ROCO222: Intro to sensors and actuators

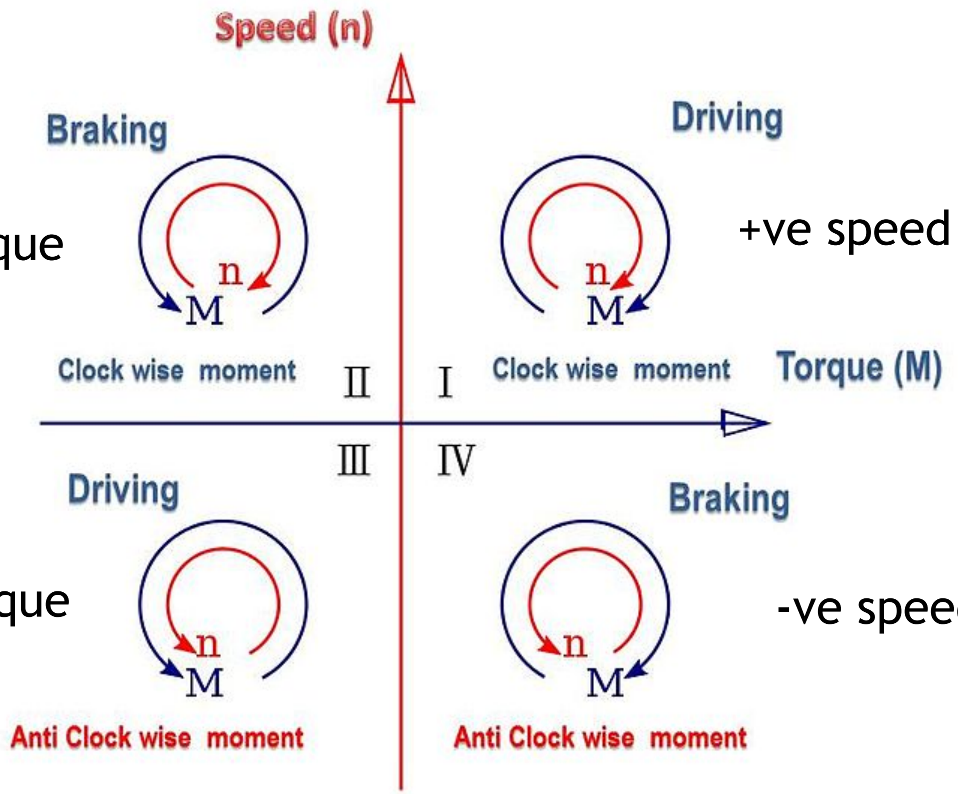
Lecture 7

Four quadrant control

Motor speed-torque chart

+ve speed and -ve torque

+ve speed and +ve torque



-ve speed and -ve torque

-ve speed and +ve torque

- Quadrant I – Driving forward with positive speed and positive torque
- Quadrant II -- Generating or braking with positive speed and negative torque
- Quadrant III – Driving with negative speed and negative torque
- Quadrant IV - Generating or braking with negative speed and positive torque

One and two quadrant operation

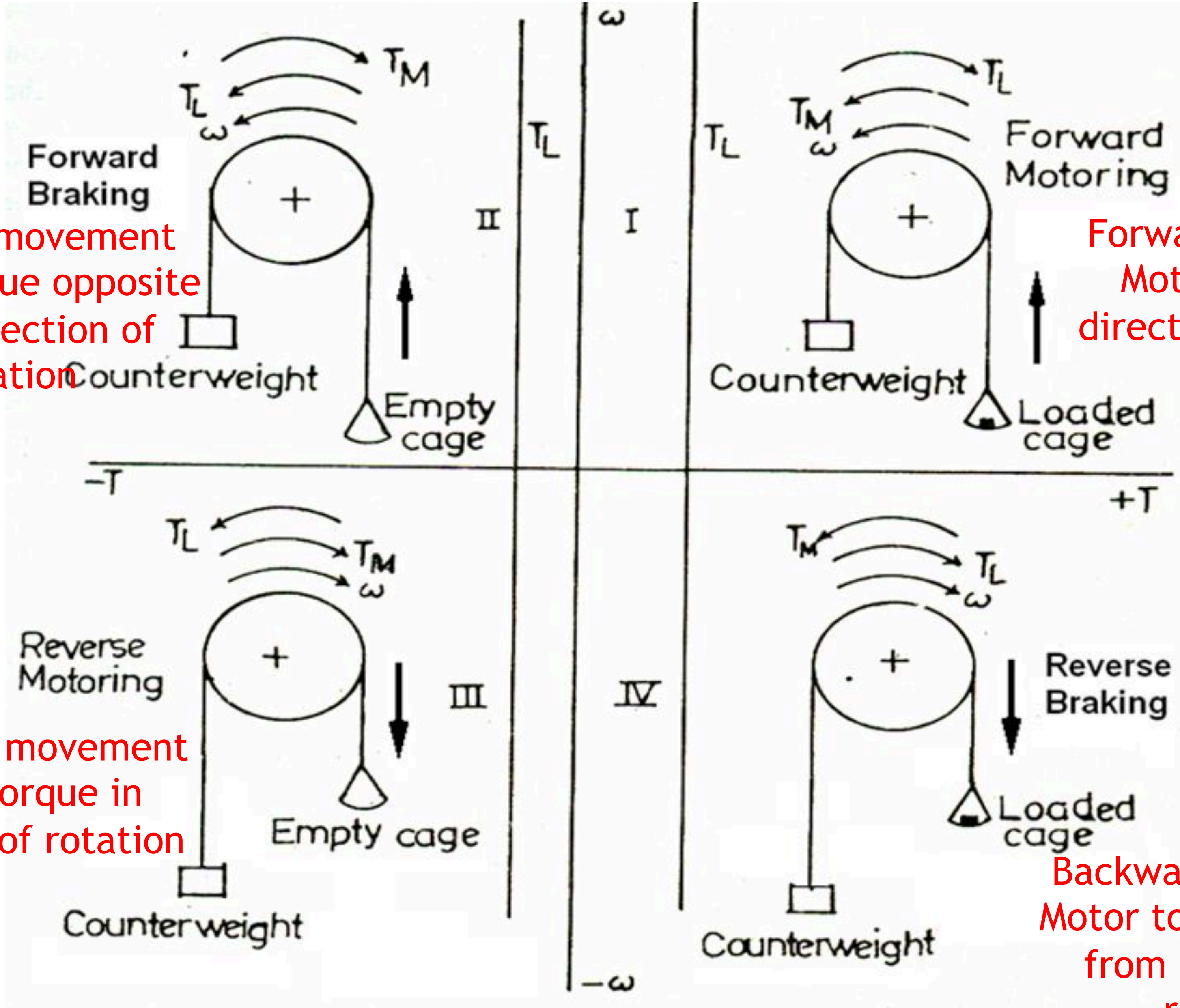
One quadrant operation

- Motoring with +ve speed and +ve torque
- Lots of simple applications of motors involve single-quadrant loads operating in quadrant I
- E.g., fan blowing air forwards
- Torque always in the same direction as speed
- Can drive fan in a single direction but not slow down under its own power

Two quadrant operation

- Motoring with +ve speed and +ve torque OR -ve speed and -ve torque
- Switch to change direction
- E.g., fan that can blow air forwards or backwards
- Torque always in the same direction as speed
- Can drive fan in a both directions but not slow down under own power

Four quadrant operation - hoist example



Forward movement
Motor torque opposite from direction of rotation

Forward movement
Motor torque in direction of rotation

Backward movement
Motor torque in direction of rotation

Backward movement
Motor torque opposite from direction of rotation

Four quadrant operation

Four quadrant operation

- Motoring with +ve speed and +ve torque OR -ve speed and -ve torque OR
- Breaking with +ve speed and -ve torque OR -ve speed and +ve torque
- Controller drive must be able to behave as source and sink electrical power from the motor
- Act either as a power source or as a load
- Where does the sink energy go?

- Regenerative systems put it back into the power supply
- The motor acts like a generator
- This can lead to very efficient operation

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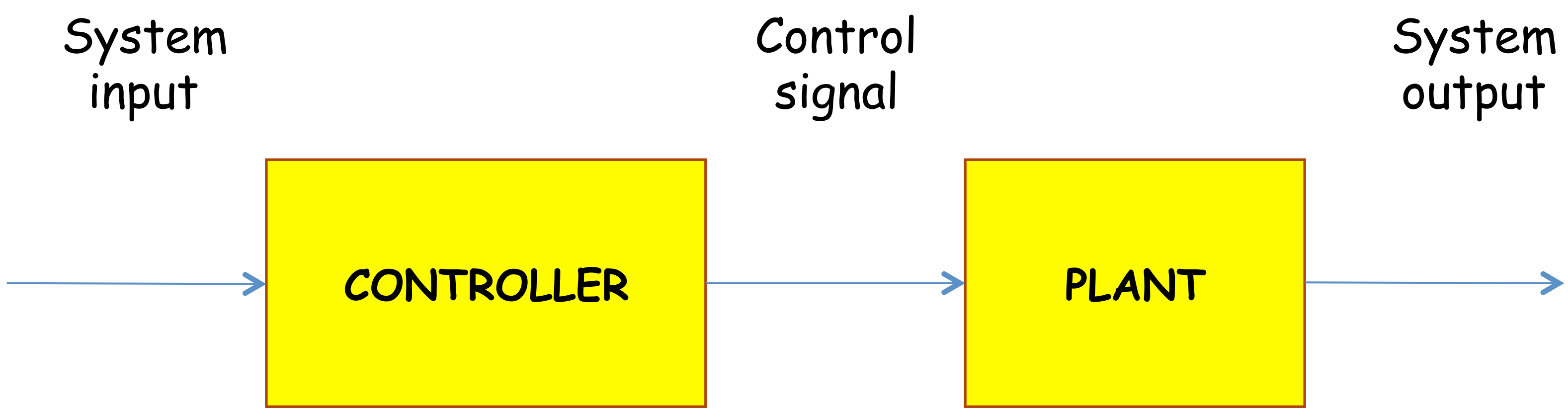
Lecture 7

Feedback control

Open-loop control systems

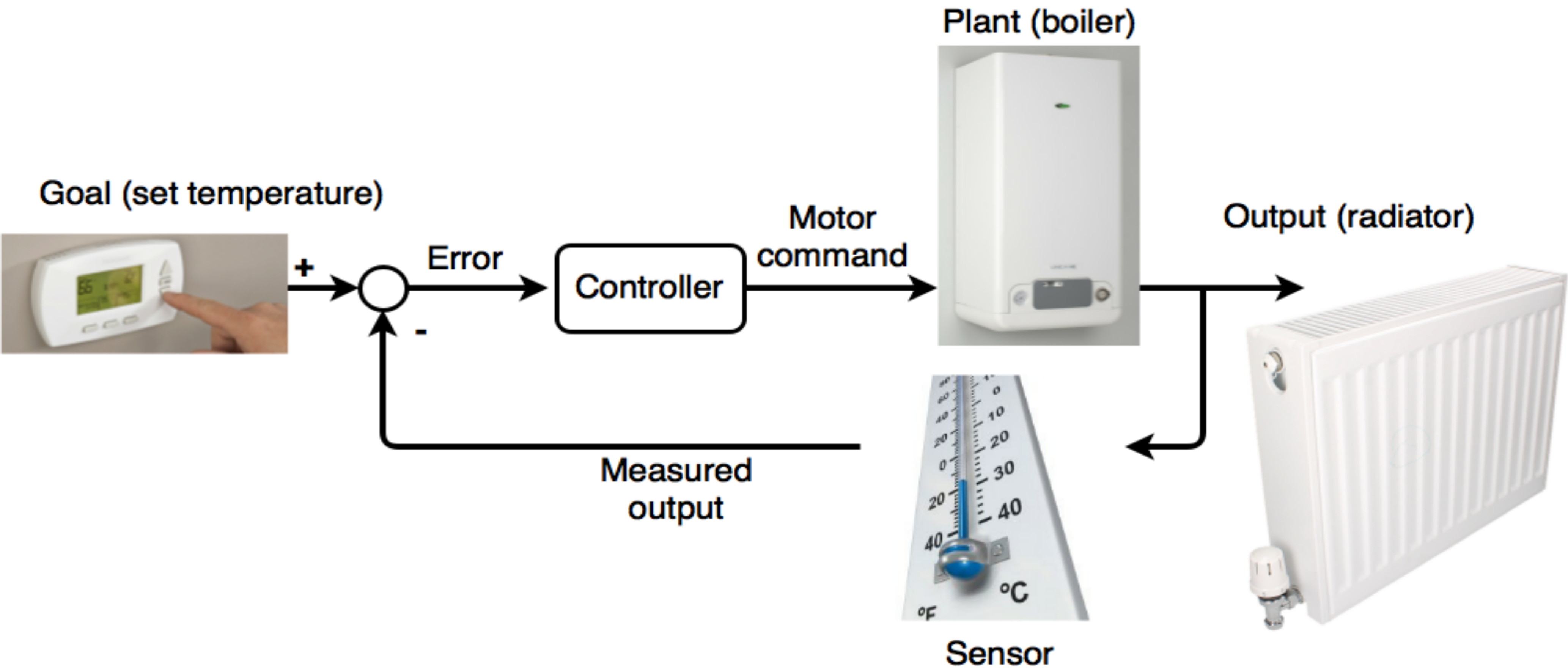
- In open-loop control systems the output has no effect on the control action
- The output is neither measured nor fed back for comparison with the input
- Open loop system can work well if the controller is appropriate and the plant properties don’t change over time and there are no disturbances to the system



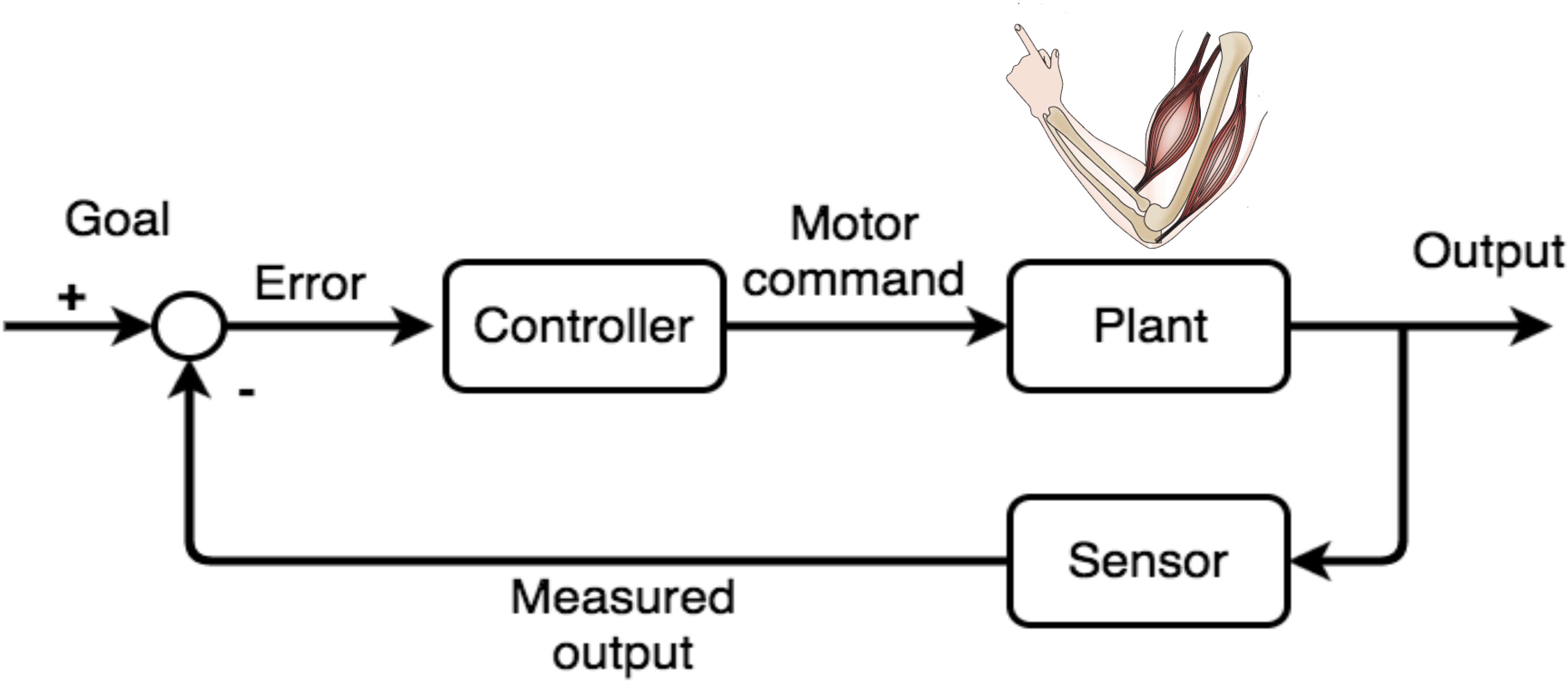
Open-loop control systems

- The accuracy of the system depends on calibration.
- Example: Stepper motor control used in 3D printers
- BUT: In the presence of disturbances, an open-loop system will not perform the desired task!
- E.g., if stepper looses pulses then calibration lost
- This is why feedback can be useful

Simple feedback controller

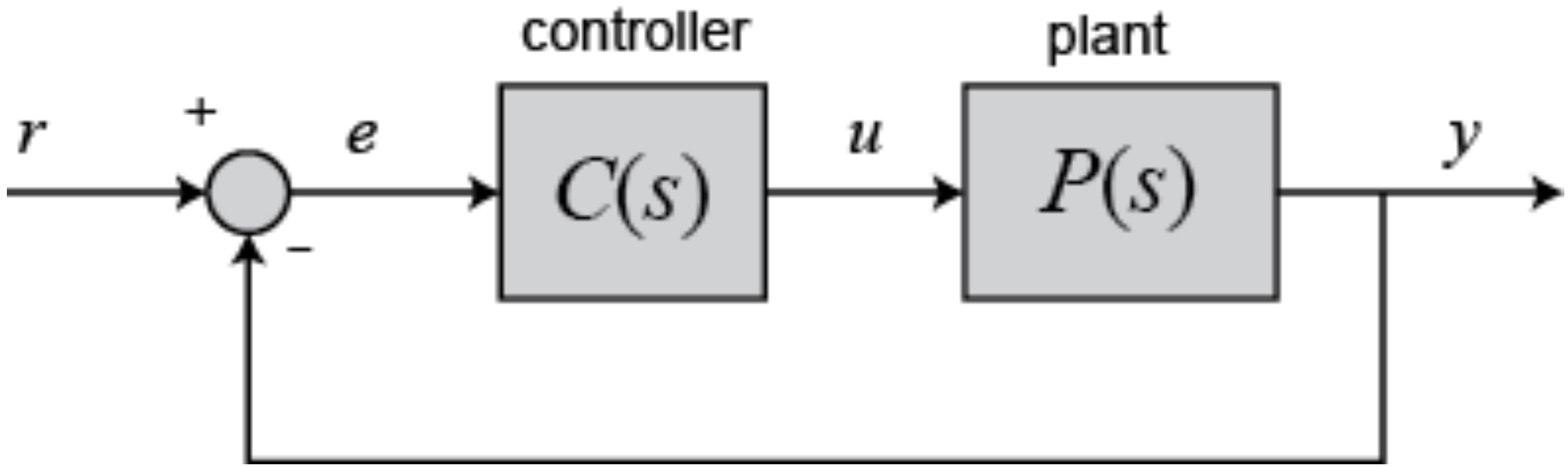


Simple feedback controller



- In closed-loop systems feedback control makes use of a measurement of output to modify input to the controller
- feedback control can improve performance. It involves
- Specify target goal
- Comparing sensory feedback with goal to calculate error
- Feeding the error via a controller to generate plant commands
- The causes the system output to move to goal

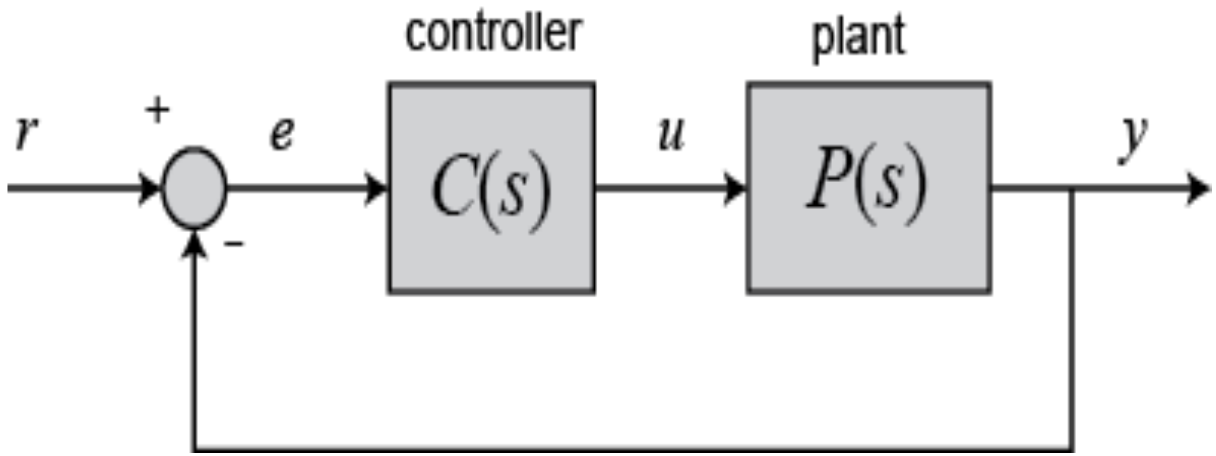
Simple feedback controller



- Plant characteristics are often fixed
- We need to design the controller to achieve required plant performance
- Have to be careful because feedback system can go unstable!
- So what should the controller be?

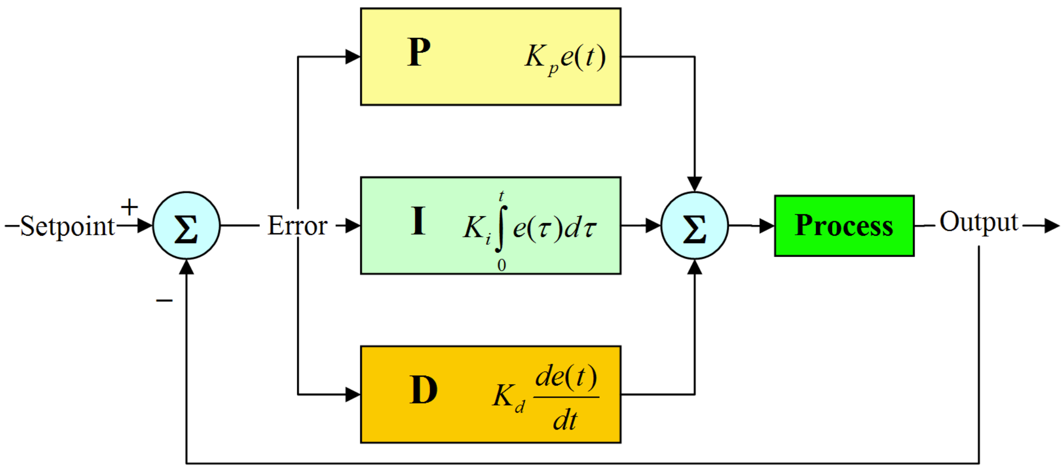
Adding a PID controller

- Place a PID controller C(s) in series with the plant P(s) and make use of negative feedback



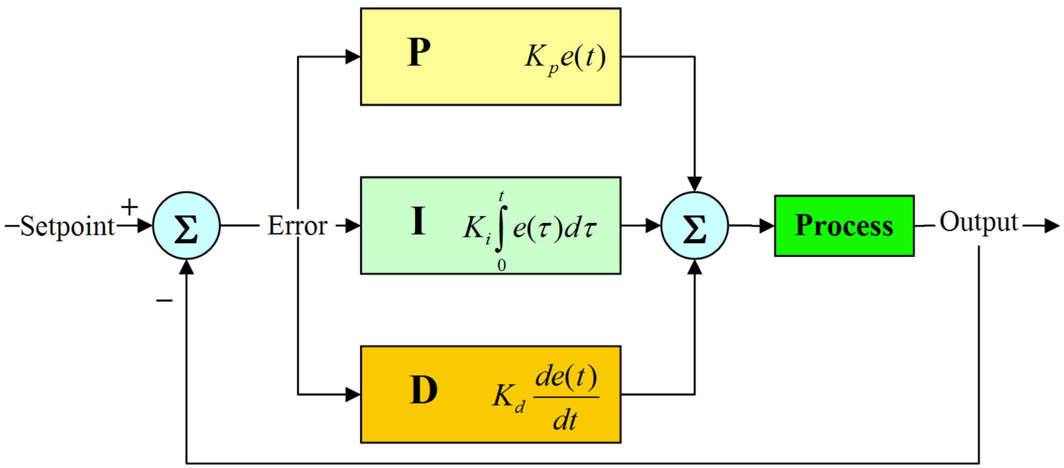
- A well-designed control system will ensure
  - We reach a target value quickly
  - Without overshoot
  - With low steady state error.

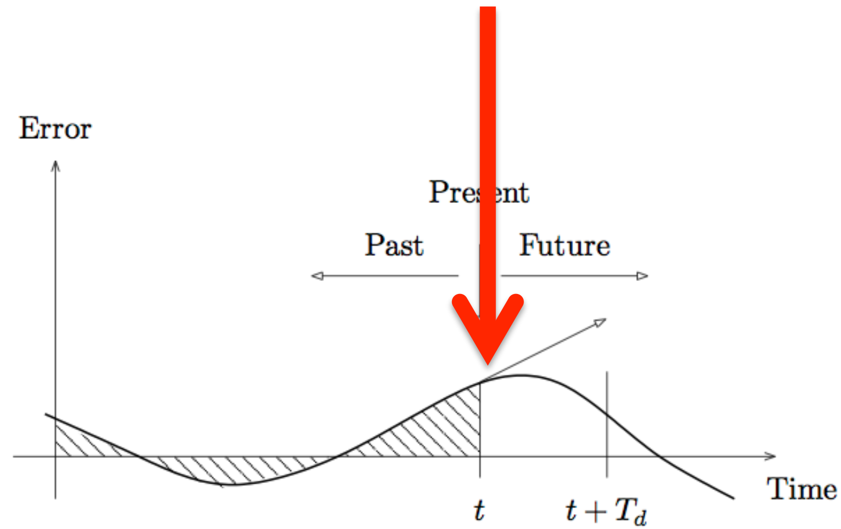
PID parallel pathways



- PID is a mathematical algorithm that the controller uses to compensate for load fluctuations and changes in set point.
- These operations are executed on the error between the set point and the actual value.
- They determine ow the plant will react to change
- A PID controller consists of 3 parallel elements that are located in the forward path in a feedback controller scheme located before the plant
- The plant to be controller received the sum of these three processed signals as its input
- The 3 PID elements have different effects

Proportional term

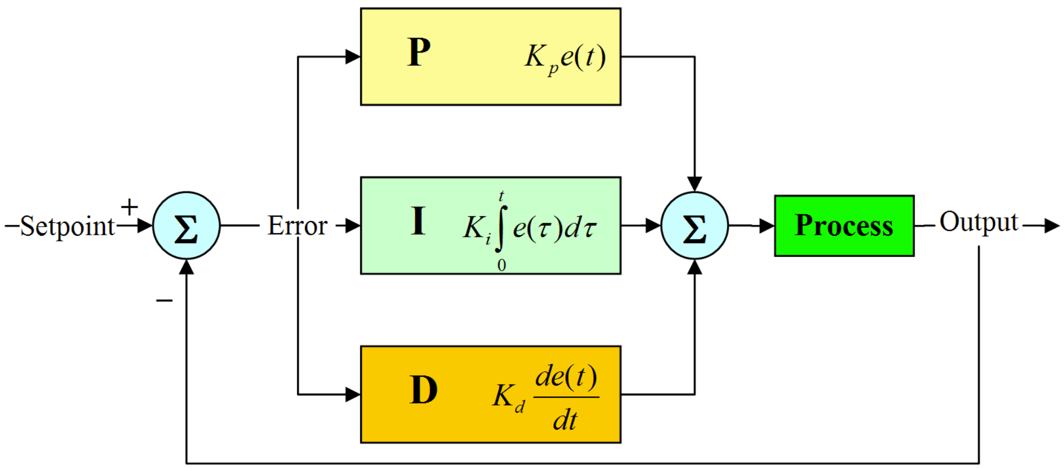


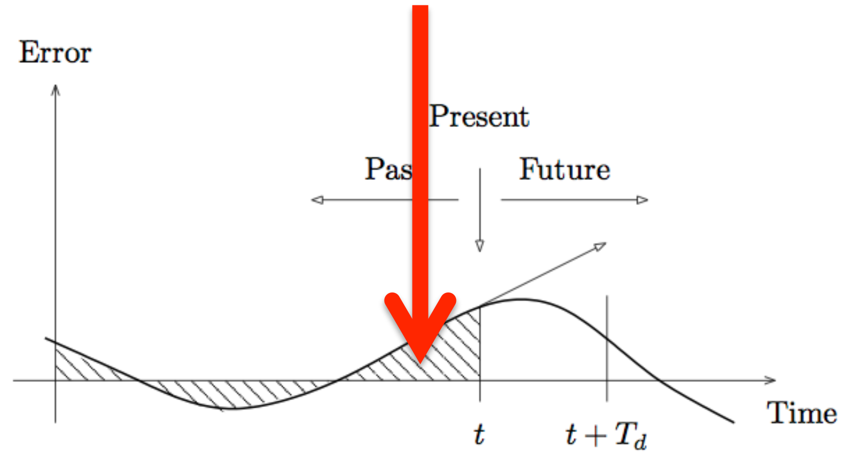


The proportional term directly relates to the error value at the present moment in time

- The proportional gain is given as K_p
- Proportional gain can improve rise time
- If K_p too high the system can become unstable

Integral term



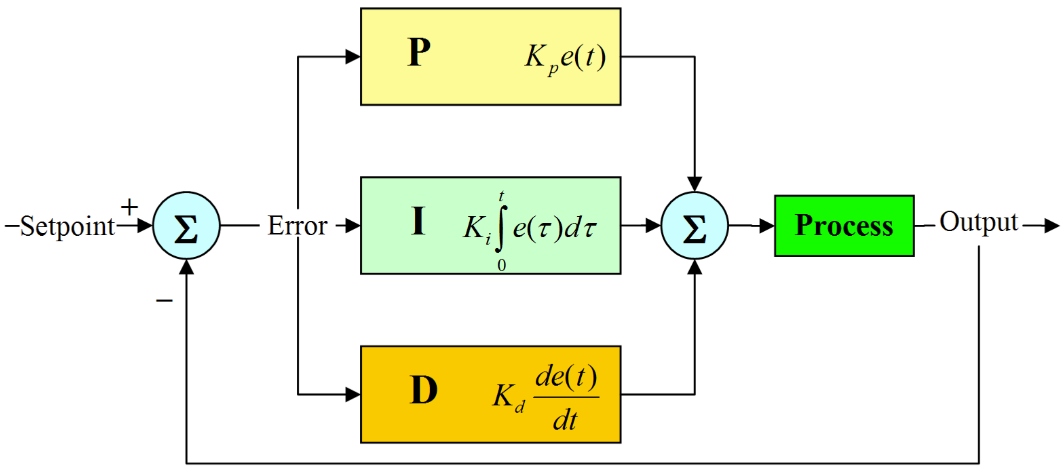


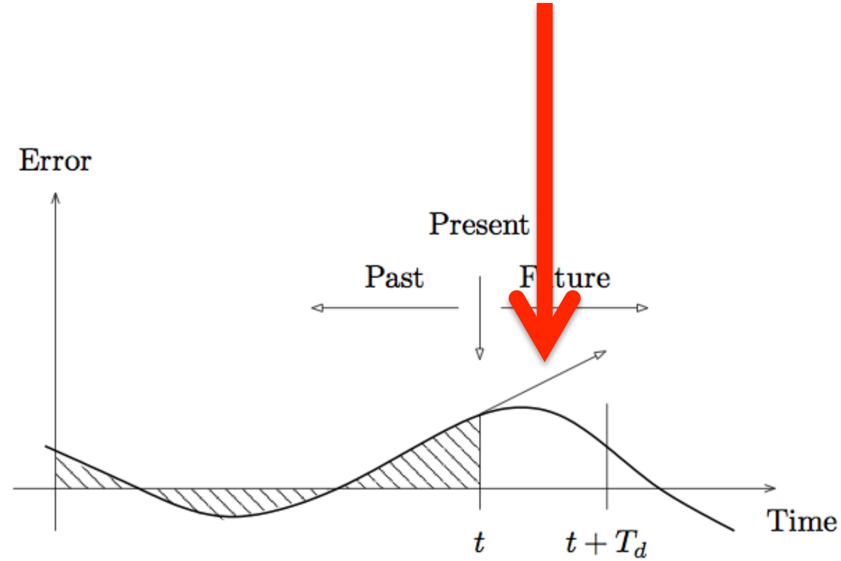
The integral term relates to a past values of the error up to the present point in time

It is proportional to both the magnitude of the past error and its duration

- The integrator gain is given as K_i
- Integral term eliminates residual steady-state error

Derivative term

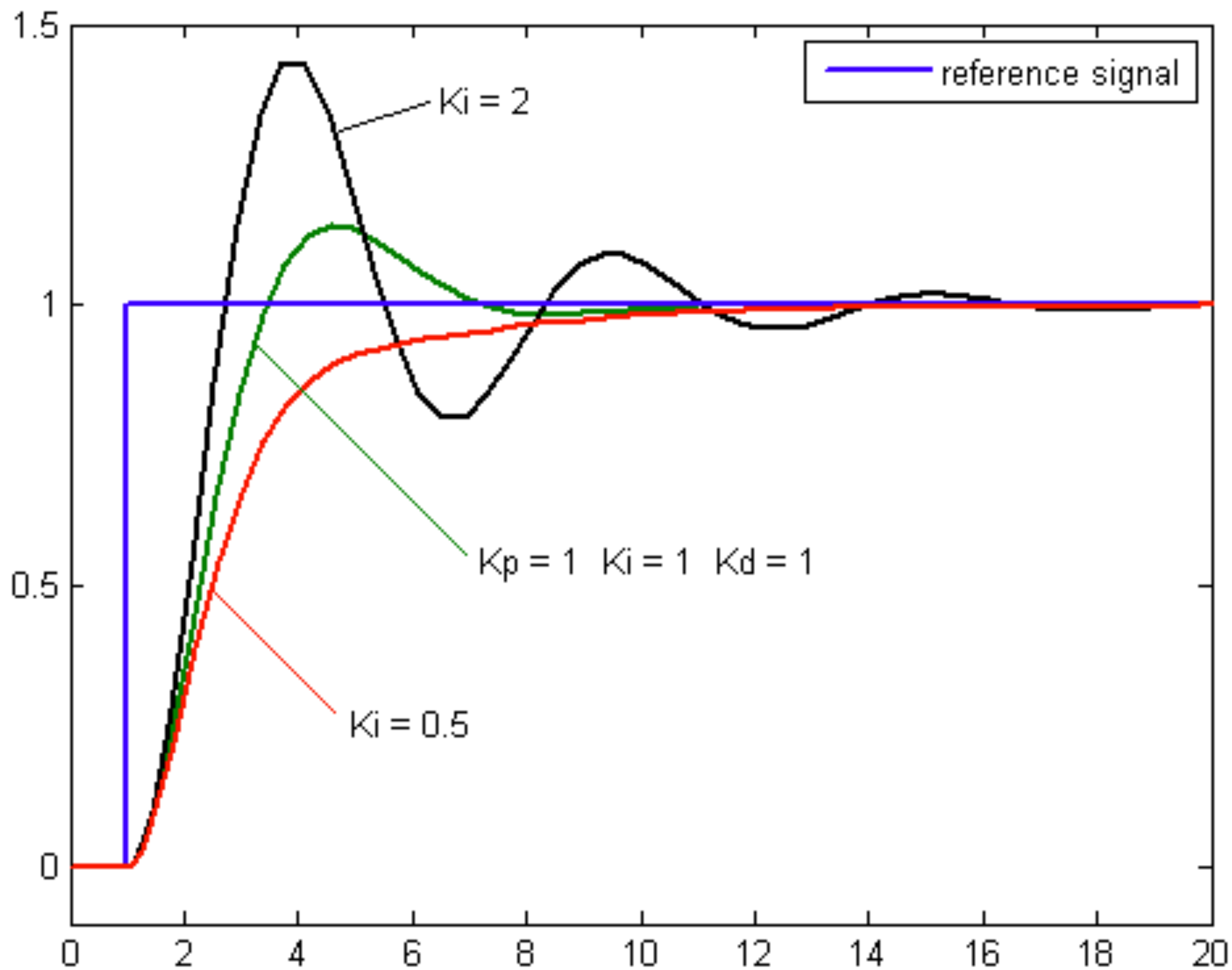




The derivative term that is proportional to the slope of the error over time and relates to a prediction of what the error will be like in the future

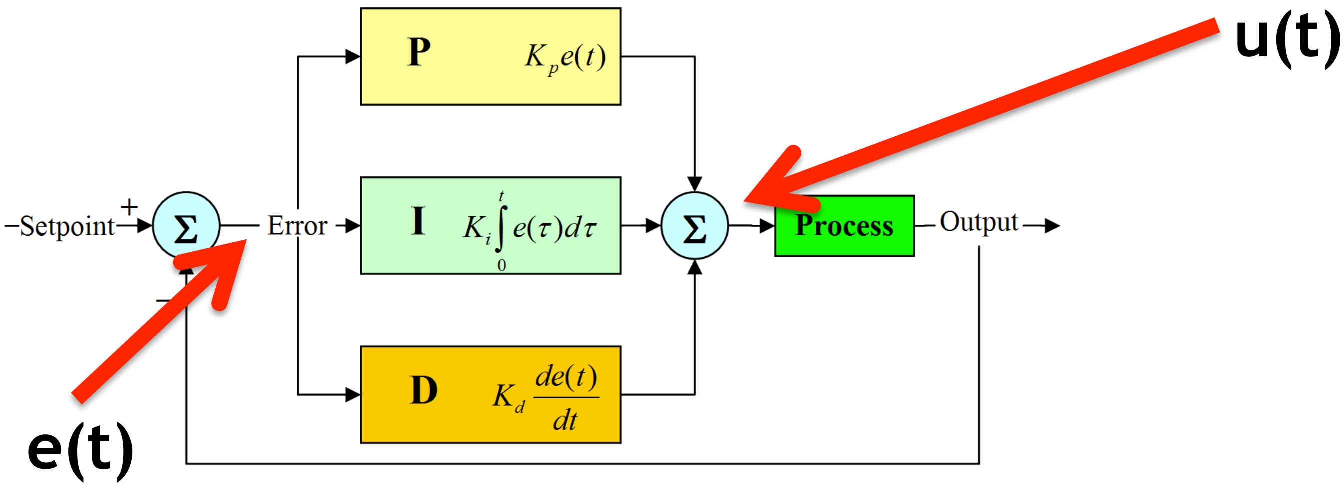
- The differentiator gain is given as K_d
- Derivative term improves settling time and stability of the system

Changing PID controller characteristics



Tuning PID parameters strongly affects controller performance

PID differential equation



- Relationship between input error e(t) and output control signal u(t) captured by the differential equation:

$$u(t) = K_p e(t) + K_i \int e(t)\,dt + K_d \frac{de}{dt}$$

Transfer function of PID controller

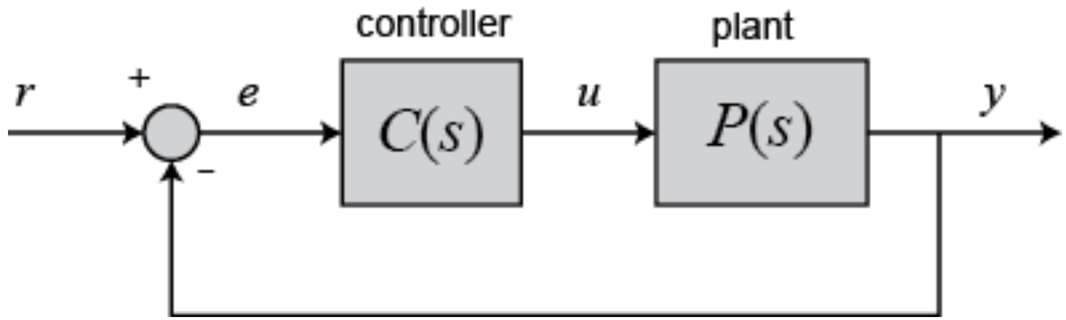
- Differential equation that described PID controller

$$u(t) = K_p e(t) + K_i \int e(t)\,dt + K_d \frac{de}{dt}$$

- Taking Laplace transformations and rearranging gives the transfer function for the PID controller:

$$\frac{U(s)}{E(s)} = K_p + \frac{K_i}{s} + K_d s$$

Example: Overall open-loop transfer function



Controller gives

$$C(s) = K_p + \frac{K_i}{s} + K_d s$$

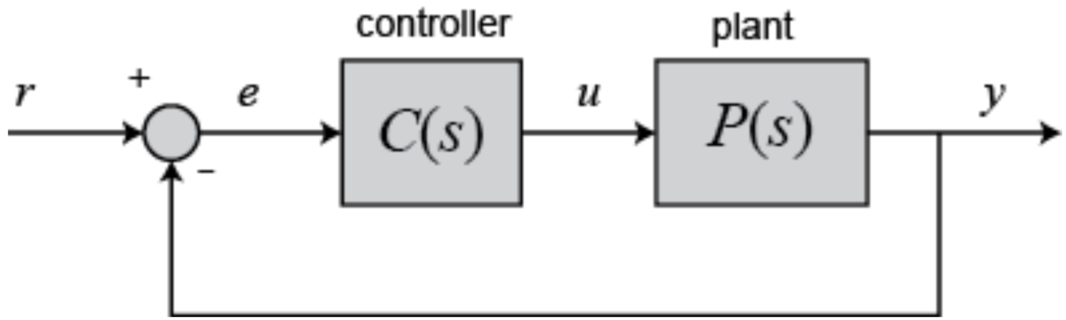
Plant gives

$$P(s) = \frac{1}{0.5s^2 + 5s + 10}$$

Product of these series elements gives

$$C(s)P(s) = \frac{K_p + \frac{K_i}{s} + K_d s}{0.5s^2 + 5s + 10} = \frac{K_p s + K_i + K_d s^2}{0.5s^3 + 5s^2 + 10s}$$

Overall closed-loop transfer function

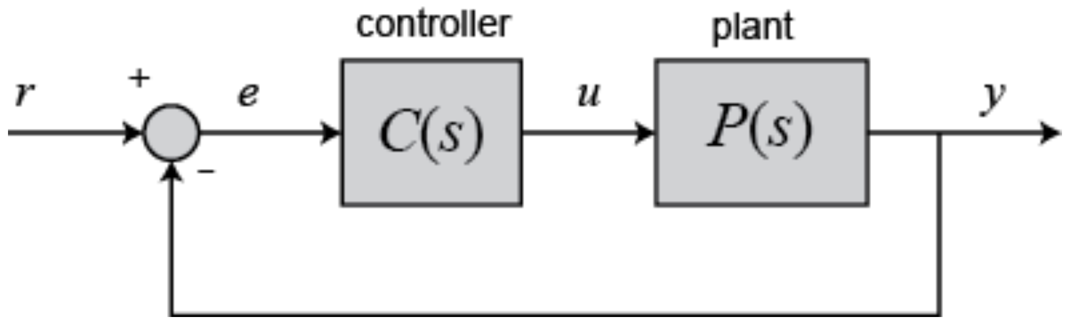


Given this feedback arrangement and serial controller and plant configuration

The close loop transfer function is

$$\frac{Y(s)}{R(s)} = \frac{C(s)P(s)}{1+C(s)P(s)}$$

Example: Overall closed-loop transfer function



Given $$C(s)P(s) = \frac{K_p s + K_i + K_d s^2}{0.5s^3 + 5s^2 + 10s}$$

The close loop transfer function is $\frac{Y(s)}{R(s)} = \frac{C(s)P(s)}{1 + C(s)P(s)}$

$$\frac{Y(s)}{R(s)} = \frac{\dfrac{K_p s + K_i + K_d s^2}{0.5s^3 + 5s^2 + 10s}}{1 + \dfrac{K_p s + K_i + K_d s^2}{0.5s^3 + 5s^2 + 10s}} = \frac{K_d s^2 + K_p s + K_i}{0.5s^3 + (K_d + 5)s^2 + (K_p + 10)s + K_i}$$