ELTE | FACULTY OF INFORMATICS

Embodied Intelligence – L04
Actuators

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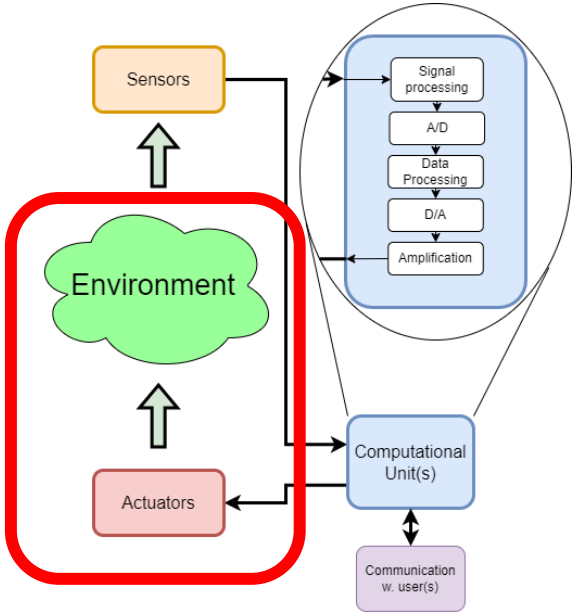
Introduction

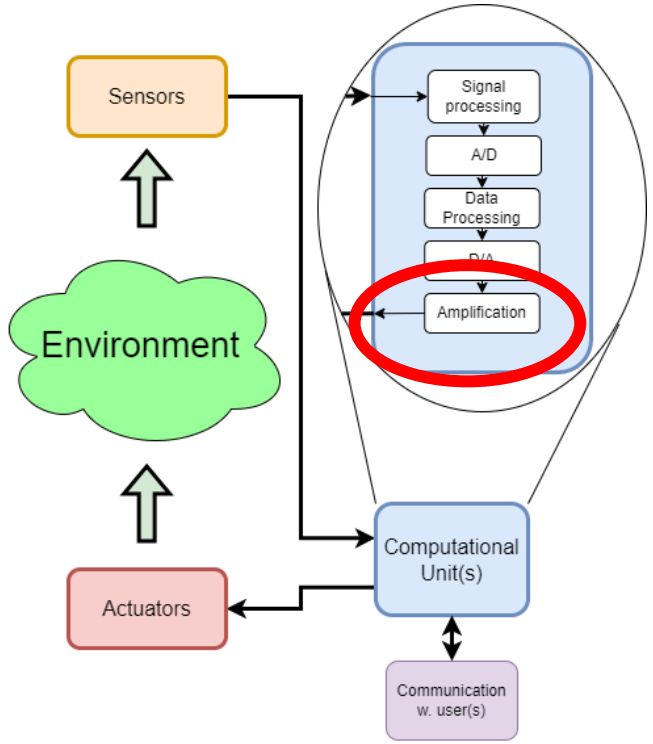
Looking back …

- Actuators are elements (usually some kinds of motors) of embedded systems, which purpose is to interact with the environment based on the Computational unit's commands.
- Human actuators:
  - Muscles



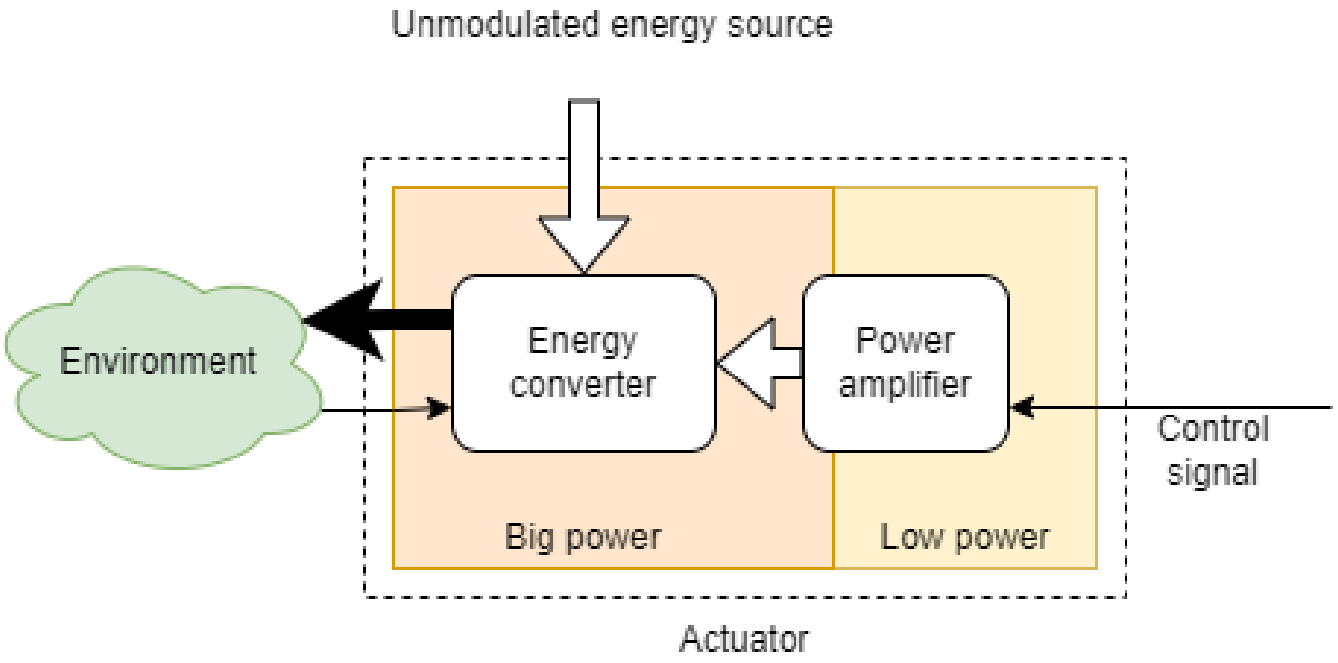
Some clarification

- We enlisted amplification to the computational unit, however it is frequently built in inside the actuators
- The definition here is also not always applicable to all possible cases
- Between the control unit and the environment in the impact chain.



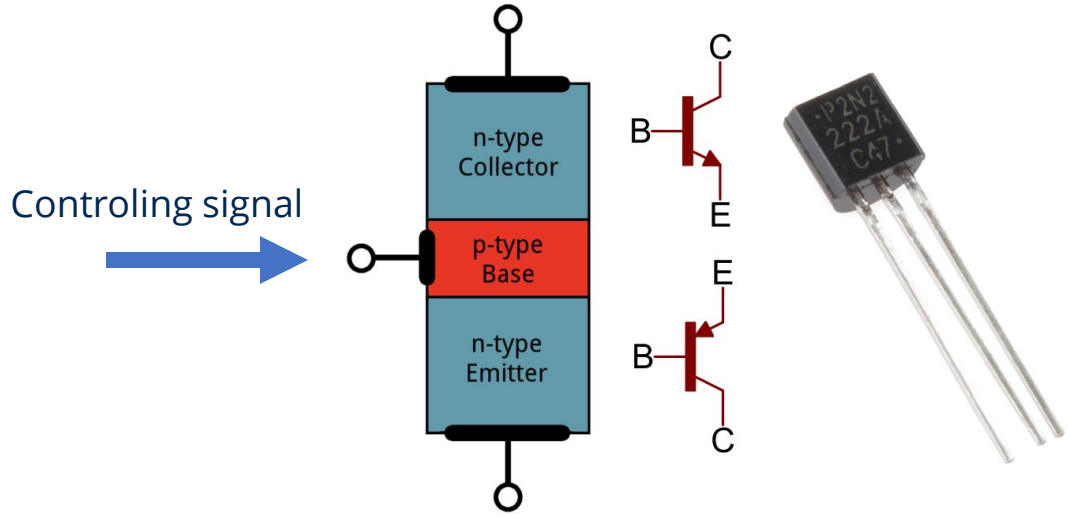
From unmodulated energy to some kind of actuation

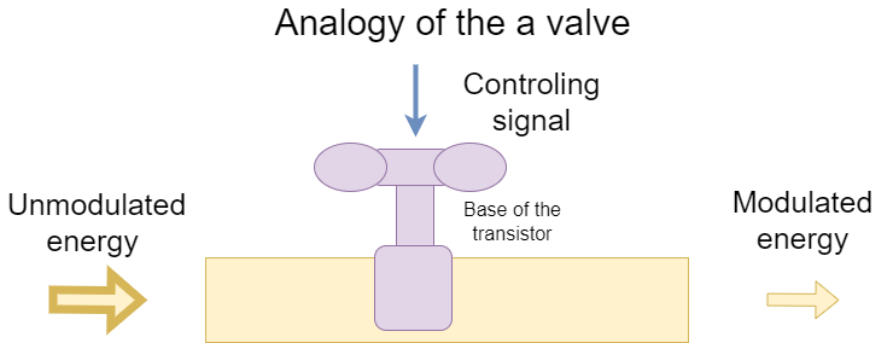
- Control signal
- Power amplification
  - Unmodulated energy
  - Modulated high power energy
- Energy conversion
  - Motors etc.
- Environment usually has a feedback on the actuation device



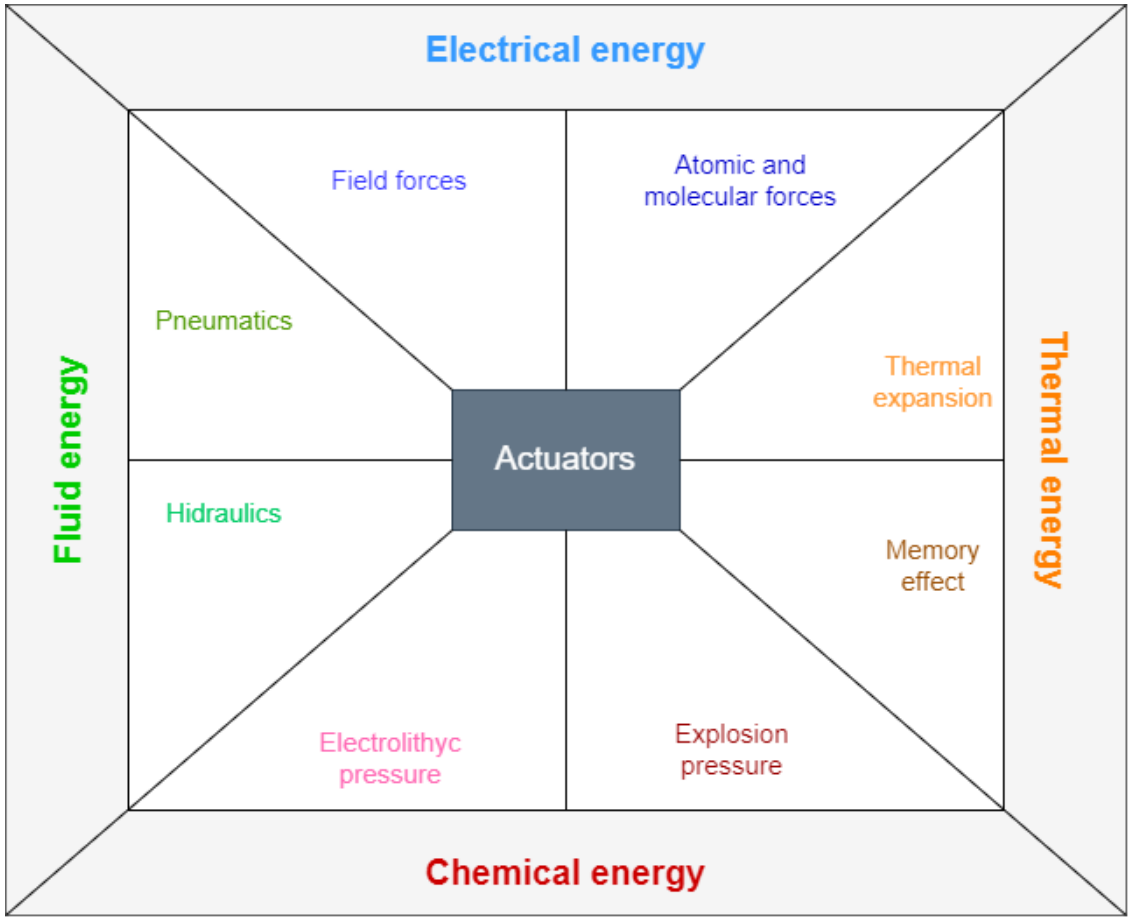
Electrical amplifiers oversimplified

- Converts the unmodulated energy from the energy source to a modulated energy based on the controlling signal
- In electrical devices this is usually achieved with transistors
- Only this slide could be discussed in 2-3 or more courses alone





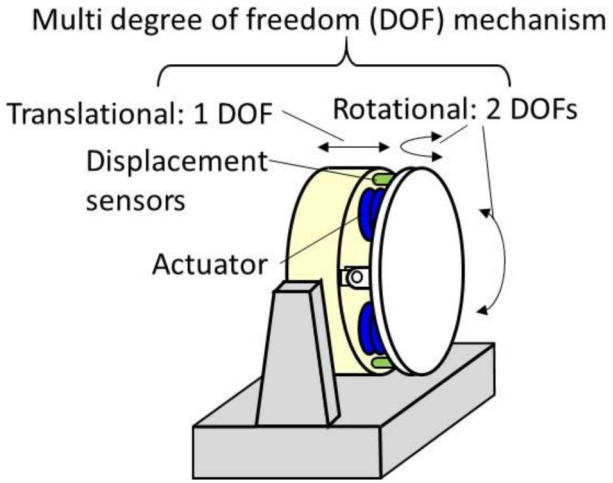
Energy sources and their principle of use



Power machines are different to actuators !!!

- „Not all fingers are little finger … but all little fingers are fingers… „

- What is the difference?



Main differences

- Power machines
  - Continuous operation
  - No need for complex control
  - Usually no need for sensig the environment

  → Not for precise operation but more to drive a machine that is processing something

- Actuators
  - Intermittent operation
  - Complex conrol
  - Sensing of the environment is inevitable

  →Precise operation for intelligently interact into a process or environment

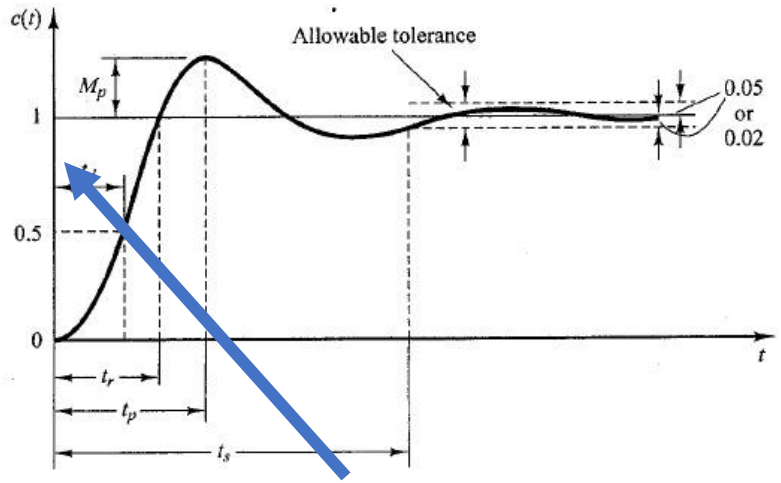
What we usually demand from actuators

- Four-quarter operation (drive and braking in both directions)
- High overload capacity
- High resolution to achieve accurate positioning
- Favorable static properties (preferably linear transmission, low friction, etc.)
- Fast operation, good damping (low time constant, no overshoot adjustment)
- Wide speed and rpm range
- High power and torque delivery, self-locking

Two type of description of an actuator

- Transient response

(loosly saying: When the operation starts (device is plugged in or an another control signal is given) and the real actuation is in effect because the system has so-called energy storing elements.)

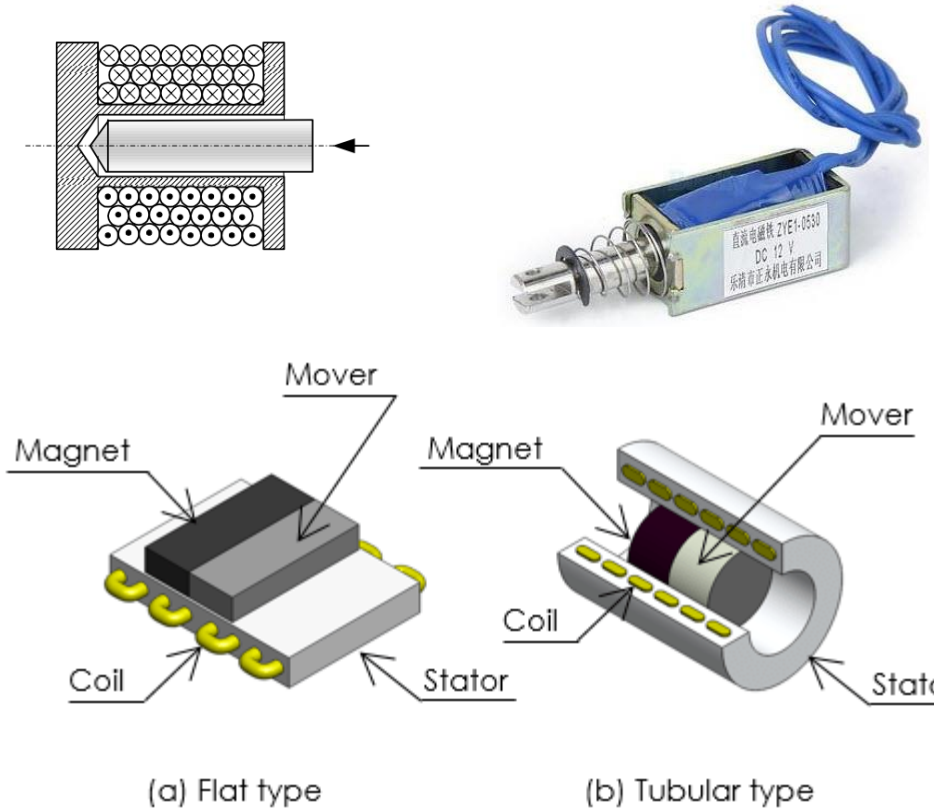


This shape is determined by the properties of the controling regulator

- Static behavior (steady state)
  - The changes (transient response) are small (within a tolerance) or wanish.

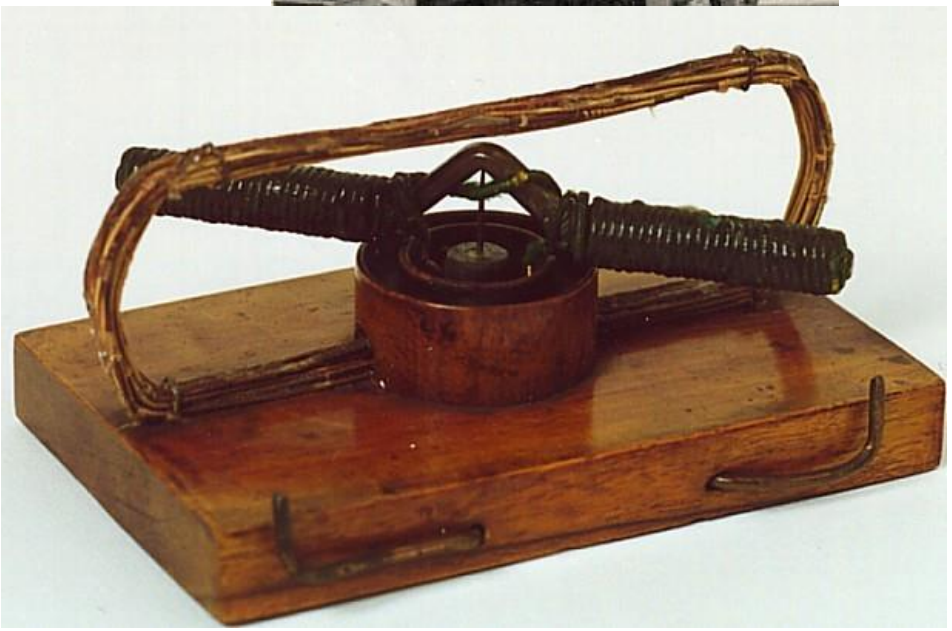
Positioning mechanical parts - Electromagnet

- Usually consist of an electric coil and a magnet with the mover
- The current in the coil induces magnetic field which will force the permanent magnet to move
- Small but fast movements
- Non-linear (problem for controling)
- Usual (max) range: 10-25 mm

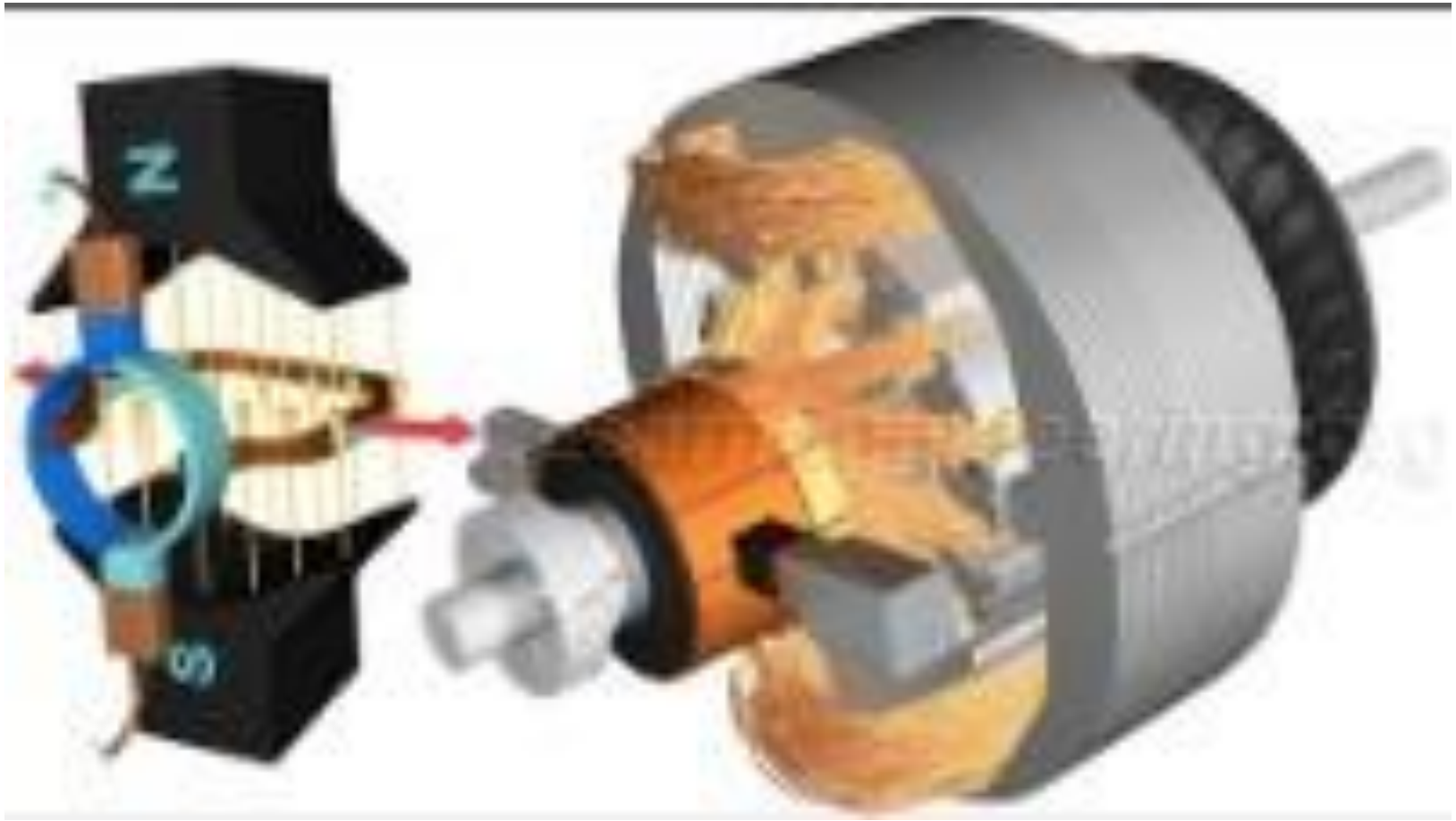


DC motor

- First principle is a Hungarian invention
- Ányos Jedlik
  - Born in Szímő (currently Slovakia)
- „Villamdelejes forgony”

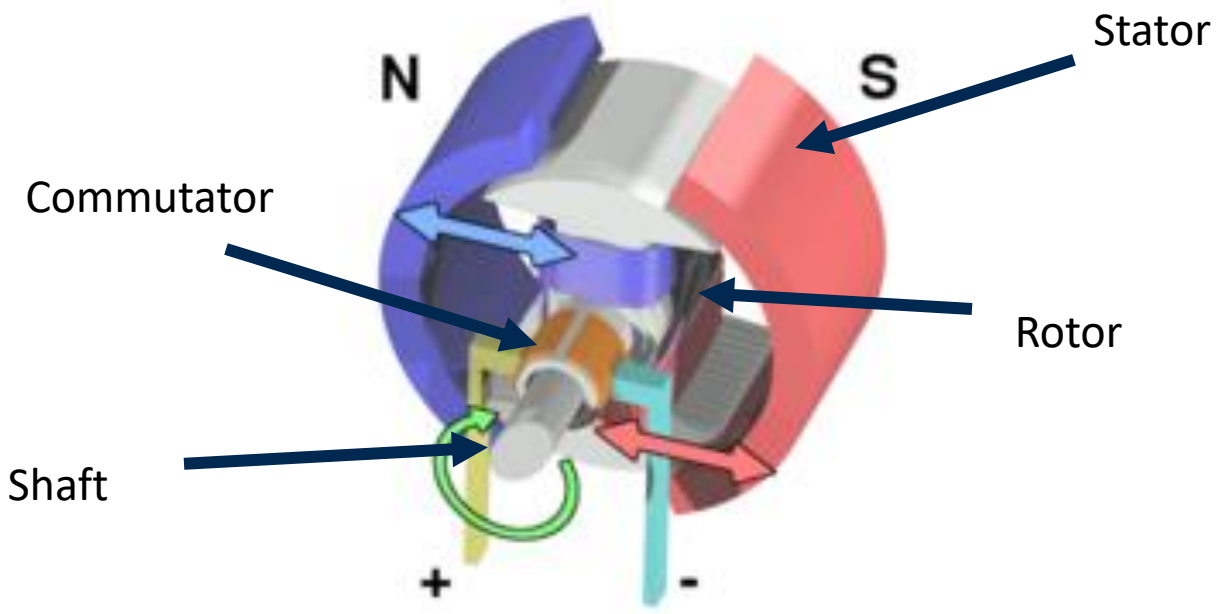


DC motor (cont.)

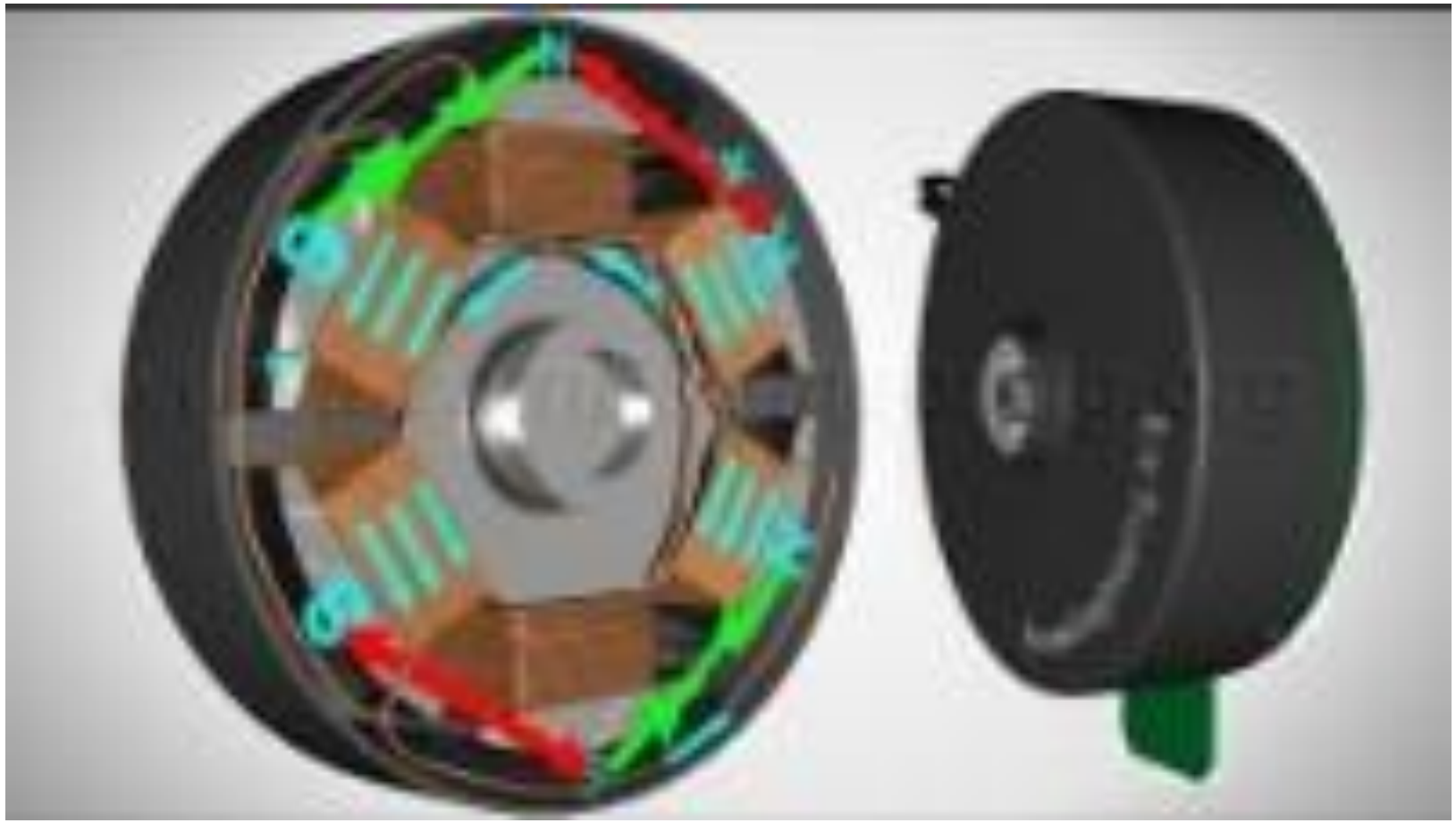


DC motor (cont.)

- Linear function between the supply current and the torque given
- Easy control
- Good dynamical properties
- Can have high rpm range

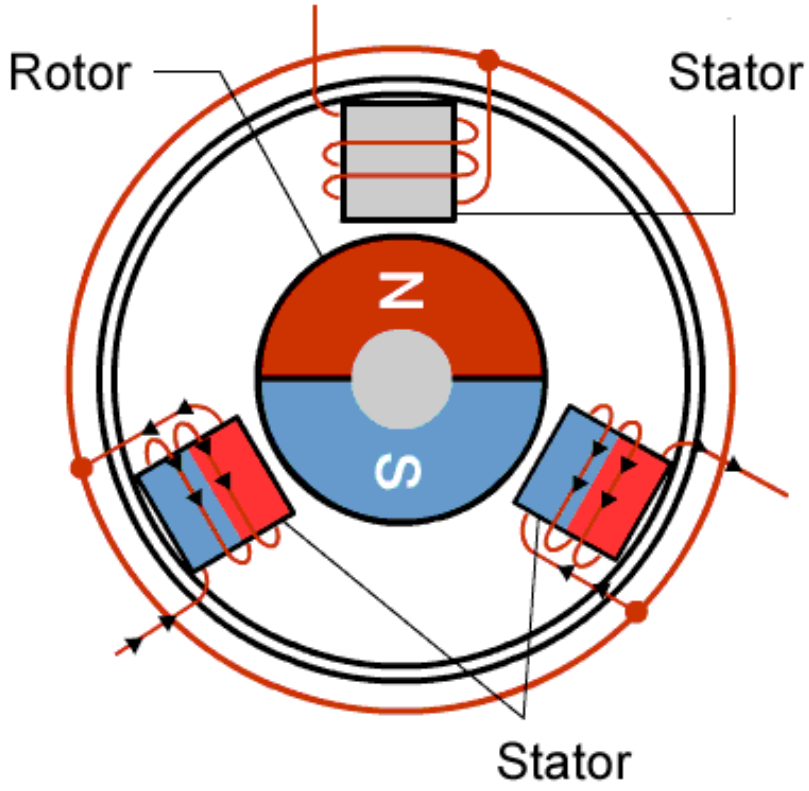


BLDC – Brushless DC motor



BLDC (cont.)

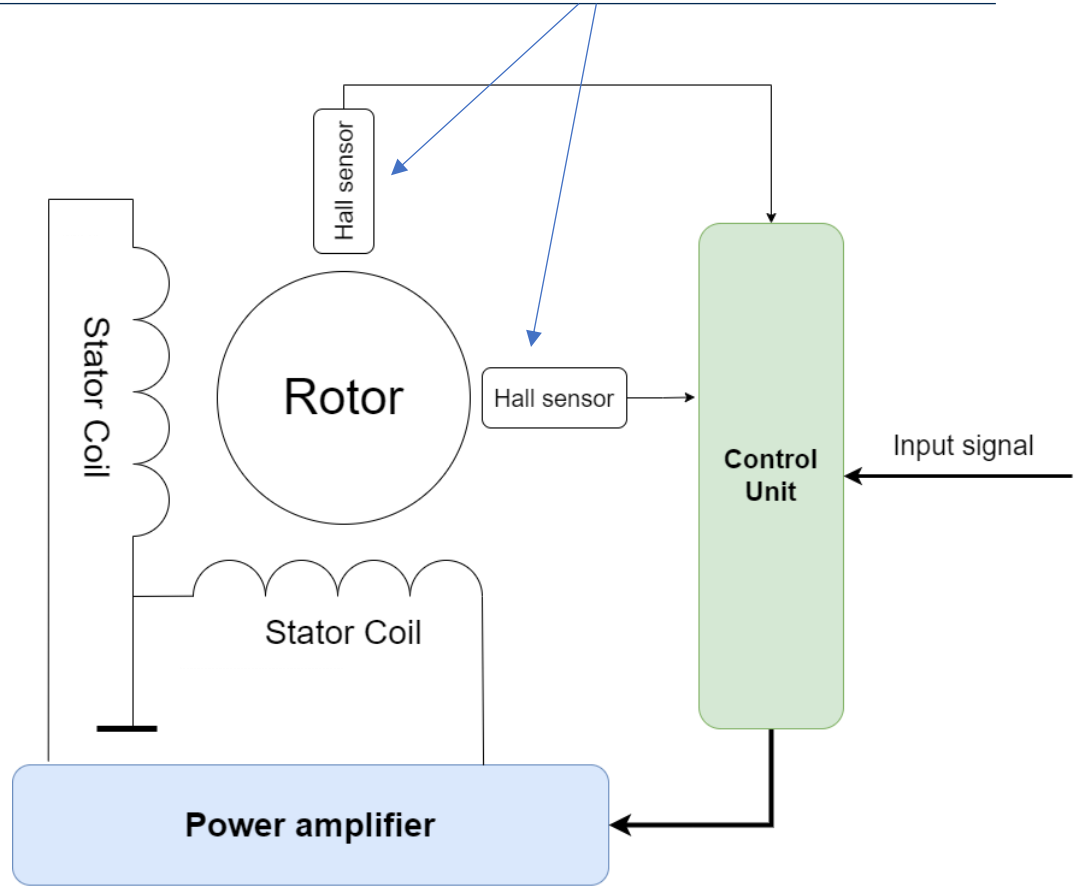
- The rotor is usually made from a permanent magnet
- Stator has the coils
- The alternated energization of the coils are made not mechanically but with some kind of control



BLDC (cont.)

- Hall sensors are used for the sensing of the position
- Additional control is needed for the functioning (BLDC driver electronics)

Remember this sensing method from the previous lecture?



Pros and Cons of BLDC (compared to DC motor)

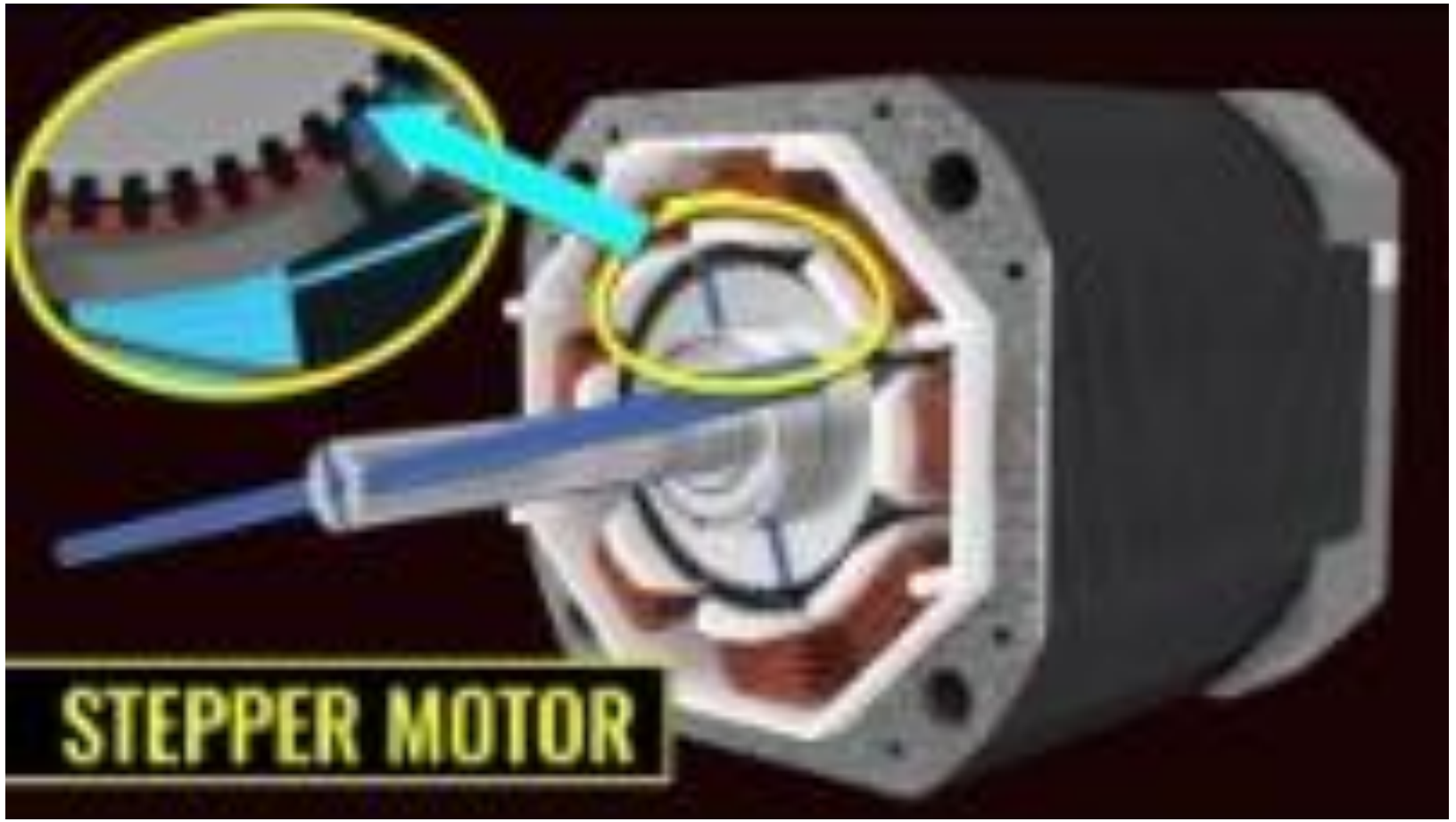
Pros:

- Less maintenance
- More lifecicle time
- Beter heat reduction opportunities (because the stator has the coils)
- Can be further more overloaded
- No sparking

Cons:

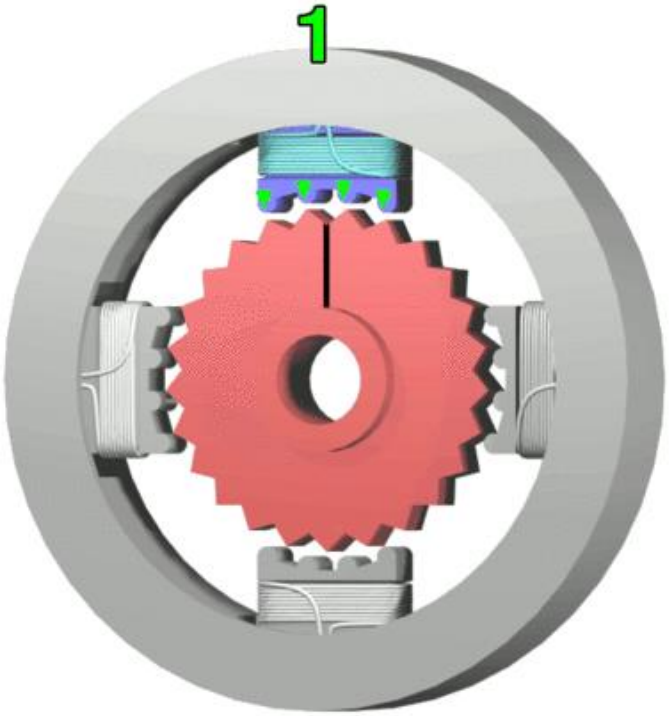
- Extra sensors and control needed
- More expensive
- Non-uniform torque

Stepper motor



Stepper motor (cont.)

- Highly used due to its simplicity
- For low power applications
- Usually permanent magnet in the rotor and coils on the stator
- No need for sensing the position (just for the operation)



Stepper motor – Pros and Cons

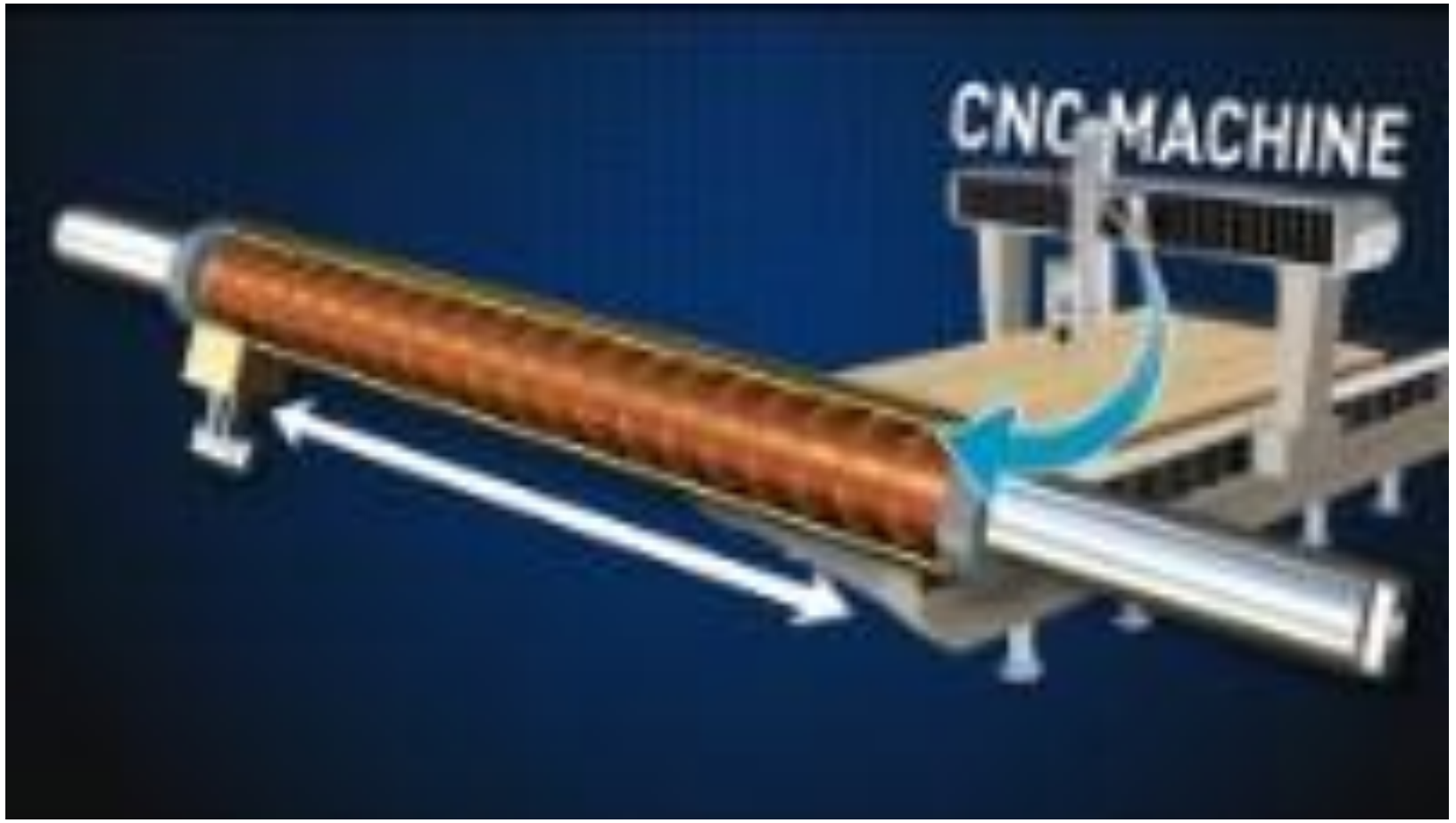
Pros:

- Low cost
- High torque and low speeds
- Robustness
- Low maintenance needs
- High reliability
- Usually no need for gearing

Cons:

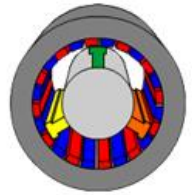
- Miss stepping (to avoid → over design)
- Resonances in low speed
- Low efficiency
- Low power density

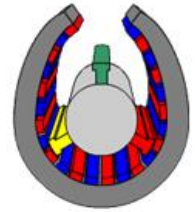
Linear motor

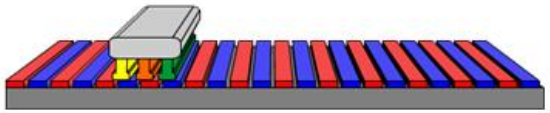


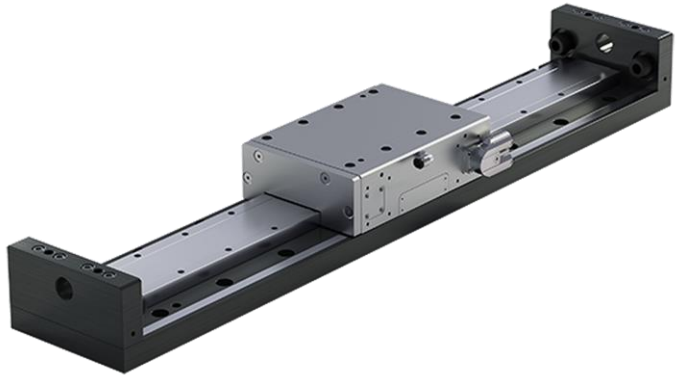
Linear motor (cont.)

- Relatively new kind of motor
- Linear movement (no need for conversion with gears)
- Can be looked as a flattened asyncronous motor
- Moving magnetic field in the coils
- If the mover's speed is less than the magnetic field's movement then electric voltage will be induced → … → force for moving the mover part







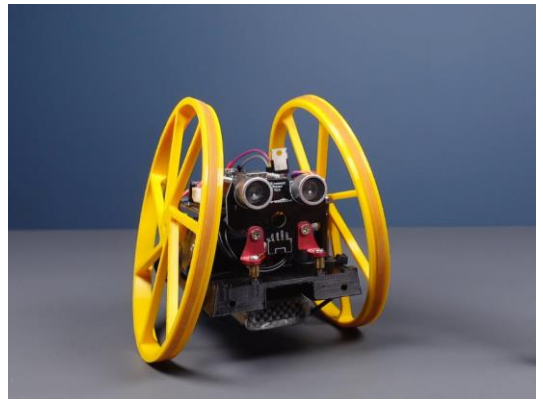


Some applications from the real life - BLDC

- Wheels in electric vehicles (e.g.: Mars rovers)
- Computer hard drives and DVD/CD players
- Industrial robots, CNC machine tools, and simple belt driven systems

Some applications from real life – Stepper motors

- Printers
- 3D printers
- Robots



Some applications from real life – linear motor

- CNCs

Fluid actuation – Pneumatics and hidraulics

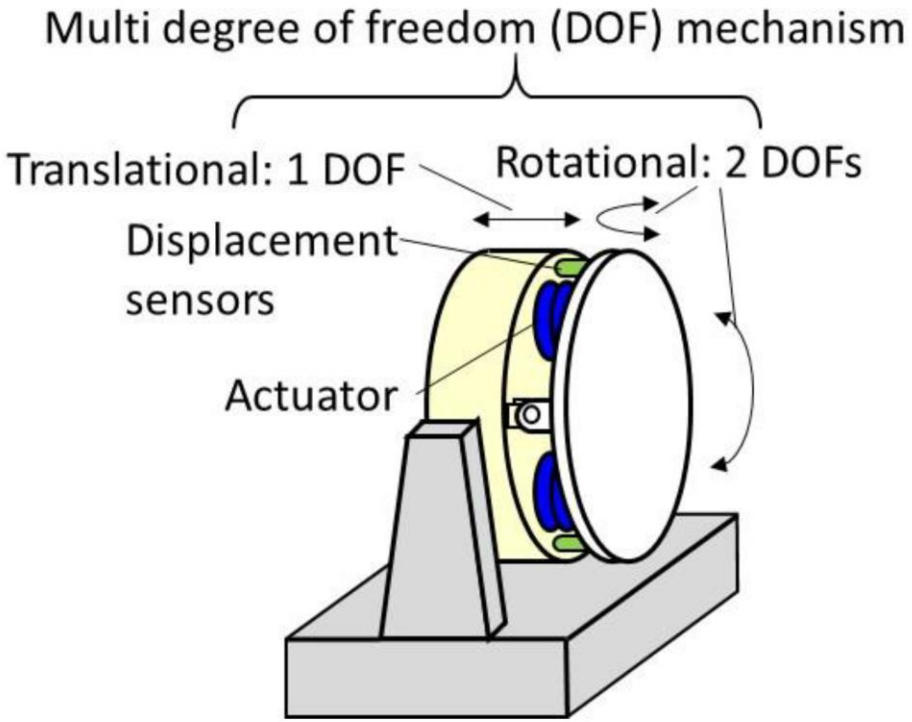
- Hidraulics and Pneumatics
- Robust
- High power density compared to electric actuation
- Lower efficiency comparedt to electric actuation
- Power supply is often hard to provide
- Expensive parts/devices

Application of fluid actuation

Some interesting novel actuation methods

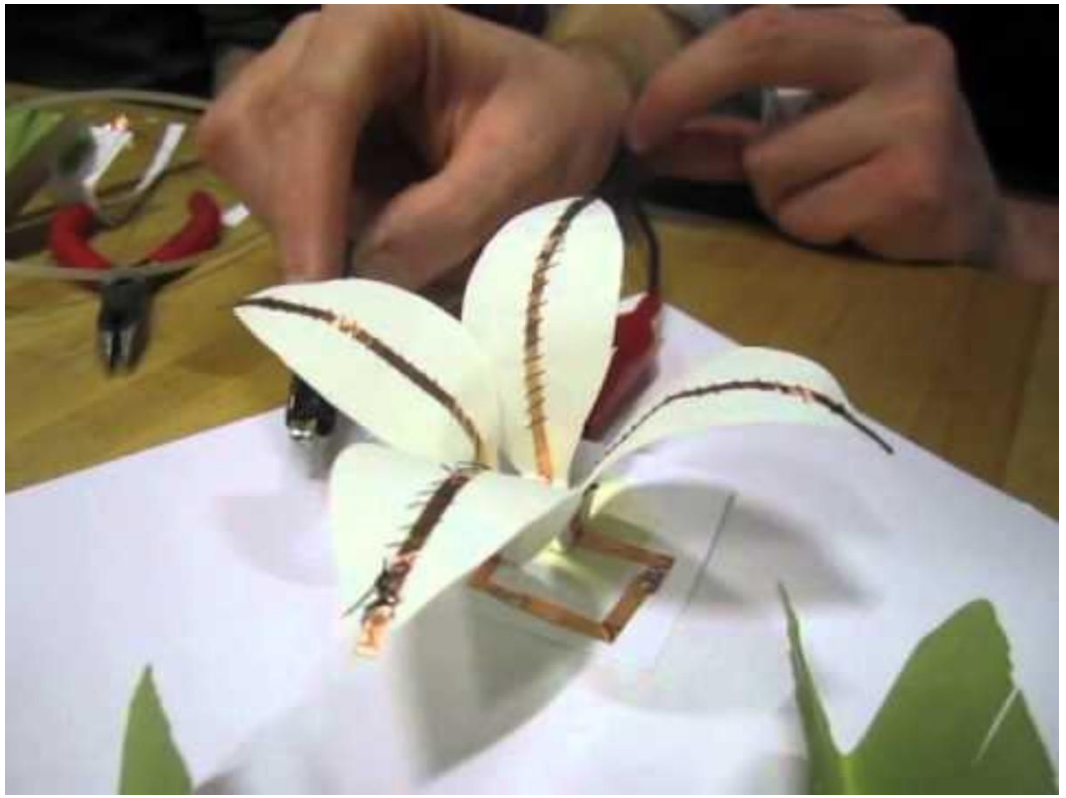
Piezzo motors

- Piezzo effect – electric voltage on a specific crystal will change it’s width
- For highly precise positioning, vibration generation, tension control



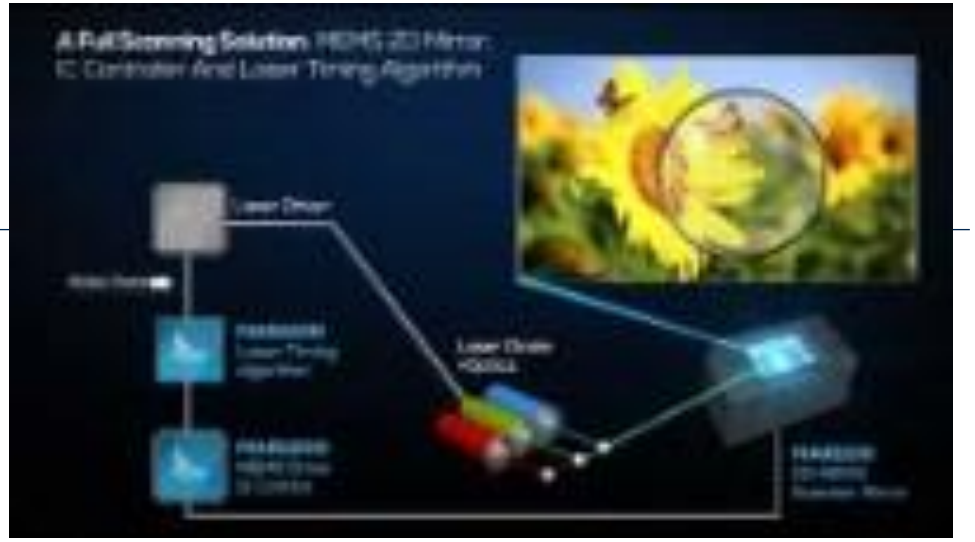
Memory alloy

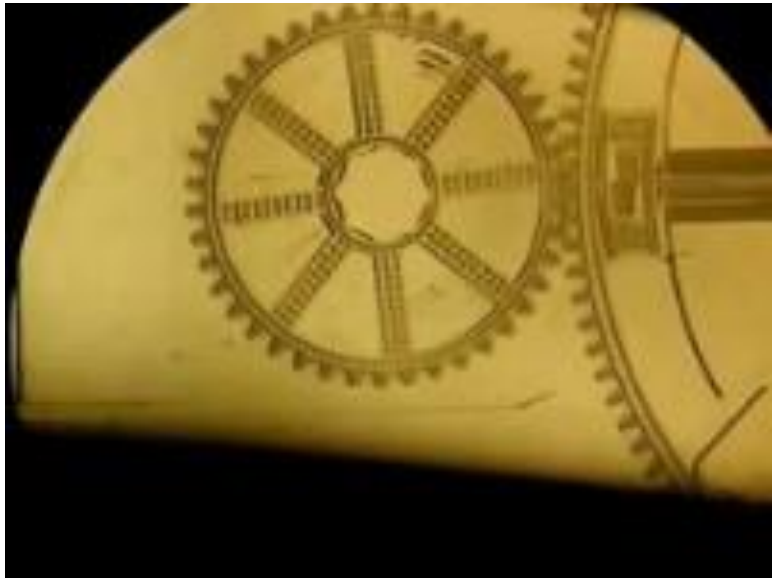
- NiTiNol
- Can repeat the „pre-programmed” shape on heating
- Applications:
  - Form recovery
  - Constrained recovery
  - Work production
  - Superelasticity



MEMS

- Micro-electromechanical systems
- Various applications:
  - Healthcare, spacetech, biotechnologies





Servo motors

Why are we making such deal about Servos

- Insanely huge range of applications
  - Robotics
  - Automatization
- Relatively easy to understand
- Used in our robots as well

What is a servo motor?

- A device, either with
  - *revolut or translational movement*
- that has a goal of a precise
  - ***torque,***
  - ***force,***
  - ***position,***
  - ***velocity,***
- output,
- by using some kind of *closed-loop control*.

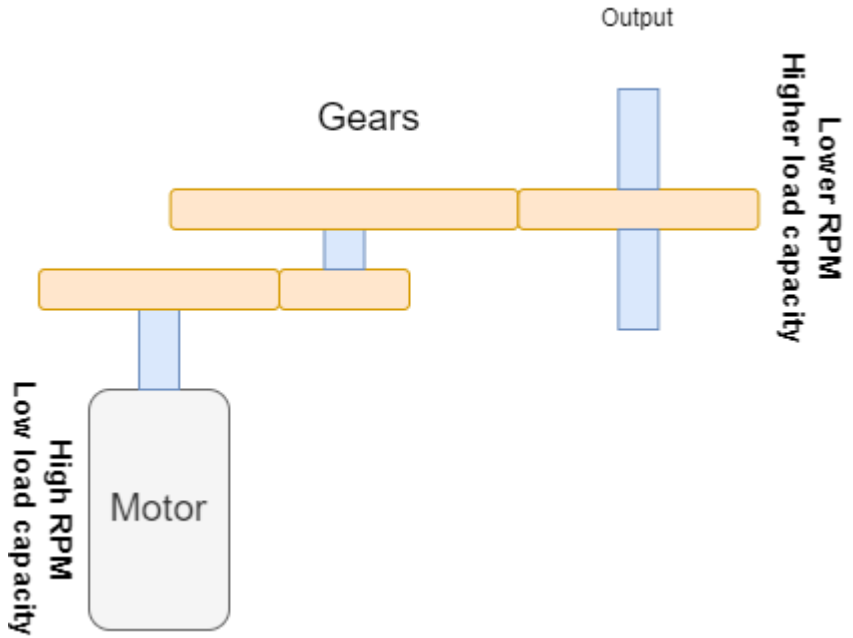

WHAT IS
A SERVO MOTOR?

How they work?

- We will need (for the simplest):
  - Motor
  - Gears
  - Potentiometer (or sensor for positioning)
  - Control electronics
    - Pulse demodulator
    - Comparator electronics
    - Motor driver (H bridge)

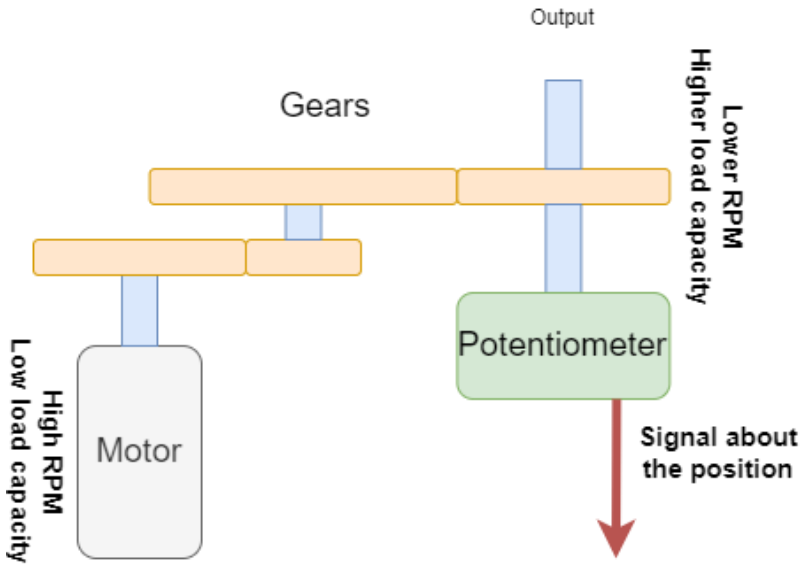
Putting together – Motor + Gears = drive chain

- We have a motor that usually has higher rpm but lower load capacity (torque) than needed
- We put gears that will reduce the rpm and in the same time increase the load capacity in the same ratio
  - Eg.: ratio of 1:200 will decrease the rpm by 200 folt and increase the load capacity by 200 fold



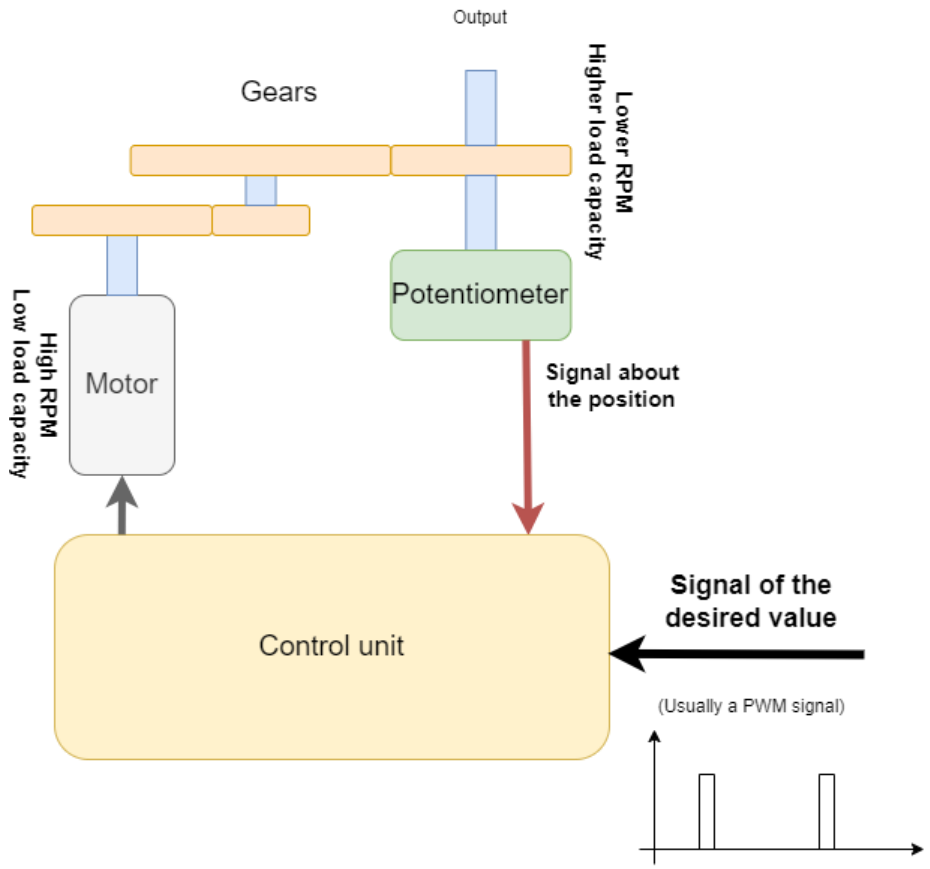
Putting together – drive chain + sensing

- We attach to the output shaft a potentiometer for the purpose of sensing the exact position
- Usually as a voltage divider circuit



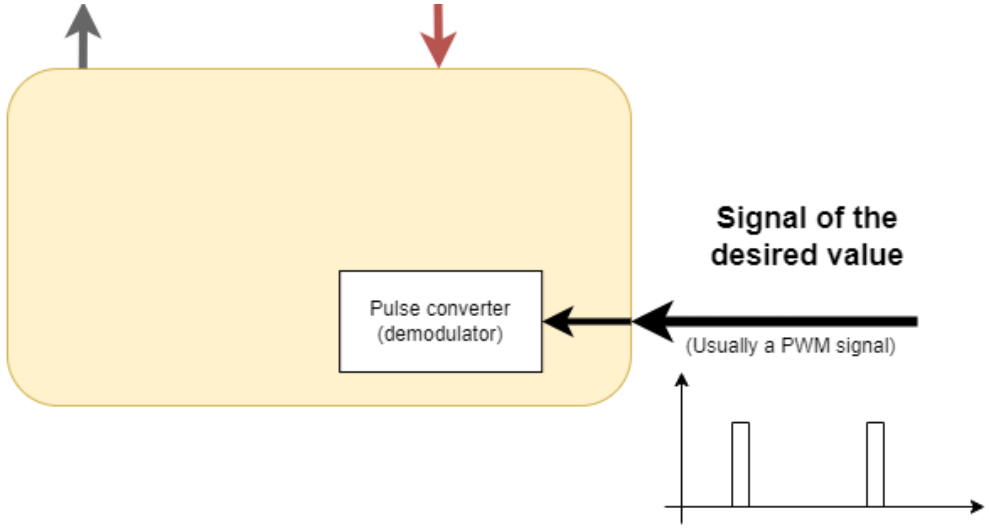
Putting together – adding the control

- For usage we need to „command” the servo
- We set a desired value
- Control unit based on the desired value and the position signal sends the motor a signal
- Done ☺



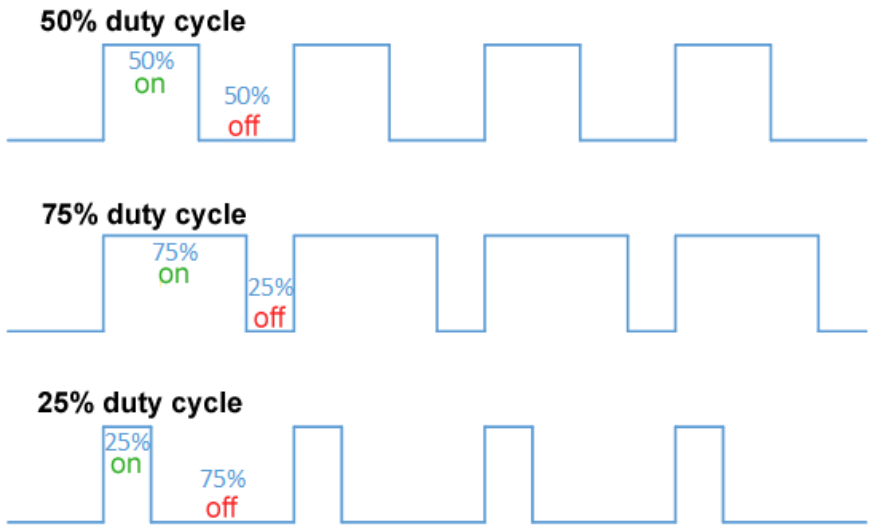
Zooming in the control – Interpret the desired signal

- The desired value's signal is usually sent in a PWM (Pulse Width Modulation) signal
- We interpret this signal and convert to a (usually) analog signal



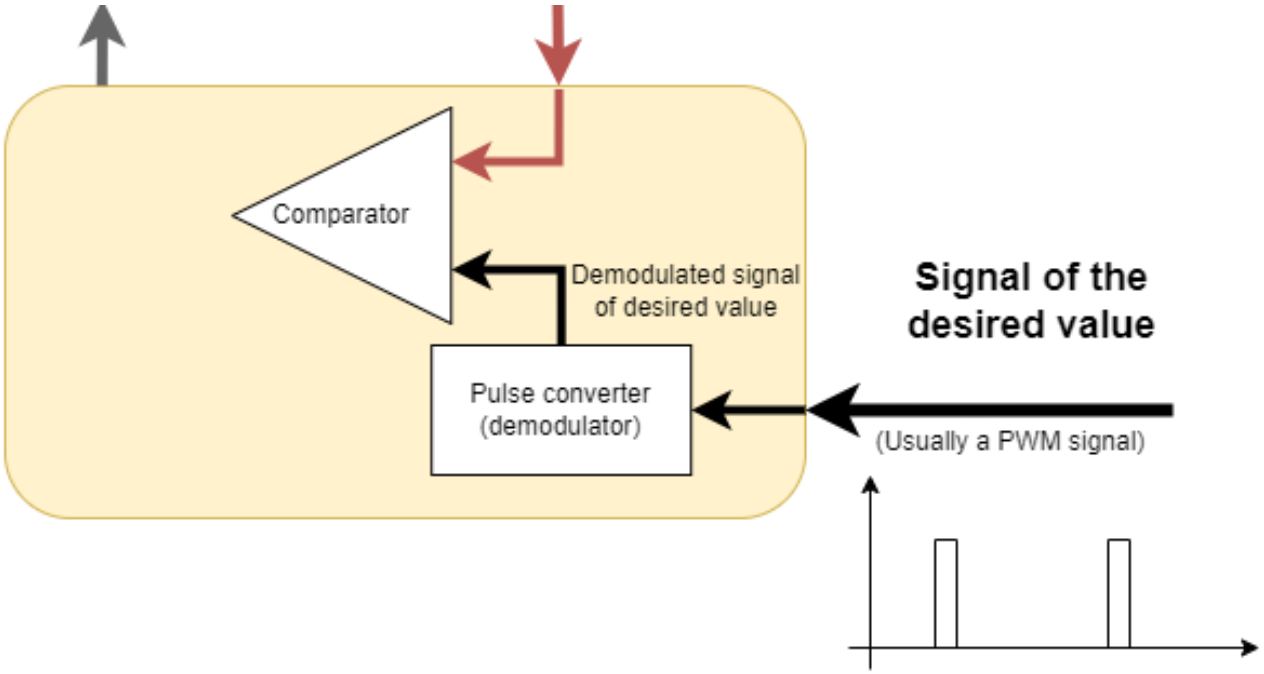
PWM – Pulse Width Modulation

- A method of controlling the average power delivered by an electrical signal
- Parameters:
  - Frequency
  - Duty cycle
- Usually used with higher inertia systems:
  - Light sources (~100Hz)
  - Motors (>kHz)



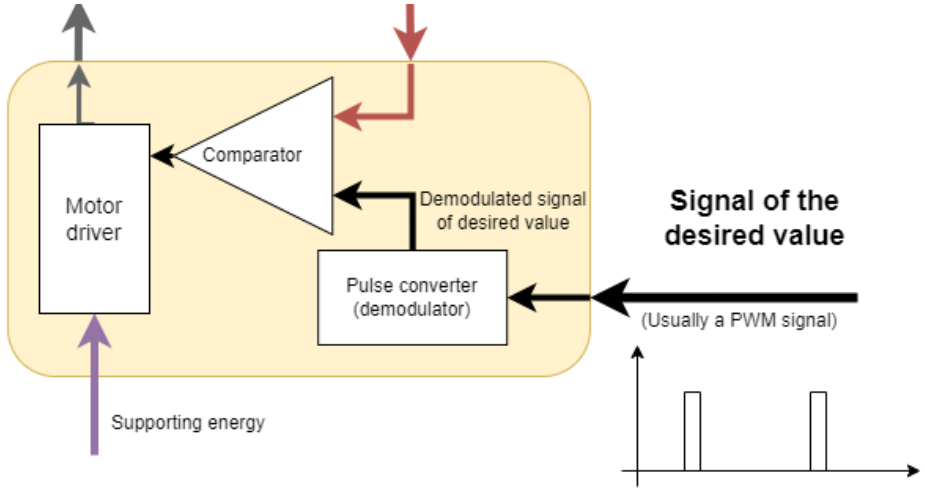
Zooming in the control - Comparator

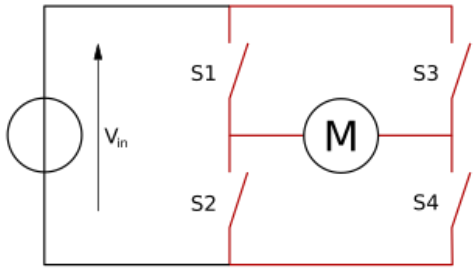
- We need to determine how much we are off compared to the desired outcome
- Comparator simly compares the desired values's signal and the sensor's signal, and gives a signal based on the comparison
(like an if statement)



Zooming in the control – Motor driver

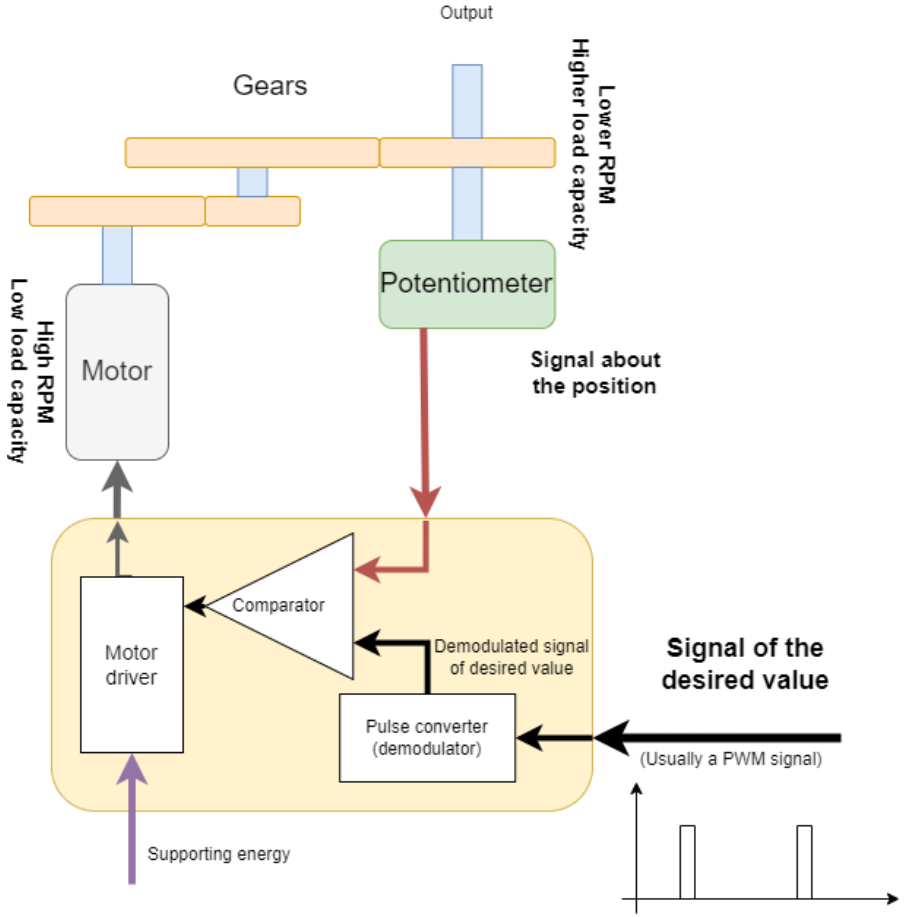
- After we have our intervening signal we need to couple the small power signal to a high power one
- Motor drivers used
  - Usually H bridge
  - With FET transistors as switches (higher efficiency)





Complete overview

- Does this whole system resembles You to something?



For a more visual presentation of the topic

Pros and Cons of Servos

Pros:

- High efficiency
- Closed loop control
- Precise
- Applications for changing load

Cons:

- Some servos are expensive
- Failures due to overloading
- Hard to fix them

Some things to consider during the desing

- Wide range of possible good solutions
  - We can usually achieve the same goal with different actuator setups

- 3 main things to consider:
  - Force (or torque)
  - Range of motion
  - Available time for the positioning

(extra) We didn’t talked about …

- Exact control opportunities for each actuator (system theory, modeling of systems) – out of scope
- How to convert the high rpm into the operation range or change the revolut movement to linear (gearboxes, transmissions)

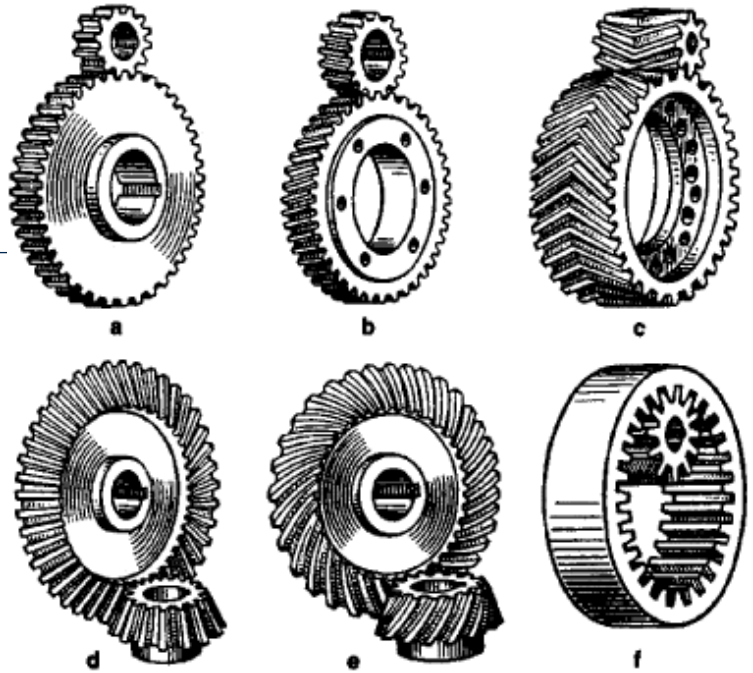
(extra) How to change the motors output

- Numoerous methods and principles were invented

Application's need \ Motor side	Linear	Revolut
Revolut	Not used	gears, chain drive, belt drive etc.
Linear	Leverage	Spindle gear, rack gear etc.

(extra) Revolut to revolut

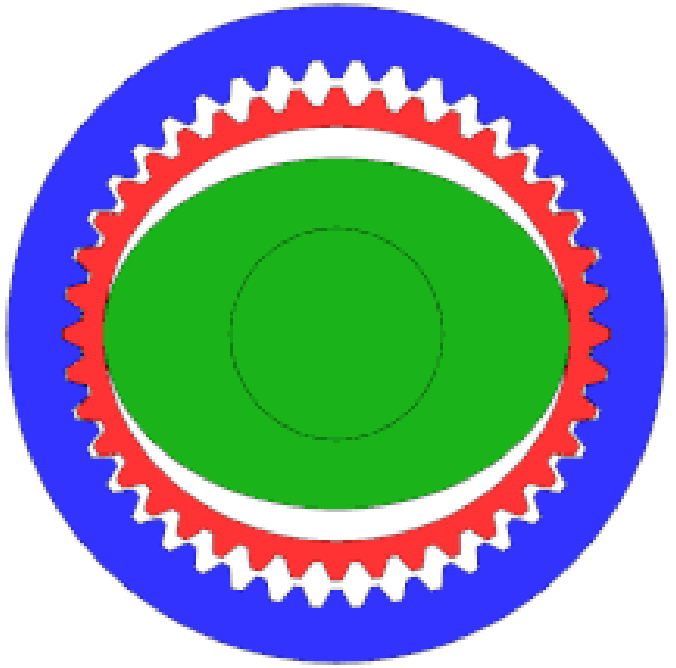
- Gear drive
  - Widely used
  - „Simple”
  - Good efficiency



- Epicyclic gearing
  - high power density
  - Low efficiency loss
  - Much complicated

(extra) Revolut to revolut (cont.)

- In industrial robots there is not much space for the motors and gears in the joints.
- Motor + Gears + bearing MUST be small volume
- Wave drive → huge reduction ratio in one step typically 30:1 – 320:1
- (this means we can have smaller motors)



(extra) Revolut to linear

- Spindle – nut drive
  - Widely used
  - With or without bearing inside
  - The spindle is attached to the motor
  - The nut moves linearly on the spindle