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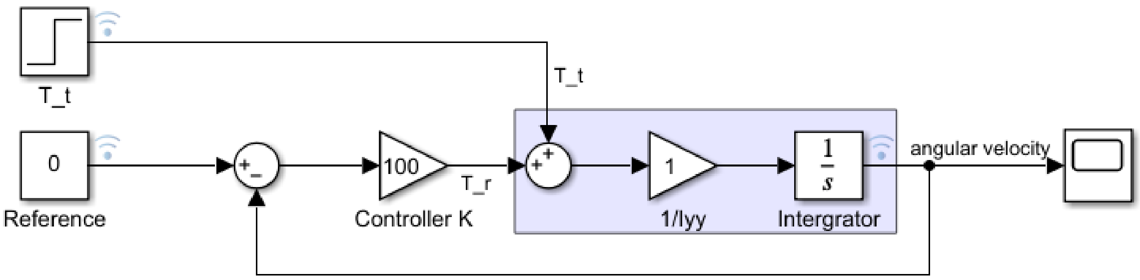
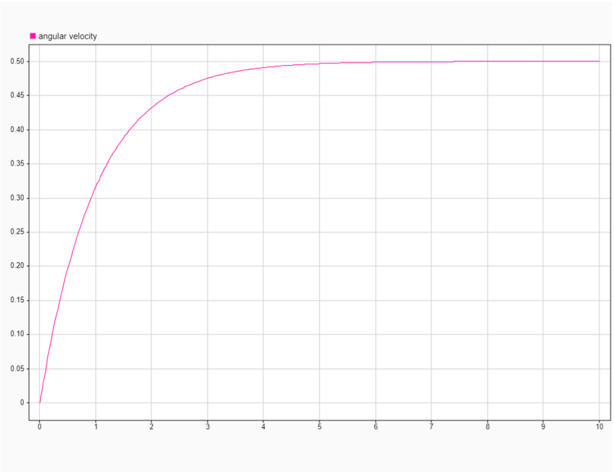
Total: **40 marks**

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.

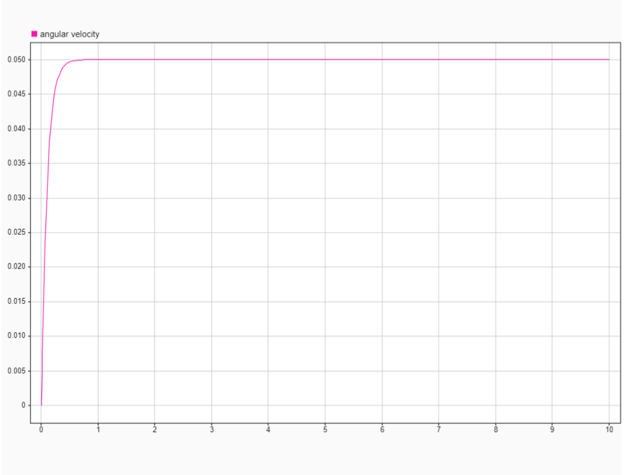
(a) Helicopter model with separately controlled torques for the top and tail rotors :



Plot of y for K=1 :



Plot of y for K=10 :



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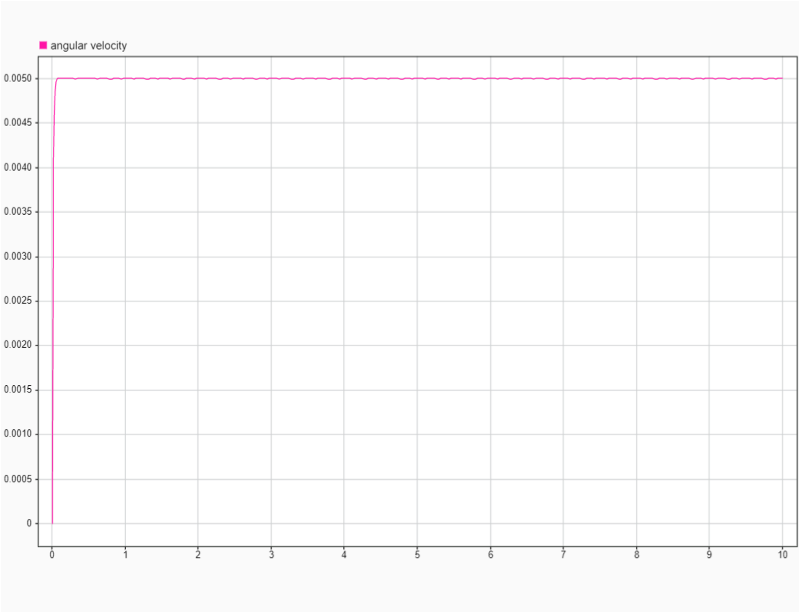
Plot for K=100 :



We see that the angular velocity soon stabilises at a constant value of 0.05 = 0.5/K when the controller gain is set to K = 10, and when the top-rotor torque is set at T_t(t) = 0.5u(t). The steady-state inaccuracy may be brought down to 0.005 if K is increased to 100. Due to the fact that the error in steady state occurs in the angular velocity, the angle of the helicopter gradually increases (i.e., the helicopter rotates despite a desired angular velocity of zero).

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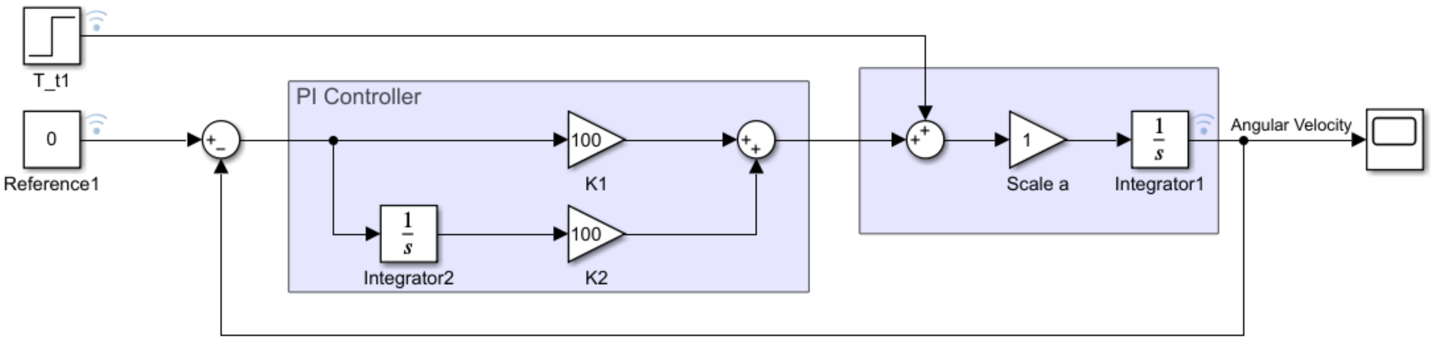
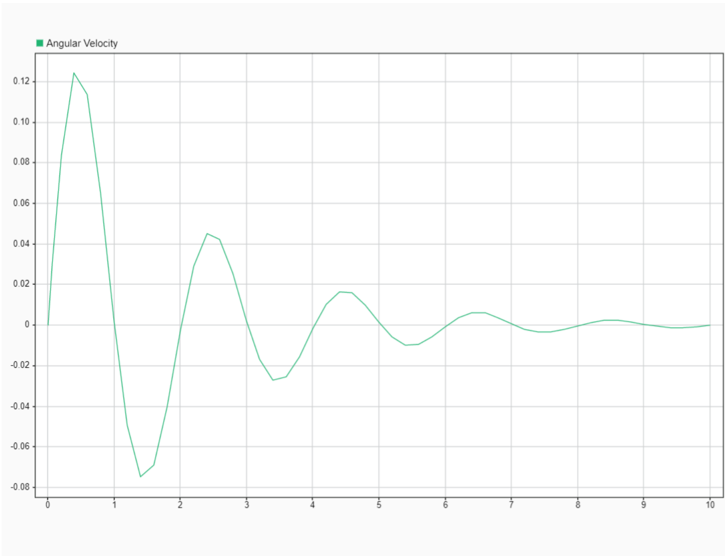
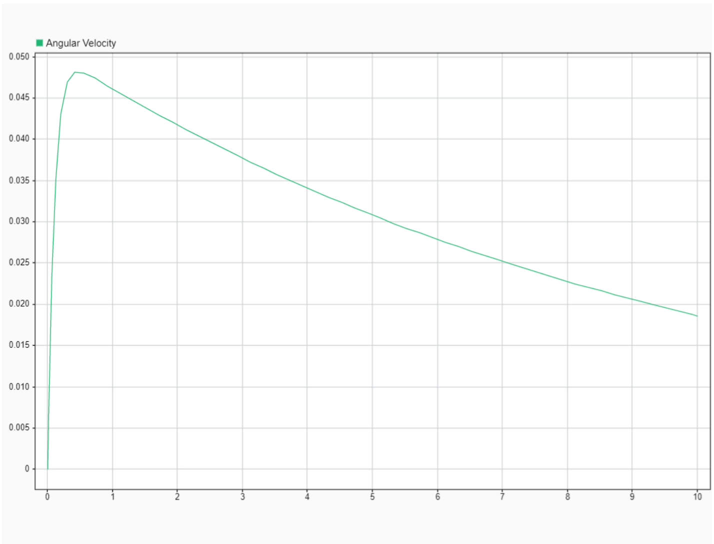
(b) Helicopter model with separately controlled torques for the top and tail rotors including a PI controller :



Plot for K1=1 and K2=10 :



Plot for K1=10 and K2=1 :



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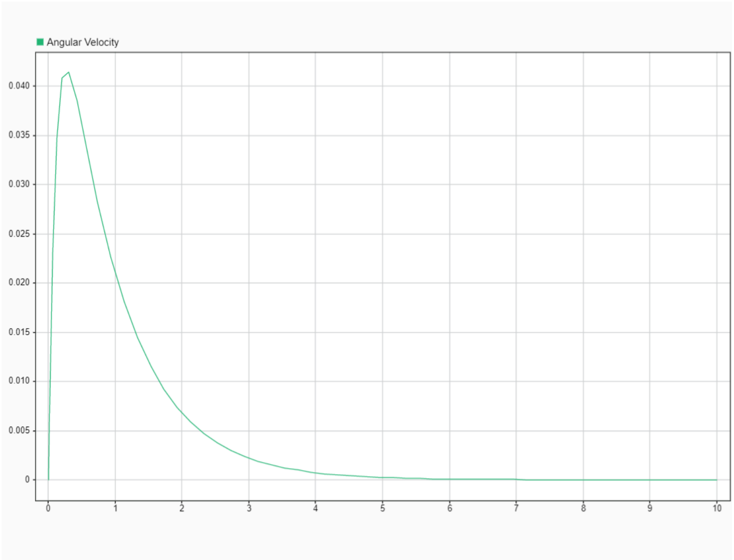
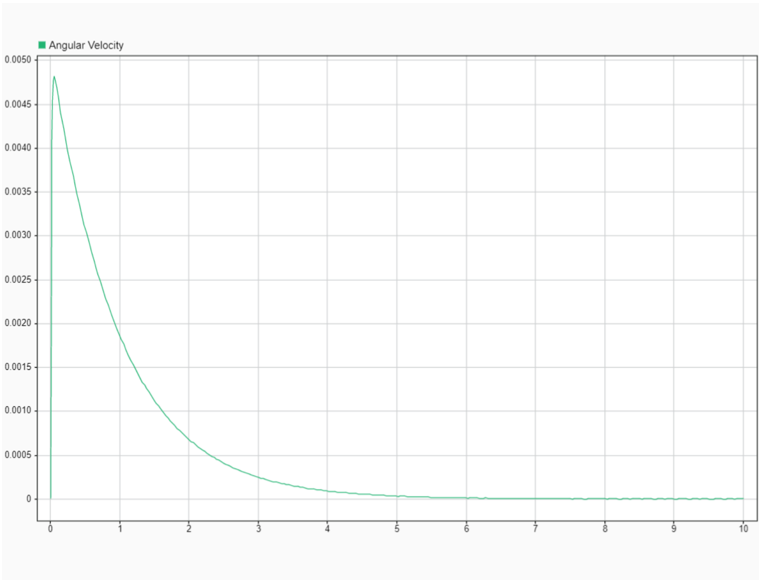
Plot for K1=10 and K2=10 :



Plot for K1=100 and K2=100 :



In this example, the controller gains are set to K1 = 100 and K2 = 100, and the top-rotor torque is set to T_t(t) = 0.5_u(t). As a result, the angular velocity will finally become zero. When the value of K1 is raised, the peak error is reduced. Increasing K2 causes the settling time to decrease, but it also causes some overshoot.

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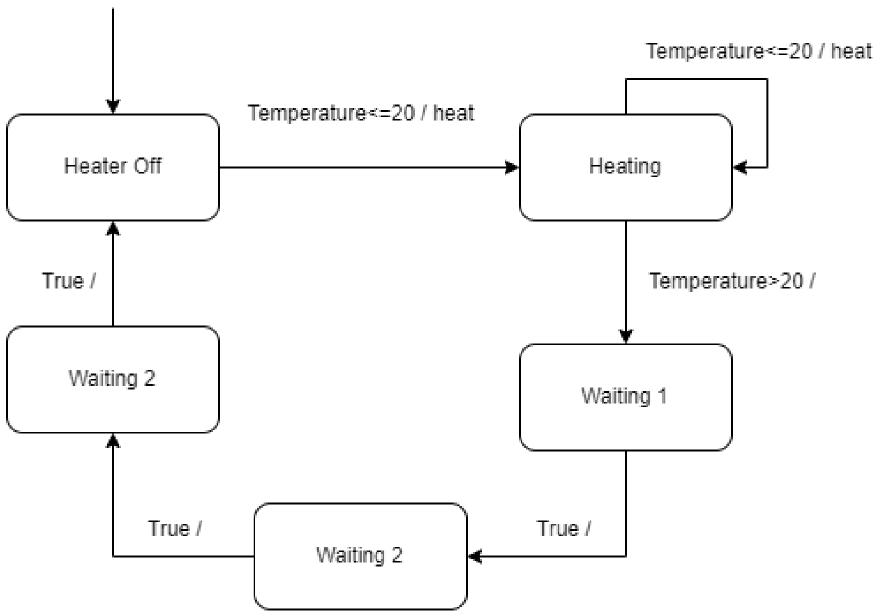
Problem 2. (10 points) Problem 2 in the Exercises of Chapter 3 in [LS15].
[LS15] Edward A. Lee and Sanjit A. Seshia, Introduction to Embedded Systems, A Cyber-Physical Systems Approach, Second Edition, http://LeeSeshia.org, ISBN 978-1-312-42740-2, 2015.

(a) We assume that it reacts exactly once every 30 seconds.



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(b) How many possible states does your thermostat have? Is this the smallest number of states possible?
Solution: The FSM has five states. I believe this is the minimum possible states in this model as we require the model to have a minimum reaction time of atleast 30 seconds.

(c) Does this model thermostat have the time-scale invariance property?
Solution: No, The model lacks the hysteresis attribute because the timeout is fixed, hence shifting the time scale of the input will result in various behaviour changes.

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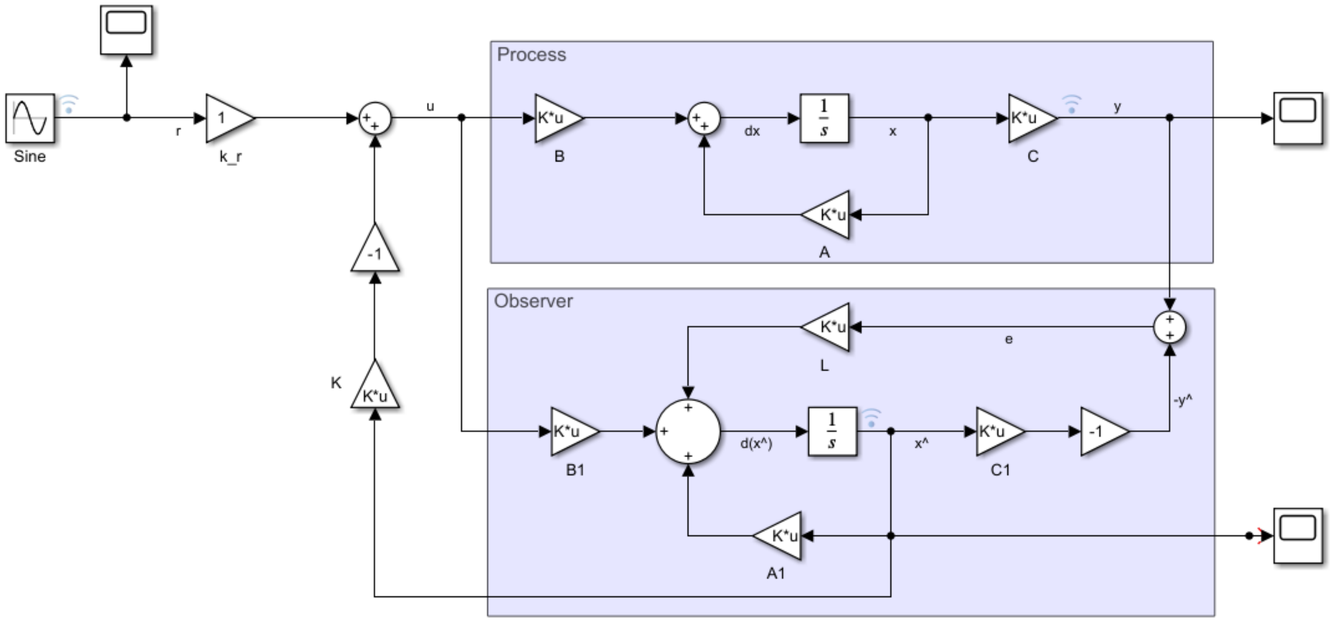
Problem 3. (10 points) The states of the linearized model of a vehicle steering system represent the lateral deviation of the vehicle from the x-axis and the angle between the vehicle axis and the x-axis. The output of the linearized model is only the first state. Construct a Simulink model for the vehicle 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.
http://www.cds.caltech.edu/ murray/books/AM08/pdf/am08-complete_22Feb09.pdf .

Model of Vehicle Steering System :



The following values were taken for the above model :

$$A = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix} \qquad B = \begin{bmatrix} 0.4 \\ 1 \end{bmatrix} \qquad C = \begin{bmatrix} 1 & 0 \end{bmatrix} \qquad D = 0$$

Using $p = \begin{bmatrix} -5 \\ -1 \end{bmatrix}$, we get the matrix $K = \begin{bmatrix} 5 & 4 \end{bmatrix}$ from $K = place(A, B, p)$ in MATLAB

Similarly, using $L = place(A', C', p).'$, we get the estimator gain L of Observer, where $L = \begin{bmatrix} 6 \\ 5 \end{bmatrix}$.

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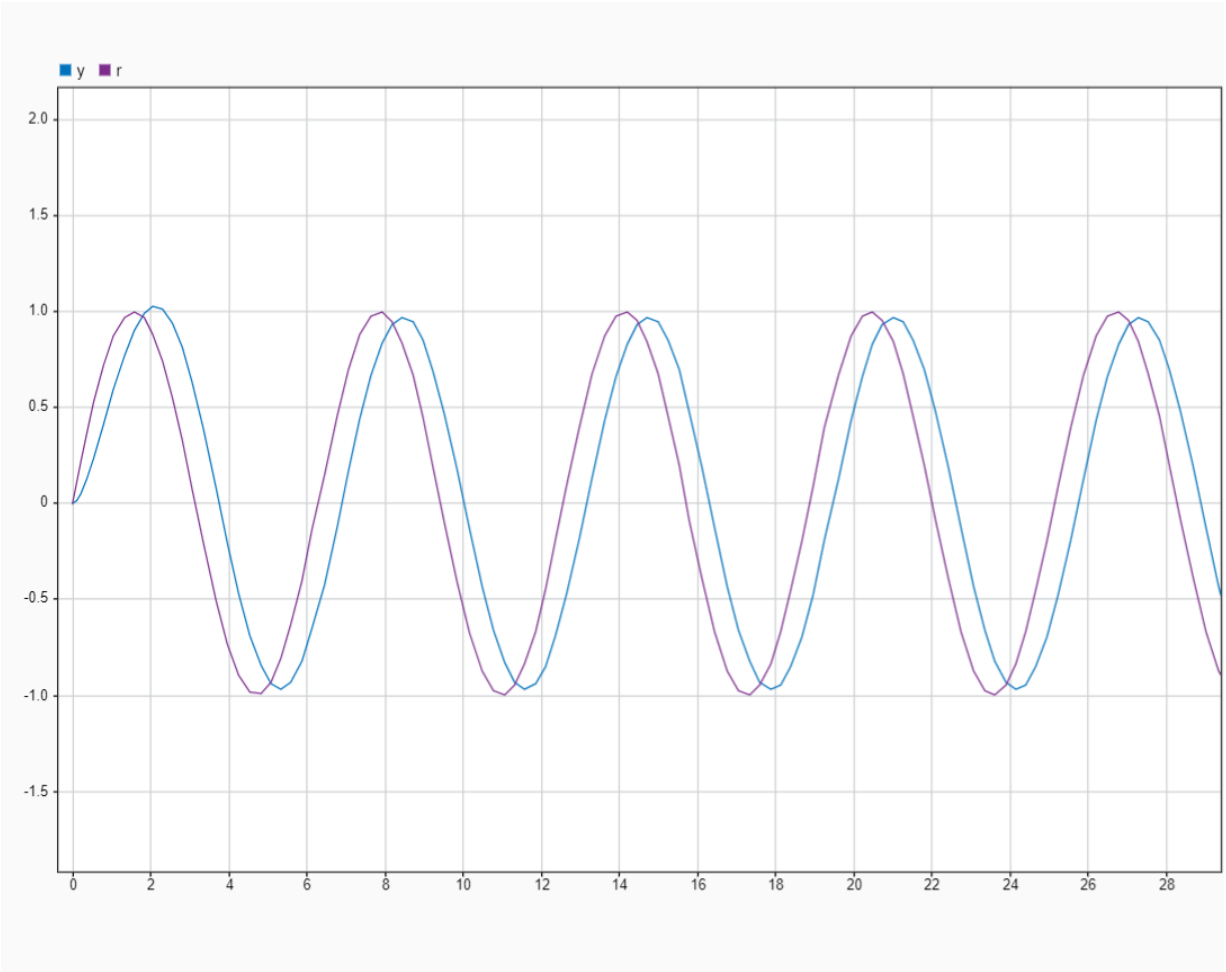
Plots of the reference(r) and actual(y) deviation of the vehicle from the x axis with time :



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