Lab 01

Introduction to Feedback Control Systems

1.1 Objective

To introduce basic elements and block diagram representation of feedback control systems

1.2 Introduction to Control Systems

Control systems are an integral part of modern society. Numerous applications are all around us: The rockets fire, and the space shuttle lifts off to earth orbit; a self-guided vehicle delivering material to workstations in industries; air conditioners controlling the temperature of indoor environment in offices and houses. These are just a few examples of the automatically controlled systems that we have created.

In general, a ***system*** is an arrangement of physical components connected or related in such a manner as to form and/or act as an entire unit. The word ***control*** is usually taken to mean regulate, direct, or command. Combining the above definitions, we can say that "*a **control system** is an arrangement of physical components connected or related in such a manner as to manage, command, direct, or regulate itself or another system.*" In engineering, we usually restrict the meaning of control systems to apply to those systems whose major function is to dynamically or actively command, direct, or regulate.

Control systems are found everywhere, from kitchen appliances to cars and from airplanes to hard drives and medical devices. They help ensure system's *performance*, *stability*, and *efficiency*. Through this lab, you will explore real-life examples to understand and gain insights into control systems. It introduces the working principles behind the open-loop and closed-loop control systems. You will also learn the basic components of a ***feedback*** control system and how these components are referred to in control theory.

1.3 Feedback Control Systems

A control system constitutes a number of *elements* which are combined in a manner such that they *modify* the behavior of the system and help us obtain a desired ***response*** from a system. The system to be controlled is usually termed as ***plant*** or ***process***. Control systems may have more than one input or output. The ***input*** is the *stimulus*, *excitation* or *command* applied to a control system and the ***output*** is the *response* or *behavior* obtained from a *controlled* system. A plant is thus controlled by a ***controller*** that takes appropriate ***control actions*** and provides required ***manipulated*** input to the plant.

Control systems are classified widely into two categories: **the open-loop** and **the closed-loop** systems.

- An open-loop control system is one in which the control action is independent of the output.
- A closed-loop control system is one in which the control action is somehow dependent on the output.

The input-output configurations for the open-loop and the closed-loop systems are shown in Figure 1 and 2, respectively.

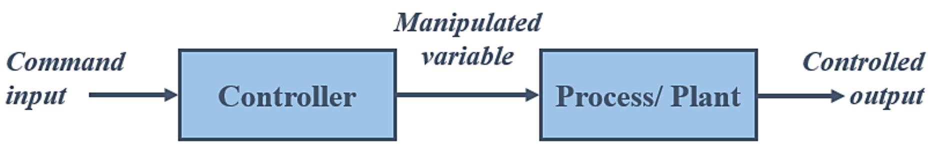


Figure 1: Input-output configuration of an open-loop control system

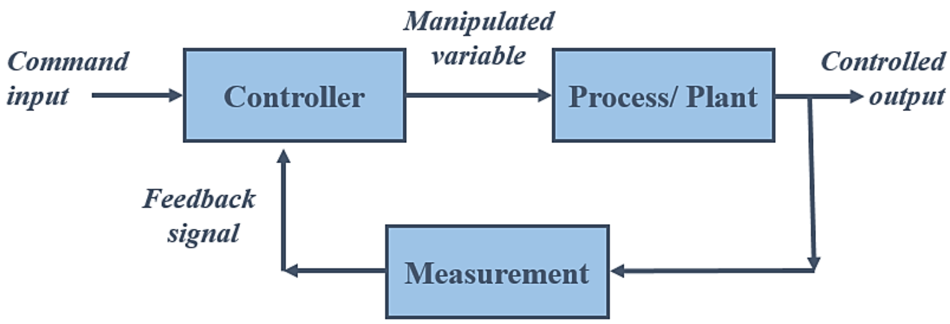


Figure 2: The input-output configuration of a closed-loop control system

In an open-loop control system the output is neither "measured" nor "fed back" for comparison with the input. From these representations, it can be deduced that a closed-loop control system uses the concept of an open loop system as its forward path but has one or more ***feedback*** loops or paths between its output and its input. The reference to *feedback*, simply means that some portion of the output is returned "back" to the input to form part of the systems excitation. Such systems are therefore known as ***Feedback Control Systems***. These systems are designed to automatically achieve and maintain the desired output by comparing it with the actual input. It does this by generating an ***error*** signal which is the difference between the output and the reference input. A general representation of feedback control system is shown in Fig. 3.

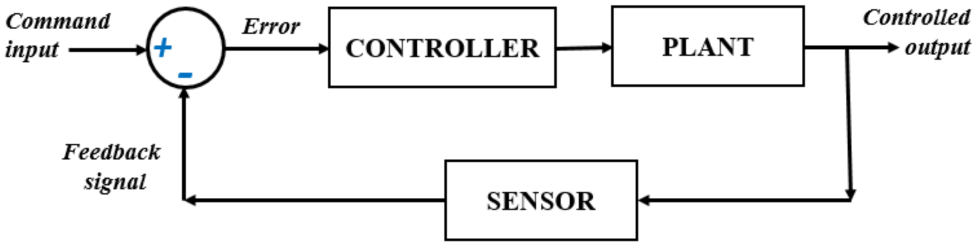


Figure 3: Block diagram representation of a feedback control system

We are not the only creators of automatically controlled systems; these systems also exist in nature. Within our own bodies are numerous control systems, such as the pancreas, which regulates our blood sugar. As rightly stated by M.B. Hoagland and B. Dodson, *The Way Life Works* (1995), that "*The process of feedback governs how we grow, respond to stress and challenge, and regulate factors such as body temperature, blood pressure and cholesterol level. The mechanisms operate at every level, from the interaction of proteins in cells to the interaction of organisms in complex ecologies.*"

In the following tasks, you will be utilizing a series of videos on ***Control Systems*** by ***MATLAB Tech Talks***. MATLAB is one of the software tools that are frequently used in modelling and analysis of control systems.

Task 1: Learning about open-loop control systems

In this task, you will explore the open-loop control systems by walking through some introductory examples and learn how open-loop systems are found in every day appliances; watch the complete video:

[Understanding Control Systems, Part 1: Open-Loop Control Systems]

to explore input and output of the systems, and finding the required input to attain the desired response.

Task 1A: What two open-loop systems are described in the video? Specify their input and output variables.

	Open-Loop System	**Input parameter(s)**	**Output parameter(s)**
	Toaster	Timer level	Bread colour
	Shower	Handle Position	Water temperature

Task 1B: Other than the open-loop systems described in the video, list down two more examples of open-loop control systems from daily life. Also specify their inputs and outputs.

	Open-Loop System	**Input parameter(s)**	**Output parameter(s)**
	Microwave (Here we set the timer, and the microwave runs for that time, it has no information regarding the temperature and makes no attempt it maintaining it since no feedback system)	Timer level	Food warmth
	Air fryer (Here we set the timer, and the air fryer runs for that time, it has no information regarding the temperature and makes no attempt it maintaining it since no feedback system)	Timer level	Food (whether its completely cooked or somewhat raw)

Task 1C: Write down three disadvantages of the open-loop control systems.

(a)It fails if there are are variations in your system
(b) Its unreliable when there are unexpected environment changes
(c)Lack of self-correction. These systems cannot self-correct themselves when disturbed.

Task 2: Learning about basic closed-loop (feedback) control systems

This task lets you understand how a feedback mechanism can help you solve problems encountered in an open loop control system. Watch Understanding Control Systems, Part 2: Feedback Control Systems and answer the following:

Task 2A. How does a closed-loop feedback control system work? Briefly explain.

The closed-loop feedback control system, additional to the open-loop system, has sensors which monitor the output, it calculates the difference between desired output and monitored output, it sends this result called "feedback" to the controller so it can adjust the controls accordingly in order to achieve the desired output.

Task 2B: Other than the closed-loop systems described in the video, list down two more examples of closed-loop control systems from daily life. Also specify their inputs and outputs.

	Closed-Loop System	**Input parameter(s)**	**Output parameter(s)**
	Iron (It's a closed loop system because it maintains the temperature that is desired by the user)	Temperature knob	The heat being produced
	AC (It's a closed loop system because it maintains the temperature that is desired by the user)	Temperature sensors and remote (used to set the desired temp.)	The cool air being produced

Task 2C: Write down three advantages of the closed-loop control systems.

(a) Improved Accuracy and Precision: Closed-loop control systems continuously compare the actual system output to the desired setpoint, allowing them to make real-time adjustments to minimize errors
(b) Adaptability to Changing Conditions: Since they are continuously monitoring their environment and adjusting their control actions, they are able to processes variations or disturbances
(c) Increased Stability: Feedback mechanisms allow them to detect and correct deviations from the desired setpoint, preventing the accumulation of errors that can lead to instability.

Task 3: Learning block diagram representation of feedback control systems

This task would help you learn about the basic terminologies used in a feedback control system and the representation of a system by using a simple *block diagram*. Watch the video Understanding Control Systems, Part 3: Components of a Feedback Control System.

Task 3A: Refer to the aforementioned video for help, and fill the following boxes with the terminologies used to describe these components (Figure 4):

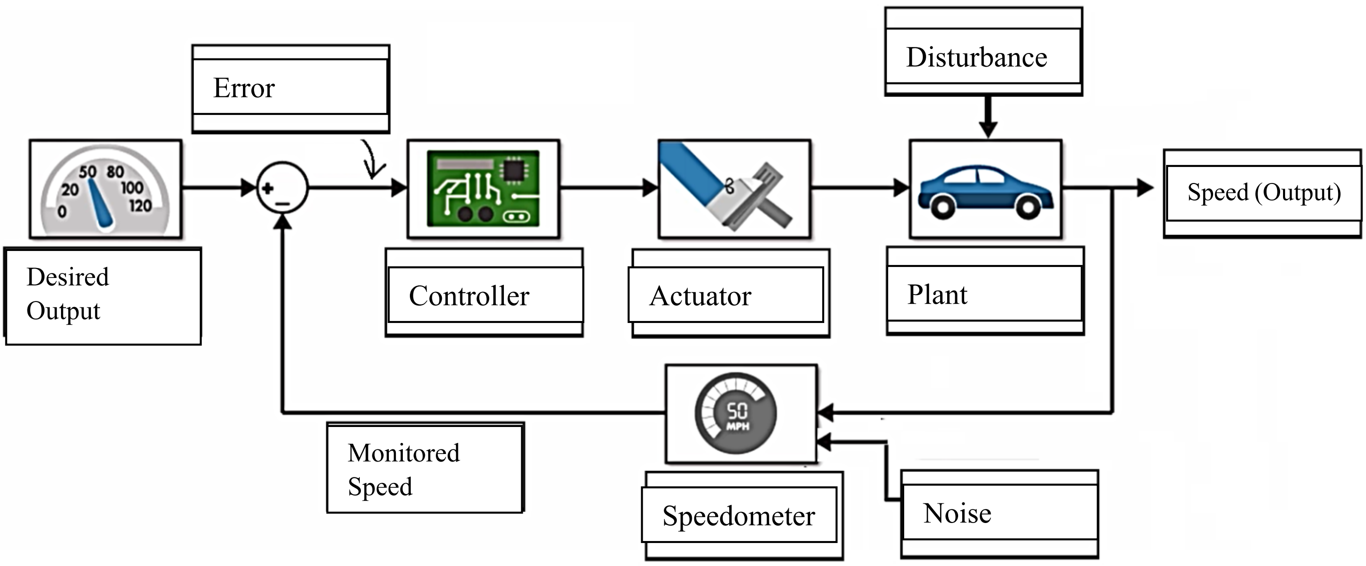


Figure 4: Block diagram representation of car speed control

Task 3B: For your comprehension, describe the following terms in your own words to complete Table 1.

Table 1: Description of terminologies in the context of feedback control system

Terminology	Description
Plant	The object whose parameters/output you try to control e.g: car
Input	Desired speed which influences the actuator
Output	Measured speed (the output of the plant)
Set Point	This is the output desired by the user
Error	The difference between desired output & measured output
Sensor	Which measures the environment variables
Actuator	Through the actuator, the controller influences the plant
Controller	Decides on the control action
Disturbance	Unexpected environmental changes which changes the output in an undesired way
Noise	Unwanted signal affecting your measured output value

Task 4: An Overhead Water Tank and Motorized Pump

Scenario 1: Consider the system shown in Figure 5 where an overhead tank in a factory premises gets water supply from a nearby river pumped through a motorized mechanism.

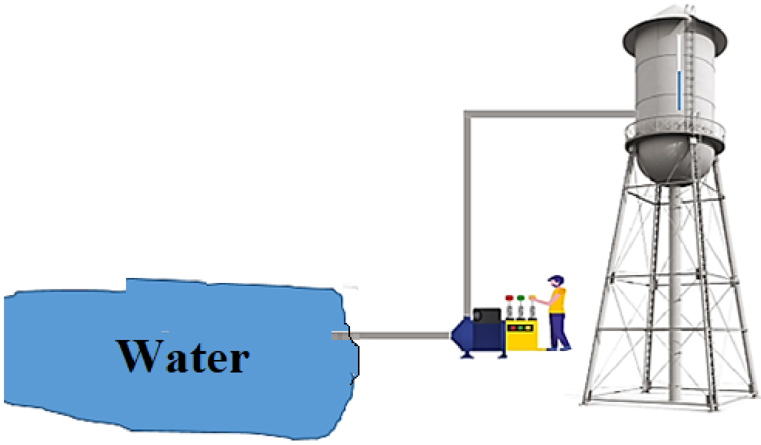


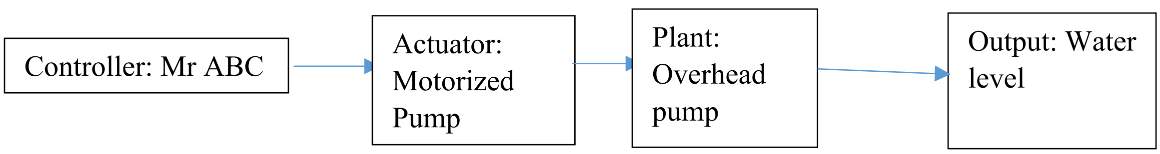
Figure 5: The overhead tank water level control example with a single worker

Task 4A: Early in the morning, Mr. ABC turns the motor on for 2 hours to ensure that the overhead tank gets sufficient water for the day. Identify the basic elements of system and fill in Table 2.

Table 2: Control system terminology applied to tank water level control system in scenario 1

Plant	Overhead tank
Output	Water level in the overhead tank
Actuator	Motorized pump
Sensor	No sensor
System type: Is this an open-loop, a closed-loop human-controlled, or a fully-automated feedback control system? Explain your choice.	Open-loop because Mr. ABC only turns it on for 2 hours and doesn't check the actual water level in the overhead tank

Task 4B: Sketch block diagram representation of the system with each block labelled appropriately.



Scenario 2: People in the factory often face nuisance when water supply from taps stops suddenly in case of unexpectedly higher consumption. To maintain a sufficient water level in the over-head tank all the time, Mr. ABC hires Mr. XYZ to monitor the level of tank every half an hour as shown in Figure 6. Mr. XYZ checks the water level and reports; Mr. ABC turns the pump on accordingly. When water-level attains the required level as reported by Mr. XYZ, Mr. ABC turns the pump off.

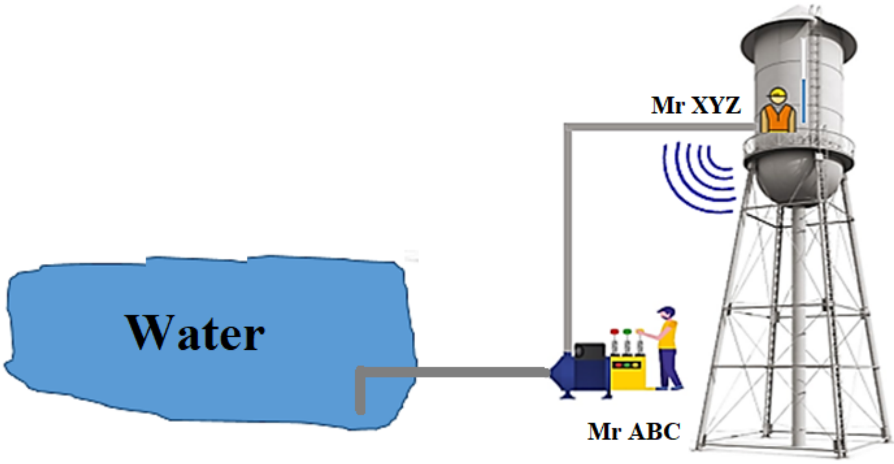


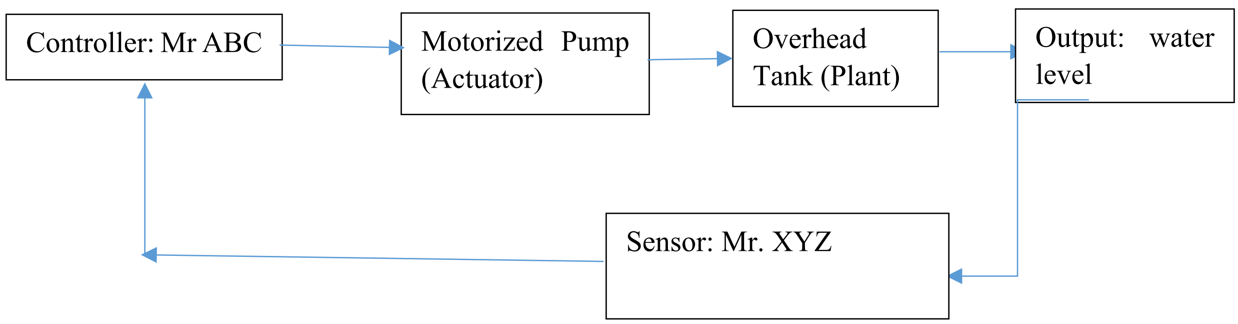
Figure 6: The overhead tank water level control example with two workers

Task 4C: In the given scenario, identify the basic elements of system and fill in Table 3.

Table 3: Control system terminology applied to tank water level control system with two workers

Plant	overhead tank
Output	Water level in the overhead tank
Actuator	Motorized pump
Sensor	Mr XYZ
System type: Is this an open-loop, a closed-loop human-controlled, or a fully-automated feedback control system? Explain your choice.	closed-loop human-controlled

Task 4D: Sketch block diagram representation of the system with each block labelled appropriately.



Scenario 3: As Mr. XYZ sometimes doesn't give the required information timely, therefore, Mr. ABC wants to completely automate the process without any dependency on human.

Task 4E: Help Mr. ABC in designing a fully-automated feedback control system. What changes do you recommend to Mr. ABC? Please provide your suggestions in pointwise manner.

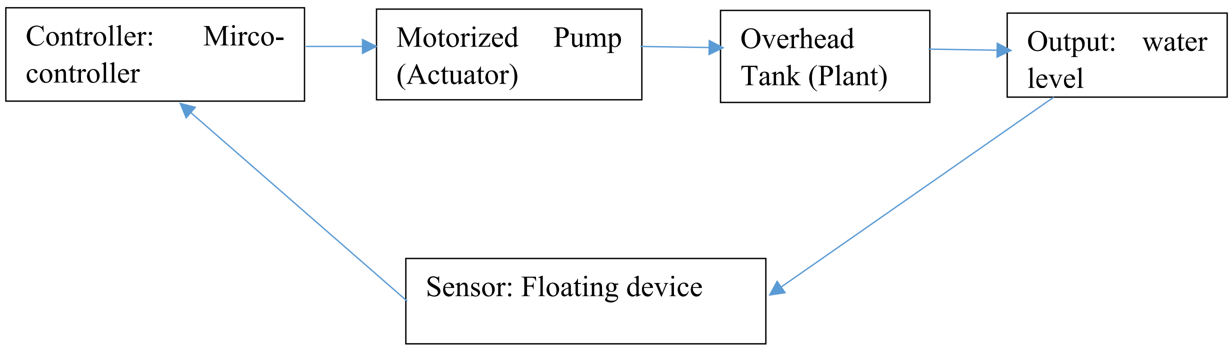
- Replace Mr. XYZ with an altimeter, to monitor the water level (output). Once water reaches the desired level, a signal is sent to microcontroller.
- Replace Mr. ABC with a microcontroller that switches the motor off when the desired level is reached or keeps the motor on if the water level is lesser than required. It gets signal from the altimeter

Task 4F: In case of fully-automated feedback control system, identify basic elements of the system and fill in Table 4.

Table 4: Elements of tank water level control in a fully-automated feedback control system

Plant	Overhead tank
Output	Water level in the overhead tank
Set Point	sufficient water level in the over-head tank all the time
Error	Difference in the current water level and desired water level
Controller	Mirco-controller
Actuator	Motorized pump
Sensor	Floating device

Task 4G: Sketch block diagram representation of the system with each block labelled appropriately.



Post Lab Tasks

Task 5: Analyzing natural glucose-level control mechanism in human body

Glucose concentration in the blood must be maintained in a narrow band of values. Glucose in the blood is controlled by the pancreas by modifying the concentrations of insulin and glucagon. When the glucose concentration increases, the pancreas delivers more insulin and less glucagon, which has the following effects:

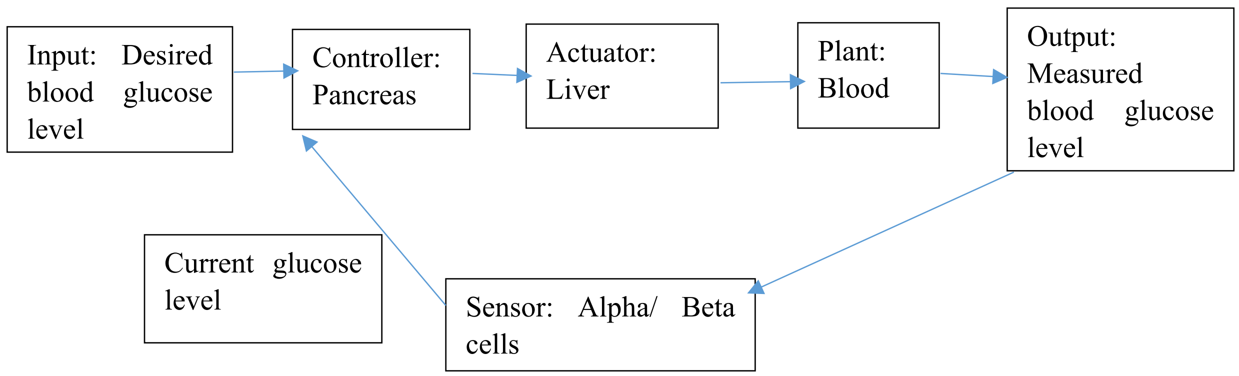
- It favors transportation of glucose from blood to cells.
- It increases demand for glucose in cells.
- It stimulates the liver for glucose consumption to produce glycogen, fats, and proteins. The effect of this set of actions is a reduction of glucose concentration in the blood to safe, healthy levels.

On the other hand, if the glucose concentration in the blood diminishes, the pancreas delivers more glucagon and less insulin, which has the following effects:

- It stimulates the liver cells to produce glucose, which is delivered into the blood.
- It stimulates the degradation of fats into fatty acids and glycerol, which are delivered into the blood.
- It stimulates the liver to produce glucose from glycogen, which is delivered into the blood. The effect of this set of actions is the increase of the glucose concentration in the blood to safe, healthy levels.

Go through the reading material and videos provided under Additional Resources header in Week 01 Module on LMS to complete the following task.

Use the concepts of a feedback control system; describe the above process using a labelled block diagram to describe the input, output, plant, feedback component, controller, command input, manipulated input or inputs, any disturbances, etc.



Task 6: Simulating open-loop and closed-loop systems using Simulink

The following two videos demonstrate the performance of a car as an open-loop and as a closed-loop system using MATLAB Simulink.

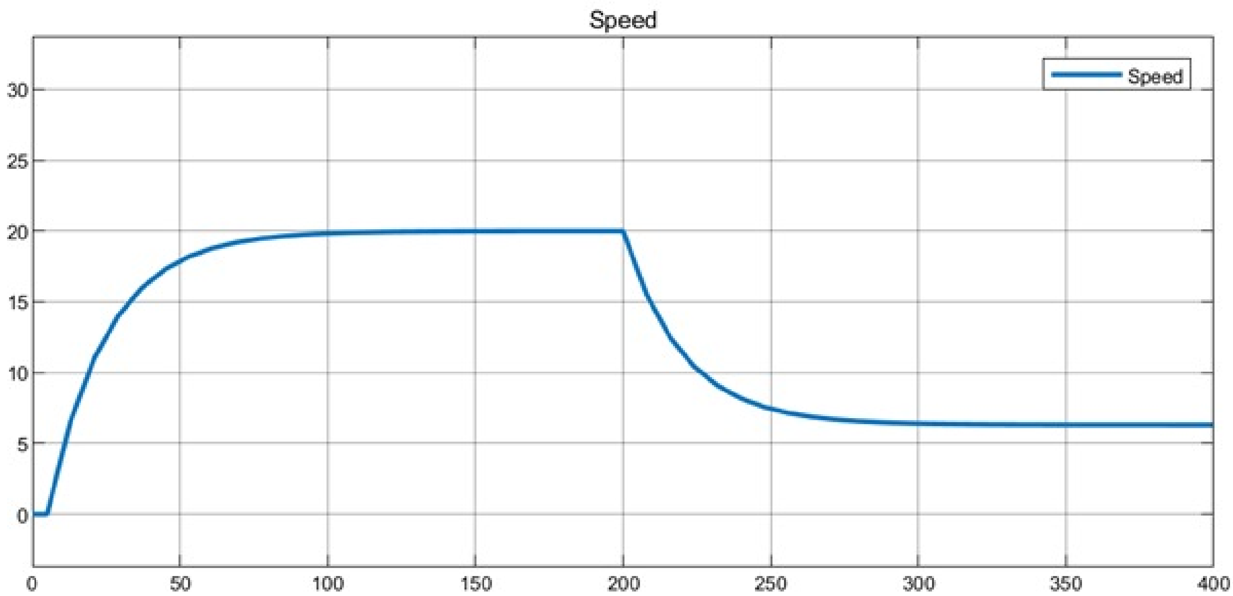
- Understanding Control Systems, Part 4: Simulating Disturbance Rejection in Simulink
- Understanding Control Systems, Part 5: Simulating Robustness to System Variations in Simulink

Watch the above videos to learn how to use Simulink to simulate open-loop systems, closed-loop systems, disturbance rejection, and robustness to system variations. Use the plots shown in the above videos for different scenarios and briefly **compare** the performance of car as open-loop and closed-loop systems in the presence of disturbance and system variations. Show the plots being used in your analysis.

Open-loop Control System

Open-loop control system is suitable when there is no disturbance. However, when the car comes across a disturbance such as a hill, the open loop system fails to perform.

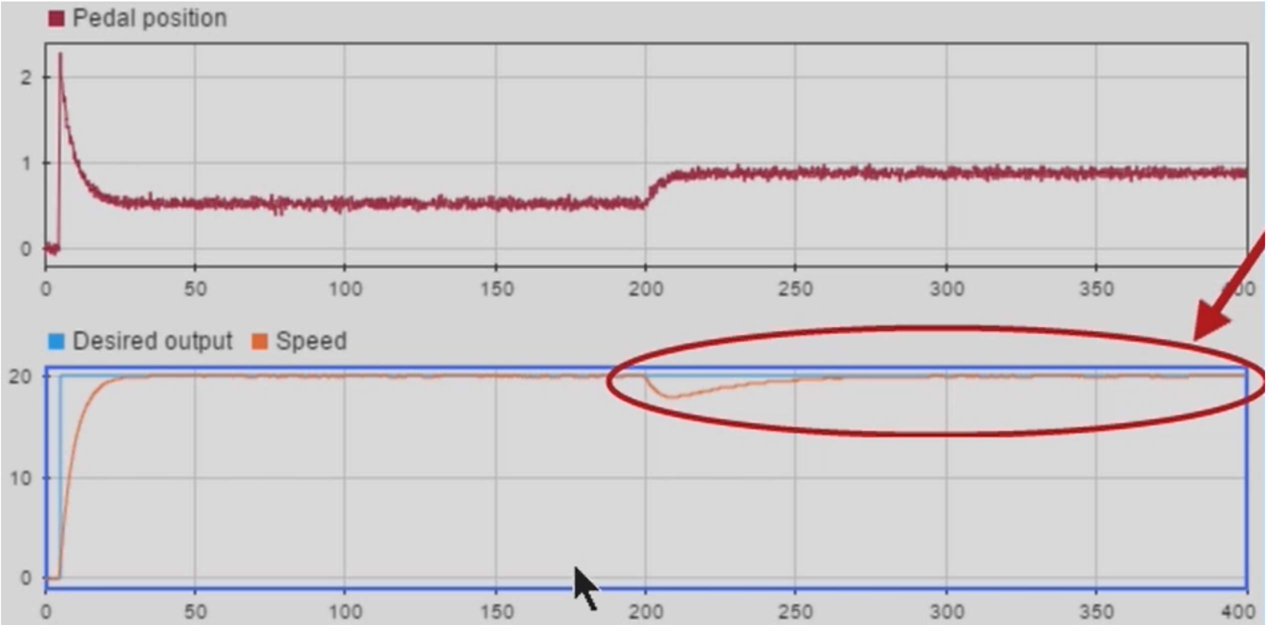
Following is the graph of open-loop system when it encounters a disturbance.



Here, we can see that at t=200 seconds, the car starts facing disturbance such as when climbing a hill. Consequently, we see the speed of the car decrease immediately. Although the speed stabilizes at t=300 sec, the car is unable to attain the speed which it previously had at t=100 sec. This shows that the open loop system that we had employed has failed, since there is no feedback system which senses and attempts to maintain the desired speed

Closed-loop Control System

Alternatively, if we consider the closed-loop system, where the graph appears like this:



We can clearly see that at t=200 sec, when the disturbance appears, the speed of the car takes a momentary hit, but then reattains its original value. This correction in speed was due to the increase in pedal position which allowed the engine to work harder, speeding up the car in spite of the load due to the disturbance. This increase in pedal position was due to the feedback system employed in this system, which allowed it to decrease the error and maintain the desired speed.

Comparison: We can see that the closed-loop system was a better system as it allowed for self-correction in speed, making it more reliable than its open-loop counterpart. The closed-loop system, because of it's feedback system, was able to adjust the pedal position to keep the speed of the car maintained at the desired setpoint. The feedback system allows the system to gain awareness of the disturbances so the controller acts accordingly to reduce the difference between desired and monitored outputs (i.e speed in this case)

Assessment Rubric

Lab 01
Introduction to Feedback Control Systems

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Points Distribution

Task No.	LR5 Figures/Plots	LR 10 Analysis	AR 6 Class Performance
Task 1	-	/12	-
Task 2	-	/12	-
Task 3	/4	/12	-
Task 4	/12	/12	-
Task 5	/12	/12	-
Task 6	-	/12	-
SEL	-	-	/20
Total Points	/100 Points		/20 Points
Course Learning Outcomes	CLO 1		CLO 4

For details on rubrics, please refer to *Lab Evaluation Assessment Rubrics*.