1. Introduction to Control Systems

1.1 Introduction

- Consider these two systems - a tornado and an airplane …

  - *Both are capable of transporting people over long distances!*
  - *Both are highly nonlinear systems with complicated dynamics!*
  - *However, one is controlled; the other is out of control!*

- Control is the hidden technology that we encounter on a daily basis.

- Control systems exist all around us. They can be found in CD players, cars, flight control, spacecraft, robots, power plants and in countless other applications. Control systems are also used to regulate virtually every system in the human body!

- *What is a system?* A **system** is a collection of components acting together to perform a specific task. It is anything with inputs and outputs.

- A **control system** is an interconnection of components forming a system configuration, which *will provide a desired system response*. It changes the input to a system so as to achieve a desired output.

- So why do we need control systems?

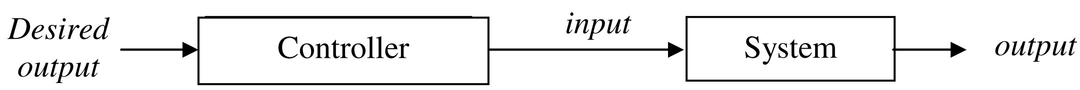
  - For convenience: room temperature control, CD players, etc.
  - To avoiding dangerous situations: bomb removal, toxic environments, extreme temperatures, etc.
  - To achieve what that which is impossible for humans: nanometer scale precision positioning, working in small spaces, etc.
  - To meet desired specifications: lower cost, higher efficiency, etc.

- As it is, control systems already exist in nature, the human body being a prime example (with blood pressure regulation, temperature control, etc.)

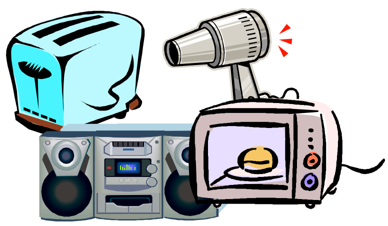
- A control system can either be **open-loop or closed-loop**, the latter is referred to as a feedback control system.

- An **open-loop control system** allows the system output to be modified by changing its inputs. However, is has no feedback, i.e. the actual output is not measured.

- The following diagram represents the basic idea of an open-loop control system (i.e. no feedback):



- Examples of common open-loop control systems include hairdryers, toasters, microwave ovens, volume control on stereos, etc.



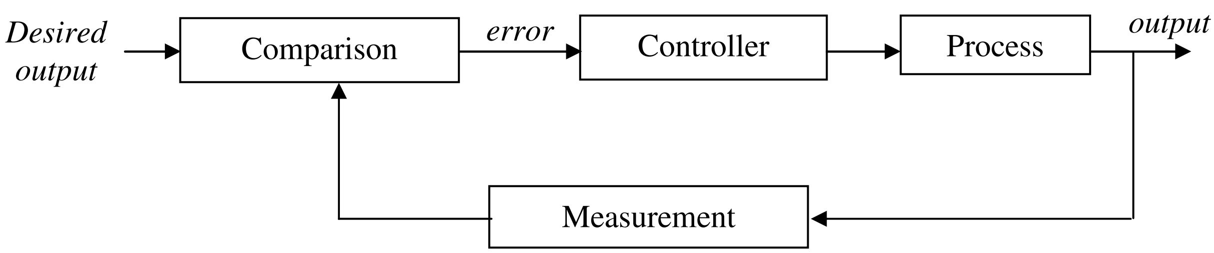
- All these systems involve changing a dial (i.e. controller) to affect the output of the system but this output is not measured by the system or fed back to the controller.

- In practice, we, as humans, observe the output and react accordingly by adjusting the system's dial. However, this action is independent of the system itself. In other words, it is not an automatic response of the system.

- *Is this a satisfactory control system? Why?*

- A **feedback control system** is one that tends to maintain a prescribed relationship between one system variable and another, by comparing functions of these variables and using the difference as a means of control.

- The basic idea of a **closed-loop feedback control system** is shown below:

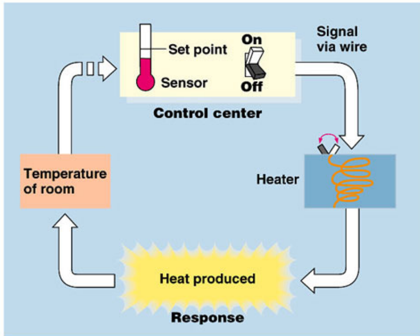


- A common example of a feedback control system is the home heating system, which has a simple on/off control to turn on and off the heating furnace (for example, the gas boiler).

- Here, a measurement sensor (for example, a thermistor in a modern digital thermostat) measures the room temperature.

- This is compared with the desired room temperature as set on the local device by the user (or, in modern cases, remotely via an app on their smart phone).

- Depending on the result, the controller will transmit an off/on signal to the furnace fuel valve (i.e. the process input) which, in turn, will allow/prevent fuel flow to the furnace and, hence, increases/decreases the room temperature.



(a) Control of room temperature

- Clearly, we can see that this is a now an *automated control system*.

1.2 Why use feedback control?

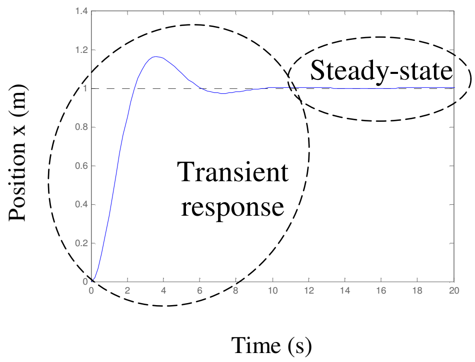
- A feedback control system offers several important advantages in comparison to an open-loop control system.

- Firstly, as we have seen, **the system output can be made to follow a desired set point automatically**.

- This provides an automatic control system and, hence, an element of convenience to the user, as they no longer need to manually adjust an input dial to achieve the same outcome … *no more trial and error!*

- Secondly, feedback control makes it **easier to achieve desired transient and steady-state response**.

- Steady-state refers to the final output of the response once it has settled while the transient refers to the initial part of the response that is changing.



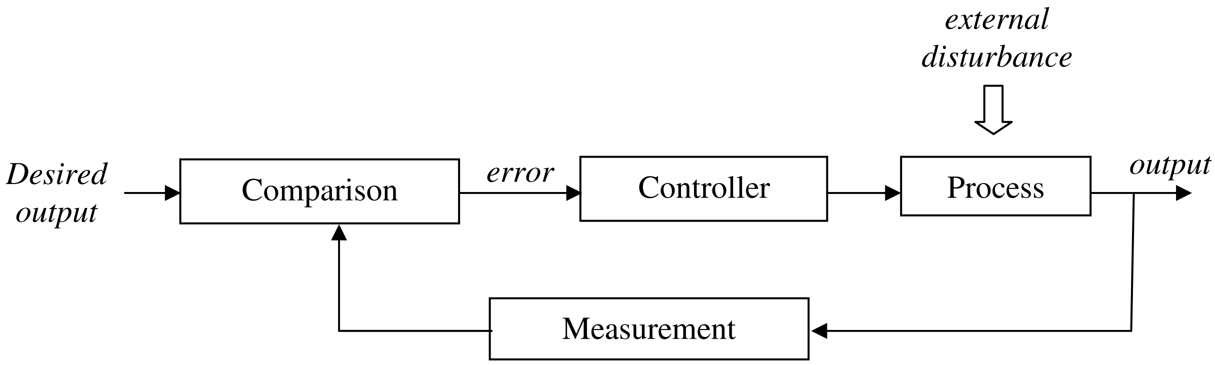
- For example, we may wish to change the altitude of an airplane. However, in doing so, it is also very important that we do not discomfort passengers in the process.

- Thus, in this situation, we can specify a desired steady-state value, i.e. the new altitude level, and also a desired transient response, i.e. minimal or no overshoot or oscillations.

- A feedback control system makes this task significantly easier to achieve.

- Thirdly, the performance of a feedback control system is **less sensitive to external disturbances**.

- External disturbances refer to anything that affects the output of the system (or process) but is not part of the system itself. We include this in the control system as follows:



- For example, consider a temperature control system for a room. As we know, the temperature of the room can be kept at a desired value using a thermostat.

- Now, if someone opens a door or a window, this will act as a disturbance to the temperature in the room, causing it to drop.

- An open-loop control system does not react to this new disturbance-based change.

- However, a feedback control system is able to adapt to this disturbance – the drop in temperature is detected by the thermostat which in turn will ensure the heating system stays on for longer in order to achieve the desired room temperature.

"With this extreme turbulence, the meals really are in flight."

- Finally, the performance of a feedback control system is **less sensitive to variations in the parameters defining the process**.

- This relates to possible changes that can occur in the process itself over time, such as wear and tear, environmental changes, etc.

- System parameters could include resistor or capacitor values in an electrical circuit, spring and damping constants in mechanical systems, the flow rate in a water-tank system, etc. These can all change over time for one reason or another.

- For example, the flow rate in a pipe can easily vary over time due to a buildup of limescale.

- Once again, an open-loop control system cannot compensate for such changes whereas a feedback control system can.

So why use open-loop control systems at all?

- The obvious drawback of a feedback control system is the requirement for additional high precision hardware, needed to measure and feedback the output.

- Such hardware can be expensive and so an engineer has to trade-off efficiency with practical cost.

- For example, in our pursuit to make the ultimate toaster, we would need special sensors that would allow us to measure the colour of the toast, the thickness of the toast and the type of bread used for the toast.

- We'd then need a mechanism to adjust the timer on the toaster to allow us to achieve the desired output.

- This would make the toaster significantly more expensive and possibly so much so that no one would actually want to buy it (except the engineer perhaps!).

- In this case, a simple open-loop system, that requires a little trial and error on our part, is more than adequate for the purpose of a toaster.

- *So burnt toast is here to stay!*

1.3 How about feedforward control?

- One of the issues with feedback control is that the controller only reacts once the output has actually deviated from the setpoint.

- Thus, for example, in the home heating system, the controller will only switch on the heating system once it has detected a drop in room temperature.

- If we knew that the temperature was due to drop, because of say a recently opened window, then we could immediately turn the heating system on before the room temperature has had a chance to drop below the setpoint.

- This type of reaction is known as **feedforward control**.

- Examples of feedforward control in practice include:

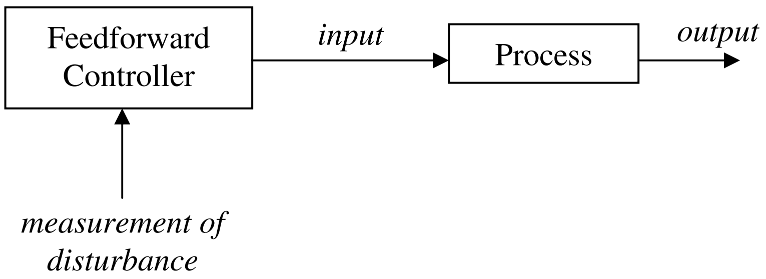
  - *Driving a car, approaching a hill* – as a driver, we typically observe how steep the hill is and we push on the accelerator in advance of the hill in order to maintain a steady pace. In feedback control, we would wait until the car slows down before pressing the accelerator.

- *Taking a shower!* – If we hear a toilet flush in the house, thus knowing the water is about to get very hot, we adjust the water to compensate. In the case of feedback control, we would have waited for the water to get hotter before changing the setting. *Feedforward allows us to avoid the 'ouch' moment!*

- Feedforward control works on the premise that we have advanced knowledge of the disturbance and a good measure of it.

- In such instances we can apply a suitable change to the input of the system before the impending disturbance has had an effect.

- The typical setup of the feedforward control system is as follows:



- Clearly, feedforward control requires *a priori* (or advance) knowledge of disturbances and a reliable means of measuring these.

- However, the biggest drawback of feedforward control is that it remains susceptible to both external disturbances which are unforeseen and/or not easily measured and variations in the system parameters.

- Feedfoward control cannot compensate for these effects as it does not monitor the final output of the system.

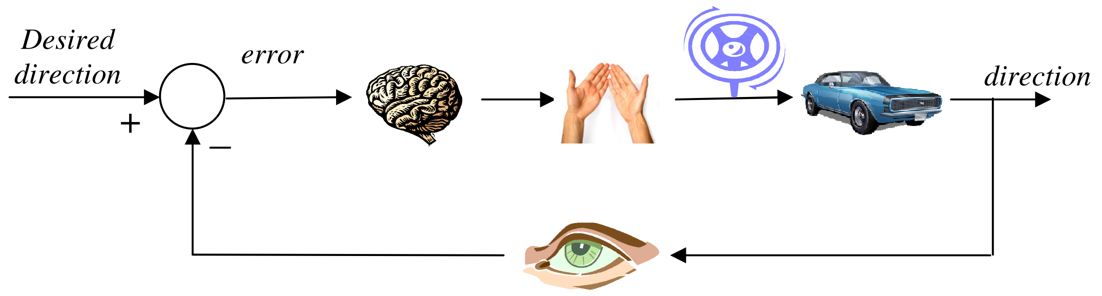
- Note, in practice feedforward and feedback control are typically used together to produce an overall better controlled system.

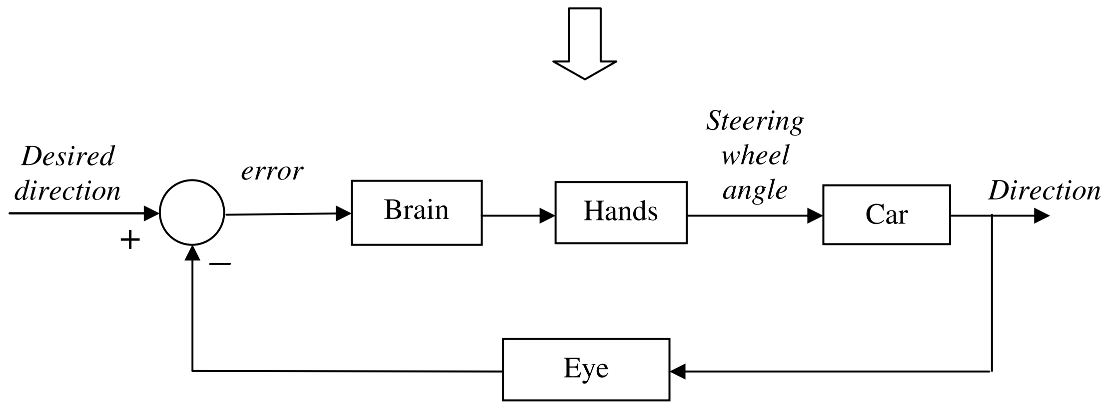
- In this module we are only going to consider feedback control.

1.4 Basic components of a feedback control system

- Consider driving a car with us, the human, as the controller. Now, let's say that we wish to change direction …

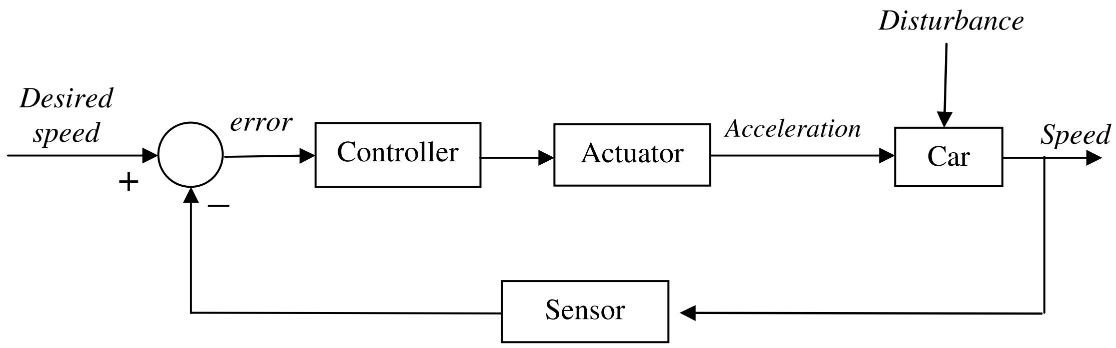
- We can represent this important (manual) feedback control system as follows:





- Interestingly, while the controlled system is the car, the input and output of the system can be different – depending on the control objectives.

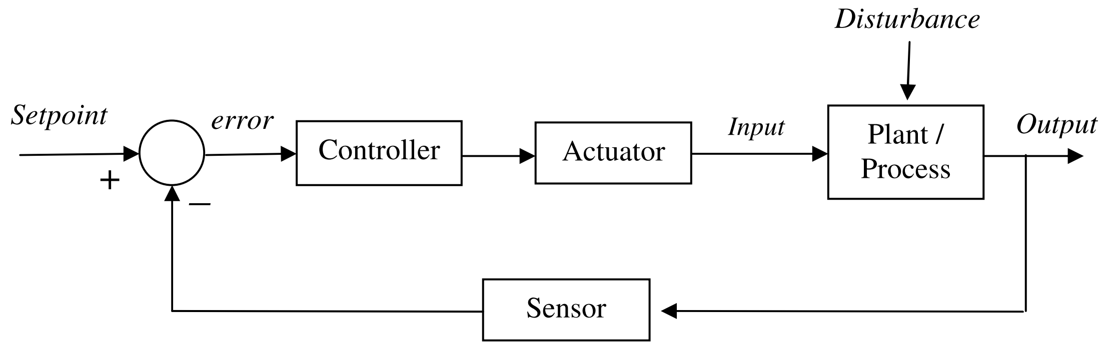
- Thus, for example, let us now consider a car cruise control system that aims to maintain a constant speed. Such a control system might take the following form:



- Here, the sensor is the mechanism by which we detect speed of the car, the actuator is the mechanism by which we affect the input to the car (in this case, the accelerator) and the disturbance would be altitude changes in the road surface.

- More importantly, note the similarity between these two control systems.

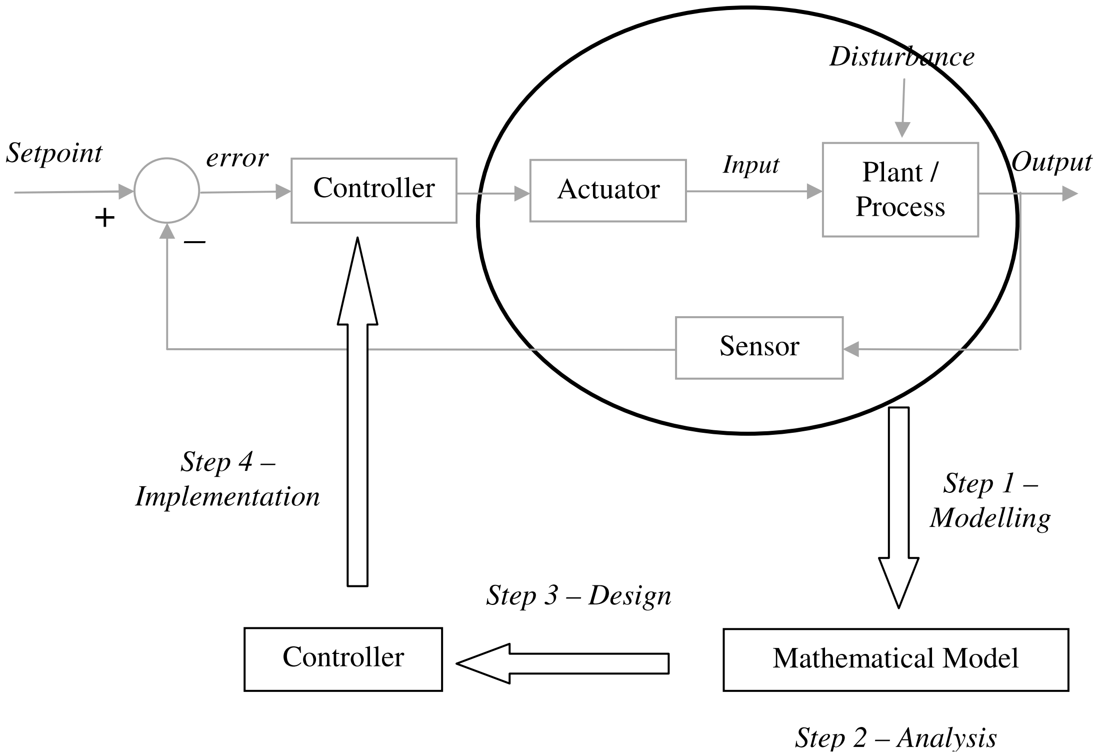
- All such feedback control systems contain the same basic components as follows:



- This represents the **standard closed-loop control system** where:
  - The **plant or process** is the system to be controlled
  - The **sensor** is the device used to measure the output
  - The **controller** is the device that outputs an appropriate control signal based on the difference between the measures output and the desired setpoint (or reference point).
  - The **actuator** is the mechanism that changes the input to the plant.
  - The **disturbance** represents any external factors that can affect the performance of the plant.

- The ultimate challenge presented to us with feedback control systems is one of **designing and implementing a suitable controller** such that the output of the system follows the setpoint in a satisfactory manner even when it is subject to external disturbances.

- The process by which we design a controller follows 4 important steps, namely **modelling, analysis, design** and **implementation**:



- Thus, in order to implement a controller, we must first obtain a model of the underlying system.

- This allows us to analyse the system which, in turn, provides us with the necessary information to design a suitable controller for the system.

- The previous diagram provides both the motivation and the **outline for the remainder of this module**:

Systems (§2)
- the basics
- dynamical systems
- categorizing systems

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Modelling (§3, §4)
- basic first and second order systems
- transfer function representation
- Laplace Transforms

⇒

Analysis (§5, §6, §7, §8)
- block diagram analysis
- time response
- stability
- transient and steady-state

⇓

Controller Design (§9)
- on/off control
- PID controller

Supported by simulation (Matlab & Simulink) & practical laboratories

- *This module provides the foundation for several other modules throughout the BE programme, including EE211 System D ynamics and EE311 Control Systems Design.*

'WELL, HIGGINS, I SEE EVERYTHING'S UNDER CONTROL.'