# RBE 500 - HW 6

Consider the following robot joint model

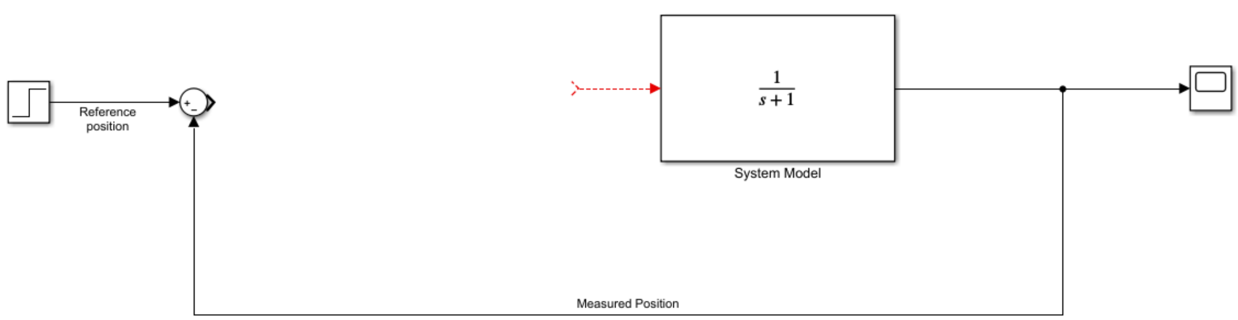
$$J\ddot{\theta}(t) + B\dot{\theta}(t) = u(t) + d(t)$$

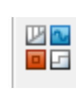
where $J$ is the inertia of the link, $B$ is the effective damping on the link, $\theta$ is the joint angle, $u$ is the actuator torque (input), and $d$ is the disturbance acting on the system.

**Question 1 (2 pts):** First, assume that disturbance is zero and take $J = 2$, $B = 0.5$. Design a PD controller such that the closed loop system is critically damped, and settling time is 2 second. **Do not do this by tuning the gains;** calculate the Kp and Kd gains using natural frequency and damping ratio.

**Question 2 (3 pts):** Now we will simulate this system in Simulink. Follow the following steps:

- Open matlab and open a new script file (m file).
- Write the system parameters to this script file
  ```
  J = 2;
  B = 0.5;
  ```
  ….[and others you might need..]
- Run this script so that the parameters are loaded to the workspace. Please beware that if you add new parameters or change the values of the parameters, you will need to run the scripts again to load them to the workspace.
- Now, run Simulink by typing "simulink" in the command window. The Simulink add-on will be lunched.
- Implement a closed loop system in Simulink. First, put down the general structure as below.




- For that you will need to open the library browser with the icon  at the ribbon. The block library includes a vast number of blocks for various purposes. The most commonly used blocks are "Continuous", "Discrete", "Math operations", "Sinks" and "Sources". Please examine these categories first. Then implement your closed loop system using the "transfer function", "scope", "sum" and "step" blocks. Modify the system model transfer function according to your system model. For that, double click to the system model, and specify the coefficients of the numerator and denominator so that the system model represents the robot joint model of this question. Enter the inertia and damping values parametrically (as J, B…. etc. not as numbers), so that when you change and load them in the script file they will be changed in the Simulink model too.

- Now add your PD controller. You will be using "gain", "sum" and "derivative" blocks. (Simulink has a PID block itself. Please do not use this block. Implement it with basic blocks as explained). While assigning values to the gains, again, use parametric names (Kp, Kd) and specify them in the script file (don't forget to run the script file again so that the values are loaded).
- The "source" or "reference position" in this simulation is a step signal that changes from zero to one. The changes in the position of the system is displayed with a "scope" block. Now run your simulation by pressing the play button. After the simulation is finished, double-click to the scope block to see the response of the system. Explain the process and be sure to include the plot to your report.

**Question 3 (1.5 pts): Tuning:** You may have noticed that the system performance (overshoot and settling time) is quite close to your goal, but it might not be exactly there. <u>Report the current settling time in your report</u> (you may need to zoom in to the plot to see the exact settling time). This is because the equations defining the relations between the damping ratio, natural frequency, settling time and overshoot, are approximations, not exact relations. Specifically, the settling time equation is only accurate when damping ratio is <<1. Now, tune the values of Kp and Kd so that you get closer to your goal performance. Please remember the Kp and Kd to the system performance from our slides and discussions. <u>Explain your process and include a plot showing the results after tuning.</u> If your values have already been good and do not require tuning, report that as well.

**Question 4 (1.5 pts):** Now add a constant disturbance to the system, (Please check the lecture slides for where to add this disturbance from to your simulink block diagram), by using "constant" block from "Sources". Assign the value D to the block. Define this same parameter in the script and set its value to $D = 0.5$. <u>Provide the plot for theta with the same gain values to the previous question. You will see some steady state error. Report the amount of steady state error.</u>

**Question 5 (2 pts):** Keeping the disturbance the same, add the integral term to your controller (using the integral Simulink blocks) and tune the P, I and D gains to obtain the desired performance and remove the steady state error even under the disturbance effect. <u>Report the current Kp, Kd and Ki values together with your new plot.</u>