Types of Regulation:
P, PD, PI, and PID Controllers

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INTRODUCTION TO REGULATION

- Regulation is the process of automatic management of systems in order to achieve and maintain a desired output value.

- **Importance of Control:**
  - Increases the accuracy and stability of the system
  - Enables automatic adaptation to changes
  - Essential for modern technological processes and devices

- **Examples of Use:**
  - Industrial automation (temperature, pressure, etc.)
  - Robotics and mechatronics
  - Vehicles – especially electric cars
  - Household appliances

BASIC CONCEPTS IN CONTROL

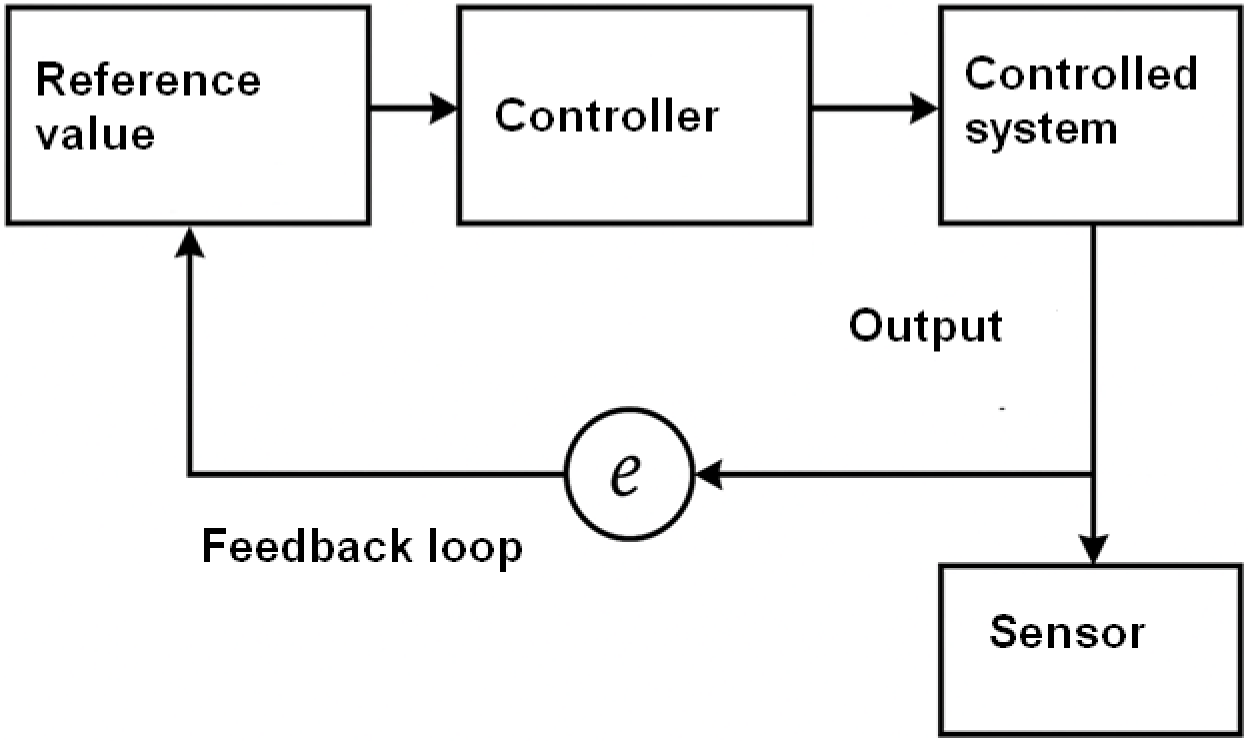
- A **controlled system** is a system on which we act in order to achieve the desired outcome (e.g., a car engine).

- The **input signal** is the signal that directly affects the controlled system in order to achieve the desired output value. It is used to control the process.

- The **output variable** represents the actual state or behavior of the controlled system, and the system tries to maintain it at the desired level through regulation.

- The **error (e)** is the difference between the desired (reference) value and the actual output value:

$$e(t) = \text{desired value} - \text{actual value}$$



Simple Feedback Loop

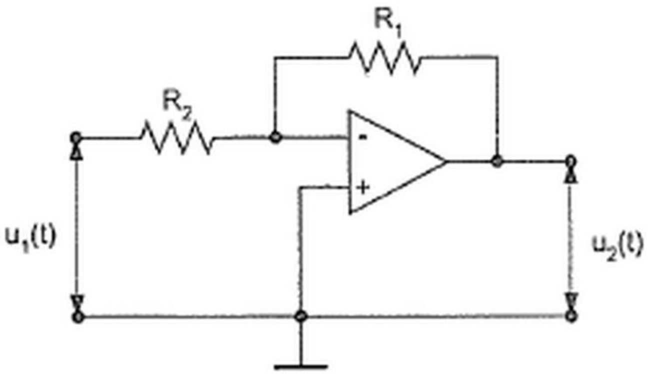
PROPORTIONAL (P) CONTROLLER

- A **P controller** generates a control signal that is proportional to the current difference between the desired and actual value of the system. It is described by the equation:

$$Y(t) = Kp \cdot u(t)$$

- **Practical application (e.g., in electric vehicles):**
    - Speed regulation of the motor – increases the voltage when the speed is lower than desired, and decreases it when the speed is higher.

Physically implemented using an operational amplifier:



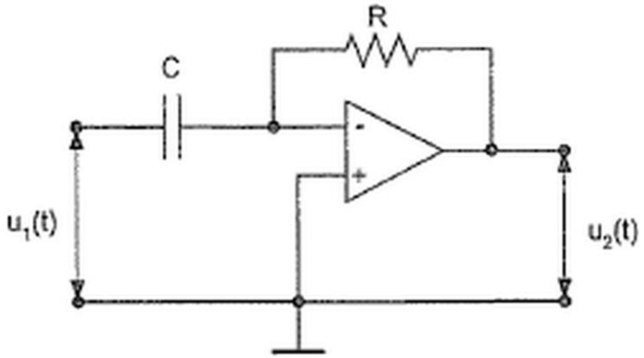
PD CONTROLLER

- The **derivative term** differentiates the input signal and is described by the equation:
  - *Y(t) = du(t) / dt*

- **Practical application** (e.g., in electric vehicles):
  - **Steering control** – provides a more precise response to changes in direction.

- This controller improves response and reduces oscillations in the system.

Physically implemented using an operational amplifier (ideal differentiator):



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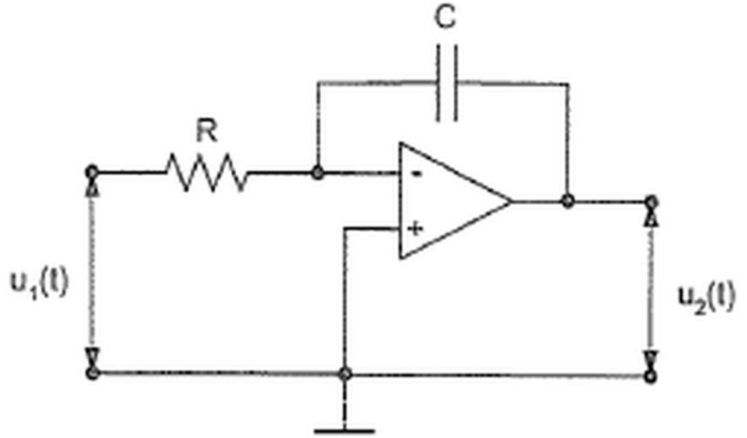
PI CONTROLLER

- The **integral term** performs the integration of the input signal and is described by the equation:

$$y(t) = \int_{-\infty}^{t} u(t)dt$$

- **Practical application (e.g., in electric vehicles):**
  - Battery charging - maintaining constant voltage and current

- This controller reduces the steady-state error. Physically implemented using an operational amplifier:



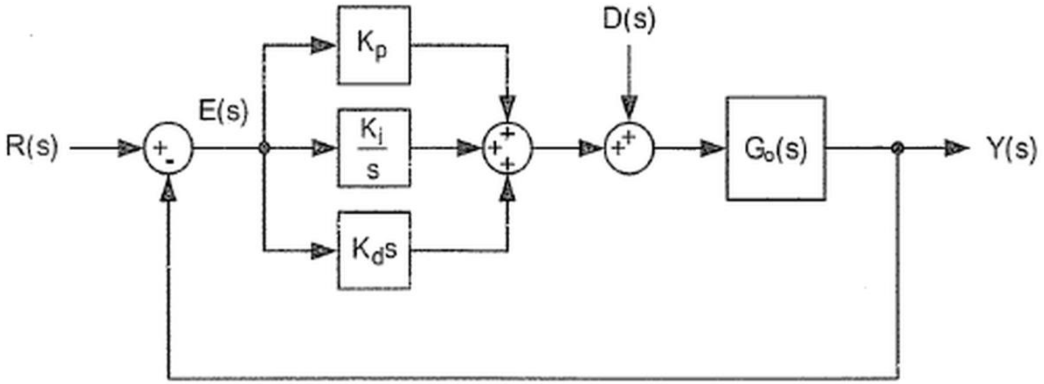
PID CONTROLLER

- The PID controller is a combination of proportional, derivative, and integral terms, and it is used to improve the transient response as well as eliminate steady-state error.

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

- **Practical application (e.g., in electric vehicles):**
  - Motor speed control (electric drive) - smooth and precise acceleration.

- This controller provides the best stability, fast response, and highest precision.



COMPARISON OF CONTROLLER CHARACTERISTICS

Controller	Error level	Stability	Response speed	Complexity
P	medium	good	fast	low
PD	medium	excellent	very fast	medium
PI	low	good	medium	medium
PID	very low	excellent	very fast	high

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PID CONTROLLERS IN ELECTRIC VEHICLES

- **Advantages of Using PID Controllers:**
  - Greater driving comfort
  - Lower energy consumption
  - Better real-time control
- **Practical application (e.g., in electric vehicles):**
  - Motor speed control (electric drive) – smooth and precise acceleration
- This controller provides the best stability, fast response, and highest precision.

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ZIEGLER–NICHOLS METHOD FOR TUNING PID CONTROLLERS

• This method is a classical experimental method.

•Set Ki = Kd = 0, then increase Kp until the system begins to oscillate. At that point, Ki and Kd are calculated according to the table.

- **Kkr** – the proportional gain value at which the system starts to oscillate (Ki = Kd = 0)
- **Tkr** – the oscillation period at the value of Kkr
- **Ti** – integration time
- **Td** – derivative time

Type of controller	Kp	Ki (Ti)	Kd (Td)
PID	0,6 x Kkr	0,5 xTkr	0,125 x Tkr

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ZIEGLER–NICHOLS METHOD
- example -

- Time delay $L = 0{,}2$ s

- Time constant $T = 0{,}8$ s

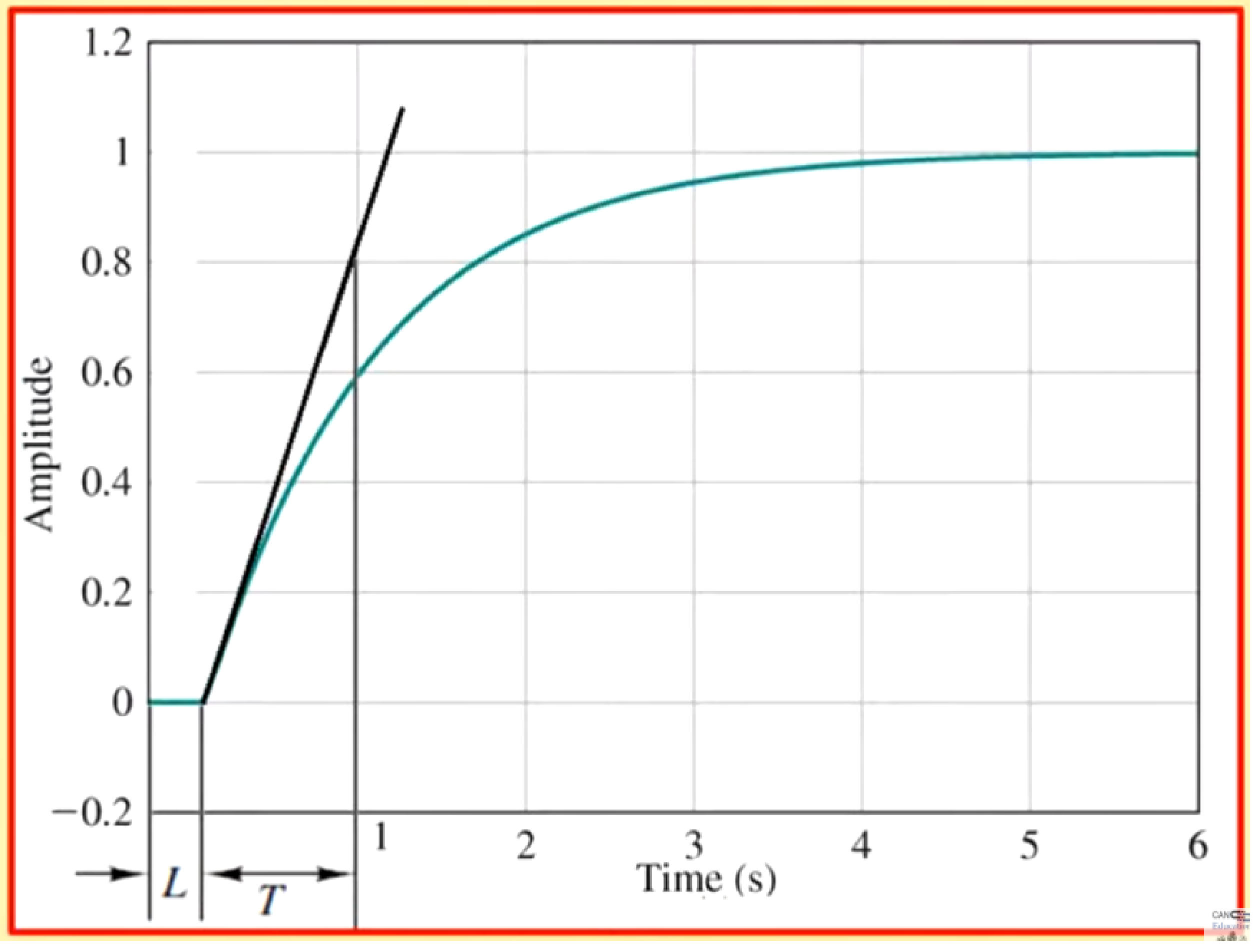
- From the table on the previous slide, we will obtain:

$$K_p = 4{,}8$$
$$T_i = 0{,}4 \text{ s}$$
$$T_d = 0{,}1 \text{ s}$$

- The transfer function is given by the expression:

$$G(s) = K_p\left(1 + \frac{1}{T_i s} + T_d s\right)$$

$$\boldsymbol{G(s) = 0{,}48\frac{(s+5)^2}{s}}$$



Transfer function diagram

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COHEN-COON RECOMMENDATIONS FOR TUNING PID CONTROLLERS

- The Cohen-Coon (C-C) procedure uses model parameters obtained from the Ziegler-Nichols procedure, it assumes a process model in the form of:

$$G(s) = K_o \frac{e^{-\tau s}}{Ts + 1}$$

- The PID controller parameters are selected from the following table:

Tip regulatora	K	T_i	T_d
PID	$\frac{1}{K}\left(0{,}25 + \frac{1{,}35}{\mu}\right)$	$\frac{2{,}5 + 0{,}46\mu}{1 + 0{,}61\mu}\tau$	$\frac{0{,}37}{1 + 0{,}19\mu}\tau$

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