Industrial Control System

Introduction

S.Venkatesan

Acknowledgement: The contents, example scripts and some figures are copied from various sources.
Thanks to all authors and sources made those contents public and usable for educational purpose

System

Example
•System: Fan without leaf
•Control System: Fan with leaf

Control System

- Control systems receive data from remote sensors measuring
  - process variables (PVs), compare the collected data with
  - desired setpoints (SPs), and derive command functions that are used to control a process through
  - the final control elements (FCEs), such as control valves.

Control Loop

- A control system is defined as a system of devices that manages, commands, directs, or regulates the behavior of other devices or systems to achieve a desired result.

- **A control system achieves this through control loops, which are a process designed to maintain a process variable at a desired set point**.

Discrete Controllers

- Discrete Controllers
  - The variables and parameters are discrete.
- Continuous Controllers
  - the variables and parameters are continuous and analog
  - the physical system will be shown through variables and it will be smooth and uninterrupted in time.

Continuous Control

- Continuous process control - measure the weight and also the volume of liquid and solid
- Discrete process control - measure the number of parts and products.

- Measurement
  - The continuous control would measure variables and parameters such as temperature, volume flow rate, and pressure.
  - The discrete control would measure velocity, force, position, and acceleration.

- Sensor
  - Continuous Control - Flow meters and thermocouples are the most used sensors in a continuous control
  - Discrete Control - Photoelectric sensors and strain gauges are used

- Actuators
  - Continuous Control - Valves, pumps, and heaters
  - Discrete Control - motors, pistons and switches are used.

Control Loop

- Open Loop: It will not use the process variable however control the system through the different mode for example time. A motor that runs to fill the water automatically stops after 10 minutes and again starts in the next 10 minutes.

- Closed: In the closed loop the process variable will be considered to control the system. The process variable is given as the feedback.

Open Loop Controller

- No Feedback
- No Measurement

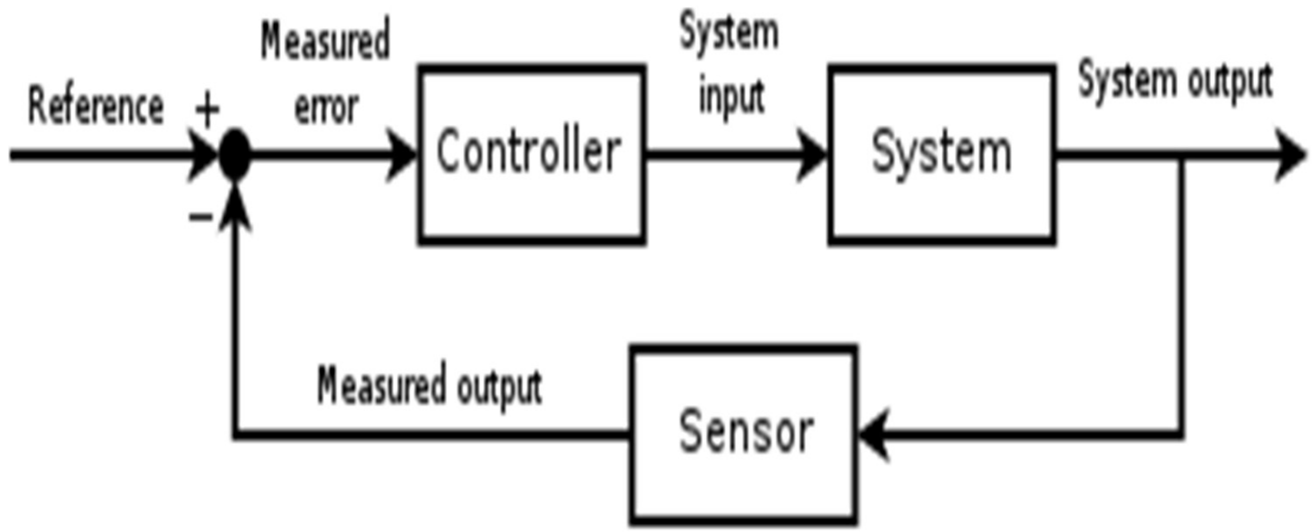
Closed Loop Controller

- Sensor Monitors
- Matching with SV and PV

Feedback Control System

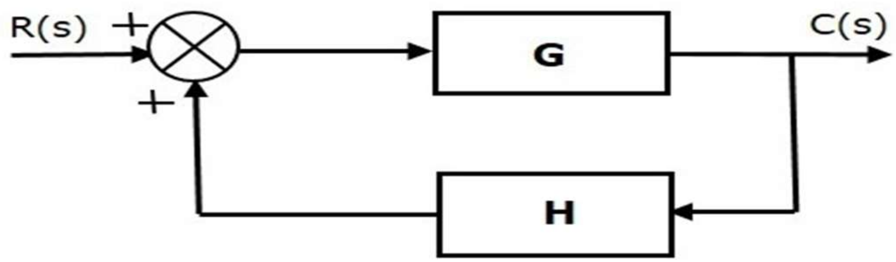
- Positive – Adds the desired and output
- Negative – Subtracts the desired and output

Negative Feedback Control Loop

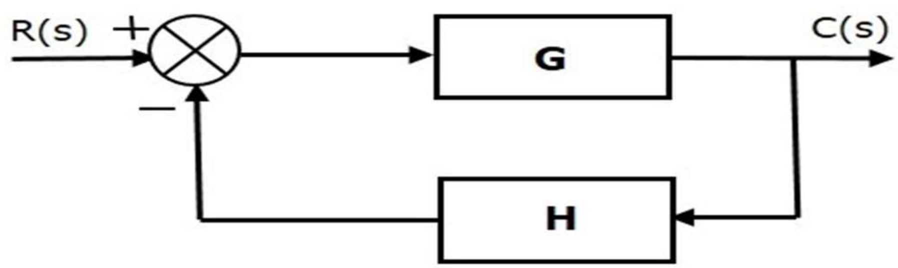


Feedback

- The feedback can be of two types
  - Positive feedback:



  - Negative feedback:

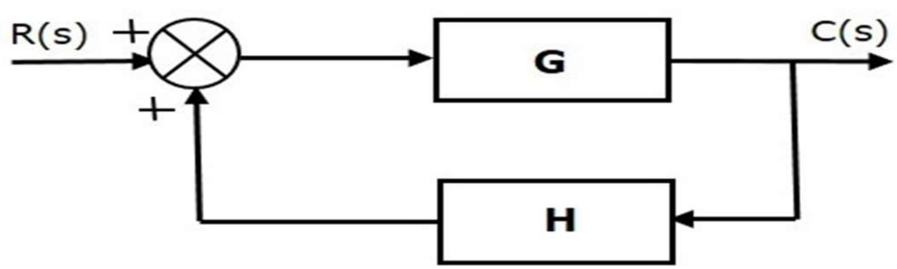


Transfer Function

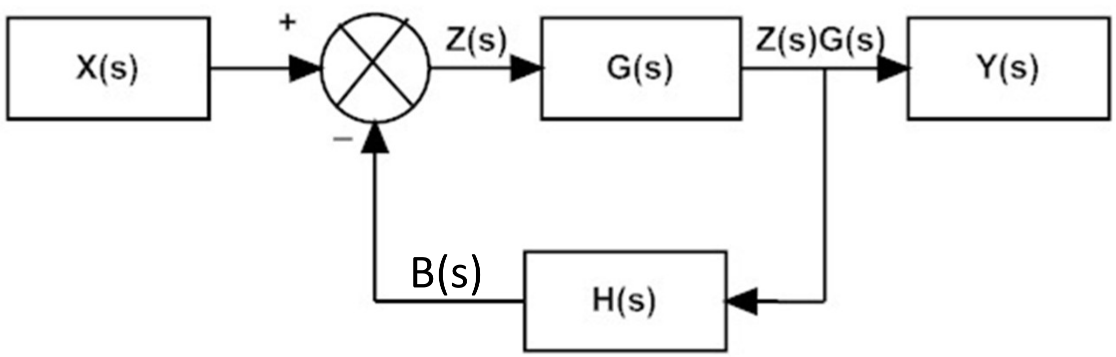
- The **Transfer Function** of any electrical or electronic control system is the mathematical relationship between the systems input and its output, and hence describes the behaviour of the system.

- Note also that the ratio of the output of a particular device to its input represents its gain. Then we can correctly say that the output is always the transfer function of the system times the input.

$$T = \frac{G}{1 - GH}$$



Transfer Function



- Y(s) = Z(s)*G(s)
- Z(s) = B(s)–X(s)
- B(s) = H(s)*Y(s)

Y(s) = Z(s)*G(s)
Y(s) = (X(s)-B(s)) * G(s)
Y(s) = (X(s) - H(s)*Y(s))*G(s)
Y(s) = X(s)*G(s) - H(s)*Y(s) *G(s)
Y(s) + H(s)*Y(s) *G(s) = X(s)*G(s)
Y(s) (1 + H(s) *G(s)) = X(s)*G(s)

$$\frac{Y(s)}{X(s)} = \frac{G(s)}{1 + H(s)G(s)}$$

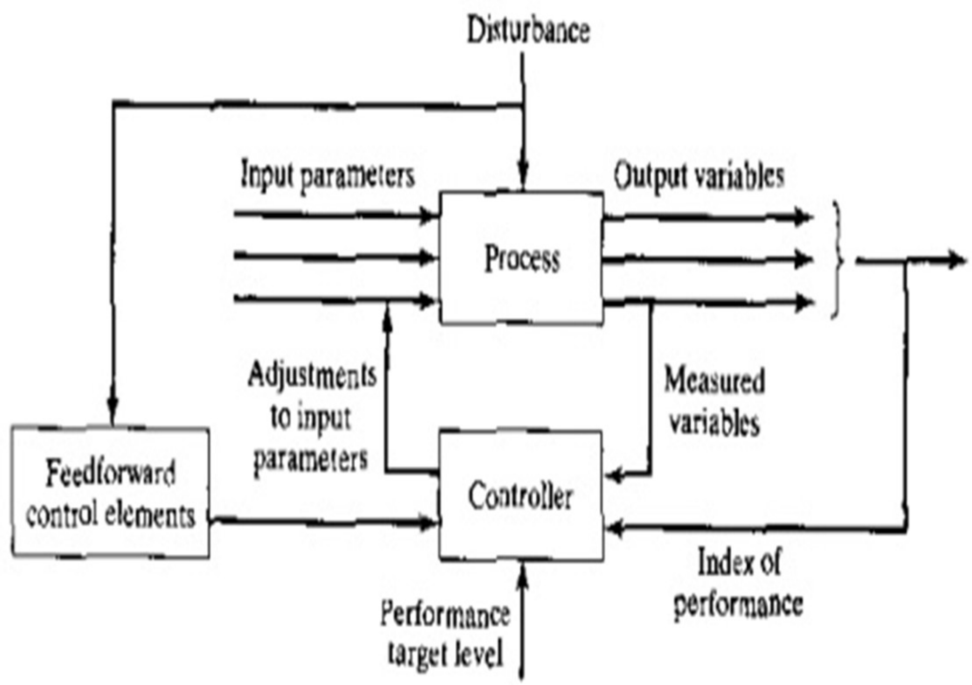
Feedforward Control

A feedforward control system improves system performance by taking preemptive action based on known or anticipated disturbances rather than reacting to the system's output.

- It sense the presence of a disturbance and take corrective action by adjusting a process parameter that compensates for any effect **the disturbance will have on the process**.

- In the ideal case, the compensation is completely effective.

- However, complete compensation is unlikely because of imperfections in the feedback measurements, actuator operations, and control algorithms, so feedforward control is usually combined with feedback control, as shown in the figure.



Industrial Control System (ICS)

- It is an electronic control system and associated instrumentation used for industrial process control.

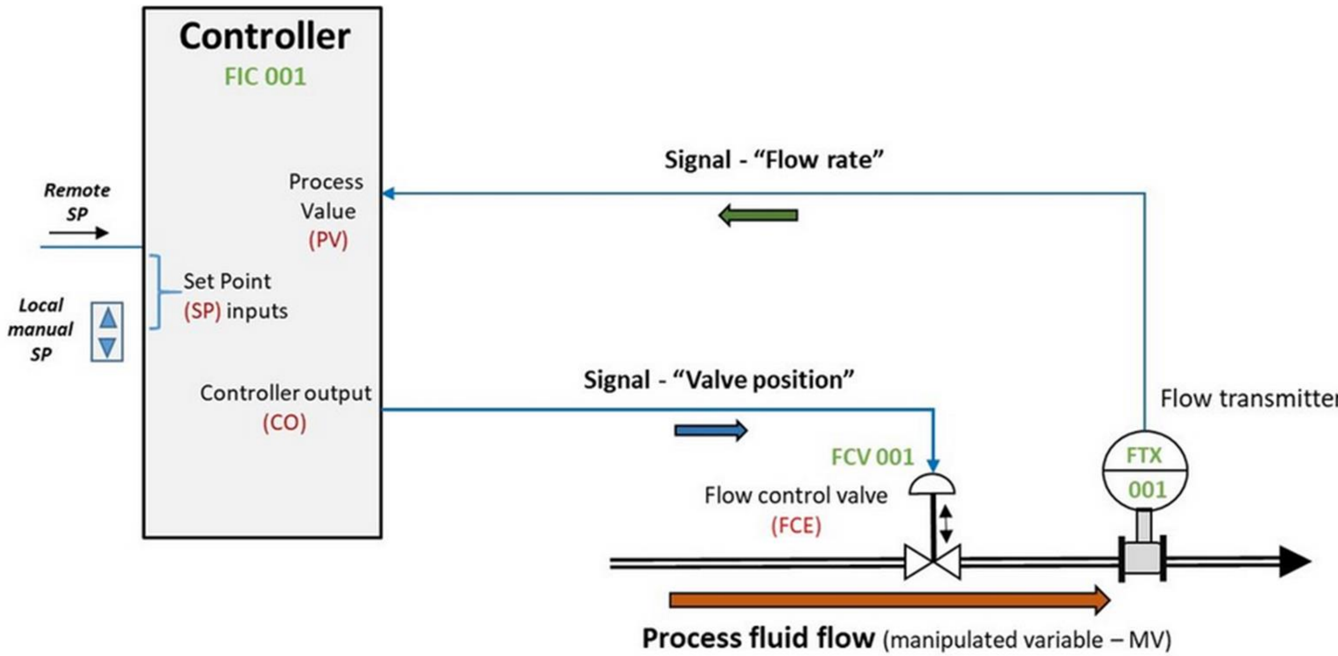
- Control systems can range in size from a few modular panel-mounted controllers to large interconnected and interactive distributed control systems (DCSs) with many thousands of field connections.

Program Logic Controller

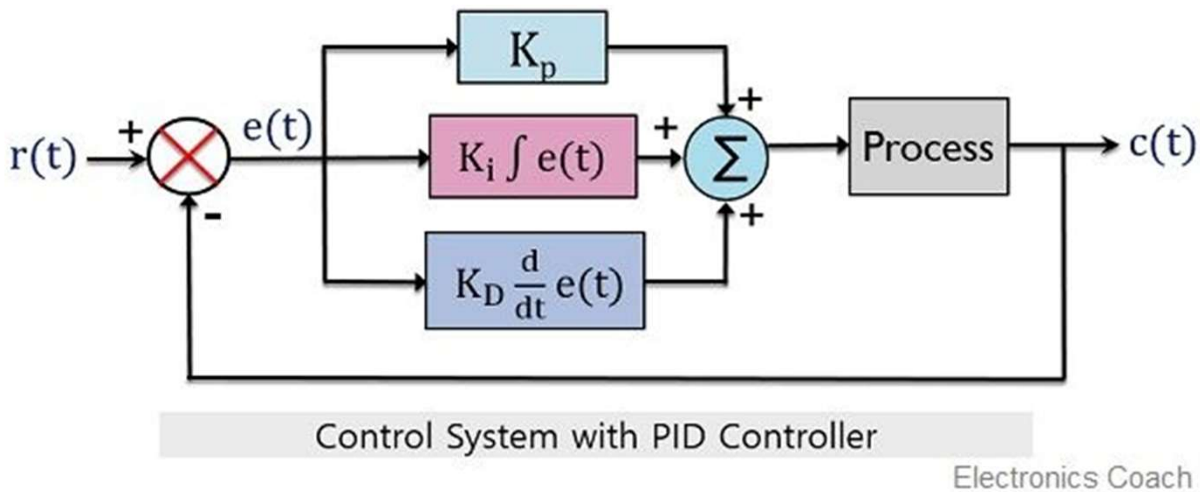
- Digitally operating electronic system to implement
  - Logic
  - Timing
  - Counter
  - Sequencing

- Uses memory for storing the instructions.

Industrial Control Loop



Proportional Integral Derivative (PID)



Control System with PID Controller

- **Proportional (P) control**: This component adjusts the output of the process based on the current error between the setpoint and the process variable (PV). The larger the error, the larger the correction applied.

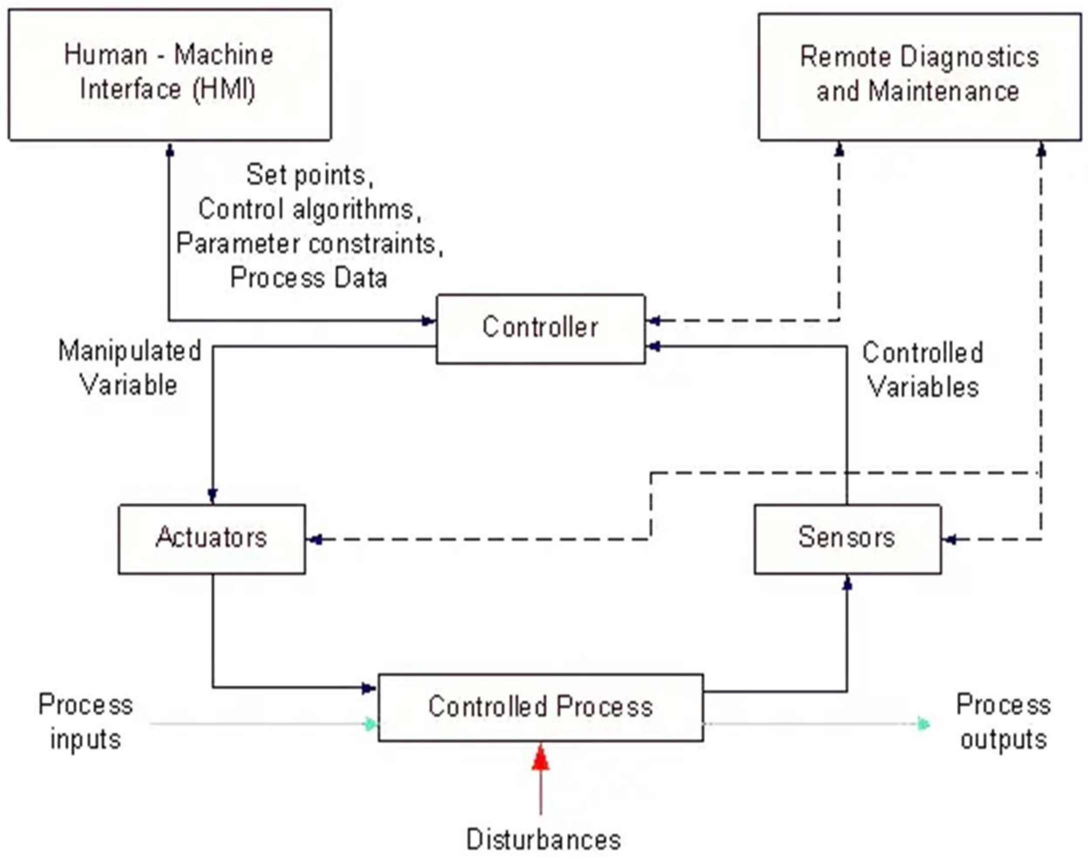
- **Integral (I) control**: This component adjusts the output based on the accumulated error over time. It helps eliminate steady-state error and can improve the stability of the control system.

- **Derivative (D) control**: This component adjusts the output based on the rate of change of the error. It helps to dampen oscillations and improve the stability of the control system but is often omitted because PI control is sufficient. The derivative term can amplify measurement noise (random fluctuations) and cause excessive output changes. Filters are important to get a better estimate of the process variable rate of change.

PID vs PLC

- Hardware
  - PLC – Combination of different hardware and Software Components
  - PID – Standalone control device
- Function
  - PLC – Digital Logic
  - PID – Analog however available for digital
- Application
  - PLC – Specific Applications
  - PID – Versatile
- Cost
  - PLC – Costly
  - PID – Comparatively Low

ICS Operation and Components



Layers (Levels)

- **Level 0:** includes the physical components that build products. Level 0 devices include motors, pumps, sensors, valves, etc.

- **Level 1**: composed of systems that monitor and send commands to the devices at Level 0. Examples include Programmable Logic Controllers (PLCs), Remote Terminal Units (RTUs), and Intelligent Electronic devices (IEDs).

- **Level 2:** devices that control the overall processes within the system. For example, human-machine interfaces (HMAs) and SCADA software enable humans to monitor and manage the process.

Air-Gapping ICS

- The ICS network is absolutely air-gapped/isolated from internet and corporate networks; therefore there is no cyber risk.

- Is it vulnerable to the attack?

Reference

- https://www.ewh.ieee.org/sb/iiee/new/tutorials/feedback.pdf
- https://www.physicsforums.com/threads/help-with-integral-time-ti-and-derivative-time-td.857205/
- https://apmonitor.com/pdc/index.php/Main/ProportionalIntegralDerivative
- https://www.youtube.com/watch?v=WOeMqgyJK-A
- https://colab.research.google.com/github/APMonitor/pdc/blob/master/pid_widget.ipynb#scrollTo=IiBEa7JVk6iB