# Design of Feedback Control Systems

## Lecture 1

# Introduction

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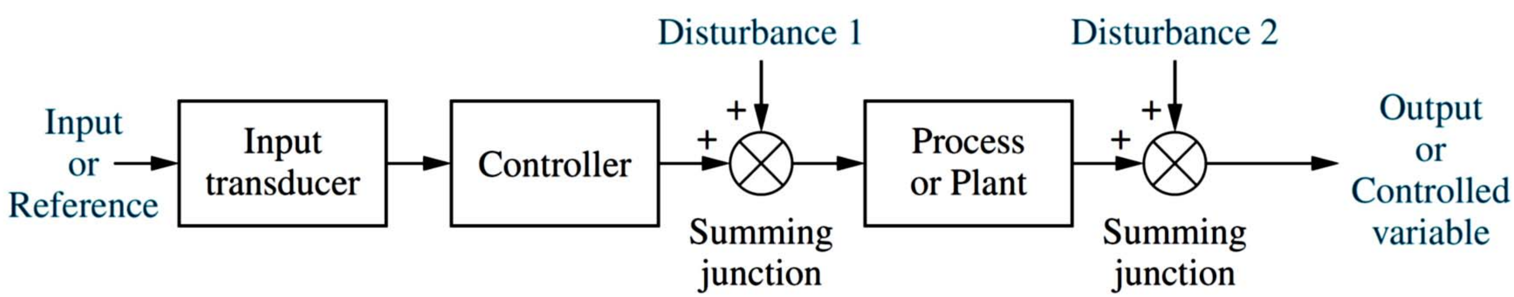
## *What is Feedback Control System?*

- **Feedback control of dynamic systems is a very old concept with many characteristics that have evolved over time.**
- **The central idea is that a dynamic system's output can be measured and fed back to a controller of some kind then used to affect the system.**
- **A system that involves a person controlling a machine, as in driving an automobile, is called manual control.**
- **A system that involves machines only, as when room temperature can be set by a thermostat, is called automatic control.**
- **Systems designed to hold an output steady against unknown disturbances are called regulators, while systems designed to track a reference signal are called tracking or servo systems.**
- **Control systems are also classified according to the information used to compute the controlling action.**
- **If the controller does not use a measure of the system output being controlled in computing the control action to take, the system is called *open-loop control*.**
- **If the controlled output signal is measured and fed back for use in the control computation, the system is called *closed-loop or feedback control*.**

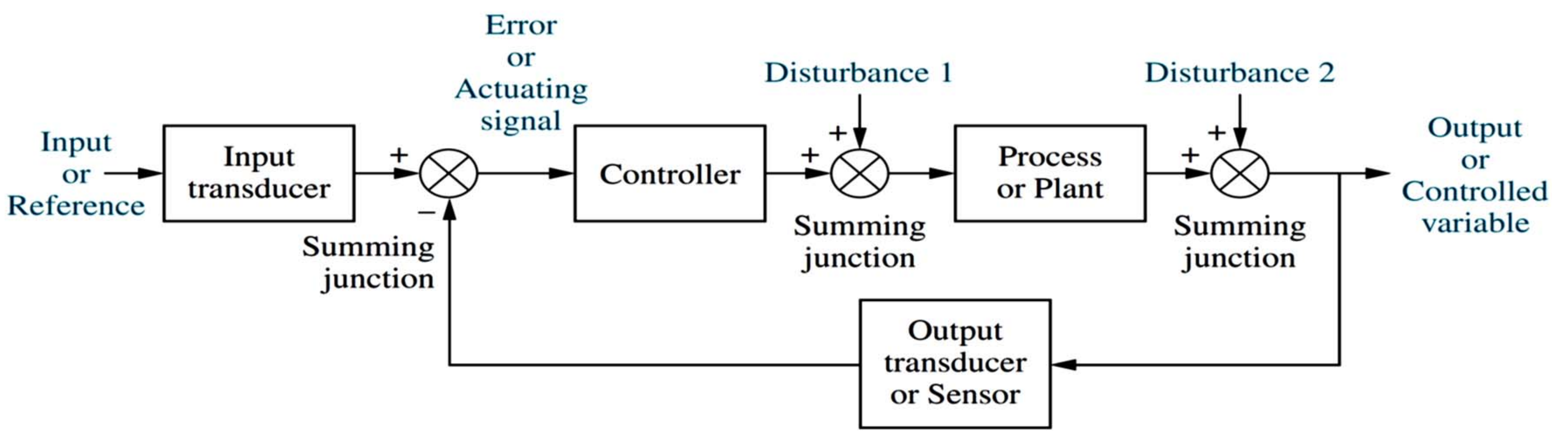
## Open loop

- **The output variables do not affect the input variables**
- **The system will follow the desired reference commands if no unpredictable effects occur**
- **It can compensate for disturbances that are taken into account**
- **It does not change the system stability**



## Closed loop

- The output variables do affect the input variables in order to maintain a desired system behavior
- Requires measurement (controlled variables or other variables)
- Requires control errors computed as the difference between the controlled variable and the reference command
- Computes control inputs based on the control errors such that the control error is minimized
- Able to reject the effect of disturbances
- Can make the system unstable, where the controlled variables grow without bound



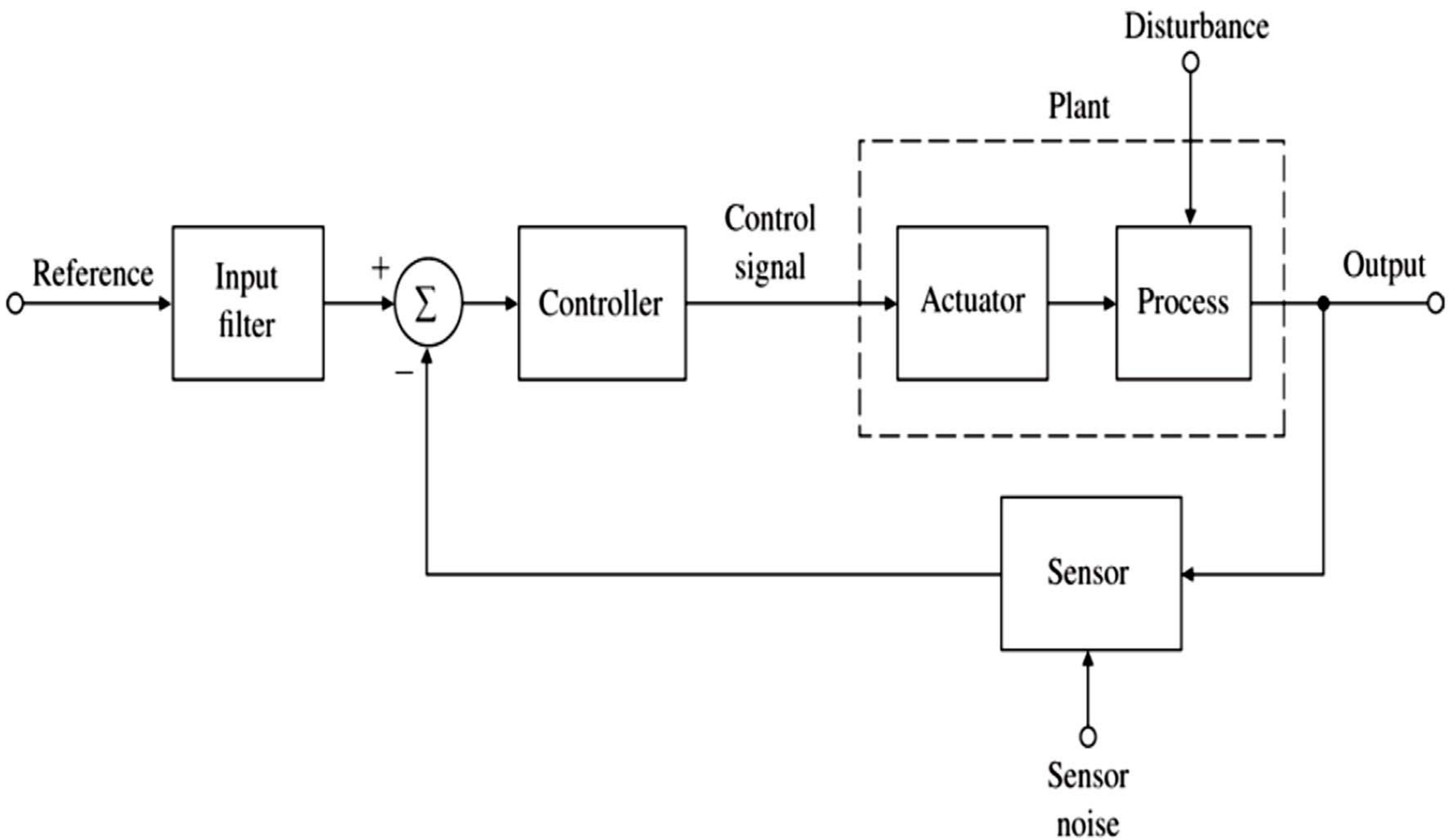
## *Advantages of Closed-Loop Systems*

- **Faster response to an input signal**
- **Effective disturbance rejection**
- **Better tracking of reference signals**
- **Low sensitivity to system parameter errors (e.g., errors in plant or controller gains)**
- **Low sensitivity to changes in calibration errors (recalibration is unnecessary)**
- **More accurate control of plant under disturbances and internal variations**
- **Effective and flexible control tuning by varying the control gain**
- **Used to stabilize systems that are inherently unstable in the open-loop form**

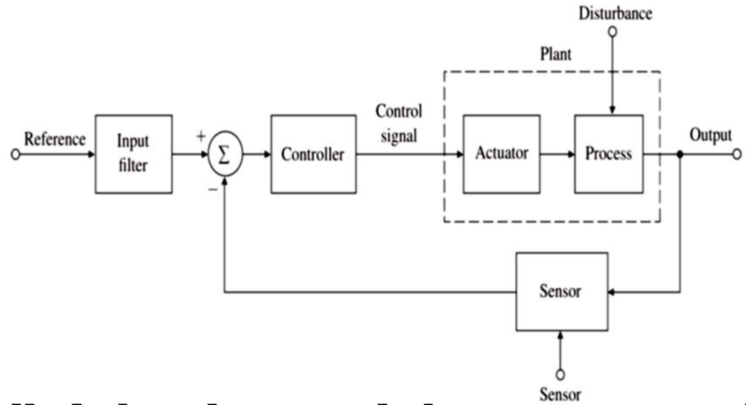
## *Disadvantages of Closed-Loop Systems*

- **Require the use of sensors which increase the system costs**
- **Involve more components which leads to more costs and complexity**
- **The power costs (due to high gains) are high**
- **More complex design, harder to build**
- **Sometimes obtaining the output measurement is either hard or not economically feasible**
- **Initial tuning is more difficult, especially if the bandwidth is narrow**
- **There is always a steady state error (with proportional controllers)**
- **The system tends to become unstable as the gain is increased beyond certain limits**
- **Closed-loop control methods are unnecessary when system inputs and the plant model are known with total certainty, and there are no external disturbances**
- **Closed-loop systems are not always controllable**

***Essentially, the advantages of closed-loop systems are the disadvantages of open-loop systems, and the disadvantages of closed-loop systems are the advantages of open-loop systems.***




- **The central component of this feedback system is the process whose output is to be controlled.**
- **The actuator is the device that can influence the controlled variable of the process.**
- **Generally, the process and the actuator are intimately connected and the control design centers on finding a suitable input or control signal to send to the actuator.**




- **The combination of process and actuator is called the plant, and the component that actually computes the desired control signal is the controller.**
- **Sensor selection and placement are very important in control design, for it is sometimes not possible for the true controlled variable and the sensed variable to be the same.**
- **Finally, there is a controller to compute the difference between the reference signal and the sensor output to give the controller a measure of the system error.**
- **The process of learning the desired setpoint is an example of artificial intelligence (AI) or machine learning, which is gaining acceptance in many fields as the power and affordability of computers improve.**
- **The combination of feedback control, AI, sensor fusion, and logic to tie it all together will become an essential feature in many future devices such as drones, driverless cars, and many others.**

**To achieve good control there are typical goals:**

- **Stability: The system must be stable at all times. This is an absolute requirement.**
- **Tracking: The system output must track the command reference signal as closely as possible.**
- **Disturbance rejection: The system output must be as insensitive as possible to disturbance inputs.**
- **Robustness: The aforementioned goals must be met even if the model used in the design is not completely accurate or if the dynamics of the physical system change over time.**

**Feedback control systems can be classified in a number of ways, depending on the purpose of the classification:**

- **Based on the method of analysis and design, control systems are classified as *linear or nonlinear, and time-varying or time-invariant*.**
- **When considering the type of signals used in the system, reference is often made to *continuous-data and discrete-data systems, or modulated and unmodulated systems*.**
- **Control systems arc also often classified according to the purpose of the system.**
- **For instance, a position-control system and a velocity-control system control the output variables according to ways implied by the names.**
- **The classification of a control system can also be defined according to the form of the open-loop transfer function.**
- **In general, there are many other ways of identifying control systems according to some special features of the system.**
- **It is important that some of these more common ways of classifying control systems are appreciated so that a proper perspective is gained before embarking on the analysis and design of these systems.**

**The different classification strategies can be summarized as follows:**

- **Linear vs. nonlinear control systems**
- **Time-variant vs. time-invariant control systems**
- **Continuous-data vs. discrete-data control systems**
- **Single-input single-output (SISO) vs. multiple-input multiple-output (MIMO) control systems**
- **Regulator vs. tracking control systems**
- **Purpose of control (e.g., position control or velocity control)**
- **Form of open-loop transfer function**

- **Engineering design is both an art and a science that together constitute one of the main functions of an engineer.**
- **It is a complex process in which both creativity and analysis play major roles.**
- **Design is the process of conceiving or inventing the forms, parts, and details of a system to achieve a specified purpose.**
- **Design actively can be thought of as planning for the emergence of a particular product or system.**
- **Design is an innovative act whereby the engineer creatively uses knowledge and materials to specify the shape, function, and material content of a system.**

**The control system design process can be summarized as follows:**

- **Establishment of control goals**
- **Identification of the variables to be controlled**
- **Development of the specifications for the variables**
- **Establishment of the system configuration and identification of the actuator**
- **Design of the controller and selection of parameters to be adjusted**
- **Optimization parameter and analysis of performance**
- **Verification and validation of design**

- **If the performance does not meet the specifications, then the configuration and the actuator are iterated.**
- **If the performance meets the specifications, the design is finalized and the parameters adjusted accordingly.**
- **The design is finalized and the results are then documented.**
- **If the performance still does not meet the specifications, there is a need to establish an improved system configuration and perhaps select an enhanced actuator and sensor.**
- **The design process is then repeated until the specifications are met, or until a decision is made that the specifications are too demanding and should be relaxed.**
- **the performance specifications could describe how a closed-loop system should perform and will include:**
  - ***Effective disturbance rejection***
  - ***Fast and desirable system response***
  - ***Realistic actuator signals***
  - ***Low sensitivities to parameter variations***
  - ***Robustness***

***End of Lecture 1!***