Lab 3 Report: Dynamics and Control

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Introduction

The objective of this lab was to learn how to accurately control the movement of the Rethink Robotics Baxter using a PID controller in Simulink. The lab also proposed to simulate an inverse dynamics controller to compare both controller's performance. The system was developed using a VM to interact with a simulated version of the Baxter Robot.

Materials and equipment

- Virtual Machine with MATLAB and Baxter RSDK

- Rethink Robotics Baxter

Experimental Procedure

1. A 30 second motion pattern was determined, and several key positions were selected. Afterwards, Baxter's left arm was moved through those positions to obtain information about the joints at those positions.
2. The data from Baxter was extracted form the text file and re-arranged in a manner that allows it to be used with the provided MATLAB file (initGoals.m). See appendix for a copy of the script used.
3. PID control loops were developed on MATLAB Simulink to provide the control mechanism of the manipulator. One PID controller was developed for each joint. See appendix for a block diagram of the system.
4. The PID controllers were manually tuned (due to the inability to auto-tune on the server) in order to best match the desired output.

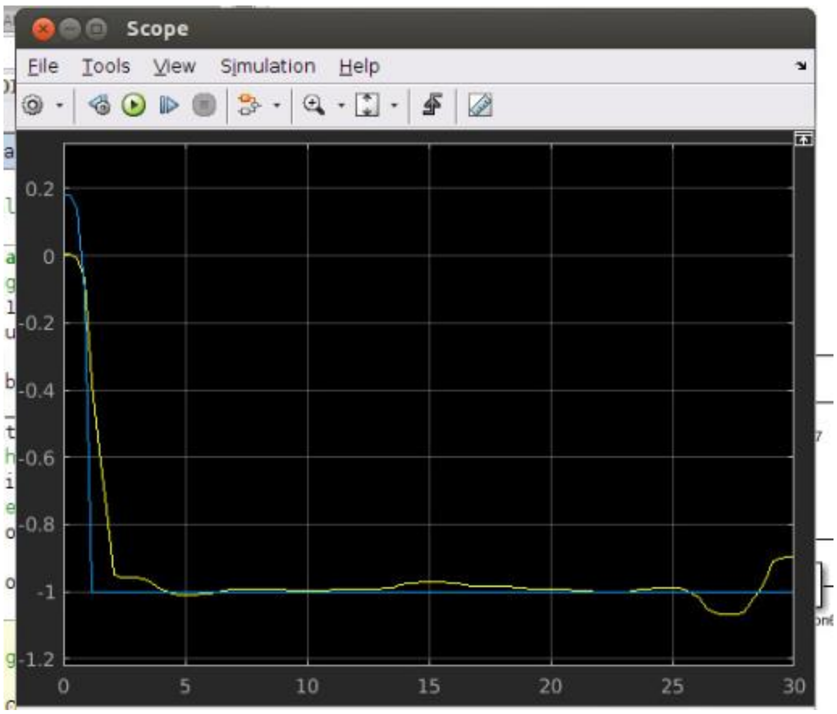
Tuning the PID Controllers

The Ziegler-Nicholson technique was used tune the PID controllers. For this technique all derivate and integral terms were set to zero initially. The proportional term was increased until the system started to oscillate. At this point, the derivate term was increased in order to eliminate the oscillations. At this point, the integral term was modified in order to reduce steady state error.

Results and Analysis

The following graphs show the output of our PID controllers for each joint. The values for the PID constants are shown below. The yellow curve represents the desired goals input, while the blue line is the actual output.

Joint 1

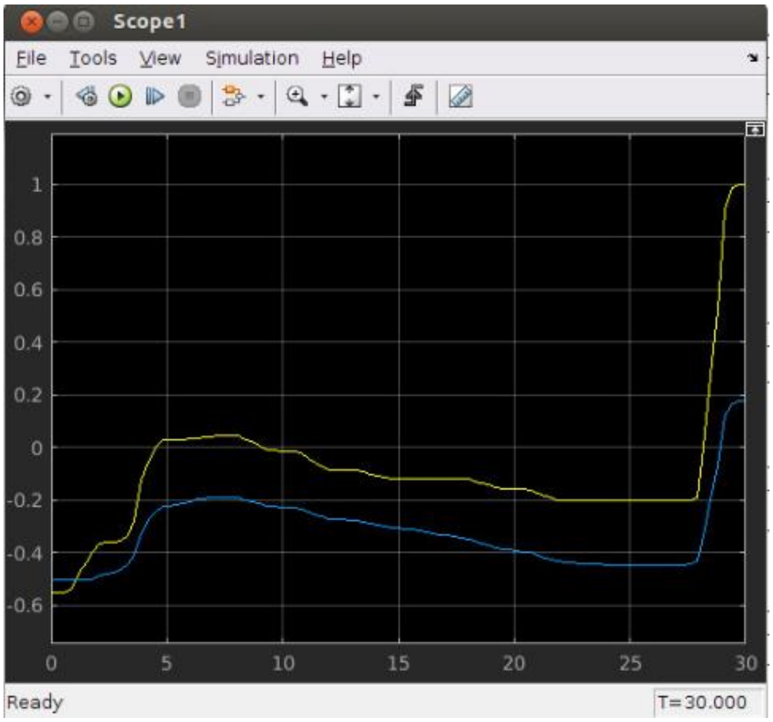


<u>Gains</u>

P=3.3, I=1.1, D=1 , N=1. The solver used was ode 1 with 0.3 step size.

As observed above the output follows the general shape of the desired input fairly well, however it could be improved. There is a small steady state error, as the blue curve is below the yellow curve at time 30s, this could be improved by tuning the gains even further, particularly by increasing the I term of the PID. However, due to time constraints and after many iterations this was the most optimal result obtained for this joint.

Joint 2

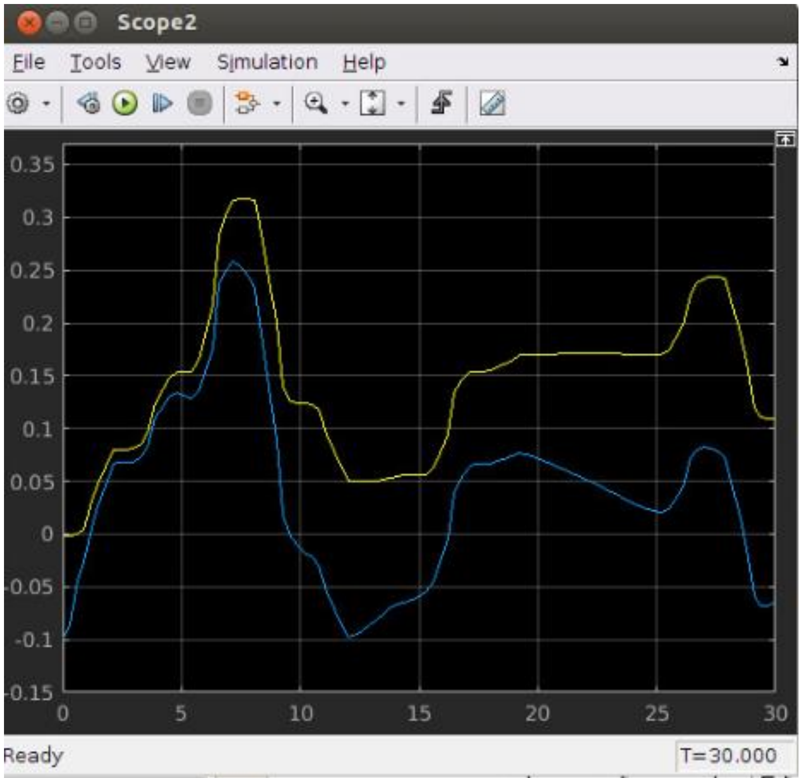


<u>Gains</u>

P=0.5, I=0.0001, D=0.0005 , N=1.

Once again, the shape of the response follows the shape of the input, however it is lower than the desired position. In order to fix this more time needs to be spent tuning the constants for the PID controller. This particular joint was difficult to tune as no combination of values seemed to allow it to rise to the set point of 1. By observation, increasing the integrator term should reduce the steady state error, however this did not seem to be the case here.

Joint 3

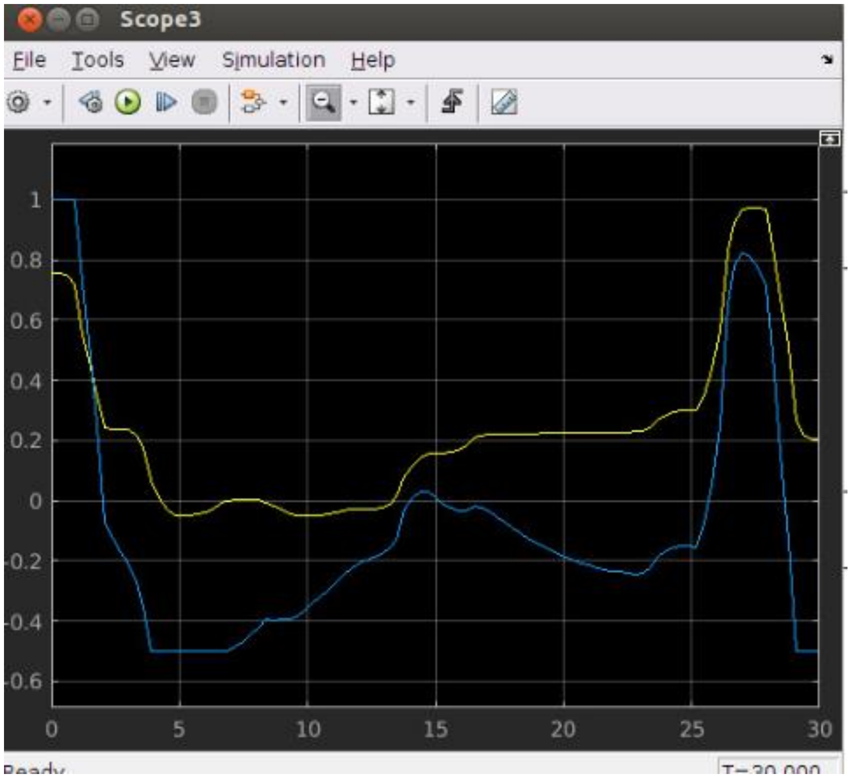


<u>Gains</u>

P=1, I= 0.00025, D= 0.0001, N= 1

The steady state error is large for this joint. In theory, increasing the Integrator would reduce this error, however this is not what we observed when tuning this PID. This might be because the remaining terms also needed adjustment. Unfortunately, this was the best response we were able to obtain in the allotted time.

Joint 4

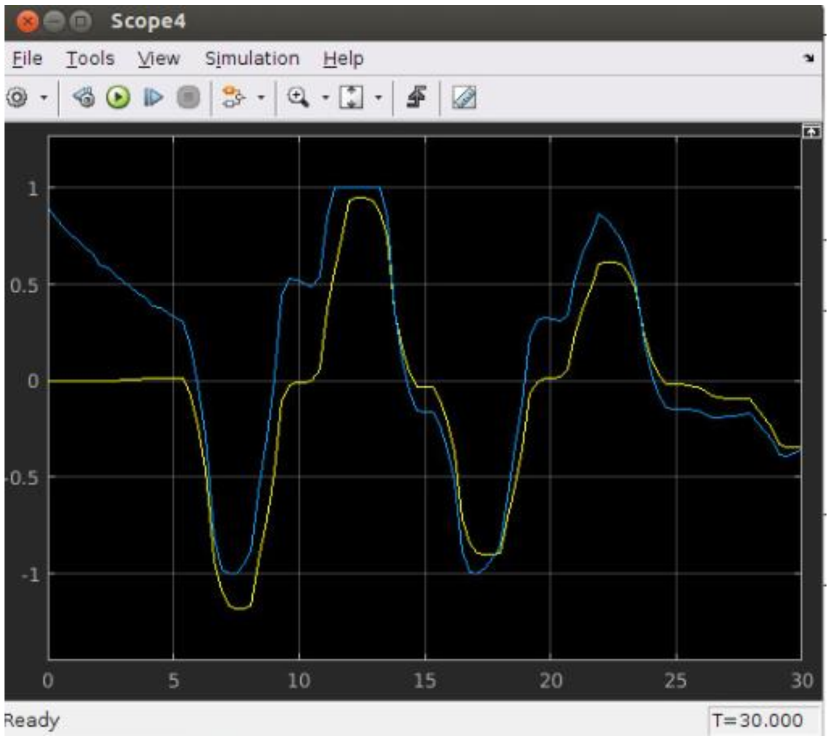


<u>Gains</u>

P=1.55, I=0.001, D=0.001, N= 1

Similarly, as above, joint 4 still has some error and does not follow the input exactly. However, the overall shape does mimic the input well. To improve this response the I or P terms could be adjusted to get it closer to the set point.

Joint 5

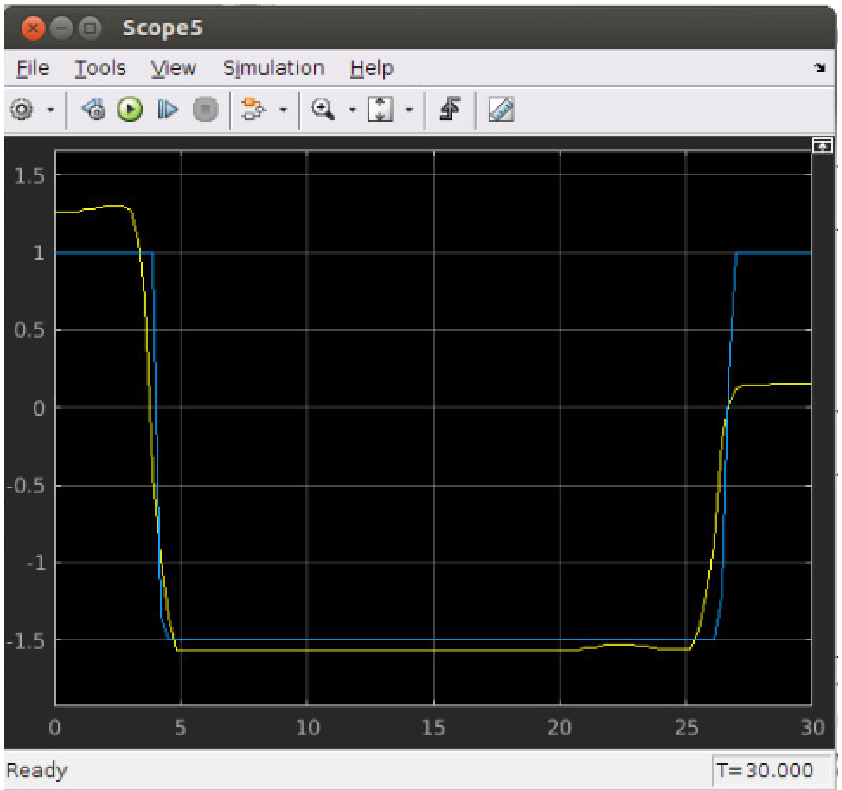


<u>Gains</u>

P=1.1 , I=0.001, D=0, N=1.

Joint 5 was one of the closest responses obtained, however it is not perfect. The response starts at 1. In theory, the D term could be increased to reduce this oscillation, however when this term was increased, the overall shape of the output would also change. More time could be spent tuning the saturation block along with the PID terms to achieve a better response.

Joint 6

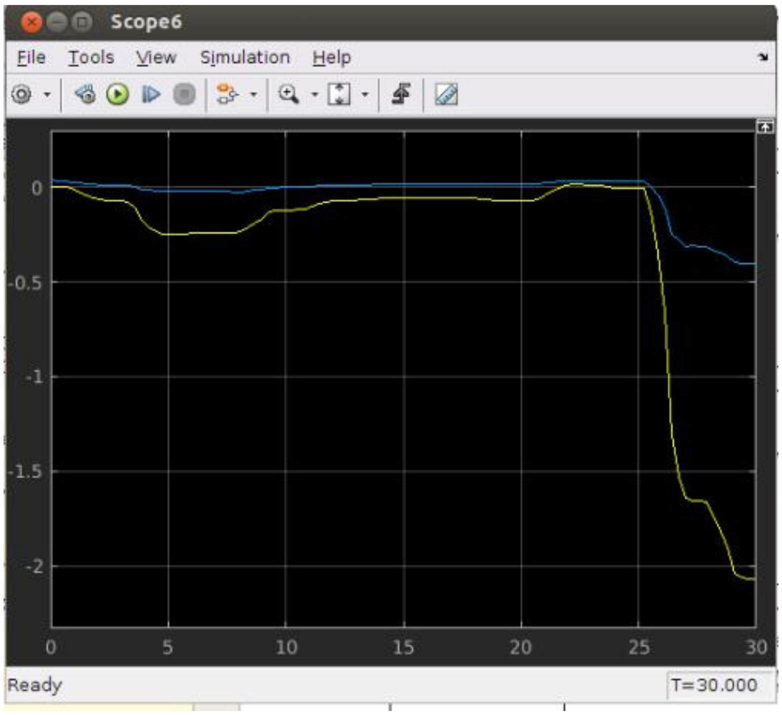


<u>Gains</u>

P= 4.1, I=1.35, D=0.0001, N=1

The performance of this PID was not the best, there is still some steady state error that could be reduced. To improve this, the Integrator value could be increased.

Joint 7



<u>Gains</u>

P=0.2 , I=0.01, D=0.005, N=1

Joint 7 behaved similarly as the rest of the joints, the response obtained could be improved by increasing the integrator term and thus reducing steady state error.

As seen in the graphs above, after several iterations of tuning, the final results show that it is possible to accurately control the motion of a manipulator with a PID controller. Due to time limitations we were unable to obtain the most accurate gains possible, however with more time, more iterations could be made to find the PID constants that make the system follow the input signal more accurately. While tuning the PID is important, it was observed that the values given to the saturation blocks also have an influence on what the output response will look like.

Discussion

There were several difficulties faced in the lab. However, some of the main issues encountered involved the performance of the virtual machine used. The inconvenience of not being able to save any of the changes made to our Simulink model slowed down the tuning process. In addition, the large number of joints in Baxter also made it difficult to finish the tuning process during the lab time, specially with the slow speed of the virtual machine.

Overall, tuning the PID controllers themselves was also a challenge as initially we did not model our system with saturation blocks. Once we incorporated saturation to limit the output of our system, tuning became more straightforward.

Because of technical difficulties with Baxter, there was no time left to see the movement in the real robot. For this reason, it is difficult know what the robot’s accuracy and repeatability would have been in real life. However, it can be inferred that the robot would have performed similarly as what the simulation showed. Although in reality motors do not have an ideal behaviour, this robot would probably have a good level of accuracy and repeatability.

Conclusion

In this lab the concepts of manipulator control were explored both in theory and practice. The emphasis was on the difference between dynamic controllers and PID controllers. Unfortunately, due to technical difficulties with the server as well as time constrains it was not possible to explore the dynamic controllers in practice. Nonetheless, the theory behind them was still considered. The focus of the practical experiment was then deterred to the PID control which had its own set of difficulties that were outlined in the discussion section above. All in all, the lab gave great insight on manipulator control in practice and the challenges associated with it.

Appendices

Init goals

```
%% Init goals
%  Sets up goal trajectories for controller to use.x

%% Discrete goals
%  Get starting position from Baxter's current position
states = ones(16,1)*-1000;
bax_sub = rossubscriber('/robot/joint_states', rostype.sensor_msgs_JointState);
%  Get updates for all joints
msg = receive(bax_sub);
states = joint_states(msg,length(msg.Position),states);
while (min(states) < -500)
   % Get another message
   msg = receive(bax_sub);
   % Get states from it
   states = joint_states(msg);
end
initial_position = [0 states'];

%% Goals
%  Setup your goals and interpolate positions here

Q_Baxter = [0.0, -0.0395000052880494, -0.0015339807878854137, 0.7570195188214517, 0.003451456772742181, -
0.5526165788357204, -0.0015339807878854137, 1.2578642460660392, -0.0003834951969713534, -0.0030679615757708274,
0.7566360236244803, 0.0023009711818281204, -0.5460971604872072, 0.0, 1.2578642460660392, 0.0011504855909140602, -
12.565987119160338;
            0.0, -0.039883500485020755, 0.08015049616701286, 0.23853401251618184, -0.9579710020344409, -
0.3608689803500436, 0.0015339807878854137, 1.3011992033238022, -0.06979612584878632, -0.002684466378799474,
0.7566360236244803, 0.0038349519697135344, -0.5445631796993219, -0.0003834951969713534, 1.257480750869068,
0.0007669903939427069, -12.565987119160338;
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12.565987119160338;
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12.565987119160338;
```

```
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0.002684466378799474, -12.565987119160338];
Q_via = [Q_Baxter(:, 5:6), Q_Baxter(:, 3:4), Q_Baxter(:, 7:9), zeros(size(Q_Baxter,1), 9)];


Q = zeros(133,16);
for i=1:12
b = zeros(10,16);
   for j=1:16
      b0= Q_via(i,j);
      b1 = 0;
      b2 = 0;
      b3 = 10*((Q_via(i+1,j)-Q_via(i,j))/9^3);
      b4 = 15*((Q_via(i,j)-Q_via(i+1,j))/9^4);
      b5 = 6*((Q_via(i+1,j)-Q_via(i,j))/9^5);
      for t = 0:9
         b(t+1,j) = b0 + b3*t^3 + b4*t^4 + b5*t^5;
      end
   end
      Q(i+(i-1)*10, :) = Q_via(i,:);
      Q(i+(i-1)*10 + 1: i+(i-1)*10 + 10, :) = b;
end

Q(133,:) = Q_via(13, :);

TIME_STEP  = 30/133;

 tStart = 0;
 dx = TIME_STEP;
 N = 133;
 t = tStart + (0:N-1)*dx;

 Q = [t',Q];

 goals = Q;
```
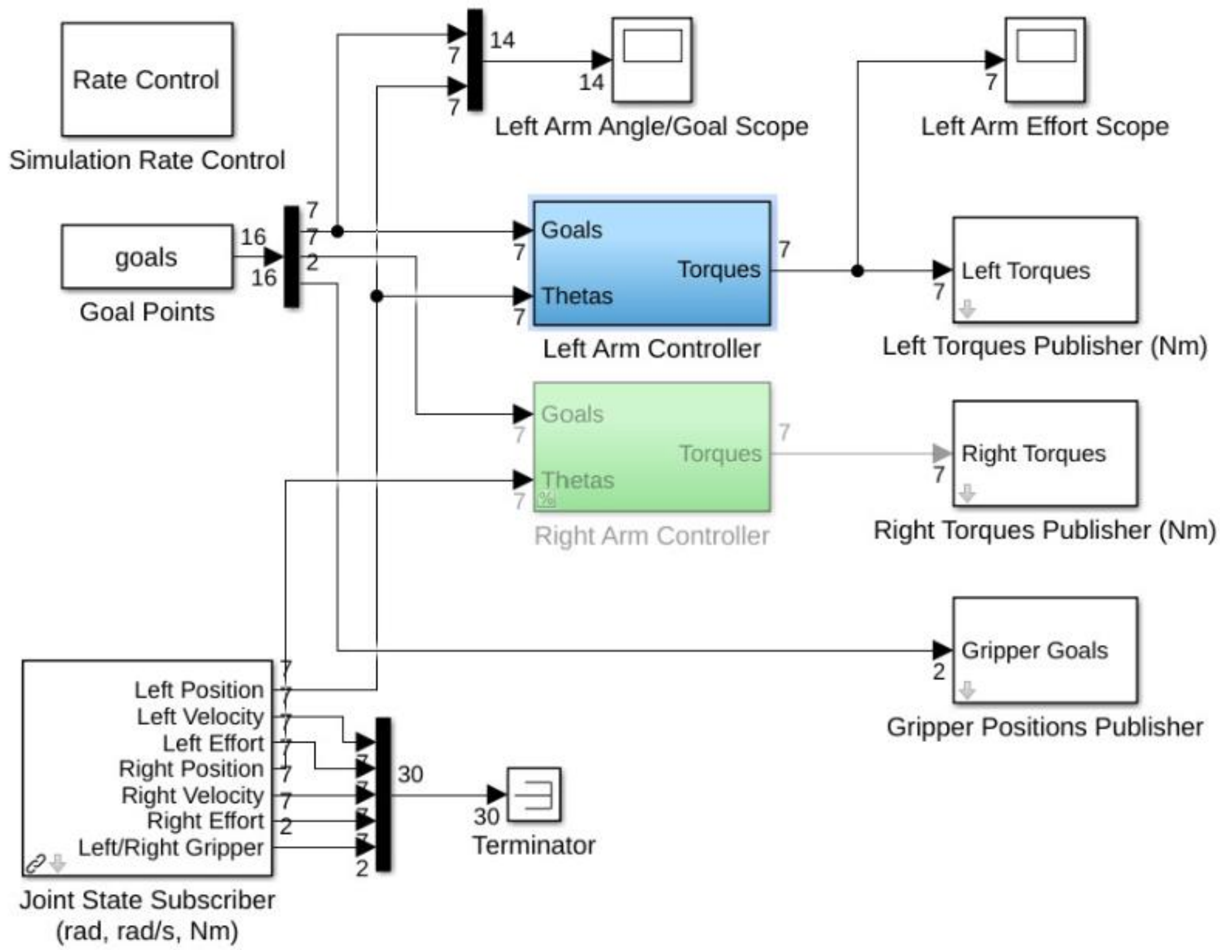

Block Diagram



Rate Control
Simulation Rate Control
14
7
7
14
Left Arm Angle/Goal Scope
7
Left Arm Effort Scope
goals
16
16
Goal Points
7
7
2
Goals
7
Torques
Thetas
7
7
Left Arm Controller
Left Torques
7
Left Torques Publisher (Nm)
Goals
7
Torques
Thetas
7
7
Right Arm Controller
Right Torques
7
Right Torques Publisher (Nm)
Gripper Goals
2
Gripper Positions Publisher
Left Position
Left Velocity
Left Effort
Right Position
Right Velocity
Right Effort
Left/Right Gripper
30
30
Terminator
Joint State Subscriber
(rad, rad/s, Nm)

PID Control block