Mechatronics Engineering Department
Faculty of Engineering
Ain Shams University

MCT344/MCT342/CSE373/CSE471: Robotics

Lecture 12: Robot Control I

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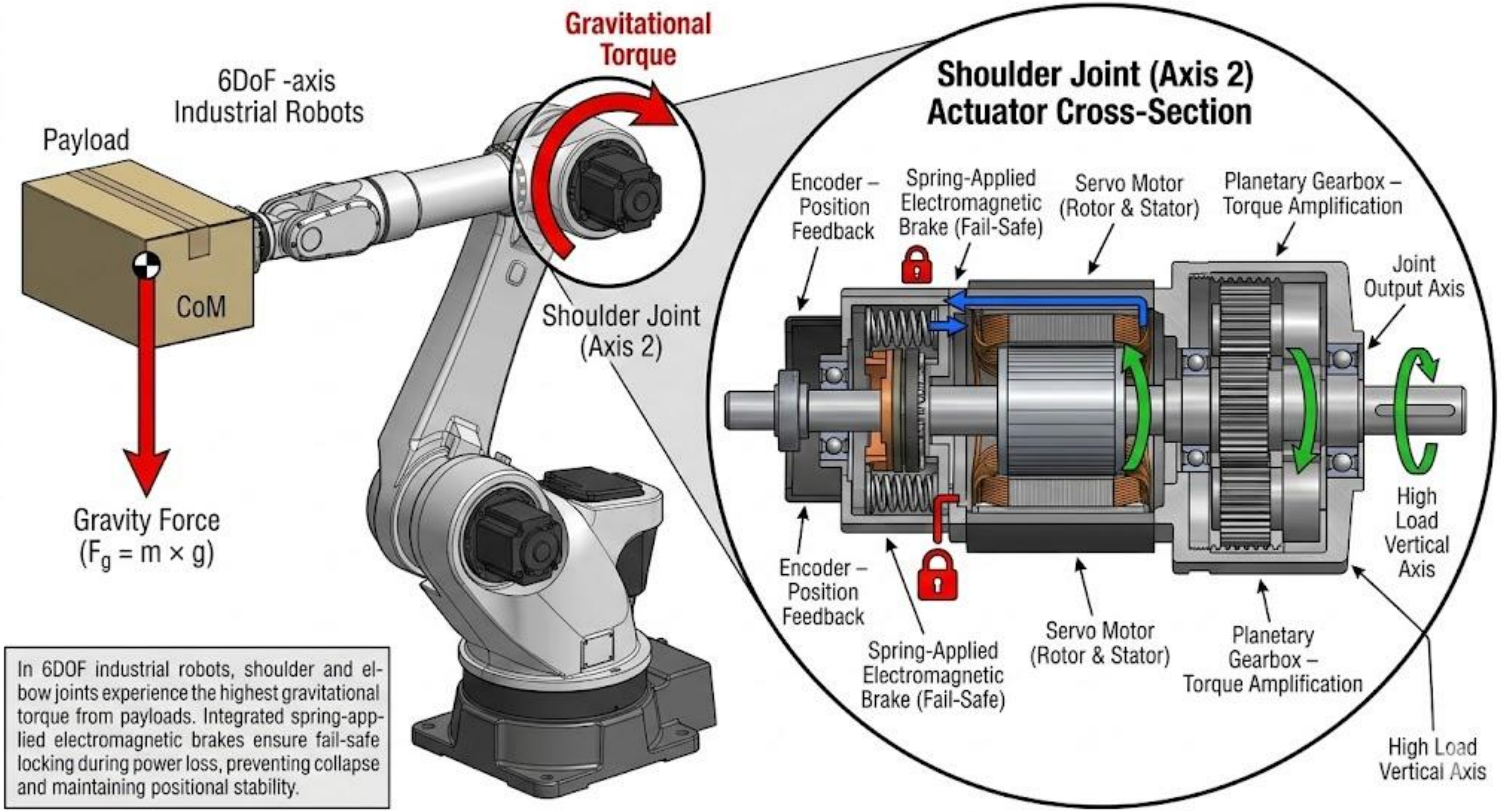
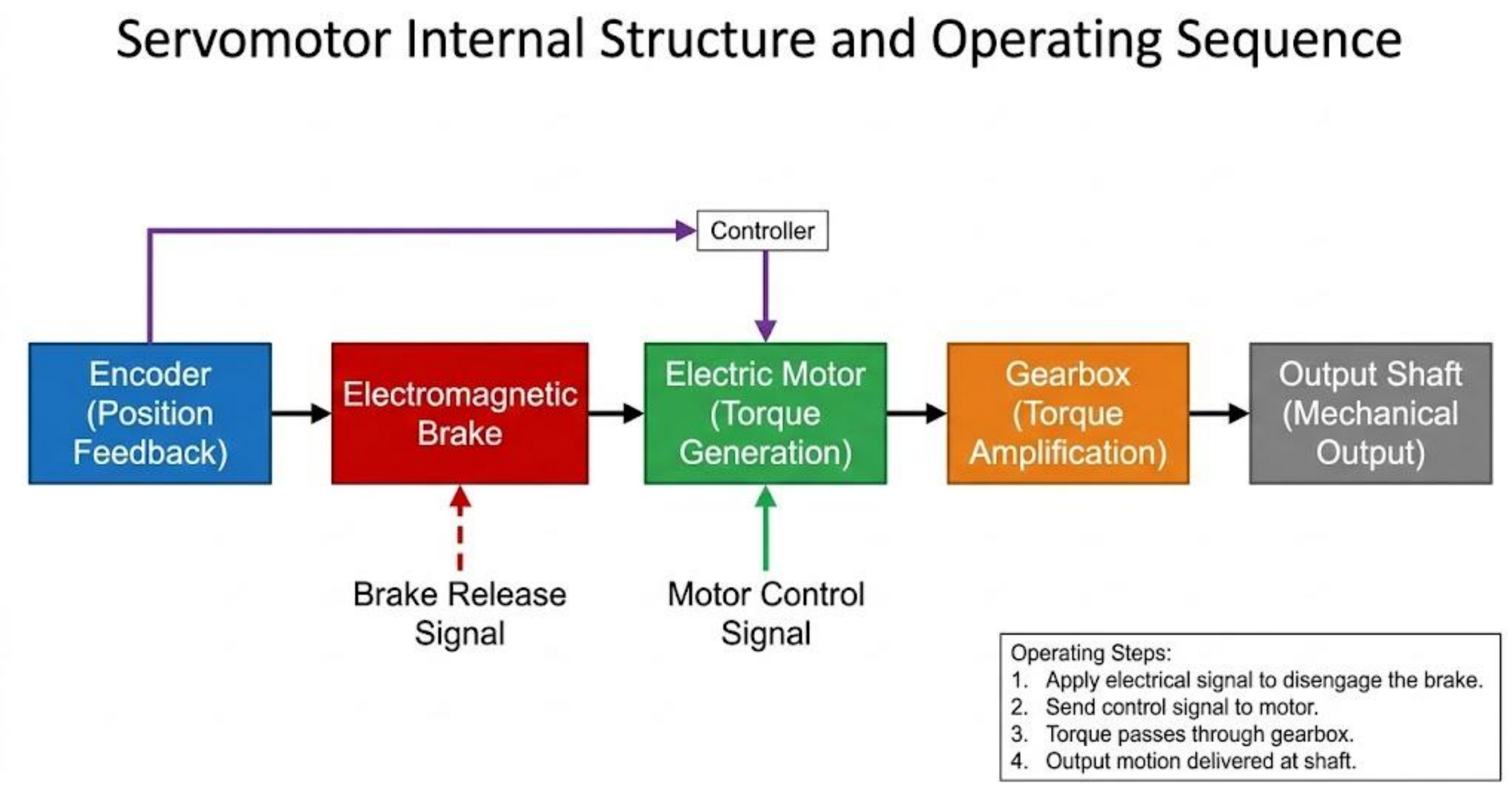
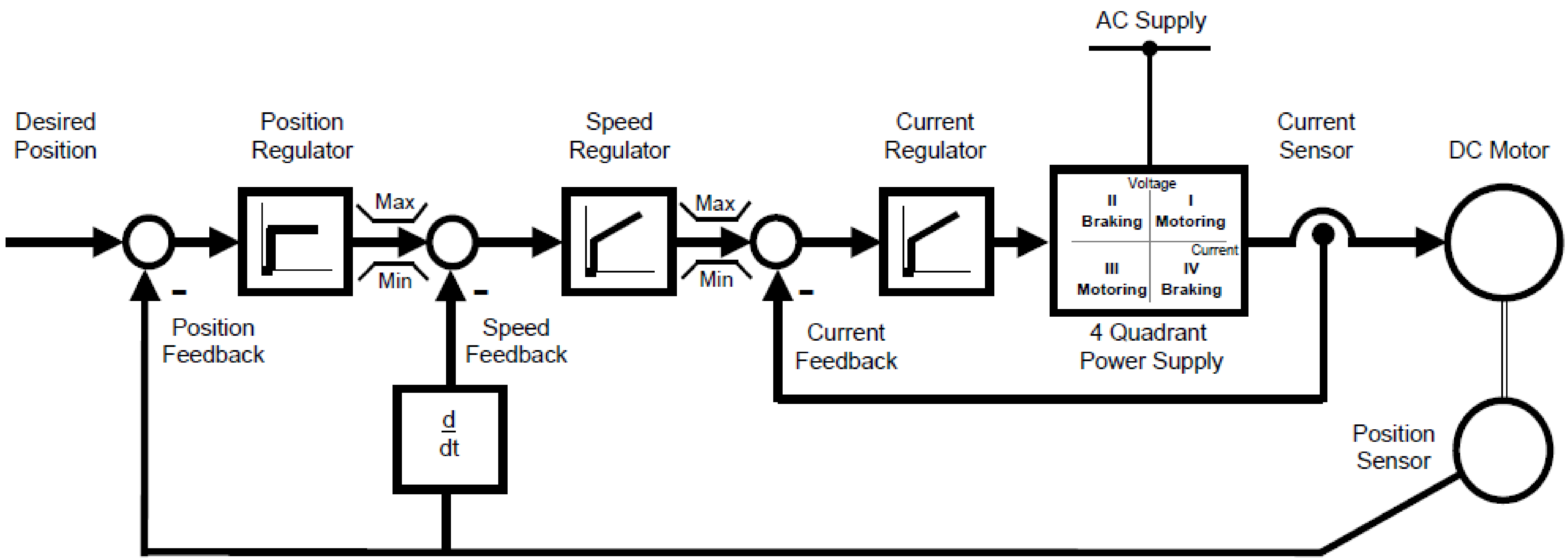
Robotic actuation system

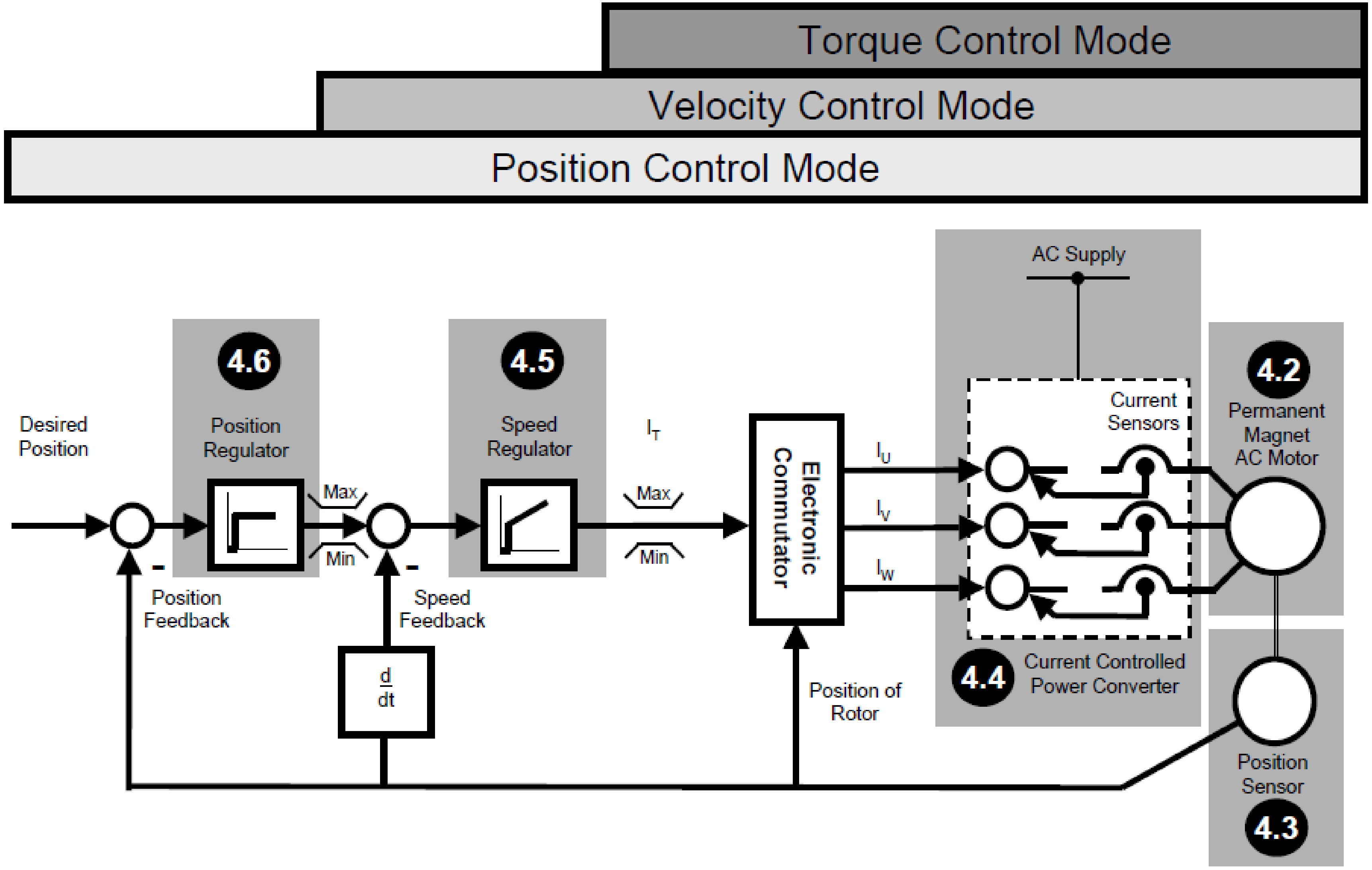


Servomotor with Electromagnetic Brake



Cascade Control Structure of High Performance DC Servo System





Block Diagram of AC Servo System

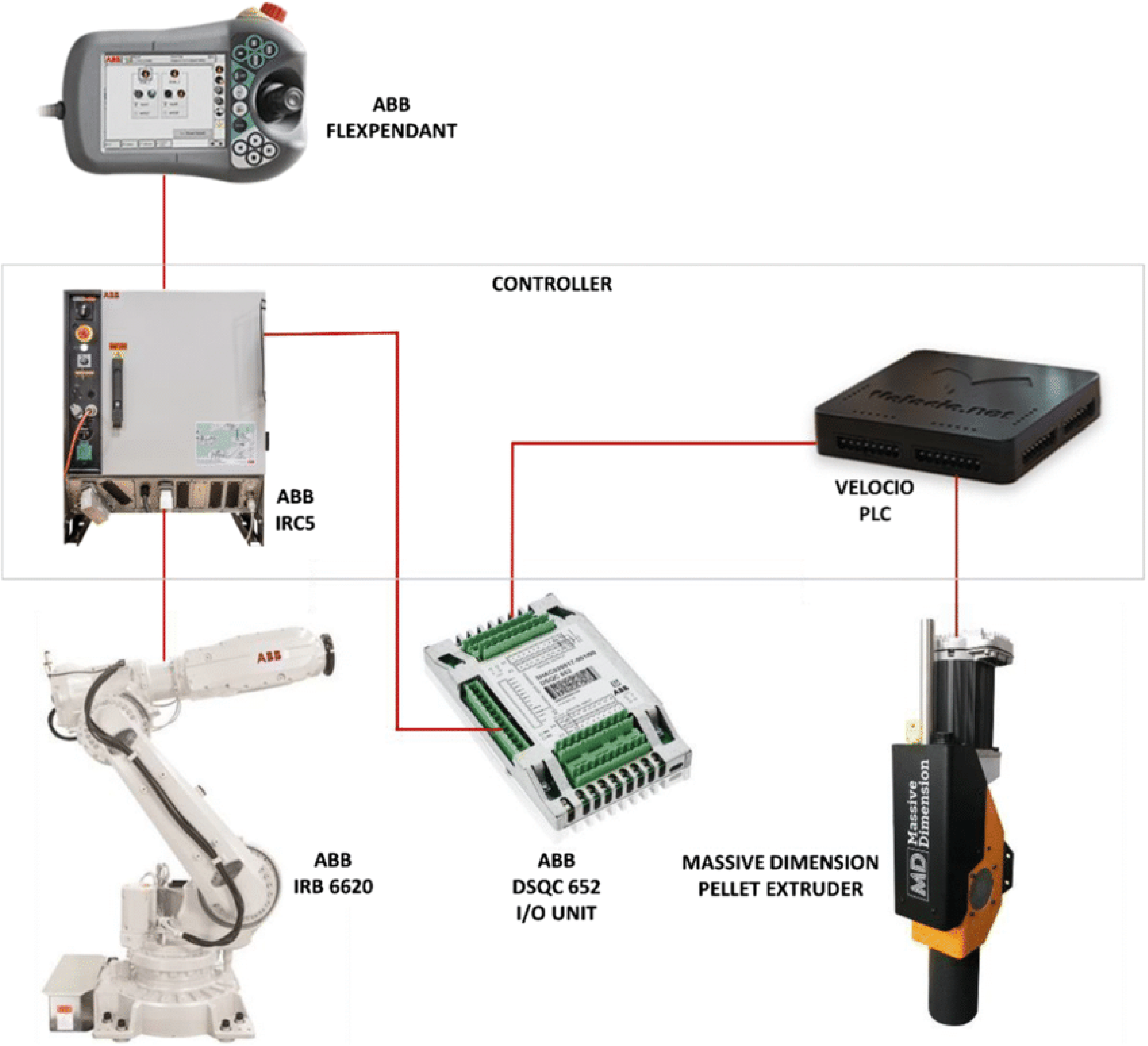
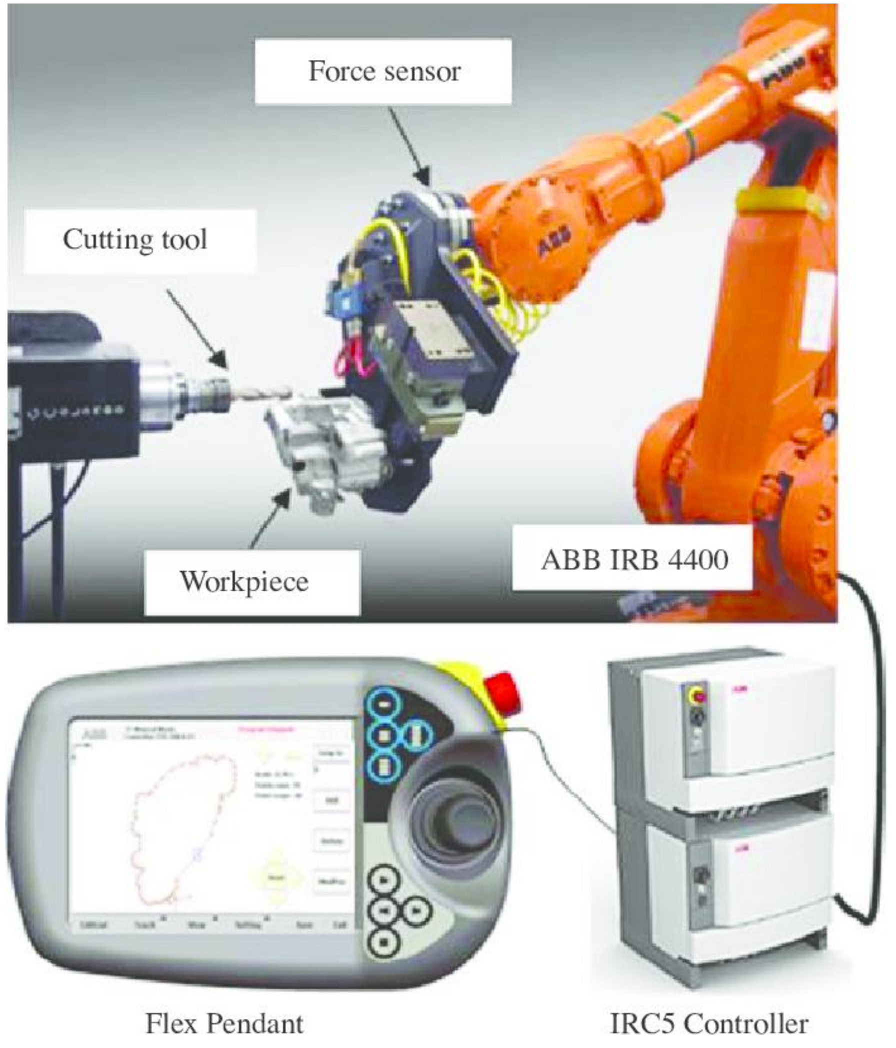
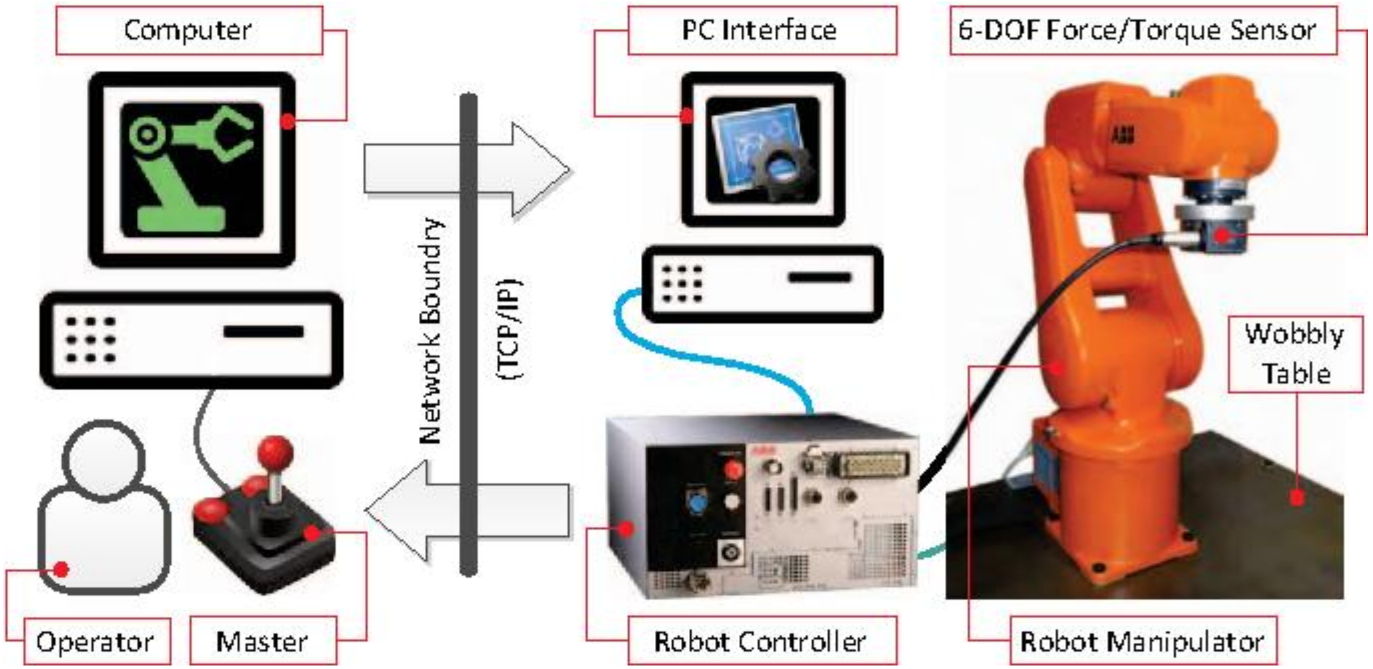
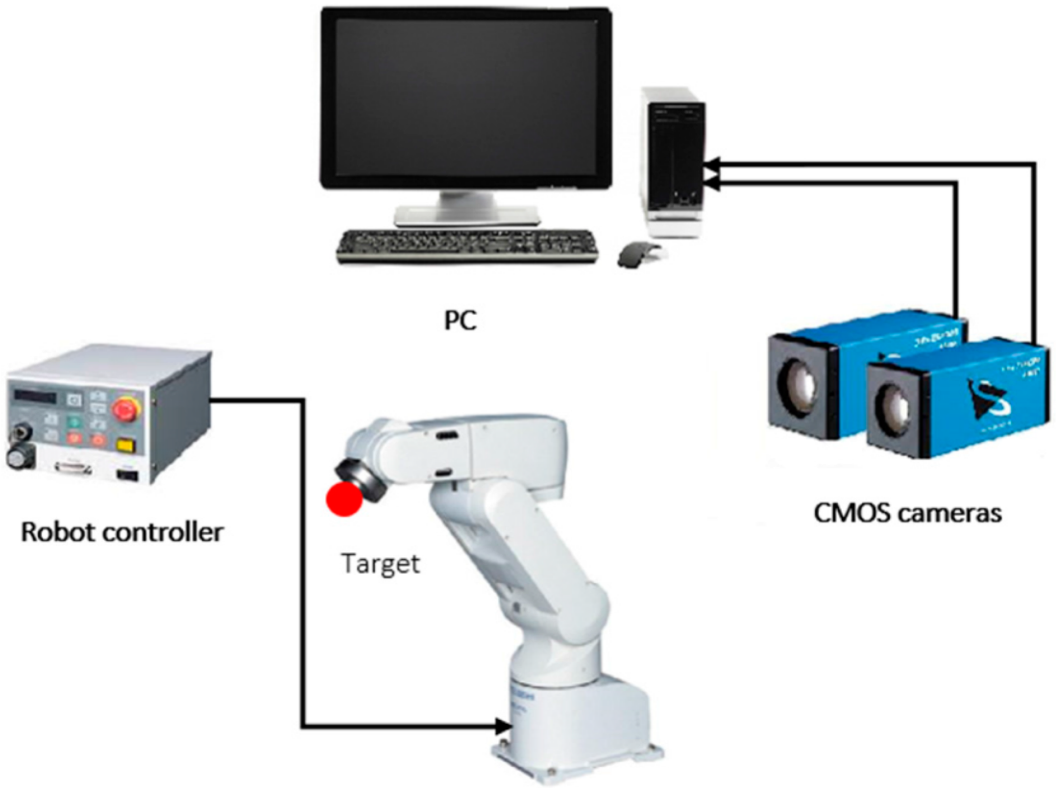
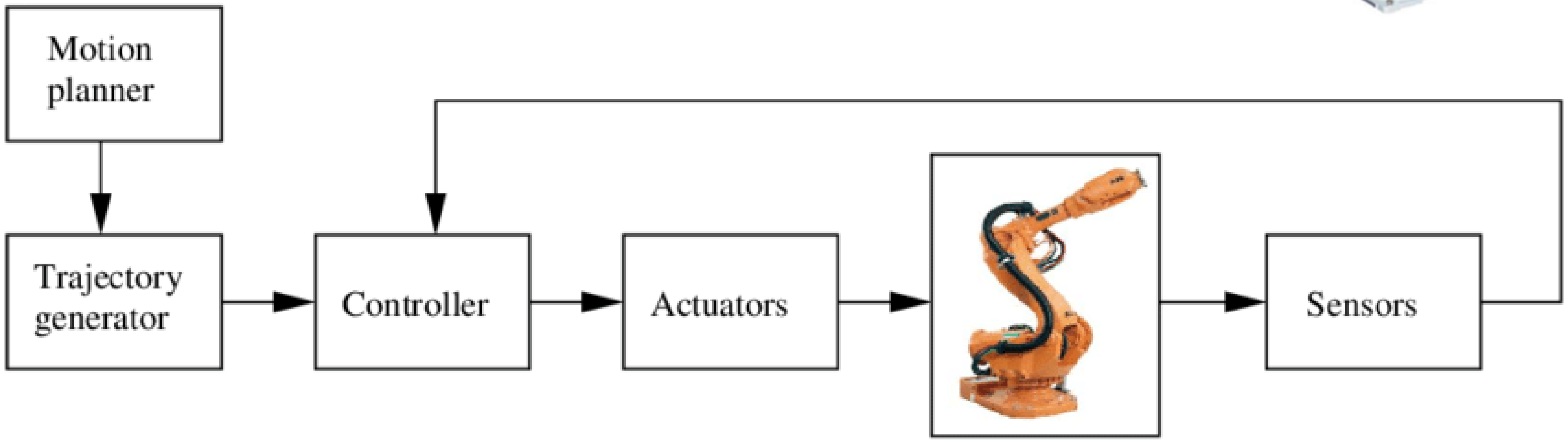


ABB
FLEXPENDANT
CONTROLLER
ABB
IRC5
VELOCIO
PLC
ABB
IRB 6620
ABB
DSQC 652
I/O UNIT
MASSIVE DIMENSION
PELLET EXTRUDER
Massive Dimension


Force sensor
Cutting tool
Workpiece
ABB IRB 4400
Flex Pendant
IRC5 Controller


Computer
PC Interface
6-DOF Force/Torque Sensor
Network Boundry
(TCP/IP)
Wobbly
Table
Operator
Master
Robot Controller
Robot Manipulator


PC
Robot controller
Target
CMOS cameras


Motion
planner
Trajectory
generator
Controller
Actuators
Sensors

Robot control

Control problem: definition of the input signals for the joints (e.g. *torques* or *actuator input voltages*) in order to achieve a predefined behavior for the manipulator.

The achievable performances can be very different because of:

- The many control techniques available to solve such a problem
- The hardware used to implement the control algorithms
- The mechanical configuration of the robot (anthropomorphic, cartesian, ...)

The robot performances are mainly influenced by the mechanical design and by the actuation system. For example:

- The cartesian configuration decouples the dynamics of the joints;
- DC motor with gearboxes have a linear dynamics that results "decoupled" from the non-linear dynamics of the robot. However, gearboxes usually introduce non linear effects such as dead-zones, friction, elasticity, ...;
- Direct Drive motors on one hand ensure better performances and do not introduce non-linearities in the transmission chain; on the other hand a more relevant dynamic coupling between joints is present, and the (nonlinear) load dynamics is directly applied to the actuators without reduction effects.

Robot control

Control problems:

- Control of the robot's motion (*position control* schemes);
  - joint-space control
  - workspace control.
- Control of the interaction with the workspace (*force control* schemes).

Control schemes:

- Decentralized (or independent) control schemes (SISO)
- Centralized control schemes (MIMO).

Dynamic model of a manipulator:

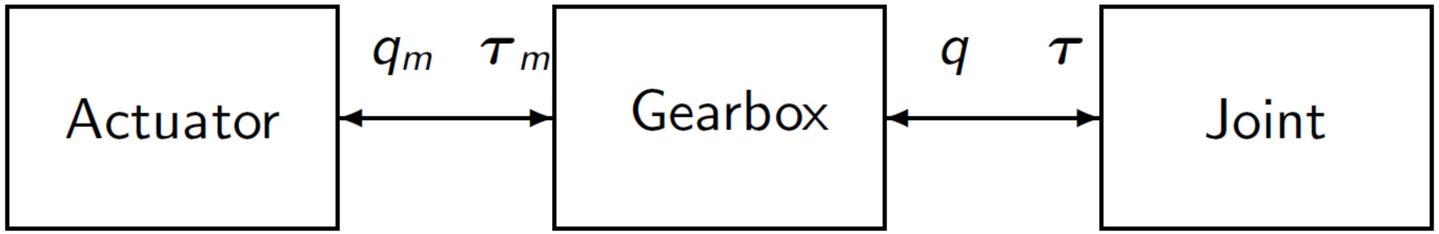
$$\mathbf{M}(\mathbf{q})\ddot{\mathbf{q}} + \mathbf{C}(\mathbf{q}, \dot{\mathbf{q}})\dot{\mathbf{q}} + \mathbf{D}\dot{\mathbf{q}} + \mathbf{g}(\mathbf{q}) = \boldsymbol{\tau} + \mathbf{J}^T(\mathbf{q})\mathbf{F}_a$$

Control problem: define the generalized forces $\boldsymbol{\tau}$ to be applied to the joints in order to obtain a desired trajectory $\mathbf{q}_d(t)$.

1. Robot Position Control
   - Introduction
   - Decentralized position control
     - Cascade Control
     - Position feedback
     - Position and velocity feedback
     - Position, velocity and acceleration feedback
     - Feed-forward control
   - Centralized position control
     - PD controller with gravity compensation
     - Inverse dynamics control

Joint space control

Consideration #1



Actuators:	positions $\mathbf{q}_m(t)$, torques $\boldsymbol{\tau}_m(t)$;
Gearboxes:	reduction ratio $\mathbf{K}_r$;
Joints:	positions $\mathbf{q}(t)$, generalized forces $\boldsymbol{\tau}(t)$;

$$\mathbf{K}_r\, \mathbf{q} = \mathbf{q}_m \qquad\qquad \boldsymbol{\tau}_m = \mathbf{K}_r^{-1} \boldsymbol{\tau}$$

$\mathbf{K}_r$ is a diagonal matrix with elements $\gg 1$.

Joint space control

Consideration #2

The diagonal of the matrix $\mathbf{M}(\mathbf{q})$ is composed by two kinds of elements

- Inertia terms that do not depend on the robot's configuration
- Terms that depend on the robot's configuration.

Therefore:

$$\mathbf{M}(\mathbf{q}) = \bar{\mathbf{M}} + \Delta\mathbf{M}(\mathbf{q})$$

where $\bar{\mathbf{M}}$ is a diagonal matrix with constant elements (i.e. the mean values of the joints inertia). From the robot dynamic model it follows

$$\boldsymbol{\tau}_m = (\mathbf{K}_r^{-1}\bar{\mathbf{M}}\mathbf{K}_r^{-1})\ddot{\mathbf{q}}_m + \mathbf{D}_m\dot{\mathbf{q}}_m + \mathbf{d}$$

where

$$\mathbf{D}_m = \mathbf{K}_r^{-1}\mathbf{D}\mathbf{K}_r^{-1}$$

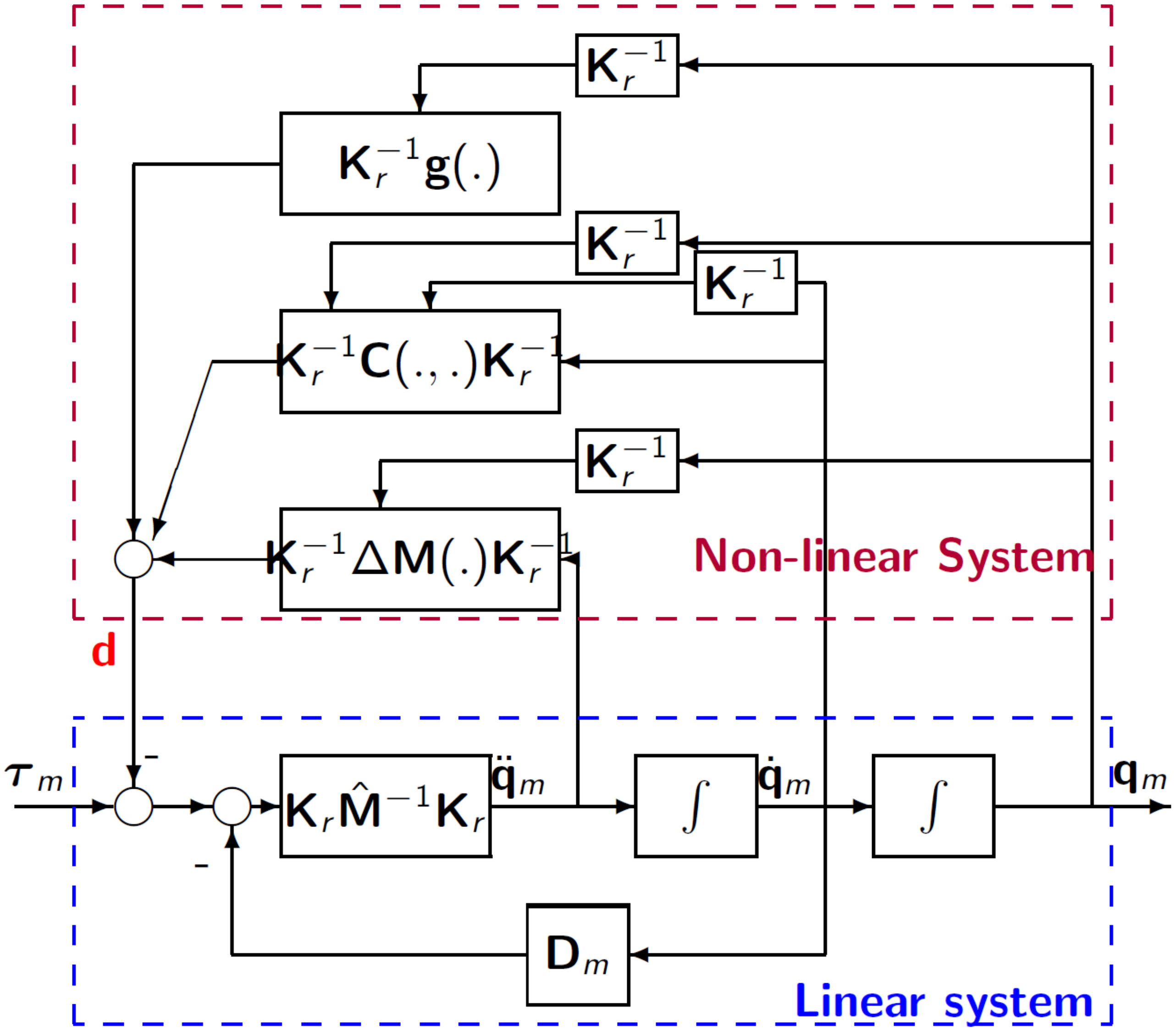
is the matrix collecting the motors friction coefficients, and

$$\mathbf{d} = (\mathbf{K}_r^{-1}\Delta\mathbf{M}(\mathbf{q})\mathbf{K}_r^{-1})\ddot{\mathbf{q}}_m + (\mathbf{K}_r^{-1}\mathbf{C}(\mathbf{q},\dot{\mathbf{q}})\mathbf{K}_r^{-1})\dot{\mathbf{q}}_m + \mathbf{K}_r^{-1}\mathbf{g}(\mathbf{q})$$

is a term that can be considered as a disturbance.

Joint space control

$$\ddot{\mathbf{q}}_m = \mathbf{K}_r\hat{\mathbf{M}}^{-1}\mathbf{K}_r(\tau_m - \mathbf{D}_m\dot{\mathbf{q}}_m - \mathbf{d}) \Longrightarrow$$



A manipulator (+ the actuation system) can be regarded as the composition of:

- a system with input $\ddot{\mathbf{q}}_m, \dot{\mathbf{q}}_m, \mathbf{q}_m$ and output $\mathbf{d}$, *non linear and with couplings*
- a system with input $\boldsymbol{\tau}_m$ and output $\mathbf{q}_m$, *linear and decoupled*

Questions

Thank You