
1	θ_1	l_1	0	$-\frac{\pi}{2}$
2	θ_2	0	l_2	0
3	$\theta_3 + \frac{\pi}{2}$	0	0	$\frac{\pi}{2}$
4	$\theta_4 - \frac{\pi}{2}$	$l_3 + l_4$	0	$\frac{\pi}{2}$
5	θ_5	0	0	$-\frac{\pi}{2}$
6	θ_6	$l_5 + l_6$	0	0

$T = A_1 A_2 A_3 A_4 A_5 A_6$

Contents


```
% This file is part of The Robotics Toolbox for Matlab (RTB).
%
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clear L

%%%% these are the DH parameters that we came up with
%%%% in class to describe the Forward Kinematics

l = 0.3;
L(1) = Link([ 0     l      0         -pi/2     0       0], 'standard');
L(2) = Link([ 0         0      l            0      0       0], 'standard');
L(3) = Link([ 0     0      0          pi/2     0       pi/2], 'standard');
L(4) = Link([ 0     l+l    0          pi/2     0       -pi/2], 'standard');
L(5) = Link([ 0     0      0         -pi/2     0       0], 'standard');
L(6) = Link([ 0     l+l    0            0      0       0], 'standard');
```
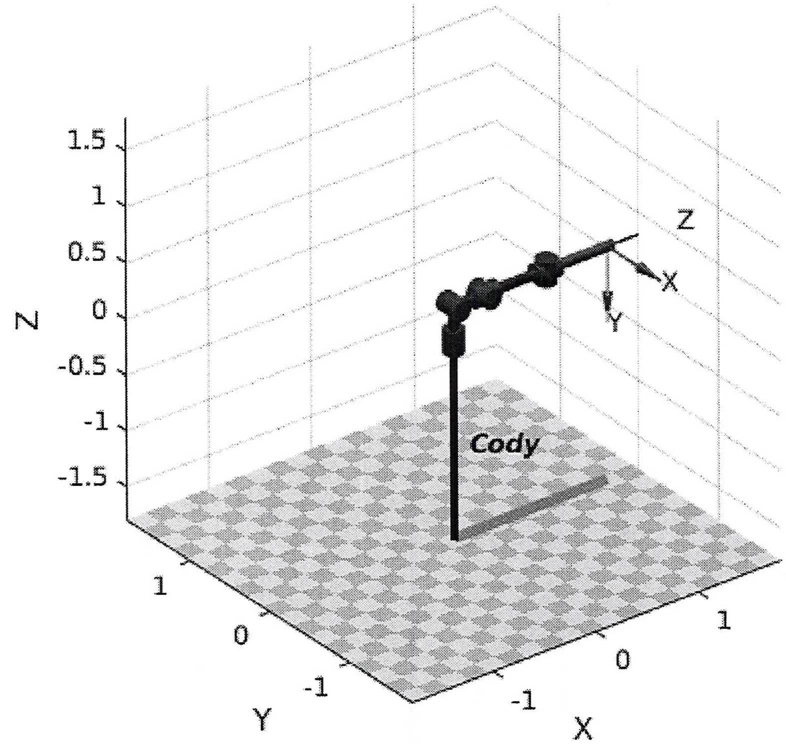
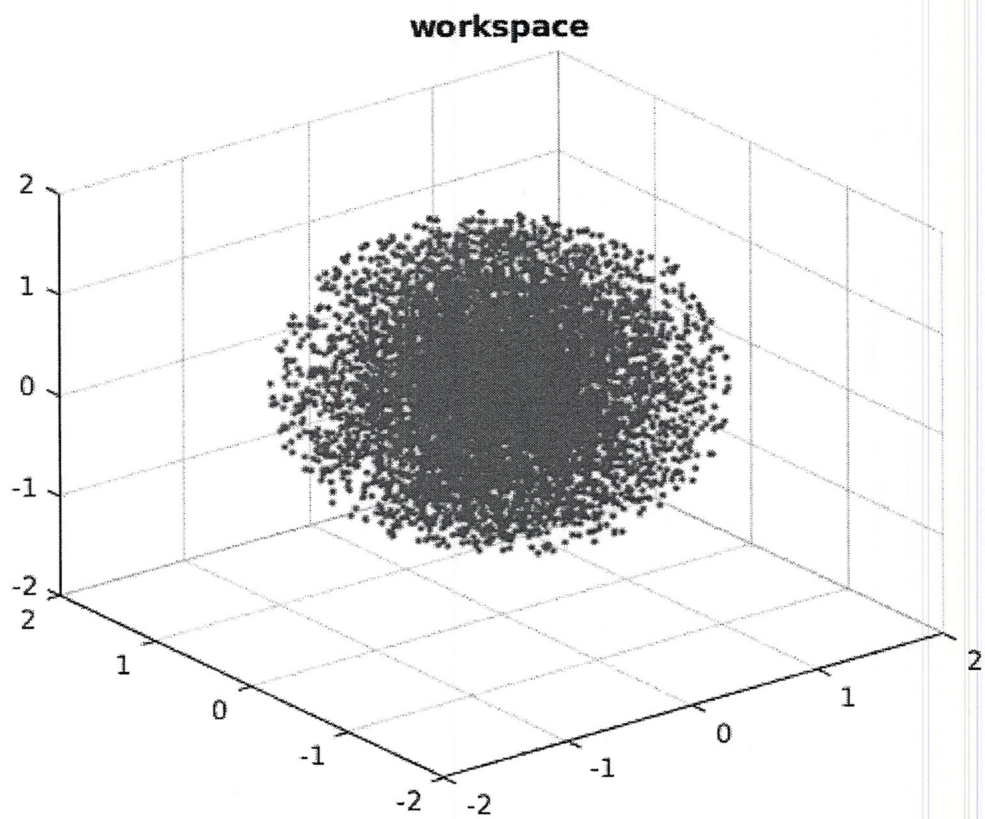

defining the robot now

```
cody = SerialLink(L, 'name', 'Cody', ...
    'manufacturer', 'Meka', 'comment', 'params from Meka');

%%this allows use to line up the first or base frame in a way we want, it
%%is a static transformation that gets added to all of our FK calculations
cody.base = [1 0 0 0;
             0 1 0 0;
             0 0 1 0;
             0 0 0 1];

% some useful poses
qz = [0 0 0 0 0 0]; % zero angles, L shaped pose

clear L

figure(1);
cody.plot(qz);
final_origin = [0; 0; 0; 1];

n = 10000;
points = [];
```

```
for i=1:n
    qz = rand([1,6])*2*pi;
    T = cody.fkine(qz);
    base_point = T*final_origin;
    points = [points base_point];
end

figure(2);
scatter3(points(1,:), points(2,:), points(3,:),'.');
title('workspace');
```


1.5
1
0.5
0
-0.5
-1
-1.5
Z
Cody
Z
X
Y
1
0
-1
Y
-1
0
1
X


workspace
2
1
0
-1
-2
2
1
0
-1
-2
-2
-1
0
1
2