Due: Friday November 13

In this homework we will simulate and study minimum order observers coupled with state variable feedback, and then we will add on integral control. Minimum order observers only estimate those states we don't know or can't measure. If a state is known, the minimum order observer uses that state. We will also simulate and study optimal tracking for both one and two degree of freedom systems.

All of the problems utilize the continuous time torsional system models you used on your last homework. You should put all of your figures in a memo and e-mail it to me.

1a) Copy your program **DT_sv1_observer_driver.m** to **DT_sv1_min_obs_driver.m** You will need to modify the part of the code that determines the observer gains, and you will have to have the program call the simulation **DT_sv1_min_observer.mdl.** Copy the Simulink file **DT_sv1_observer.mdl** to **DT_sv1_min_observer.mdl .** Modify this ***new*** file to implement state variable feedback using a minimum order observer to estimate the states for a one degree of freedom system. In addition, you will need to modify your code so that you can utilize different sampling rates.

Assume we want the state vector written as $\begin{bmatrix} x & u_d & \dot{x} \end{bmatrix}^T$. You need to modify both G and H to reflect this new ordering. You also need to fix the demuxes in your Simulink file to reflect this new order.

b) Assume the only known state is the position of the first disk, and the output is the position of the first disk. Use a sampling interval of 0.05 seconds, assume all the state feedback poles are at 0.5, and the observer poles are at 0.2 and 0.3. Also assume the system initially starts at a position of 10 degrees, with an initial velocity of 10 degrees, and an initial delayed input of 10 degrees (be careful of units here! The model works in radians.). The initial estimates of the observer are zero. For a 10 degree step input you should get the graph shown in Figure 1. Turn in your plot.

c) Now assume the same initial conditions as in part a, but both the position of the disk and the delayed input signal are known. The observer pole is placed at 0.3 and the sampling interval is still at 0.05. For a 10 degree step input you should get the graph shown in Figure 2. Turn in your plot.

d) Now assume the same conditions as **c**, but with a sampling interval of 0.03 seconds. For a 10 degree step input you should get the graph shown in Figure 3. Turn in your plot.
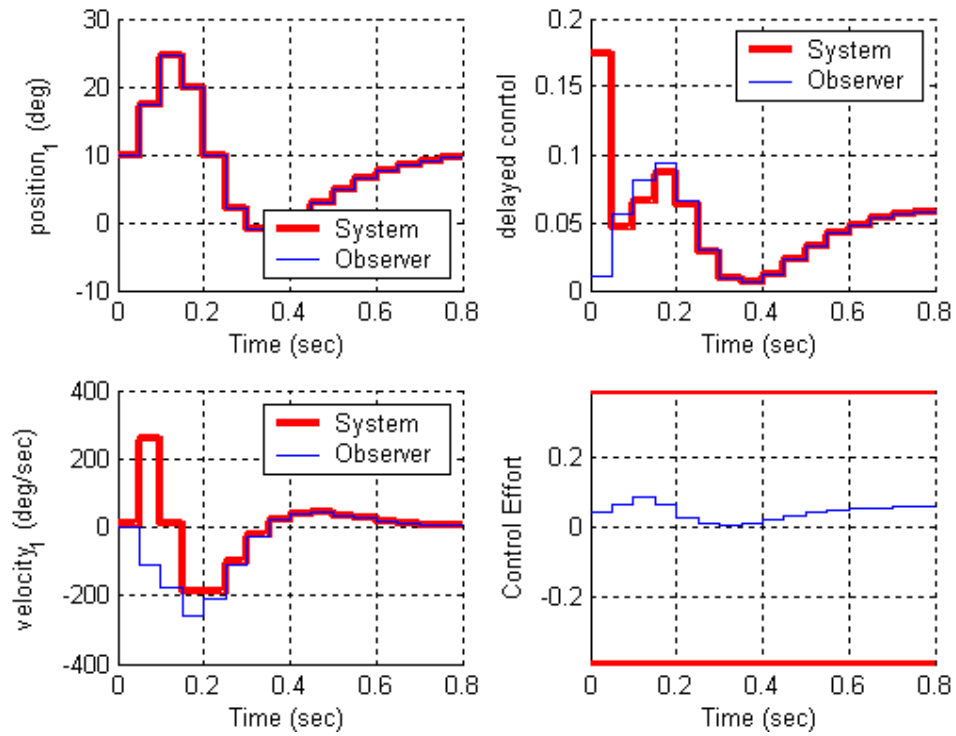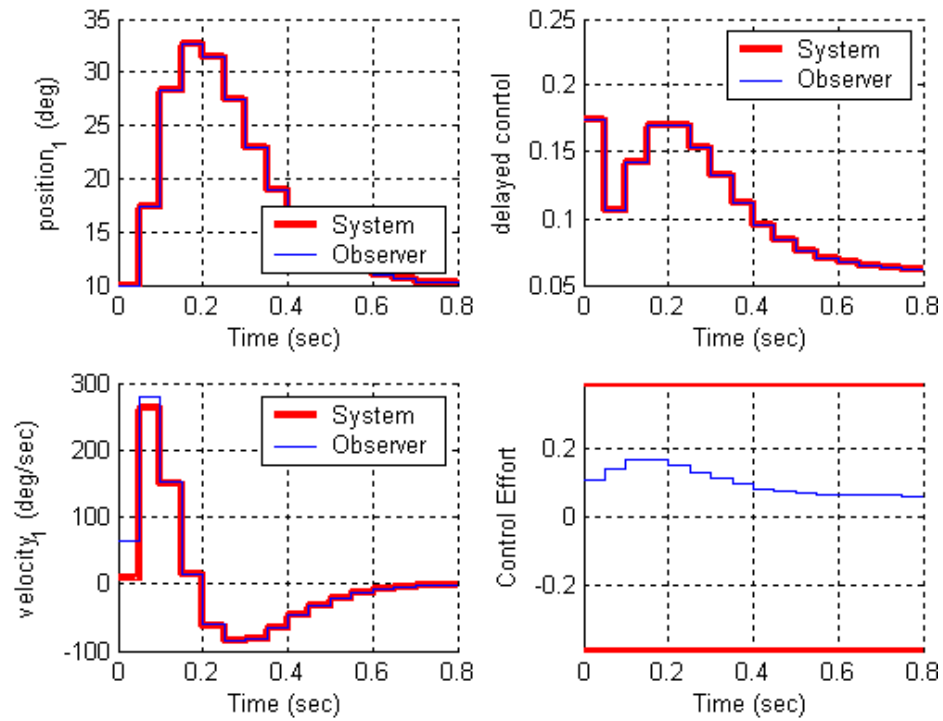
Figure 1. Results for problem **1b**.
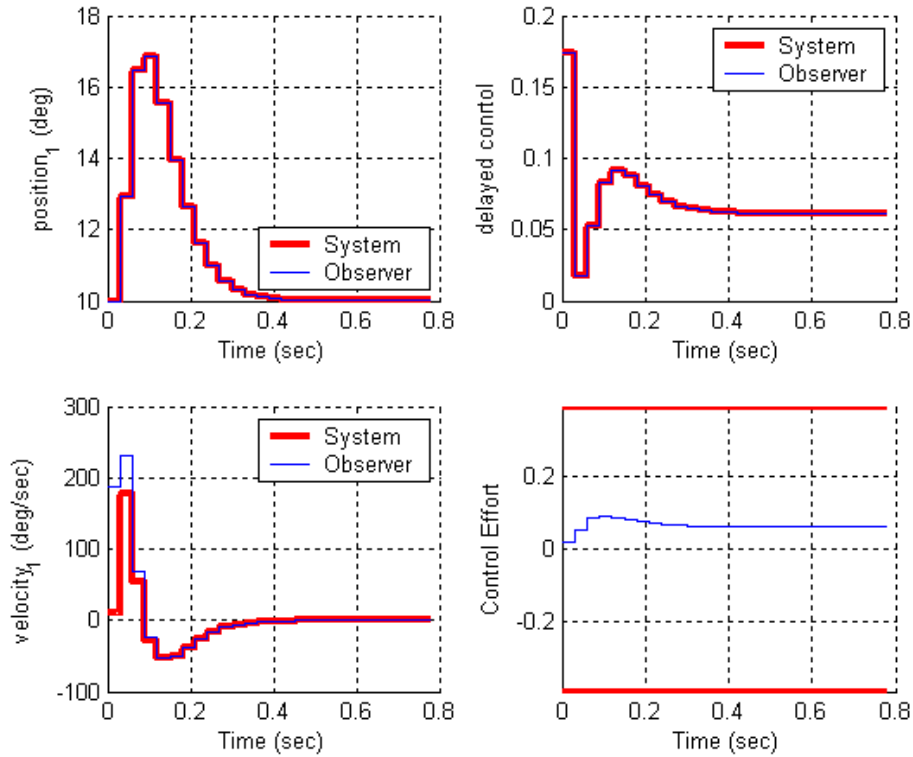

Figure 2. Results for problem **1c**.

Figure 3. Results for problem **1d**.

2) Now we want to combine the minimum observer and state feedback with integral control for the one degree of freedom system.

a) Create a driver file **DT_sv1_min_obs_servo_driver.m** and a corresponding Simulink file **DT_sv1_min_obs_servo.mdl.** Modify this **_new_** file to implement state variable feedback using a minimum order observer to estimate the states for a one degree of freedom system. In addition, you will need to modify your code so that you can utilize different sampling rates.

Assume we want the state vector written as $\begin{bmatrix} x & u_d & \dot{x} \end{bmatrix}^T$. You need to modify both G and H to reflect this new ordering. You also need to fix the demuxes in your Simulink file to reflect this new order.

 b) Assume the only known state is the position, and the output is the position of the disk. Use a sampling interval of 0.05 seconds, assume all the state feedback poles are at 0.5, and the observer poles are at 0.2 and 0.3. Also assume the system initially starts at a position of 10 degrees, with an initial velocity of 10 degrees, and an initial delayed input of 10 degrees (be careful of units here! The model works in radians.). The initial estimates of the observer are zero. For a 10 degree step input you should get the graph shown in Figure 4. Turn in your plot.

c) Now assume the same initial conditions as in part **b**, but both the position of the disk and the delayed input signal are known. The observer pole is placed at 0.3 and the sampling interval is still at 0.05. For a 10 degree step input you should get the graph shown in Figure 5. Turn in your plot.

d) Now assume the same conditions as part **c**, but with a sampling interval of 0.03 seconds, For a 10 degree step input you should get the graph shown in Figure 6. Turn in your plot.
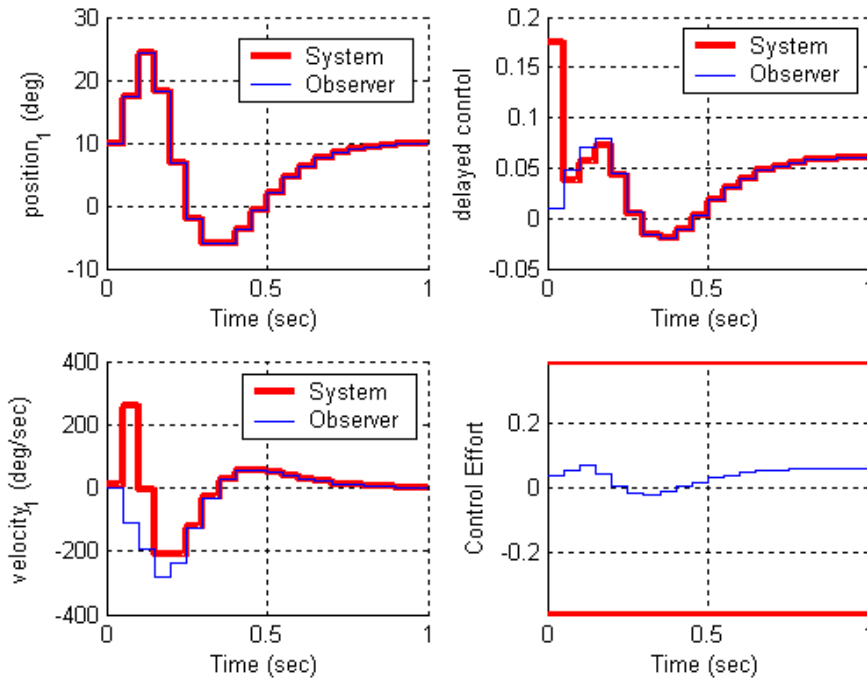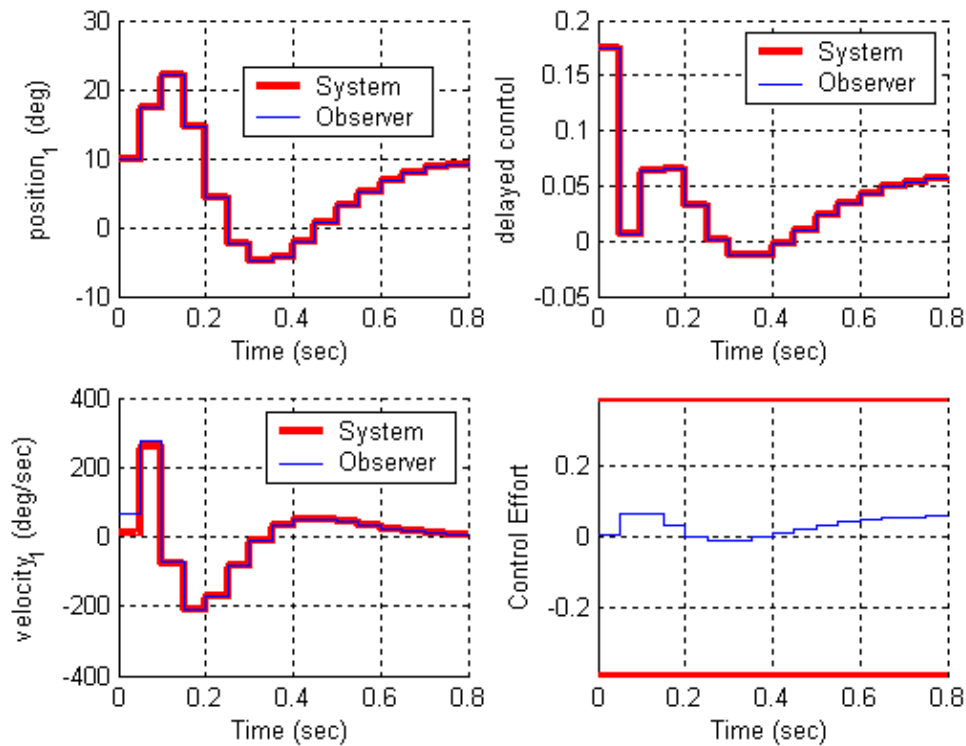

Figure 4. Results for problem **2b**.

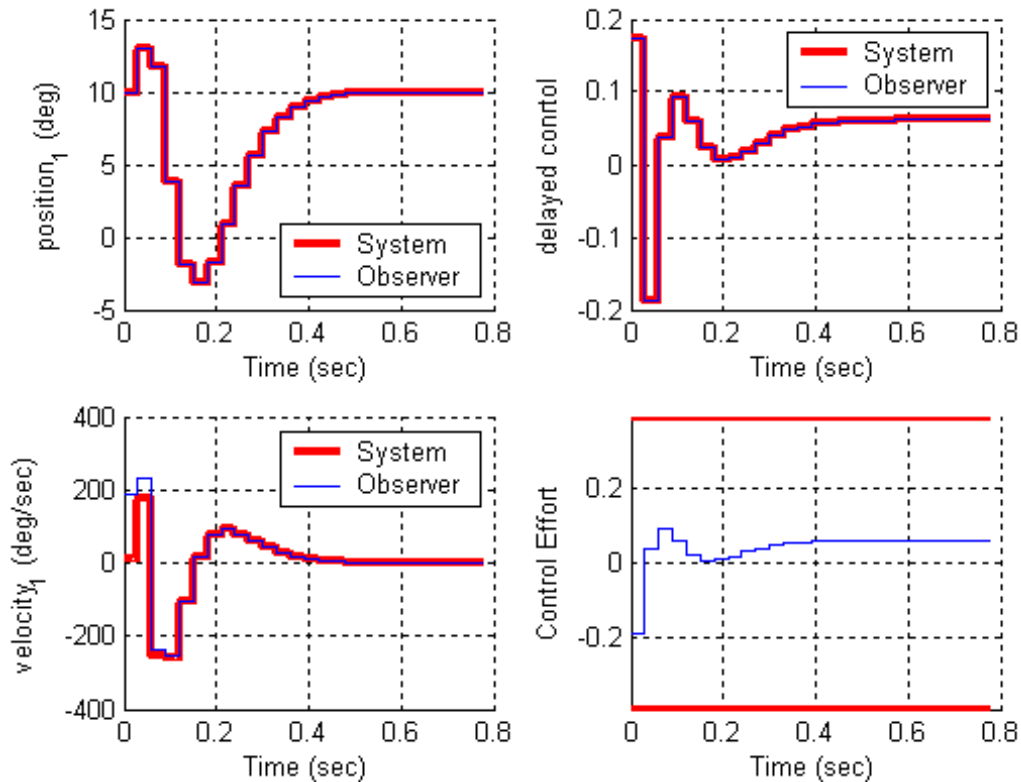Figure 5. Results for problem **2c**.

Figure 6. Results for problem **2d**.

3) Copy your program **DT_sv2_observer_driver.m** to **DT_sv2_min_obs_driver.m** You will need to modify the part of the code that determines the observer gains, and you will have to have the program call the simulation **DT_sv2_min_observer.mdl.** Copy the Simulink file **DT_sv2_observer.mdl** to **DT_sv2_min_observer.mdl .** Modify this _**new**_ file to implement state variable feedback using a minimum order observer to estimate the states for a one degree of freedom system. In addition, you will need to modify your code so that you can utilize different sampling rates.

Assume we want the state vector written as $\begin{bmatrix} x_2 & x_1 & \dot{x}_1 & \dot{x}_2 & u_d \end{bmatrix}^T$. You need to modify both G and H to reflect this new ordering. You also need to fix the demuxes in your Simulink file to reflect this new order.

b) Assume the only known state is the position of the second disk, and the output is the position of the first disk. Use a sampling interval of 0.05 seconds, assume all the state feedback poles are at 0.5, and the observer poles are at [0.01 0.015 0.02 0.025]. Also assume the system initially starts with disk 2 at zero degrees, disk 1 at 5 degrees, and both disks with an initial velocity of 5 degrees/sec (be careful of units here! The model works in radians.). The initial estimate of the delayed input signal is zero. The initial estimates of the observer are zero. For a 10 degree step input you should get the graph shown in Figure 7. Turn in your plot.

c) Same conditions as in **b**, but assume the output is the position of the second disk. For a 10 degree step input you should get the graph shown in Figure 8. Turn in your plot.

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d) Same conditions as **b,** but now the positions of both disk 1 and disk 2 are known (the output is the position of the first disk). Place the state feedback poles all at 0.2 and the observer poles at [0.01 0.015 0.02]. For a 10 degree step input you should get the graph shown in Figure 9. Turn in your plot.
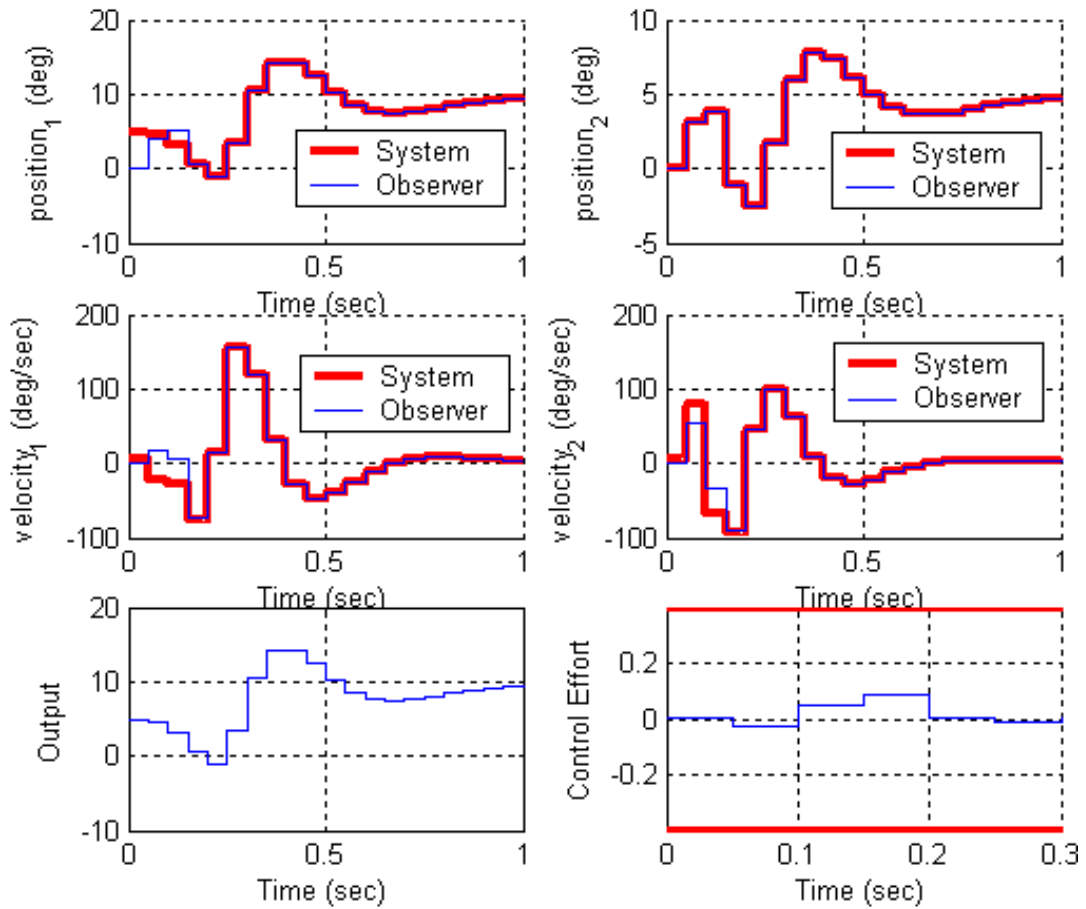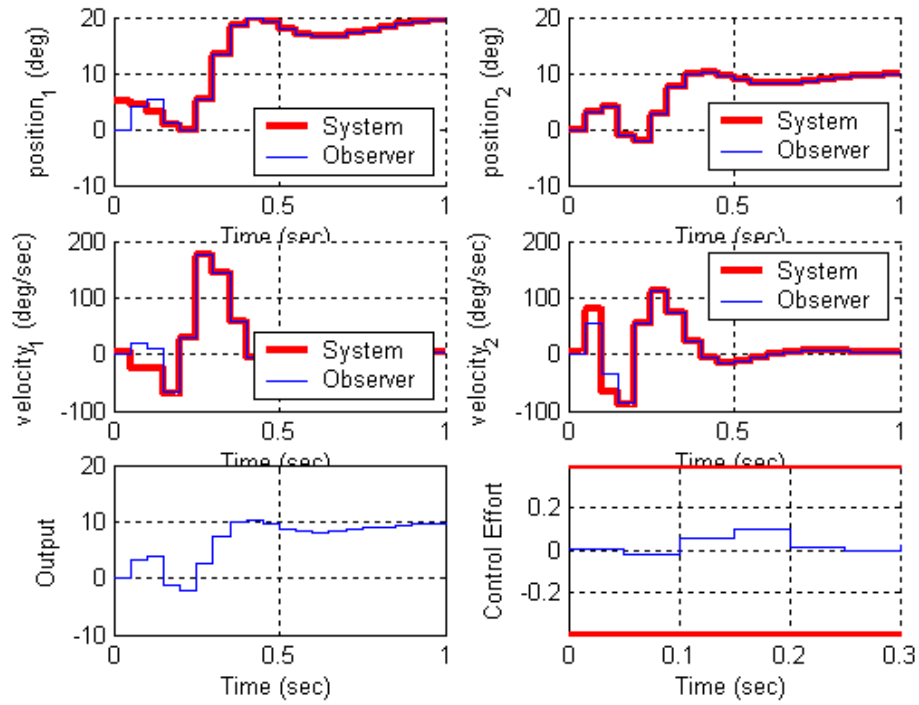

Figure 7. Results for problem **3b**.
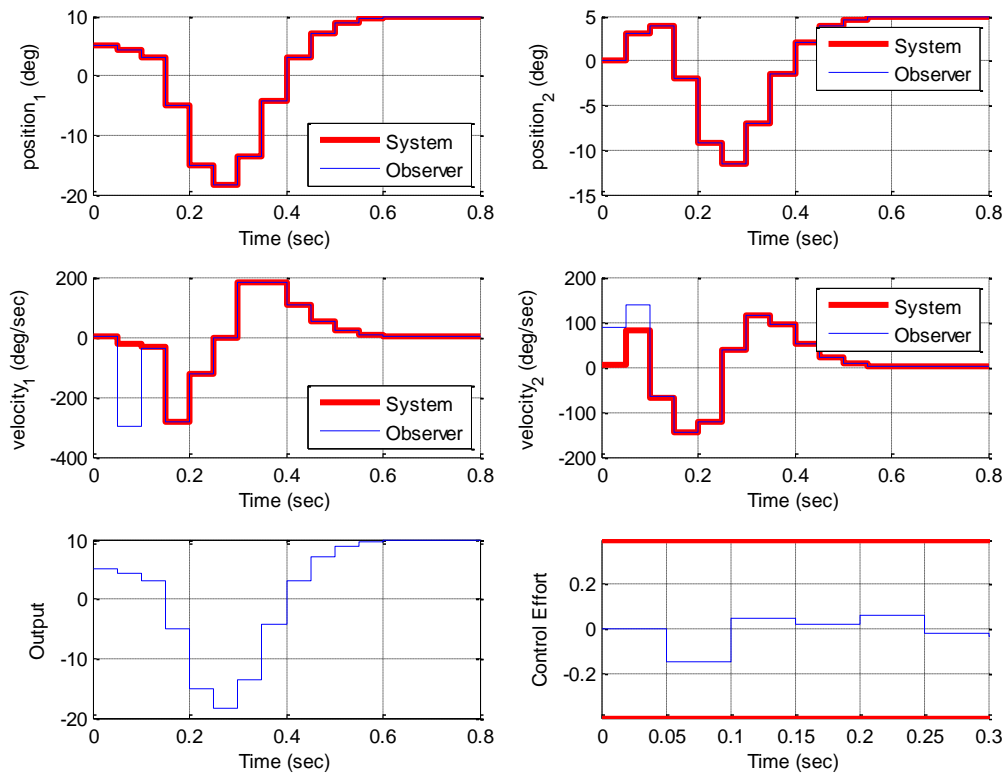
Figure 8. Results for problem **3c**.

Figure 9. Results for problem **3d**.

4) Now we want to combine the minimum observer and state feedback with integral control for the two degree of freedom system. Create a driver file **DT_sv2_min_obs_servo_driver.m** and a corresponding Simulink file **DT_sv2_min_obs_servo.mdl.** Modify this _**new**_ file to implement state variable feedback using a minimum order observer to estimate the states for a two degree of freedom system. In addition, you will need to modify your code so that you can utilize different sampling rates.

Assume we want the state vector written as $\begin{bmatrix} x_2 & x_1 & \dot{x}_1 & \dot{x}_2 & u_d \end{bmatrix}^T$. You need to modify both G and H to reflect this new ordering. You also need to fix the demuxes in your Simulink file to reflect this new order.

 b) Assume the only known state is the position of the second disk, and the output is the position of the first disk. Use a sampling interval of 0.05 seconds, assume all the state feedback poles are at 0.5, and the observer poles are at [0.01 0.015 0.02 0.025]. Also assume the system initially starts with disk 2 at zero degrees, disk 1 at 5 degrees, and both disks with an initial velocity of 5 degrees/sec (be careful of units here! The model works in radians.). The initial delayed input is assumed to be 0. The initial estimates of the observer are zero. For a 10 degree step input you should get the graph shown in Figure 10. Turn in your plot.

c) Same conditions as in **b**, but assume the output is the position of the second disk. For a 10 degree step input you should get the graph shown in Figure 11. Turn in your plot.

d) Same conditions as **b,** but now the positions of both disk 1 and disk 2 are known (the output is the position of the first disk). Place the state feedback poles all at 0.2 and the observer poles at [0.01 0.015 0.02]. For a 10 degree step input you should get the graph shown in Figure 12. Turn in your plot.
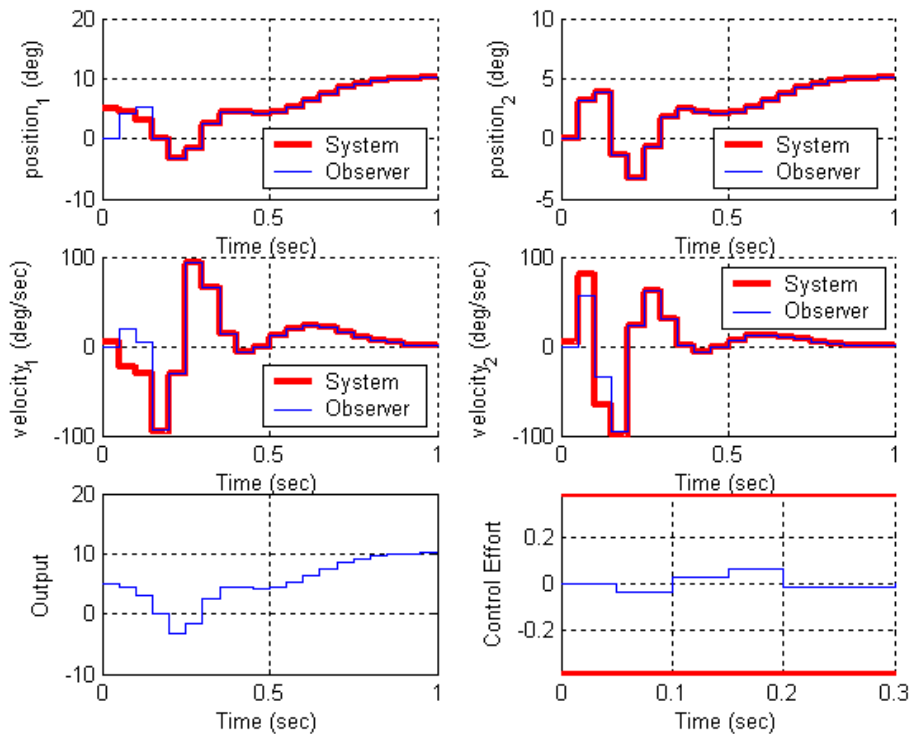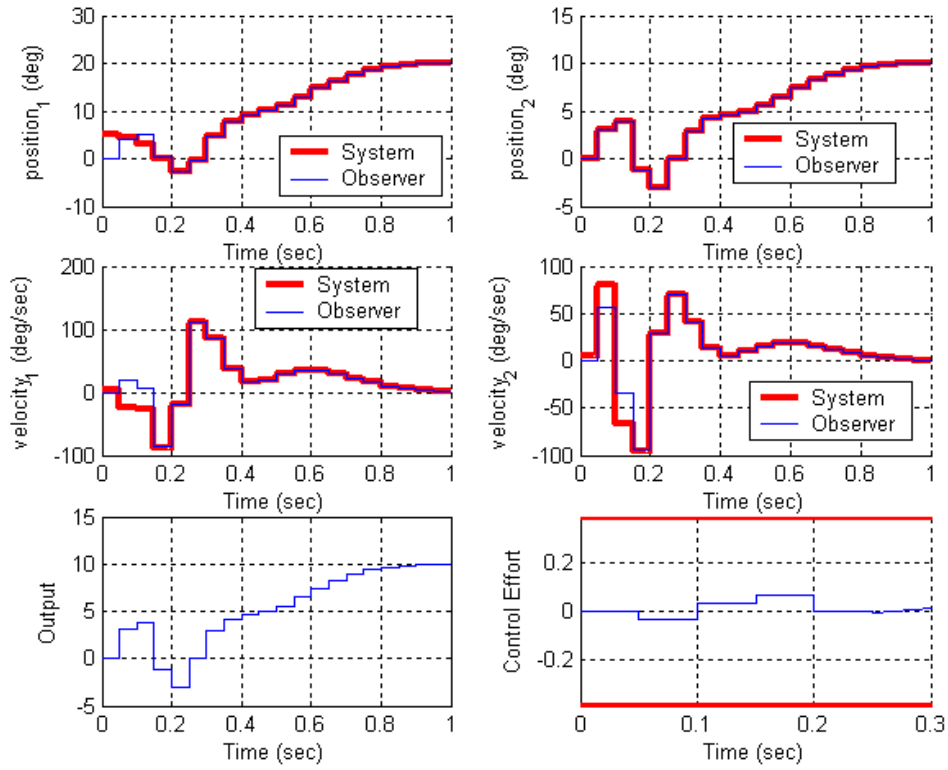

Figure 10. Results for problem **4b**.
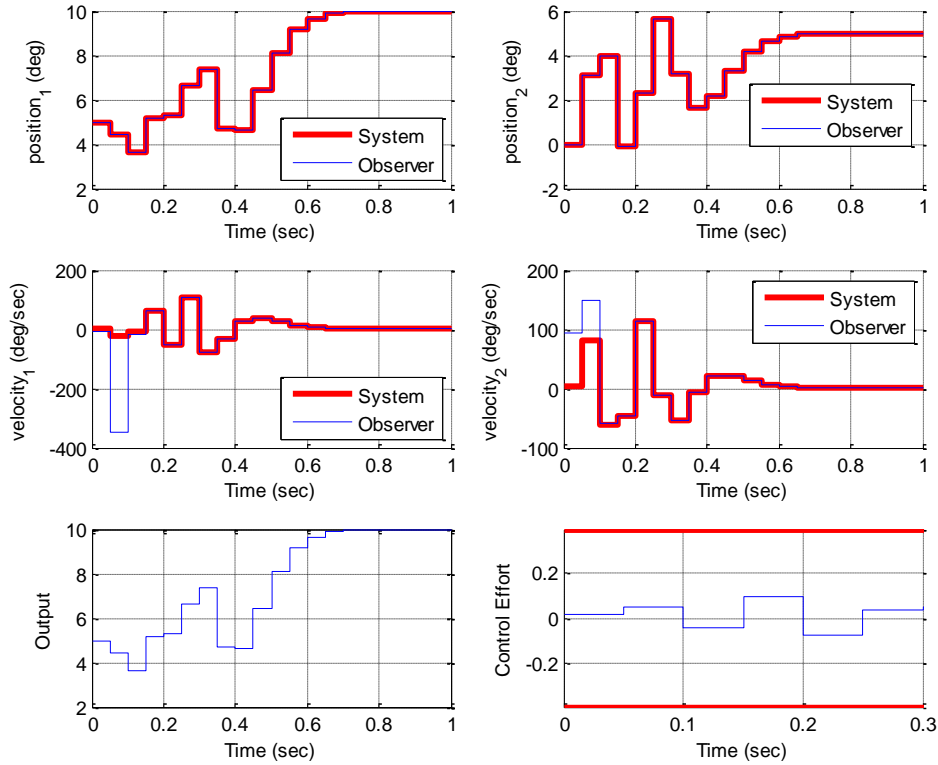
Figure 11. Results for problem **4c**.

Figure 12. Results for problem **4d**.

For the remainder of the problems on this homework, use the optimal tracking programs available on the class website

5a) For the 1 degree of freedom torsional system, using time varying feedback gains and $Q = 0.01$, $R = 0.1$, and $Q_f = 0.05$, for a 10 degree step input, you should get the output shown in Figure 15.

5b) Modify Q, R, and Q_f so $|r(N) - y(N)| < 0.5$ and the control effort does not saturate. Turn in your plot with your values of the weights you used.

5c) Modify Q, R, and Q_f so $|r(N) - y(N)| < 0.5$ and $|r(k) - y(k)| < 0.4$ over 75% of the time. Turn in your plot with your values of the weights you used.

5d) Modify the program to use constant feedback gains (uncomment lines 88 and 89) and repeat problems 5b and 5c. Turn in your plots with your values of the weights you used.

5e) Change the signal we want to track to $r(k) = 15^o \sin(10\pi k \Delta T)$, modify Q, R, and Q_f so the system tracks the reference signal reasonably well using constant feedback gains. You should note that the feedforward control signal leads the signal we want to track. Turn in your plots with your values of the weights you used.
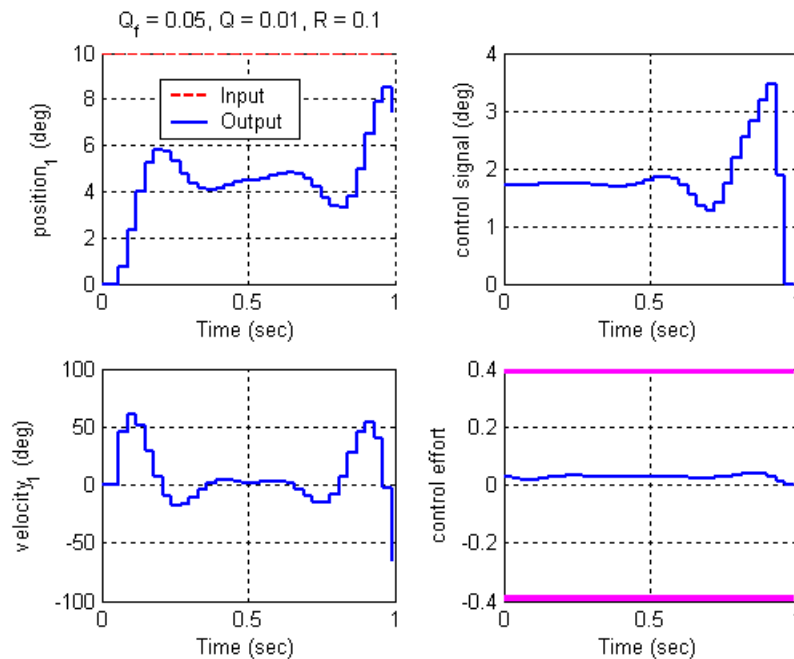

Figure 15. Results for Problem **5a.**

6a) For the 2 degree of freedom torsional system, controlling the position of the **second** disk, using time varying feedback gains and $Q = 0.01$, $R = 0.1$, and $Q_f = 0.05$, for a 10 degree step input, you should get the output shown in Figure 16.

6b) Modify Q, R, and Q_f so $|r(N) - y(N)| < 0.5$ and the control effort does not saturate. Turn in your plot with your values of the weights you used.

6c) Modify Q, R, and Q_f so $|r(N) - y(N)| < 0.5$ and $|r(k) - y(k)| < 1$ over 75% of the time. Turn in your plot with your values of the weights you used.

6d) Modify the program to use constant feedback gains (uncomment lines 91 and 92) and repeat problems 6b and 6c. Turn in your plots with your values of the weights you used.

6e) Change the signal we want to track to $r(k) = 15^o \sin(10\pi k\Delta T)$, modify Q, R, and Q_f so the system tracks the reference signal reasonably well using constant feedback gains. You should note that the feedforward control signal leads the signal we want to track. Turn in your plots with your values of the weights you used.
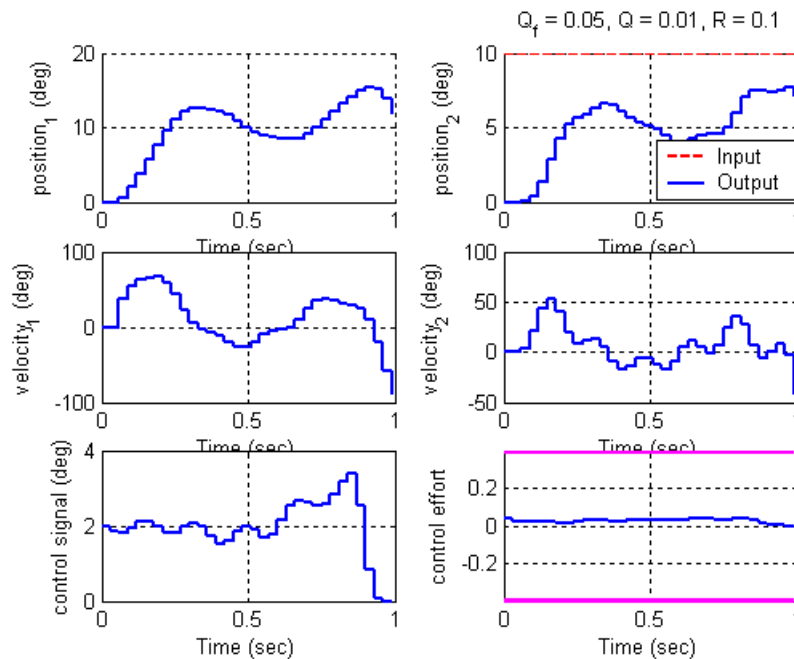

Figure 16. Results for Problem **6a.**

7a) For the 2 degree of freedom torsional system, controlling the position of the **first** disk, using time varying feedback gains and $Q=0.01$, $R=0.1$, and $Q_f=0.05$, for a 10 degree step input, you should get the output shown in Figure 17.

7b) Modify Q, R, and Q_f so $|r(N)-y(N)|<0.5$ and the control effort does not saturate. Turn in your plot with your values of the weights you used.

7c) Modify Q, R, and Q_f so $|r(N)-y(N)|<0.5$ and $|r(k)-y(k)|<1$ over 75% of the time. Turn in your plot with your values of the weights you used.

7d) Modify the program to use constant feedback gains (uncomment lines 91 and 92) and repeat problems 7b and 7c. Turn in your plots with your values of the weights you used.

7e) Change the signal we want to track to $r(k)=15^o\sin(10\pi k\Delta T)$, modify Q, R, and Q_f so the system tracks the reference signal reasonably well using constant feedback gains. You should note that the feedforward control signal leads the signal we want to track. Turn in your plots with your values of the weights you used.
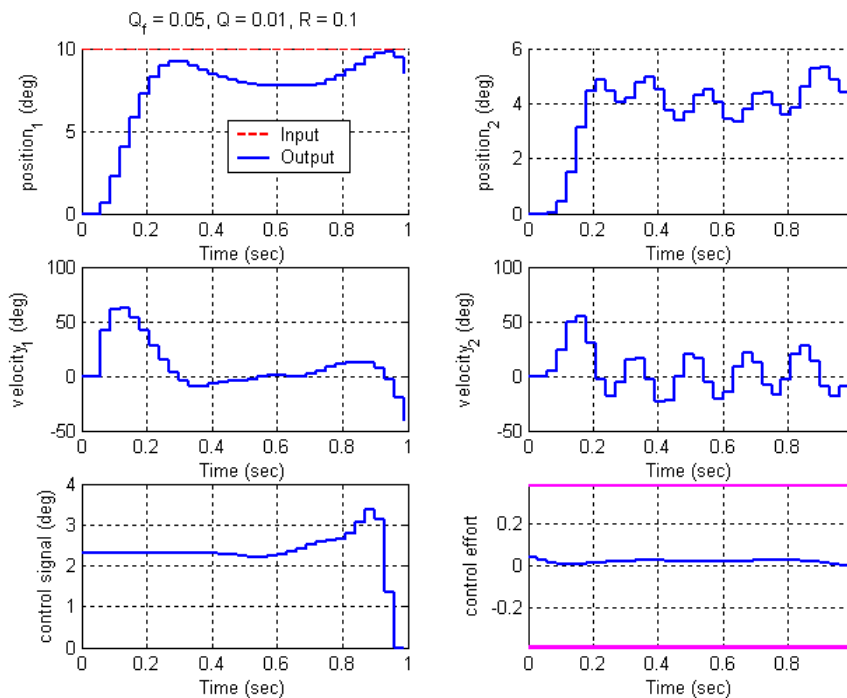

Figure 17. Results for Problem **7a.**