University of Pisa
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Robot Control

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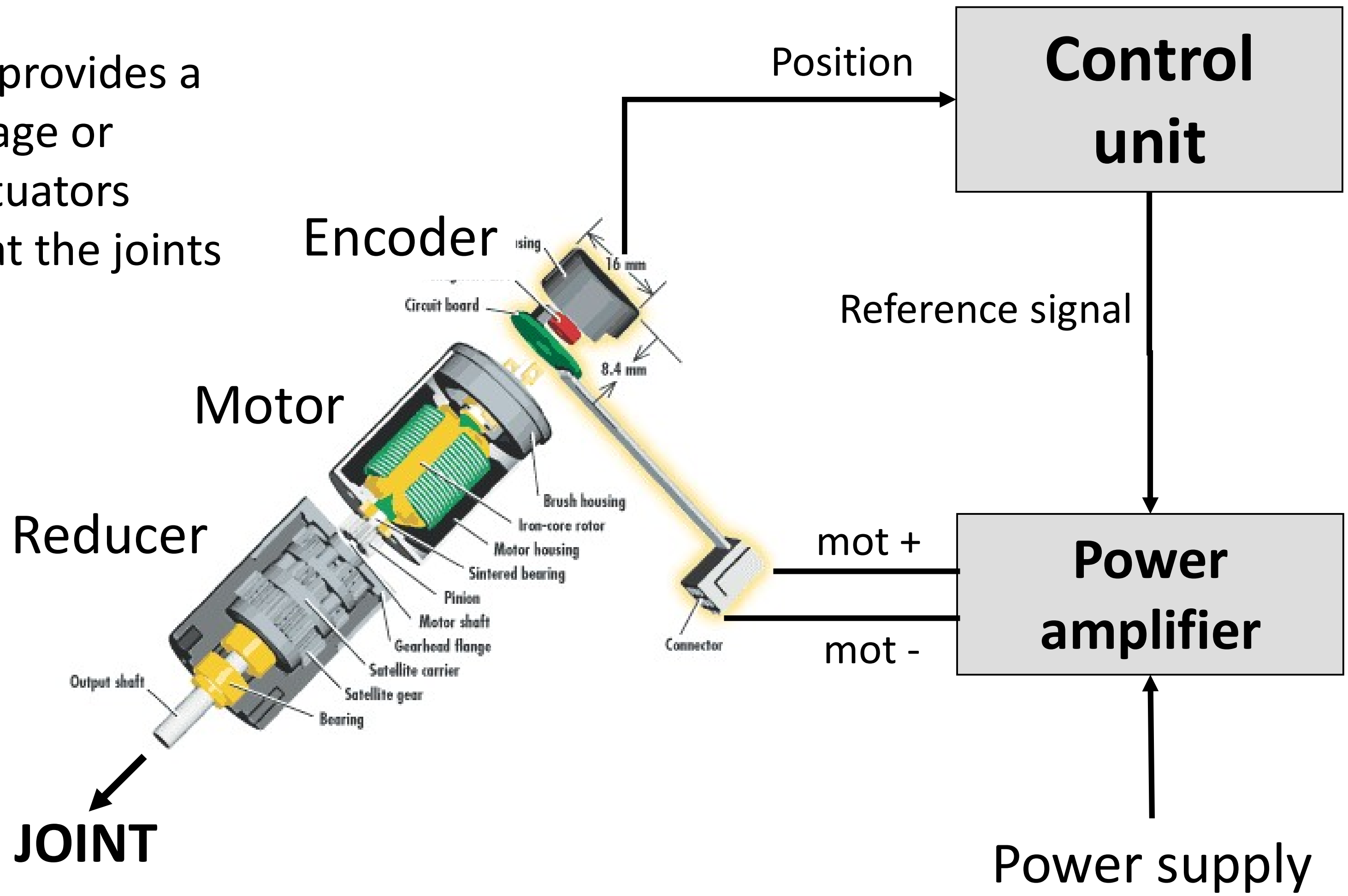
Robot Control

- Control of one joint motion:
  - PID controller
- Control of the manipulator motion:
  - Trajectory planning
  - Motion control in joint space
  - Motion control in operational space
- The Dexter Arm example:
  - Mechanics, Kinematics, Control, Software interfaces

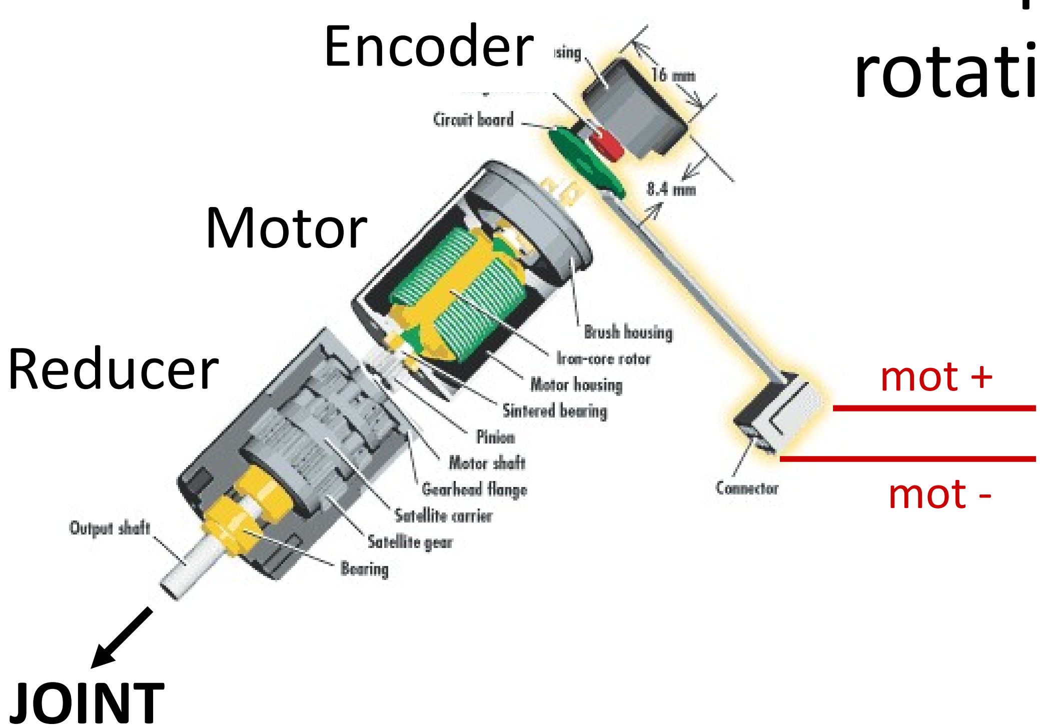
Scheme of a control system

A control system provides a command in voltage or current to the actuators (motors) such that the joints reach a desired configuration



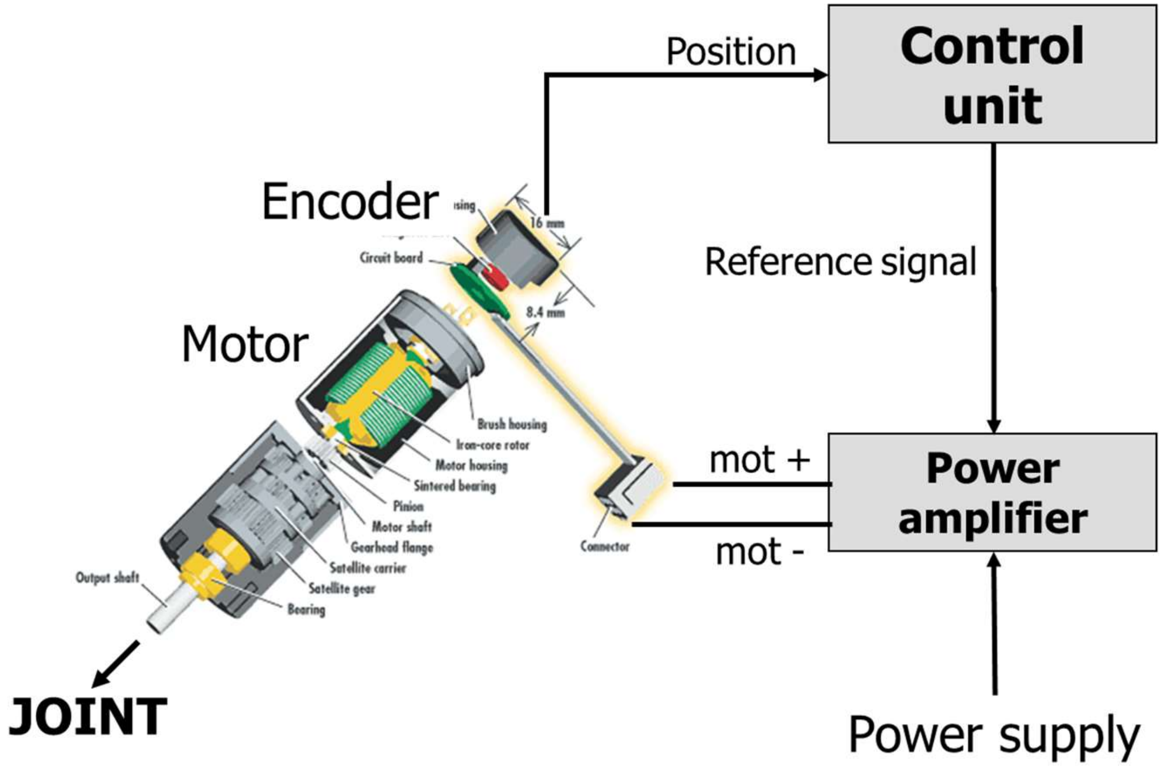
Scheme of a control system

Opposite-sign voltages produce opposite rotations of the motor



Scheme of a control system

- **Encoder**: sensor measuring joint rotations, either as an absolute or a relative value. The measurement is given in "*encoder steps*"
- **Reducer:** mechanism reducing the motor rotations with respect to the rotations of the axis mounted on the motor (ex. 1:k reduction)
- **Power amplifier:** it amplifies a reference signal into a power signal for moving the joint
- **Control unit**: unit producing the reference signal for the motor



Relations between joint position and encoder position

- q: joint angular position (in degrees)
- θ: joint position in encoder steps
- k: motor reduction ratio
- R: encoder resolution (number of steps per turn)

$$q = \frac{\theta \times 360°}{R \times k}$$

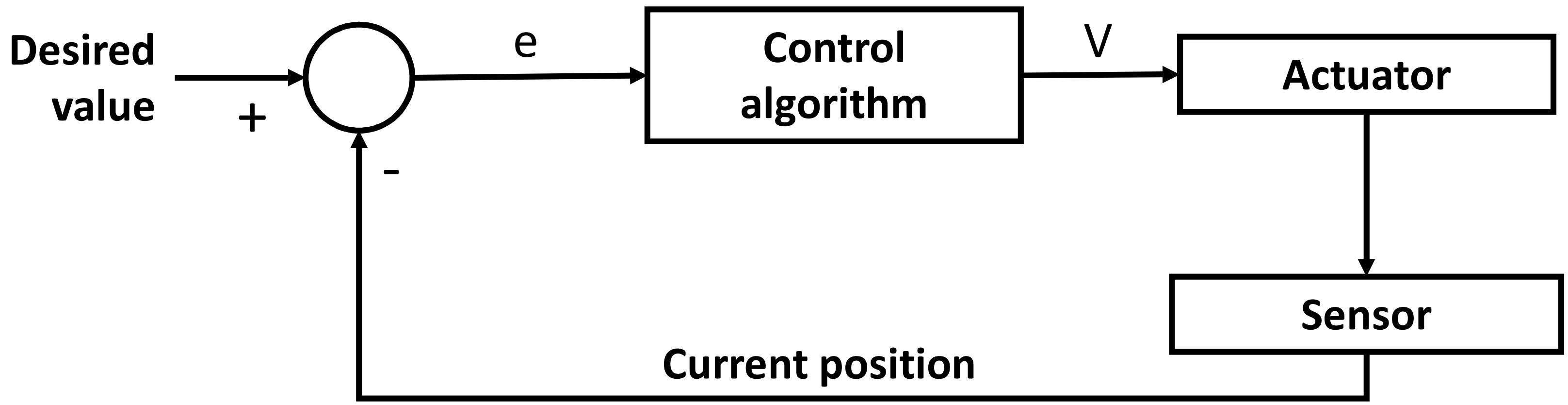
Control of one joint motion

- Objective: move the joint from the current position q_i (in degrees) to the desired position q_f, in a time interval t :

$$q_i \Rightarrow q_f$$

Closed-loop (feedback) control

- The variable to control is measured and compared with the desired value
- The difference, or error, is processed by an algorithm
- The result of processing is the input value for the actuator

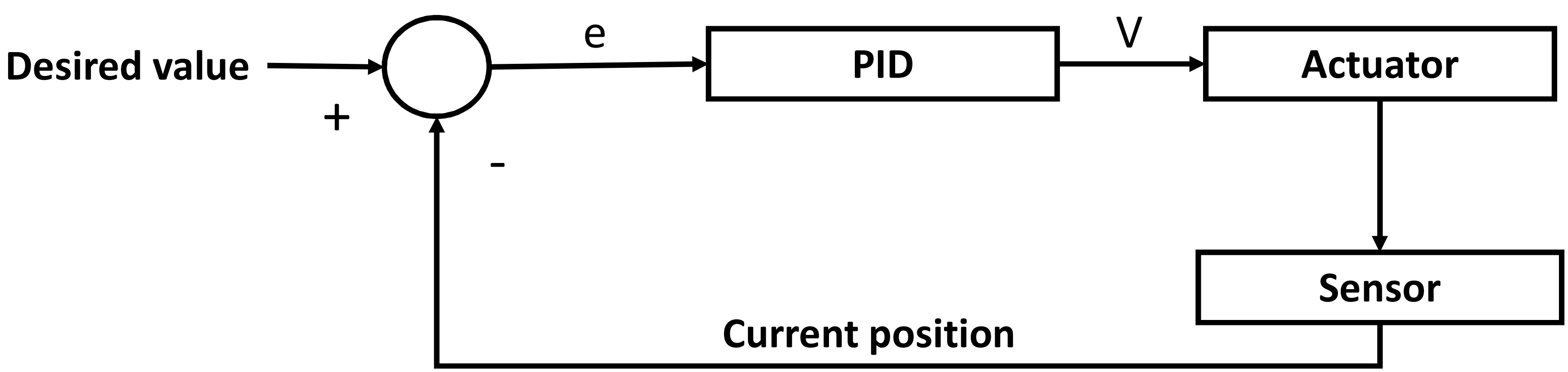


PID control
(Proportional, Integral, Derivative)

- It is a closed-loop control in which the error is processed with an algorithm including **Proportional, Integral and Derivative** components.
- The algorithm processes the error and provides an input to the actuator, with 3 components:
  - **Proportional**, producing a correction proportional to the error;
  - **Integral**, producing a correction given by the error integral in time;
  - **Derivative**, producing a correction which is a function of the error first derivative.
- Not all closed-loop control systems use a PID algorithm

PID control
(Proportional, Integral, Derivative)

- In a PID control system, the error is given to the control algorithm, which calculates the derivative and integral terms and the output signal V



PID control
(Proportional, Integral, Derivative)

$$V = K_p e_q + K_d \dot{e_q} + K_i \int e_q(t)dt$$

$$e_q = q_d - q_a$$

$$\dot{e_q} = \frac{de_q}{dt}$$

K_p is the *proportional* gain or constant

K_i is the *integral* gain or constant

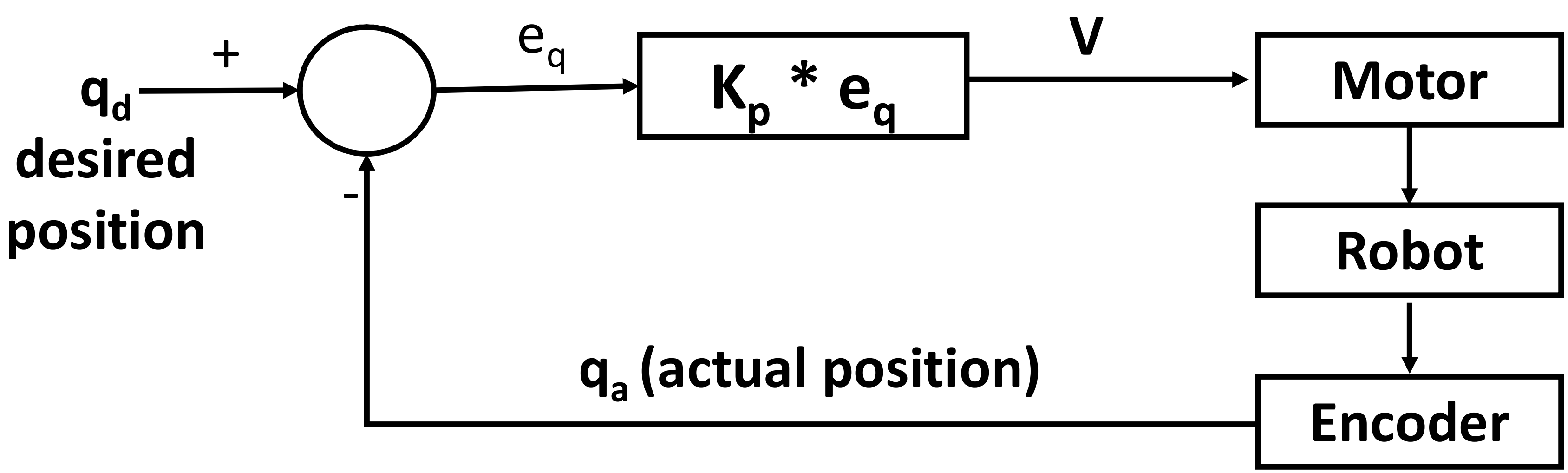
K_d is the *derivative* gain or constant

e_q is the error, i.e. the difference between the desired position and the current (or actual) position

PID control

Proportional term

- The voltage V given to the motor is proportional to the difference between the actual position measured by the sensor and the desired position



PID control

Proportional term:

- The voltage V given to the motor is proportional to the difference between the actual position measured by the sensor and the desired position

$$V = K_p e_q$$

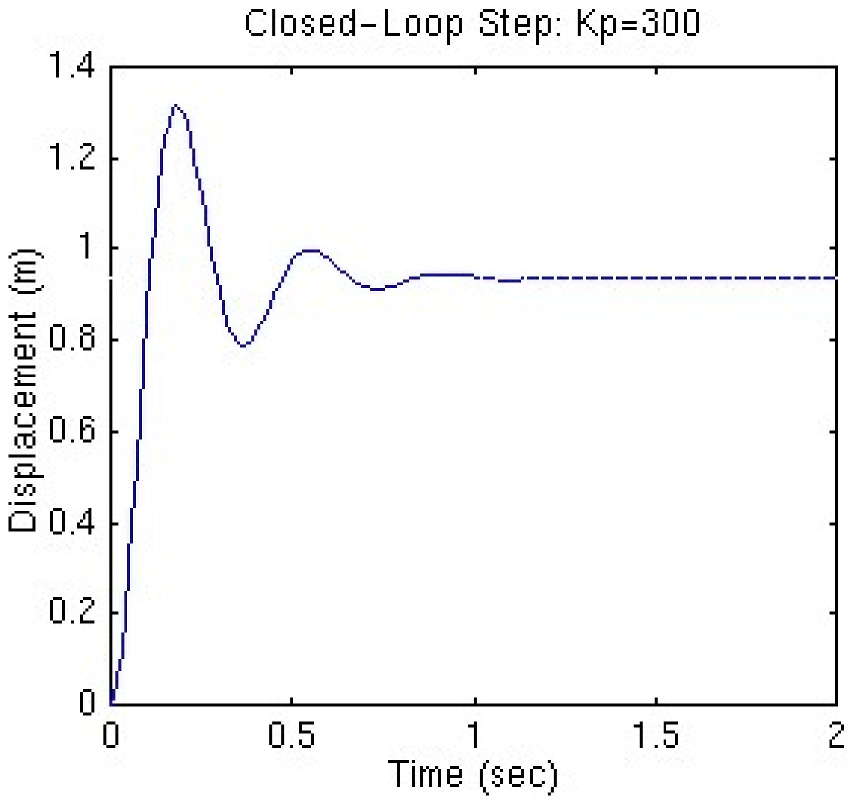
$$e_q = q_d - q_a$$

K_P : proportional constant

PID control

Proportional term: system behaviour

Desired position: 1



- The motor oscillates before converging towards the desired position
- The system may settle without cancelling the error

PID control

Derivative term:

$$V = K_p e_q + K_d \dot{e_q}$$

$$\dot{e_q} = \frac{de_q}{dt}$$ Error derivative in time

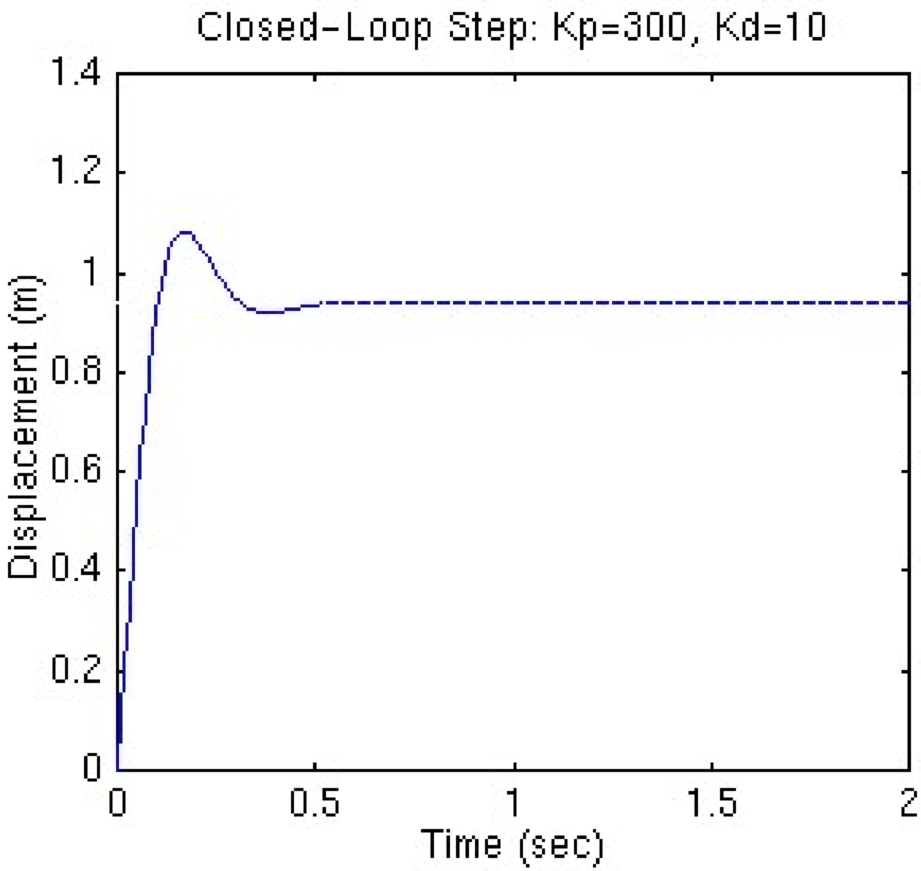
$$e_q = q_d - q_a$$

K_d : derivative constant

PID control

Proportional and derivative terms:

Desired position: 1



- Oscillation reductions
- Reduction of settlement time
- The system may settle without cancelling the error

PID control

Integral terms:

$$K_i \int e_q(t)\,dt$$ Error integral in time

$$V = K_p e_q + K_i \int e_q(t)\,dt$$

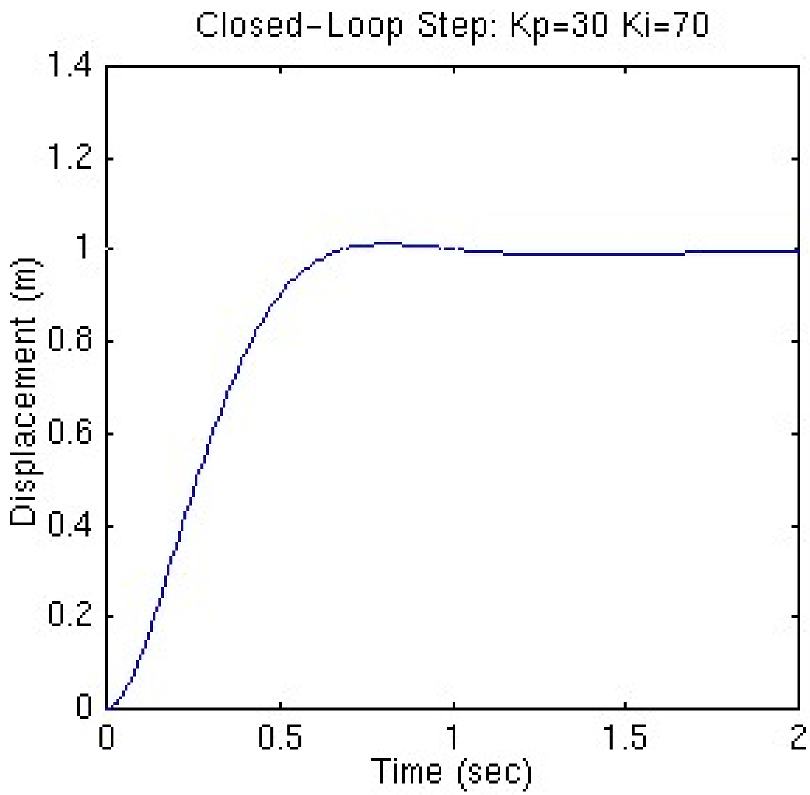
$$e_q = q_d - q_a$$

K_i : integral constant

PID control

Proportional and integral terms:

Desired position: 1



The system settles and cancels the error

PID control

Proportional, Integral and Derivative terms:

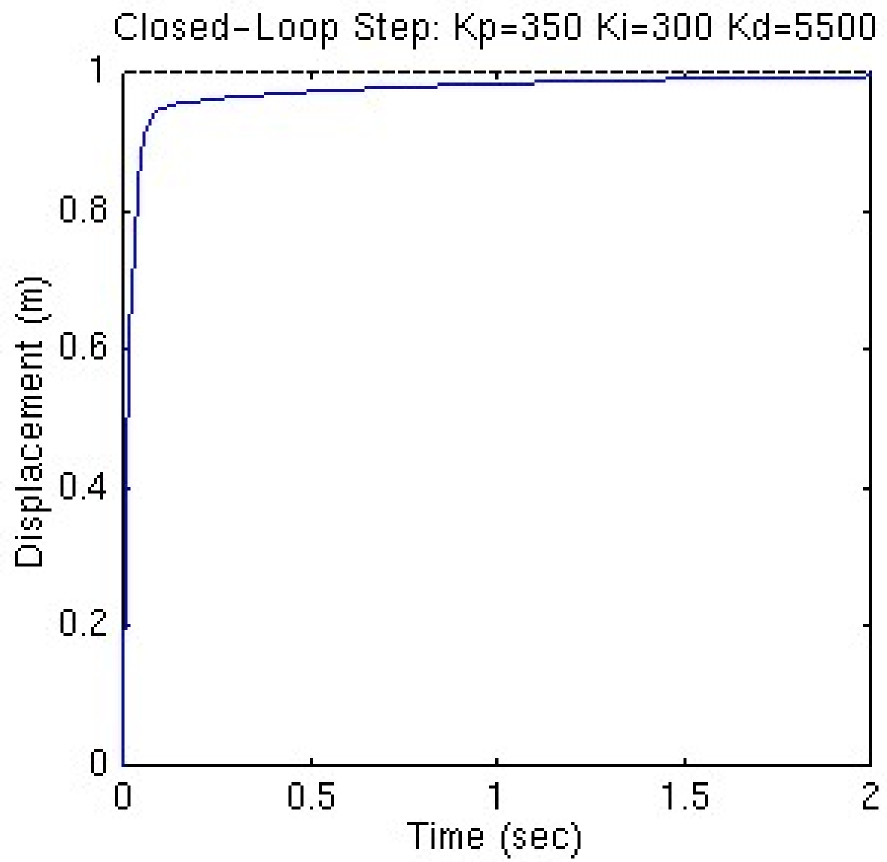
$$V = K_p e_q + K_d \dot{e_q} + K_i \int e_q(t)dt$$

$$e_q = q_d - q_a$$

$$\dot{e_q} = \frac{de_q}{dt}$$

PID control

Proportional, Integral and Derivative terms:



K_p, K_d, K_i constants are set empirically or with specific methods

Video: https://www.youtube.com/watch?v=wkfEZmsQqiA