ASSUMPTION UNIVERSITY

VINCENT MARY SCHOOL OF ENGINEERING

FINAL EXAMINATION 1 / 2020 (Part 2)-SET3

SUBJECT : **MCE4101-Introduction to Robotics**

LECTURER : **Asst. Prof. Dr. Narong Aphiratsakun (narongphr@au.edu)**

DATE :

TIME : **130 Min**

NAME ......Todsavad..............	SURNAME ....Tangtortan.........	ID.NO. ...6114215	SEC....641

Make sure you have all the questions.

- Total examination paper: **2** question (Q2 and Q3), **3** page (not including cover page).

Instructions:

1. This examination is worth a total of **140** points. This examination will contribute to **33.2% 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.
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NAME ....Todsavad.................... **SURNAME** ....Tangtortan.......... **ID.NO.** ..6114215 **SEC.**..641....

2. (80 minutes). The iVMERobot with a wrist gripper robot is given as in Figure 2.1. $\theta_1^*, \theta_2^*, L_4^*, \theta_{end}^*$ are variables and L_1, L_2, L_3 and L_5 are the links and wrist offset respectively.

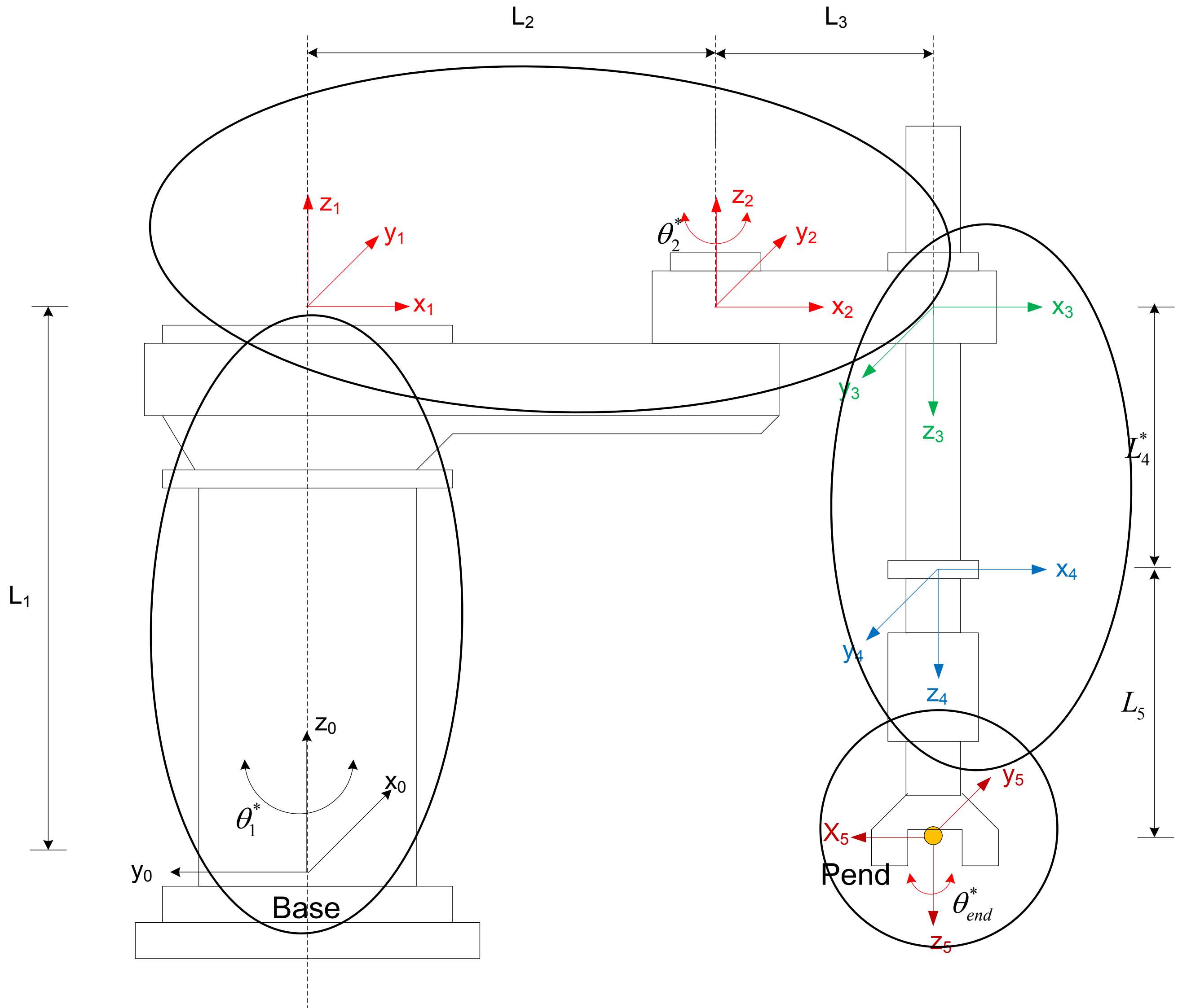

Figure. 2.1: iVMERobot and 1 DOF wrist

a) (20 marks) Evaluate the homogenous transformation matrices **equation** T_{end}^{0} (in term of variables $\theta_1^*, \theta_2^*, L_4^*, \theta_{end}^*$ and L_1, L_2, L_3, L_5) for the iVMERobot with a 1-DOF wrist gripper by ***Denavit-Hartenberg*** (DH) method of defining reference frames, where reference frames starting from the base [x_0, y_0, z_0] to the end point, Pend.

b) (10 marks) Determine the matrix **value** T_{end}^{0} when $\theta_1^* = 0°, \theta_2^* = 0°, L_4^* = 40, \theta_{end}^* = 0°$ and $L_1 = 100, L_2 = 40, L_3 = 15, L_5 = 5$.

c) (2.5 marks) Compute the gripper location (P_{end}) with reference to base where
$\theta_1^* = 0°, \theta_2^* = 0°, L_4^* = 40, \theta_{end}^* = 0°$ and $L_1 = 100, L_2 = 40, L_3 = 15, L_5 = 5$.

d) (2.5 marks) Compute the gripper location (P_{end}) with reference to base where
$\theta_1^* = 90°, \theta_2^* = 0°, L_4^* = 40, \theta_{end}^* = 0°$ and $L_1 = 100, L_2 = 40, L_3 = 15, L_5 = 5$.

e) (5 marks) Obtain one set of possible solutions ($\theta_1^*, L_2^*, L_4^*, \theta_{end}^*$) for end point location
Pend1 = [27.5, -47.6, 55] with using **ikine function** from MATLAB.
Given IC as `th1= -pi/10, th2= -pi/10, L4= 10, thend= 0. Show your working steps.`

f) (15 marks) Obtain one set of possible solutions ($\theta_1^*, \theta_2^*, L_4^*, \theta_{end}^*$) for end point location
Pend1 = [27.5, -47.6, 55] with using analysis method. Given data for Transformation matrix T0_end1 as:

NAME ..Todsavad.................. **SURNAME** ....Tangtortan............ **ID.NO**6114215.. **SEC**641....

```
T04 =

    0.5000   -0.8660   -0.0000   27.5000
   -0.8660   -0.5000   -0.0000  -47.6314
         0    0.0000   -1.0000   55.0000
         0         0         0    1.0000
```

Rotational matrix T0_3 (from joint 0 to joint 3) for Pend1 as:

```
R03 =

    0.5000   -0.8660   -0.0000
   -0.8660   -0.5000   -0.0000
         0    0.0000   -1.0000
         0         0         0
```

g) (5 marks) Obtain one set of possible solutions ($\theta_1^*, L_2^*, L_4^*, \theta_{end}^*$) for end point location Pend2 = [42.1, 33, 55] with using **ikine function** from MATLAB.
Given IC as `th1= pi/10, th2= pi/10, L4= 10, thend= 0. Show your working steps.`

h) (15 marks) Obtain one set of possible solutions ($\theta_1^*, \theta_2^*, L_4^*, \theta_{end}^*$) for end point location Pend2 = [42.1, 33, 55]. Given data for Transformation matrix T0_end2 as:

```
T04 =

    0.5000    0.8660    0.0000   42.1410
    0.8660   -0.5000   -0.0000   32.9904
         0    0.0000   -1.0000   55.0000
         0         0         0    1.0000
```

Rotational matrix T0_3 (from joint 0 to joint 3) for Pend2 as:

```
R03 =

    0.5000    0.8660    0.0000
    0.8660   -0.5000   -0.0000
         0    0.0000   -1.0000
         0         0         0
```

i) (15 marks) From Pend1 to Pend2, obtain the required polynomial trajectories, velocities and accelerations equation for required joints to move from Pend1 to Pend2 within 3s (start at 0s, end at 3s). Initial and final velocity both are 0°/s. Assume initial and final acceleration is not concerned.

Total 90 Marks

(a)

```
T04 =

[ cos(th5)*(cos(th1)*cos(th2) - sin(th1)*sin(th2)), sin(th5)*(cos(th1)*cos(th2) - sin(th1)*sin(th2)), - cos(th1)*sin(th2) - cos(th2)*sin(th1), cos(th1)*cos(th2)*(L2 + L3) - (cos(th1)*sin(th2) + cos(th2)*sin(th1))*(L4 + L5) - sin(th1)*sin(th2)*(L2 + L3)]
[ cos(th5)*(cos(th1)*sin(th2) + cos(th2)*sin(th1)), sin(th5)*(cos(th1)*sin(th2) + cos(th2)*sin(th1)),   cos(th1)*cos(th2) - sin(th1)*sin(th2), (cos(th1)*cos(th2) - sin(th1)*sin(th2))*(L4 + L5) + cos(th1)*sin(th2)*(L2 + L3) + cos(th2)*sin(th1)*(L2 + L3)]
[                                        sin(th5),                                        -cos(th5),                                        0,                                                                                                              L1]
[                                               0,                                                0,                                        0,                                                                                                               1]
```

(b)

```
T04 =

[ cos(th5)*(cos(th1)*cos(th2) - sin(th1)*sin(th2)), sin(th5)*(cos(th1)*cos(th2) - sin(th1)*sin(th2)), cos(th1)*sin(th2) - cos(th2)*sin(th1), 55*cos(th1)*cos(th2) - 55*sin(th1)*sin(th2) - (cos(th1)*sin(th2) + cos(th2)*sin(th1))*(L4 + 5)]
[ cos(th5)*(cos(th1)*sin(th2) + cos(th2)*sin(th1)), sin(th5)*(cos(th1)*sin(th2) + cos(th2)*sin(th1)), cos(th1)*cos(th2) - sin(th1)*sin(th2), 55*cos(th1)*sin(th2) + 55*cos(th2)*sin(th1) + (cos(th1)*cos(th2) - sin(th1)*sin(th2))*(L4 + 5)]
[                                        sin(th5),                                        -cos(th5),                                      0,                                                                                            100]
[                                               0,                                                0,                                      0,                                                                                              1]
```

(c)

```
P0end_1 =

    55
    45
   100
     1
```

(d)

```
P0end_1 =

   -45
    55
   100
     1
```

(e)

```
Data1_rad =

   -0.5235   -0.5235   -0.0000   -2.0947


Data1_deg =

  -29.9918  -29.9918   -0.0000 -120.0164
```

(f)

(g)

(h)

(i)

```
%i) Polynomial trajectories, velocities amd accelerations equation
%Cubic Polynomial
t0 = 0; tf = 3;
%joint 1
q1_0 = th1_1
q1_f = th1_2
v1_0 = 0; v1_f = 0;
Y1 = [q1_0;v1_0;q1_f;v1_f];
B1 = [1 t0 t0^2 t0^3; 0 1 2*t0 3*t0^2; 1 tf tf^2 tf^3; 0 1 2*tf 3*tf^2];
A1 = inv(B1)*Y1 %A1 = [a1_0; a1_1; a1_2; a1_3];
%joint 2
q2_0 = th2_1
q2_f = th2_2
v2_0 = 0; v2_f = 0;
Y2 = [q2_0;v2_0;q2_f;v2_f];
B2 = [1 t0 t0^2 t0^3; 0 1 2*t0 3*t0^2; 1 tf tf^2 tf^3; 0 1 2*tf 3*tf^2];
A2 = inv(B2)*Y2 %A2 = [a2_0; a2_1; a2_2; a2_3];
%joint 3
q3_0 = L4_1+L5
q3_f = L4_2+L5
v3_0 = 0; v3_f = 0;
Y3 = [q3_0;v3_0;q3_f;v3_f];
B2 = [1 t0 t0^2 t0^3; 0 1 2*t0 3*t0^2; 1 tf tf^2 tf^3; 0 1 2*tf 3*tf^2];
A3 = inv(B2)*Y3 %A3 = [a3_0; a3_1; a3_2; a3_3];
%joint 4
q4_0 = th5_1
q4_f = th5_2
v4_0 = 0; v4_f = 0;
Y4 = [q4_0;v4_0;q4_f;v4_f];
B2 = [1 t0 t0^2 t0^3; 0 1 2*t0 3*t0^2; 1 tf tf^2 tf^3; 0 1 2*tf 3*tf^2];
A4 = inv(B2)*Y4 %A4 = [a2_0; a2_1; a2_2; a2_3];
```

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

3. (50 minutes). The iVMERobot with a wrist gripper robot is given as in Figure 3.1. $\theta_1^*, \theta_2^*, L_4^*, \theta_{end}^*$ are variables and L_1, L_2, L_3 and L_5 are the links and wrist offset respectively. Given $L_1 = 100, L_2 = 40, L_3 = 15, L_5 = 5$.

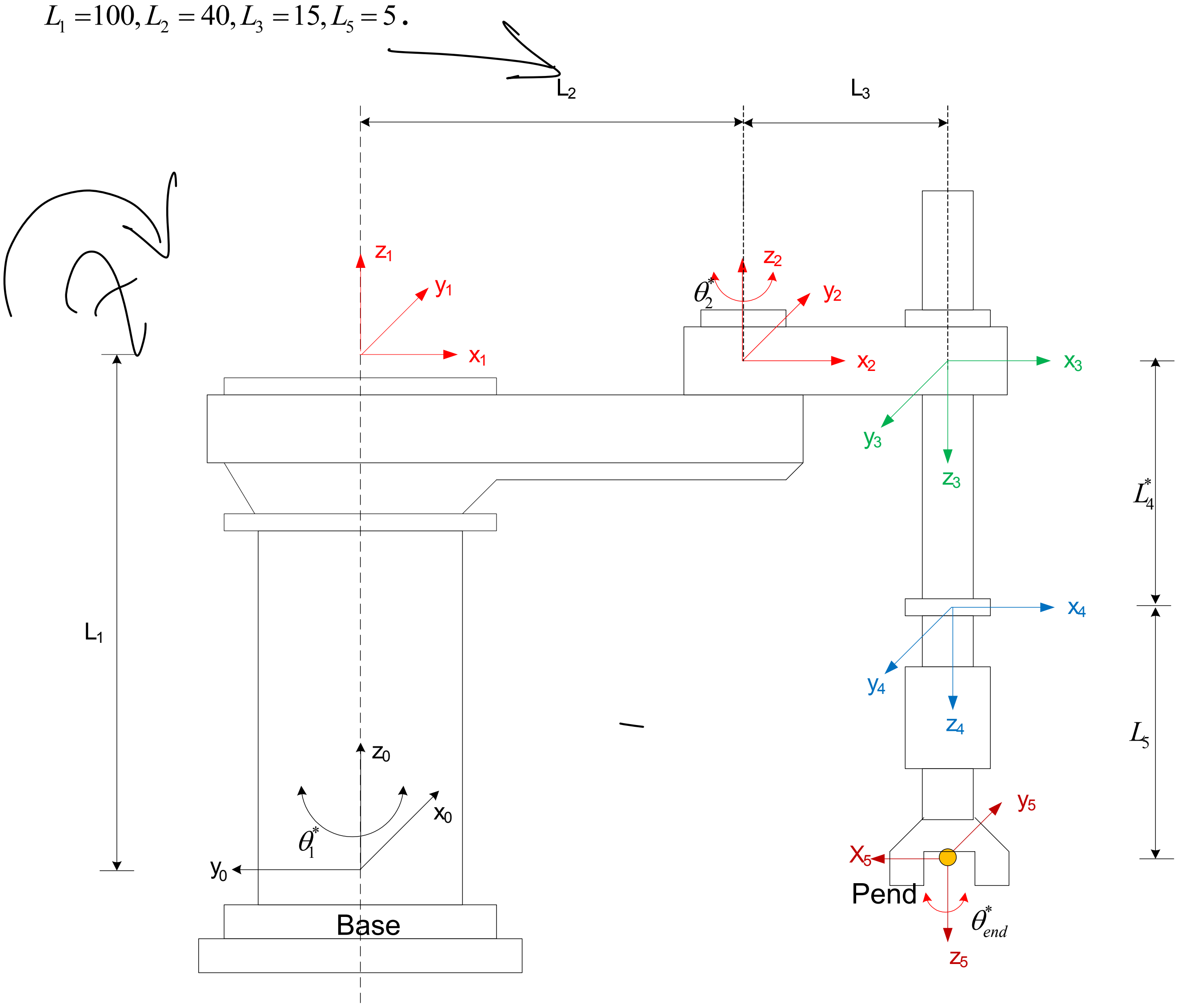

Figure. 3.1: iVMERobot and 1 DOF wrist

a) (10 marks) Obtain o_i and z_i with variables $\theta_1^*, \theta_2^*, L_4^*, \theta_{end}^*$.

b) (25 marks) Determine the **Jacobian matrix <u>equation</u>** for the iVMERobot and 1 DOF wrist with variables $\theta_1^*, \theta_2^*, L_4^*, \theta_{end}^*$.

c) (5 marks) Compute the Jacobian matrix value **<u>from b)</u>** when $\theta_1^* = 90°, \theta_2^* = 0°, L_4^* = 10, \theta_{end}^* = 0°$.

d) (2.5 marks) Compute the Jacobian matrix value **<u>by "jacobian function" with MATLAB toolbox</u>** when $\theta_1^* = 90°, \theta_2^* = 0°, L_4^* = 5, \theta_{end}^* = 0°$.

e) (5 marks) Compute the Jacobian matrix value **<u>from b)</u>** when $\theta_1^* = 0°, \theta_2^* = 90°, L_4^* = 10, \theta_{end}^* = 0°$.

f) (2.5 marks) Compute the Jacobian matrix value **<u>by "jacobian function" with MATLAB toolbox</u>** when $\theta_1^* = 0°, \theta_2^* = 90°, L_4^* = 5, \theta_{end}^* = 0°$.

<u>Total 50 Marks</u>

%%%%%%%%%%%%%%%Enjoy Robotics, End of Questions2 and 3%%%%%%%%%%%%%%%

(a)

```
O1 =

   0
   0
 100
   1


O2 =

 55*cos(th1)*cos(th2) - 55*sin(th1)*sin(th2)
 55*cos(th1)*sin(th2) + 55*cos(th2)*sin(th1)
                                         100
                                           1


O3 =

 55*cos(th1)*cos(th2) - 55*sin(th1)*sin(th2) - (cos(th1)*sin(th2) + cos(th2)*sin(th1))*(L4 + 5)
 55*cos(th1)*sin(th2) + 55*cos(th2)*sin(th1) + (cos(th1)*cos(th2) - sin(th1)*sin(th2))*(L4 + 5)
                                                                                            100
                                                                                              1


O4 =

 55*cos(th1)*cos(th2) - 55*sin(th1)*sin(th2) - (cos(th1)*sin(th2) + cos(th2)*sin(th1))*(L4 + 5)
 55*cos(th1)*sin(th2) + 55*cos(th2)*sin(th1) + (cos(th1)*cos(th2) - sin(th1)*sin(th2))*(L4 + 5)
                                                                                            100
                                                                                              1
```

```
Z1 =

 0
 0
 1
 0


Z2 =

 - cos(th1)*sin(th2) - cos(th2)*sin(th1)
   cos(th1)*cos(th2) - sin(th1)*sin(th2)
                                       0
                                       0


Z3 =

 cos(th1)*sin(th2) + cos(th2)*sin(th1)
 sin(th1)*sin(th2) - cos(th1)*cos(th2)
                                     0
                                     0


Z4 =

 cos(th1)*sin(th2) + cos(th2)*sin(th1)
 sin(th1)*sin(th2) - cos(th1)*cos(th2)
                                     0
                                     0
```

(b)

RRPR

$$j = \begin{bmatrix} j_v \\ j_w \end{bmatrix}$$

$$j_v = [Z_0(O_4 - O_0) \; Z_1(O_4 - O_1) \; Z_2 \; Z_3(O_4 - O_3)]$$

$$= \left[\frac{\partial}{\partial 1}\left(\quad \right) \; \begin{matrix} 0 \\ 0 \\ 1 \end{matrix} \; \begin{matrix} C_1S_2 + C_2S_1 \\ S_1S_2 - C_1C_2 \\ -1 \end{matrix} \; \frac{\partial}{\partial 1}\left(\quad \right) \right]$$

$$= \begin{bmatrix} \quad \end{bmatrix}$$

$$j_w = [Z_0, Z_1, 0, Z_3]$$

$$= \begin{bmatrix} 0 & 0 & 0 & C_1S_2 + C_2S_1 \\ 0 & 0 & 0 & S_1S_2 - C_1C_2 \\ 1 & 1 & 0 & -1 \end{bmatrix}$$

$$jeq = \begin{bmatrix} & & & \\ & & & \\ & & & \\ 0 & 0 & 0 & C_1S_2 + C_2S_1 \\ 0 & 0 & 0 & S_1S_2 - C_1C_2 \\ 1 & 1 & 0 & 0 \end{bmatrix}$$

(c) $\theta_1^* = 90°, \theta_2^* = 0°, L_4^* = 10, \theta_{end}^* = 0°$

$$jeq = \begin{bmatrix} -55 & -55 & -1 & 0 \\ -15 & -15 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 \end{bmatrix}$$

(e) $\theta_1^* = 0°, \theta_2^* = 90°, L_4^* = 10, \theta_{end}^* = 0°$

$$jeq = \begin{bmatrix} -55 & -55 & -1 & 0 \\ -15 & -15 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 \end{bmatrix}$$

(d)

```
Jequation =

  -55.0000  -55.0000   -1.0000         0
  -10.0000  -10.0000    0.0000         0
   -0.0000   -0.0000    0.0000         0
   -0.0000   -0.0000         0    1.0000
    0.0000    0.0000         0   -0.0000
    1.0000    1.0000         0   -0.0000
```

(f)

```
Jequation =

  -55.0000  -55.0000   -1.0000         0
  -10.0000  -10.0000    0.0000         0
   -0.0000   -0.0000    0.0000         0
   -0.0000   -0.0000         0    1.0000
    0.0000    0.0000         0   -0.0000
    1.0000    1.0000         0   -0.0000
```

N_2021_Q2.m FN_2021_Q3.m* +

```
%RPP+1DOF
clear all; clc;
syms th1 th2 th5
syms L1 L2 L3 L4 L5
%Given Data
L1 = 100; L2 = 40; L3 = 15; L5 = 5;
%th5 = 0;
%D) when %th1 = pi/2; th2 = 0; L4 = 5; th5 = 0;
%F) when %th1 = 0; th2 = pi/2; L4 = 10; th5 = 0;
%SCARA(RRP) + 1DOF
%%L = link([alpha A theta D])
A1 = link([0 L2 th1 L1,0]);
A2 = link([-pi/2 L3 th2 0,0]);
A3 = link([pi 0 0 L4+L5,1]);
A4 = link([0 pi th5 0,0]);
RPP_1 = robot({A1});
RPP_2 = robot({A1 A2});
RPP_3 = robot({A1 A2 A3});
RPP_4 = robot({A1 A2 A3 A4});
T01 = fkine(RPP_1, [th1]);
T02 = fkine(RPP_2, [th1 th2]);
T03 = fkine(RPP_3, [th1 th2 L4+L5]);
T04 = fkine(RPP_4, [th1 th2 L4+L5 th5]);
Jequation = jacob0(RPP_4, [th1 th2 L4+L5 th5])
%A)
O1 = T01(:,4)
O2 = T02(:,4)
O3 = T03(:,4)
O4 = T04(:,4)
Z1 = T01(:,3)
Z2 = T02(:,3)
Z3 = T03(:,3)
Z4 = T03(:,3)
```