Automation and Control Lab

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Lecture 4: Introduction to PID Controller

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Introduction

A **proportional-integral-derivative controller** (**PID controller**) is a control loop feedback mechanism (controller) widely used in industrial control systems (Programmable Logic Controllers, SCADA systems, Remote Terminal Units etc).

More than 90% of all industrial controllers are implemented using this popular control law.

A PID controller calculates an "error" value as the difference between a measured process variable and a desired set point.

The controller attempts to minimize the error in outputs by adjusting the process control inputs.

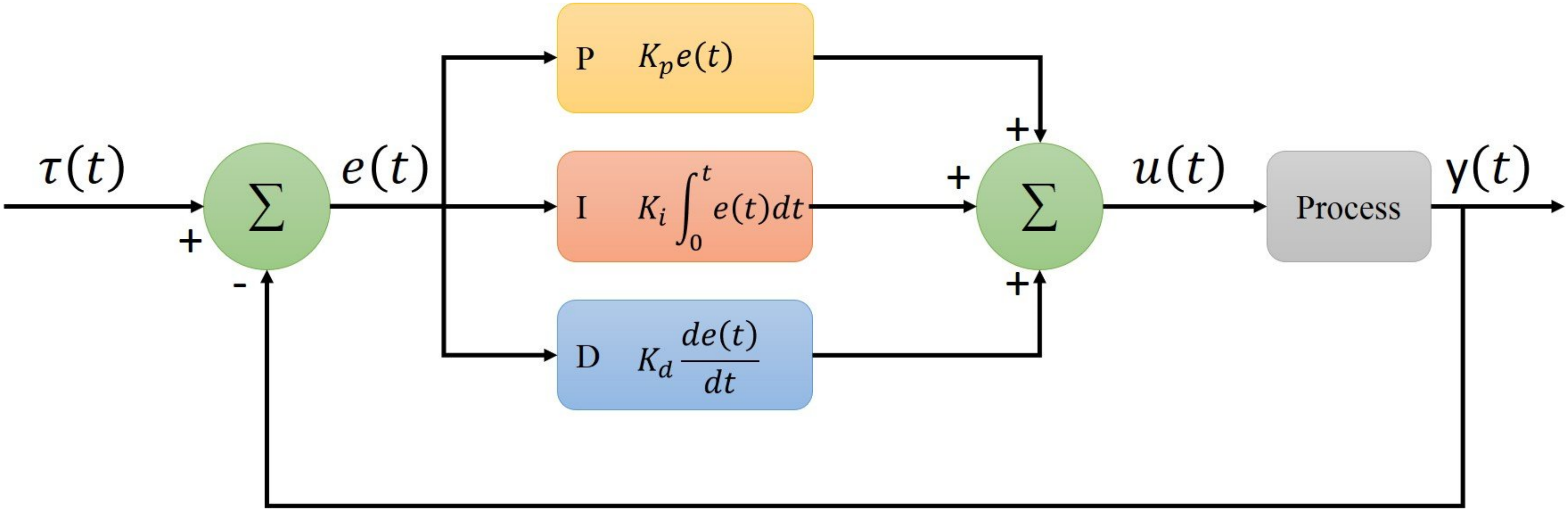
Introduction

☐ The PID controller algorithm involves three separate constant parameters, and is accordingly sometimes called **three-term control**: the proportional, the integral and derivative values, denoted *P, I,* and *D.*

☐ Simply put, these values can be interpreted in terms of time: *P* depends on the *present* error, *I* on the accumulation of *past* errors, and *D* is a prediction of *future* errors, based on current rate of change.

☐ The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve, a damper, or the power supplied to a heating element.

PID Controller



PID Controller

- The output of the controller is proportional to the error signal (P-term), the integral signal (I-term), and the derivative of the error signal (D-term) through the gains K_p, K_i, and K_d, respectively.

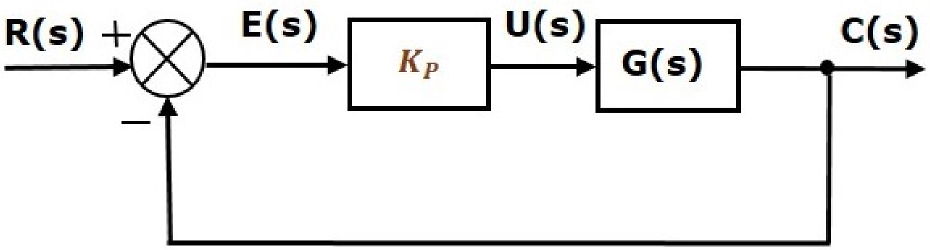
- In practice, variations of the above control law are also implemented, such as a PI controller, which has only the P and I terms, or a PD controller, which has only the P and D terms.

P - Controller

- ❑ With the proportional mode, the size of the controller output is proportional to the size of the error.

- ❑ This means that the correction elements of the control system (eg: valve), will receive a signal which is proportional to the size of the correction required.

- ❑ A gain element with transfer function Kp in series with the forward-path element G(s)



$$U(s) = K_P E(s)$$

$$\frac{U(s)}{E(s)} = K_P$$

D- Controller

- ☐ With the derivative mode of control the controller output is proportional to the rate of change with time of the error signal. This can be represented by the equation

$$\mathit{controller}\ \text{output} = K_D \frac{de}{dt}$$

Kp is the constant of proportionality. The transfer function is obtained by taking Laplace transforms, thus

$$\mathit{controller}\ \text{output(s)} = K_D sE(s)$$

Hence the transfer function is $K_D s$

D- Controller

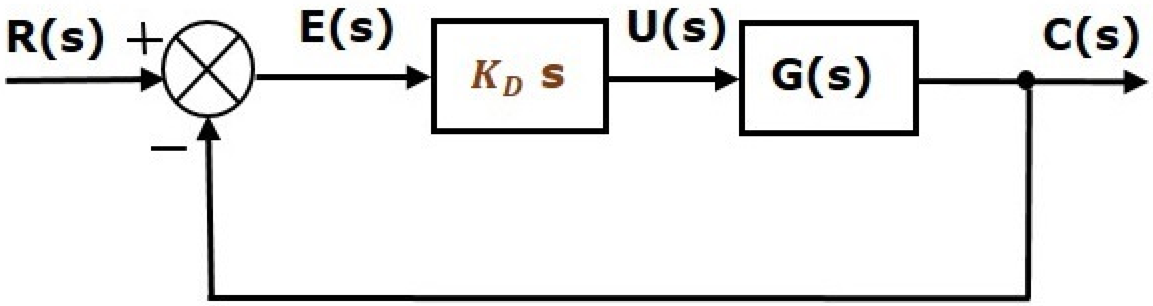
- With derivative control, as soon as the error signal begins to change, there can be quite a large controller output since it is proportional to the rate of change of the error signal and not its value.
    - Rapid initial responses to error signals thus occur.

- The controller output is constant because the rate of change is constant and occurs immediately the deviation occurs.

- Derivative controllers do not, however, respond to steady-state error signals, since with a steady error the rate of change of error with time is zero.

- Because of this, derivative control is always combined with proportional; the proportional part gives a response to all error signals, including steady signals, while the derivative part response to the rate of change.

D- Controller



$$U(s) = K_D s E(s)$$

$$\frac{U(s)}{E(s)} = \boxed{K_D s}$$

PD- Controller

- Derivative control is never used alone because it is not capable of giving an output when there is a steady state error signal and so no correction is possible.

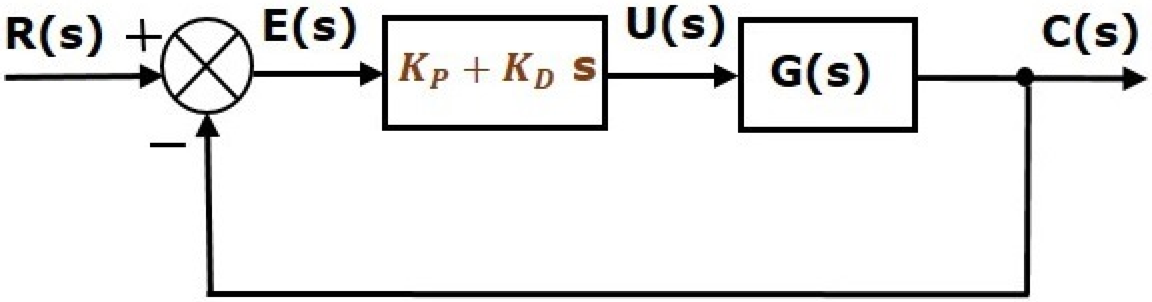
- It is thus invariably used in conjuction with proportional control so that this problem can be resolved.

- With proportional plus derivative control the controller output is given by

$$\mathit{controller}\ \text{output} = K_p e + K_D \frac{de}{dt}$$

K_P is the proportionality constant and K_D the derivative constant, de/dt is the rate of change of error.

PD- Controller



$$U(s) = (K_P + K_D s)E(s)$$

$$\frac{U(s)}{E(s)} = K_P + K_D s$$

I - Controller

- The integral mode of control is one where the rate of change of th control output I is proportional to the input error signal e:

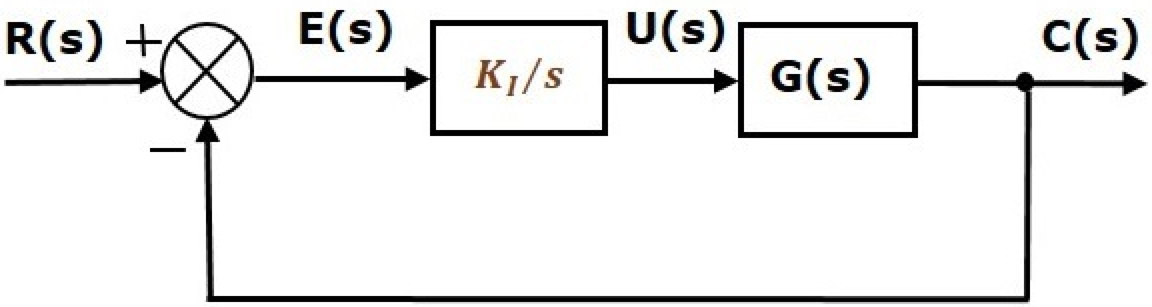
$$\frac{dI}{dt} = K_I e$$

K_I is the constant of proportionality and has units of 1/s. integrating the above equations gives

$$\int_{Io}^{Iout} dI = \int_0^t K_I e \, \mathrm{d}t \qquad I_{out} - I_0 = \int_0^t K_I e \, \mathrm{d}t$$

I_0 is the controller output at zero time, I_{out} is the output at time t.

I - Controller



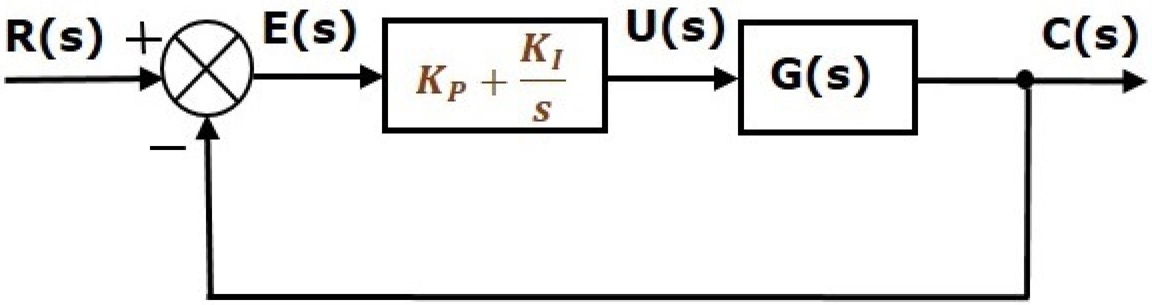
$$U(s) = \frac{K_I E(s)}{s}$$

$$\boxed{\frac{U(s)}{E(s)} = \frac{K_I}{s}}$$

PI - Controller

- The integral mode of control is not usually alone but is frequently used in conjuction with the proportional mode. When integral action is added to a proportional control system the controller output is given by

$$\text{controller output} = K_p e + K_I \int e \, dt$$

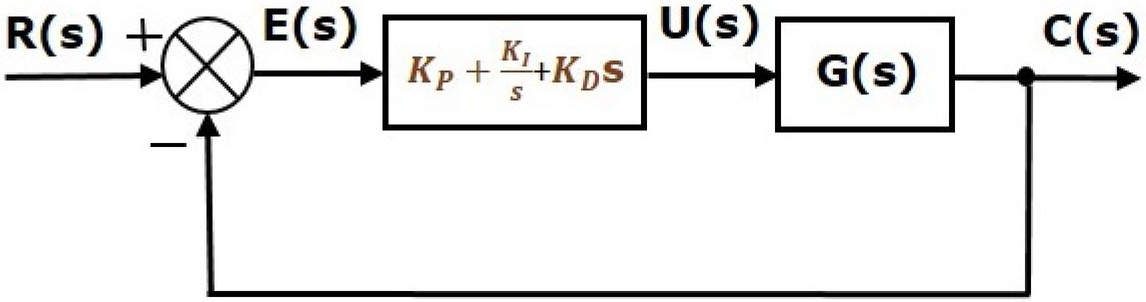


$$U(s) = \left(K_P + \frac{K_I}{s} \right) E(s)$$

$$\frac{U(s)}{E(s)} = K_P + \frac{K_I}{s}$$

PID - Controller

- Combining all three modes of control gives a controller known as a three-mode controller of PID controller.



$$u(t) = K_P e(t) + K_I \int e(t)dt + K_D \frac{\mathrm{d}e(t)}{\mathrm{d}t}$$

Apply Laplace transform on both sides -

$$U(s) = \left(K_P + \frac{K_I}{s} + K_D s\right) E(s)$$

$$\frac{U(s)}{E(s)} = K_P + \frac{K_I}{s} + K_D s$$

The Characteristics of P, I, and D controllers

A proportional controller (Kp) will have the effect of reducing the rise time and will reduce, but never eliminate, the steady-state error.

An integral control (Ki) will have the effect of eliminating the steady-state error, but it may make the transient response worse.

A derivative control (Kd) will have the effect of increasing the stability of the system, reducing the overshoot, and improving the transient response.

Proportional Control

By only employing proportional control, a steady state error occurs.

Proportional and Integral Control

The response becomes more oscillatory and needs longer to settle, the error disappears.

Proportional, Integral and Derivative Control

All design specifications can be reached.

The Characteristics of P, I, and D controllers

CL RESPONSE	**RISE TIME**	**OVERSHOOT**	**SETTLING TIME**	**S-S ERROR**
Kp ↑	Decrease	Increase	Small Change	Decrease
Ki	Decrease	Increase	Increase	Eliminate
Kd	Small Change	Decrease	Decrease	Small Change

Tips for Designing a PID Controller

1. Obtain an open-loop response and determine what needs to be improved
2. Add a proportional control to improve the rise time
3. Add a derivative control to improve the overshoot
4. Add an integral control to eliminate the steady-state error
5. Adjust each of Kp, Ki, and Kd until you obtain a desired overall response.

Lastly, please keep in mind that you do not need to implement all three controllers (proportional, derivative, and integral) into a single system, if not necessary. For example, if a PI controller gives a good enough response (like the above example), then you don't need to implement derivative controller to the system. Keep the controller as simple as possible.