Robótica Móvel e Inteligente

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Robot architecture:

- Sensors
- Actuators
- Locomotion

Actuators in mobile robotics

An actuator can be broadly defined as an active device that converts a primary energy source into physical movement.

Given this definition, the actuators can be generally classified considering:

1. The type of **primary energy** which is used to generate motion in the actuator
2. The type of **generated movement**

For each of the above types of classification it is also possible to classify the actuators according to the type of technology (physical principle of energy transformation into physical movement).

NOTE: some devices which are classified as distinct actuators may, actually, be a more sophisticated version of simple actuators (for example through the integration of the control system at the actuator level).

Actuators in mobile robotics

Classification of the actuators according to the **type of primary energy** that is used to generate movement in the actuator:

1. Electrical. Transform primary electrical energy, usually stored in batteries (…rechargable), into the intended movement. As we will see, there are different technologies depending on the characteristics of the specific application of the actuator. In mobile robotics, electrical actuators represent the main class of actuators used due to its diversity and adaptability to every type of application

Examples of a small and medium size electrical DC motors

Actuators in mobile robotics

Classification of the actuators according to the **type of primary energy** that is used to generate movement in the actuator:

2. Pneumatic. Powered by energy stored as compressed air (or another compressed gas). These actuators are used in situations where **accurate and easy to control movements is desired** but where the required force is not a critical criteria.

Requires very high pressures and therefore an extremely robust and heavy container.

Less efficient in converting energy than electrical solutions, therefore being less common in mobile robotics applications.

Example: pneumatic pistons

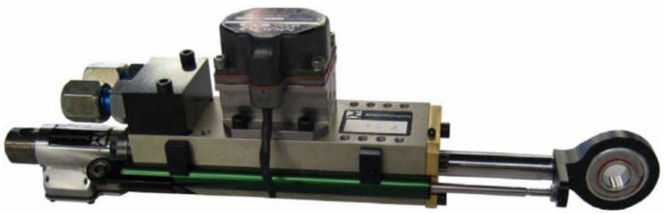
Actuators in mobile robotics

Classification of the actuators according to the **type of primary energy** that is used to generate movement in the actuator:

3. Hydraulic. They use the flow and pressure of a fluid to convert the primary energy into linear and/or rotational motion or torque.

Such actuators are used only in **situations where the force required is extremely high**. They also require **heavy and bulky mechanical structures**.

Typically found in large machines such as autonomous mobile robots working in mines. In the field of robots covered by this course this is not a relevant type of actuator.



Actuators in mobile robotics

Classification of the actuators according to the type of **generated movement** produced by the actuator:

1. **Rotary.** The primary energy is converted into rotating motion, which in turn may be continuous, positional or a source of application of force (torque)

2. **Linear.** The primary energy is converted into linear motion. The purpose of this movement can also include the direct application of a force, the positioning of a mechanical element or the execution of a continuous repetitive motion (*reciprocating system*).

Actuators in mobile robotics

NOTES:

1. When the objective is the direct application of a force, it is common to find solutions where the primary power applied to the actuator is partially stored in a mechanical device (e.g. a spring) so that the original configuration can be restored when the primary energy source is removed. Passive energy storage elements can also adjust target positions based on external forces (**compliant actuators as opposed to stiff**).

2. In some cases, the very primary energy of electric, pneumatic and / or hydraulic actuators can in fact be of a different nature, particularly when the required power is very significant.

One example of what is stated above is the use of an internal combustion engine in which the primary energy, derived from the combustion of hydrocarbons, is in turn converted into electrical, pneumatic or hydraulic energy.

Example of hydrocarbons as primary source

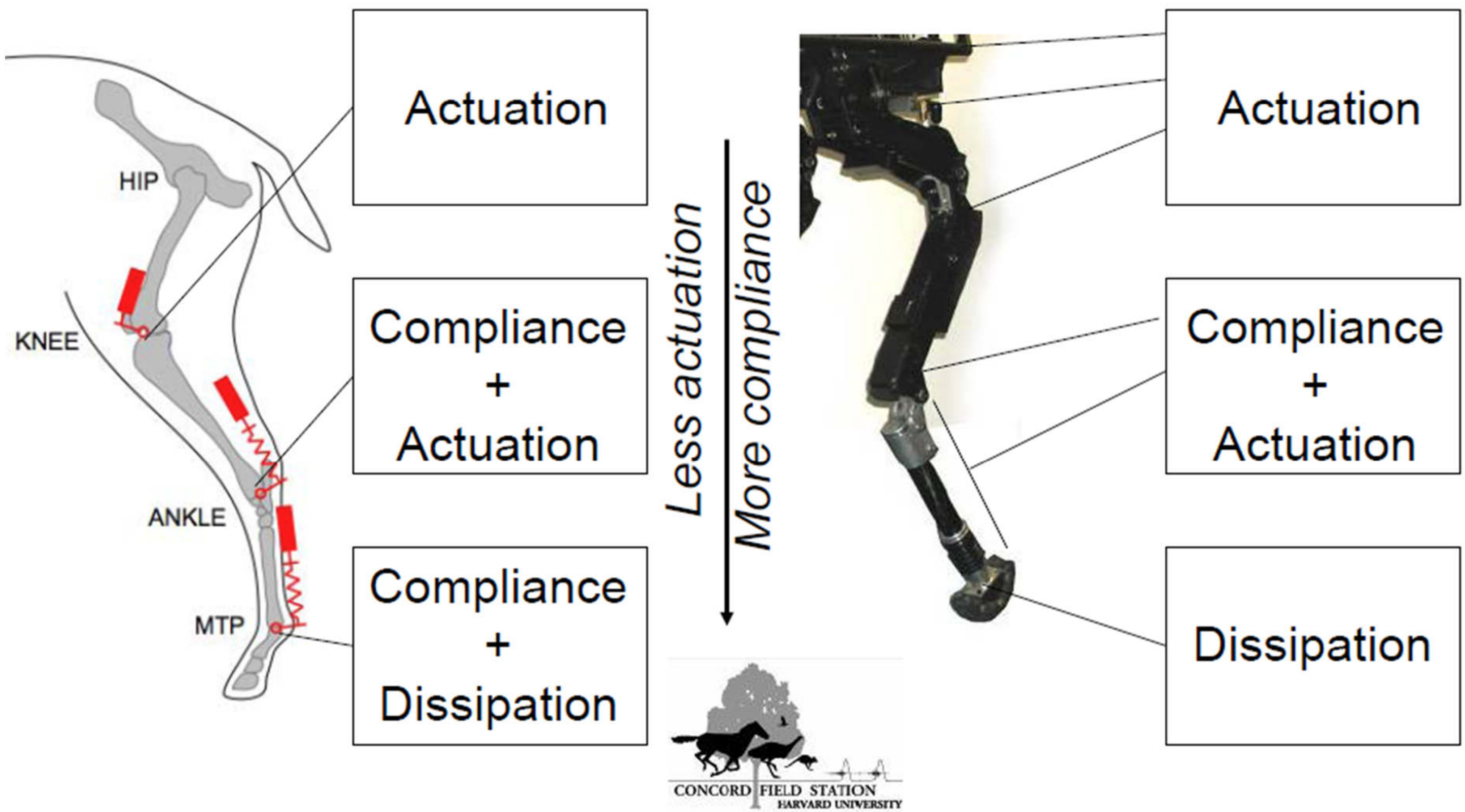
BigDog by Boston Dynamics

- powered by a **two-stroke**, **one-cylinder**, 15-HP go-kart engine operating at over 9,000 RPM.
- **engine drives an hydraulic pump**, which in turn drives the hydraulic leg actuators.
- Each leg has four actuators
  - Each actuator unit consists of a hydraulic cylinder, servo valve, position sensor, and force sensor.

http://www.bostondynamics.com/img/BigDog_Overview.pdf

Multi-jointed Legs

Animal | **BigDog**



http://www.bostondynamics.com/img/BigDog_Overview.pdf

Actuators in mobile robotics

Rotary Actuators

The most common rotary actuators used in autonomous mobile robots (if we exclude the very large robots) use electricity as its primary source of energy.

These actuators, are commonly referred to as "drivers“ or “motors”.

Because they are an essential component in the mechanism of locomotion of robots, they may in turn be of various types regarding the way the electrical energy is transformed into mechanical energy.

Given their relevance in intelligent mobile robotics, there are three types that must be highlighted:

- **Brushed DC motors**
- **Brushless DC motors**
- **Stepper motors**

Rotary Actuators

Regardless of their types, electric motors may be characterized by a set of attributes whose values may be more or less important according to its application. In general, it is the specific application what determines the required characteristics of the motor, and hence, its final selection. Some of the most important parameters to consider are:

- Nominal supply voltage [V] - Range(3 .. 48)*
- Torque response as a function of rotation speed [Nm/min^{-1}]
- Stall torque [Nm] - Range(mNm .. 100sNm)
- Steady duty maximum torque (BMrc) [Nm] - Range(mNm .. 100sNm)
- Typical current in steady duty [A] - Range(mA .. 100A)
- Nominal angular velocity with no load [min-1] - Range(0.1 .. 50,000RPM)**
- Nominal angular velocity in steady duty (VAnrc)] - Range(0.1 .. 35,000RPM)**
- Nominal power (typ: BMrc * VAnrc) [W]] - Range(mW .. 500W)

** Indicative figures for mobile robotics applications*

*** The rotation speed of the main shaft is often dependent on the mechanical gearing box which is coupled to the motor*

Rotary Actuators

We may also consider other parameters such as

- Startup current [A] - Range(mA .. >100A)
- Peak current [A] - Range(mA .. >100A)
- Mechanical time constant[s] - Range(ms .. >100ms)
- Rotor inertia [gcm^2] - Range(0.1 .. >2500 gcm2)
- Motor volume [cm^3] - Range(2cm^3 .. >200cm^3)
- Weight [Kg] - Range(<10g .. >10Kg)

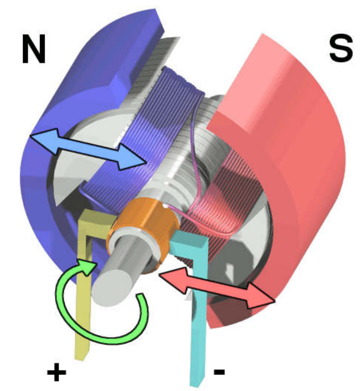
Depending on the technology and the application, we may also need to consider other parameters such as:

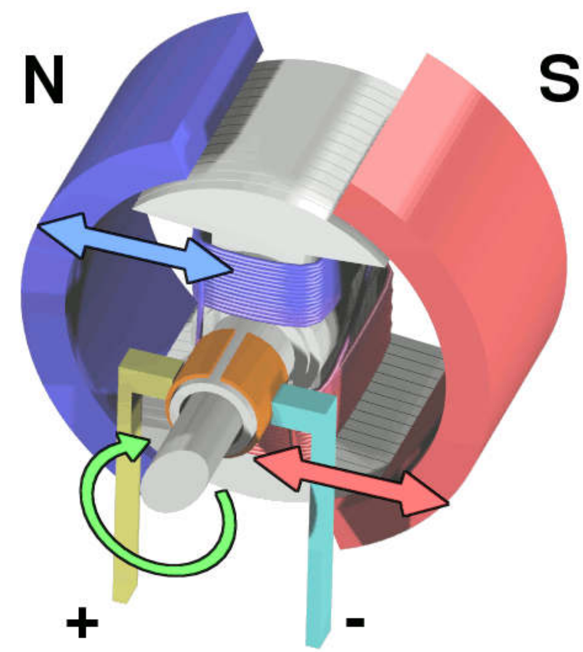
- Efficiency [%]
- Number of poles
- Magnetic characteristics of the rotor and / or stator of the motor
- Mechanical rotor configuration (inrunner or outrunner)
- Geometry of the motor (e.g. planar motors)

Brushed DC motors

In the version shown in the image, there are two poles (**permanent magnets**) which constitute the **stator**.

The **rotor** includes two coils wounded around ferromagnetic armatures that, when traversed by current, generate a magnetic field that, in conjunction with the field of the permanent magnets, generates a **rotational force**.





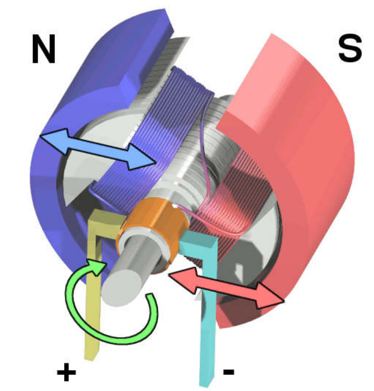
http://en.wikipedia.org/wiki/Brushed_DC_electric_motor

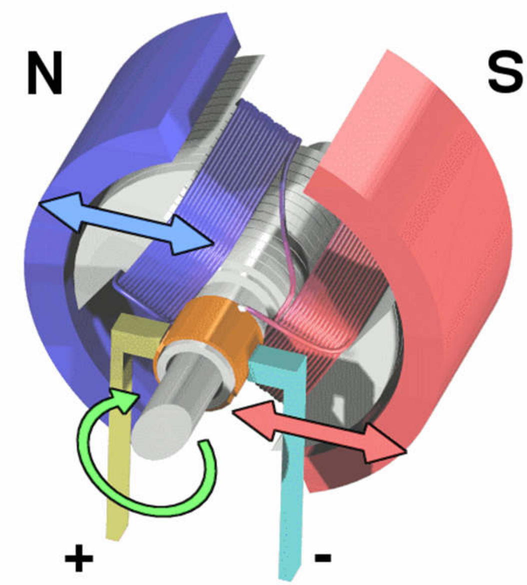
Brushed DC motors

Switching the direction of current flow for ensuring that the torque remains in the same direction **is performed mechanically** (by the so called **brushes**).

In a simple version as that of the image (only two poles) there is a balance point that cancels the forces. A motor in this configuration can not start by itself.

In real solutions, the number of coils in the armored rotor is, at least, equal to or greater than three.



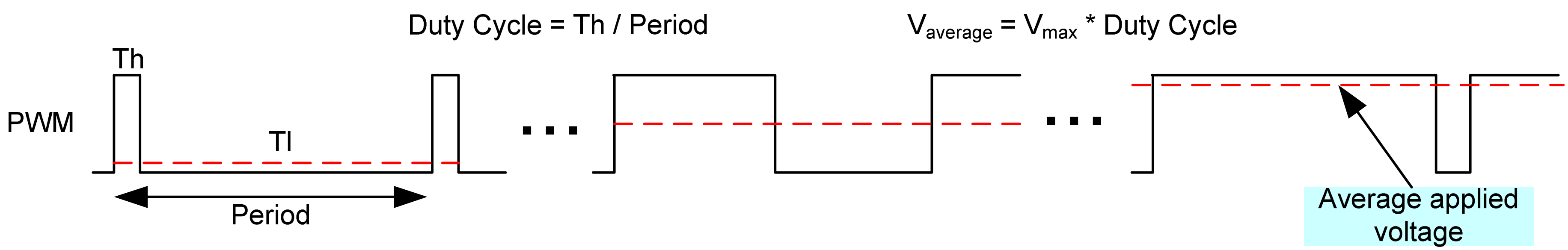


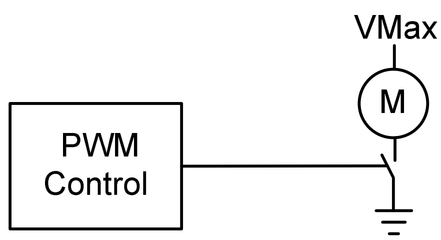
http://en.wikipedia.org/wiki/Brushed_DC_electric_motor

Brushed DC motors

Speed control of DC motors can be carried out by directly **varying the voltage applied to the terminals**.

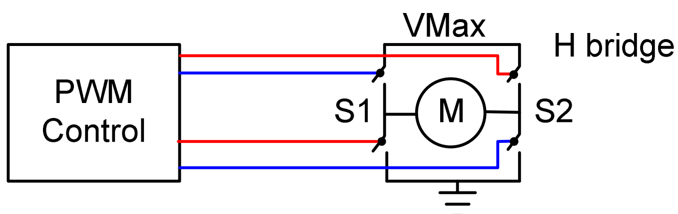
Since most of the current controllers are digital, this voltage variation is done by modulating the pulse width of a constant voltage (**PWM** controller) that is applied at a fixed frequency to the motor terminals.

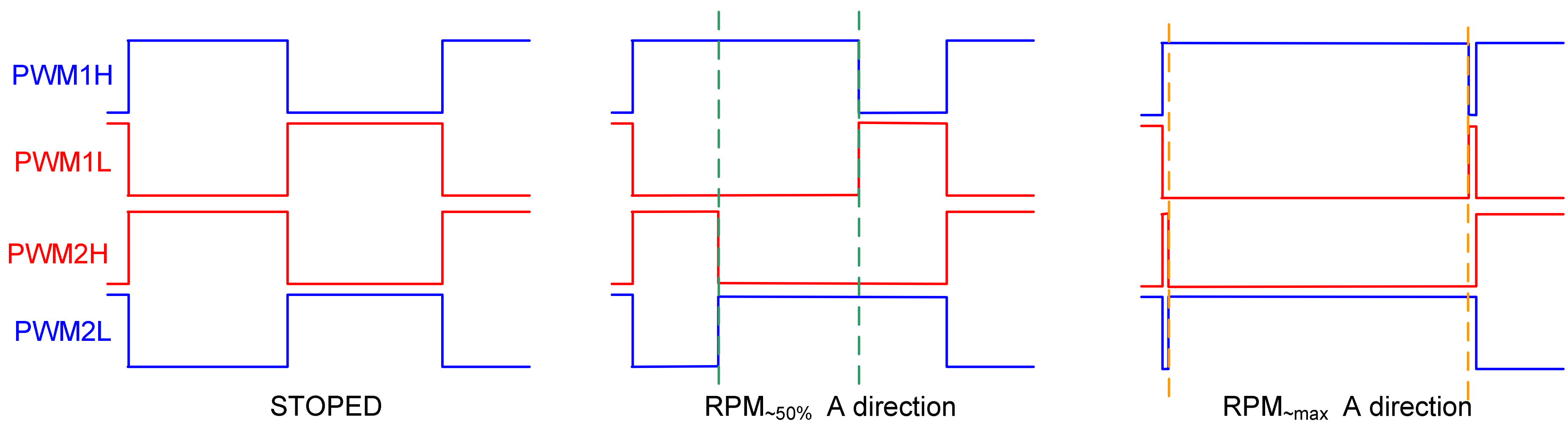




To **change the direction of rotation** of a DC motor, the polarity of the applied **voltage must be reversed**.

For that an H-bridge circuit is normally used, allowing the full control of the motor, in terms of speed and direction of rotation.





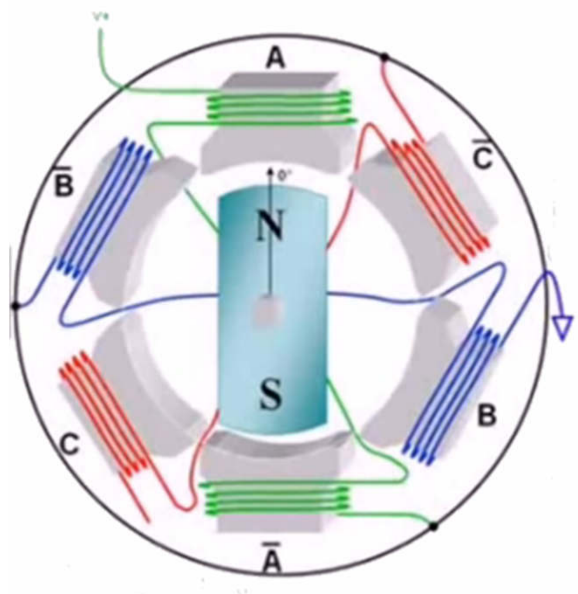
BrushLess DC motors (BLDC)

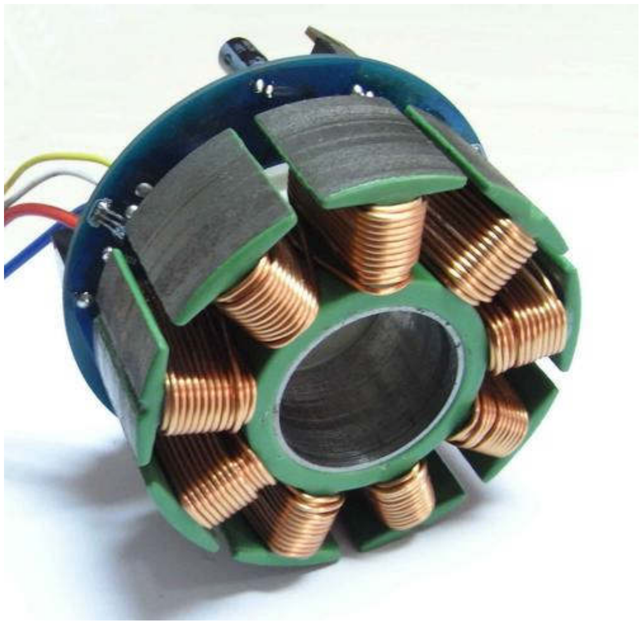
A brushless DC motor uses **permanent magnets, mounted on the rotor**, and a fixed armature on which a group of winding pairs of electromagnetic poles are mounted.

These **poles are excited by an externally applied voltage**.

This configuration **eliminates the need for a mechanical switching** system (**brushes**)

However, it **requires an electronic control system which ensures the correct sequential switching of the poles**, in order to generate the necessary torque that produces the correct rotation of the rotor.





BrushLess DC motors(BLDC)

The BLDC motors require virtually **no mechanical maintenance** and exhibit greater **efficiency** when compared with the brushed

In contrast, to control a BLDC is more complicated, in particular since **it requires a mechanism to provide information on the absolute position of the rotor** (Hall effect sensors or EMF measurements). The # of pairs of transistors should be equal to 2 * #poles (or 4*#poles for bi-directional control).

800W Out-runner at 9,000RPMs

Mechanical configurations for BLDC solutions include inner rotors (in-runners), outer rotors (out-runners) or overlapping rotors and stators (planar motor).

From the electrical point of view, the interconnection of the poles can also adopt triangle or star configurations.

Stepper Motors

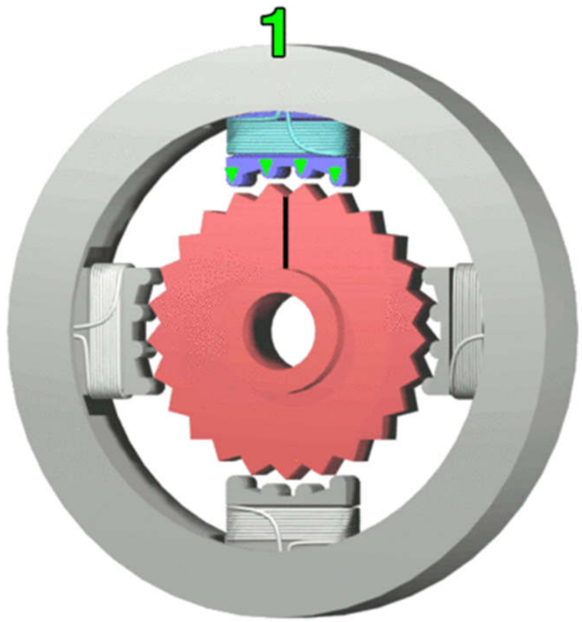
The stepper motor consists of a **rotor containing multiple magnets arranged on a central piece of iron**, and a **set of electrical coils disposed about the periphery** ferromagnetic materials, which is also **toothed**.

When a **current** is injected in one of the coils, it **generates a magnetic field** that attracts a subset of the permanent magnets until their **teeth become aligned**.

In this configuration, **the teeth of the other coils** are **slightly out of phase** relative to the rotor teeth.

Thus, when switching the current to the next coil, a new binary is generated to trigger a new alignment.

By **sequentially feeding the coils**, one can generate a rotary motion to a controlled-speed or put the rotor in a desired fixed angle.



Brief comparison between the three types of motors

Brushed DC	Brushless DC	Stepper Motors
+ cheap	+ efficiency	+ very precise (can be used in open loop)
+ simple to control	+ large range of rotational speeds	+ good for planar topologies
+ large power range	+ maintenance	+ useful in positioning applications
+ very simple startup	+ power vs. volume	+ maintenance
-	+ good for planar topologies - price	+- reasonable compromise between complexity and control
- mechanical wear-out	- complex control	-- price
- efficiency	- complex startup and/or need for acurate position sensors	-- efficiency
- power vs. volume		- mechanical vibration

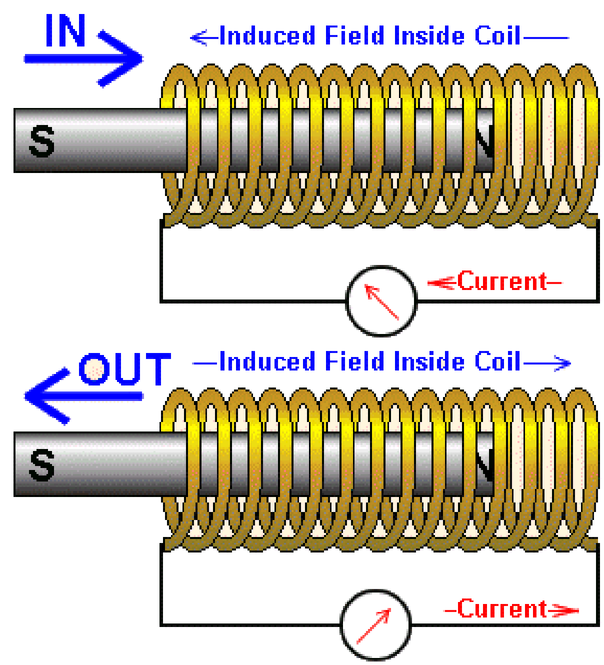
Solenoids

A solenoid is typically built from a winding (**coil**) mounted around a **movable plunger** within an air gap.

The plunger consists of a ferromagnetic material or a permanent magnet (which is the case of image below).

If it consists of a ferromagnetic material, when a **current is applied to the coil a magnetic field is produced** that, in turn, creates a dipole field in the plunger which generates a force to **align its geometrical center with the center of the coil**.

In those situations in which the plunger is a permanent magnet, the direction of the current and the starting position of the plunger generates a force that may be repulsive or attractive

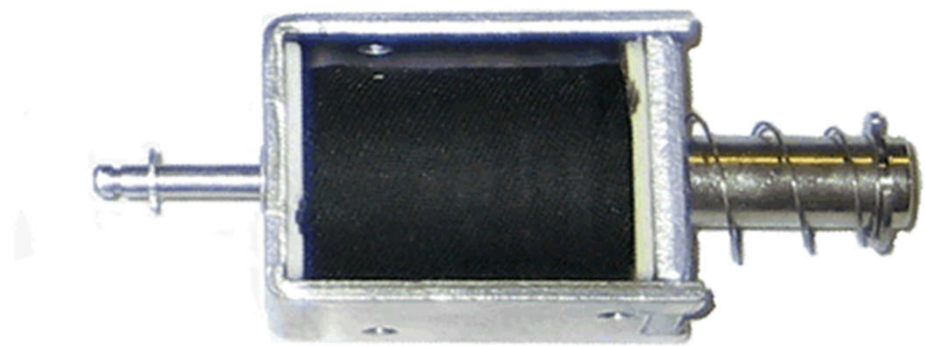


Solenoids

In most cases, the solenoid starts from a position where the plunger is geometrically offset with respect to the center, and is rapidly attracted in the opposite direction when the coil is energized.

In order to maintain the exerted force, the plunger is mechanically locked before reaching the equilibrium point.

To reset the initial conditions, a passive element (eg. spring) that accumulates the resulting energy from the shift, pushes the plunger again to the starting position when power is removed.

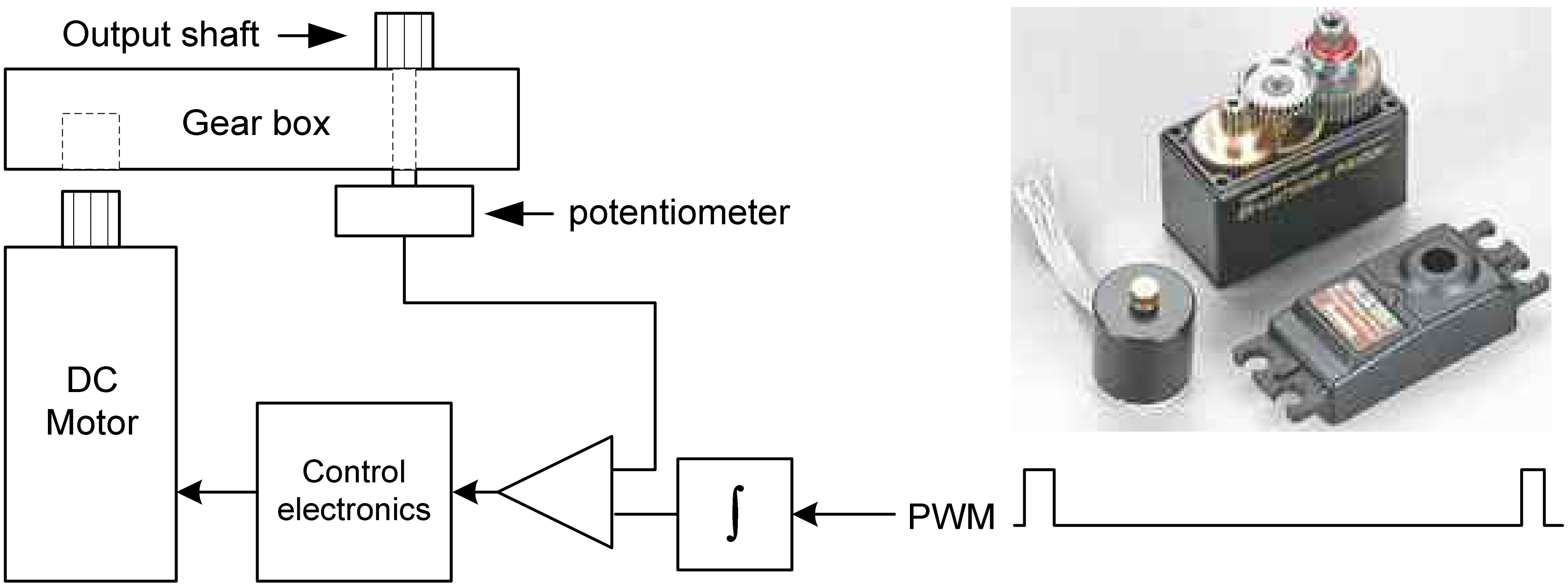


Servo Motors

Servo (or **servo motor**) is the name given to a combination of a **DC (or BLDC) motor**, a **reduction gear box** and an **electronic control loop**.

Servos are intended, usually, for applications of **angular positioning** which require **good accuracy** (which can also be transformed into linear movement)

In the simplest servos, the control is carried out by applying a PWM signal to the servo. The feedback loop includes a potentiometer which indicates the angular position of the output shaft.



Servo Motors

The main parameters to consider when choosing a servo are:

- Maximum available torque
- Angular velocity range
- Maximum covered angle (or free rotation)
- Angular resolution
- Gear box materials
- Type of control
- Dimension and weight

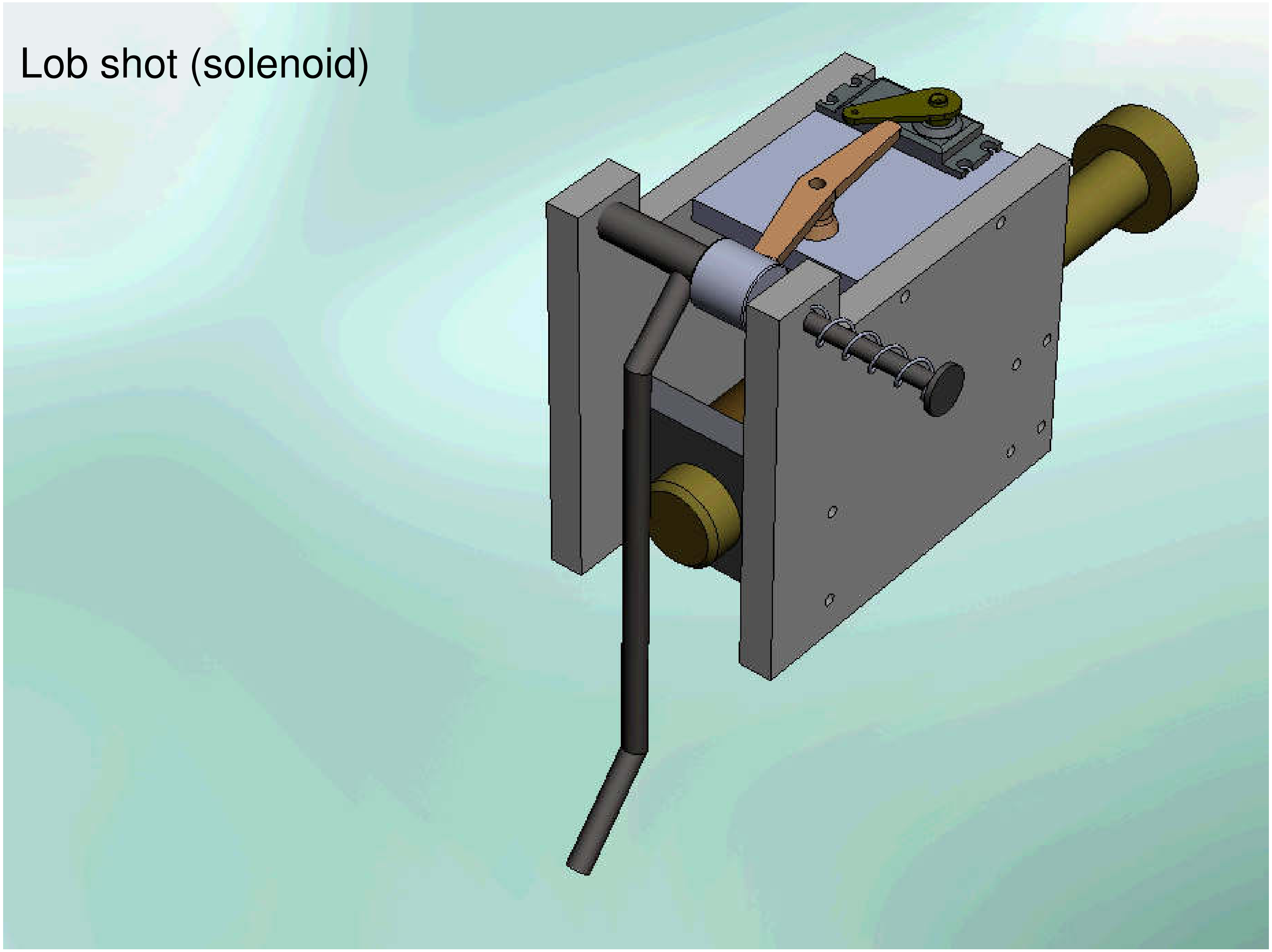
E.g. – In the case of Dynamixel servos, control is performed via digital commands sent through a digital multi-drop bus, allowing, among others, a precise control (within some limits) of parameters such as end angle, angular velocity and maximum torque to be applied.

Hobby servo

Industrial servo

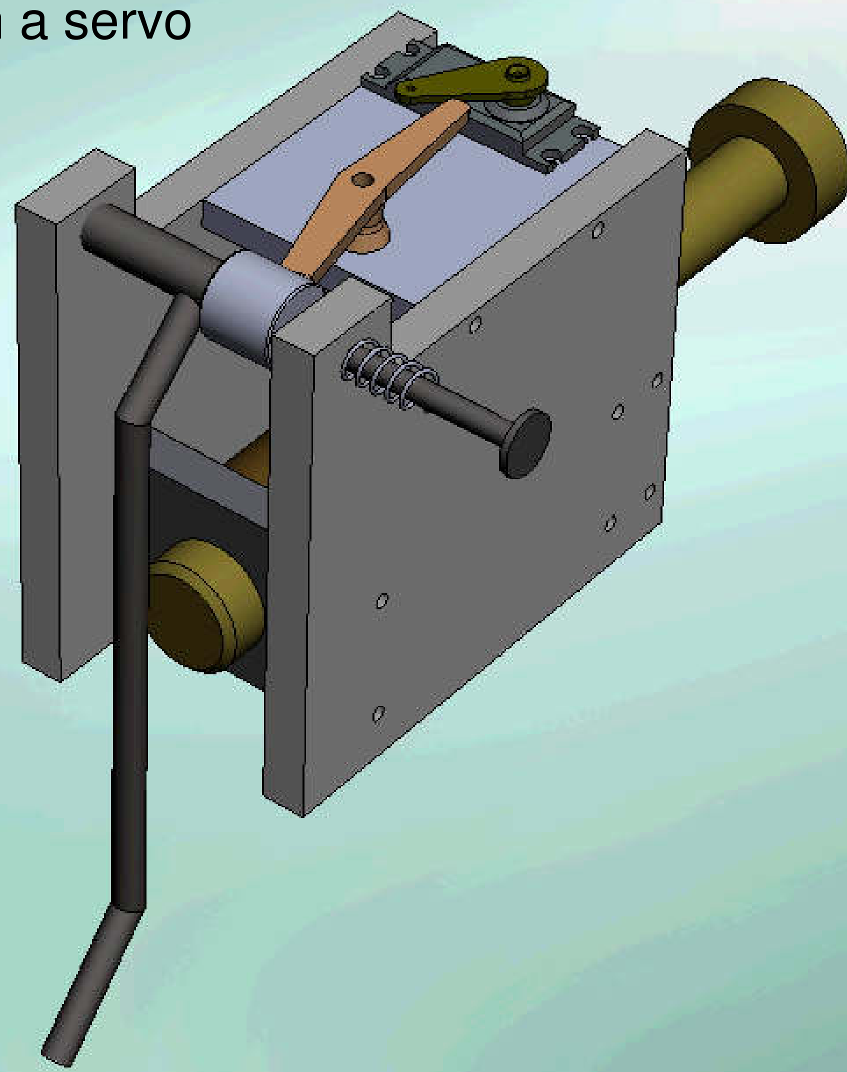
Dynamixel servo

Combination of actuators - example (CAMBADA)



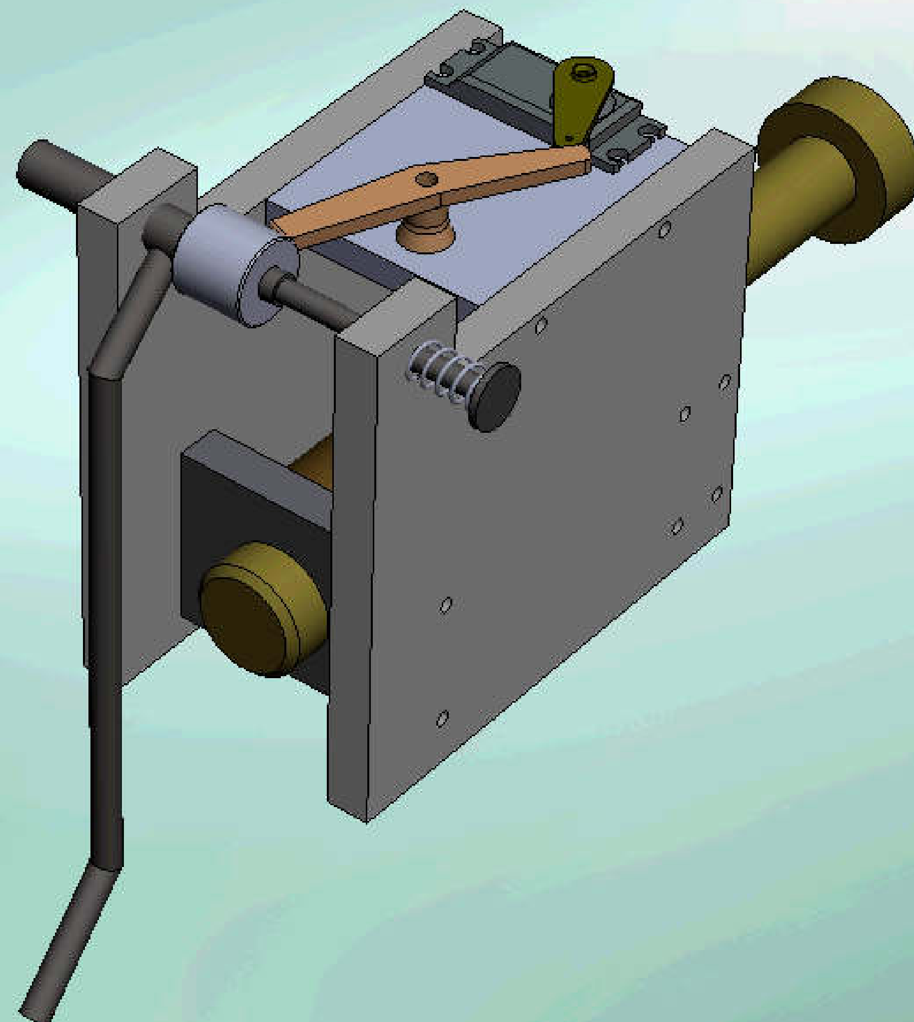
Combination of actuators - example (CAMBADA)

Acting mechanism based on a servo



Combination of actuators – example (CAMBADA)

Low shot (solenoid)

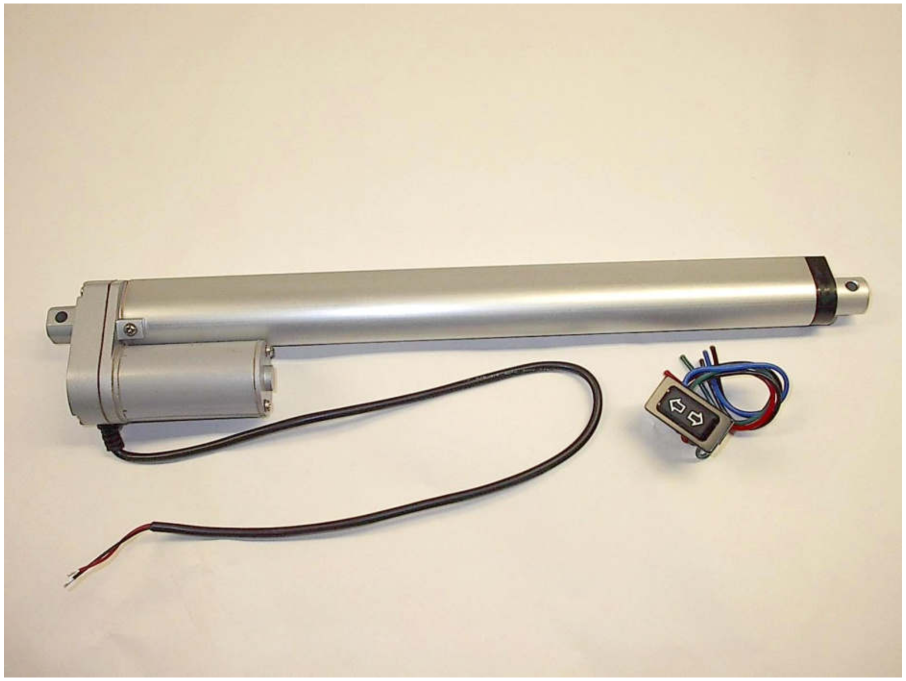


Linear Actuators

A linear actuator normally comprises a DC motor associated with a worm screw on which, or from which, the actuating element is moved.

Depending on the direction of rotation of the DC motor, the actuating element approaches or moves away from the original boundary of motion. The inclusion of a potentiometer and/or limit switches is common in this type of actuators.

Equally common are the linear actuators using pneumatic or hydraulic energy. In these cases the actuator is associated to a piston that is subject to positive or negative pressures to trigger the desired movement.



Other actuators

Pneumatic artificial muscles - also known as **air muscles** are based on the stretch and contraction of an elastic tube by varying the air pressure within the same. Contractions can raise up to about 40% of the original dimension.

Wire muscle - based on a compound known as Nitinol or Flexinol, this type of string can **shrink (up to about 5%) when subjected to an electric current**. Can be used in small dimension applications.

Electroactive polymers – based on plastic materials (EAPs or EPAM: electroactive Polymer Artificial Muscle) they **can expand substantially due to an electrical signal applied**. This type of actuator does not support, however, large mechanical loads.

Piezo-electric motors - used in micro and nano robotics, they use the piezo-electric principle to produce electro-mechanical vibration (tens of kilohertz) which can be transformed into rotational or linear motion.