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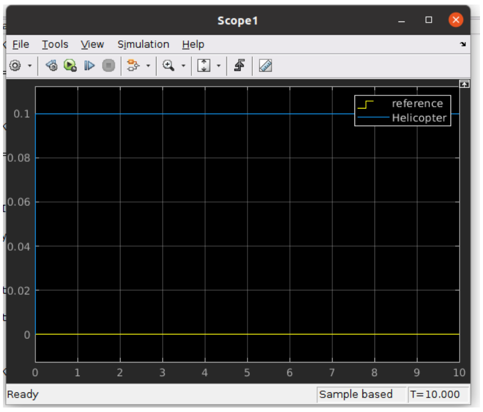
Indian Institute of Technology Kanpur
CS637 Embedded and Cyber-Physical Systems
Homework Assignment 1
Deadline: August 29, 2021

Instructions: *Total:* **40 marks**

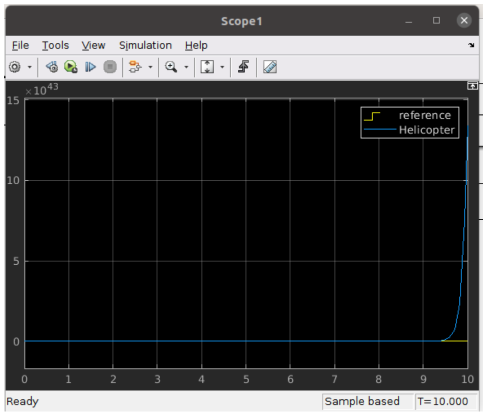
1. Write the answers **neatly** in the given boxes.
2. You may discuss the solutions with the other students, but you have to write them in your own words.

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.

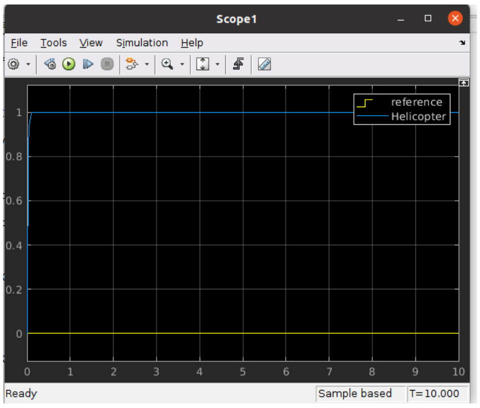
Q1. a).



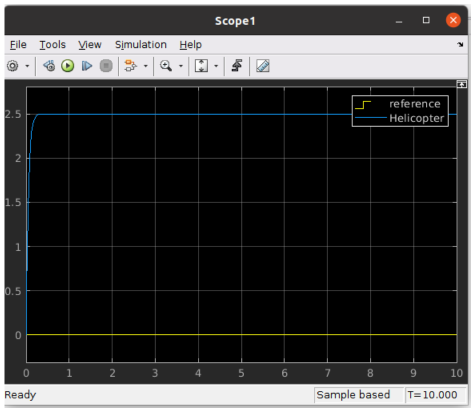
K = 50



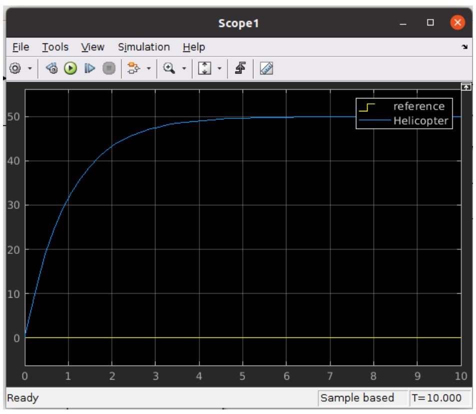
K = -1



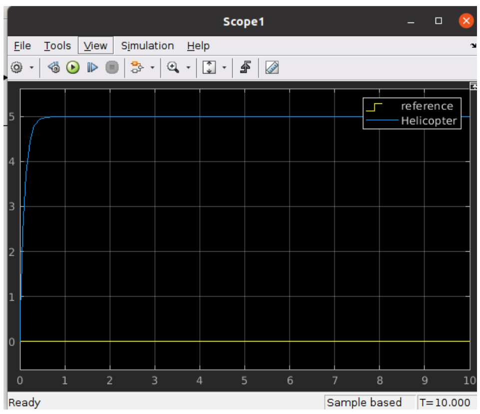
K = 5



K = 2



K = 0.1



K = 1

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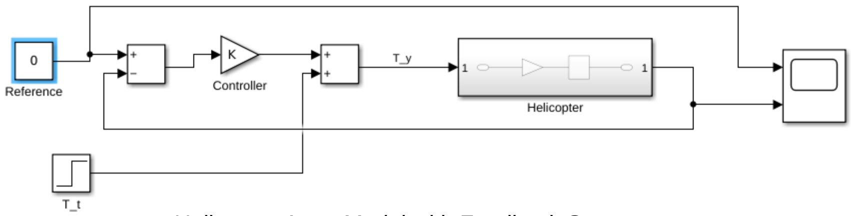
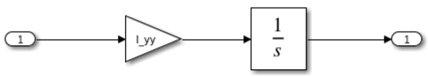


Helicopter Actor Model with Feedback System

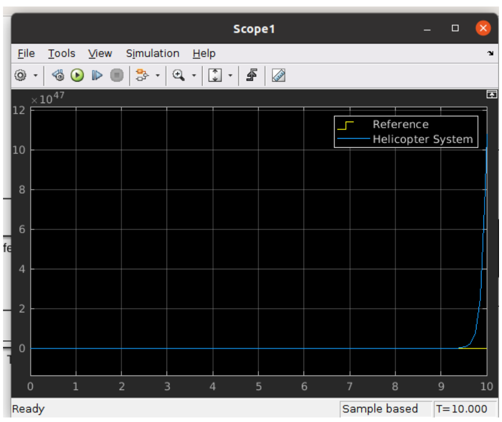


Actor Model of Helicopter System

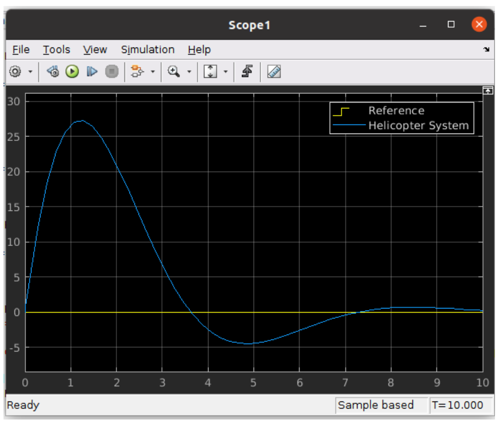
Observations

- Here, we are trying to bring our system to a stable angular velocity zero, as our reference signal is zero
- After applying different values of the control parameter, K, we have obtained a set of plots as shown above
- As we increase the value of K, the control system tries to bring the angular velocity to zero, but it never approaches zero with a simple control system
- With negative K, the control system can never achieve stability
- Angular velocity decreases with an increasing K

Q1. b) As we know that a PI Controller is a powerful controller as compared to a simple controller designed in part a of the question. Now we see the output values (angular velocity) with different set of values for K1, K2.



K1=K2=-1



K1=K2=0.1

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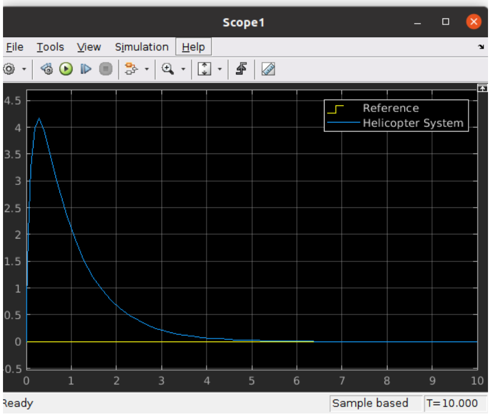
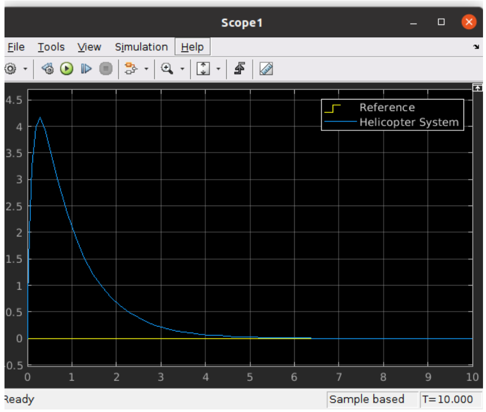
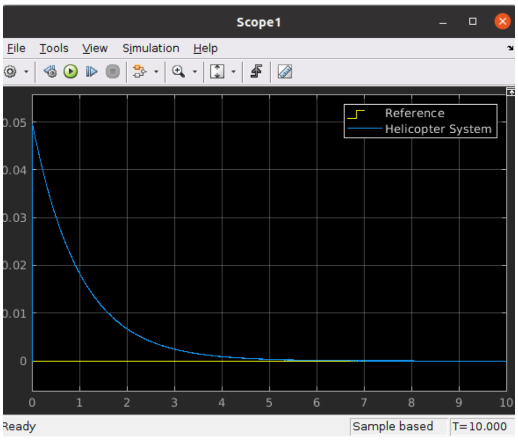


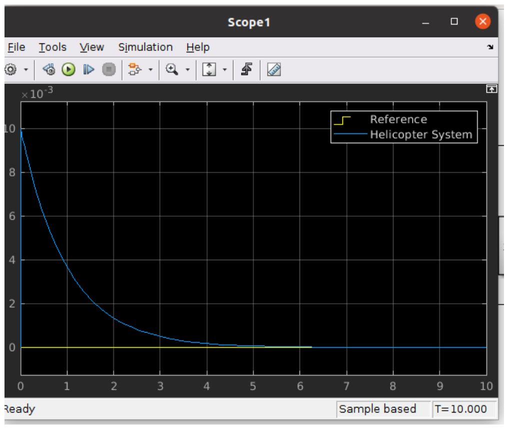
K1=K2=1



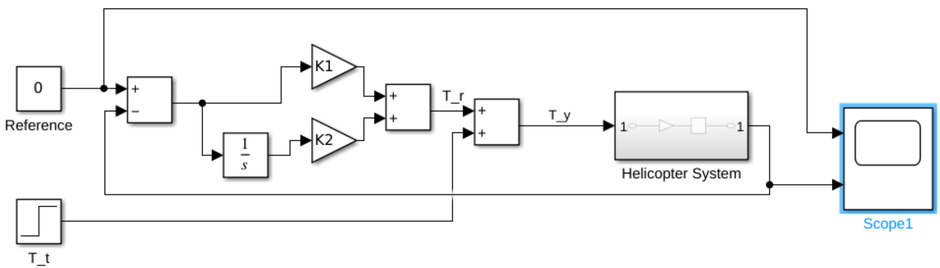
K1=K2=10



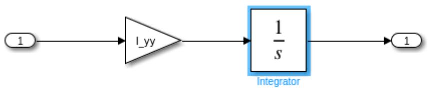
K1=K2=100



K1=K2=500



Helicopter Feedback System Model with PI Controller



Helicopter System: Actor Model

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Inference

- The PI Controller is more powerful than a simple controller. Therefore, we can see that after an initial hiccup, the angular reduces to 0 (desired reference signal).

- Moreover, as we increase the values of K1 and K2, the size of the hiccup gradually reduces. Thus, we can reduce the chances of damage to the device.

- Thus, by keeping reasonable K1 and K2 values, we can maintain the size of the initial hiccup as well as brings the angular velocity to 0.

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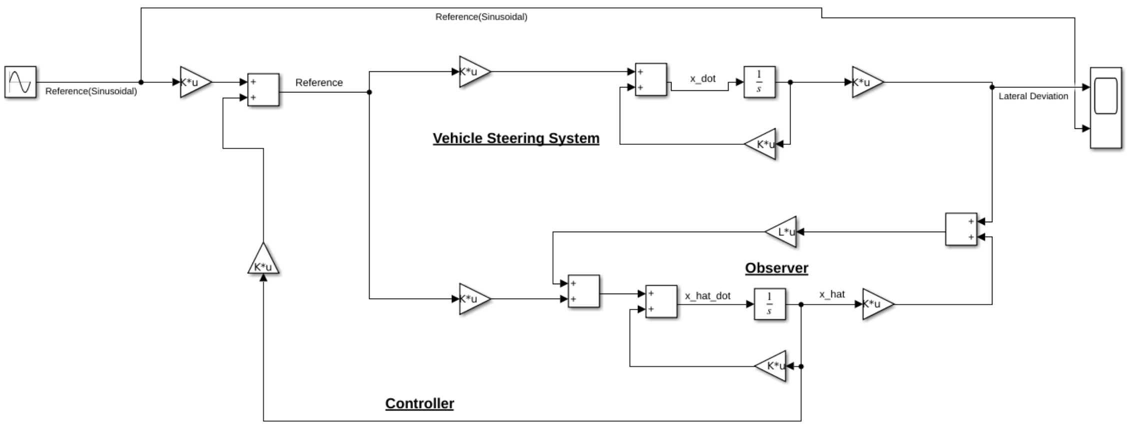
Problem 2. (10 points) The states of the linearized model of a vehicle steering system represent the lateral deviation of the vehicle from the x-axis and the angle between the vehicle axis and the x-axis. The output of the linearized model is only the first state. Construct a Simulink model for the vehicle 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/AM05/pdf/am08-complete_22Feb09.pdf.



SIMULINK model of Vehicle Steering System

The model contains the following components:

1. Process: This shows the actor model of a vehicle steering system. The output shows the lateral deviation of the vehicle.

2. Controller: Feedback control of the process and Observer

a	4
A	[0,1;0,0]
b	10
B	[0.4000;1]
C	[1,0]
D	0
gamma	0.4000
K	[0.2400,0.9040]
Kr	0.2400
L	[2;1]
out	1x1 SimulationO...
P	[-0.4000;-0.6000]
tmp	[0.0960,0.3616;0...
tmp1	[-0.0960,0.6384;...
tmp2	[-3.7667,-2.6600...
tmp3	-4.1667

Assumtions and Calculations

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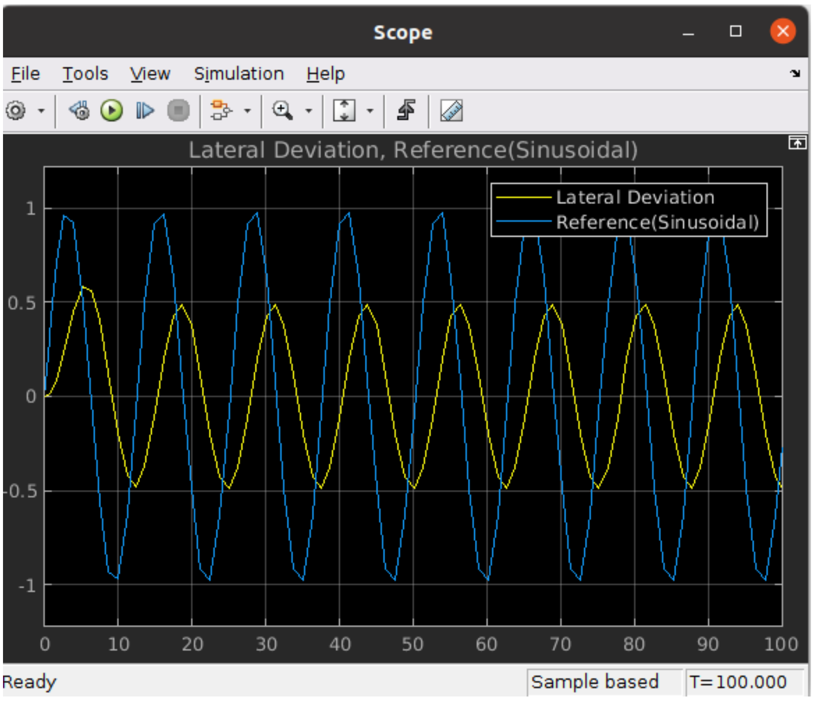

Input: Sine wave(Amp:1, Freq: 0.5)

Conclusion:

The model tries to follow the reference signal. As we can see that the yellow line is the reference signal given in the sinusoidal form.

The lateral deviation of the vehicle shown in the blue line shows the effect that the model makes to follow the reference signal.

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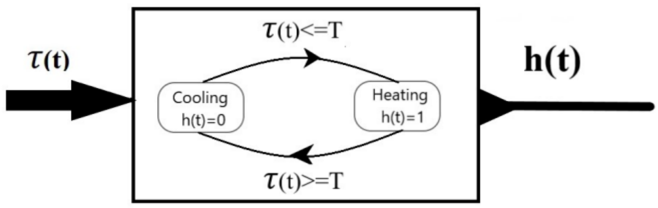
Problem 3. (10 points) Consider the following model for a thermostat system.

temperature.pdf

The thermostat has been designed to maintain the temperature of a room at T°C. The model has two states: *cooling* and *heating*. When the system is in the *cooling* state and the temperature of the room goes below T°C, the system generates a signal to switch on a heater and moves to the *heating* state. When the temperature of the room goes over T°C, the system generates a signal to switch off the heater and moves to the *cooling* state.
(a) Represent the system as an actor that takes the current temperature as input and produces a signal to control the heater. The actor uses the set point T as a parameter.
(b) Identify a design problem in the model.
(c) Provide two different remedies to address the problem.
(d) Compare your proposed two solutions in terms of ease of implementation and guaranties on the system behavior.

a). Actor Model of Thermostat



b). Design Problem in the above model:

- At the point when the current temperature is near the ideal temperature, that is temperature (t) is either a little above T or a little beneath T, then, at that point, the machine switches states quickly.

- The heater would turn on and off quickly when the temperature is close to the setpoint temperature. This condition is called CHATTERING.

c). The problem of Chattering can be solved in two ways:

(i) Hysteresis: Hysteresis method means that the there should be a temperature gap between transition guards. If the desired temperature is 'T', then the guard signal should be :

'T+gap' for changing from Heating to Cooling mode.
'T -gap' for changing from Cooling to Heating mode.

This gap temperature is used to implement Hysteresis.

(ii) Dwell Time: When the system enters a state, it stays in that state for a specified period of time irrespective of the transition guard signal. Thus the system doesn't switch states rapidly. Dwell Time is implemented by using a Timed-Automata.

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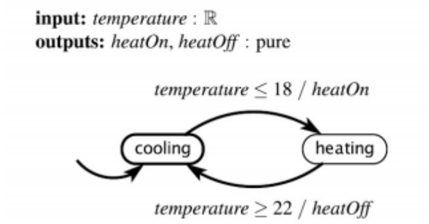
d) (i) Hysteresis Implementation

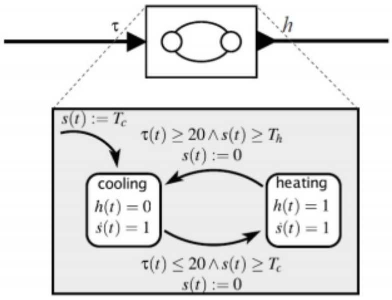


Model of thermostat with hysteresis

The above model shows a state subordinate conduct called hysteresis. The framework has memory, however moreover has a helpful property called time-scale invariance which implies that scaling the time axis at the information brings about scaling the time axis at the yield, so the absolute time scale is insignificant.

Accordingly, by utilizing this strategy the framework doesn't change state often close to the ideal temperature. A period scale gap is presented so that the framework doesn't experience chattering conduct.

d) (ii) Dwell time (Timed Automata)



A timed automaton modeling a thermostat with a single temperature threshold, 20, and minimum times, Tc and Th in each mode. As compared to the hysteresis method, the dwell time method uses a single threshold temperature.

However, the system does not change state only on the basis of temperature changes. Instead, the the system remains in a particular for at least a minimum duration of time before it can change state irrespective of the guard signals.

Such a system is shown in the above figure. This system is also called a timed-automata. Thus, by using dwell time in form of a timed-automata, the problem of chattering can be avoided.

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