ASSUMPTION UNIVERSITY

SCHOOL OF ENGINEERING

MIDTERM EXAMINATION 1 / 2021 (SET1: ID end with 1,3,5)

SUBJECT : **MCE4101-Introduction to Robotics**

LECTURER : **Asst. Prof. Dr. Narong Aphiratsakun**

DATE : **29 June 2021**

TIME : **18.00-20.00 (2 Hr)**

NAME ......Todsawad............	**SURNAME** ....T....................	**ID.NO.**6114215	**SEC.**641..

Make sure you have all the questions.

- Total examination paper: **3** questions, **4** pages (not including cover page).

Instructions:

1. This examination is worth a total of **100** points. This examination will contribute to **25% of your final grade**.
2. **Open books Examination**.
3. **Any** calculator can be used.
4. The University's examination regulations are on the reverse page. Students are expected to read and strictly observe them while the examination is in progress. Failure to do so would subject students to the terms of punishments.

This is to inform that

- Students are NOT allowed to use Smart Watches in examinations. Should they be brought into examination rooms, they are required to be placed on the floor under students' desk or chair.
- Violators will be subjected to the terms of punishment for violating examination regulations and/or cheating in the examination.

Other pertinent University's examination regulations are on the reverse page.
Students are expected to read and strictly observe them while the examination is in progress.
Failure to do so would subject students to the terms of punishments for violating examination regulations and/or cheating in the examination.

NAME .... **SURNAME** .... **ID.NO.** .... **SEC.**........

1. (30 Minute). Consider the VME robot shown in Figure 1.1 below.

a) (20 Marks) Evaluate the homogenous transformation matrices **values** for T_{drill}^{0} by using ***CURRENT FRAME*** method of defining reference frames, where reference frames starting from the base [x_0, y_0, z_0] to the end point [x_{end}, y_{end}, z_{end}] are given. Where $L_4^* = 10$ and $L_1 = 50, L_2 = 25, L_3 = 10, L_5 = 5$.

Show your working steps from base to end points.

b) (5 Marks) Compute the driller location (P_{drill}) with reference to base where $L_4^* = 10$ and $L_1 = 50, L_2 = 25, L_3 = 10, L_5 = 5$.

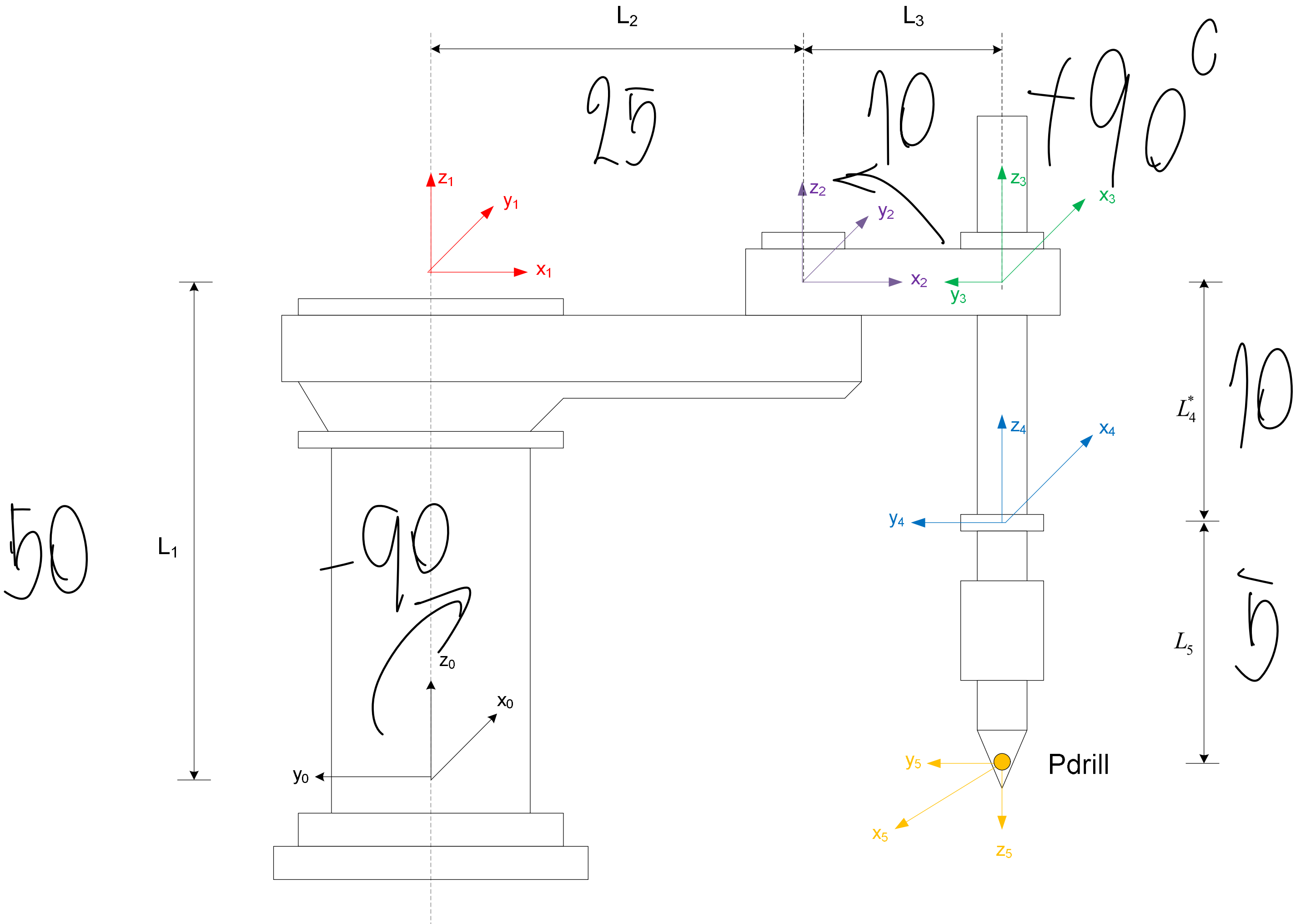

Figure 1.1: The VME robot.

Total 25 Marks

Q1

a) $T^0_1 = D(z,50) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 50 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

$T^1_1 = Rot(z,-90°) = \begin{bmatrix} \cos(-90°) & -\sin(-90°) & 0 & 0 \\ \sin(-90°) & \cos(-90°) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

$T^1_2 = D(x,25) = \begin{bmatrix} 1 & 0 & 0 & 25 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

$T^2_2 = D(x,25) = \begin{bmatrix} 1 & 0 & 0 & 10 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

$T^2_3 = Rot(z,90°) = \begin{bmatrix} \cos(-90°) & -\sin(-90°) & 0 & 0 \\ \sin(-90°) & \cos(-90°) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

$T^3_4 = D(z,-10) = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & -10 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

$T^4_4 = D(z,-5) = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & -5 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

$T^4_5 = Rot(y,180°) = \begin{bmatrix} \cos(180°) & 0 & -\sin(180°) & 0 \\ 0 & 1 & 0 & 0 \\ \sin(180°) & 0 & \cos(180°) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

```
%%Q1
%syms L1 L2 L3 L5
L1 = 50 ; L2 = 25 ; L3 = 10 ; L5 = 5;
L4= 10;
P0 = [0;0;0;1]
T01 = transl(0,0,L1)
T11 = rotz(-pi/2)
T12 = transl(L2,0,0)
T22 = transl(L3,0,0)
T23 = rotz(pi/2)
T34 = transl(0,0,-L4)
T44 = transl(0,0,-L5)
T45 = roty(pi)
T05C = T01*r2t(T11)*T12*T22*r2t(T23)*T34*T44*r2t(T45)
P5C = T05C*P0
```

$T^0_{c5} = T^0_1 T^1_1 T^1_2 T^2_2 T^2_3 T^3_4 T^4_4 T^4_5$

$= \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & -35 \\ 0 & 0 & -1 & 35 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

b) $P_{c5} = T^0_{c5} P_0$

$= \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & -35 \\ 0 & 0 & -1 & 35 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} = \begin{bmatrix} 0 \\ -35 \\ 35 \\ 1 \end{bmatrix}$

NAME .... **SURNAME** .... **ID.NO.** .... **SEC.**........

2. (30 Minute). Consider the VME robot shown in Figure 2.1 below.

a) (20 Marks) Evaluate the homogenous transformation matrices **values** for T_{drill}^{0} by using ***FIXED FRAME*** method of defining reference frames, where reference frames starting from the base [x_0, y_0, z_0] to the end point [x_{end}, y_{end}, z_{end}] are given. Where $L_4^* = 10$ and $L_1 = 50, L_2 = 25, L_3 = 10, L_5 = 5$.

Show your working steps from base to end points.

b) (5 Marks) Compute the driller location (P_{drill}) with reference to base where $L_4^* = 10$ and $L_1 = 50, L_2 = 25, L_3 = 10, L_5 = 5$.

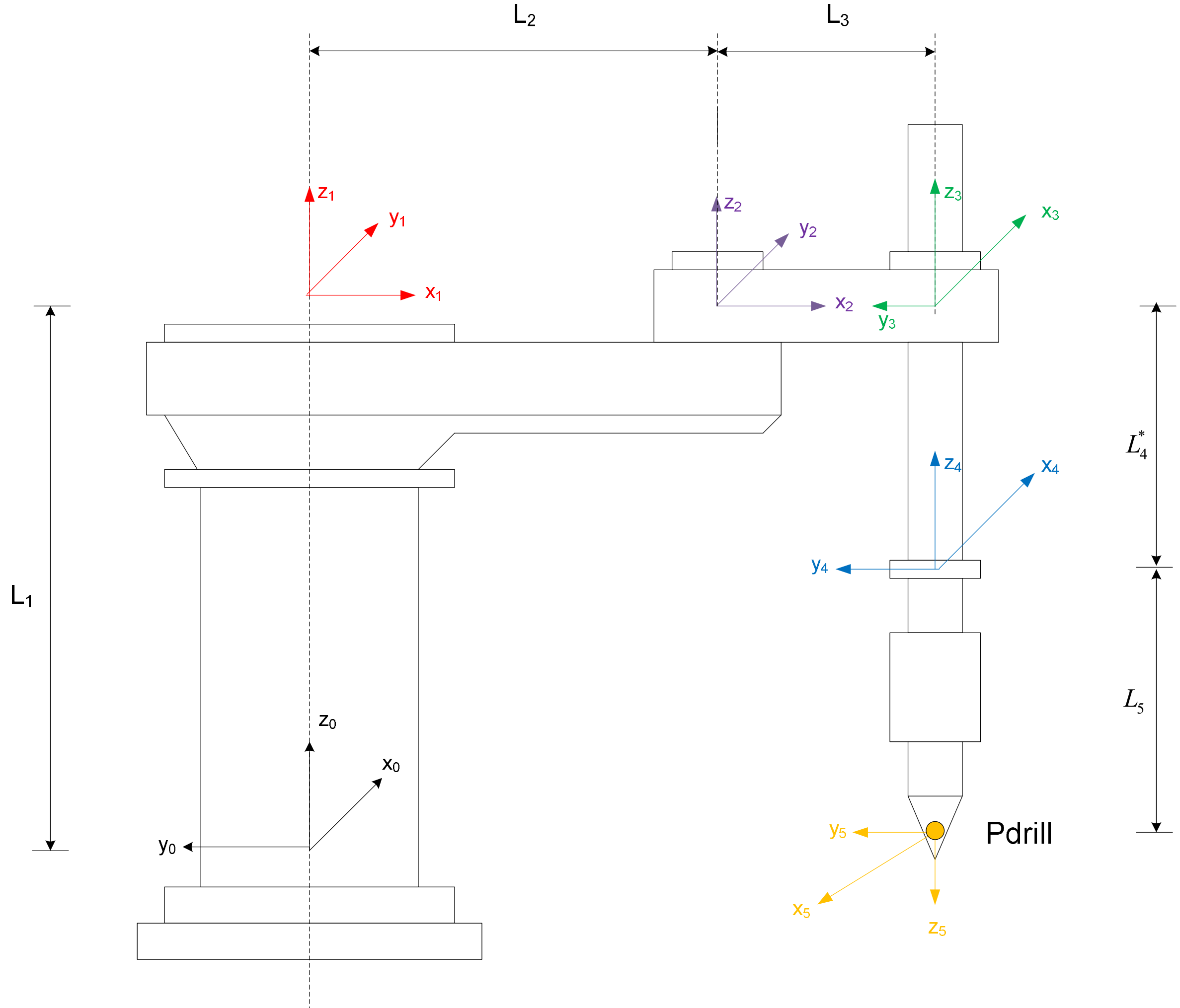

Figure 2.1: The VME robot.

Total 25 Marks

Q2

a) $T^0_1 = D(z,50) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 50 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

$T^2_3 = Rot(z,90^\circ) = \begin{bmatrix} \cos(-90^\circ) & -\sin(-90^\circ) & 0 & 0 \\ \sin(-90^\circ) & \cos(-90^\circ) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

$T^1_1 = Rot(z,-90^\circ) = \begin{bmatrix} \cos(-90^\circ) & -\sin(-90^\circ) & 0 & 0 \\ \sin(-90^\circ) & \cos(-90^\circ) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

$T^3_4 = D(z,-10) = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & -10 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

$T^1_2 = D(y,25) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & -25 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

$T^4_4 = D(z,-5) = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & -5 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

$T^2_2 = D(y,25) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & -10 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

$T^4_5 = Rot(y,180^\circ) = \begin{bmatrix} \cos(180^\circ) & 0 & -\sin(180^\circ) & 0 \\ 0 & 1 & 0 & 0 \\ \sin(180^\circ) & 0 & \cos(180^\circ) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

```
%%Q2
%syms L1 L2 L3 L5
L1 = 50 ; L2 = 25 ; L3 = 10 ; L5 = 5 ;
L4= 10;
P0 = [0;0;0;1]
T01 = transl(0,0,L1)
T11 = rotz(-pi/2)
T12 = transl(0,-L2,0)
T22 = transl(0,-L3,0)
T23 = rotz(pi/2)
T34 = transl(0,0,-L4)
T44 = transl(0,0,-L5)
T45 = roty(pi)
%tran*rot
T05F = T44*T34*T22*T12*r2t(T45)*r2t(T23)*r2t(T01)
P5F = T05C*P0
```

$$T^0_{F5} = (T^4_4 T^3_4 T^2_2 T^0_1)(T^4_5 T^2_3 T^1_2)$$

$$= \begin{bmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & -35 \\ 0 & 0 & -1 & 35 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

b) $P_{F5} = T^0_{F5} P_0$

$$= \begin{bmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & -35 \\ 0 & 0 & -1 & 35 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} = \begin{bmatrix} 0 \\ -35 \\ 35 \\ 1 \end{bmatrix}$$

NAME ……………………………… SURNAME ……………………………… ID.NO. ………… SEC………

3. (60 Minute). Consider the VME robot shown in Figure 3.1 below. VME robot is initially pointing towards x0 axis.

a) (30 Marks) Evaluate the homogenous transformation **matrices equations** (in term of variables $\theta_1^*, \theta_2^*, L_4^*, \theta_6^*$ and L_1, L_2, L_3, L_5) for $T_1^0, T_2^1, T_3^2, T_4^3$, and T_4^0 by ***Denavit-Hartenberg*** (DH) method of defining reference frames, where reference frames starting from the base [x_0, y_0, z_0] to the driller are given. $\theta_1^*, \theta_2^*, L_4^*, \theta_6^*$ and L_1, L_2, L_3, L_5 are variables as shown in the Figure 3.1.

b) (5 Marks) Determine the matrix T_4^0 **values** when
$\theta_1^* = 90°, \theta_2^* = 0°, L_4^* = 10, \theta_6^* = 0°$ and $L_1 = 50, L_2 = 25, L_3 = 10, L_5 = 5$.

c) (5 Marks) Compute the driller location (P_{drill}) with reference to base when
$\theta_1^* = 90°, \theta_2^* = 0°, L_4^* = 10, \theta_6^* = 0°$ and $L_1 = 50, L_2 = 25, L_3 = 10, L_5 = 5$.

d) (5 Marks) Determine the matrix T_4^0 **values** when
$\theta_1^* = 90°, \theta_2^* = 90°, L_4^* = 10, \theta_6^* = 0°$ and $L_1 = 50, L_2 = 25, L_3 = 10, L_5 = 5$.

e) (5 Marks) Compute the driller location (P_{drill}) with reference to base when
$\theta_1^* = 90°, \theta_2^* = 90°, L_4^* = 10, \theta_6^* = 0°$ and $L_1 = 50, L_2 = 25, L_3 = 10, L_5 = 5$.

NAME ……………………………… SURNAME ……………………………… ID.NO. ………… SEC………

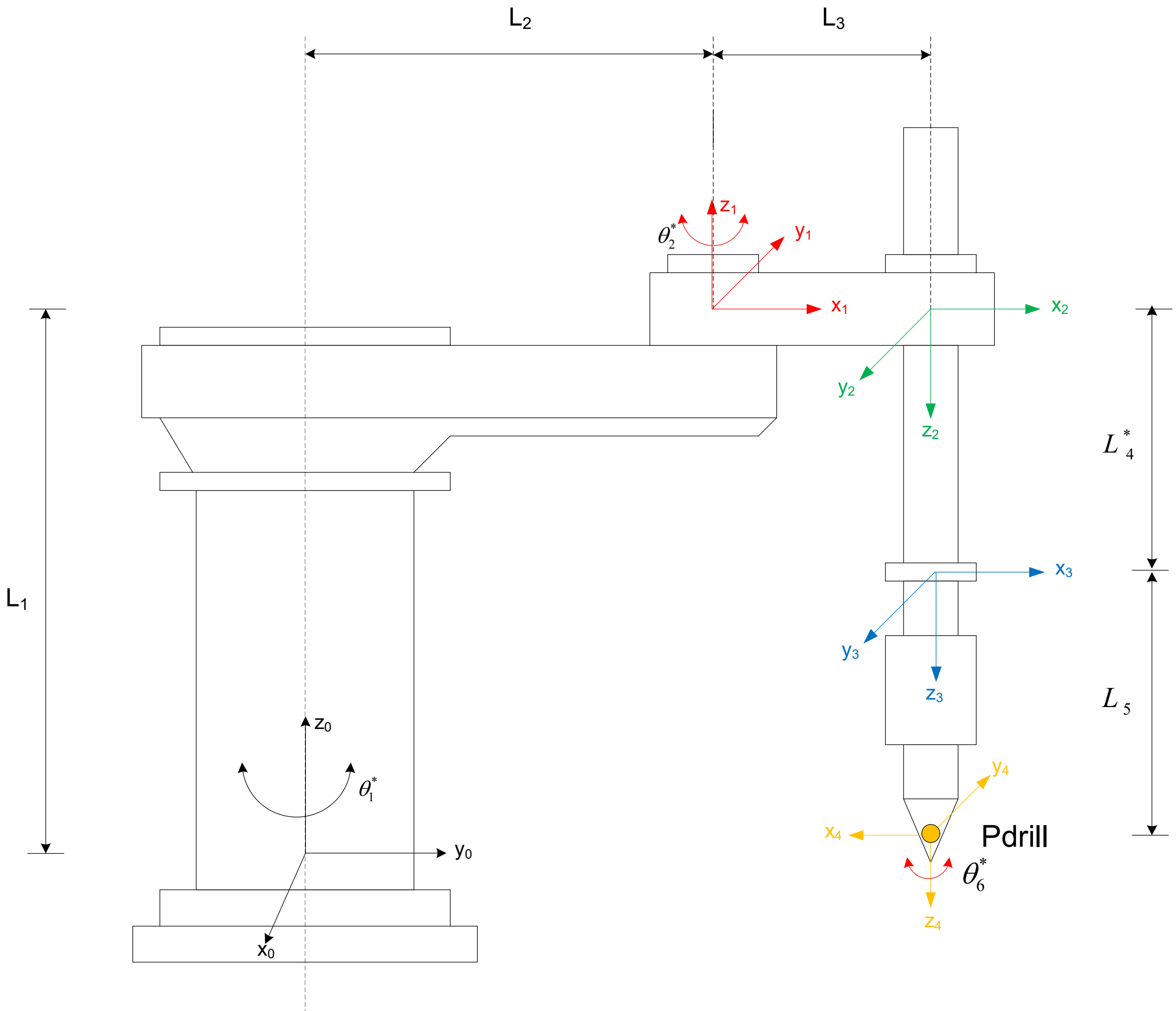

Figure 3.1: The VME robot.

Total 50 Marks

%%%%%%%%%%%%%%%%%%Enjoy Robotics, End of Questions%%%%%%%%%%%%%%%%

Q3

a) $T_4^0 = A_0 A_1 A_3 A_3 A_4$

$$= \begin{bmatrix} \texttt{cos(th6)*(cos(th1)*cos(th2) - sin(th1)*sin(th2)) + sin(th6)*(cos(th1)*sin(th2) + cos(th2)*sin(th1)),} & \texttt{sin(th6)*(cos(th1)*cos(th2) - sin(th1)*sin(th2)) - cos(th6)*(cos(th1)*sin(th2) + cos(th2)*sin(th1)),} & \texttt{0,} & \texttt{L2*cos(th1) + L3*cos(th1)*cos(th2) - L3*sin(th1)*sin(th2)]} \\ \texttt{cos(th6)*(cos(th1)*sin(th2) + cos(th2)*sin(th1)) - sin(th6)*(cos(th1)*cos(th2) - sin(th1)*sin(th2)),} & \texttt{cos(th6)*(cos(th1)*cos(th2) - sin(th1)*sin(th2)) + sin(th6)*(cos(th1)*sin(th2) + cos(th2)*sin(th1)),} & \texttt{0,} & \texttt{L2*sin(th1) + L3*cos(th1)*sin(th2) + L3*cos(th2)*sin(th1)]} \\ \texttt{0,} & \texttt{0,} & \texttt{1,} & \texttt{L1 + L2 - L4 - L5]} \\ \texttt{0,} & \texttt{0,} & \texttt{0,} & \texttt{1]} \end{bmatrix}$$

$$P_{end} = T_4^0 P_0 = \begin{bmatrix} \texttt{L2*cos(th1) + L3*cos(th1)*cos(th2) - L3*sin(th1)*sin(th2)} \\ \texttt{L2*sin(th1) + L3*cos(th1)*sin(th2) + L3*cos(th2)*sin(th1)} \\ \texttt{L1 + L2 - L4 - L5} \\ \texttt{1} \end{bmatrix}$$

b) $\theta_1 = 90^\circ \; \theta_2 = 0^\circ \; \theta_6 = 0^\circ$

c) $L_1 = 50 \; L_2 = 25 \; L_3 = 10 \; L_4 = 10 \; L_5 = 5$

$$T_3^0 = \begin{bmatrix} 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 35 \\ 0 & 0 & 1 & 60 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad P_{end} = \begin{bmatrix} 0 \\ 35 \\ 60 \\ 1 \end{bmatrix}$$

$$\begin{matrix} -15 \\ 34.692 \\ 4.6323 \\ 1 \end{matrix}$$

d) $\theta_1 = 90^\circ \; \theta_2 = 90^\circ \; \theta_6 = 0^\circ$

e) $L_1 = 50 \; L_2 = 25 \; L_3 = 10 \; L_4 = 10 \; L_5 = 5$

$$T_3^0 = \begin{bmatrix} -1 & 0 & 0 & -10 \\ 0 & -1 & 0 & 25 \\ 0 & 0 & 1 & 60 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad P_{end} = \begin{bmatrix} 40 \\ 25 \\ 60 \\ 1 \end{bmatrix}$$

$$\begin{matrix} 0 & 0 & 1 & -15 \\ 0.9912 & 0.1324 & 0 & 34.692 \\ 0.1324 & 0.9912 & 0 & -4.6323 \\ 0 & 0 & 0 & 1 \end{matrix}$$

	Z		X	
Links	θ	d	a	α
0	θ_1^*	L_1	0	0
1	0	0	L_2^*	0
2	θ_2^*	0	L_3	180°
3	0	L_4^*	0	0
4	θ_6^*	L_5	0	180°

```
%%Q3
syms th1 th2 th6
syms L1 L2 L3 L4 L5
%bc
%th1 = pi/2; th2 = 0 ; th6 = 0 ;
%L1 = 50; L2 = 25 ; L3 = 10 ; L4 = 10 ; L5 = 5;
%de
%th1 = pi/2; th2 = pi/2 ; th6 = 0 ;
%L1 = 50; L2 = 25 ; L3 = 10 ; L4 = 10 ; L5 = 5;
%%L = link([alpha A theta D])
A0 = link([0  0 th1 L1, 0]); %%0 is revolute (and default), 1 is prismatic
A1 = link([0 L2 0 0, 1]);
A2 = link([pi L3 th2 0, 0]);
A3 = link([0 0 0 L4, 1]);
A4 = link([pi 0 th6 L5, 0]);
RRR_Assginment = robot({A0 A1 A2 A3 A4});
T03 = fkine(RRR_Assginment,[th1 L2 th2 L4 th6])
Pend = T03*[0;0;0;1]
```