```
    clc;
    clear;
    close all
    init_val=1;
    rho=2710;
    cd('C:\Users\Rezaei\Desktop\MechatronicsCourseProject\Matlab_Files')
warning('off')
```

Automation Final Project

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Scara Robot Structure

scara robot as 4 Dof simple serial robot with a shematic Depicted in figure 1.this robot composed from 4 joints,which are 3 revolute joints and one prismatic.

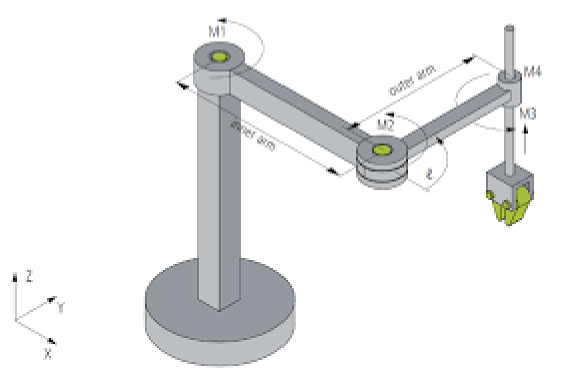


figure 1: scara robot

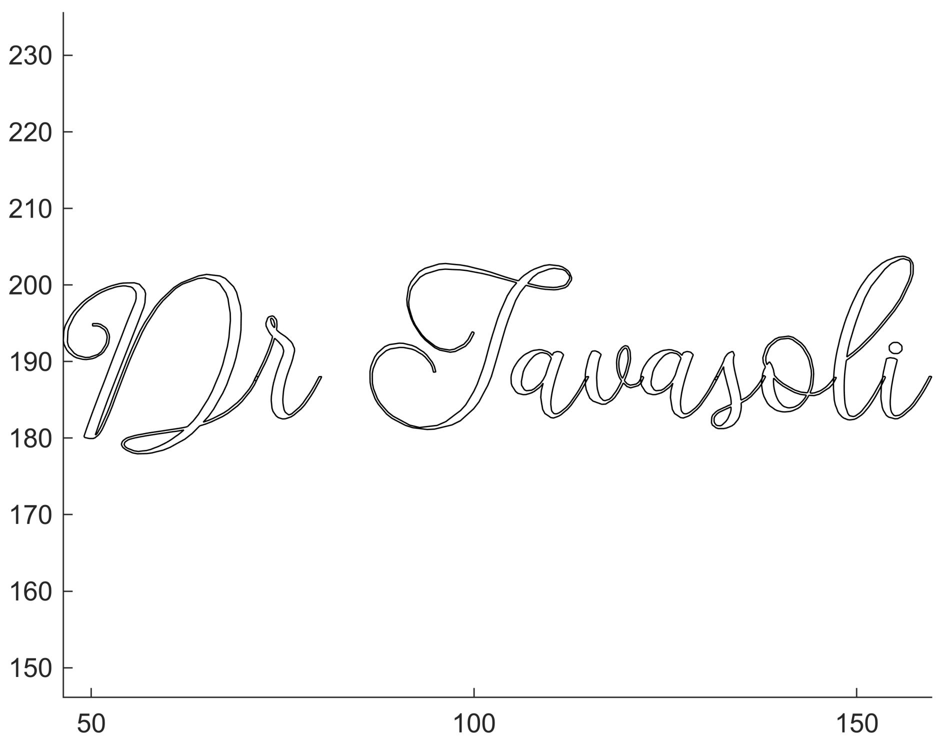
Drawing Application

in a drawing application we have a given trajectory for the end effector,and the goal is to calculate each joint motion in order to Tarck the trajectory correctly. in robotics nomenclature we call this process, Inverse Kinematics

Preparing the Trajectory for drawing

here we first import and read the trajectory file which produced by a thirdparty software named **inkspace** and exported in **.dxf** format. here we used the matlab DxfTool to read file data. the results are shown as follow:

```
figure();
 dxf=DXFtool("Tavasoli.dxf");
```



here we save the dxf trajectory file in matlab .fig format in case to extract the lines and splines x-y coordinates as follow

```
    fig_axes = findobj(gcf, 'type', 'axes');

%     EE_x=0;
%     EE_y=0.4;
%     scale=0.5;

    h = findobj(fig_axes,'Type','line');
```

after retriving data from dxf file we now store this data in "traj" variable

```
    for i=length(h):-1:1
        traj(i).y=-10^-3*h(i).XData;
        traj(i).x=10^-3*h(i).YData;
    end

% modifying data so each field have a same size
    for i=1:length(traj)
    if(length(traj(i).x)~=4)
        traj(i).x=cat(2,traj(i).x,traj(i).x(end)*ones(1,4-length(traj(i).x)));
        traj(i).y=cat(2,traj(i).y,traj(i).y(end)*ones(1,4-length(traj(i).y)));
    end
end
```

Inverse Kinematics of Scara robot

as it is shown in figure 2 we used the Denavit-Hartenberg method in order to

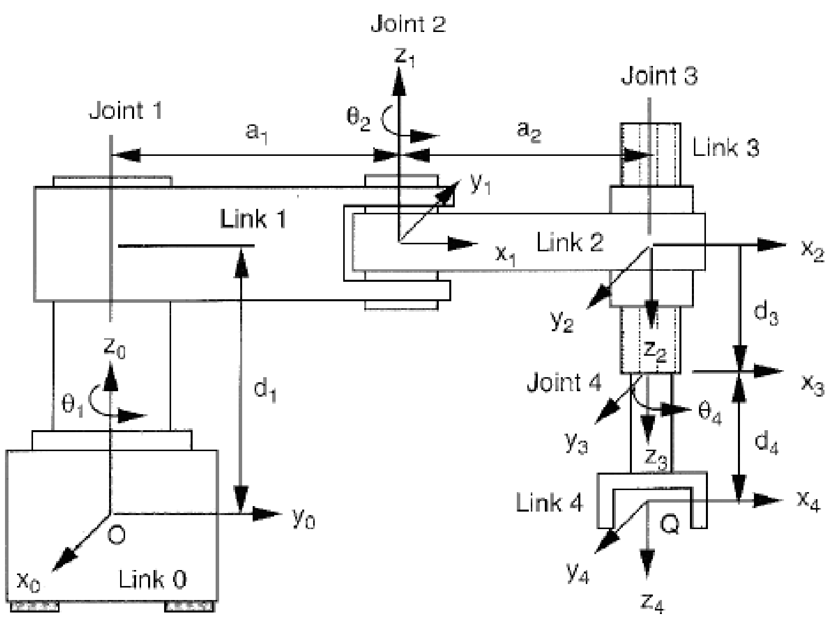


Figure 2: Scara robot shematic

calculate the Transform matrix ${}^{0}T_4$ as follow

$$ {}^{0}T_4 = {}^{0}T_1 \times {}^{1}T_2 \times {}^{2}T_3 \times {}^{3}T_4 $$

$$ {}^{0}T_4 = \begin{bmatrix} -\sin(\theta_1+\theta_2-\theta_4) & \cos(\theta_1+\theta_2-\theta_4) & 0 & -a2\sin(\theta_1+\theta_2) - a1\sin(\theta_1) \\ \cos(\theta_1+\theta_2-\theta_4) & \sin(\theta_1+\theta_2-\theta_4) & 0 & a2\cos(\theta_1+\theta_2) + a1\cos(\theta_1) \\ 0 & 0 & -1 & -d4 - d + d1 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

from ${}^{0}T_4$ we can find the Rotation matrix (${}^{0}R_4$) as it is the uper left 3*3 matrix

$$ R = \begin{bmatrix} -\sin(\theta_1+\theta_2-\theta_4) & \cos(\theta_1+\theta_2-\theta_4) & 0 \\ \cos(\theta_1+\theta_2-\theta_4) & \sin(\theta_1+\theta_2-\theta_4) & 0 \\ 0 & 0 & -1 \end{bmatrix} $$

accordingly the position vector from base frame can be calculate from ${}^{0}T_4$ as follow

$$ P = \begin{bmatrix} -a2\sin(\theta_1+\theta_2) - a1\sin(\theta_1) \\ a2\cos(\theta_1+\theta_2) + a1\cos(\theta_1) \\ -d4 - d + d1 \end{bmatrix} $$

now that we have the relations between EE_pose: $[P, R]$ and the joints parameters $[\theta_1, \theta_2, d, \theta_3]$ .for the inverse kinematic alanysis we need to find joint variables in respect to end effector pose which accomplished as follow:

first we suppose that position and orientation of the end-effector is given in the form of transformation matrix as follow

$$ {}^{0}T_4 = \begin{bmatrix} nx & ox & ax & px \\ ny & oy & ay & py \\ nz & oz & az & pz \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

the set of equations now derived as follow

$$ \begin{bmatrix} -\sin(\theta_1+\theta_2-\theta_4) & \cos(\theta_1+\theta_2-\theta_4) & 0 & -a2\sin(\theta_1+\theta_2) - a1\sin(\theta_1) \\ \cos(\theta_1+\theta_2-\theta_4) & \sin(\theta_1+\theta_2-\theta_4) & 0 & a2\cos(\theta_1+\theta_2) + a1\cos(\theta_1) \\ 0 & 0 & -1 & -d4 - d + d1 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} nx & ox & ax & px \\ ny & oy & ay & py \\ nz & oz & az & pz \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

here the right matrix is known and in the left matrix joint variables are unknown

$$ [-a2\sin(\theta_1+\theta_2) - a1\sin(\theta_1) = px, a2\cos(\theta_1+\theta_2) + a1\cos(\theta_1) = py, -d4 - d + d1 = pz] $$

$d = -pz - d4 + d1$

for θ_1, θ_2 we get two solution as follow

$$\cos(\theta_2) = -\frac{a1^2 + a2^2 - px^2 - py^2}{2a1a2}$$

$$\theta_1 = -\arctan\left(\frac{\cos(\theta_2)a2\,px + a2\,py\sin(\theta_2) + a1\,px}{-a2\,px\sin(\theta_2) + a2\,py\cos(\theta_2) + a1\,py}\right)$$

$$\theta_4 = \theta_1 + \theta_2 + \arcsin(nx)$$

Robot WorkSpace

to be sure that the trajectory will fit into robot workspace we need to do a workspace analysis . this analysis will use matlab robotic toolbox

```
a1=0.25;
a2=0.15;
d1=0.18;
d2=0.15;


Knt_Scara=rigidBodyTree;

body1=rigidBody('Column1');
joint=rigidBodyJoint('fix','fixed');
setFixedTransform(joint,trvec2tform([0 0 0]));
body1.Joint=joint;
addBody(Knt_Scara,body1,'base');

body2=rigidBody('arm1');
joint=rigidBodyJoint('rev1','revolute');
setFixedTransform(joint,trvec2tform([0 0 d1]));
body2.Joint=joint;
addBody(Knt_Scara,body2,'Column1');


body2=rigidBody('arm2');
joint=rigidBodyJoint('rev2','revolute');
setFixedTransform(joint,trvec2tform([a1 0 0]));
body2.Joint=joint;
addBody(Knt_Scara,body2,'arm1');
```

```
body2=rigidBody('Column2');
joint=rigidBodyJoint('rev3','revolute');
setFixedTransform(joint,trvec2tform([a2 0 0]));
body2.Joint=joint;
addBody(Knt_Scara,body2,'arm2');


body2=rigidBody('endeffector');
joint=rigidBodyJoint('Fixjoint','Fix');
setFixedTransform(joint,trvec2tform([0 0 -d2]));
body2.Joint=joint;
addBody(Knt_Scara,body2,'Column2');
```

to generate the workspace figure we can use the following function. but here i used the pre calculated results ,becuase of time consuming simulation

```
% ScaraWorkSpace=Scara_WorkSpace(ScaraRobotTree=Knt_Scara);
% hold on
% PlotTraj(traj);

f=openfig("Scara_WorkSpace.fig");
```

Fig3 : scara workspace

```
% f2 = figure;
% set(f.Children,'Parent',f2)
```

as we can see in figure 3, the robot showed in it's two configuration. one in it's minimum radius and second in its maximum radius.

in figure 4 its clear that the given trajectory correctly fit inside robot workspase. so now we can proceed to final stage

```
% f=openfig("Scara_WorkSpace_Text.fig");
% f3 = figure(4);
% set(f.Children,'Parent',f3)
```

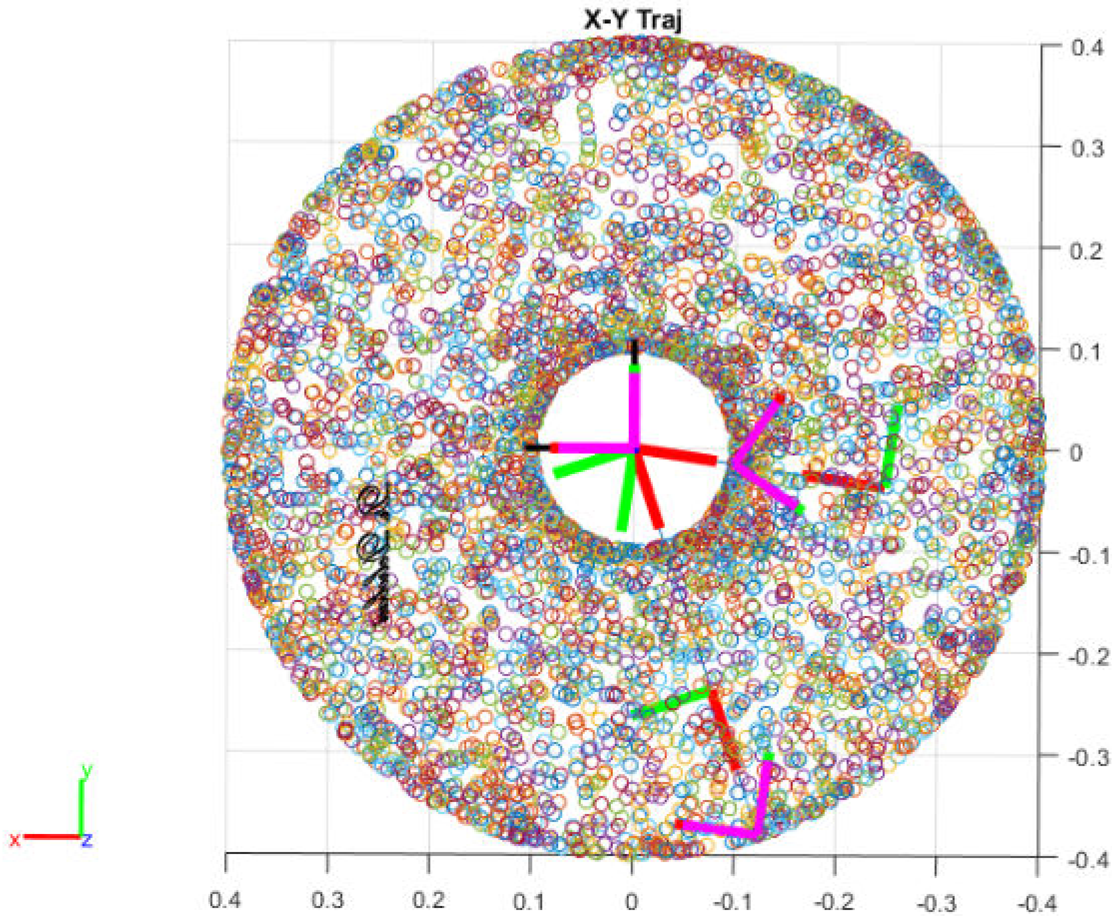


Fig 4: Robot Workspace and the fitted trajectory

Simscape and simulink simulation

here we simulate the Scara robot drawing application in simscape and simulink.

the robot multibody structure simulated in matlab multibody simscape as shown in fig 5

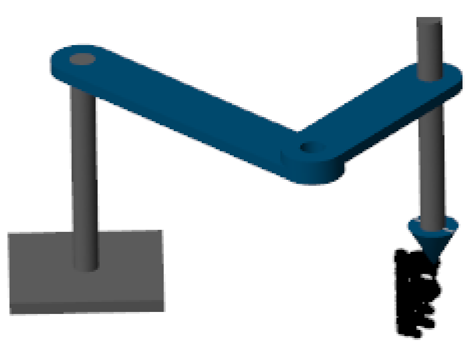


Fig 5: Scara robot multibody in simscape

the functional block of the drawing simulation implemented in simulink as shown in fig 6

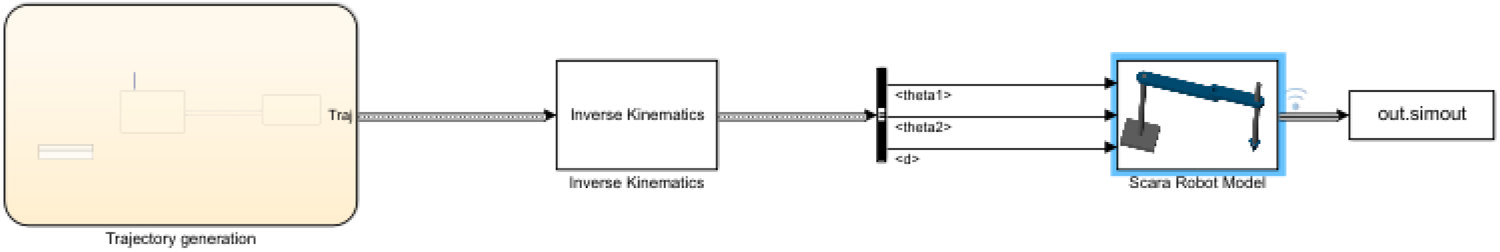


Fig 6:Simulink Block For Drawing simulation of scara robot

the final simulation of the robot can be shown in the simulation animation attached to the files

```
tf_sim=5;


t_samples=length(h)*4;


t.value=linspace(0,tf_sim,t_samples);
t.type="time";



RobotStruct.a1=0.25; %m
RobotStruct.a2=0.15; %m
RobotStruct.d1=0.18;%m
RobotStruct.d4=34.5e-03;%m





x.type="Trans";
x.value= [traj(1).x,traj(1).x(end)*ones(1,length(t.value)-length(traj(1).x))];
x.name="x";

y.type="Trans";
y.value= [traj(1).y,traj(1).y(end)*ones(1,length(t.value)-length(traj(1).y))];
y.name="y";

z.type="Trans";
z.name="z";
z.value=zeros(1,length(t.value));
```

```
Trajectory={x,y,z,t};

trajj=traj;
EE_Pose_forSim=TaskSpace(Trajectory);

open('Scara_simulink');
out=sim('Scara_simulink');
```

```
Error due to multiple causes.

Caused by:
    Error using Main (line 123)
    Error in 'Scara_simulink/Scara Robot Model/Arm1/Link': Failed to evaluate mask initialization commands.
        Error using Main (line 123)
        Undefined function 'Extr_Data_LinkHoles' for input arguments of type 'double'.
    Error using Main (line 123)
    Failed to load library 'Multibody_Parts_Lib' referenced by 'Scara_simulink/Scara Robot Model/Cone'.
    Error using Main (line 123)
    Failed to load library 'Multibody_Parts_Lib' referenced by 'Scara_simulink/Scara Robot Model/Link1'.
```

```
EE_Pose_bus = Simulink.Bus.createObject('Scara_simulink','Scara_simulink/
TaskSpace/Bus Creator');
EE_Pose_simscape_bus = Simulink.Bus.createObject('Scara_simulink','Scara_simulink/
Scara Robot Model/Bus Creator');
%
% delete('BusObjects.m');
% Simulink.Bus.save('BusObjects');
```

```
% if you changed the dxf file change the dxfchanged to true to generate new
% spline data for updating the sketch visualization
dxfchanged=false;
generateSplineData(dxfchanged);
```