Elec Eng 3EY4

Trajectory Generation

LAB 4 REPORT

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Course Code: Elec Eng 3EY4
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1. Navigate:

1.

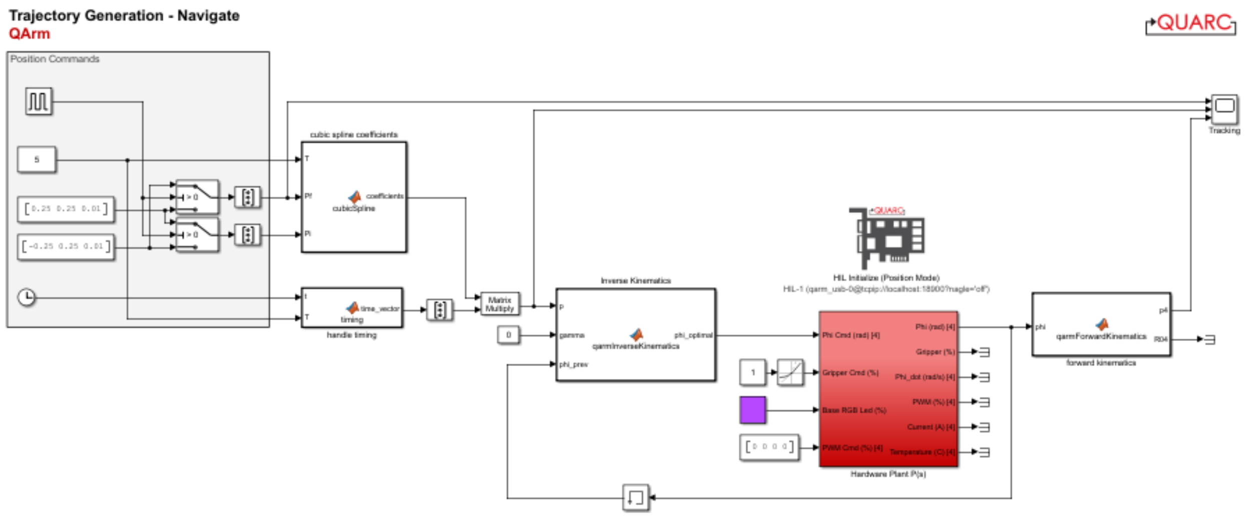
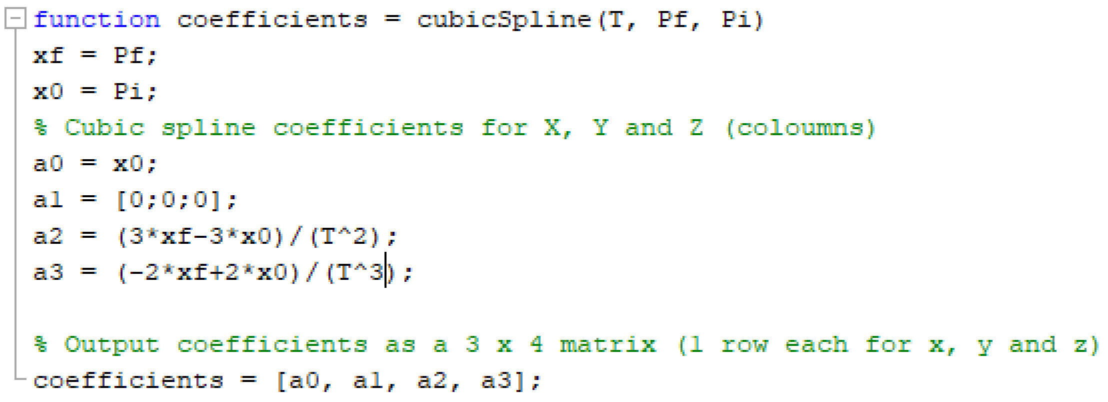


Figure 1: The Simulink model for Navigate

2.

From lab 2 and 3 we have used the previous codes to modify the inverse and forward kinematics codes.

3.

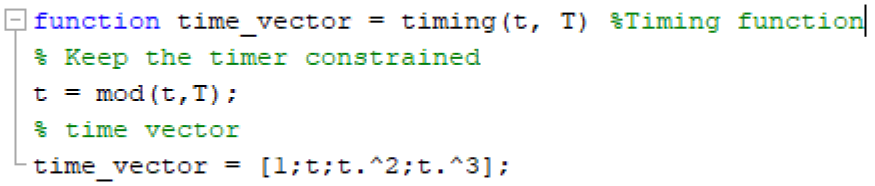


```
function coefficients = cubicSpline(T, Pf, Pi)
xf = Pf;
x0 = Pi;
% Cubic spline coefficients for X, Y and Z (coloumns)
a0 = x0;
a1 = [0;0;0];
a2 = (3*xf-3*x0)/(T^2);
a3 = (-2*xf+2*x0)/(T^3);

% Output coefficients as a 3 x 4 matrix (1 row each for x, y and z)
coefficients = [a0, a1, a2, a3];
```

Figure 2: A snippet of the cubicSpline

From Figure 2, we've shown a snippet of the modification we did on cubicSpline code.

4 - 7.



```
function time_vector = timing(t, T) %Timing function
% Keep the timer constrained
t = mod(t,T);
% time vector
time_vector = [1;t;t.^2;t.^3];
```

Figure 3: A snippet of the Timing Matlab block

In figure 3, our complete version of the timing function is shown. For t variable, we get the remainder of the division of t/T. While the time_Vector variable has the output as a 1x4 vector.

8.

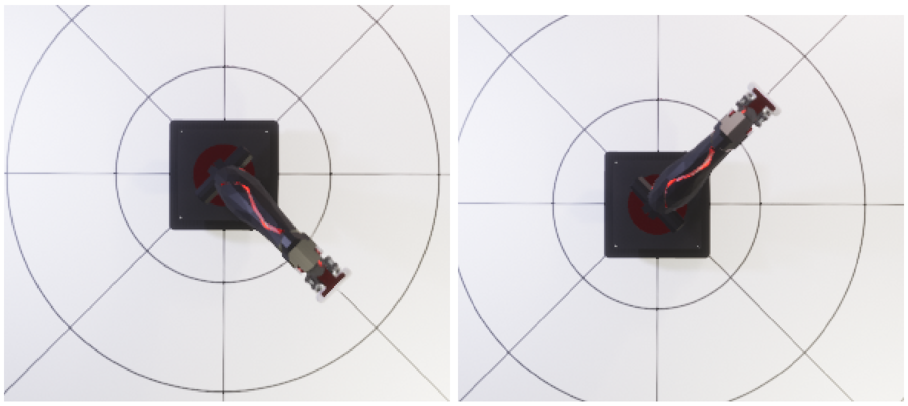
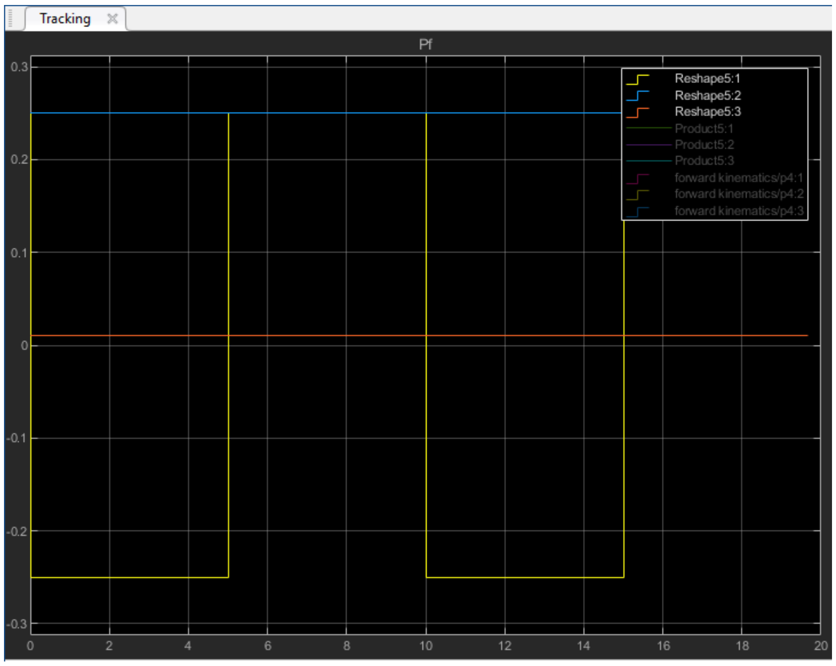
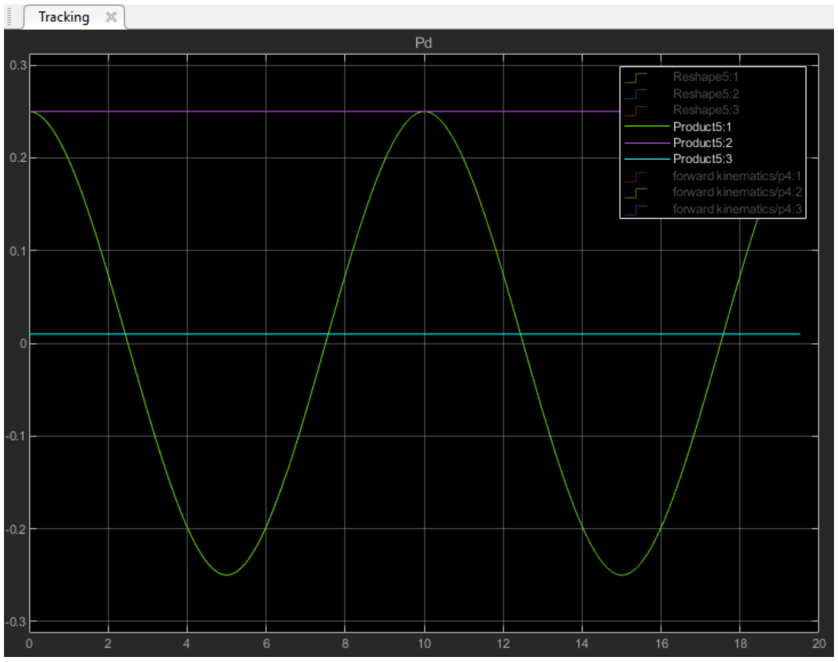


Figure 4: A picture of the end-effector movement

We notice in figure 4 that the end-effector moves in a straight line from the 2 points ([0.25, 0.25, 0.01] and [-0.25, 0.25, 0.01]).

9-10.





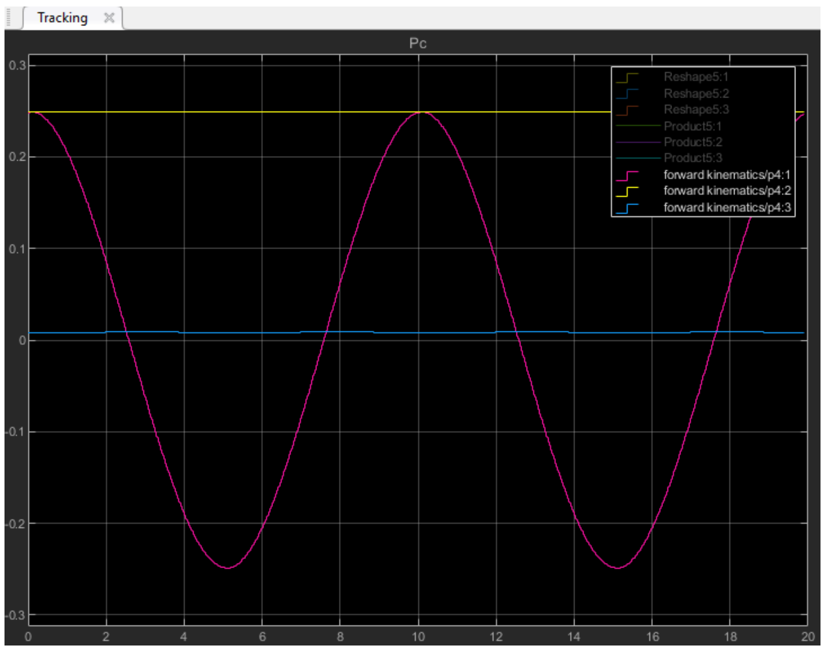


Figure 5-7: A picture of manipulator joints and task space trajectories

The figures above show in order, the clock, the desired position and finally, the end-effector's current position within the task space with coordinates x,y,z. We can notice from the last 2 plots that both the desired position and the current positions match, confirming that our model follows the orders commanded. We also notice that every 5 seconds the end-effector moves from one point to another and then reverses the position back to the original position it was in, having 10 seconds cycle each movement.

11-13.

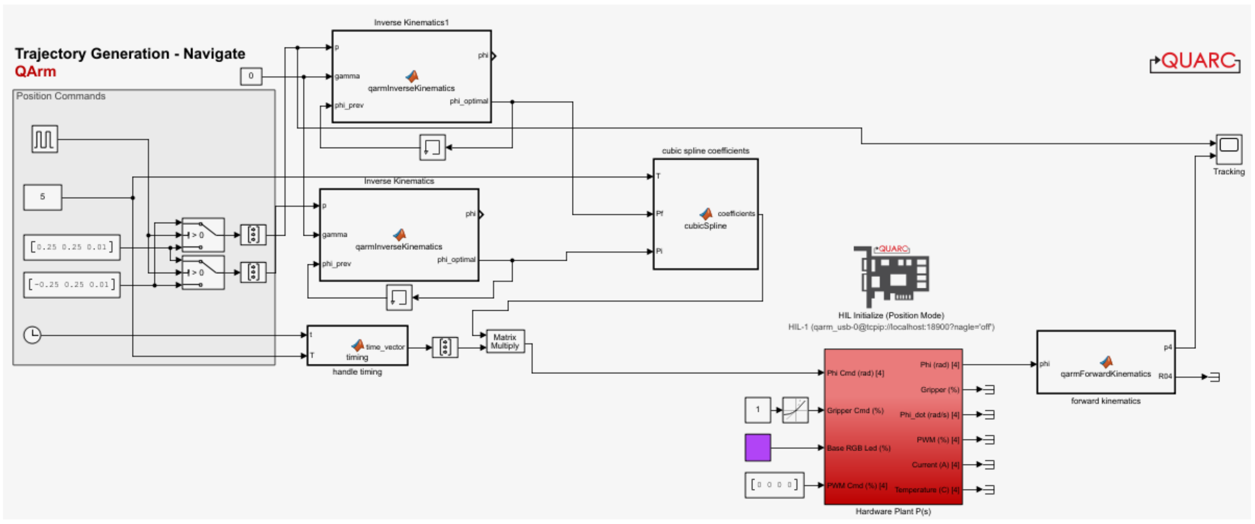
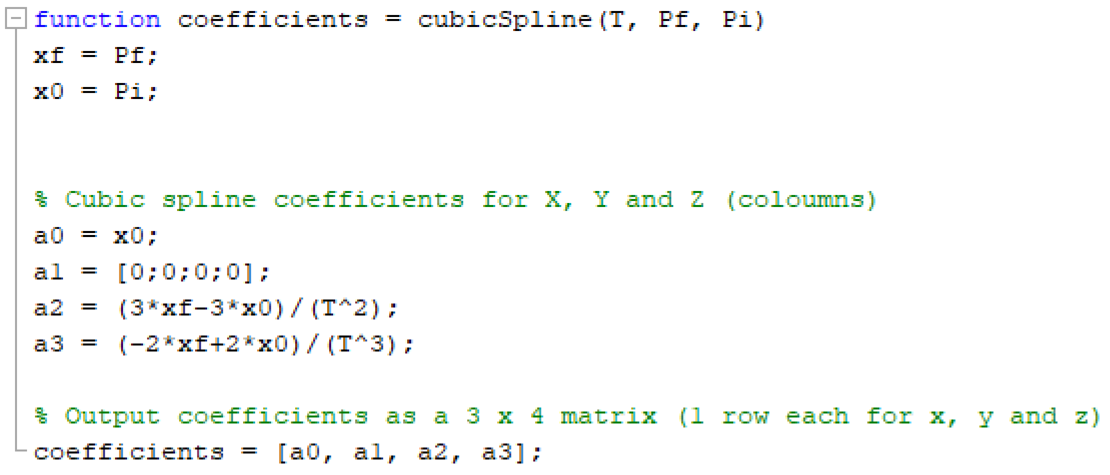


Figure 8: Adjustment of Navigate file



```
function coefficients = cubicSpline(T, Pf, Pi)
xf = Pf;
x0 = Pi;


% Cubic spline coefficients for X, Y and Z (coloumns)
a0 = x0;
a1 = [0;0;0;0];
a2 = (3*xf-3*x0)/(T^2);
a3 = (-2*xf+2*x0)/(T^3);

% Output coefficients as a 3 x 4 matrix (1 row each for x, y and z)
coefficients = [a0, a1, a2, a3];
```

Figure 9: Modification of cubicSpline code

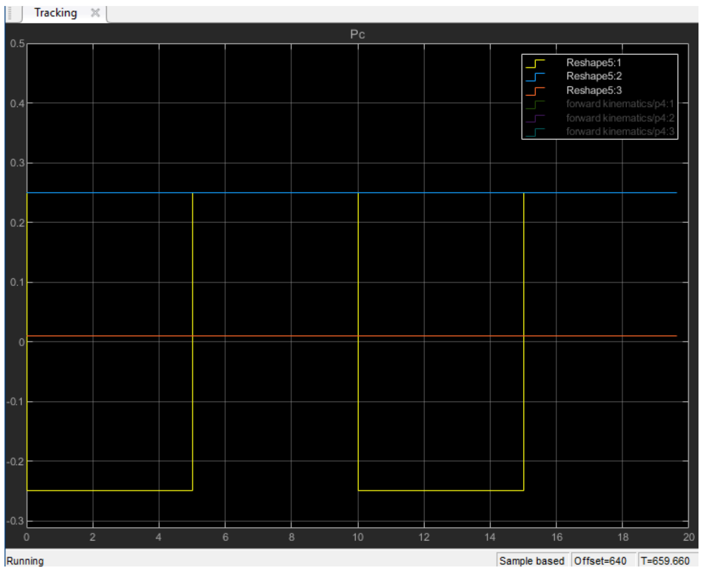


Figure 10: Clock graph

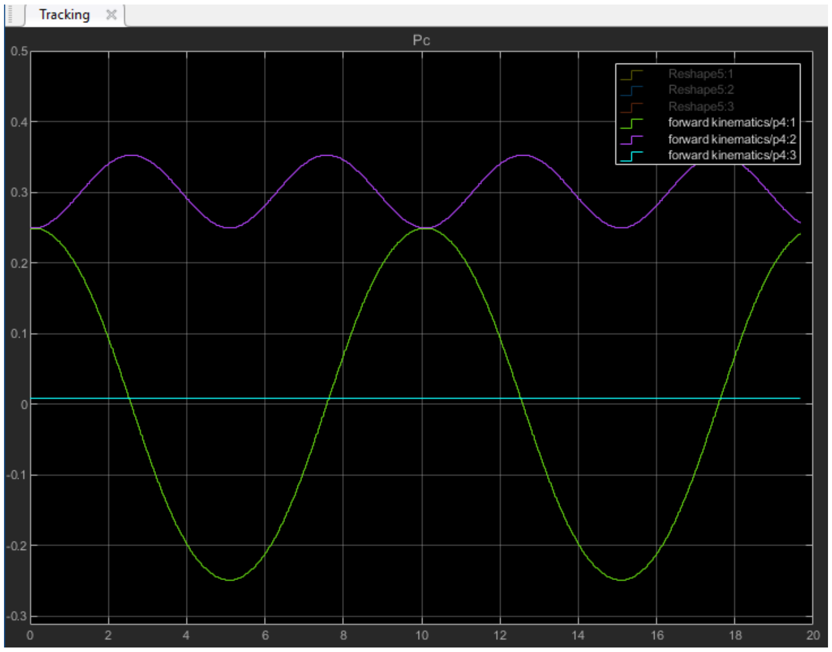


Figure 11: End-effector position scope

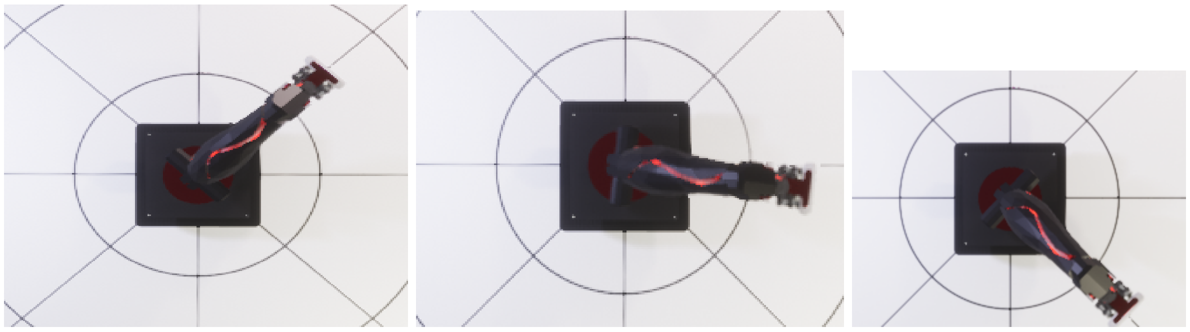


Figure 12: End-effector position

We notice in figure 11, that the scope of the end-effector is different than that in the previous part of the lab. We also notice in figure 12, that the pathway the end-effector takes is different than that in the previous part of the lab because the end-effector moves around an arc from the assigned 2 waypoints not in a straight line.

2. <u>Welding</u>:

1.

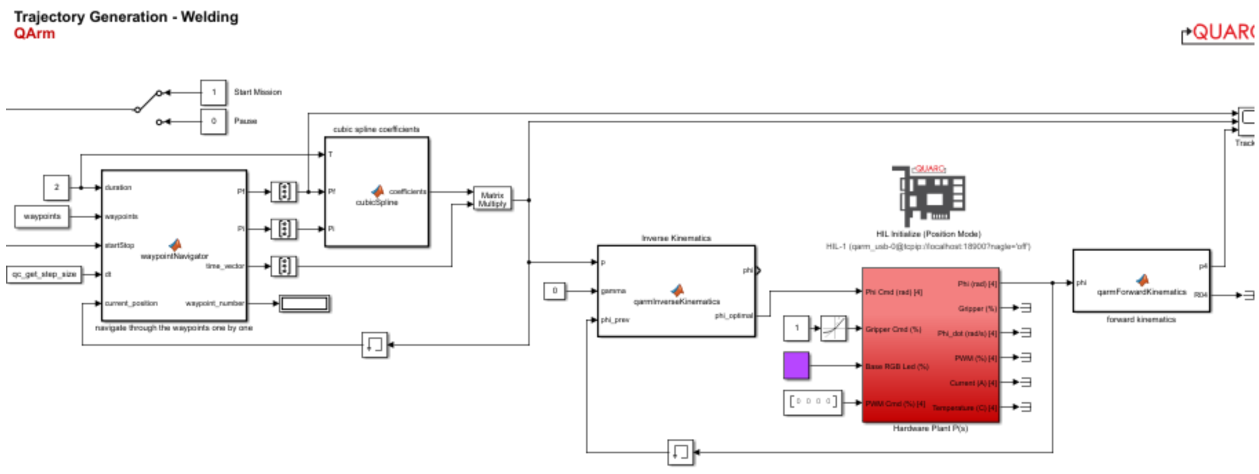
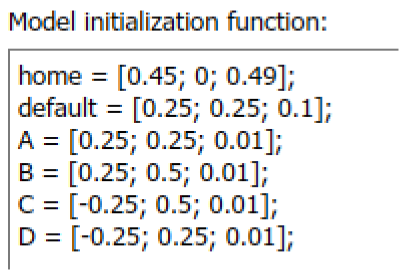


Figure 13: The Simulink model for Welding

2.

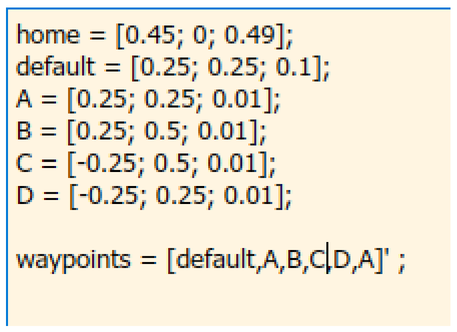


Model initialization function:

```
home = [0.45; 0; 0.49];
default = [0.25; 0.25; 0.1];
A = [0.25; 0.25; 0.01];
B = [0.25; 0.5; 0.01];
C = [-0.25; 0.5; 0.01];
D = [-0.25; 0.25; 0.01];
```

Figure 14: The Simulink model properties edit

3.



```
home = [0.45; 0; 0.49];
default = [0.25; 0.25; 0.1];
A = [0.25; 0.25; 0.01];
B = [0.25; 0.5; 0.01];
C = [-0.25; 0.5; 0.01];
D = [-0.25; 0.25; 0.01];

waypoints = [default,A,B,C,D,A]' ;
```

Figure 15: The Simulink model properties edit

4-6.

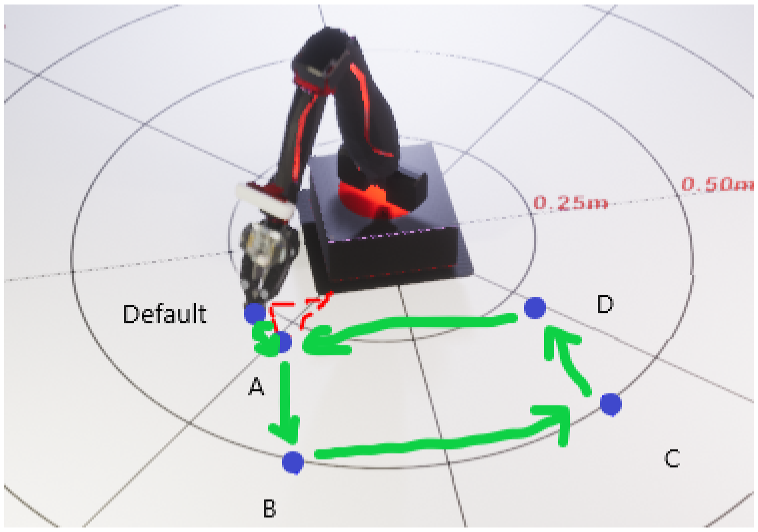


Figure 16: A diagram showing the order of waypoints the end-effector visits

When running the simulink model we notice that when the duration is set to 2 seconds, the end-effector moves from default,A,B,C,D,A in order as commanded. However, we notice that A to B and C to B have the same speed when executed however both of them are slower to be reached than B to C and D to A, since the timer is time dependent meaning that the longer the destination, the faster the end-effector has to move to be able to reach the waypoint within the assigned 2 seconds.

Therefore, we can conclude that the welding is achieved properly and the movement of the end-effector is seen in figure 16.

7-8.

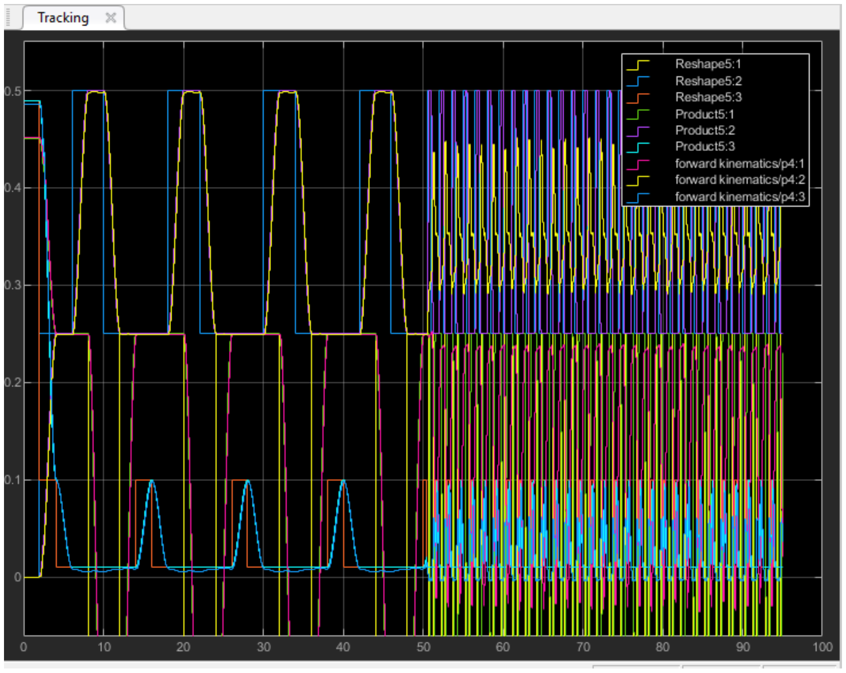


Figure 17: The tracking scope of the end-effectors movement

From figure 17, we set the duration to 2 seconds, we notice that the end-effector achieves the commanded waypoints properly for the first 50 seconds of the tracking scope. Then we change the duration to 0.25 seconds for the last 50 seconds of the tracking scope, we notice that the frequency of the signals are significantly smaller. Taking that into account, along with observing the quanser model, we notice that it is physically impossible for the end-effector to reach the waypoints given 0.25 seconds. Meaning that the manipulator cannot weld correctly at this duration because of the speed limitation of the QArm.

3. <u>Assembly</u>:

1-6.

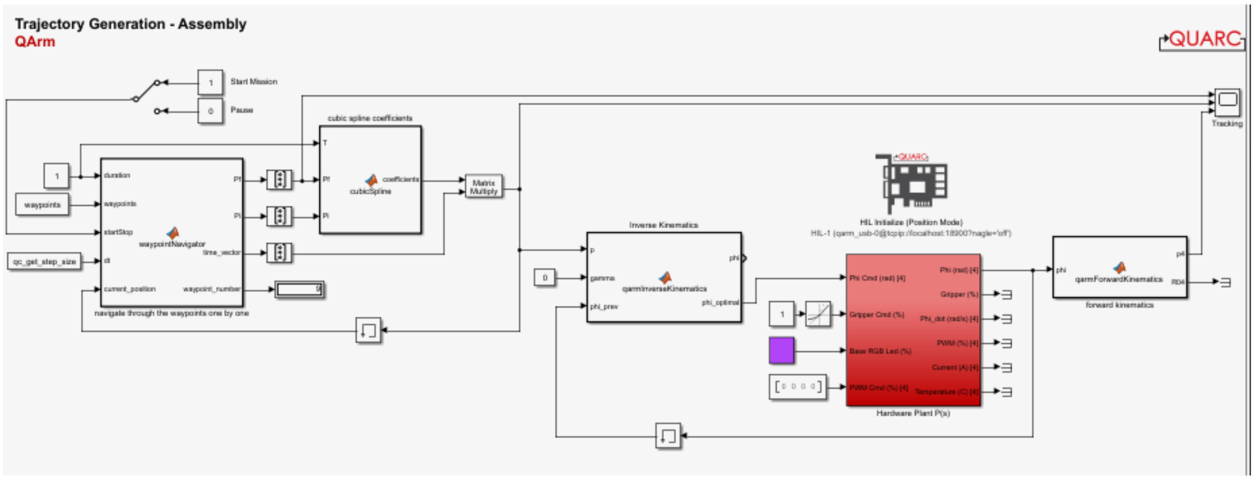


Figure 18: The Simulink model for Assembly

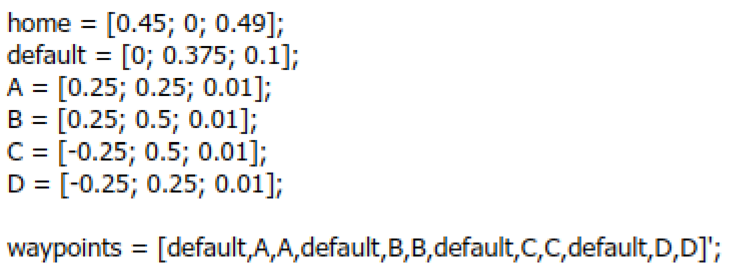

```
home = [0.45; 0; 0.49];
default = [0; 0.375; 0.1];
A = [0.25; 0.25; 0.01];
B = [0.25; 0.5; 0.01];
C = [-0.25; 0.5; 0.01];
D = [-0.25; 0.25; 0.01];

waypoints = [default,A,A,default,B,B,default,C,C,default,D,D]';
```

Figure 19: The model properties edit

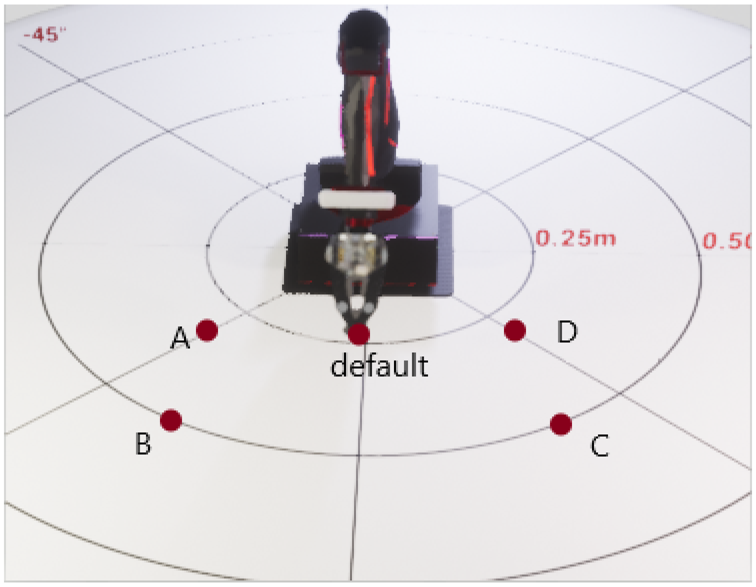


Figure 20: Diagram of movement

We notice that running the simulink file in figure 18, we get the movement as seen in figure 20, and we can observe that the manipulator traverses between points accurately and as expected. We can observe that the repetition of each point and the return to default between each point is needed to traverse accurately to each point.
The end effector moves in the following order of waypoints [default,A,A,default,B,B,default,C,C,default,D,D].

4. <u>Pick and Place</u>:

1.

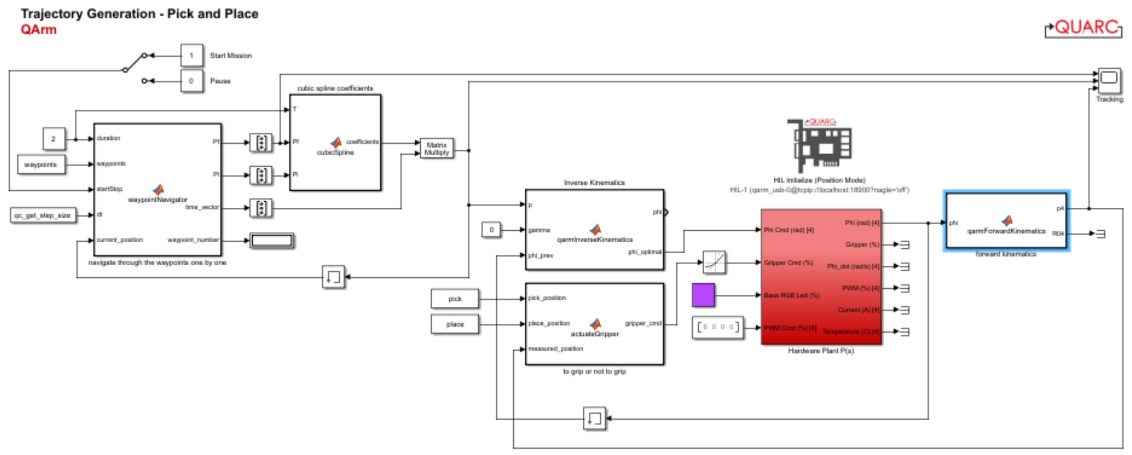
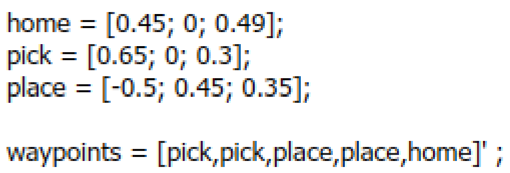


Figure 21: The Simulink model for Pick and Place

2.

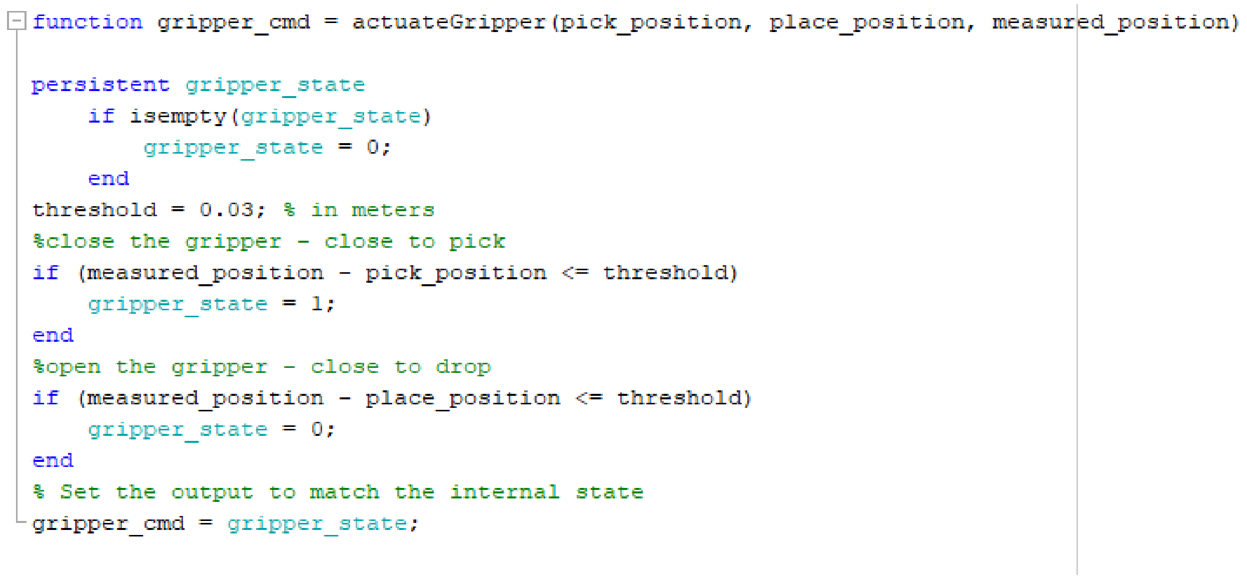


```
home = [0.45; 0; 0.49];
pick = [0.65; 0; 0.3];
place = [-0.5; 0.45; 0.35];

waypoints = [pick,pick,place,place,home]' ;
```

Figure 22: The waypoints for pick and place we selected

We notice in figure 22, that we set the end of one cycle of pick and place with a home waypoint. This step is added to ensure consistency in the movement of the robot because if home was not added then any error in one cycle would propagate through to the next cycle making the traverse between the waypoints incorrect or inaccurate. Also, we duplicated each of the pick and place movements to allow for the gripper to open or close depending on the current position it is in.

3-5.

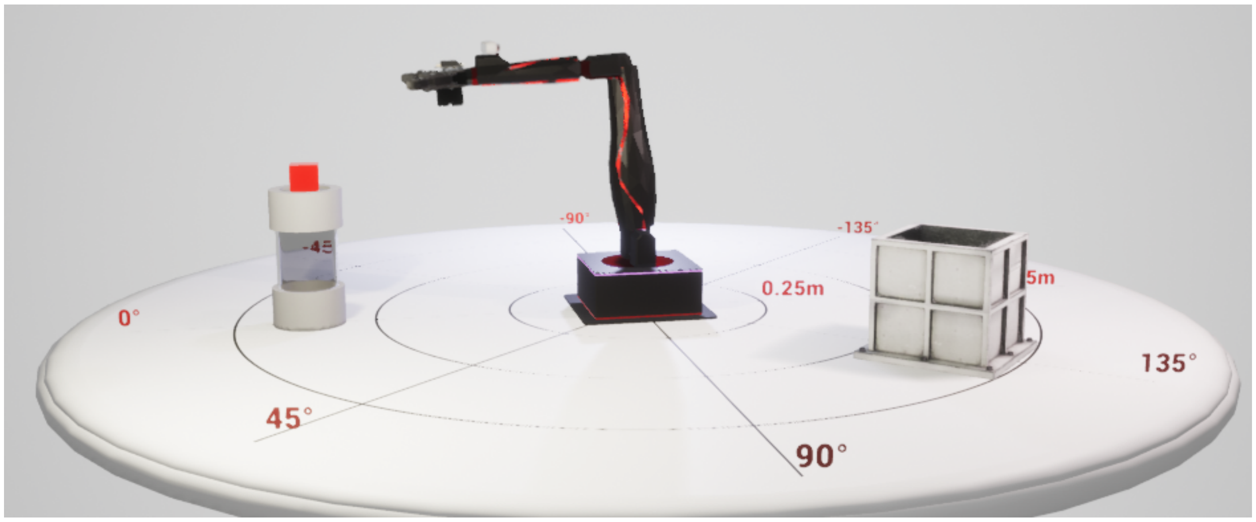


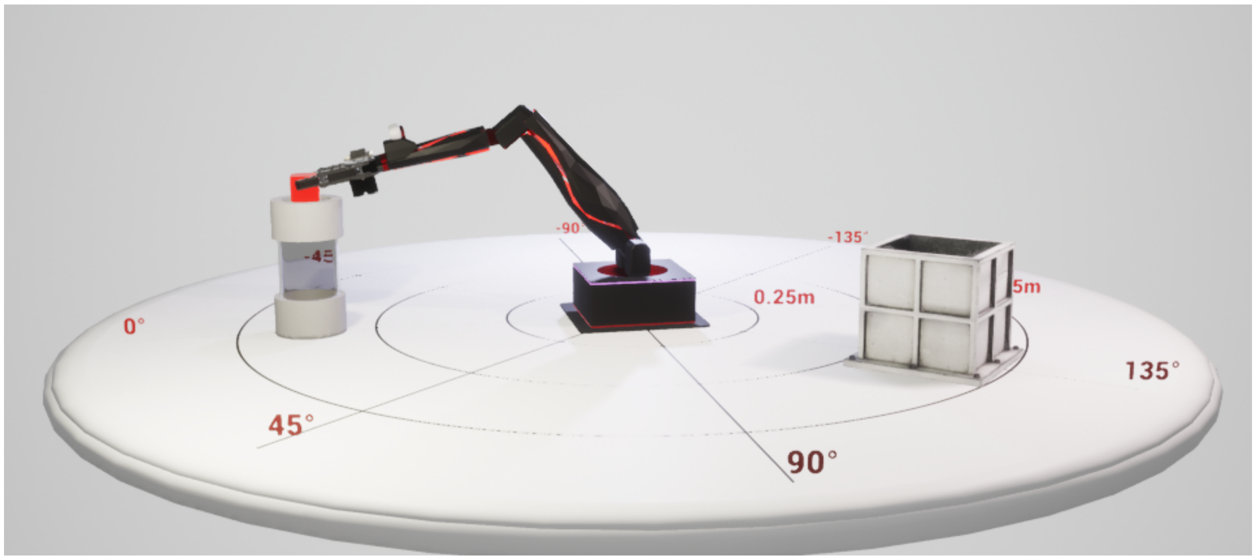
```
function gripper_cmd = actuateGripper(pick_position, place_position, measured_position)

persistent gripper_state
    if isempty(gripper_state)
        gripper_state = 0;
    end
threshold = 0.03; % in meters
%close the gripper - close to pick
if (measured_position - pick_position <= threshold)
    gripper_state = 1;
end
%open the gripper - close to drop
if (measured_position - place_position <= threshold)
    gripper_state = 0;
end
% Set the output to match the internal state
gripper_cmd = gripper_state;
```

Figure 23: The actuateGripper code modification

In figure 23, we have the gripper to close when we reach the object to pick up and we have the gripper to open when we reach the desired end position of the object.

6-7.





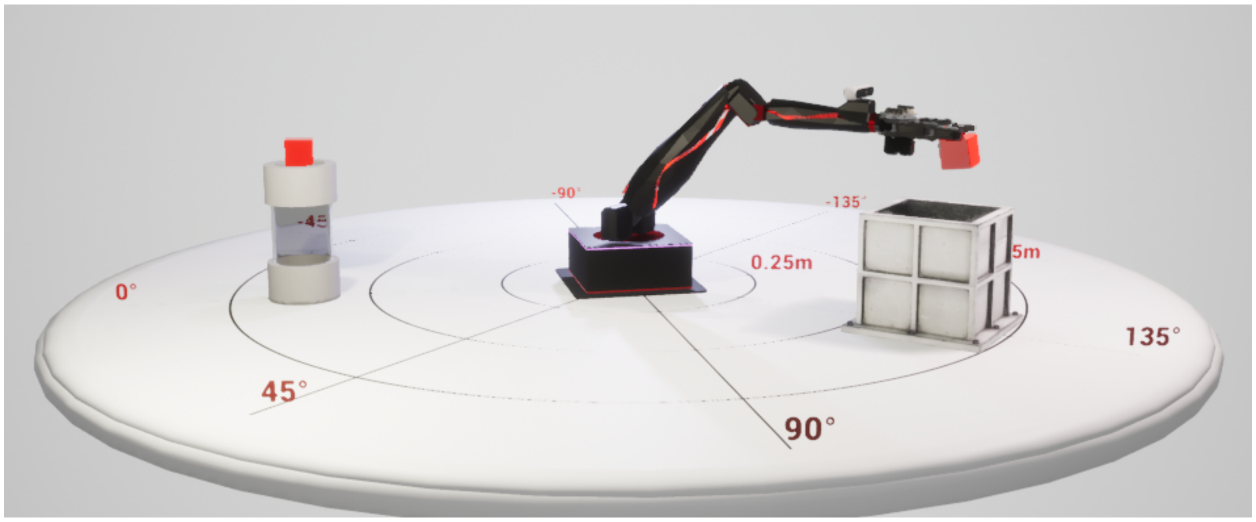


Figure 24-26: The different positions of the robot

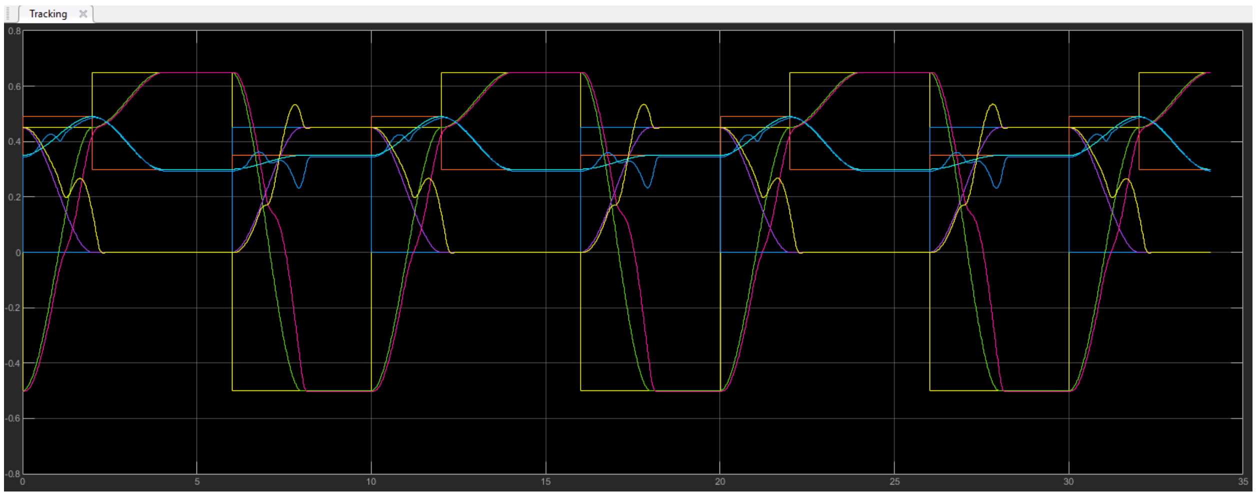


Figure 27: The movement of the end-effector

In Figure 24-27, we notice the motion of the end-effector is exactly as expected, as the end-effector starts in the home position, moves to the object, closes the gripper, moves to the drop area, opens the gripper and finally goes back to the home position. We notice that through each signal, the movement is the exact same and there aren't any noticeable errors that carry through the cycles.

Finally, we would like to mention that the movement has no errors that carry through the cycles because the object's weight is negligible, however, if the weight of the object was significant, we might have a completely different outcome as different things need to get accounted for now and not just the movement of the end-effector itself.