Lecture #0.3

Standard industrial regulators

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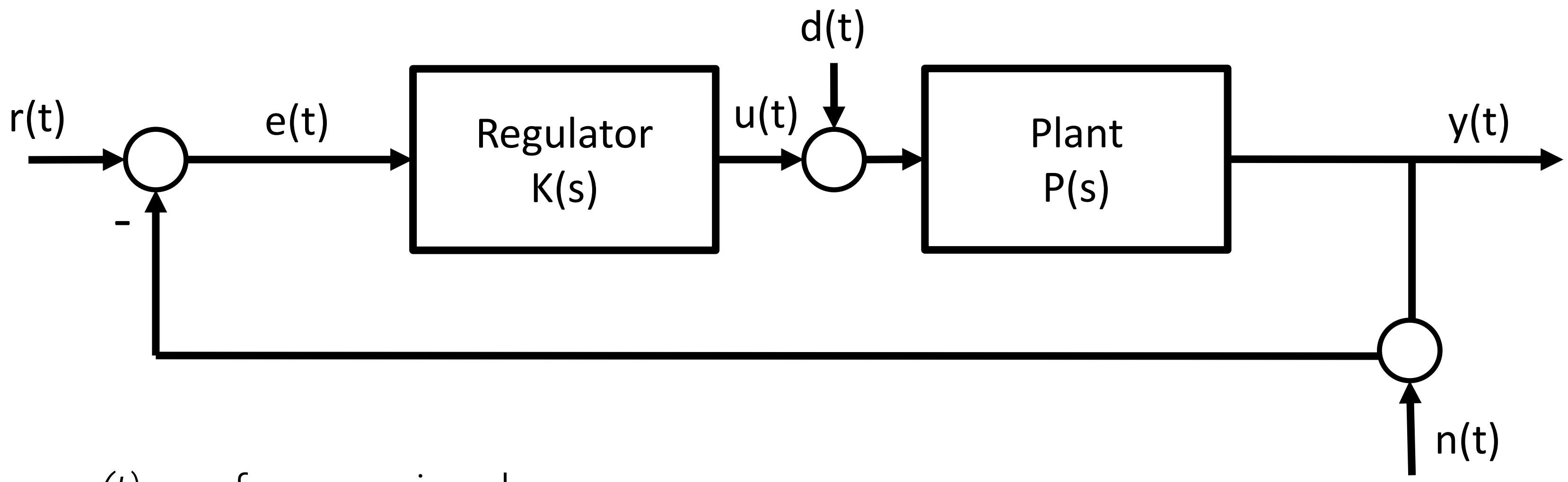
Overview

- Introduction to PID controllers
- PID control law:
  - Ideal
  - Real
- Some rules of thumb

Reference scheme



- *r(t)* – reference signal
- *e(t)* – control error
- *u(t)* – control action
- *y(t)* – controlled output
- *n(t)* – measurement noise
- *d(t)*– additive (control action) disturbance

Standard regulators

- The **dynamic characteristics** of controlled systems can vary greatly depending on the application

- However, it would be convenient to have controllers with a **standard structure**, to be configured according to the application

→ use controllers with a fixed structure
→ only tune some parameters

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Standard regulators

The most common standard controllers are

- LTI Controllers
  → Proportional Integral Derivative (PID)

- NL Controllers
  → Relay

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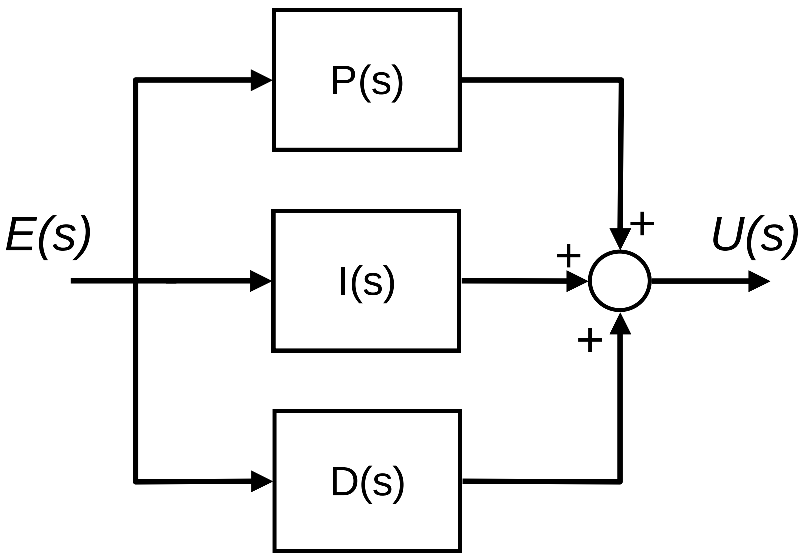
Industrial PID regulators

In a PID regulator the control action *u(t)* is obtained as the sum of three terms

1. The first is proportional to the error *e(t)*
2. The second is proportional to the integral of *e(t)* (i.e. to its average value);
3. The third is proportional to the derivative of *e(t)*



Industrial PID regulators
Advantages

The success of PID regulators in the industrial field is essentially due to the following reasons:

- efficiently regulate processes of different nature
  (thermal, mechanical, etc.)
- realizable with different types of technology
  (pneumatic, electronic, etc.)
- convenience of a standard structure
  (reduction of project costs, management and maintenance, benefits in the management of warehouse stocks)
- often do not require a detailed model of the process
  (auto-tuning procedures also exist)

Control law

- In the time domain

$$u(t) = K_P e(t) + K_I \int_0^t e(\tau)d\tau + K_D \frac{de(t)}{dt}$$

Proportional gain

Integral gain

Derivative gain

Control law

- Another common representation:

$$u(t) = K_P\left(e(t) + \frac{1}{T_I}\int_0^t e(\tau)d\tau + T_D\frac{de(t)}{dt}\right)$$

Integral (or *reset*) time

Derivative time

Ideal control law

In the **Laplace domain**

- **Ideal** control law: it is **not physically achievable (non-proper)**

$$U(s) = K_P\left(1 + \frac{1}{T_I s} + T_D s\right)E(s) = K_P\left(\frac{T_D T_I s^2 + T_I s + 1}{T_I s}\right)E(s)$$

- **Real** control law obtained by **filtering the derivative action**

$$U(s) = K_P\left(1 + \frac{1}{T_I s} + \frac{T_D s}{1 + s\frac{T_D}{N}}\right)E(s)$$

Some rules of thumb

How does varying the parameters of a PID affect control performance?

Proportional action

$$U_P(s) = K_P E(s)$$

- a high value of K_P reduces the steady-state error and can make the system's response faster

- On the other hand, a too high value of K_P may destabilize the system

Proportional action

Steady-state error

- The residual steady state error can sometimes be handled with a **feedforward compensation** (e.g. resistive terms in electrical circuits)

$$\rightarrow U_P(s) = K_P E(s) + U_{FF}$$

Proportional action

Effect of noise

- Moreover, computing the tf from the **measurement noise** $n(t)$ **to the output** ***y(t)***

$$Y(s) = \frac{K_p P(s)}{1 + K_p P(s)} \left(R(s) - N(s) \right)$$

- A high K_P increases the **system's bandwidth** and worsens the effect of measurement noise

Integral action

$$U_I(s) = \frac{K_P}{T_I s} E(s)$$

- null steady-state error for constant *r(t)* and *d(t)*
- 90° phase lag, bad for stability
- may cause actuator saturation
  (so-called integral ***wind-up***)

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Derivative action

$$U_D(s) = \frac{K_P T_D s}{1 + \frac{T_D}{N} s} E(s)$$

- 90° phase lead, good for stability
- amplifies the noise *n(t)* at high-frequency, which may cause **actuator damage** for high control actions *u(t)*

  → choose N wisely!
- must be cautious when dealing with discontinuous signals (e.g. step reference)

Overview

- In general not all control actions need be present
  - P
  - I
  - PI
  - PD
  - PID

	stability	e_∞	T_a	overshoot
$K_P \uparrow$	Worsens	Decreases	Decreases	Increases
$T_I \downarrow$	Worsens	0 if $K_I \neq 0$	Decreases	Increases
$T_D \uparrow$	Improves	Not influenced	Not influenced	Decreases

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