Feedback Control System Design

ICT 41205 Digital Control Systems

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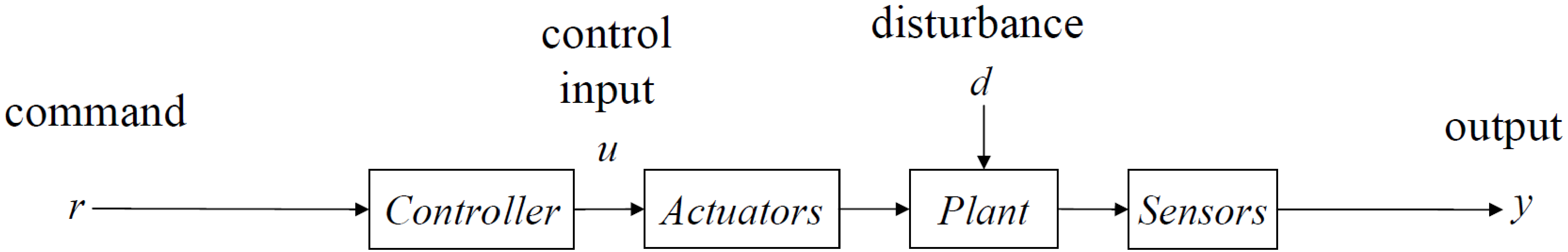
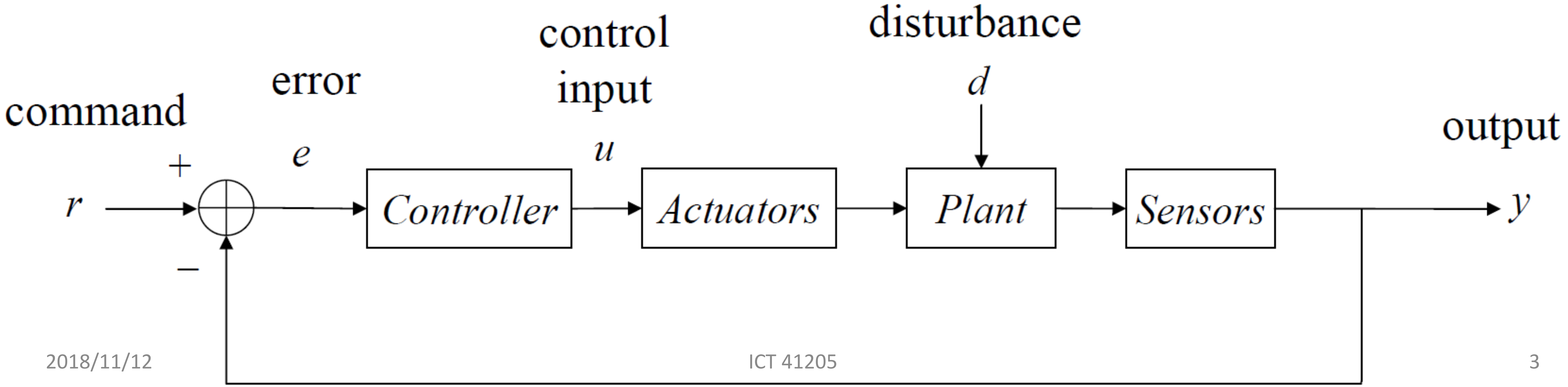
Types of Control Systems

- **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



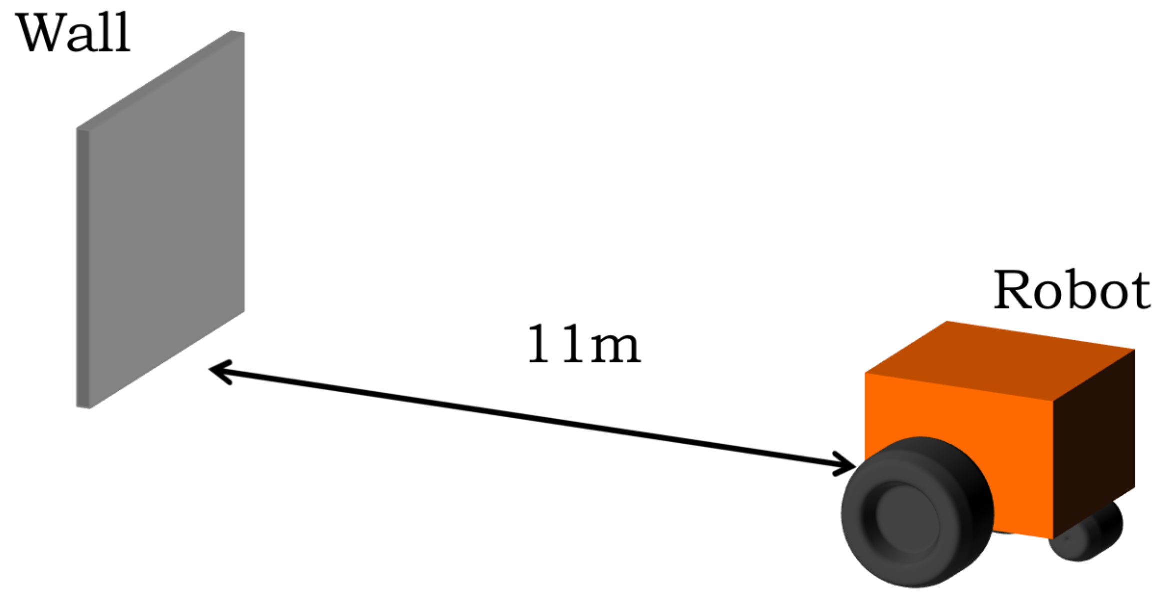
Types of Control Systems

- **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
  - 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

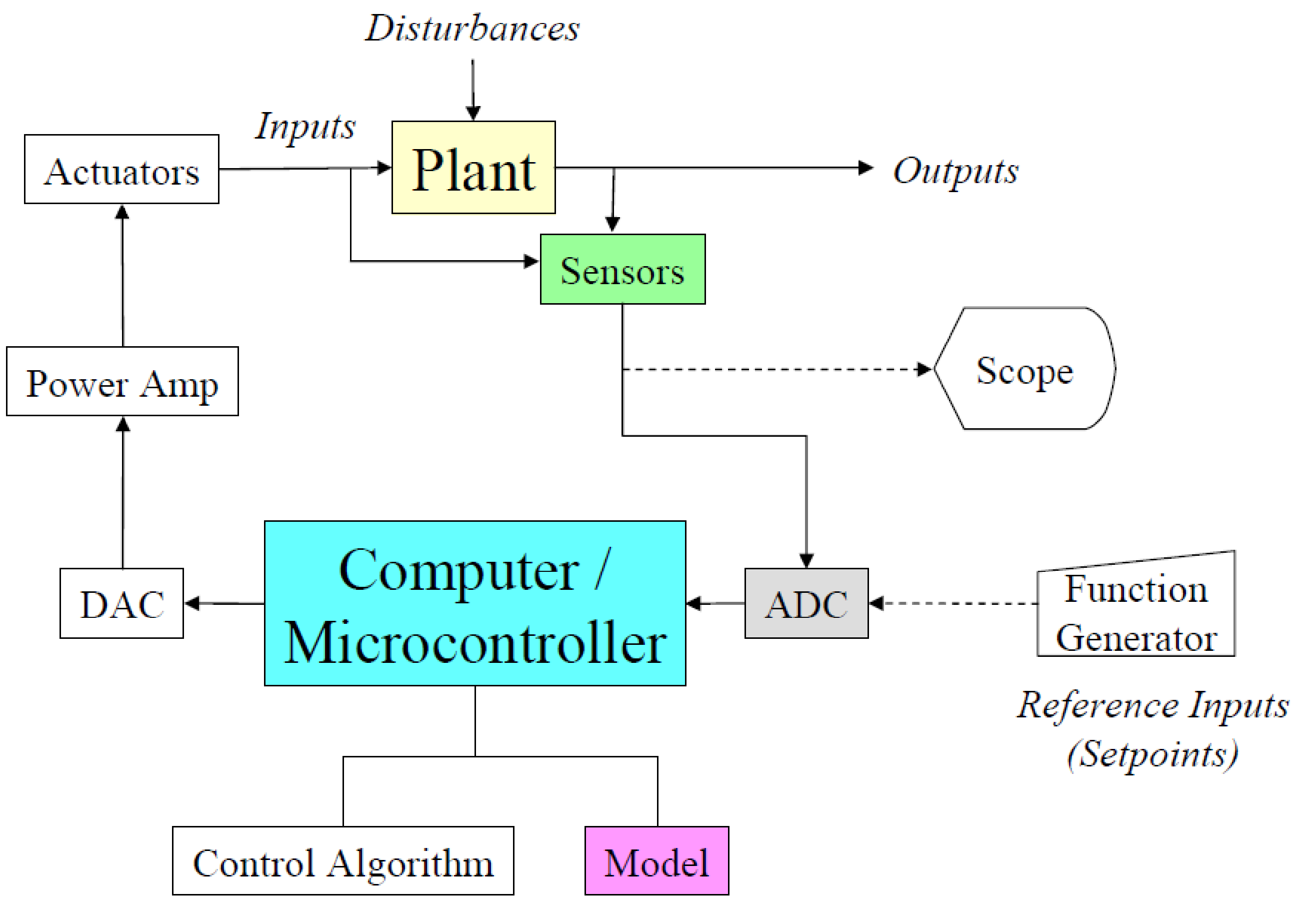


A Hitting the Wall Example

- 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, feed-forward and feedback.

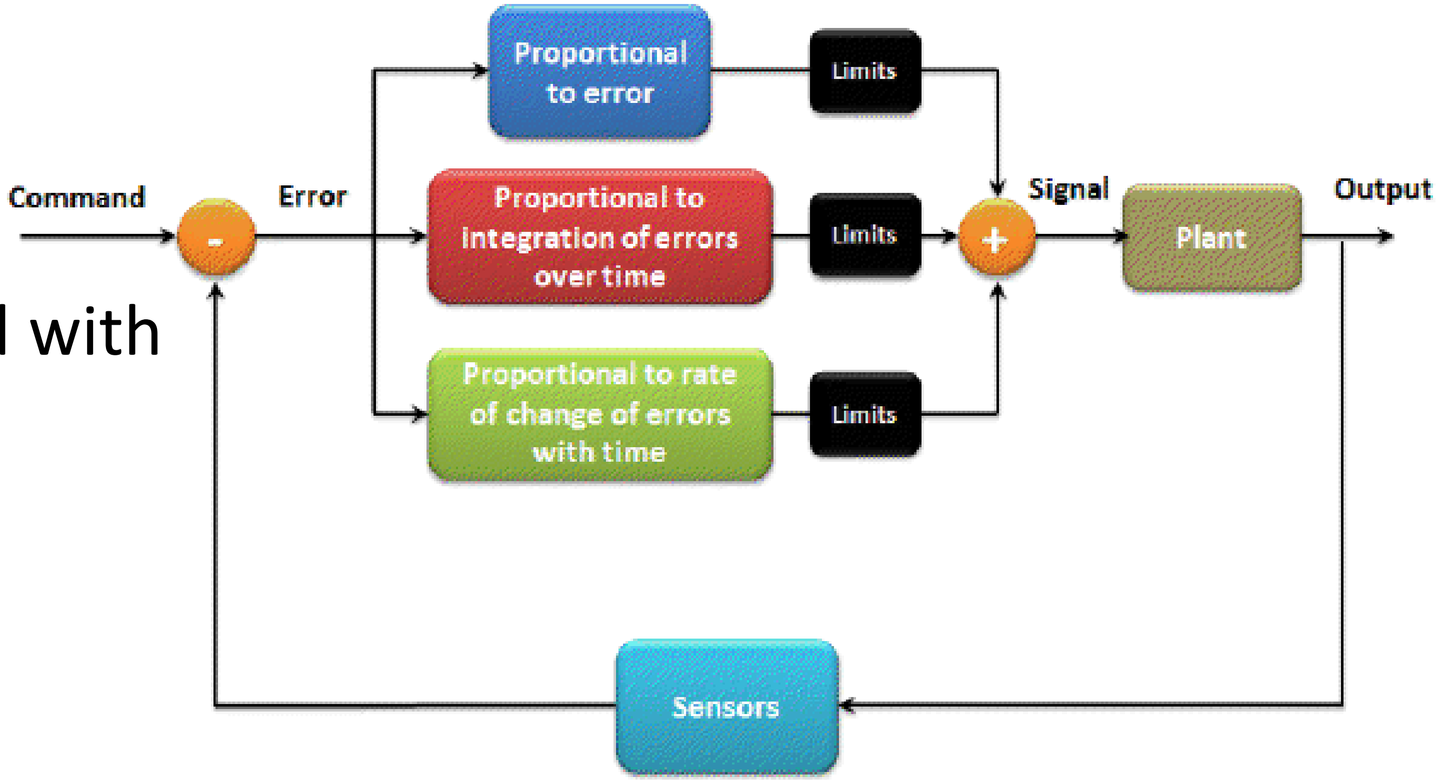


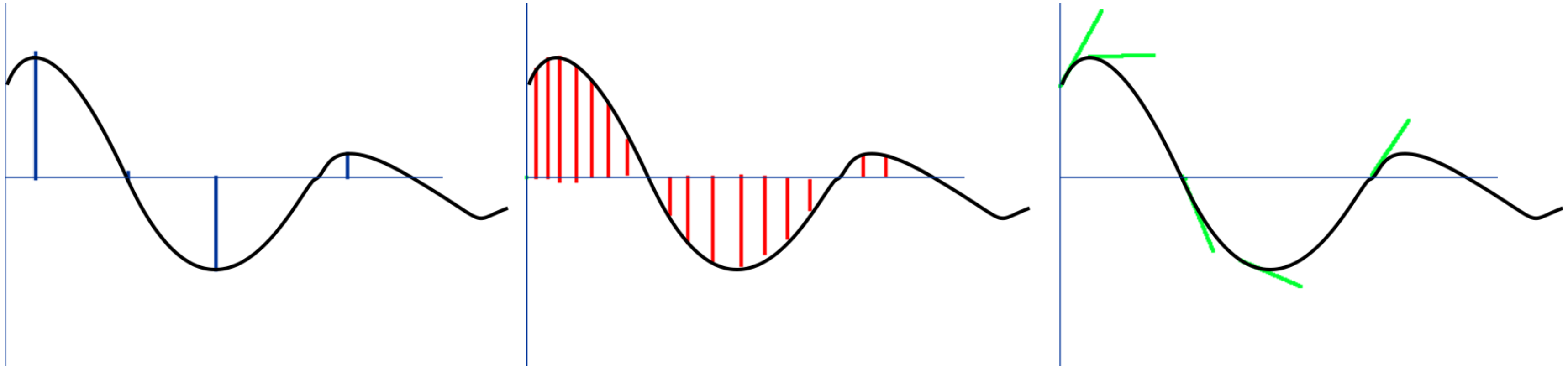
Overview of Closed Loop Control Systems



PID Control

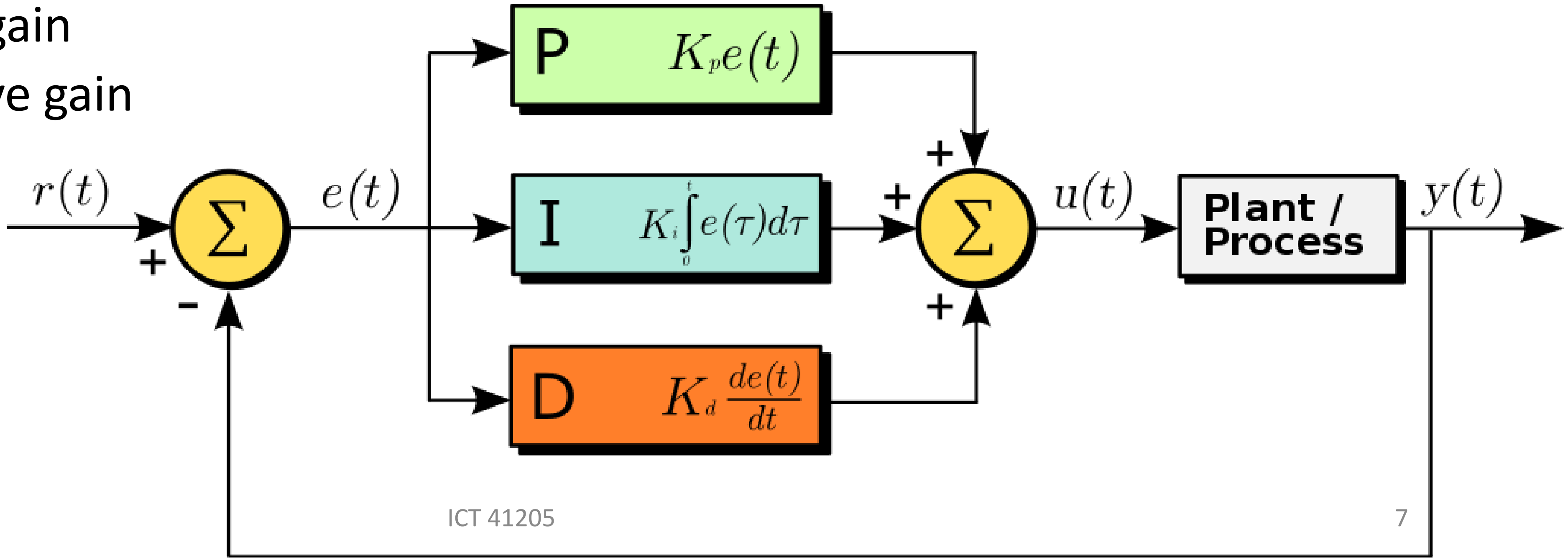
- Dynamic Systems controlled with a three term compensator known as PID:
    - P – Proportional Control
    - I – Integral Control
    - D – Derivative Control





PID Control

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

- 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 guarantied to be zero
  - Amplifies the noise signals produced in the system

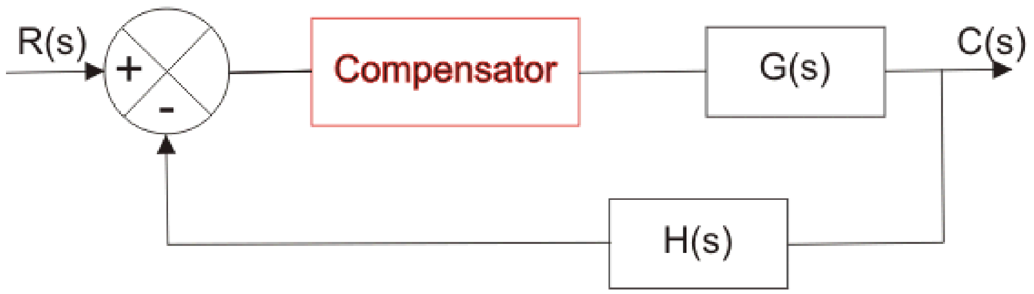
PID Controller

- 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

Further Learning

- 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

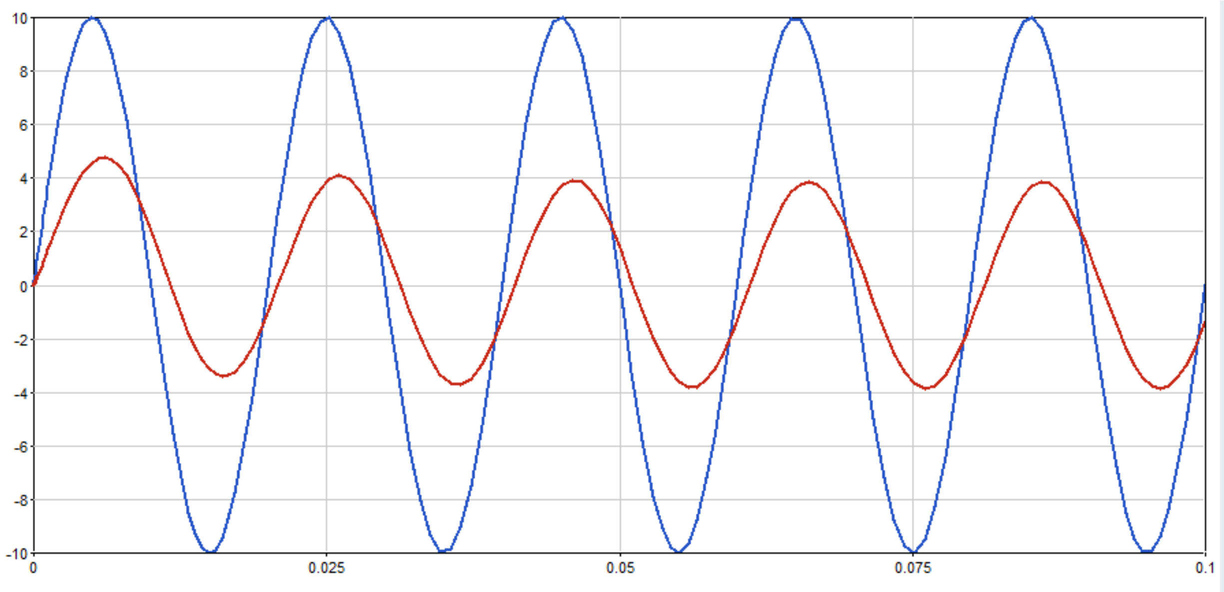


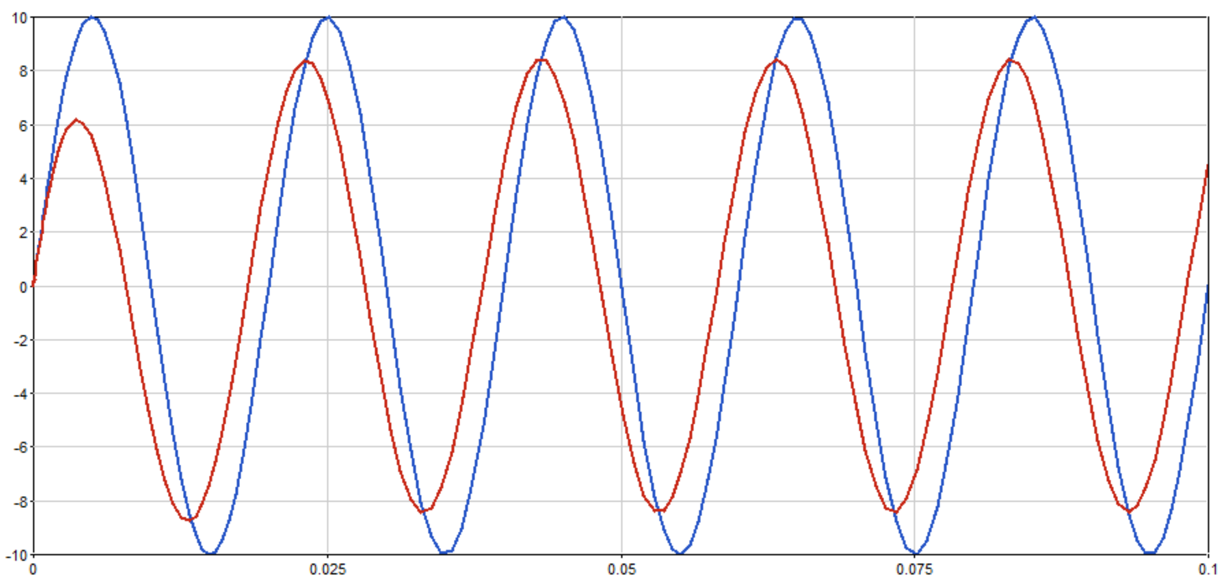
- *Lead-lag compensators come from the days when control engineers cared about constructing controllers from networks of op amps using frequency-phase methods.*
  - *These days pretty much everybody uses PID, but you should at least know what the heck they are in case someone asks.*
- Compensating networks 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