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Indian Institute of Technology Kanpur
CS637 Embedded and Cyber-Physical Systems
Homework Assignment 1
Deadline: August 19, 2022

Total: **40 marks**

Problem 1. (20 points) Problem 7 in the Exercises of Chapter 2 in [LS15].
[LS15] Edward A. Lee and Sanjit A. Seshia, Introduction to Embedded Systems, A Cyber-Physical Systems Approach, Second Edition, http://LeeSeshia.org, ISBN 978-1-312-42740-2, 2015.

The following was done on SimuLink.

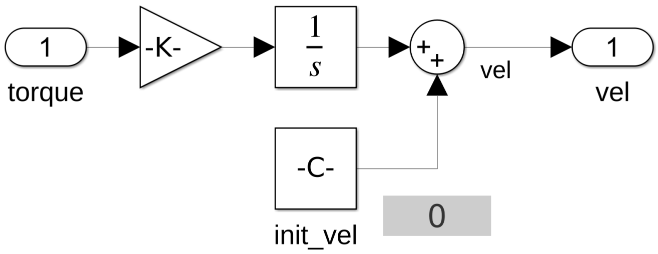

Figure 1: Simplified Helicopter plant transferring torque applied to angular velocity about y

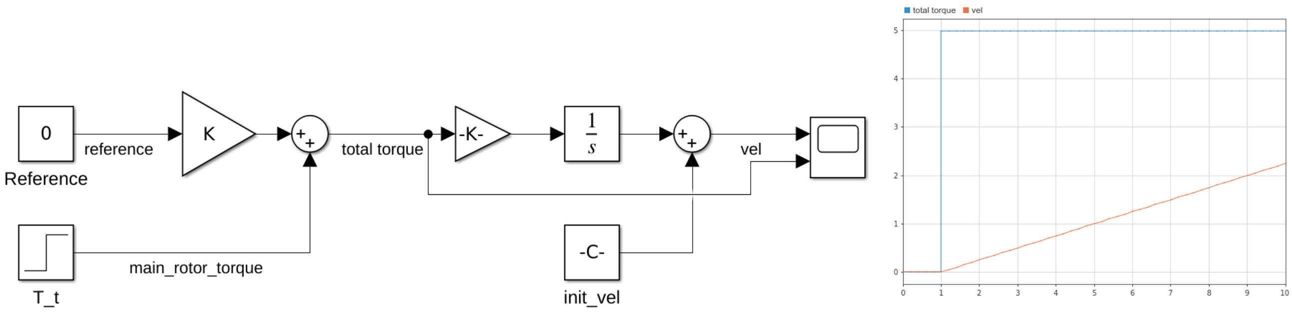

Figure 2: Block diagram and response of open loop system

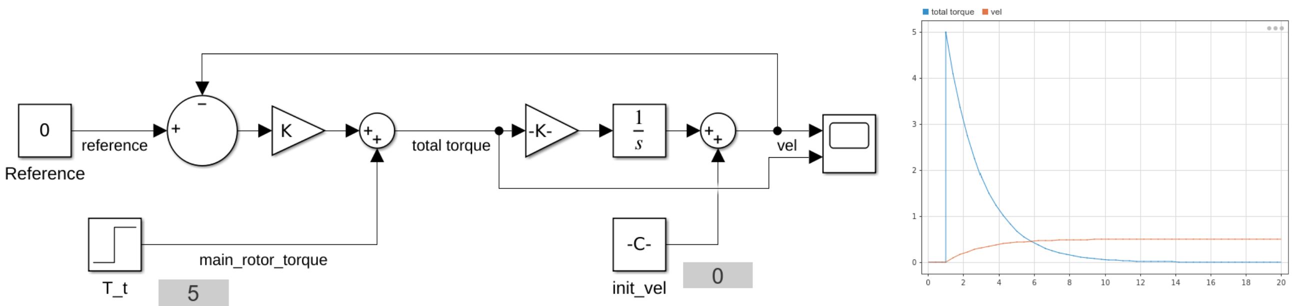

Figure 3: Block diagram and response of closed loop system

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Part (a)

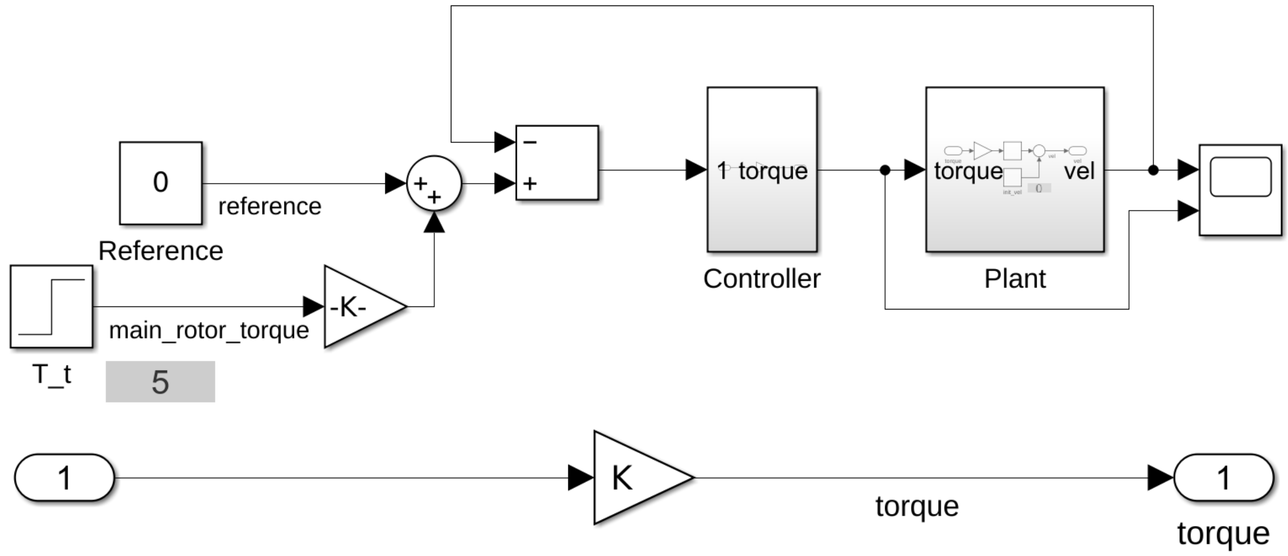
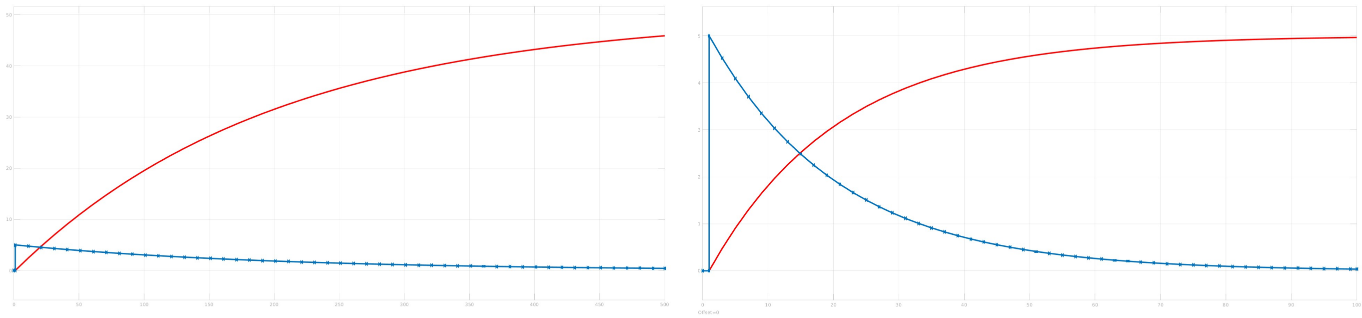
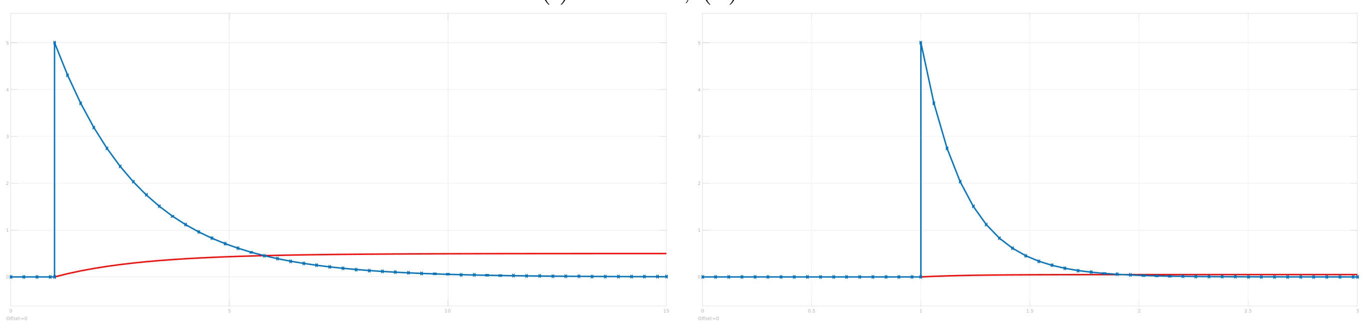


Figure 4: Proportional Control System Block Diagram (above)
Proportional Controller (below)



(i) $K = 0.1$, (ii) $K = 1$



(iii) $K = 10$ (iv) $K = 100$

Figure 5: Response with P controller. Total Torque (blue) and Angular Velocity (red)

Part (b)

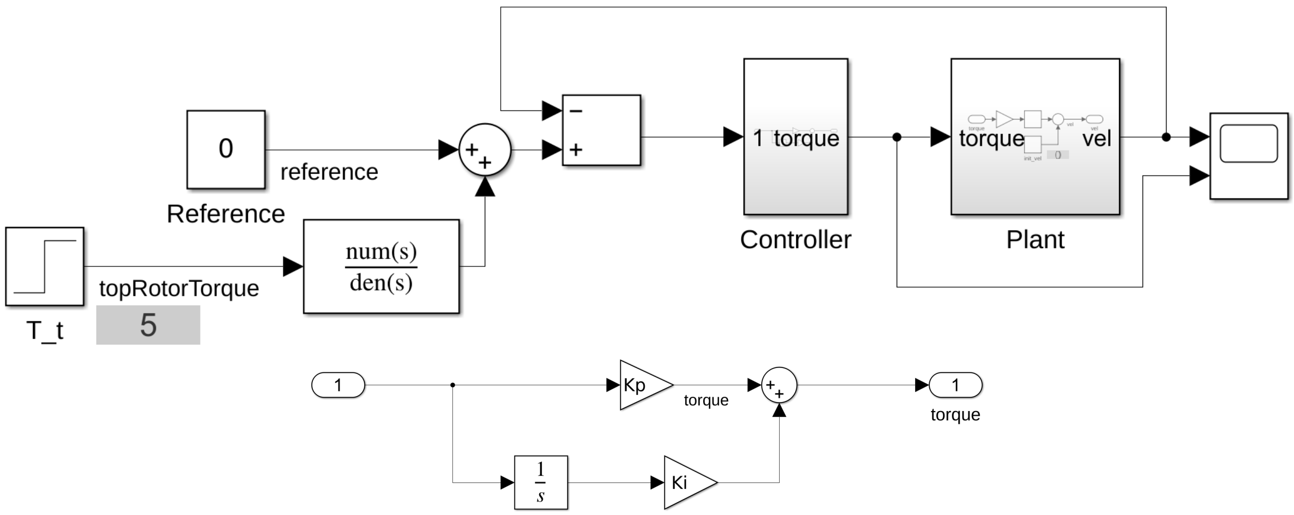
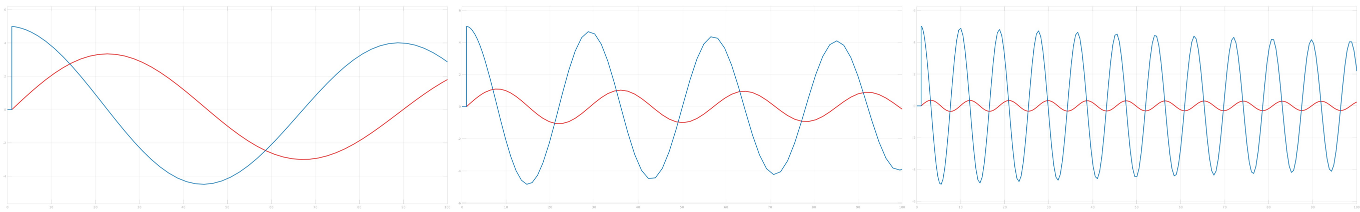
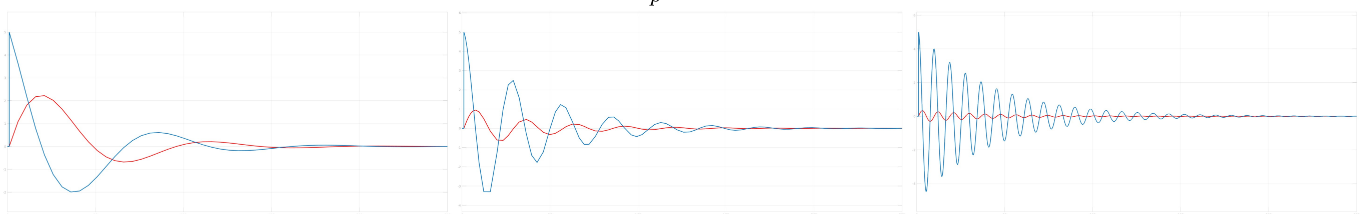


Figure 6: PI Control System Block Diagram (above)
PI Controller (below)

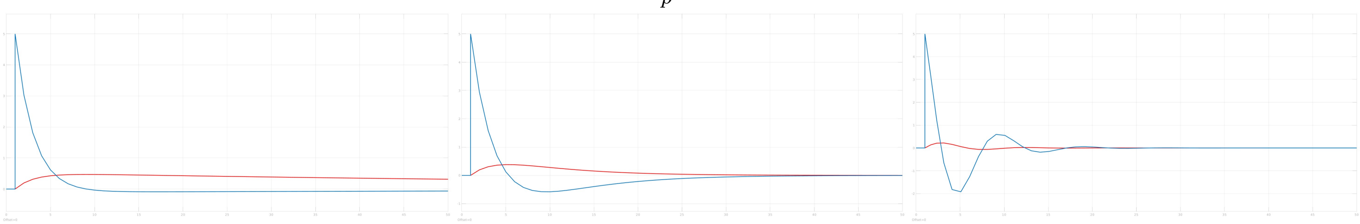
Transfer function used in front of Top rotor torque is $\frac{s}{K_p s + K_i}$.



(i) $K_i = 0.1$ (ii) $K_i = 1$, (iii) $K_i = 10$
$K_p = 0.1$



(i) $K_i = 0.1$ (ii) $K_i = 1$, (iii) $K_i = 10$
$K_p = 1$



(i) $K_i = 0.1$ (ii) $K_i = 1$, (iii) $K_i = 10$
$K_p = 10$

Figure 7: Response with PI controller. Total Torque (blue) and Angular Velocity (red)

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Problem 2. (10 points) Problem 2 in the Exercises of Chapter 3 in [LS15].

LS15
Edward A. Lee and Sanjit A. Seshia, Introduction to Embedded Systems, A Cyber-Physical Systems Approach, Second Edition, http://LeeSeshia.org, ISBN 978-1-312-42740-2, 2015.

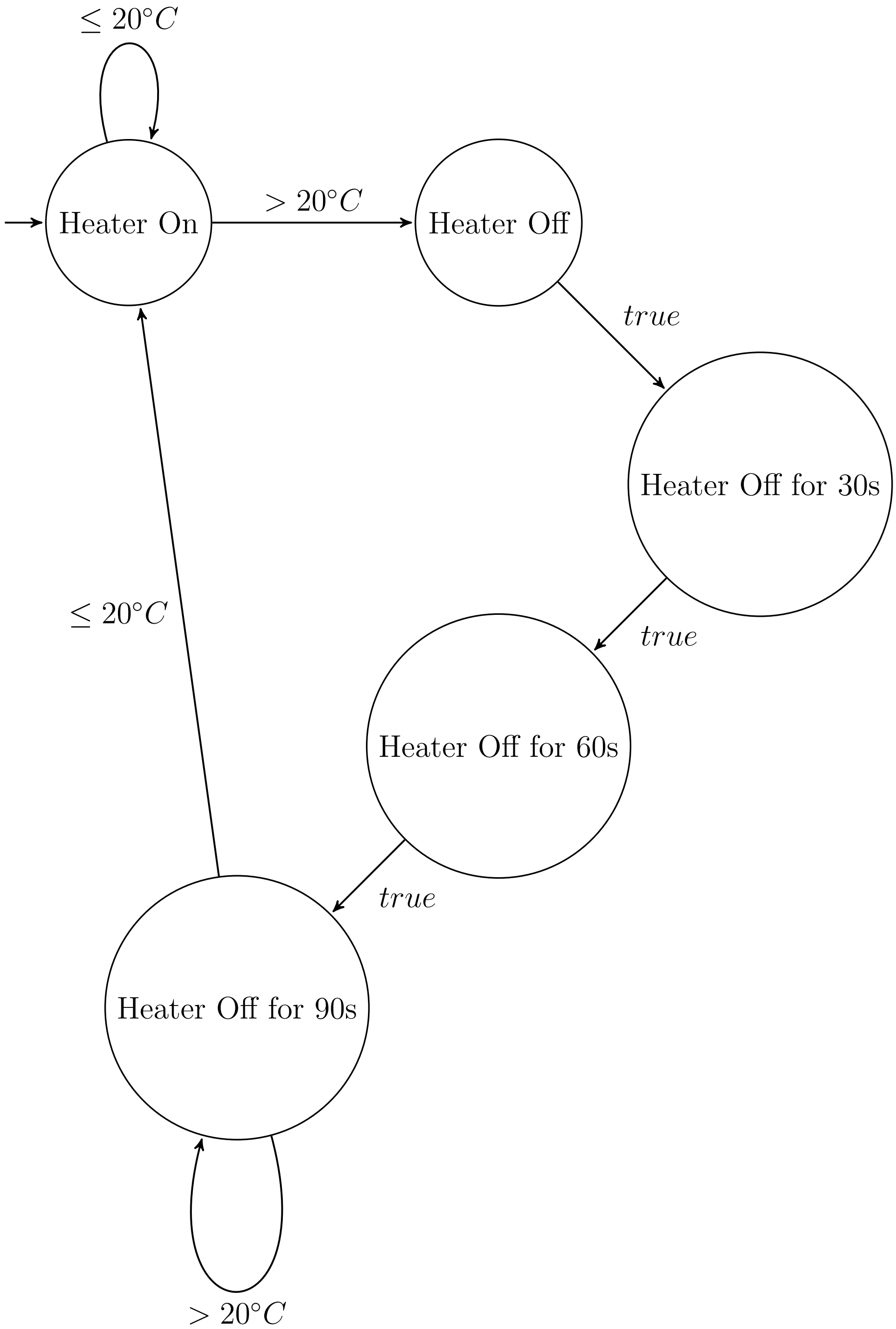

Figure 8: FSM for heater-only Thermostat

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Indian Institute of Technology Kanpur
CS637 Embedded and Cyber-Physical Systems
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(b) Note that the thermostat must remain on one state at least 30 seconds according to the given constraint.
The above designed thermostat has 5 states. It covers all valid configurations described in the problem statement including

1. Heater must remain ON for at least 30 seconds - This always happens because every transition is followed by a delay of 30 seconds.

2. Heater must remain OFF for at least 60 seconds - A heater would be OFF at least for 30 seconds implicitly from the above logic. Now to keep track of it being off for 3 more cycles, we must include 3 more states. At the end of the last state, i.e. "Heater Off for 90s", 120 seconds have passed for the next query to initialise.

Therefore this is the minimum number of states for this FSM.

(c) Yes, this model does have time-scale invariance property. Suppose the time scale of the system is reduced from by $\frac{1}{a}$, resulting in reaction time reducing to $\frac{30}{a}$ seconds. Therefore each output would be sent out in $\frac{30}{a}$ seconds as well.

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CS637 Embedded and Cyber-Physical Systems
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CS637 Embedded and Cyber-Physical Systems
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Problem 3. (10 points) The states of the linearized model of a vehicle steering system represent the lateral deviation of the vehicle from the x-axis and the angle between the vehicle axis and the x-axis. The output of the linearized model is only the first state. Construct a Simulink model for the vehicle steering system with its controller that includes an observer. The dynamics are available in Example 6.4 and Example 7.3 in [AM09]. Apply a sinusoidal signal as the reference trajectory that specifies the desired deviation of the vehicle from the x-axis with time. Plot the output (lateral deviation of the vehicle from the x-axis) with time.
[AM09] K. J. Astrom and R. M. Murray. Feedback Systems: An Introduction for Scientists and Engineers. Princeton University Press, 2009.

The following was simulated using SimuLink.

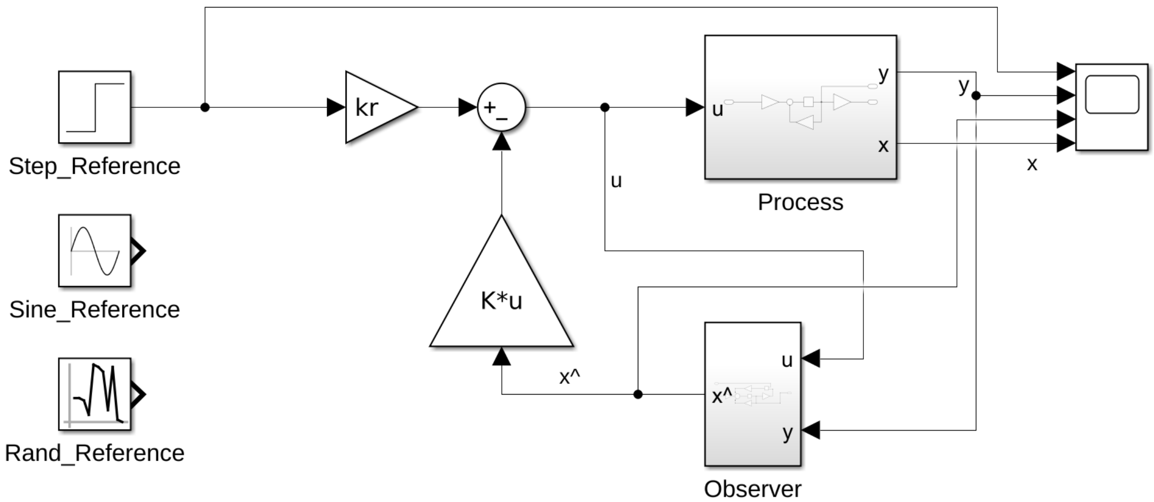


Figure 9: Block Diagram of Vehicle Control System

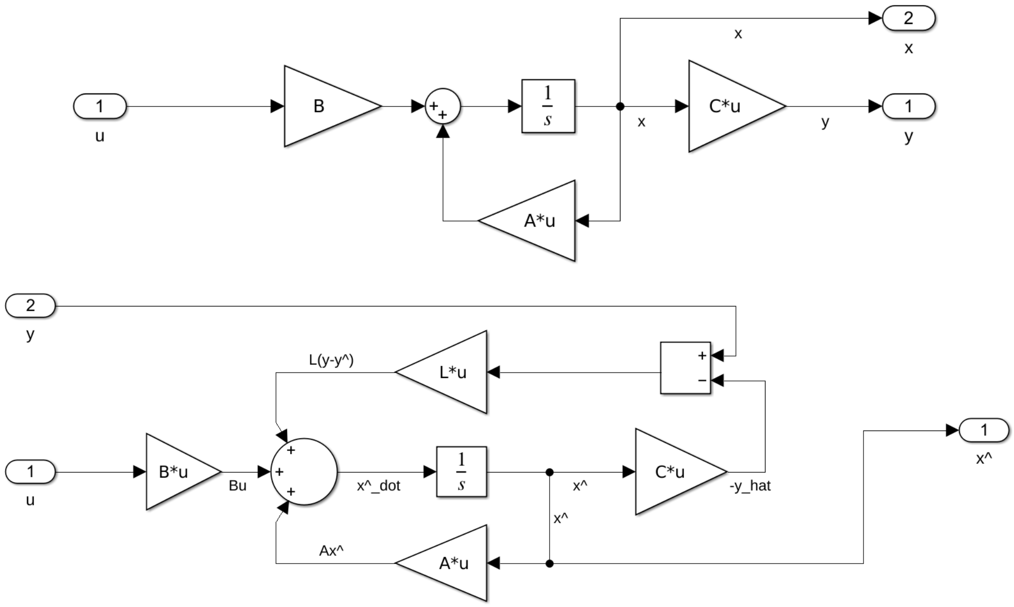
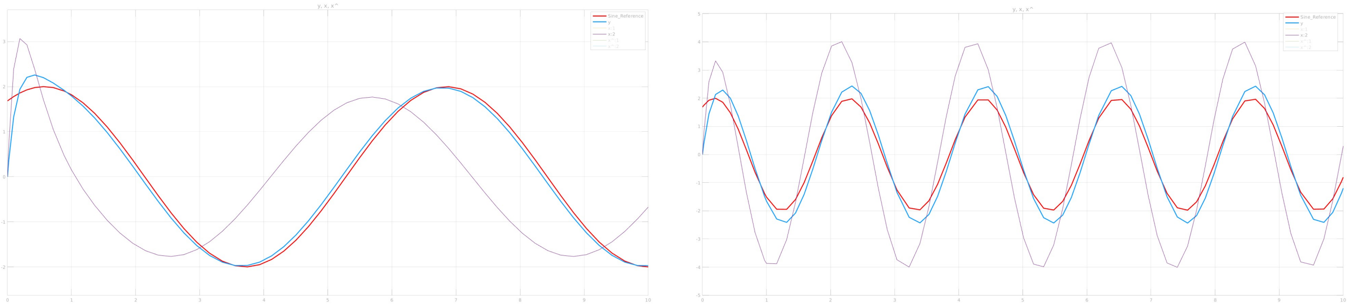


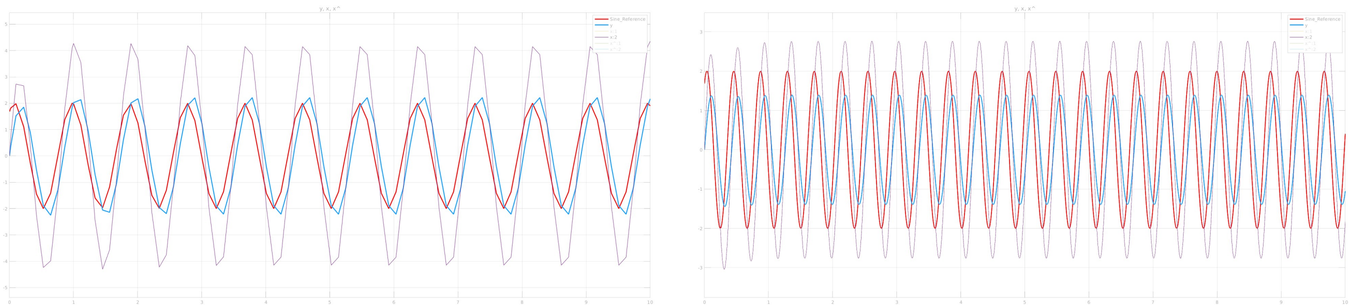
Figure 10: Process (above) and Observer (below)

Values used for state space and observer models:

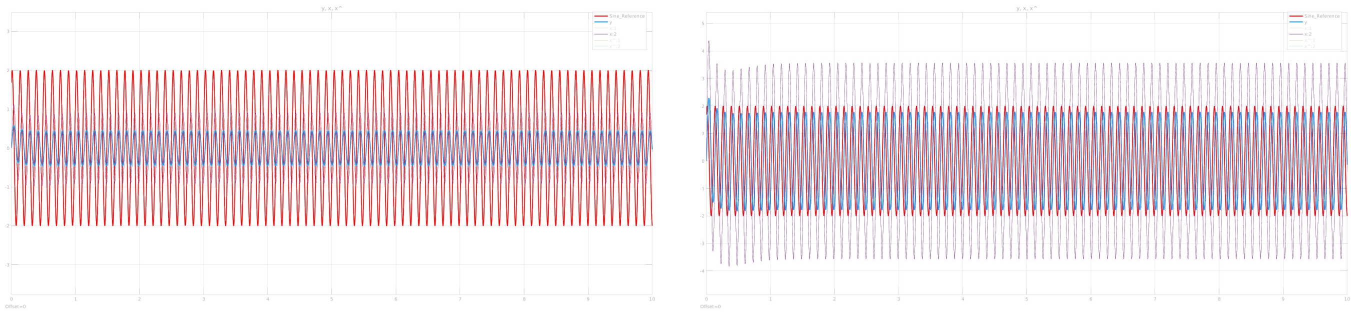
```
a = 0.5;
b = 1;
A = [0, 1; 0, 0];
B = [a/b; 1];
C = [1, 0];
D = 0;
P = [-5, -5];
% P = [-50, -50];
kr = 23;
% kr = 2300;
K = acker(A, B, P);
L = [100; 1000]; % from hit and trial
```



Freq (i) 1 Hz (ii) 3 Hz



Freq (i) 7 Hz (ii) 15 Hz



Freq (i) 50 Hz (ii) 50 Hz (kr = 90)

Figure 11: Response of lateral deviation (blue), Reference (red)

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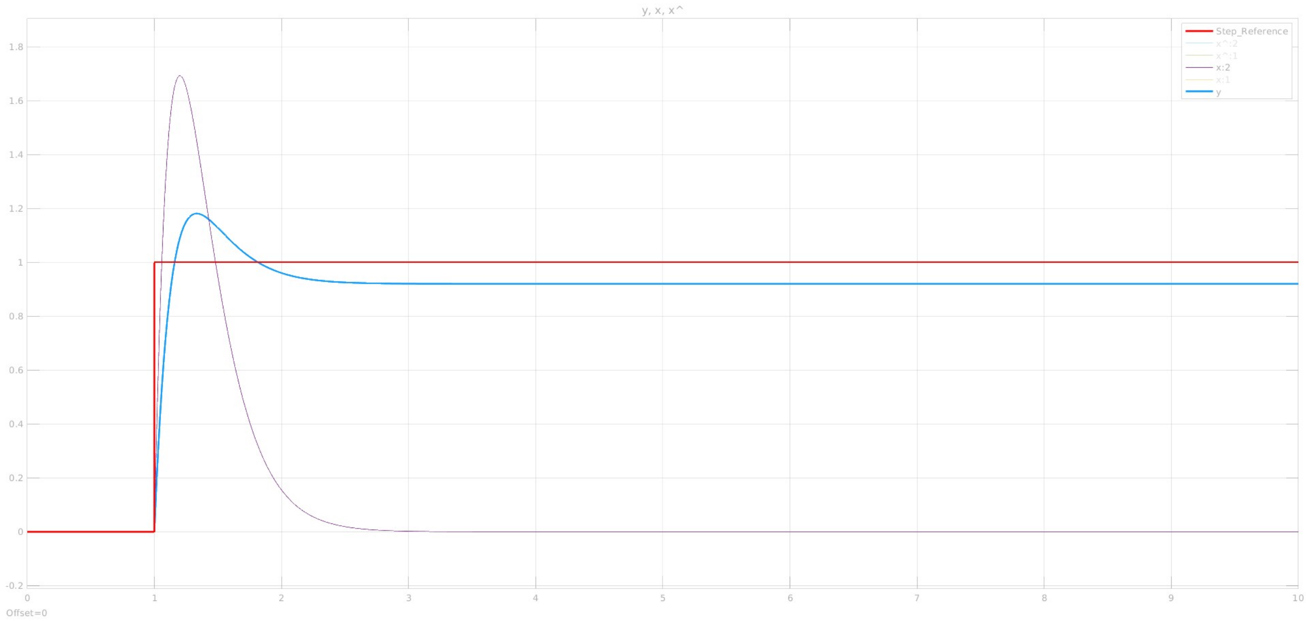
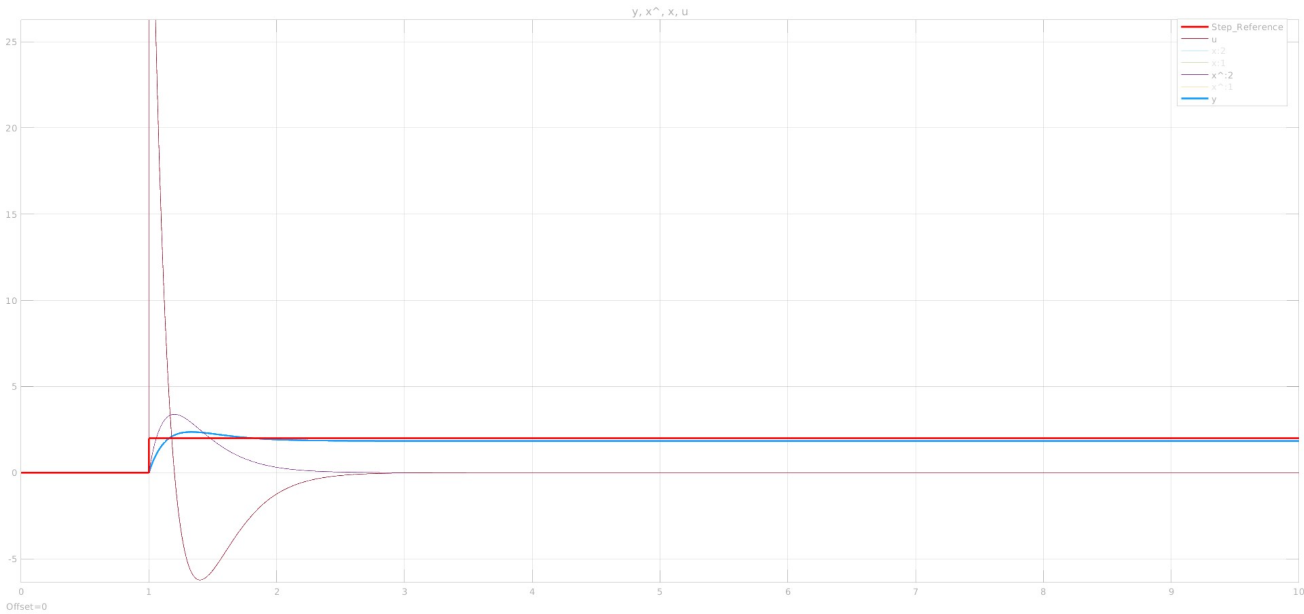
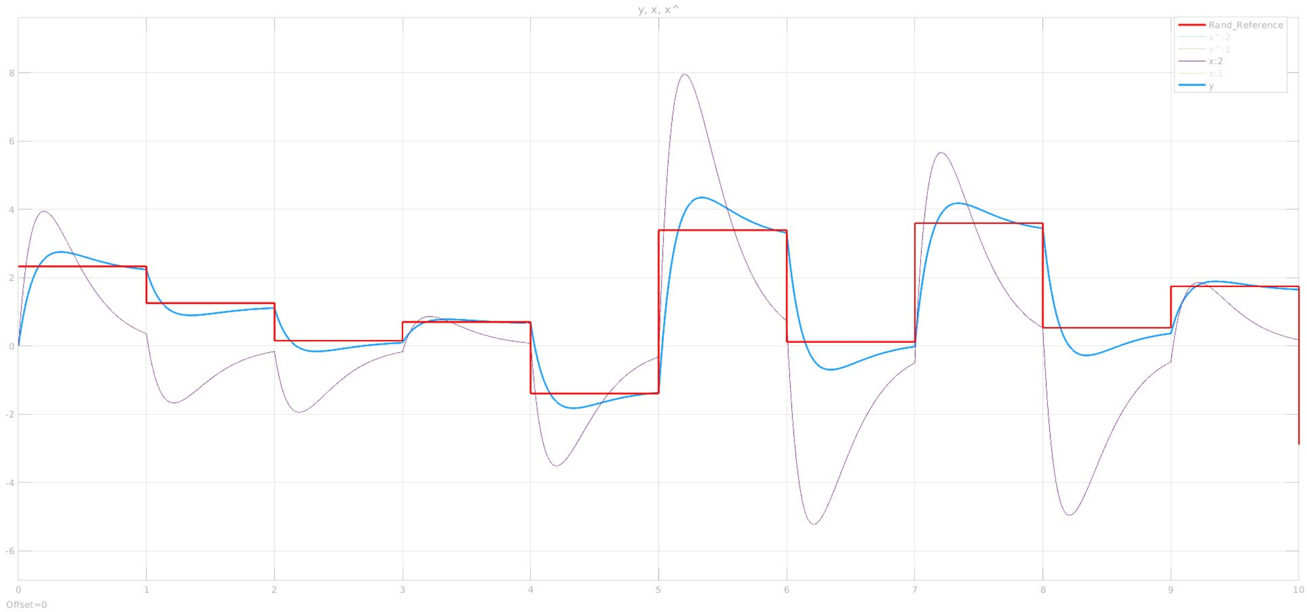


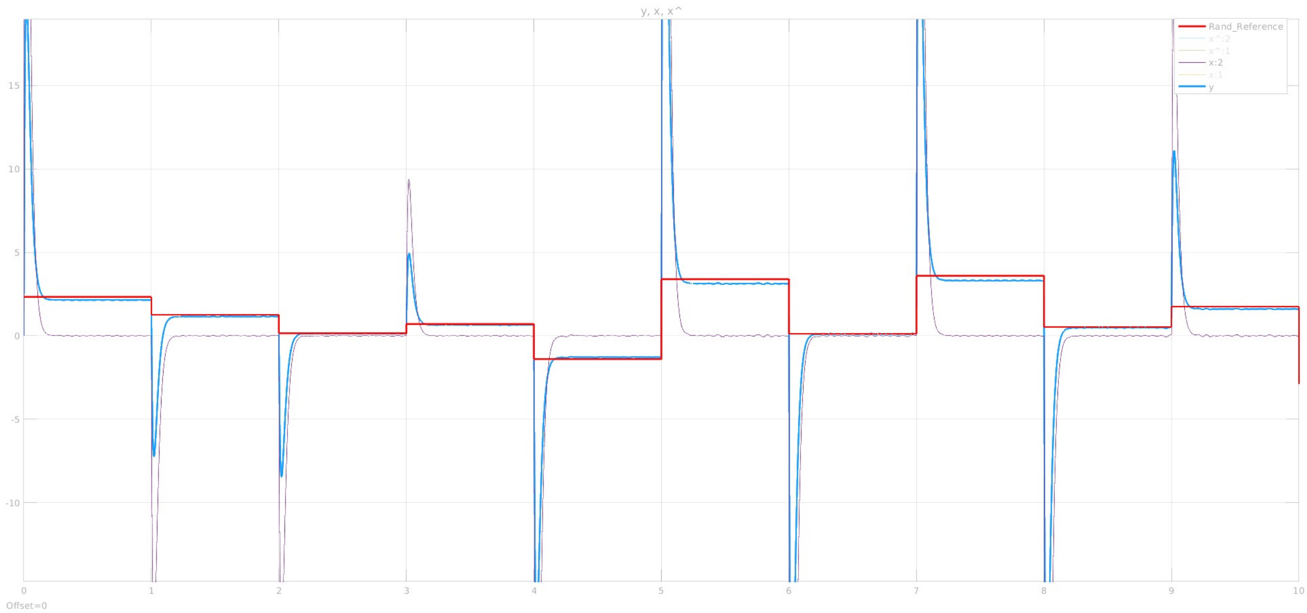
(i) Response to Step Input



(ii) Control signal shown



(i) Response to Random number reference



(ii) Response generated with more negative eigen values