Feedback Control System Design

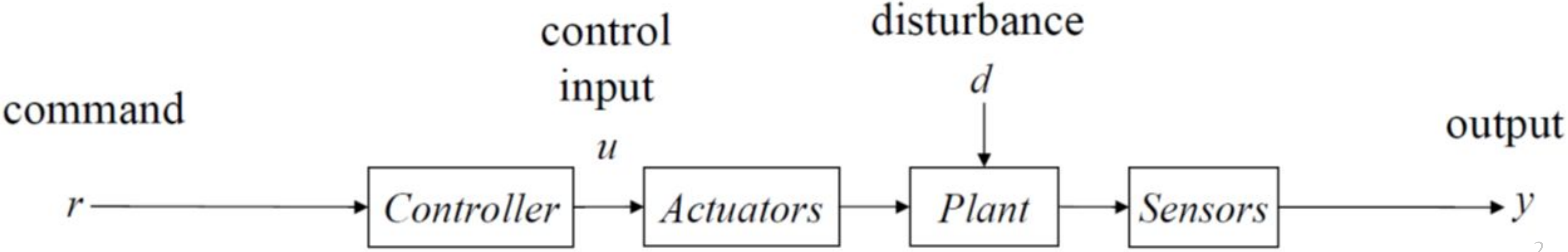
Nimal Skandhakumar

Faculty of Technology
University of Sri Jayewardenepura

2019

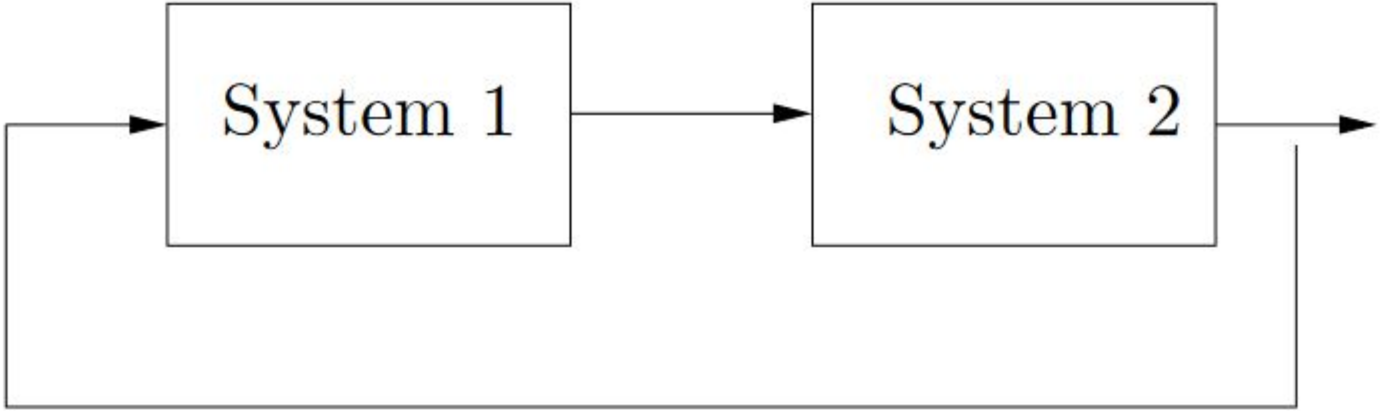
Types of Control Systems - Open loop

- 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



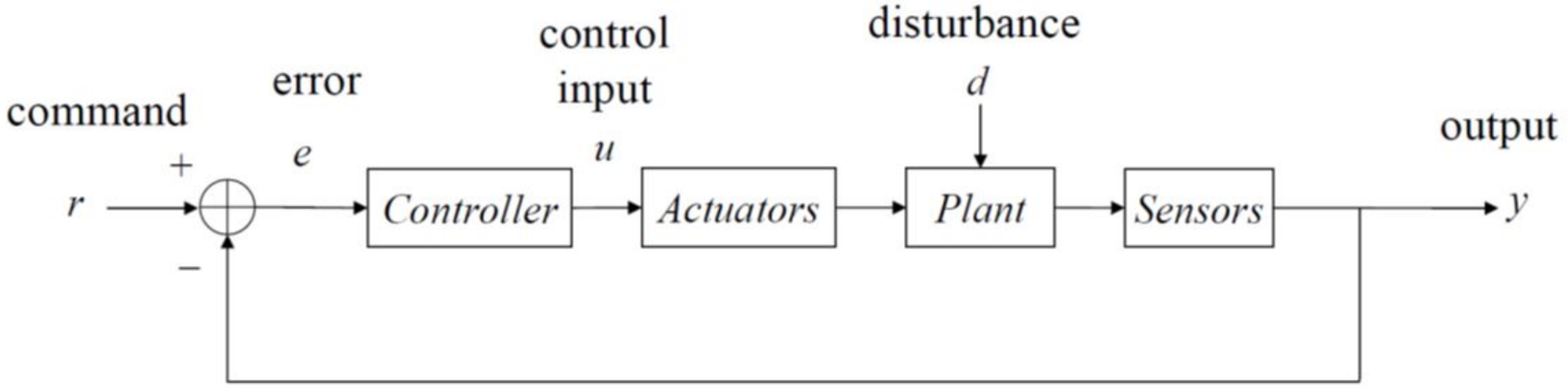
Types of Control Systems - Closed loop/Feedback

- The output variables do affect the input variables in order to maintain a desired system behaviour
- Requires measurement (controlled variables or other variables)
- Requires control errors computed as the difference between the controlled variable and the reference command



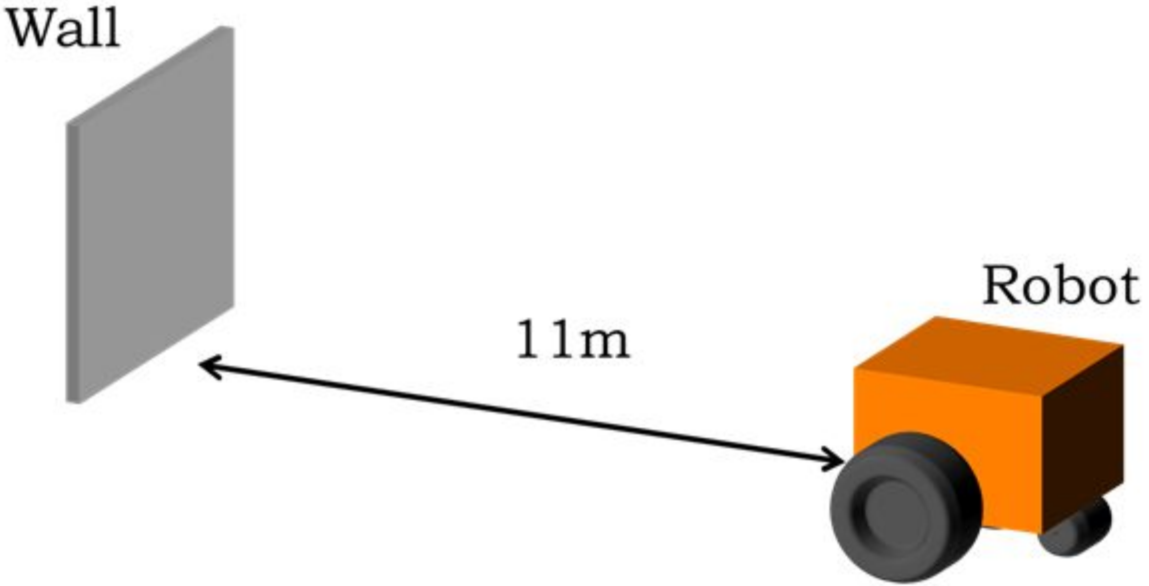
Types of Control Systems - Closed loop/Feedback

- 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



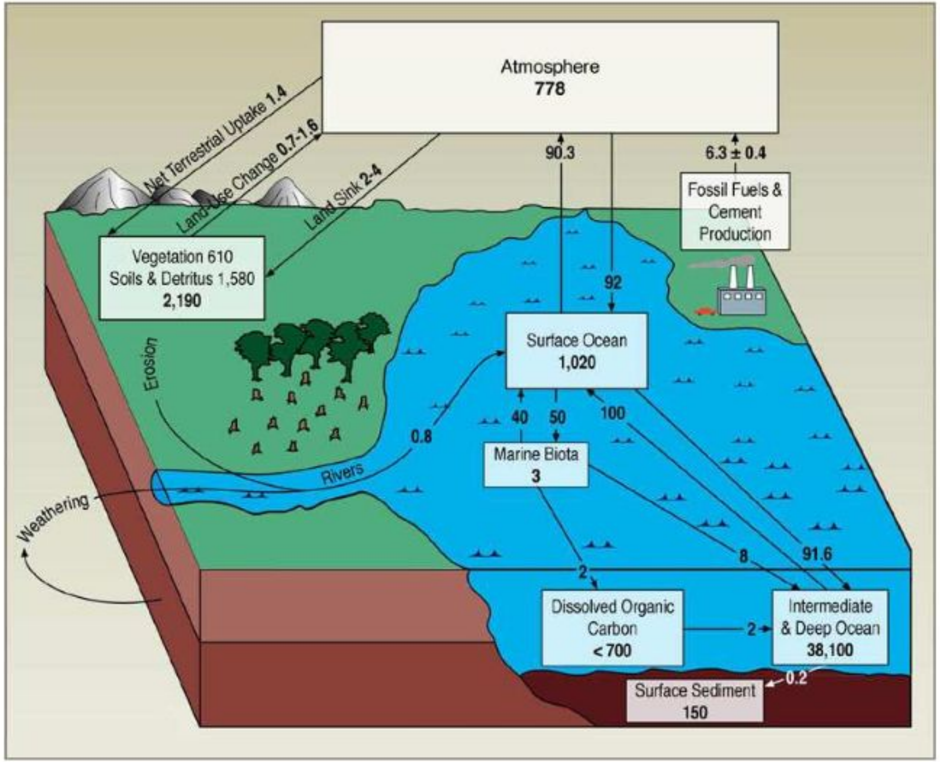
A Hitting the Wall Example

- A simple robot that moves forward when turned on.
- Task: Move from initial position to destination 1 meter from wall.
- Q? Give two control strategies, open loop and closed loop..



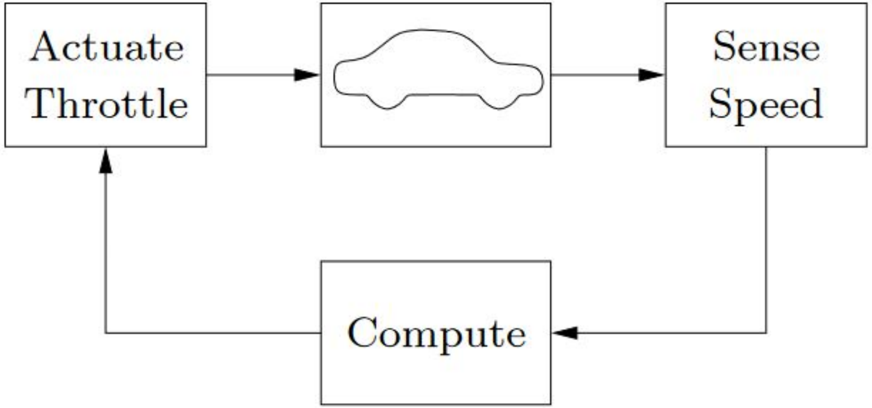
Example of a feedback system in nature

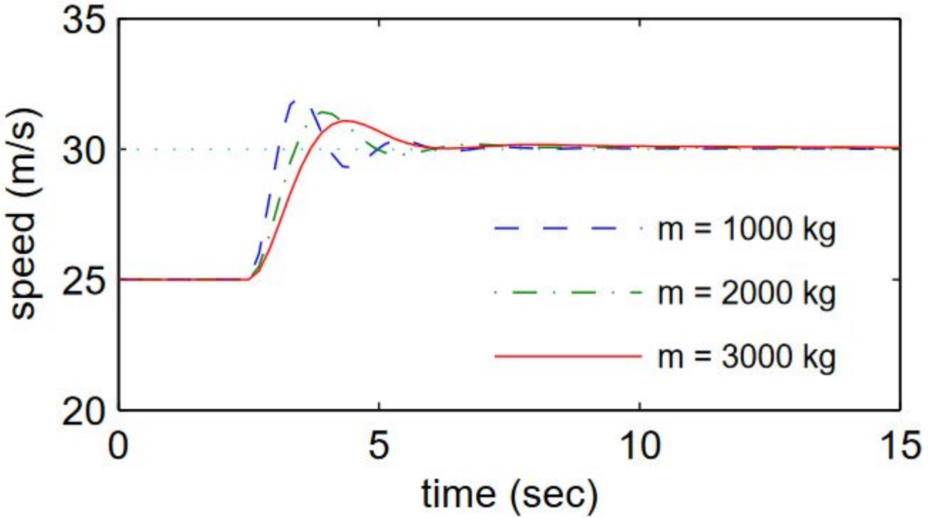
- Global carbon cycle



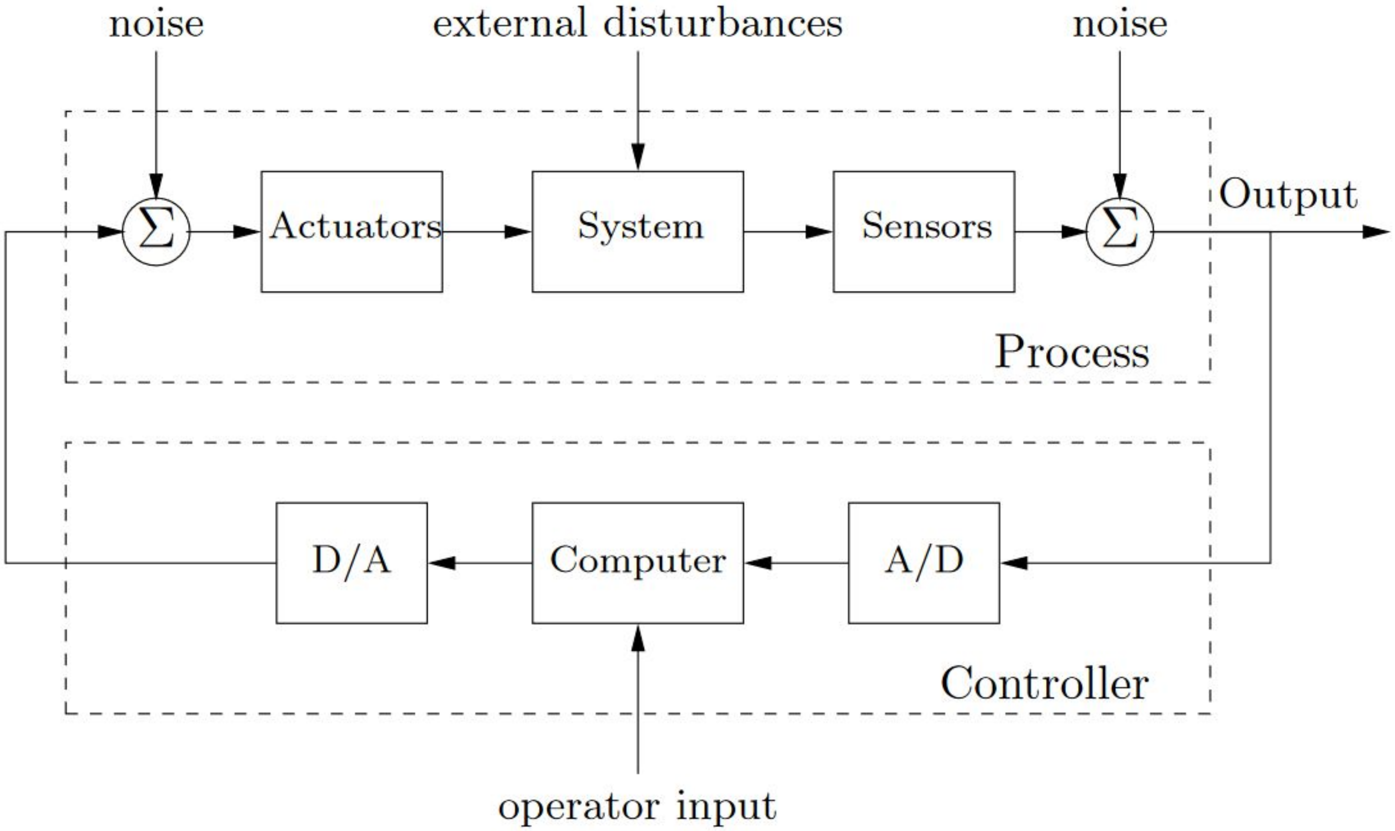
Example of feedback system using digital control

A simple feedback system for controlling the speed of a vehicle.

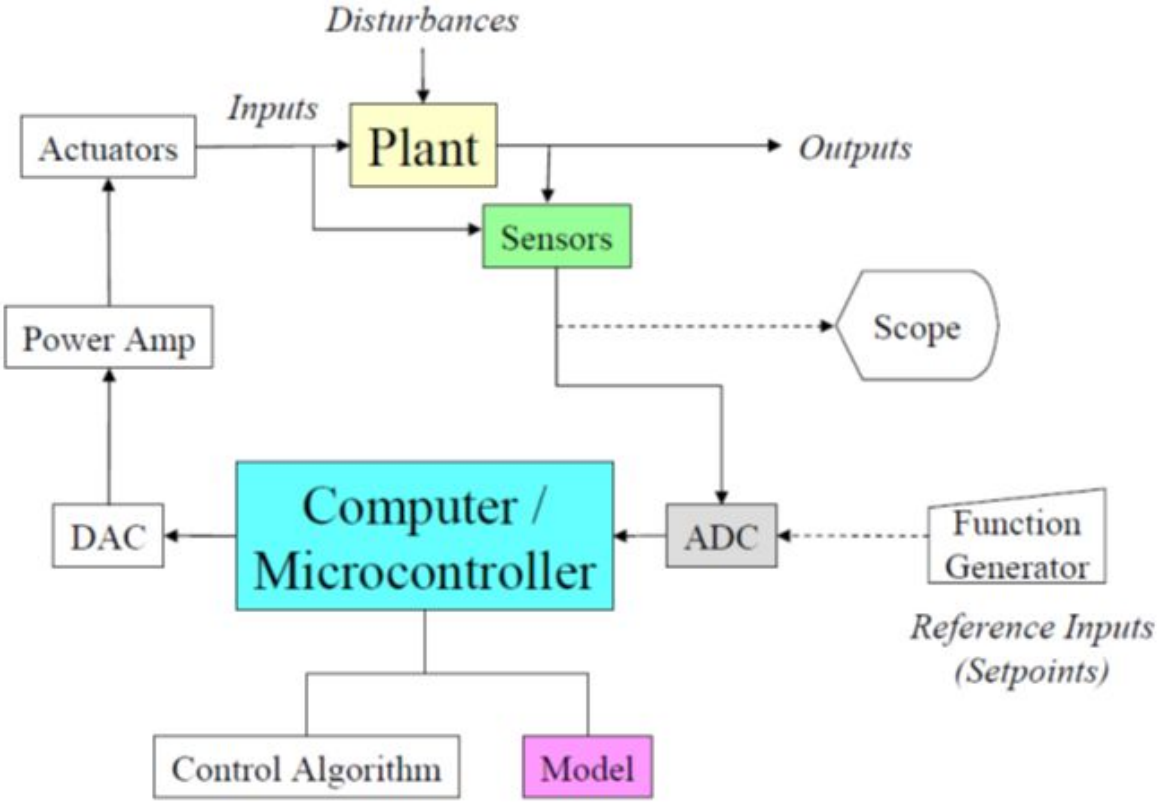




Components of a computer controlled system



Overview of Closed Loop Control Systems



Compensation

- What is system compensation?
  - Given the control plant, the procedure of controller design to satisfy the requirement is called system compensation.
- Why to compensate?
  - The closed-loop system has the function of self-tuning.
    - By selecting a particular gain value K, some single performance requirement may be met.
  - Is it possible to meet more than one performance requirement?
    - Sometimes, it is not possible.
  - Something new has to be done to the system in order to make it perform as required.

Compensation

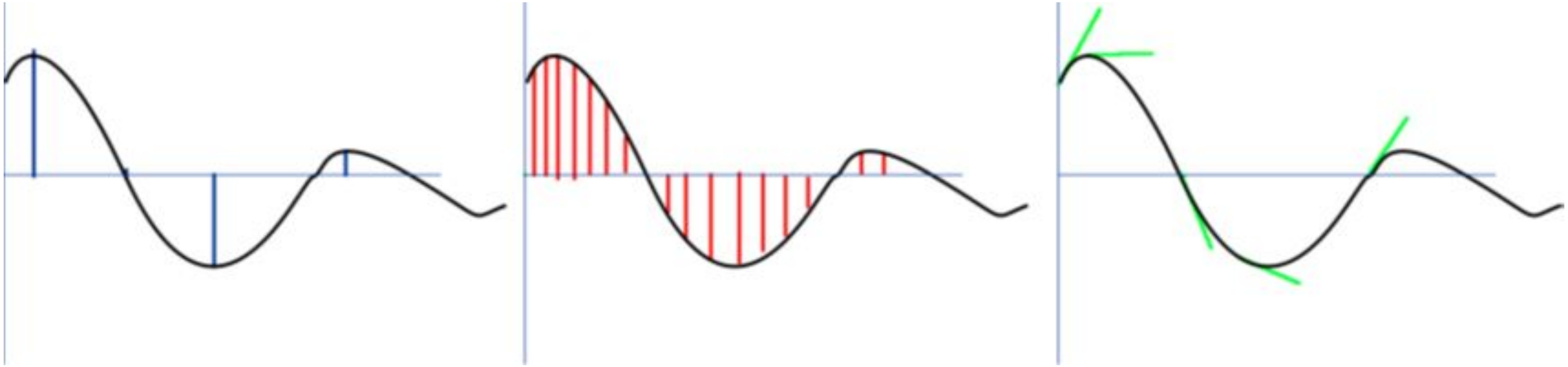
- The design of a control system is concerned with the arrangement of the system structure and the selection of a suitable components and parameters.
- A compensator is an additional component or circuit that is inserted into a control system to compensate for a deficient performance.
- Types of Compensation:
  - Cascade compensation
  - Feedback compensation
  - Output compensation
  - Input compensation

Compensation designs

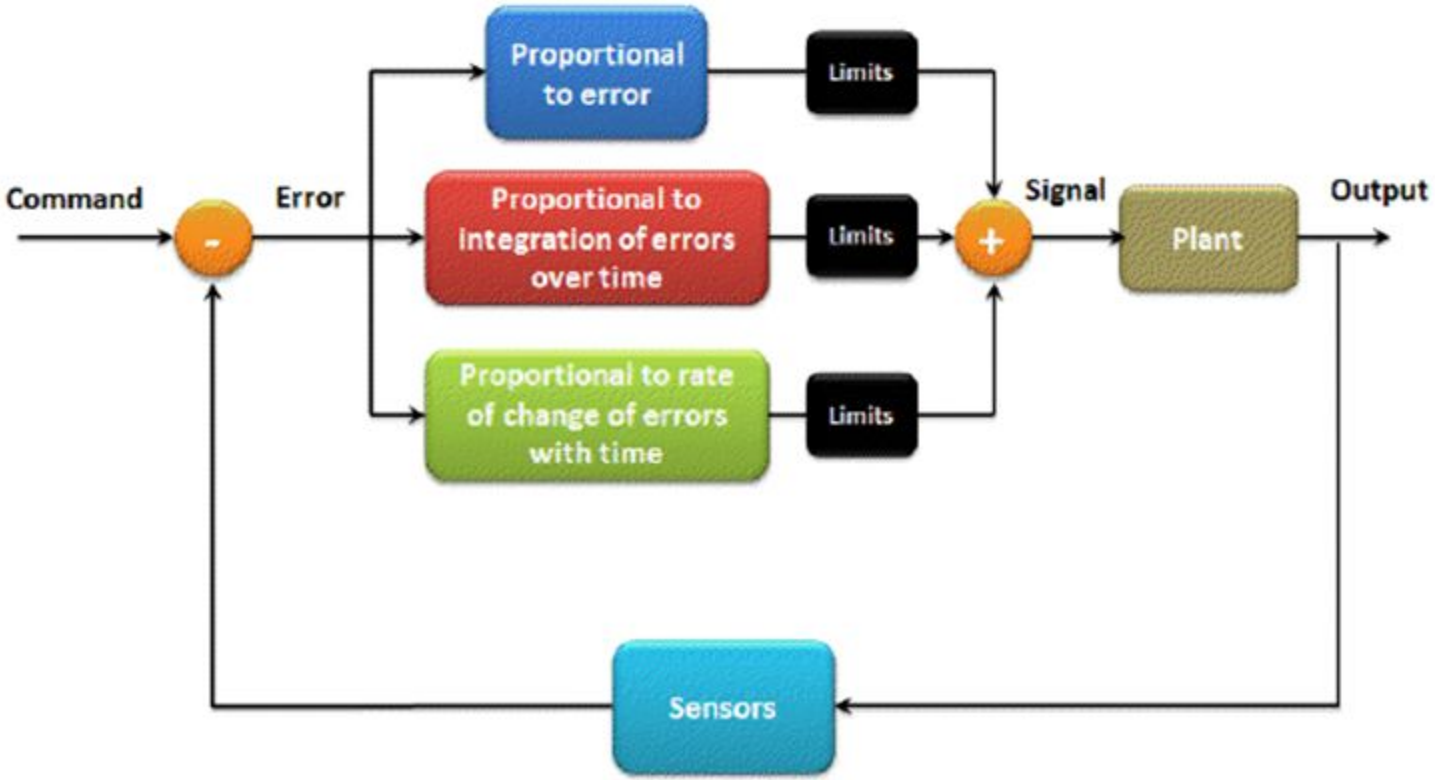
- PID Control
- Phase Lead Compensation
- Phase Lag Compensation
- Phase Lead-lag Compensation

PID Control

- Dynamic Systems controlled with a three term compensator known as PID:
  - P – Proportional Control
  - I – Integral Control
  - D – Derivative Control



PID Control

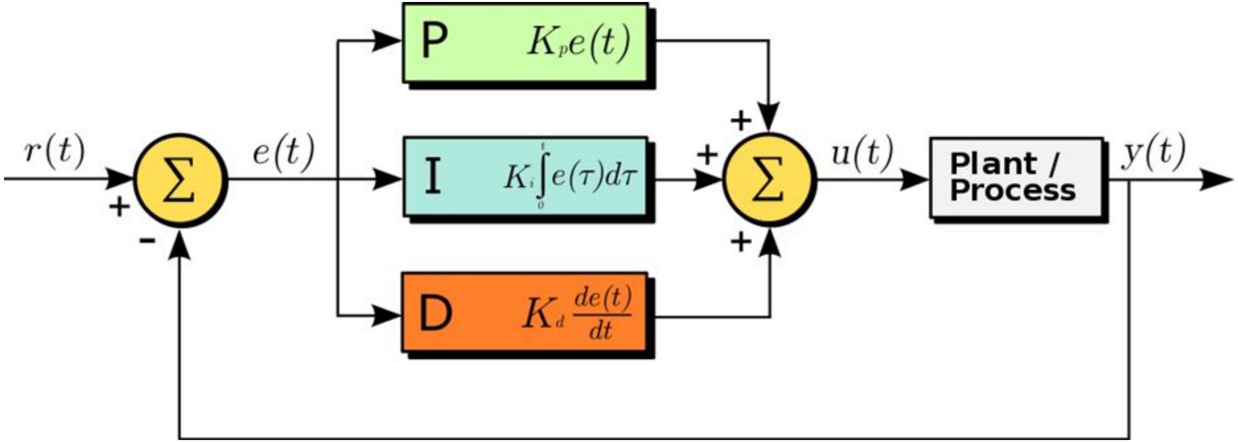


Command
-
Error
Proportional to error
Proportional to integration of errors over time
Proportional to rate of change of errors with time
Limits
Limits
Limits
+
Signal
Plant
Output
Sensors

PID Control

$$u(t) = K_p\, e(t) + K_i \int e(t) + K_d\, e(t)/dt$$

- $u(t)$ - control input
- $e(t)$ - error
- K_p - proportional gain
- K_i - integral gain
- K_d - derivative gain



PID Control

Parameters	Advantage	Limitation
K_p	Adjustment of Controller output	May cause instability
K_i	Produces zero steady state error	Slow dynamic Response and Instability
K_d	Provides rapid system response	Sensitive to Noise and non-zero offset

PID Control

- P-I-D can be independently applied based on the nature of controller
  - P controller
  - PI controller
  - PD controller
  - PID controller

Proportional (P) Controller

- Multiplies the error by the proportional gain value *K_p* to get the controller output
- Advantages
  - Easy to implement
  - Less computation needed
- Disadvantages
  - Oscillations in output may be present
  - Increases maximum overshoot

Proportional Integral (PI) Controller

- Multiplies the error by the proportional gain value K_p and adds the integral of error to the proportional term.
- Advantages
  - Integral term makes sure steady state error is zero
  - Can return the controlled variable back to the exact set point
- Disadvantages
  - Requires timer to keep track of time
  - Responds slowly towards the produced error

Proportional Derivative (PD) Controller

- Multiplies the error by the proportional gain value K_p and adds the derivative of error to the proportional term.
- Advantages
  - Minimises the maximum overshoot
  - Fast response, improves the transient response of the system
- Disadvantages
  - Steady state error cannot be guaranteed to be zero
  - Amplifies the noise signals produced in the system

Proportional Integral Derivative (PID) Controller

- Combines the advantages of all of P-I-D
- Advantages
  - No steady state error
  - Low maximum overshoot
- Disadvantages
  - Difficult to implement
  - Gain tuning is a difficult task

Characteristics of P, I, and D Controllers

- Note that these correlations may not be exactly accurate, because Kp, Ki, and Kd are dependent of each other. In fact, changing one of these variables can change the effect of the other two. For this reason, the table should only be used as a reference when you are determining the values for Ki, Kp and Kd.

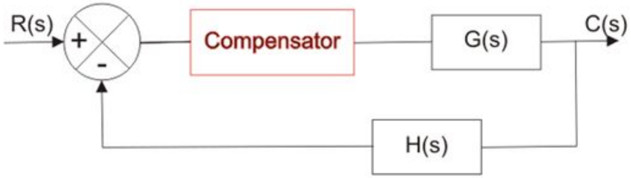
Response	Rise Time	Overshoot	Settling Time	SS Error
K_P	Decrease	Increase	Small Change	Decrease
K_I	Decrease	Increase	Increase	Eliminate
K_D	Small Change	Decrease	Decrease	Small Change

Further Learning (PID)

- Reading:
  - http://www.pacontrol.com/download/Proportional-Integral-Derivative-PID-Controls.pdf
  - http://www.ece.uvic.ca/~agullive/trans/D_p1-20.pdf
- Videos:
  - https://www.youtube.com/watch?v=UR0hOmjaHp0 (Intro)
  - https://www.youtube.com/watch?v=XfAt6hNV8XM (Examples)
  - https://www.youtube.com/watch?v=wkfEZmsQqiA (Fundamentals)
- Math
  - https://www.youtube.com/watch?v=JEpWlTl95Tw
- Demo:
  - https://www.youtube.com/watch?v=fusr9eTceEo
  - https://sites.google.com/site/fpgaandco/pid

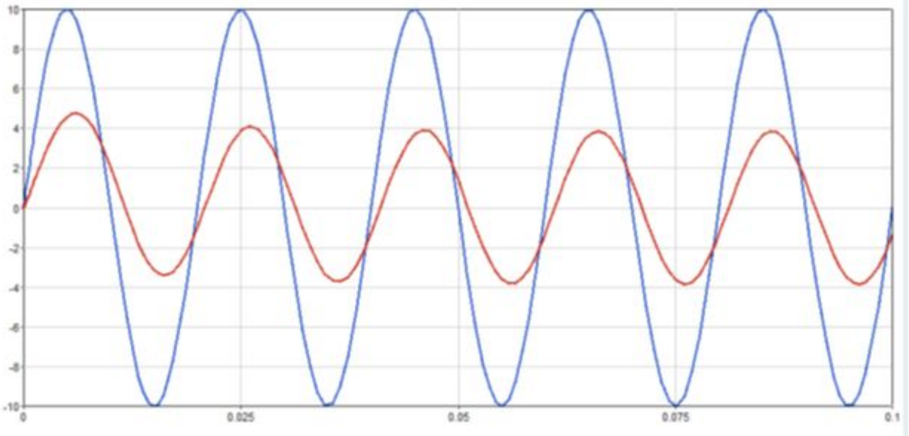
Lead–lag Compensator

- Lead-lag compensators come from the days when control engineers cared about constructing controllers from networks of op amps using frequency-phase methods.
  - ***These days pretty much everybody uses PID, but you should at least know what the heck they are in case someone asks.***
- Compensating networks are applied to the system in the form of feed forward path gain adjustment.
  - Compensate an unstable system to make it stable
  - Used to minimise overshoot
  - Increase the steady state accuracy of the system

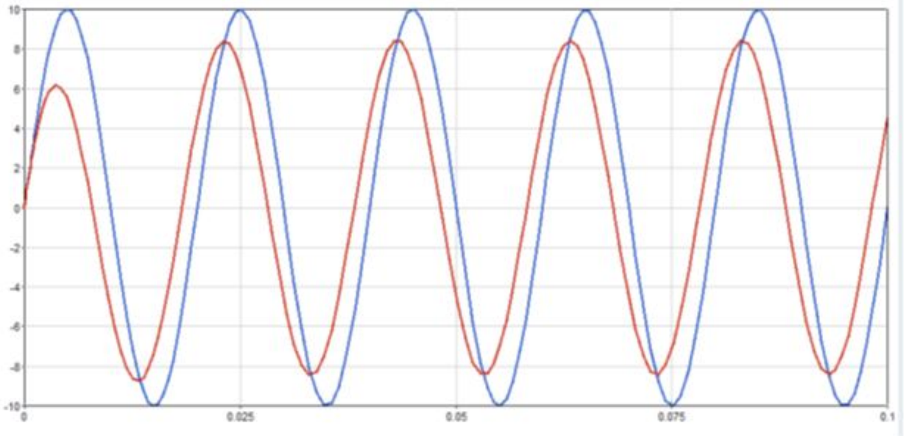


Lead–lag Compensator

Lead



Lag



https://youtu.be/xLhvil5sDcU?t=168

Summary

- Types of Control Systems
  - Open loop
  - Closed loop/Feedback
- Closed Loop Control Systems
- PID Control
- Proportional Integral Derivative (PID) Controller
- Lead–lag Compensator

Project Updates...