Intelligent Robot Control

Lecture 1: Introduction to Actuators

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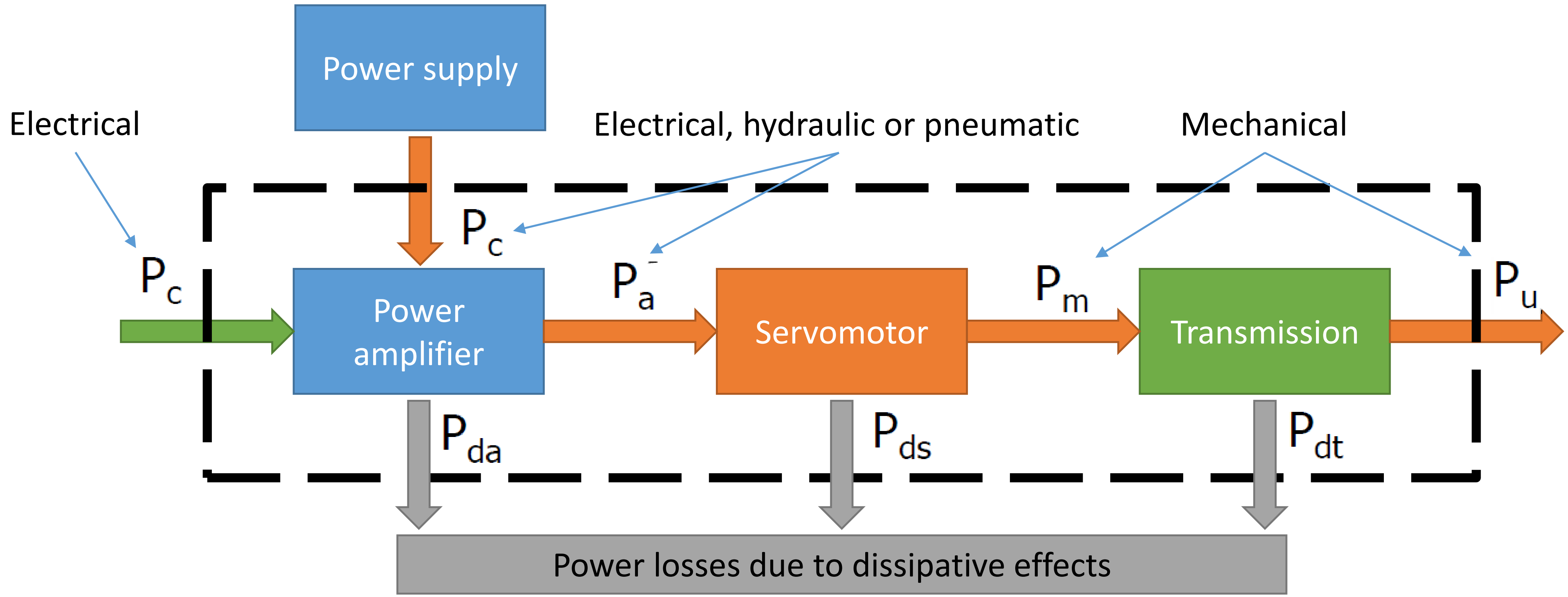
Robot system functional units

- Mechanics of robot arms
  - Rigid links connected through rotational or prismatic joints (usually each 1DOF)
  - Mechanical subdivisions:
    - supporting structure for mobility
    - wrist for dexterity
    - end-effector for task execution, e.g., manipulation
- Actuators and low-level control
  - motors (electrical, hydraulic, pneumatic)
  - motion control algorithms
- Sensors
  - proprioceptive for measuring internal robot states: position and velocity of the joints
  - Exteroceptive for measuring external parameters: force and proximity, vision, …
- Supervision units (high-level control)
  - task planning and control
  - artificial intelligence and reasoning

Actuators as a system



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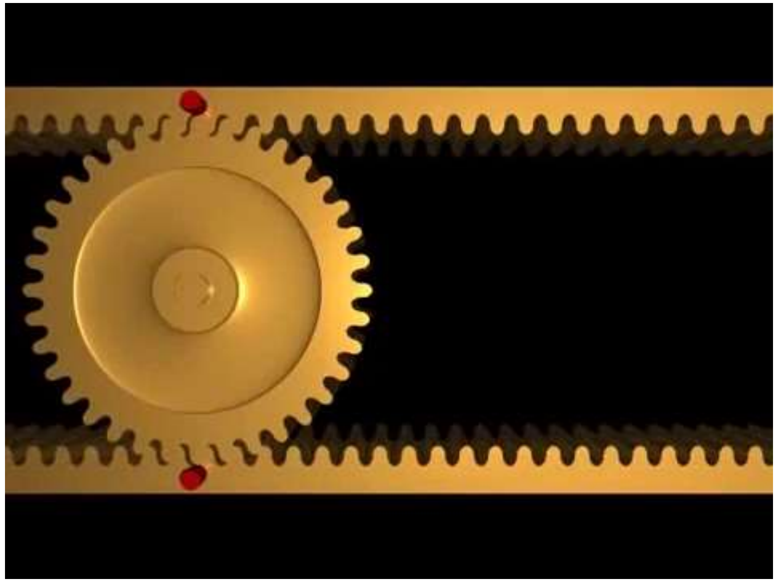
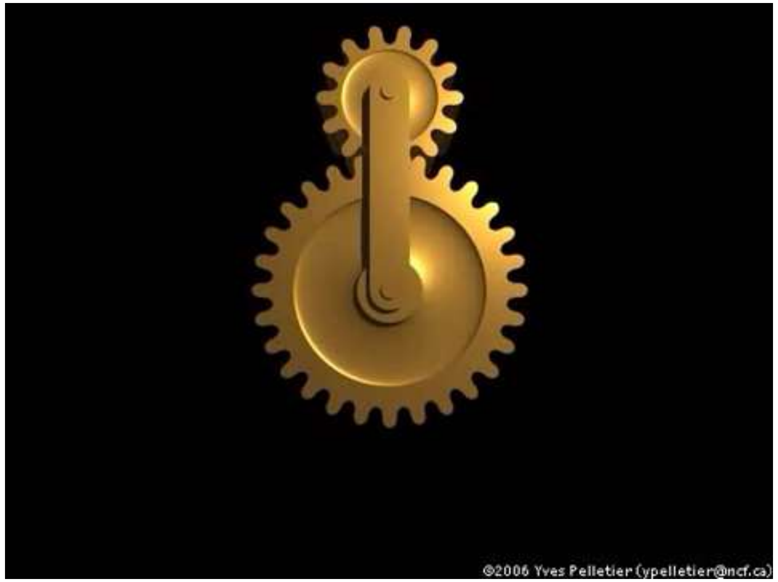
Motion transmission gears

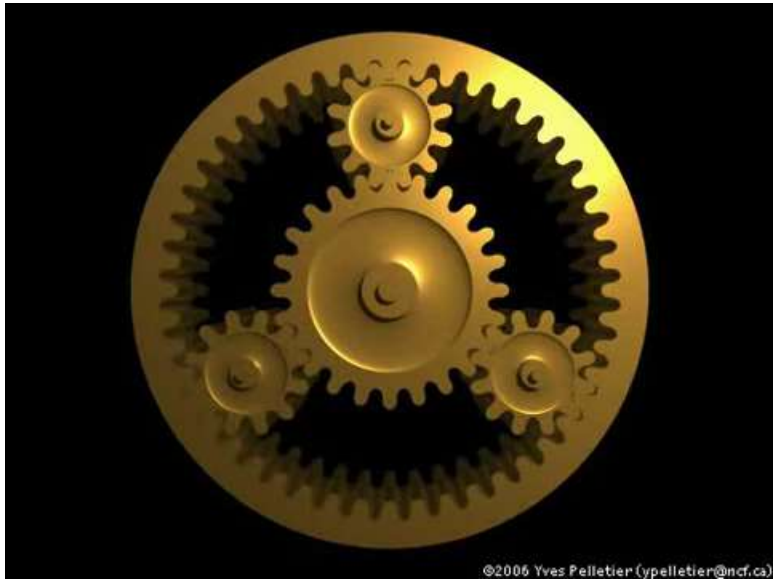
- To optimize the transfer of mechanical torque from actuating motors to driven links
- Quantitative transformation (from low torque/high velocity to high torque/low velocity)
- Qualitative transformation (from rotational motion of an electrical motor to a linear motion of a link along the axis of a prismatic joint)
- Allow improvement of static and dynamic performance by reducing the weight of the actual robot structure in motion (locating the motors remotely, closer to the robot base)

Elementary transmissions

- Racks and pinion
- Epi-cycloidal gear train
- Planetary gear set







Video source: Youtube

Transmissions in robotics

- Spur gears: modify direction and/or translate axis of (rotational or translational) motor displacement
  - problems: deformations, backlash
- Lead screws, worm gearing: convert rotational into translational motion (prismatic joints)
  - problems: friction, elasticity, backlash
- Toothed belts and chains: dislocate the motor w.r.t. the joint axis
  - problems: compliance (belts) or vibrations induced by larger mass at high speed (chains)
- Harmonic drives: compact, in-line, power efficient, with high reduction ratio (up to 150-200:1)
  - problems: elasticity
- Transmission shafts: inside the links…

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Harmonic drives example

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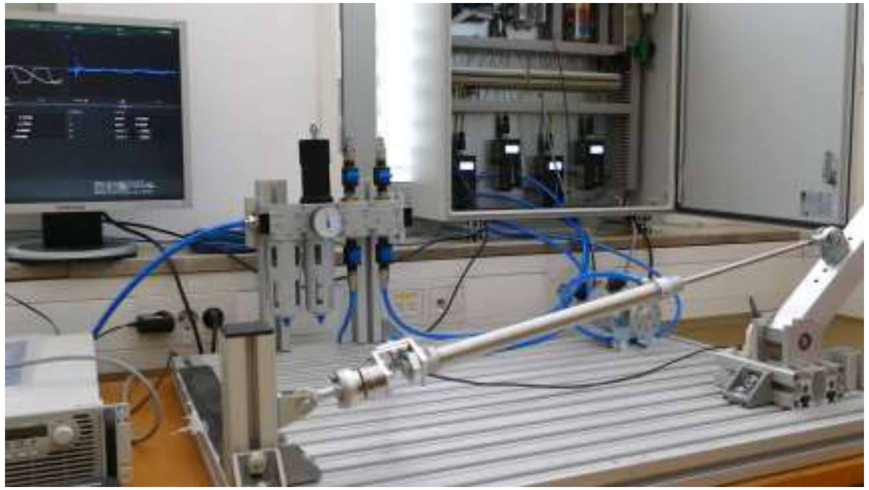
Video source: Youtube

Desired characteristics for robot servomotors

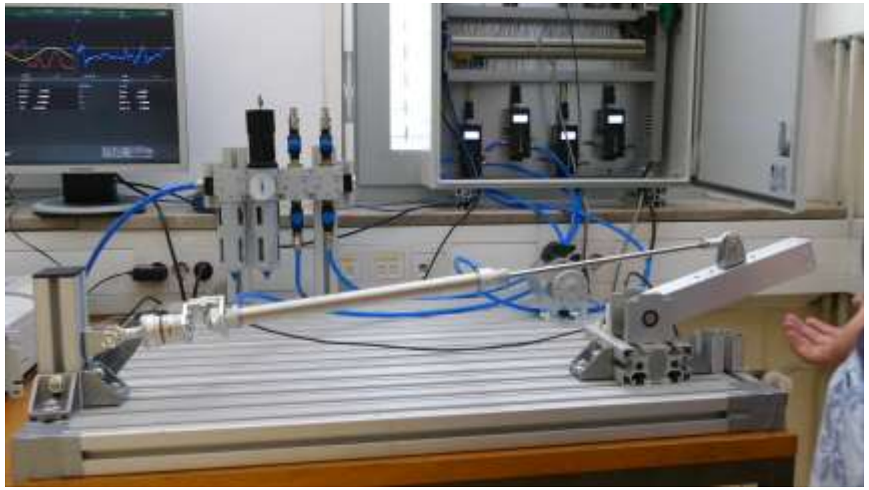
- Low inertia
- High power-to-weight ratio
- High acceleration capabilities
  - variable motion regime, with several stops and inversions
- Large range of operational velocities
  - 1 to 1000 turns/min
- High accuracy in positioning
  - at least 1/1000 of a turn
- Low torque ripple
  - continuous rotation at low speed
- Power: 10W to 10 kW

Pneumatic servomotors

- Pneumatic: pneumatic energy → pistons or chambers → mechanical energy
  - difficult to control accurately (change of fluid compressibility)
  - usually used for opening/closing grippers
  - High force capability with artificial muscles



Position and velocity control



Torque control

Artificial muscles

Source: YouTube

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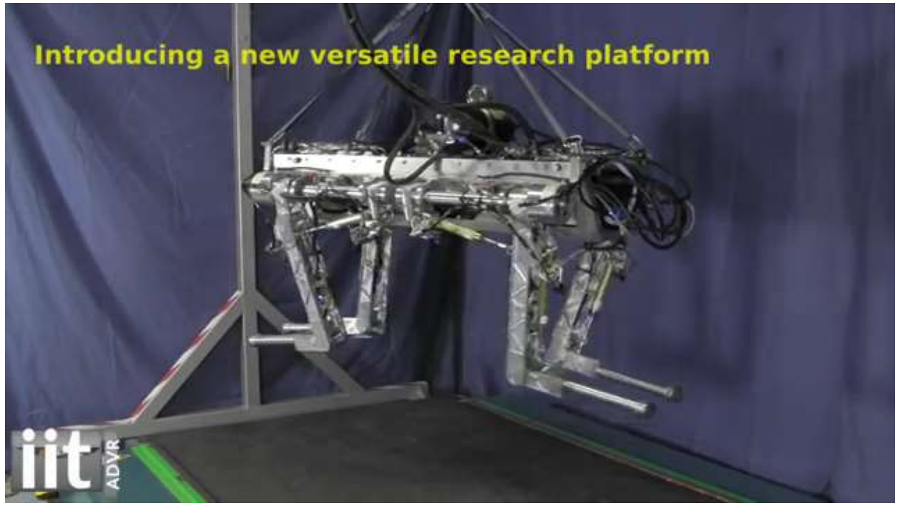
Hydraulic servomotors

- hydraulic: hydraulic energy → pumps/valves → mechanical energy
  - advantages: no static overheating, self-lubricated, inherently safe (no sparks), excellent power-to-weight ratio, large torques at low velocity (w/o reduction)
  - disadvantages: needs hydraulic supply, large size, linear motion only, low power conversion efficiency, high cost, increased maintenance (oil leaking)



HyQ - IIT's Hydraulic Quadruped Robot

Sarcos CBi – humanoid robot

Source: Youtube

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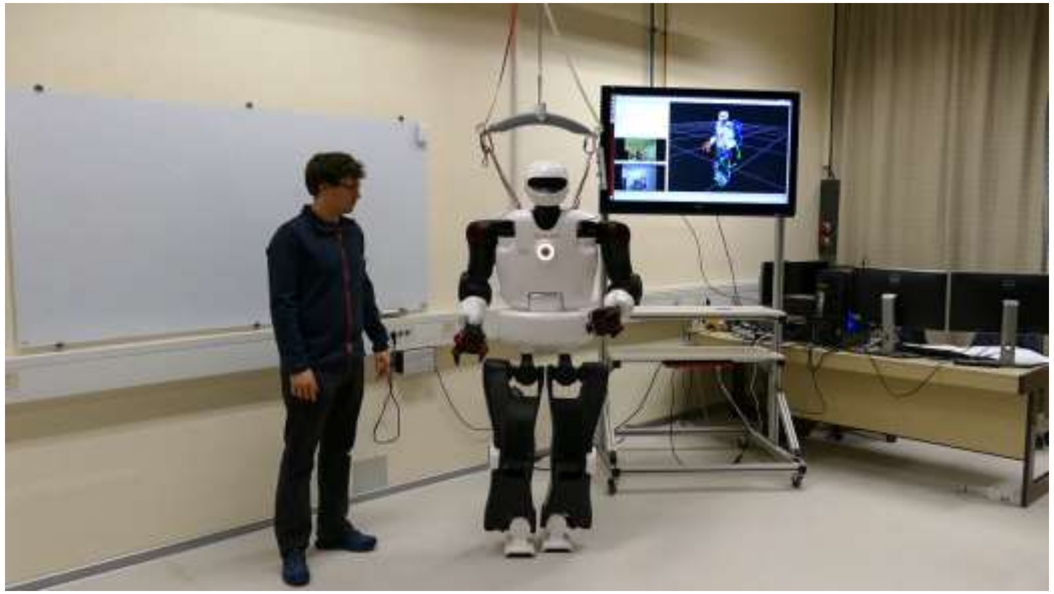
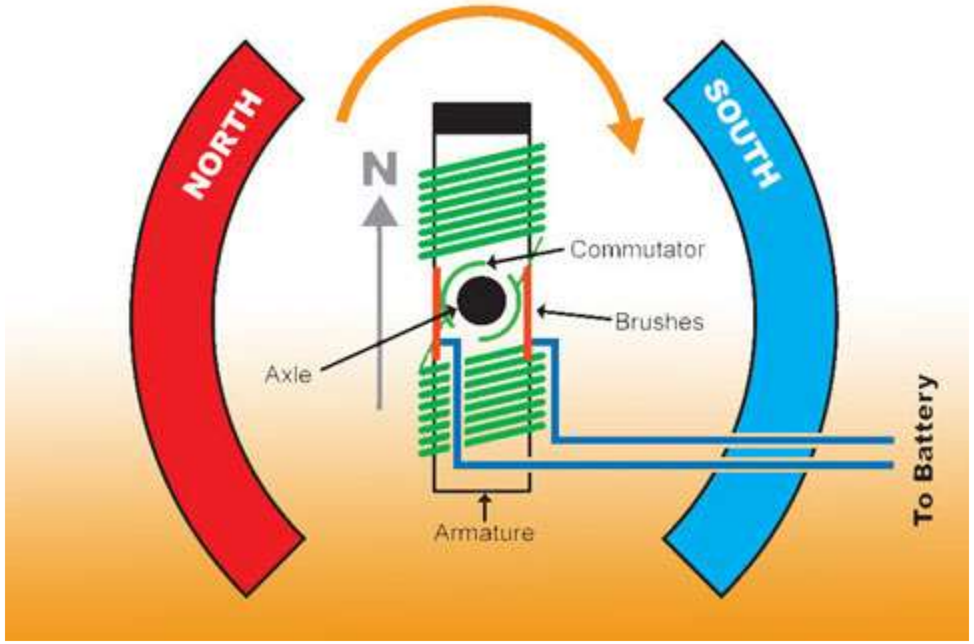
Electrical servomotors

- Advantages
  - Power supply available everywhere
  - Low cost
  - Large variety of products
  - High power conversion efficiency
  - Easy maintenance
  - No pollution in working environment
- Disadvantages
  - Overheating in static conditions (in the presence of gravity)
  - Use of emergency brakes
  - Need special protection in flammable environments



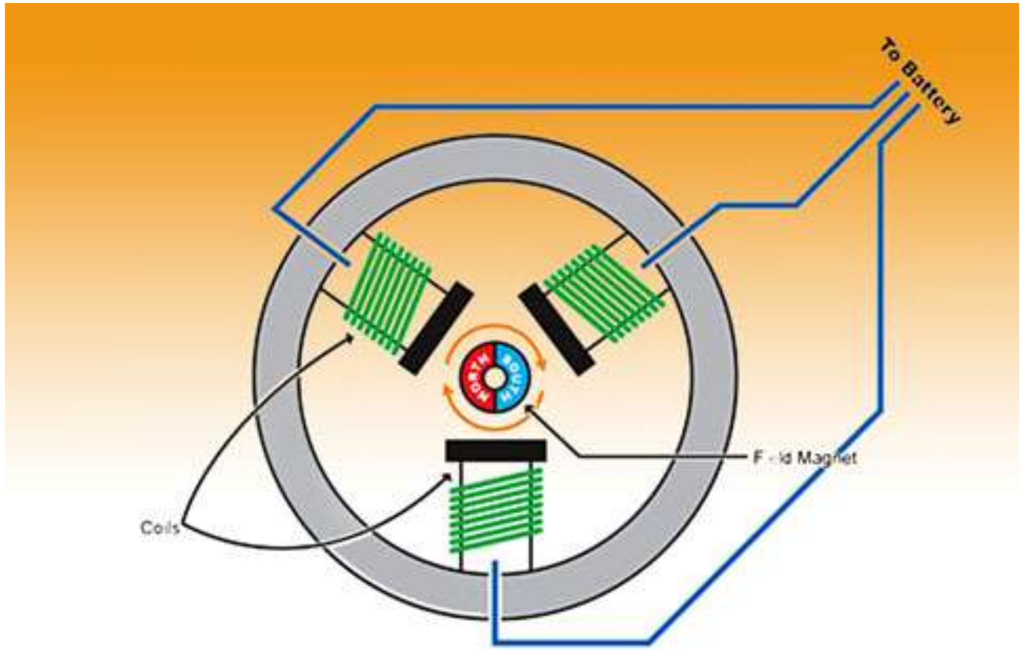
Typical types of electrical servomotors

Brushed



direct current (DC) motor

Brushless - BLDC



with electronic switches (brushless)

Picture source: Wiki

Advantages of brushless motors w.r.t brushed

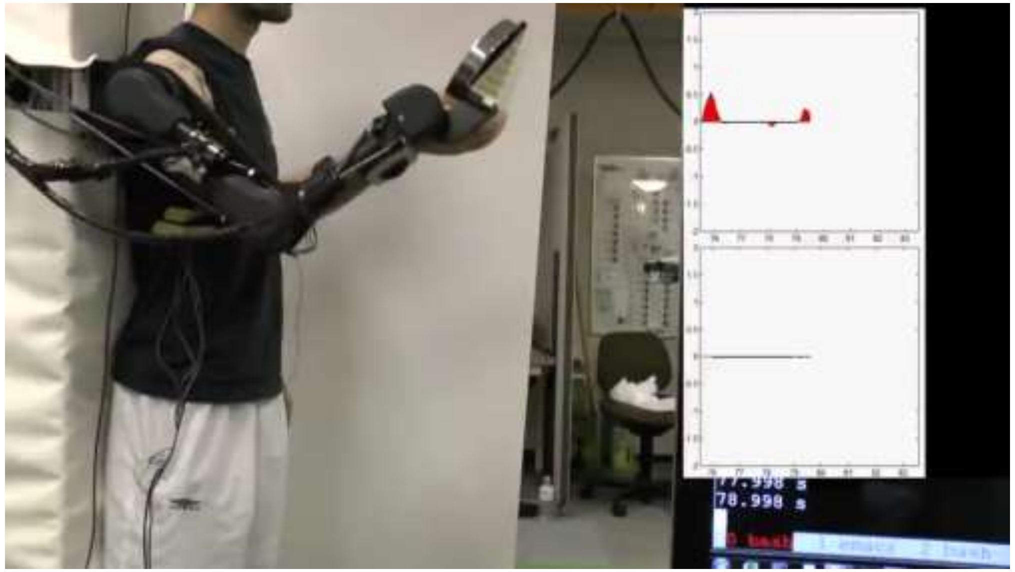
- Reduced losses, both electrical (due to tension drops at the collector-brushes contacts) and mechanical (friction)
- Reduced maintenance (no substitution of brushes)
- Easier heat dissipation
- More compact rotor (less inertia and smaller dimensions)

- Disadvantage → higher cost!

Hybrid drives

- Tunable passive compliance (series elastic actuators)
  - Working in unstructured environment
  - Safe human interaction
  - Energy storage
- Precise control
  - Manipulation tasks
- Light weight
  - Low inertia
- High ratio between load mass and mechanism mass
  - Especially important for biologically inspired mechanisms
- Low cost
  - Adequate force/torque sensors in each joints are not needed for compliance control (i.e. Kuka LWR)
- Energy efficiency could improved

Pneumatic-electric hybrid actuator system



SEA examples

DLR SEA - Source: Youtube

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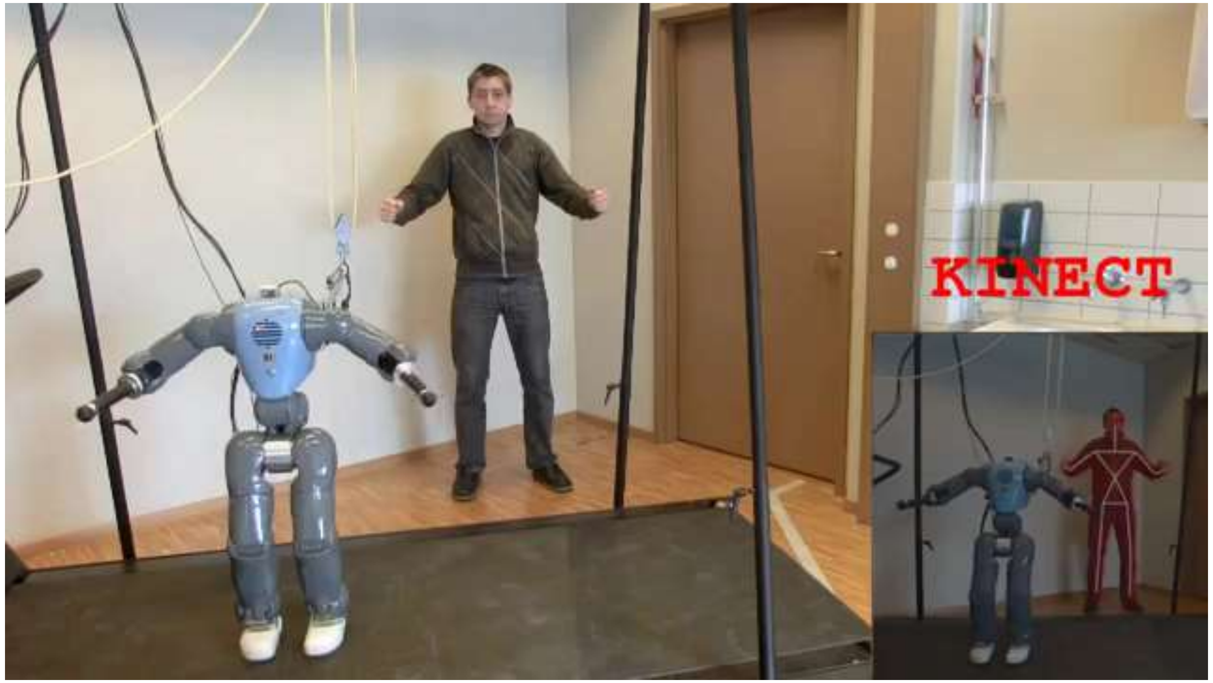

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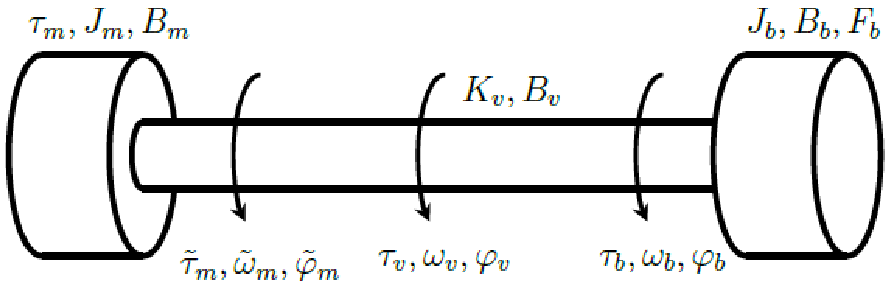
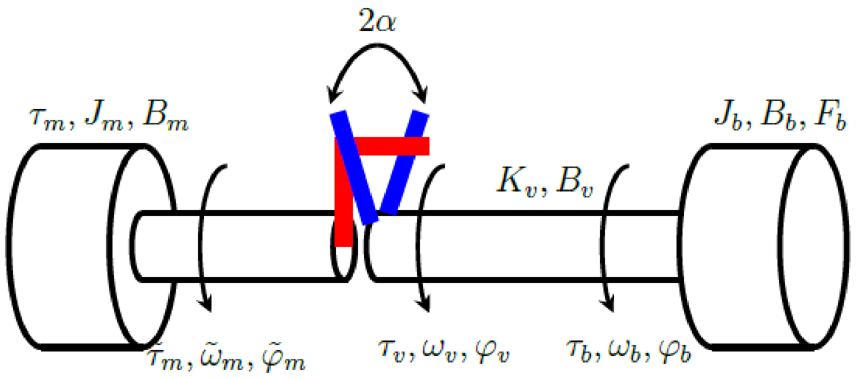
Modeling of actuators

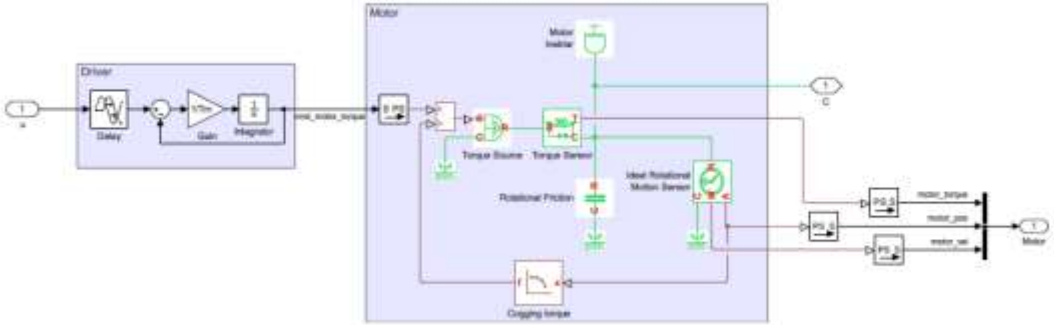
- Two mases connected with spring



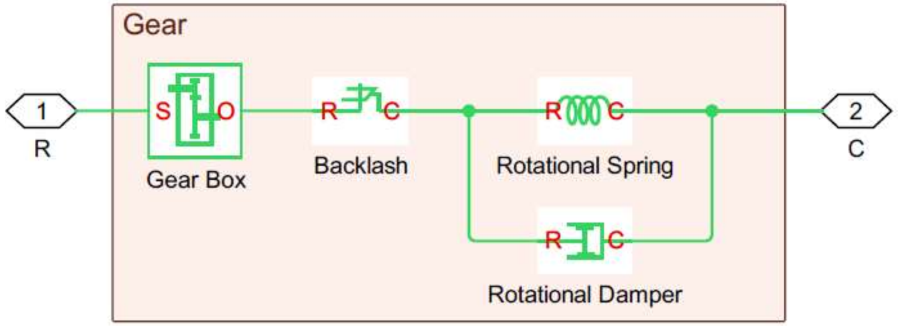
- Two mases with air gap between



Motor model in Simulink



Gearbox model in Simulink



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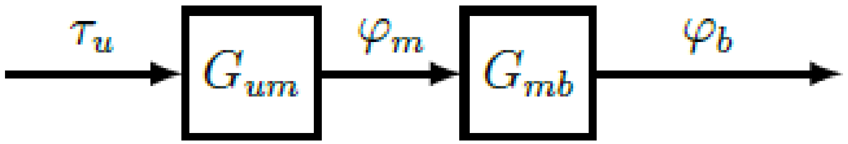
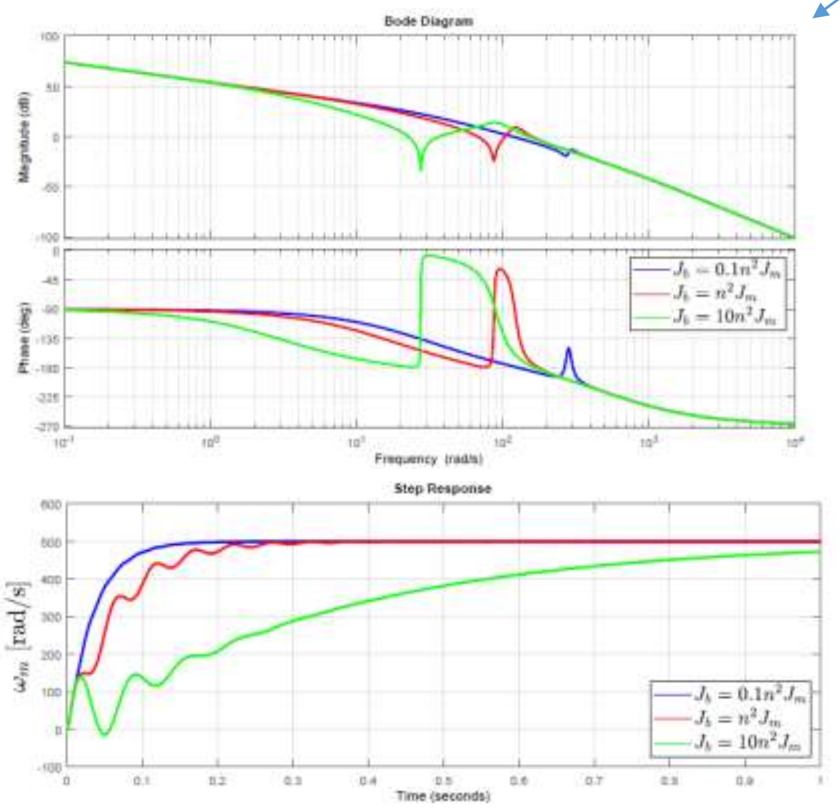
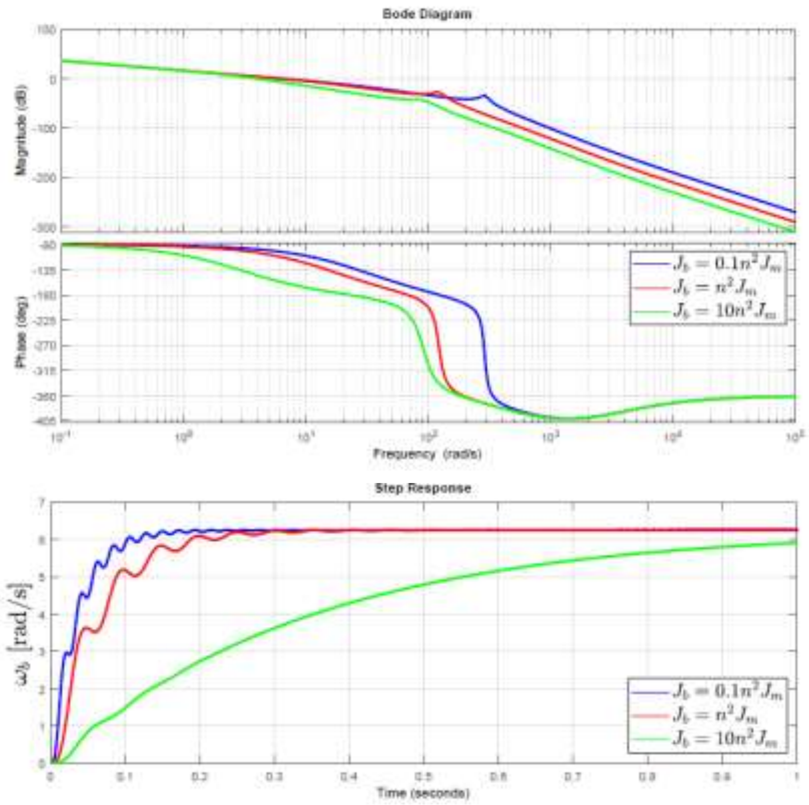
Modelling of actuators...

- Linear actuator model as a system of two mases rigidly connected

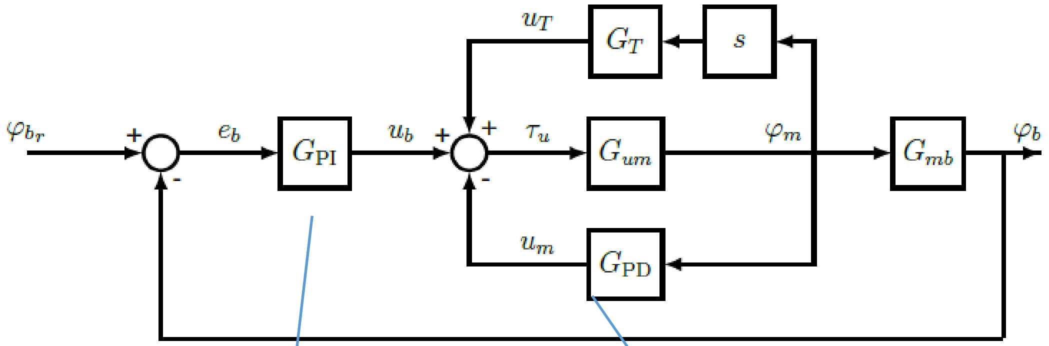


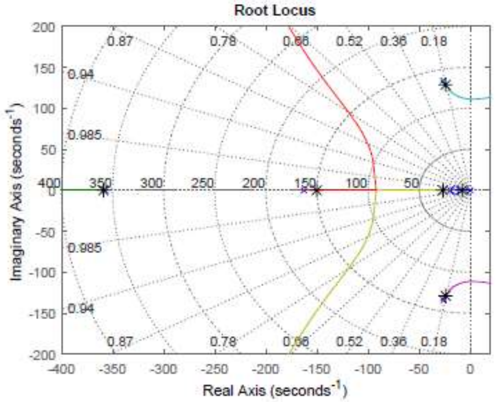


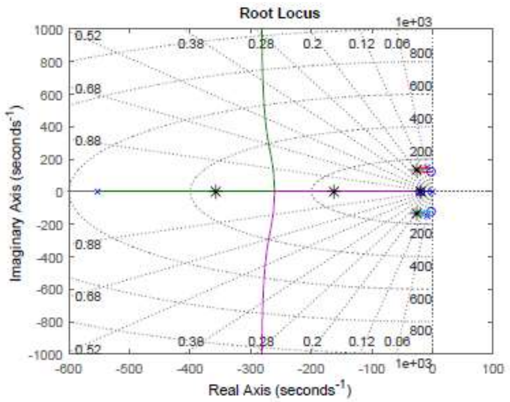


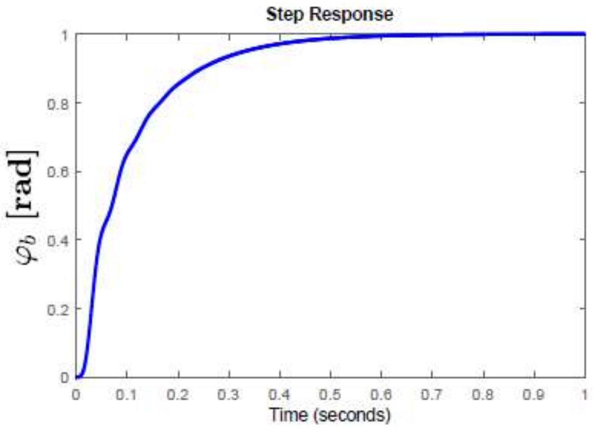
Position control

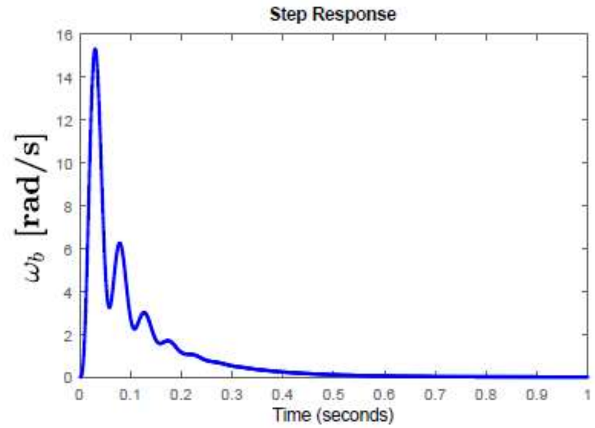
Closed loop with inner-loop (motor) PD controller and PI outer-loop (gears)

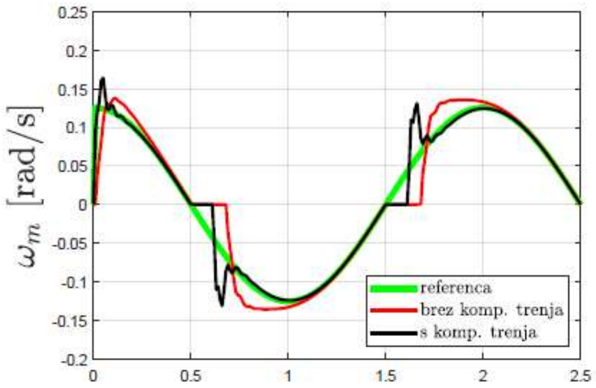




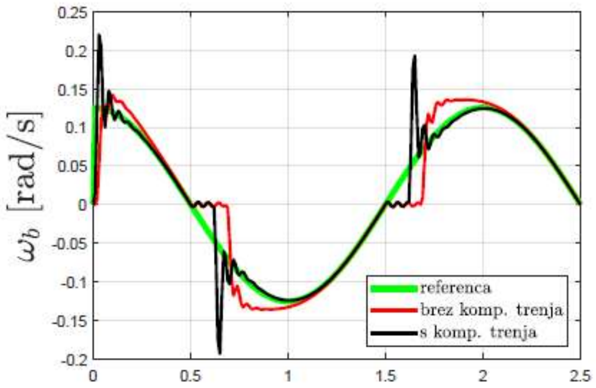




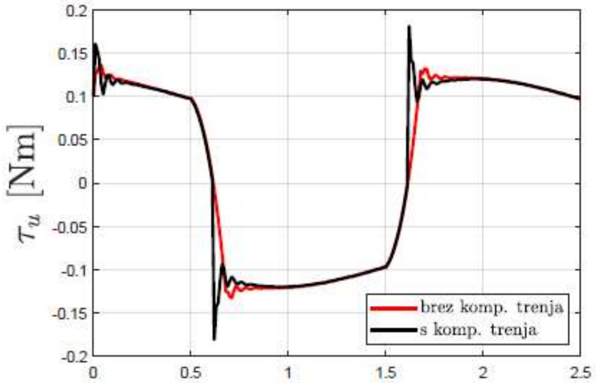




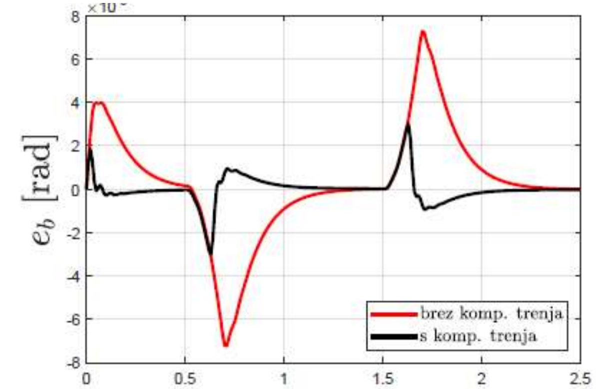
Motor speed



Load speed



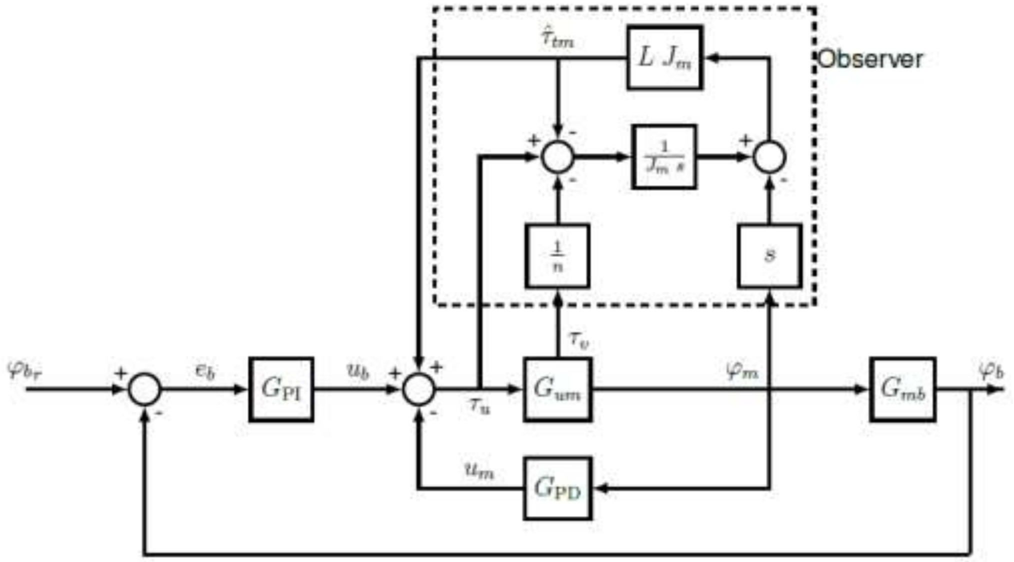
Control signal

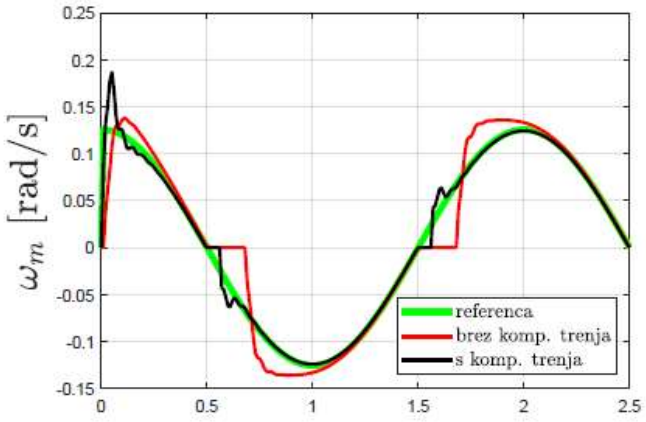


Load position error

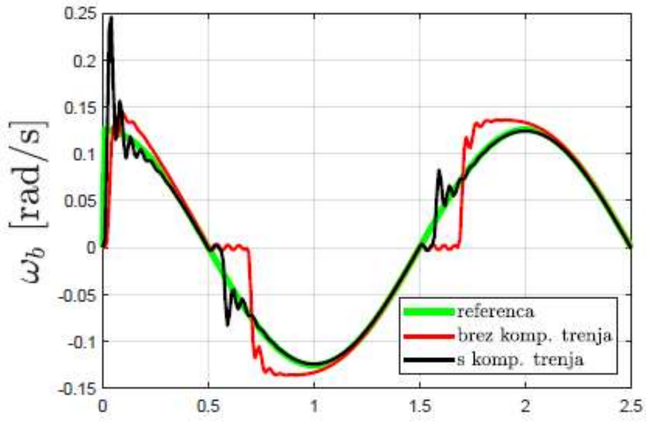
Position control…

Closed loop with inner-loop (motor) PD controller, PI outer-loop (gears) and friction compensation observer

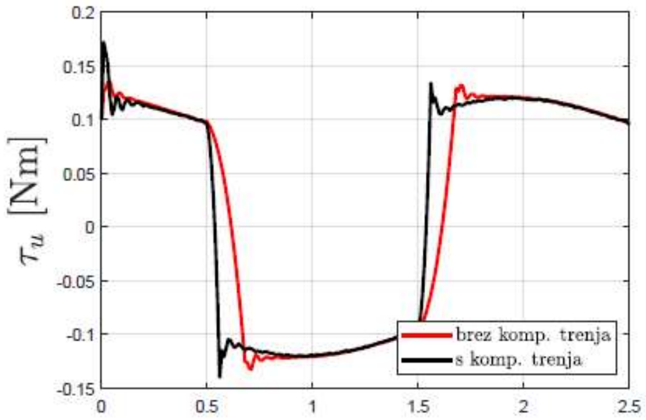




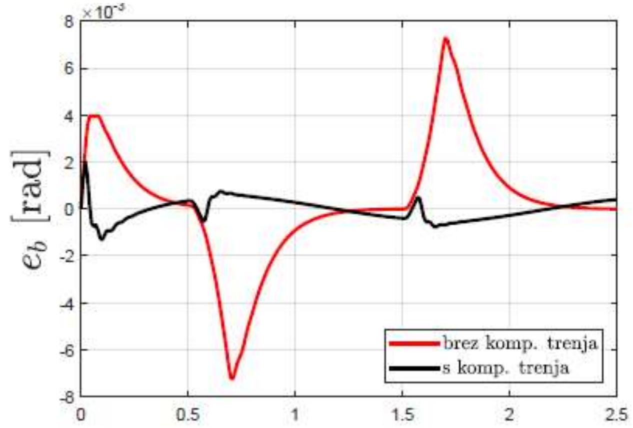
Motor speed



Load speed



Control signal



Load position error

Overview of control laws in robotics

Type of task \ Error definition		Joint space	Cartesian space	Task space
Free motion	Regulation	PD, PID, gravity compensation, iterative learning	PD with gravity compensation	Visual servoing
Free motion	Trajectory tracking	Feedback linearization, inverse dynamics + PD, passivity based control, adaptive control	Feedback linearization	
Contact motion			Impedance control	Hybrid force-velocity control