The closed-loop system block diagram in Simulink is shown in *Figure 1*.

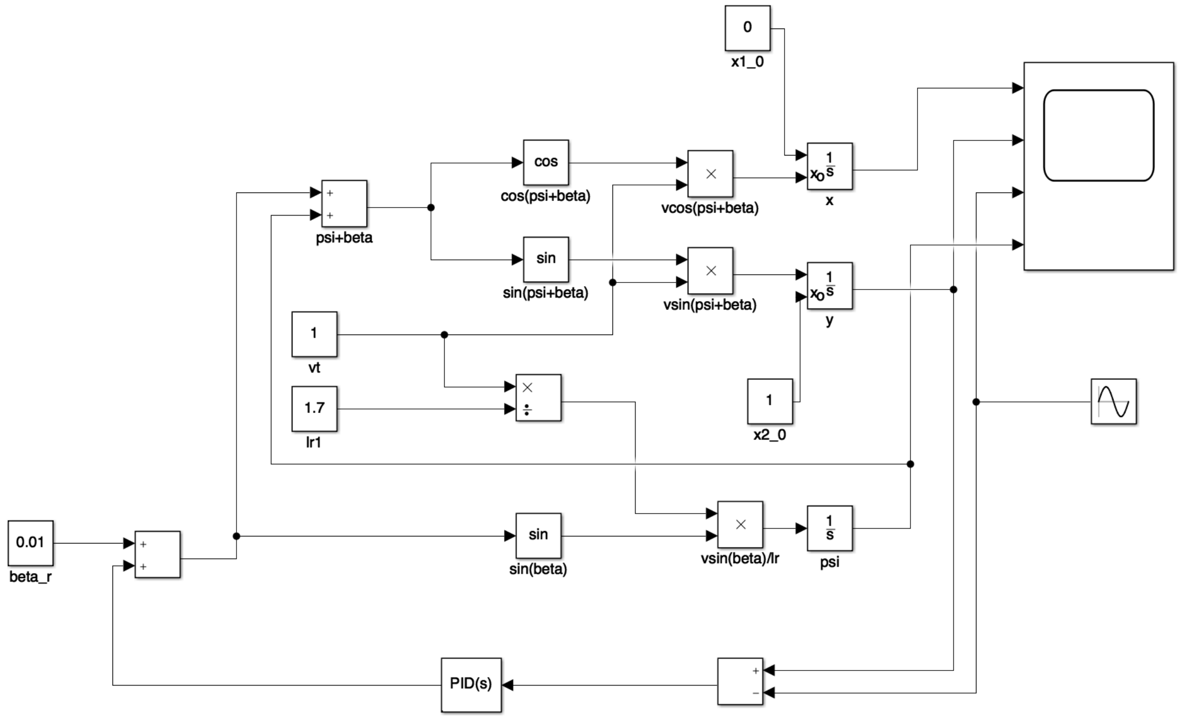

Figure 1. The Closed-Loop System Block

5. Simulink is used to simulate this closed loop system designed. In this case, all the initial conditions are set to zero. The PID control is tuned to Kp = 200, and Ki = 1. In *Figure 2*, we see that y and y_r converges as the time increases.

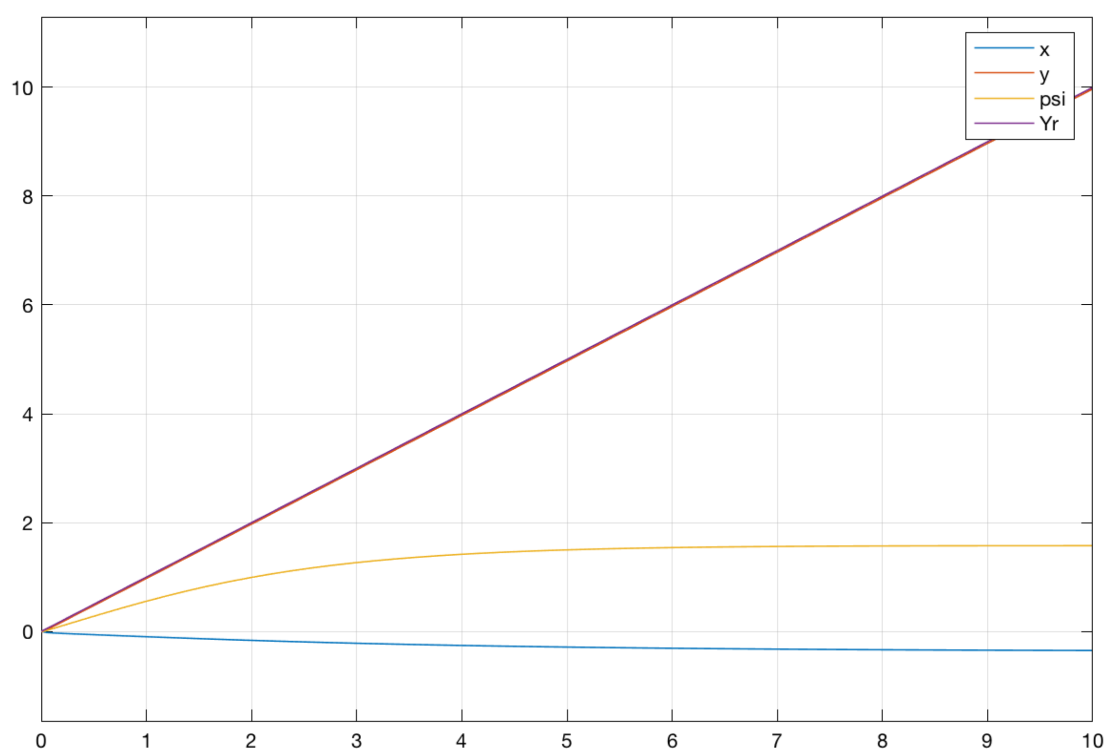

Figure 2. Plot of closed loop system for problem 5

6. In order to vary the initial condition so that the controller no longer results the desired behavior, we can set x_0 = 1, and y_0 = 0. We can see in *Figure 3* that y does not converge to y_r anymore, and they both increase in parallel as time increases.
On the other hand, if we set the initial condition to x_0 = 0, and y_0 = 1, we can clearly see in the plot that Y diverges from Yr as time increases.

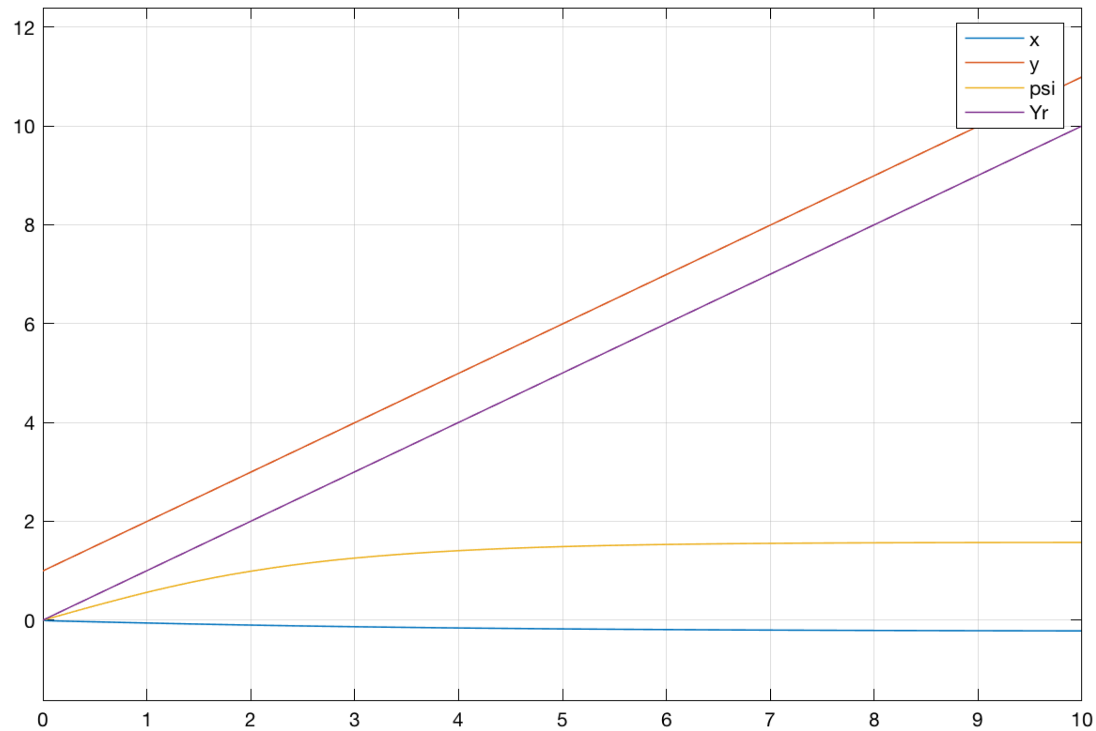

Figure 3. Plot of closed loop system for problem 6

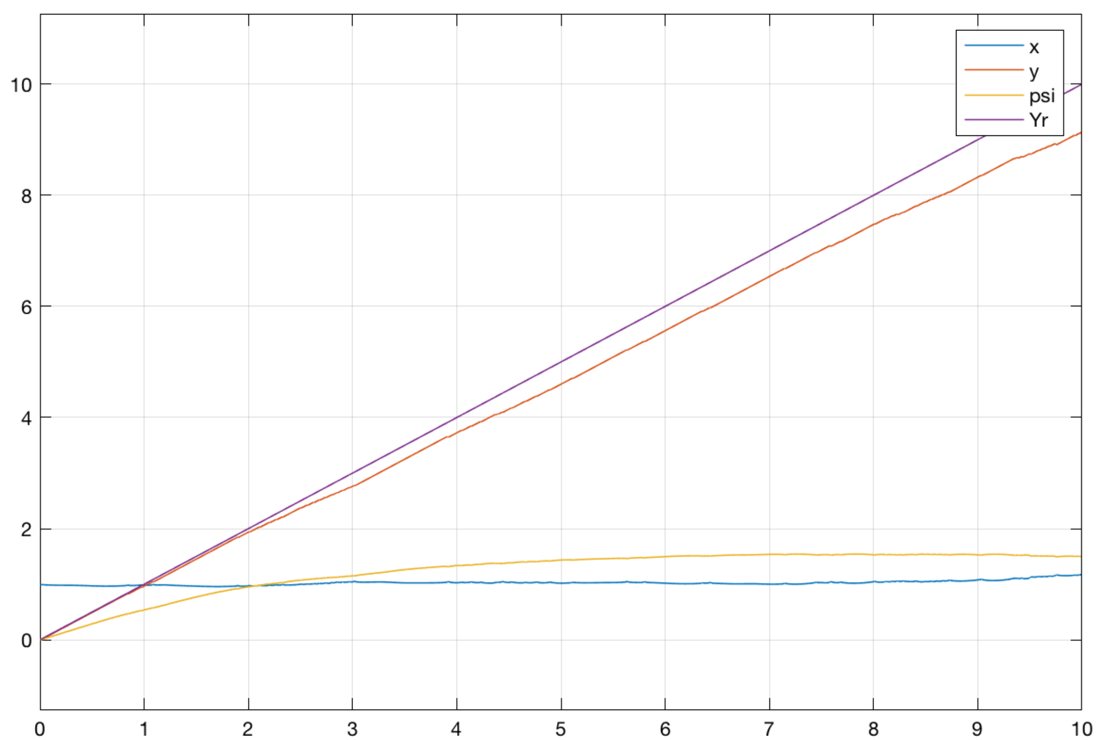

Figure 4. Plot of closed loop system for problem 6

7.If we fix the initial condition, but attempting to track more challenging reference trajectories, we may choose to switch the trajectory from a ramp to a sinusoidal input with frequency of one. As can be seen from *Figure 5*, the sinusoidal trajectory is in parallel with y curve, and both psi curve and the x curve demonstrate periodic properties in this situation.

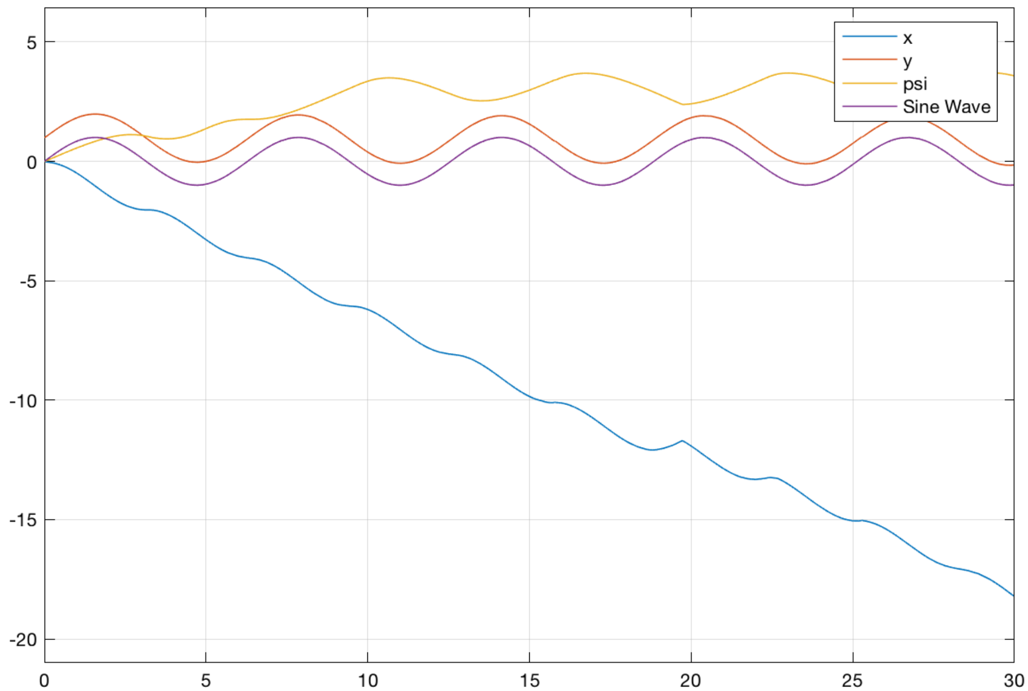

Figure 5. Plot of closed loop system for problem 7

8. In order to redesign the closed loop system and analyze its changes, we may adjust the value of the PID controller to observe its change in behavior.
Case 1: If we set the value of proportional component into very high, such as Ki = 1000, the system output will change drastically, as can be seen from *Figure 6.* The controller will be less robust, and Y will diverge from the Y_r reference drastically.

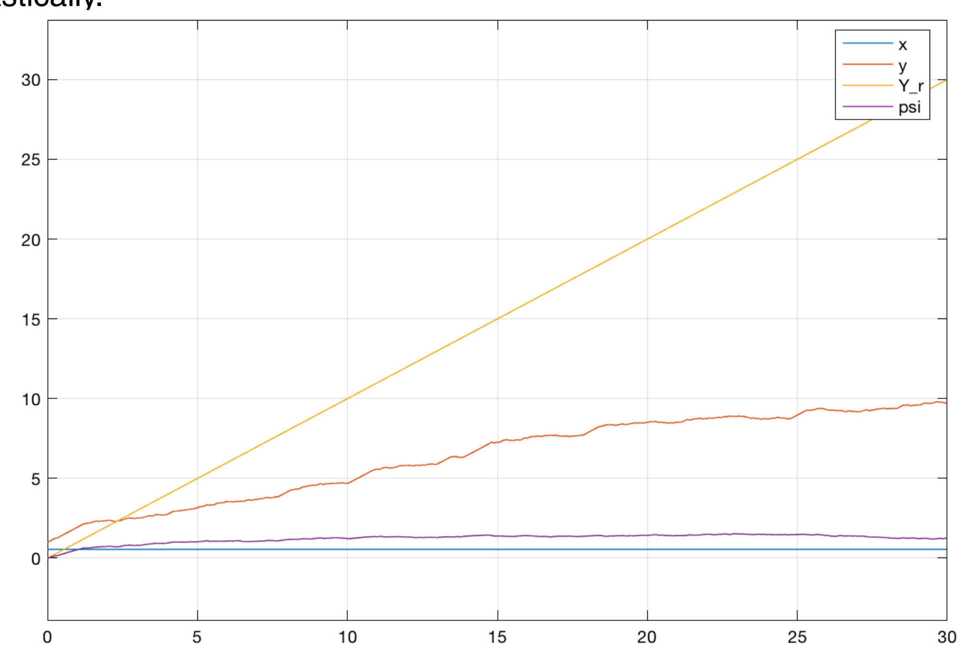

Figure 6. Plot of output for closed loop system in Problem 8

Case 2: On the other hand, if we set the integral component into very high, such as Ki = 1000, we can see from *Figure 7* that the controller will not work properly, and y will overlap with the x and there is no convergence to the reference value at all.

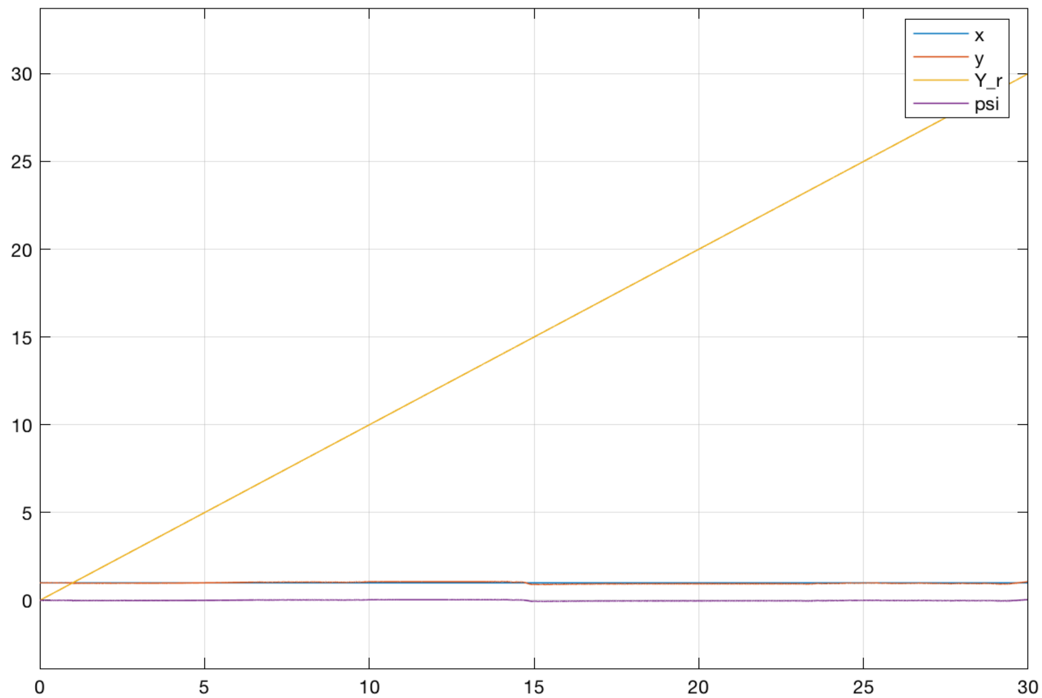

Figure 7. Plot of output for closed loop system in Problem 8

Case 3: Next, if we set the derivative component into very high, such that Kd = 1000, we may observe in *Figure 8* that the y curve will slowly converge to the ramp y reference. In this case, the controller does not work robustly, due to its relatively low response time.

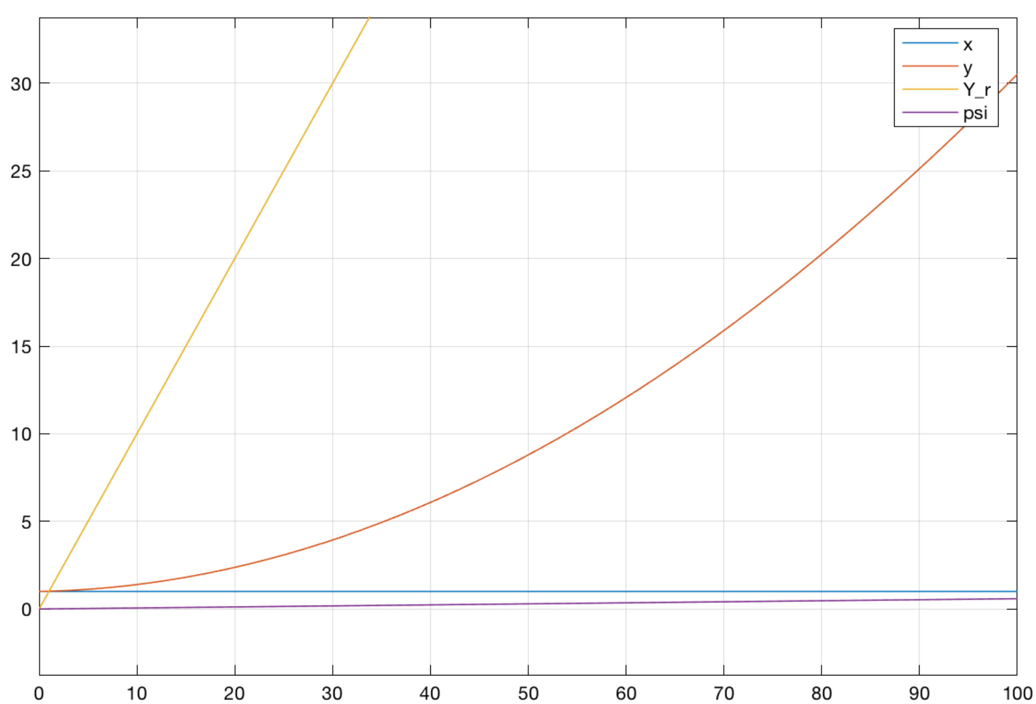

Figure 8. Plot of output for closed loop system in Problem 8

EE 141 Final Project Report
Spring 2018

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