Design Lab: Introduction

Corso Materiali intelligenti e Biomimetici
12/04/2019

ludovica.cacopardo@ing.unipi.it

Organizzazione Lab

12/04 Intro Lab

2/05 Esercitazione 1 (scelta componenti, materiali e tecniche lavorazione)

3/05 Esercitazione 2 - eCAD

8/05 Esercitazione 3 - SMA

9/05 Esercitazione 4 - QTC

16/05 Lavoro di gruppo

17/05

23/05

24/05

Tot: 4 lezioni

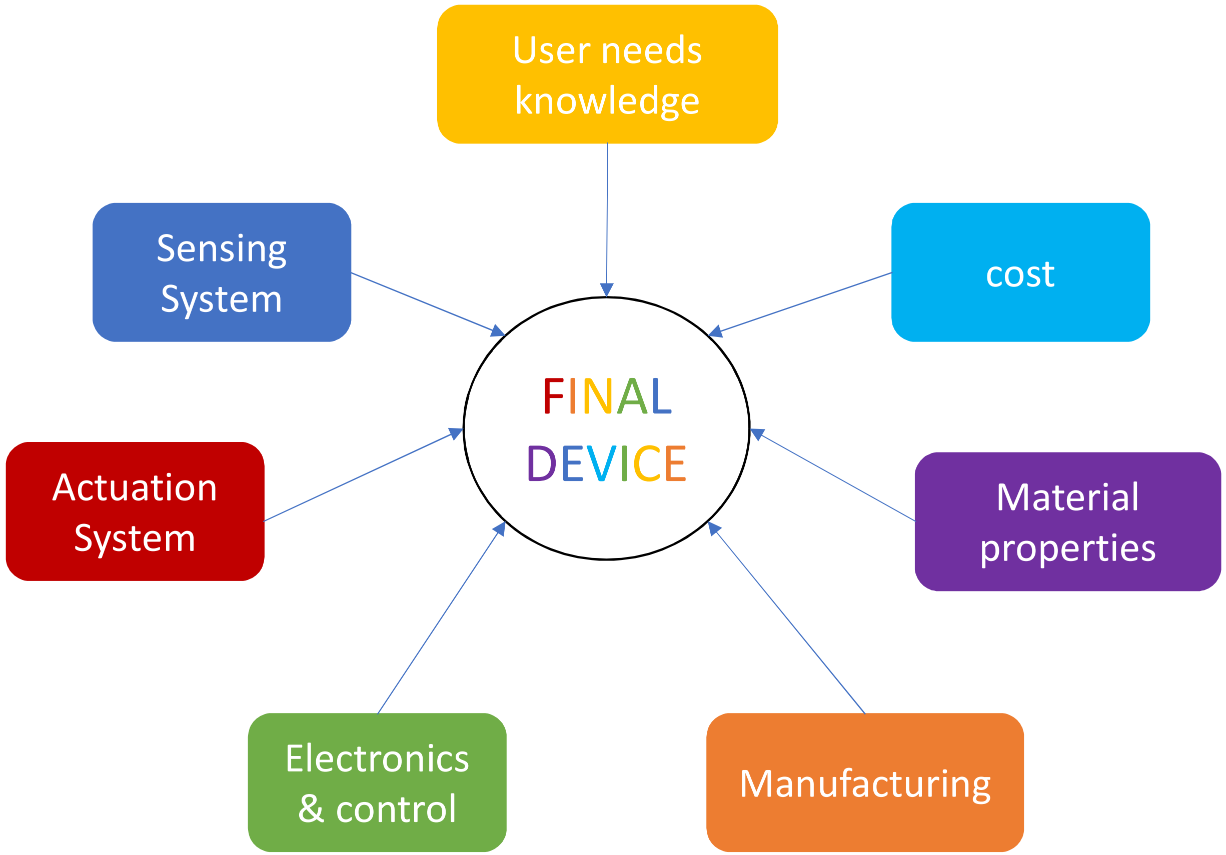
30/05 discussione lavoro di gruppo/esercitazioni (gruppo 1-5)

31/05 discussione lavoro di gruppo/esercitazioni (gruppo 6-11)

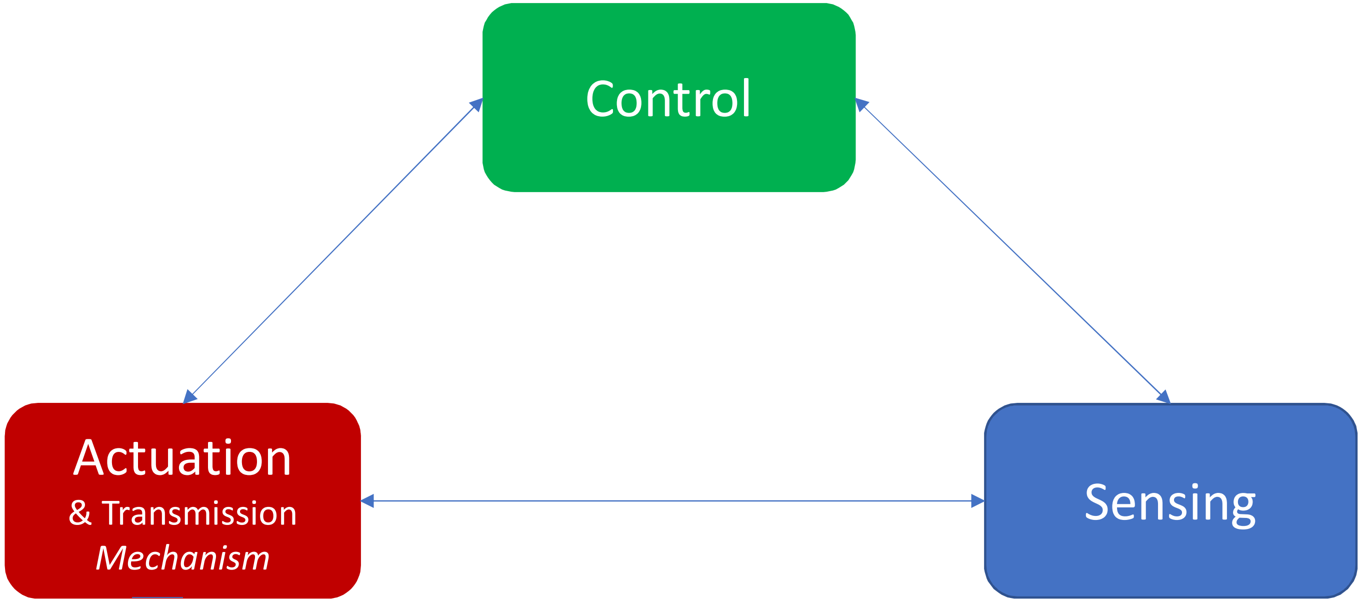
* Voto di gruppo valido solo per i presenti alla discussione

Design of intelligent systems

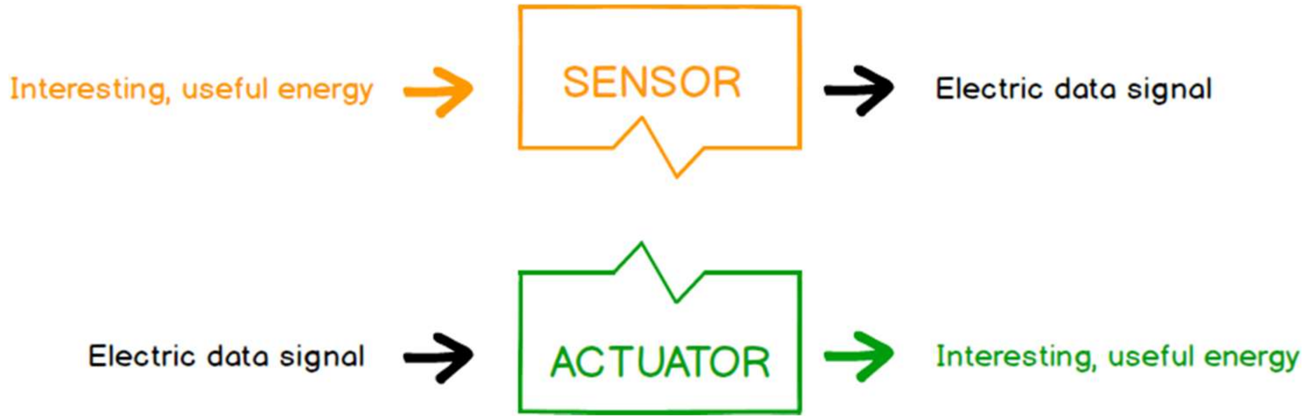
The importance of being a Biomedical Engineer



Design of intelligent structures



Sensors vs. Actuators



The word “**Transducer**” is the collective term used for both Sensors and Actuators.

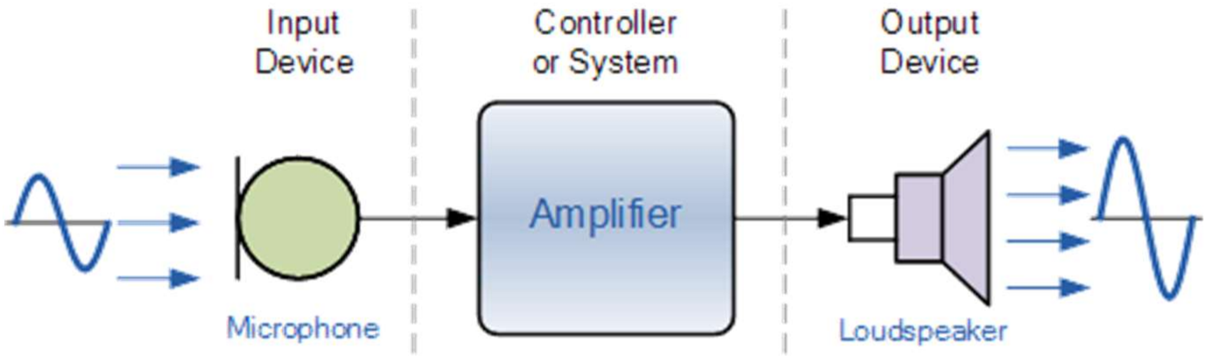
Devices which perform an **“Input” function** are commonly called **Sensors** because they “*sense” a physical change* in some characteristic and covert that into an electrical signal.

Devices which perform an **“Output” function** are generally called **Actuators** and are used to *control some external device*, for example movement or sound.

Transducers

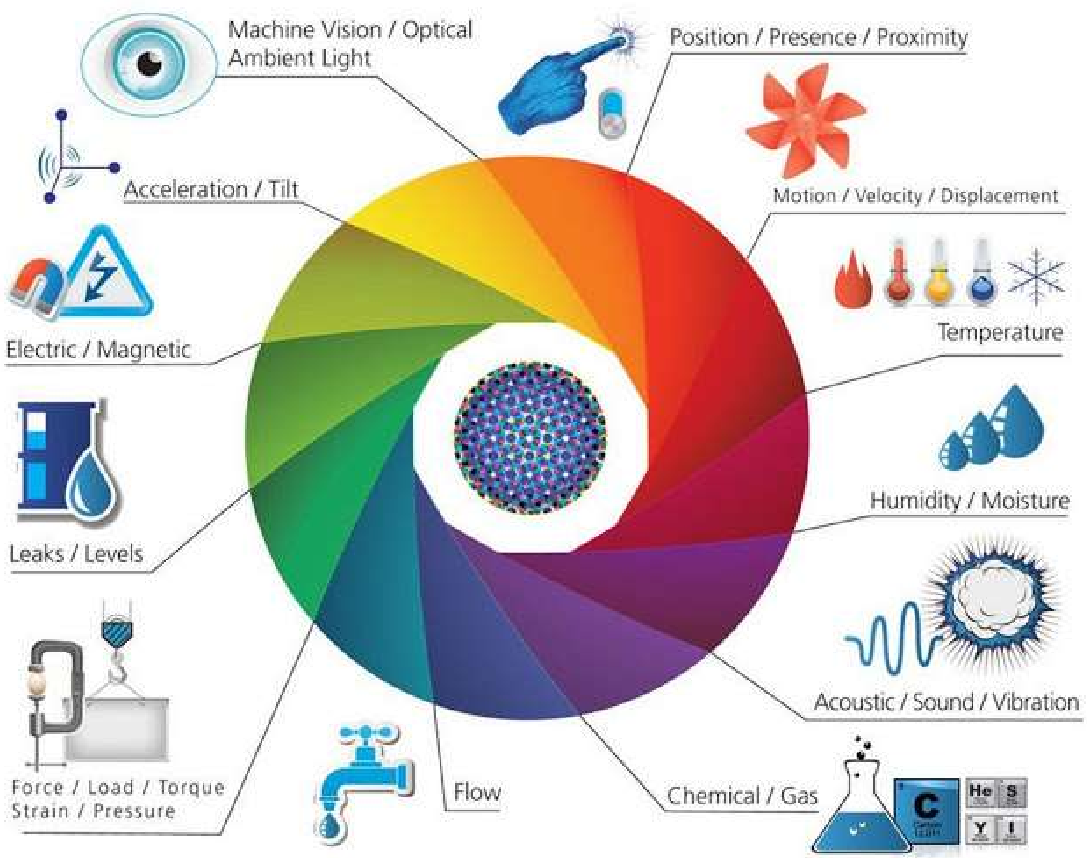
Electrical Transducers are used to **convert energy of one kind into energy of another kind.**

For example, *a microphone (input device) converts sound waves into electrical signals* for the amplifier, and *a loudspeaker (output device) converts these electrical signals* back into sound waves and an example of this type of simple Input/Output (I/O) system is given below



Transducer – types

Quantity being Measured	Input Device (Sensor)	Output Device (Actuator)
Light Level	Light Dependant Resistor (LDR) Photodiode Photo-transistor Solar Cell	Lights & Lamps LED's & Displays Fibre Optics
Temperature	Thermocouple Thermistor Thermostat Resistive Temperature Detectors	Heater Fan
Force/Pressure	Strain Gauge Pressure Switch Load Cells	Lifts & Jacks Electromagnet Vibration
Position	Potentiometer Encoders Reflective/Slotted Opto-switch LVDT	Motor Solenoid Panel Meters
Speed	Tacho-generator Reflective/Slotted Opto-coupler Doppler Effect Sensors	AC and DC Motors Stepper Motor Brake
Sound	Carbon Microphone Piezo-electric Crystal	Bell Buzzer Loudspeaker



Sensors

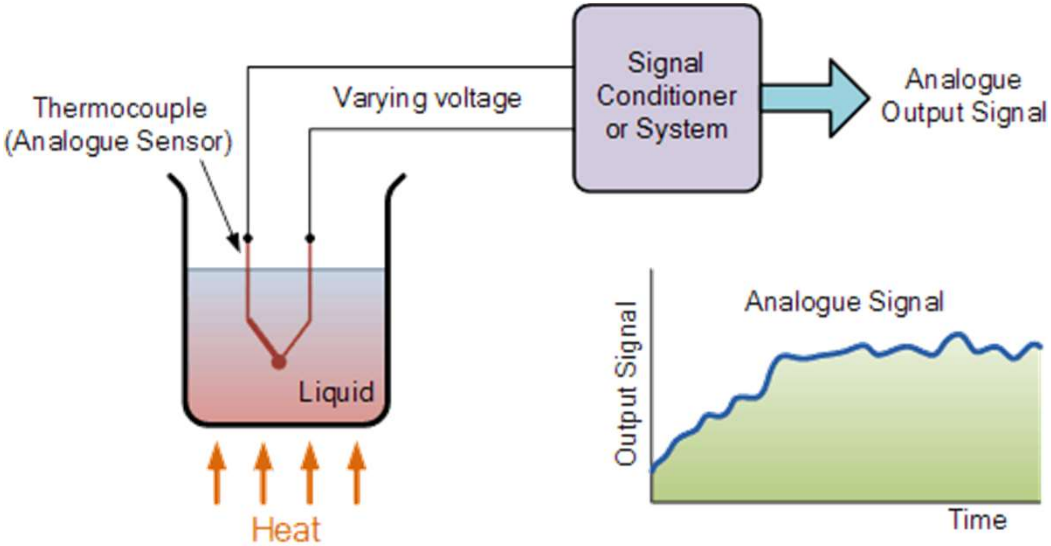
Input type transducers or sensors, produce a **voltage or signal output response, which is proportional to the change in the quantity that they are measuring** (the stimulus). The type or amount of the output signal depends upon the type of sensor being used.

- **active sensors** require an **external power supply to operate**, called an excitation signal which is used by the sensor to produce the output signal. Active sensors can also produce signal amplification. A good example of an active sensor is an LVDT sensor or a *strain gauge*. Strain gauges are pressure-sensitive resistive bridge networks that are external biased (excitation signal) in such a way as to produce an output voltage in proportion to the amount of force and/or strain being applied to the sensor.

- A **passive sensor** does **not need any additional power source** or excitation voltage. Instead a passive sensor generates an output signal in response to some external stimulus. For example, a *thermocouple* which generates its own voltage output when exposed to heat.

Analogue Sensors

Analogue Sensors produce a **continuous output signal** or voltage which is generally *proportional to the quantity being measured*.
Physical quantities such as Temperature, Speed, Pressure, Displacement, Strain etc are all analogue quantities as they tend to be continuous in nature. For example, the temperature of a liquid can be measured using a thermometer or thermocouple which continuously responds to temperature changes as the liquid is heated up or cooled down.



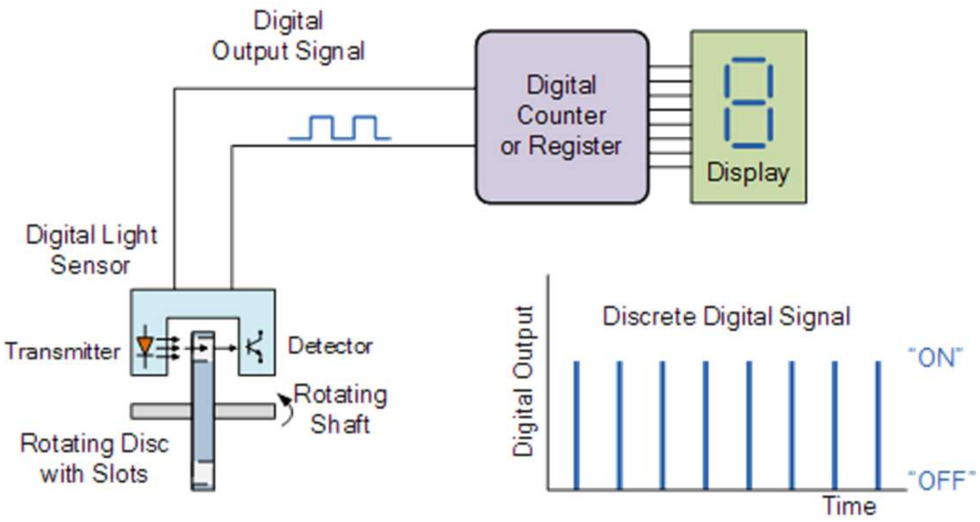
Also **analogue signals can be easily converted into digital type** signals for use in micro-controller systems by the use of **analogue-to-digital converters** (ADC).

Digital Sensors

Sensing

Digital Sensors produce a **discrete digital output signals** or voltages that are a *digital representation of the quantity being measured*.

Digital sensors produce a **Binary output signal** in the form of a logic “1” or a logic “0”, (“ON” or “OFF”). This means then that a digital signal *only produces discrete (non-continuous) values* which may be outputted as a single “bit”, (serial transmission) or by combining the bits to produce a single “byte” output (parallel transmission).



For example, the speed of the rotating shaft can measured by using a digital LED/Opto-detector sensor.

The disc which is fixed to a rotating shaft has a number of transparent slots within its design. As the disc rotates with the speed of the shaft, each slot passes by the sensor in turn producing an output pulse representing a logic “1” or logic “0” level.

These pulses are sent to a register of counter and finally to an output display to show the speed or revolutions of the shaft. By increasing the number of slots or “windows” within the disc more output pulses can be produced for each revolution of the shaft

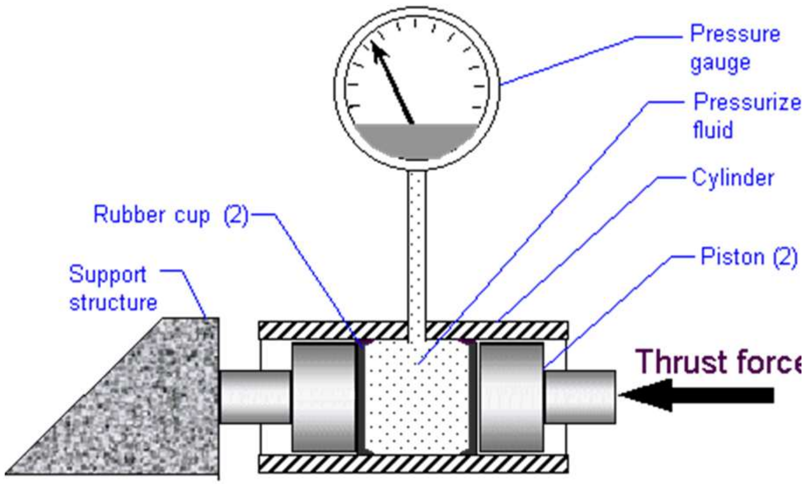
Sensing

Example: Load cells

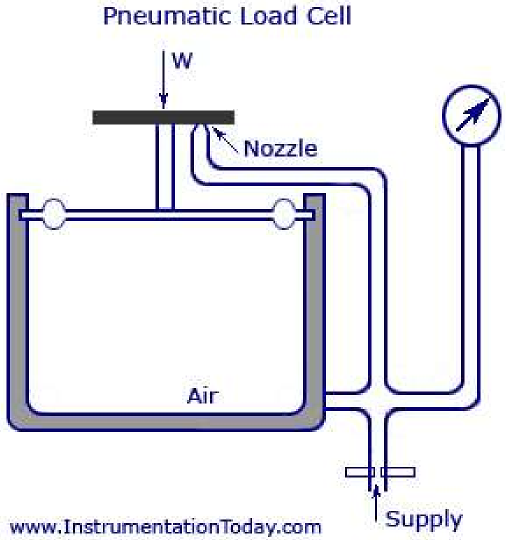
A load cell is a **transducer that tranforms pressure (force) into an electrical signal**.

Types:

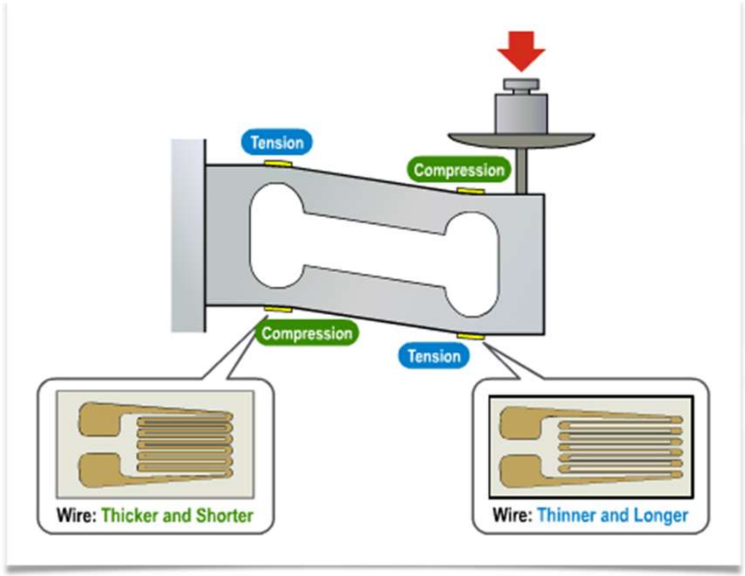
Hydraulic Load Cells



Pneumatic Load Cells

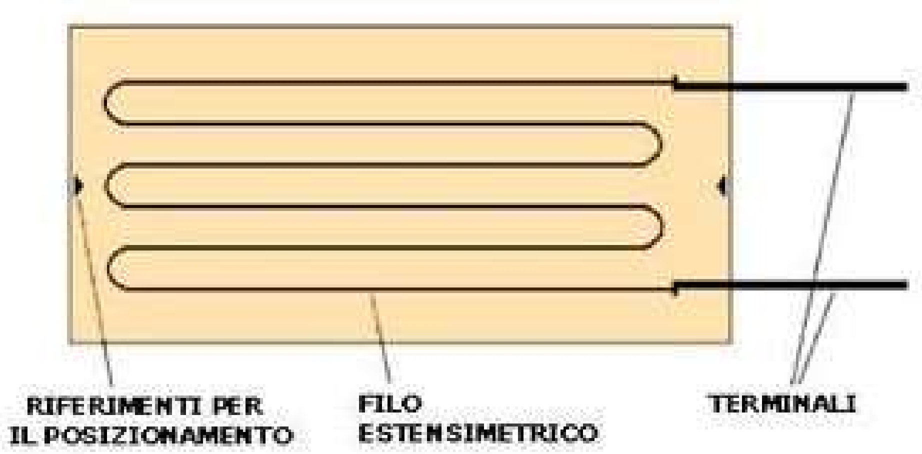


Strain Gauge Load Cells



Strain Gauge (1)

A strain gauge is a device that measures electrical **resistance changes in response to strain** (indirectly pressure/force) applied to the device.



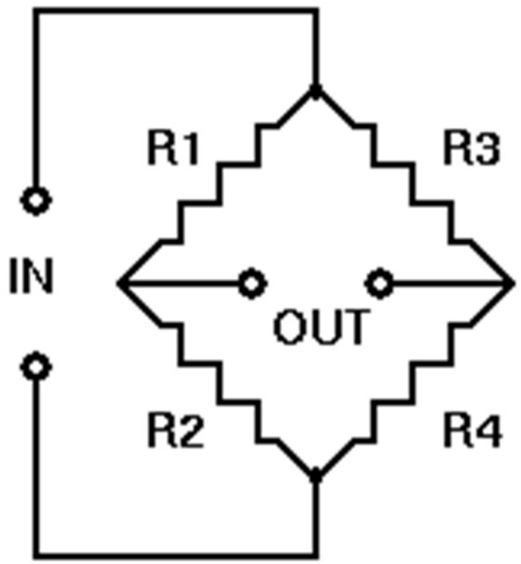
The sensitivity to strain is expressed quantitatively as the **gauge factor (GF)**, defined as the *ratio of fractional change in electrical resistance to the fractional change in strain.*

Typically resistance variation are very small (i.e. small electrical signal, difficult to detect), so we need to turn it into something that we can measure accurately.

Strain Gauge (2)

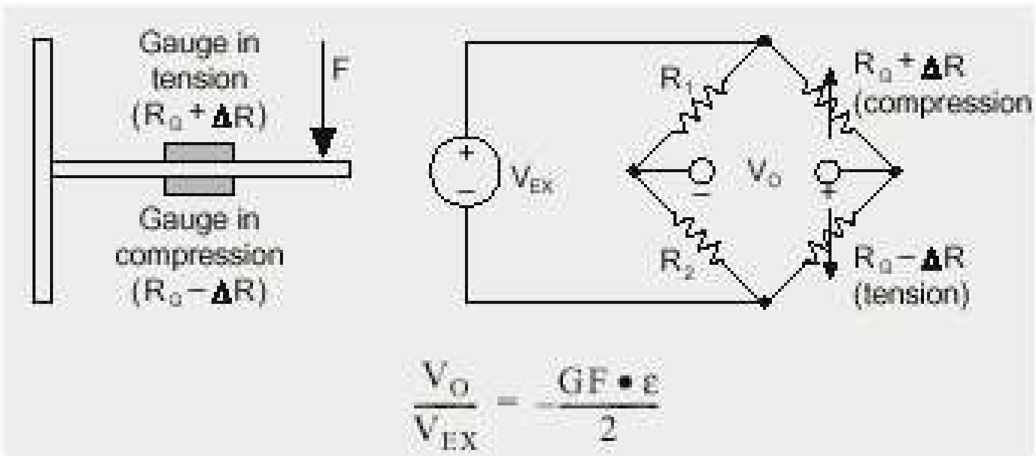
wheatstone bridge:

when $R1/R2 = R3/R4$ ➡ Vout=0



but if there is a change to the value of one of the resistors:

$$Vout = [(R3/(R3 + R4) - R2/(R1 + R2))] * Vin$$



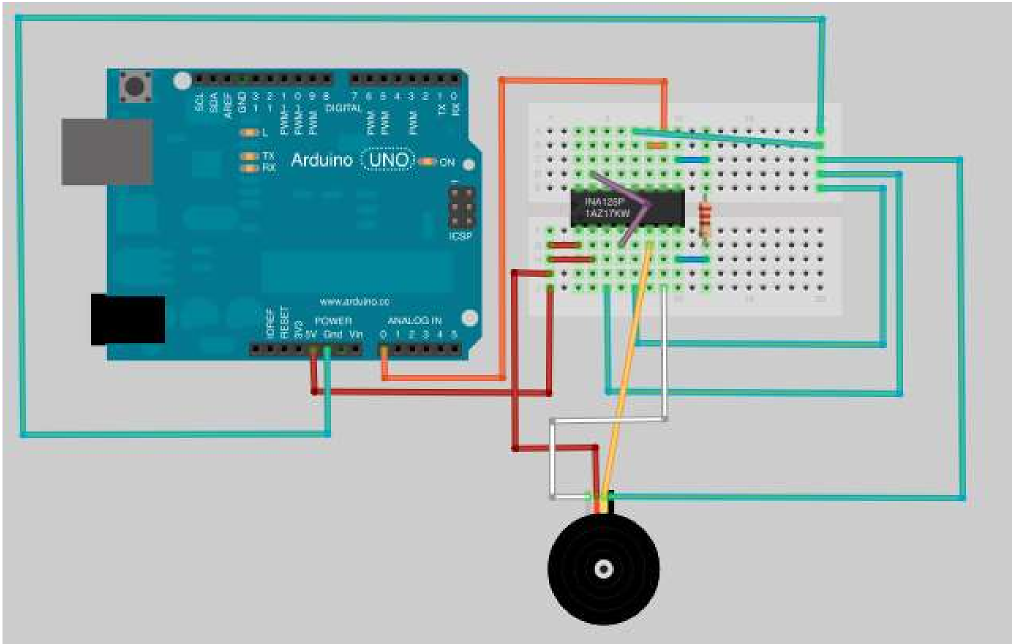
BURR - BROWN®

INA125

INSTRUMENTATION AMPLIFIER
With Precision Voltage Reference

$$V_O = (V_{IN}^{+} - V_{IN}^{-})\,G$$

$$G = 4 + \frac{60k\Omega}{R_G}$$



http://www.ti.com/lit/ds/symlink/ina125.pdf

FX1901

Compression Load Cell

SPECIFICATIONS

- High Reliability Design for OEM, Appliance and Medical Applications
- 10 – 200 lbf Ranges
- Compact Coin Cell Package
- Anti-Rotation Mounting Features
- CE Compliance

ORDERING INFORMATION

FX19	0	0	–	0001	–	0010	200	L
Model Name								

Output
0=20mA

Plastic Shell & Cable
0=NO **1**=Yes

Description
0001=Standard **SXXX**=Special
XXXX=EWR Customize

Range
0010 0025 0050
0100 0200

Force Range
0010 0025 0050
0100 0200

Units
L=lbf

CODICE PRODUTTORE

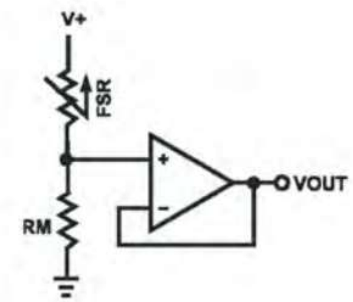
PARAMETERS	TYP	UNITS
Recommended Excitation	5	V
Full Scale Output Span	20	mV/V

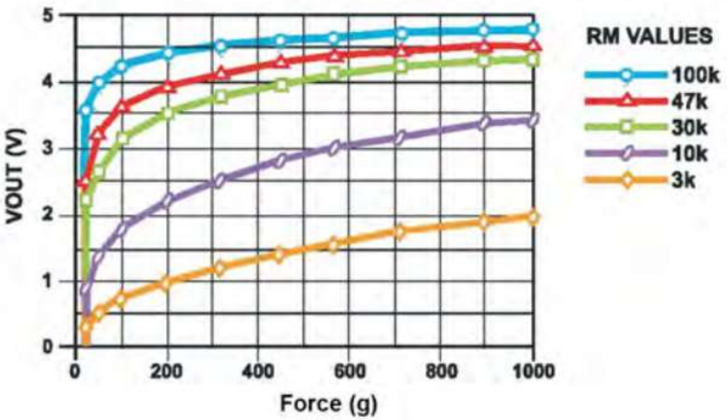
http://www.te.com/commerce/DocumentDelivery/DDEController?Action=srchrtrv&DocNm=FX19&DocType=DS&DocLang=English

INTERLINK ELECTRONICS

FSR® 400

Actuation Force*	~0.2N min
Force Sensitivity Range*	~0.2N – 20N
Force Resolution	Continuous (analog)





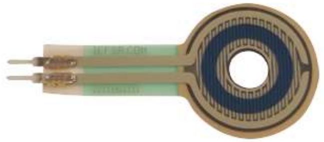
https://cdn2.hubspot.net/hubfs/3899023/Interlinkelectronics%20November2017/Docs/Datasheet_FSR.pdf

FSR® 400 Short
5mm Circle x 20mm

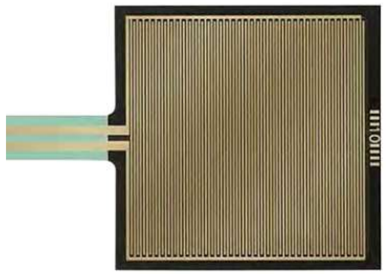
FSR® 400
5mm Circle x 38mm

FSR® 402 Short
13mm Circle x 25mm

FSR® 402
13mm Circle x 56mm



FSR® 404
20mm Donut with 5.5mm hold



FSR® 406
38mm Square x 83mm

FSR® 408-xxx
10mm Wide x xxx mm strip
xxx = 50, 100, 200, 300, 400, 500mm

Sensing

Bill of Materials (BOM)

Tutti i prezzi sono in EUR.

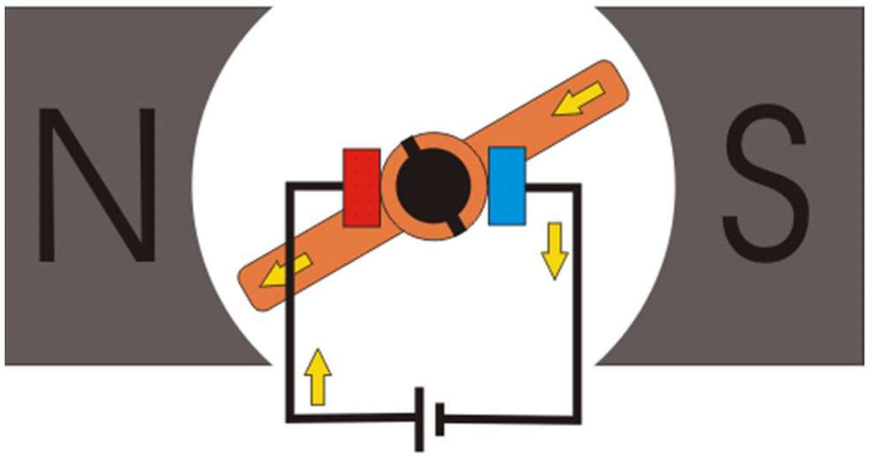
Indice	Quantità	Immagine	Codice componente	Descrizione	Riferimento cliente	Quantità disponibile	Quantità in arretrato	Prezzo unitario	Prezzo totale
☒ 1	10		1027-1014-ND	SENSOR FORCE RES 0.04-4.5LBS		10 Immediatamente	0	7,01900	€ 70,19
☒ 2	1		INA125P-ND	IC OPAMP INSTR 150KHZ 16DIP		1 Immediatamente	0	5,58000	€ 5,58
☒ 3	1		223-1528-ND	SENSOR TENSE LOAD CELL		1 Immediatamente	0	24,92000	€ 24,92
								Totale parziale	€ 100,69
								Spedizione	€ 0,00
								Totale	N/D

Digikey, RS, and Mouser are the most popular suppliers of electronic components.

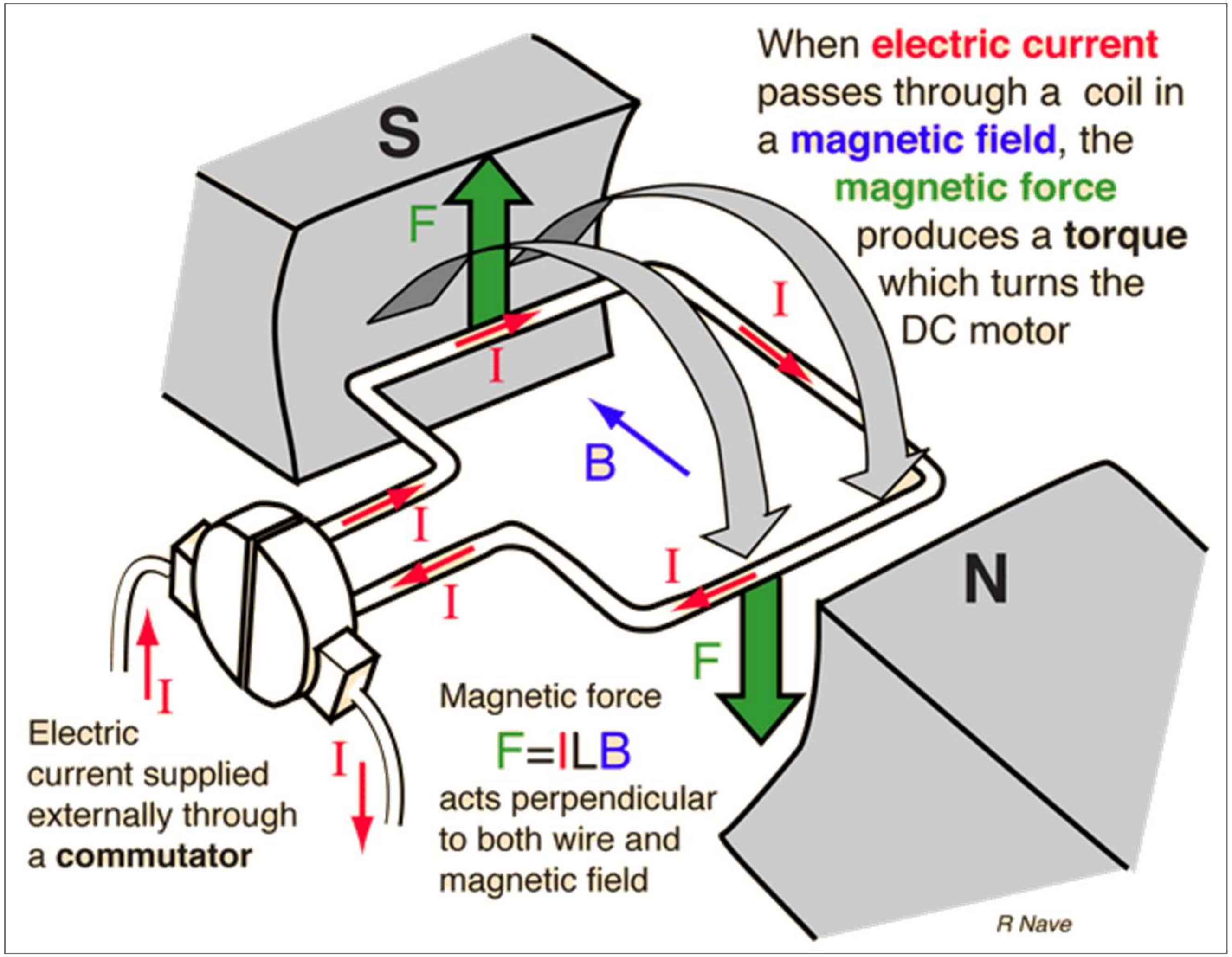
Motors

A motor is an **electro-mechanical device** that **converts electrical energy to mechanical energy**.

The very basic principal of functioning of an electrical motor lies on the fact *that force is experienced in the direction perpendicular to magnetic field and the current*, when field and current are made to interact with each other.

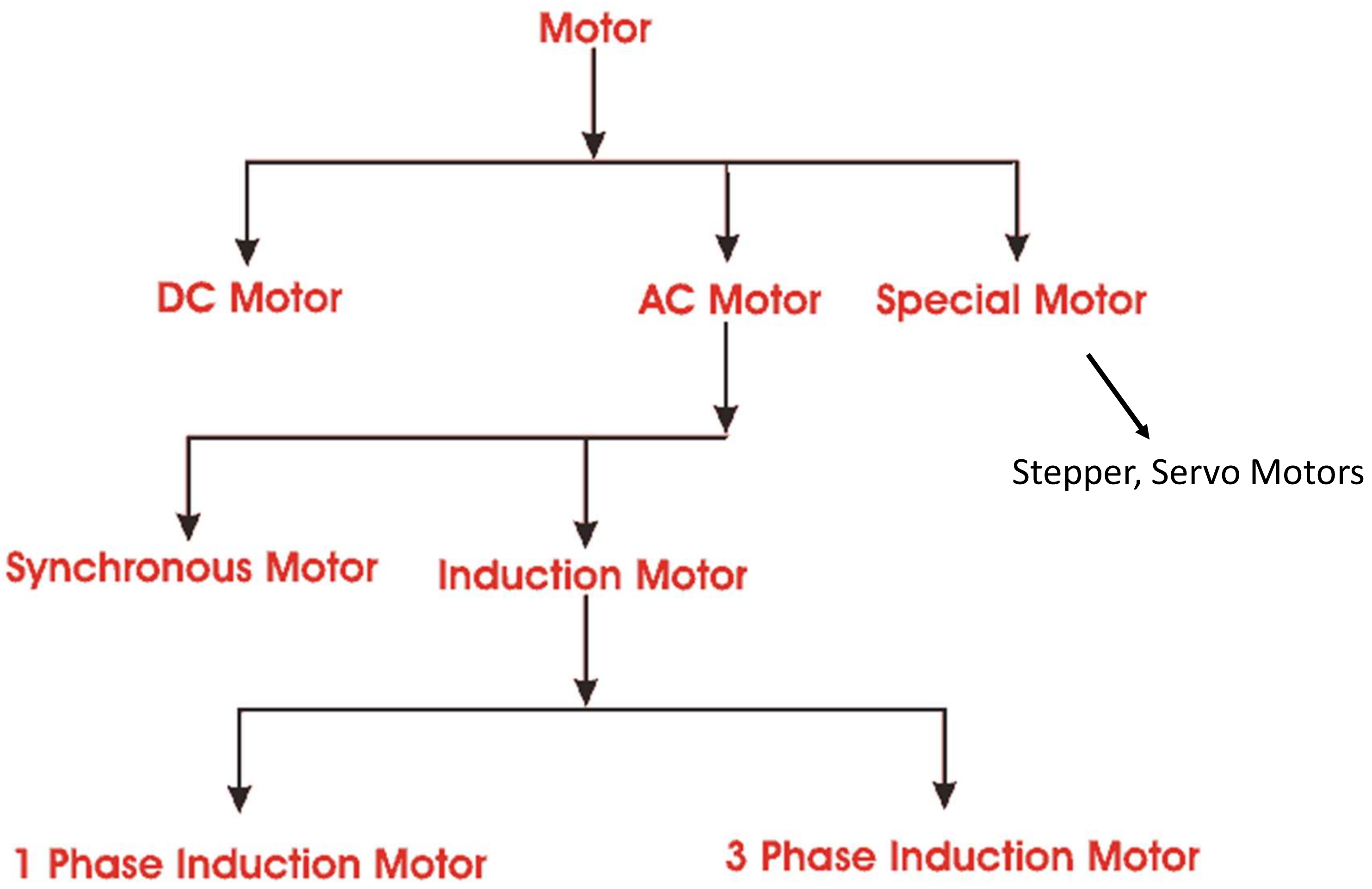


Actuation



When electric current passes through a coil in a magnetic field, the magnetic force produces a torque which turns the DC motor
S
N
F
F
I
B
Electric current supplied externally through a commutator
Magnetic force
F=ILB
acts perpendicular to both wire and magnetic field
R Nave

Types of Motors

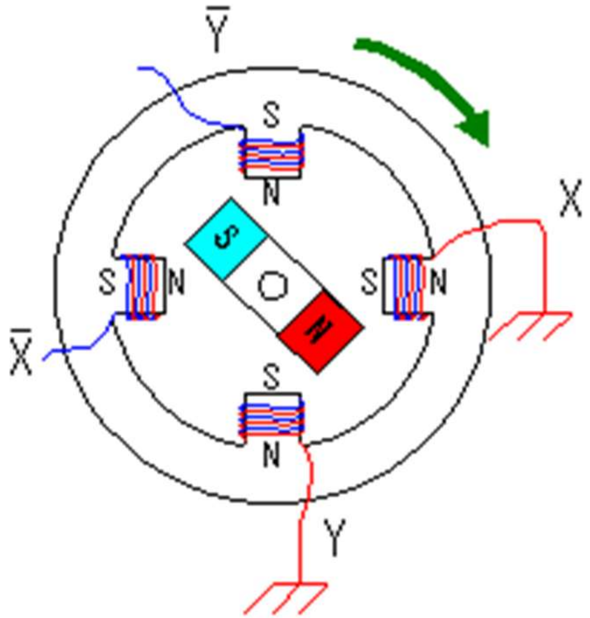


Stepper

A stepper motor is a **type of DC motor that rotates in steps**.
When electrical signal is applied to it, the motor rotates in steps:

- The **speed of rotation** depends on the *rate at which the electrical signals are applied*;
- The **direction of rotation** is dependent on the *pattern of pulses* that is followed.

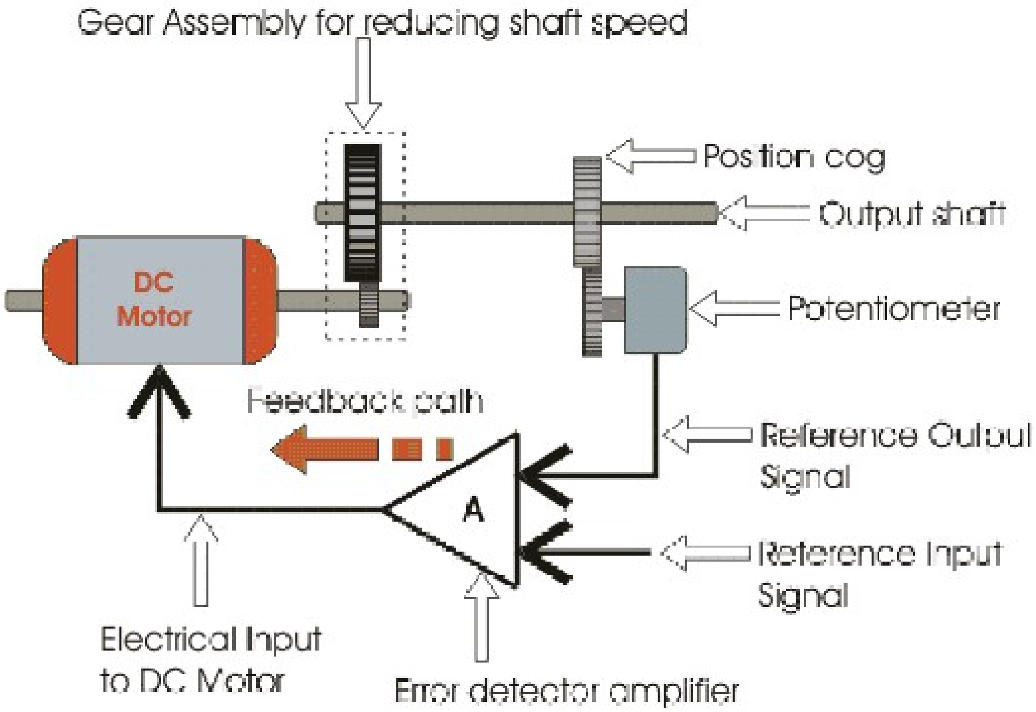
A stepper motor is made up of a **rotor**, which is normally a *permanent magnet*. A **stator** is another part which is in the form of *winding*.
The magnetic property of the stator changes and it will selectively attract and repel the rotor, thereby resulting in a stepping motion for the motor.
In order to get correct motion of the motor, a **stepping sequence** has to be followed. This stepping sequence gives the *voltage that must be applied to the stator phase*.
Normally a 4 step sequence is followed. When the sequence is followed from step 1 to 4, we get a **clock wise rotation** and when it is followed from step 4 to 1, we get a **counter clockwise rotation**.



X	$\overline{X}$	Y	$\overline{Y}$
0	1	0	1
1	0	0	1
1	0	1	0
0	1	1	0

Servo

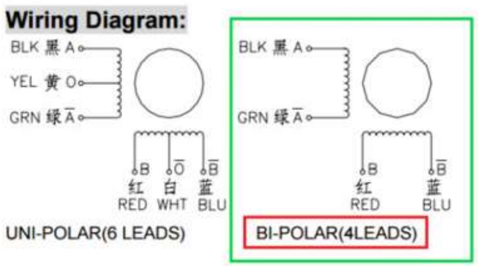
A servo system mainly consists of a **small DC motor**, a **potentiometer**, **gear arrangement** and a **feedback system.**



- The device is controlled by a feedback signal generated by comparing output signal and reference input signal. Hence, the primary task of a servomechanism is to **maintain the output of a system at the desired value** in the presence of disturbances.
- *During rotation of the shaft, the knob of the potentiometer also rotates* and creates an **varying electrical potential that is taken to the error detector feedback amplifier** along with the input reference commands i.e. input signal voltage.
- The gear mechanism is used to **step down the high rpm of the motor shaft to low rpm at the output shaft** of the servo system (small DC motor will rotate with high speed but the torque generated by its rotation will not be enough to move even a light load).

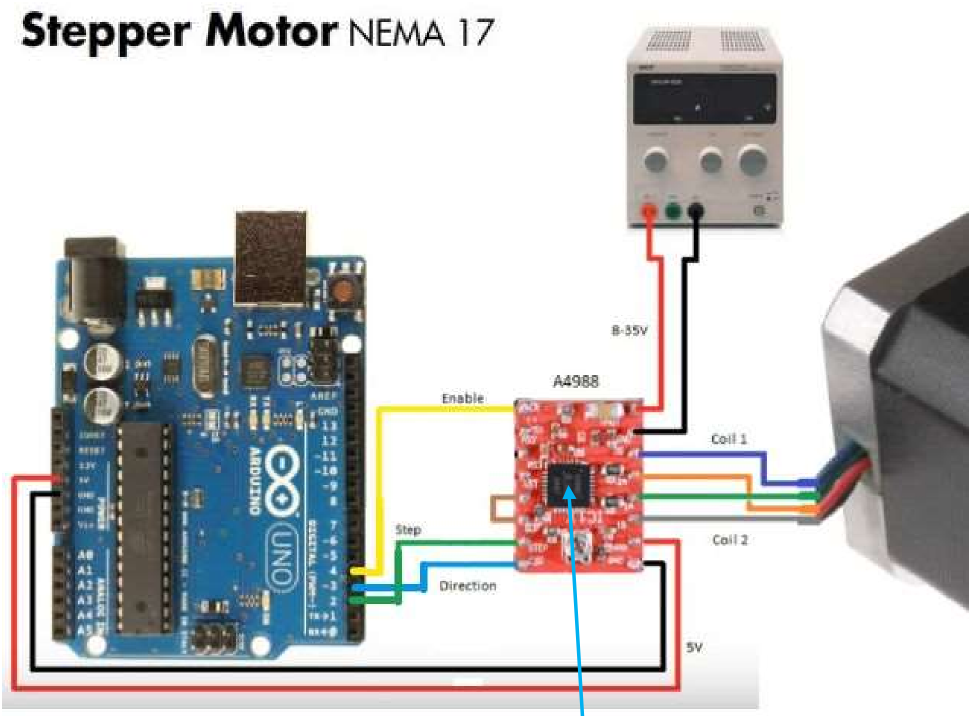
Esempio

17HS series-Size 42mm(1.8 degree)



Electrical Specifications:

Series Model	Step Angle (deg)	Motor Length (mm)	Rated Current (A)	Phase Resistance (ohm)	Phase Inductance (mH)	Holding Torque (N.cm Min)	Detent Torque (N.cm Max)	Rotor Inertia (g.cm²)	Lead Wire (No.)	Motor Weight (g)
17HS2408	1.8	28	0.6	8	10	12	1.6	34	4	150
17HS3401	1.8	34	1.3	2.4	2.8	28	1.6	34	4	220
17HS3410	1.8	34	1.7	1.2	1.8	28	1.6	34	4	220
17HS3430	1.8	34	0.4	30	35	28	1.6	34	4	220
17HS3630	1.8	34	0.4	30	18	21	1.6	34	6	220
17HS3616	1.8	34	0.16	75	40	14	1.6	34	6	220
17HS4401	1.8	40	1.7	1.5	2.8	40	2.2	54	4	280
17HS4402	1.8	40	1.3	2.5	5.0	40	2.2	54	4	280
17HS4602	1.8	40	1.2	3.2	2.8	28	2.2	54	6	280
17HS4630	1.8	40	0.4	30	28	28	2.2	54	6	280
17HS8401	1.8	48	1.7	1.8	3.2	52	2.6	68	4	350
17HS8402	1.8	48	1.3	3.2	5.5	52	2.6	68	4	350
17HS8403	1.8	48	2.3	1.2	1.6	46	2.6	68	4	350
17HS8630	1.8	48	0.4	30	38	34	2.6	68	6	350



A4988
Driver

Actuation

A4988

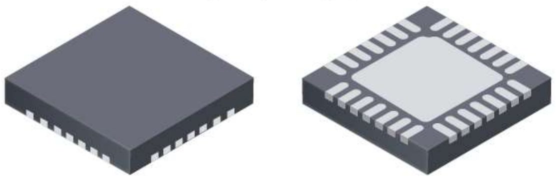
DMOS Microstepping Driver with Translator And Overcurrent Protection

Features and Benefits

- Low $R_{DS(ON)}$ outputs
- Automatic current decay mode detection/selection
- Mixed and Slow current decay modes
- Synchronous rectification for low power dissipation
- Internal UVLO
- Crossover-current protection
- 3.3 and 5 V compatible logic supply
- Thermal shutdown circuitry
- Short-to-ground protection
- Shorted load protection
- Five selectable step modes: full, $^1/_2$, $^1/_4$, $^1/_8$, and $^1/_{16}$

Package:

28-contact QFN
with exposed thermal pad
5 mm × 5 mm × 0.90 mm
(ET package)



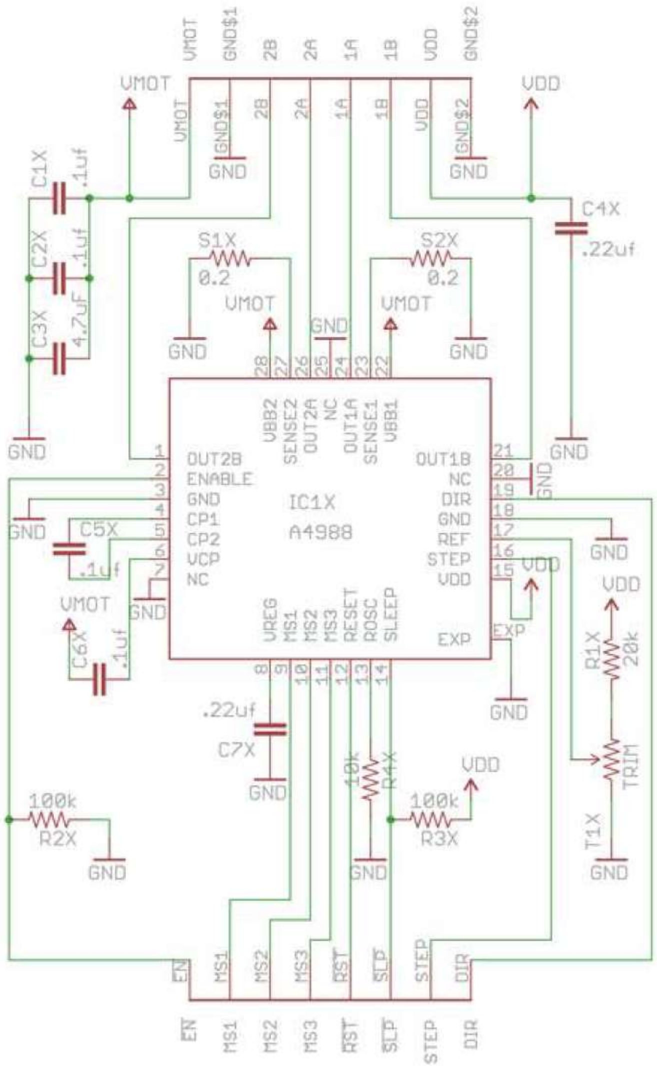
Description

The A4988 is a complete microstepping motor driver with built-in translator for easy operation. It is designed to operate bipolar stepper motors in full-, half-, quarter-, eighth-, and sixteenth-step modes, with an output drive capacity of up to 35 V and ±2 A. The A4988 includes a fixed off-time current regulator which has the ability to operate in Slow or Mixed decay modes.

The translator is the key to the easy implementation of the A4988. Simply inputting one pulse on the STEP input drives the motor one microstep. There are no phase sequence tables, high frequency control lines, or complex interfaces to program. The A4988 interface is an ideal fit for applications where a complex microprocessor is unavailable or is overburdened.

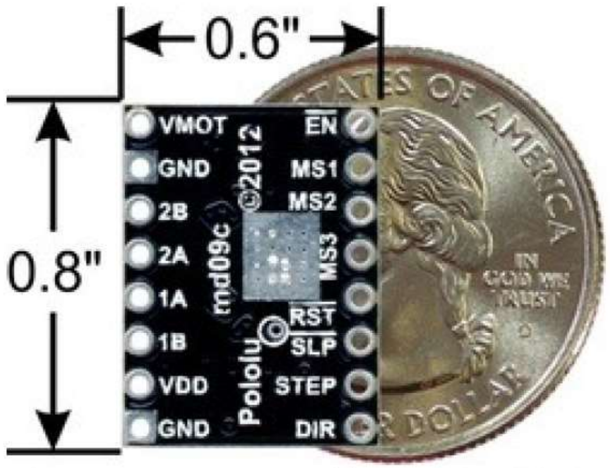
During stepping operation, the chopping control in the A4988 automatically selects the current decay mode, Slow or Mixed. In Mixed decay mode, the device is set initially to a fast decay for a proportion of the fixed off-time, then to a slow decay for the remainder of the off-time. Mixed decay current control results in reduced audible motor noise, increased step accuracy, and reduced power dissipation.

Actuation



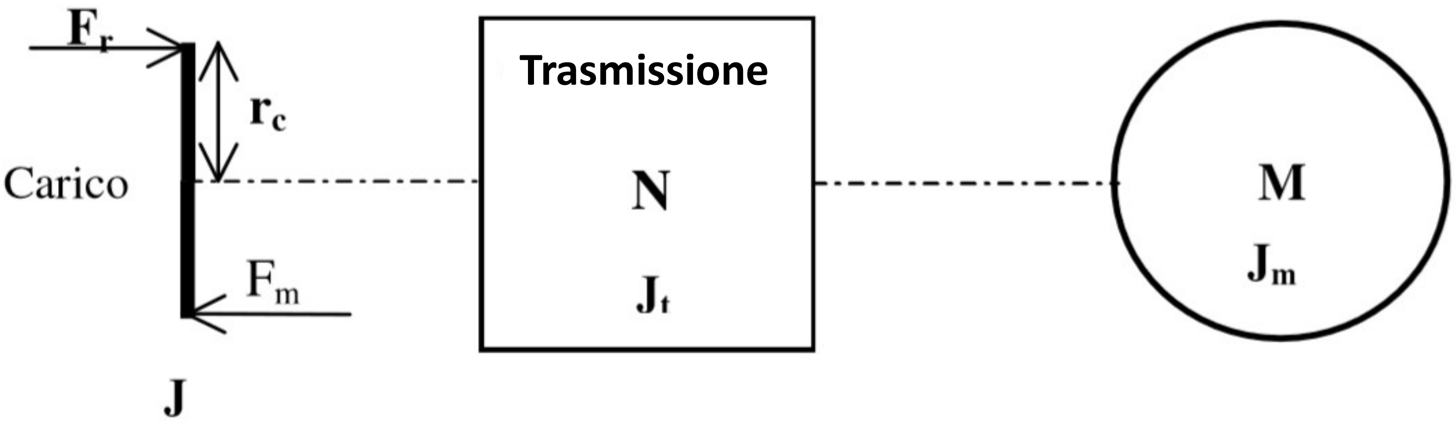
Robotics & Electronics

A4988 Stepper Motor Driver Carrier, Black Edition



A4988 stepper motor driver carrier, Black Edition, bottom view with dimensions.

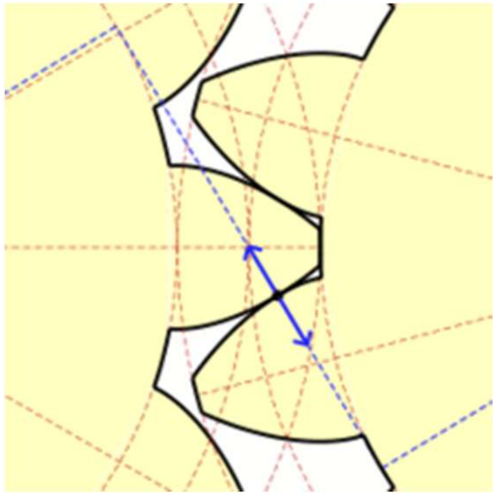
Catena Cinematica



Tutti I dispositivi interposti tra l'asse del motore (M) e l'oggetto movimentanto (carico), prendono il nome di **catena cinematica.**
J sono i relativi momenti di inerzia

$$\boldsymbol{T_{motrice\_tot}} > \underbrace{T_{carico} + T_{inerzia} + T_{attrito}}_{\text{Coppie resistenti}}$$

Trasmissione



Un ingranaggio è un meccanismo utilizzato per trasmettere un momento meccanico da un oggetto a un altro.

Generalmente è costituito da due o più **ruote dentate**, che possono essere di uguale o diversa dimensione. La ruota più piccola è comunemente chiamata *pignone*, mentre la grande è chiamata *corona*.

Ruote di diversa dimensione sono spesso usate **in coppia** per *aumentare il momento meccanico riducendo nel contempo la velocità angolare, o viceversa* aumentare la velocità diminuendo il momento.

Rapporto di trasmissione $\tau = \frac{\omega_2}{\omega_1}$

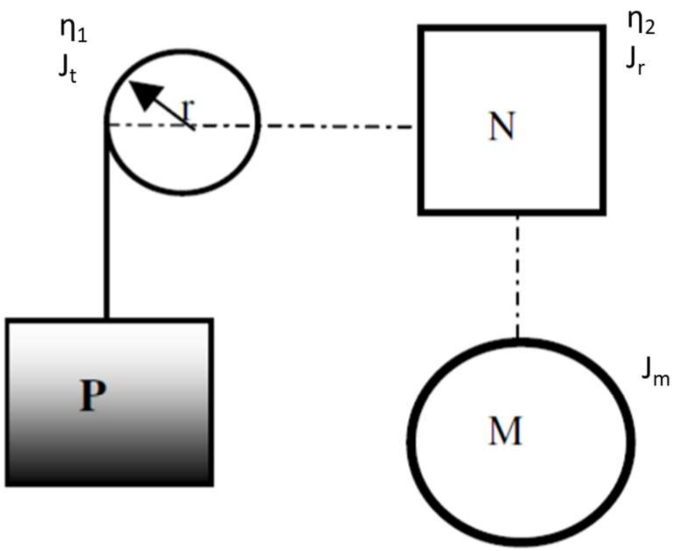
Rendimento Meccanico $\eta = P_{out}/P_{in}$

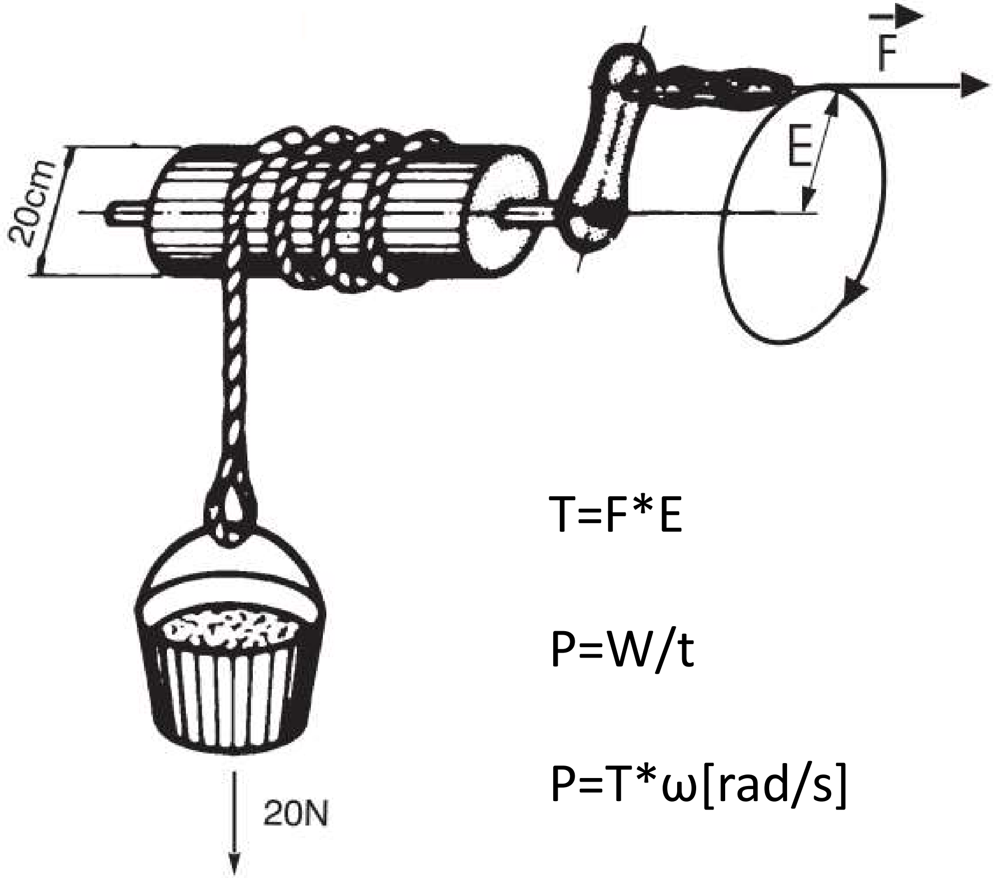
Moto traslatorio

Meccanismi che consentono la conversione del moto rotatorio in traslatorio:

- fune-tamburo
- cinghia-puleggia
- Vite a circolazione di sfere
- Pignone-cremagliera

Fune-tamburo





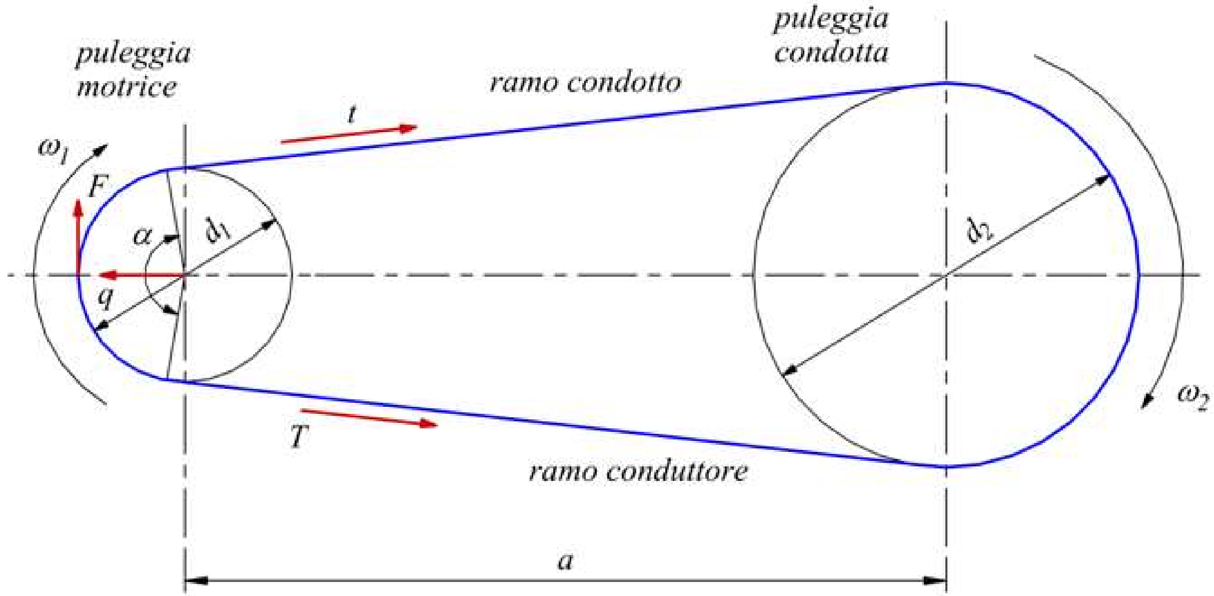
T=F*E

P=W/t

P=T*ω[rad/s]

Transmission

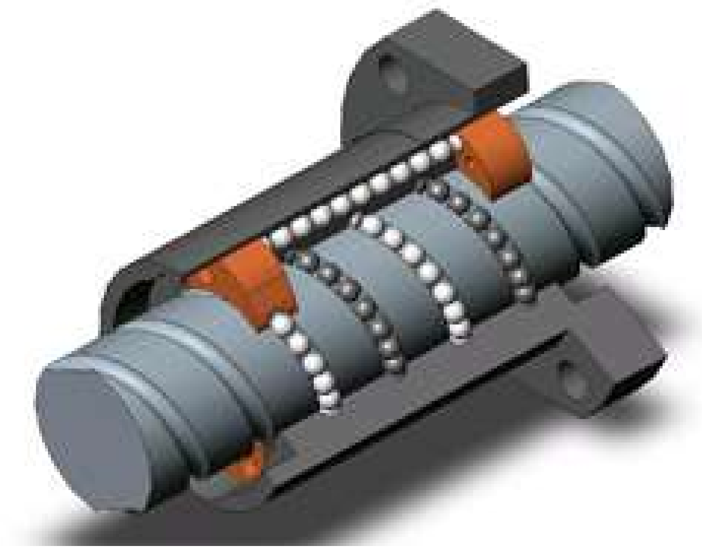
Cinghia-Puleggia



Rapporto di trasmissione

$$\tau = \frac{\omega_2}{\omega_1} = \frac{d_1}{d_2}$$

Vite a ricircolo di sfere

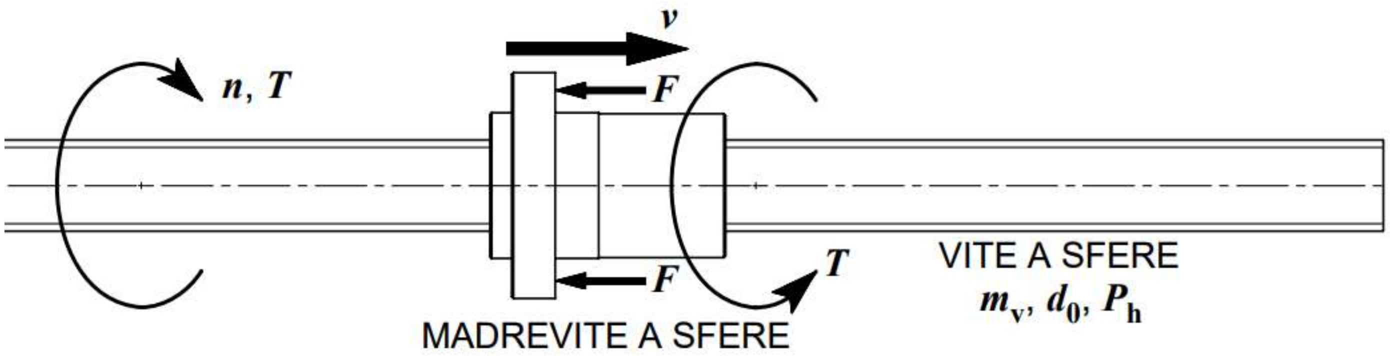


Una vite a ricircolo di sfere è un sistema a rotolamento composto da un **albero con filetto** a profilo e da una **madrevite** che, anch'essa filettata internamente secondo un profilo, contiene un numero determinato di **sfere**.

Il recupero delle sfere che durante il rotolamento effettuano un percorso all'interno della madrevite, è consentito da uno o più elementi meccanici denominati **deflettori**.

Il funzionamento delle viti a ricircolo di sfere si basa sull'azione di **rotolamento delle sfere** interposte tra l'albero filettato e la madrevite, che *trasforma il movimento rotatorio dell'albero in rettilineo (della madrevite), e viceversa, producendo un minor attrito* e *massimizzando l'efficacia* nelle applicazioni che richiedono elevati livelli di precisione.

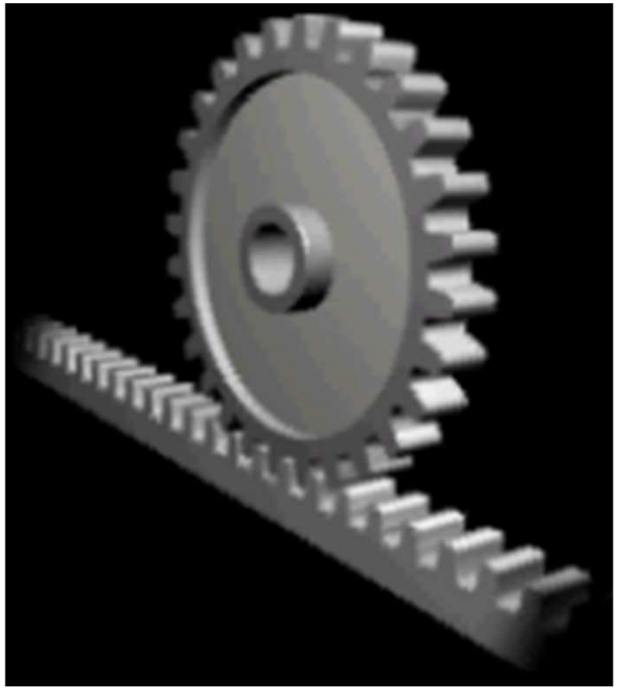
Vite a ricircolo di sfere (2)



$$T = \frac{F \times P_h}{2 \times \pi} \times \frac{1}{\eta}$$

conversione giri/min -> mm/min, considerando il passo della vite (mm/giro)

Pignone-Cremagliera



La cremagliera è una **ruota cilindrica degenere** (raggio infinito), utilizzata in coppia con un'altra **ruota non degenere** che avendo **raggio minore** del suo fa sempre da pignone (o rocchetto).

La velocità di traslazione della cremagliera è uguale a quella di un punto della primitiva della ruota dentata che la muove.

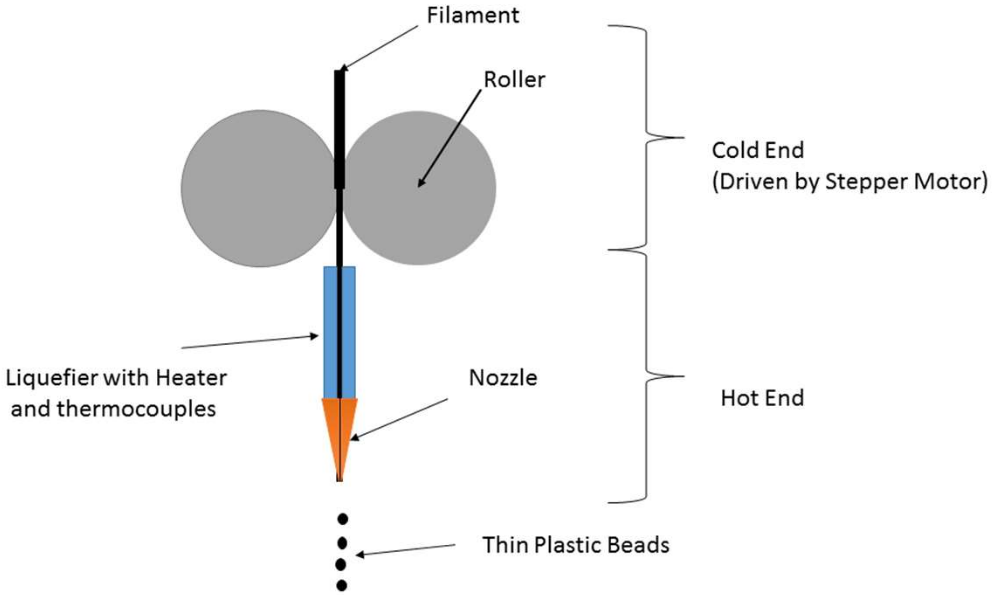
Rapid Prototyping

Rapid prototyping is a group of techniques used to quickly fabricate a scale model of a physical part or assembly using three-dimensional computer aided design (CAD) data. Construction of the part or assembly is usually done using 3D printing or "**additive layer manufacturing**" technology.

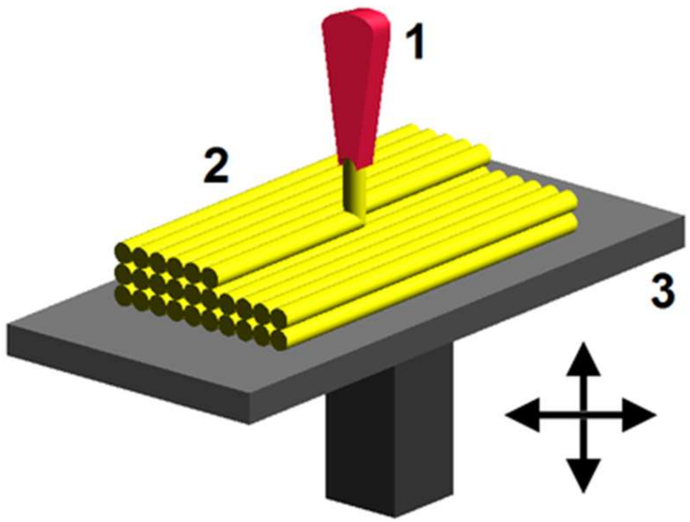
- 3D printing (3DP) -> printing of a binder material onto a powder bed with **inkjet printer** heads
- Fused deposition modeling (FDM)
- Laminated object manufacturing (LOM)
- Stereo lithography (STL)
- Selective laser sintering (SLS)

FDM

Manufacturing

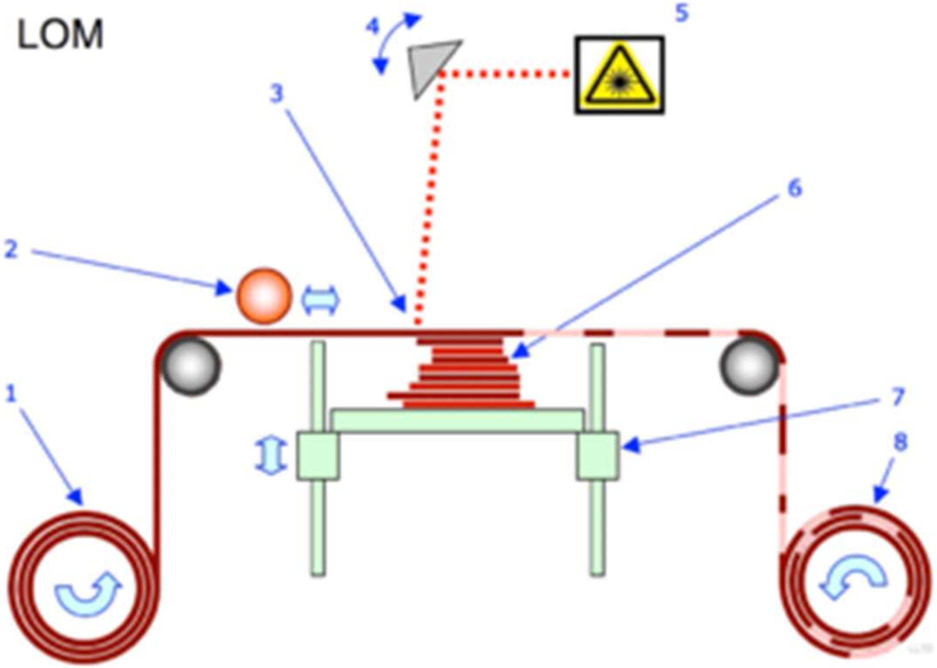


3-D Printer Extruder



thermoplastics such as *acrylonitrile butadiene styrene* (ABS), *polylactic acid* (PLA), *high-impact polystyrene* (HIPS), *thermoplastic polyurethane* (TPU), *aliphatic polyamides* (nylon)

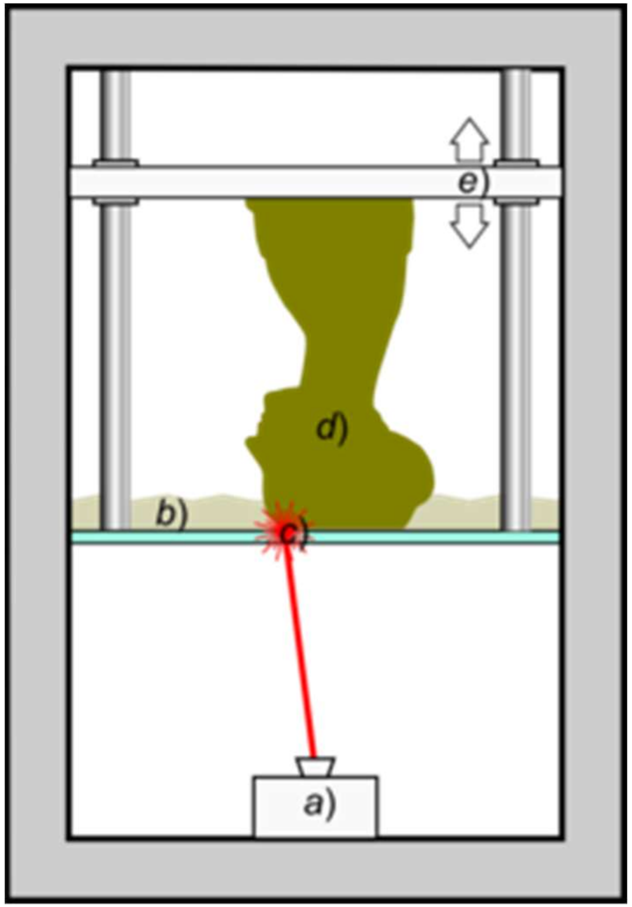
LOM



layers of adhesive-coated paper, plastic, or metal laminates are successively glued together and cut to shape with a knife or laser cutter

Manufacturing

STL

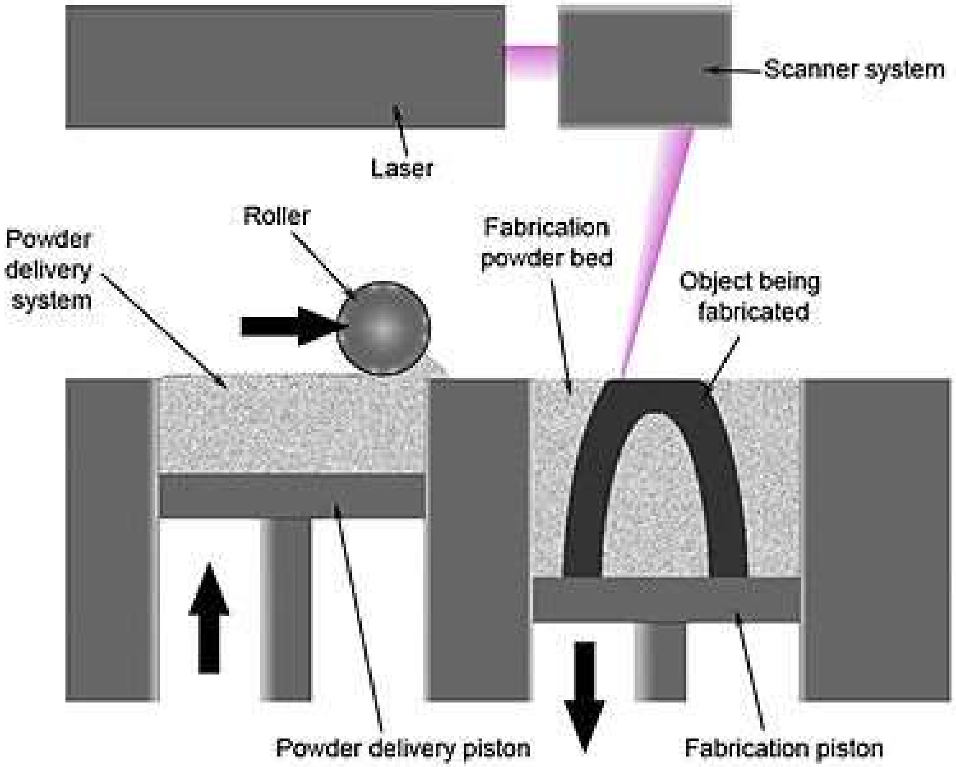


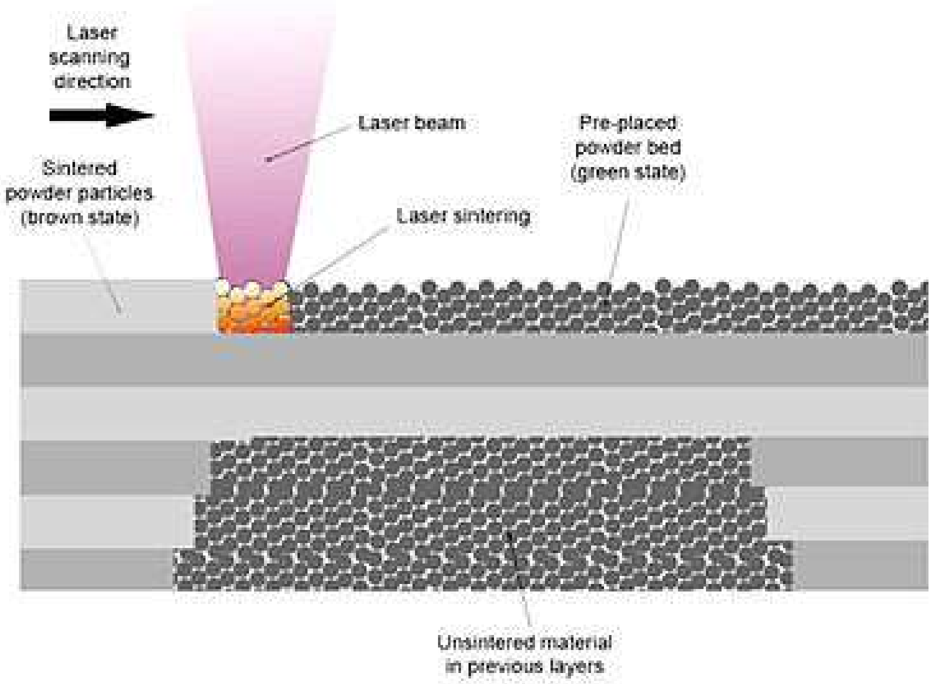
Stereolytography works by focusing an **UV laser** on to a vat of **photopolymer resin**. The UV laser is used to draw a pre-programmed design or shape on to the surface of the photopolymer vat.

Then, the build platform lowers one layer and a blade recoats the top of the tank with resin.

This process is repeated for each layer of the design until the 3D object is complete. Completed parts must be washed with a solvent to clean wet resin off their surfaces.

SLS


Scanner system
Laser
Roller
Powder
delivery
system
Fabrication
powder bed
Object being
fabricated
Powder delivery piston
Fabrication piston

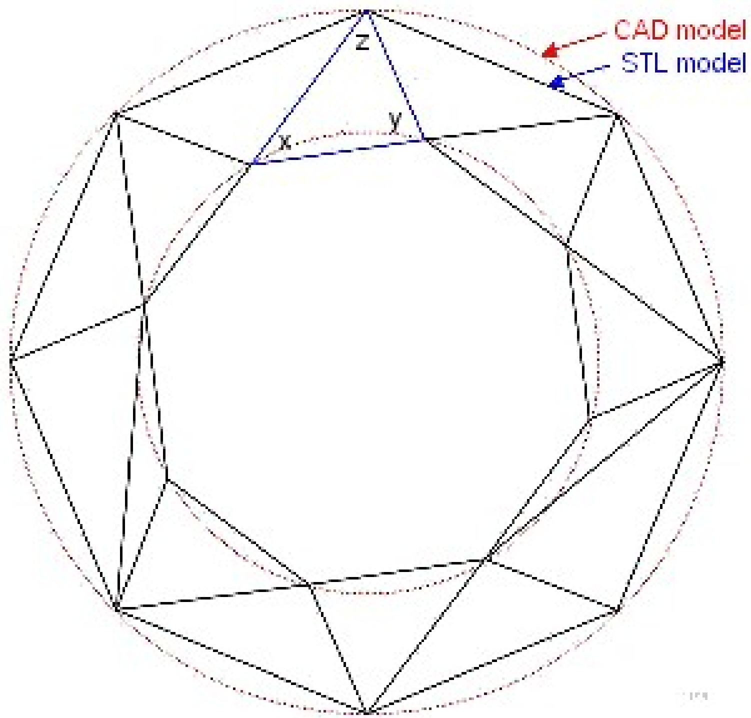

Laser
scanning
direction
Laser beam
Pre-placed
powder bed
(green state)
Sintered
powder particles
(brown state)
Laser sintering
Unsintered material
in previous layers

Manufacturing

Work Flow

1. File CAD
2. File STL
3. G-code

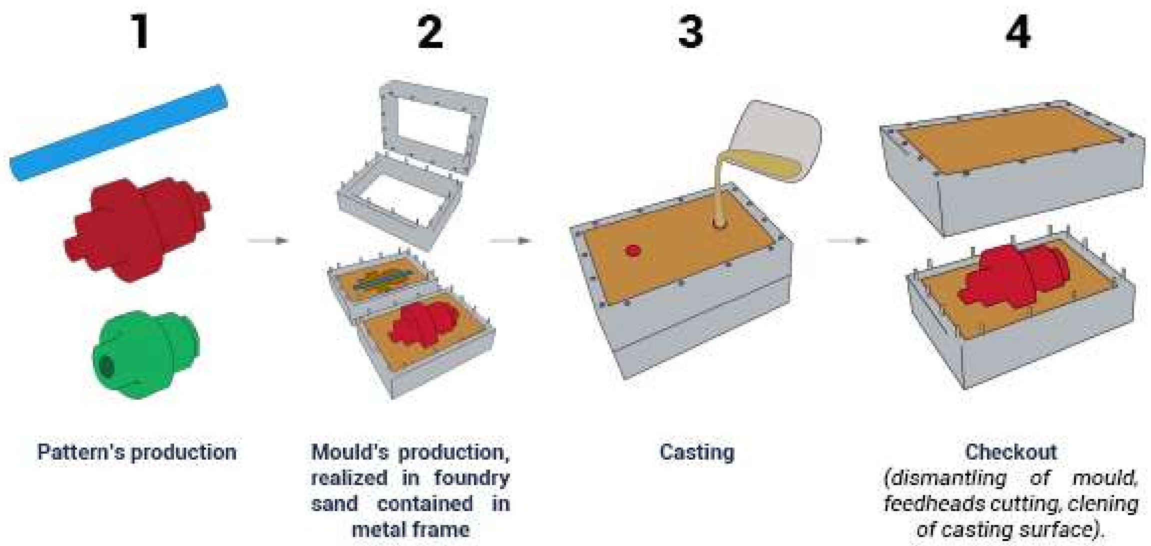
Slic3r



STL: Standard Triangle Language -> STL file describes a raw, *unstructured triangulated surface* by the unit normal and vertices;

G-code is a language in which people tell computerized machine tools how to make something. The "how" is defined by g-code *instructions provided to a machine controller* (industrial computer) that tells the motors where to move, how fast to move, and what path to follow

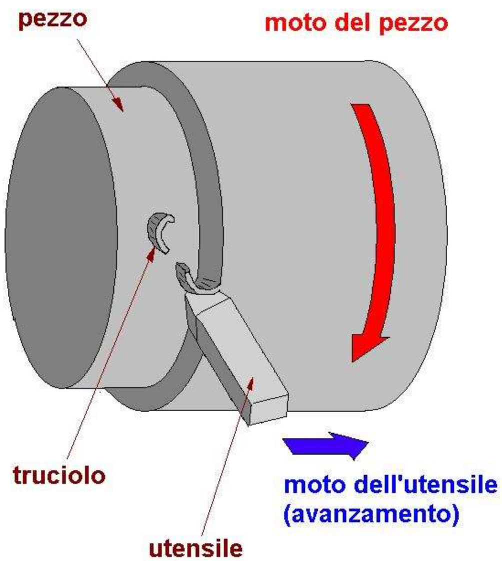
Manufacturing tecniques

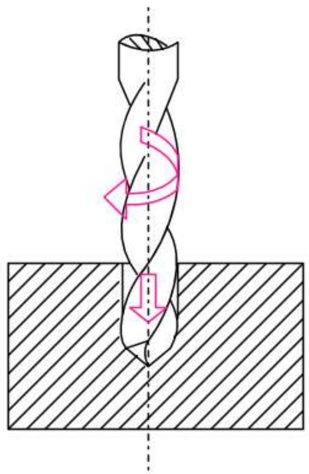


- **Casting** : Casting is a manufacturing process in which a liquid material is usually poured into a mold, which contains a hollow cavity of the desired shape, and then allowed to solidify.
- **Additive manufacturing**
- **Subtractive manufacturing** : Machining is any of various processes in which a piece of raw material is cut into a desired final shape and size by a controlled material-removal process.

Subtractive manufacturing

- **Turning** (tornitura): a cutting tool with a single cutting edge is used to remove material from a rotating workpiece to generate a cylindrical shape.
- **Drilling** (foratura) is used to create a round hole. It is accomplished by a rotating tool that typically has two or four helical cutting edges
- In **milling** (fresatura), a rotating tool with multiple cutting edges is moved slowly relative to the material to generate a plane or straight surface. The direction of the feed motion is perpendicular to the tool's axis of rotation. The speed motion is provided by the rotating milling cutter.





Manufacturing

CNC Machining

Computer numerical control (CNC) is the **automation of machine tools** by means of computers executing pre-programmed sequences of machine control commands. This is in contrast to machines that are manually controlled by hand wheels or levers.

The parts are defined using **computer-aided design (CAD)** software, and then translated into manufacturing directives by **computer-aided manufacturing (CAM)** software. The resulting directives are transformed (by "post processor" software) into the specific commands necessary for a particular machine to produce the component, and then are loaded into the CNC machine.

Manufacturing

Material Classes

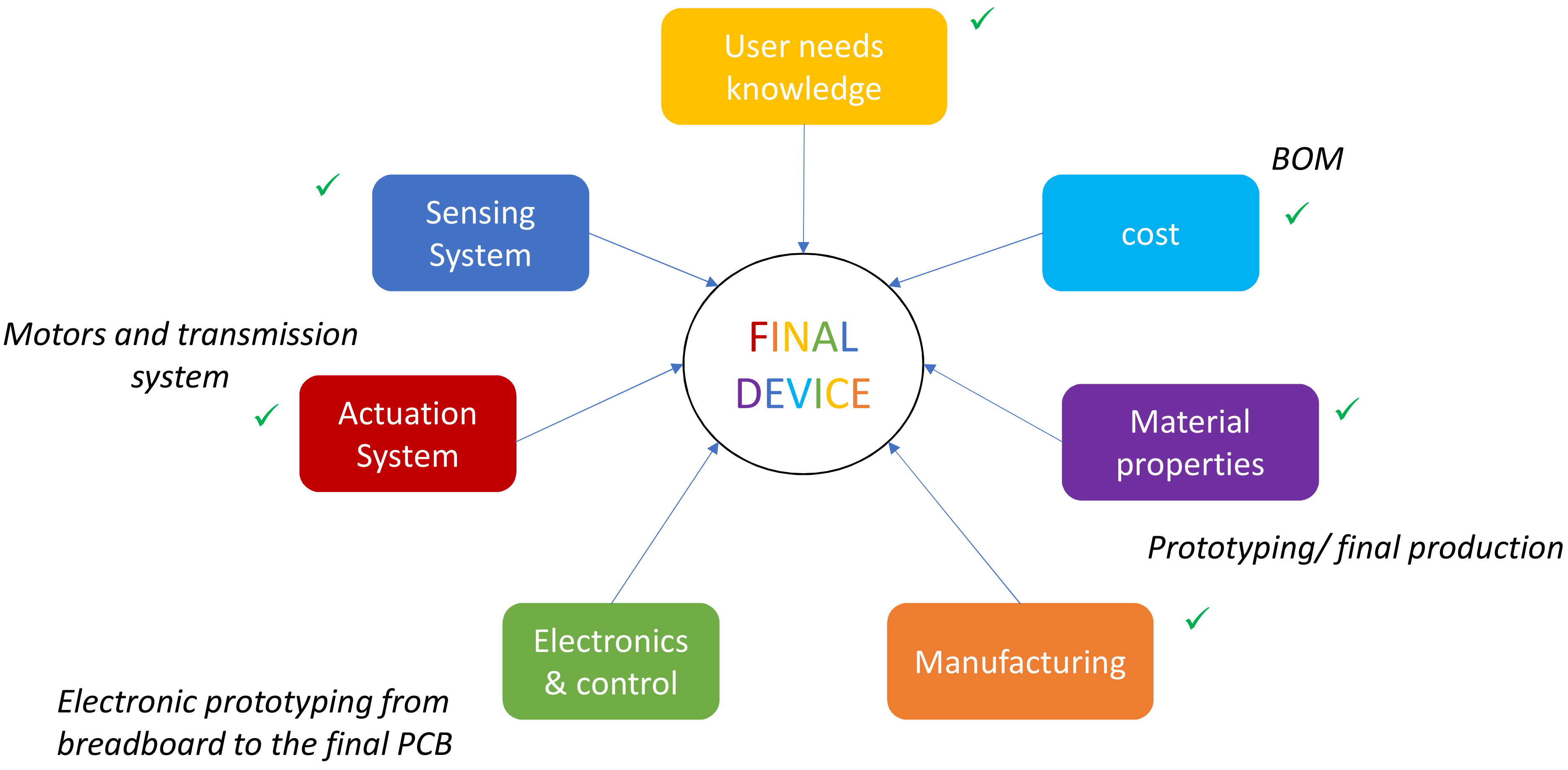
- Metals: aluminum, steel -> sintering, casting, machining
  corrosion, mechanical strength, magnetic properties

- Polymers: ABS, PVA, PLA, PC (thermoplastic) -> FDM, casting, machining
  Teflon, Delrin -> machining
  mechanical strength, transparency

- Ceramics and glass -> sintering, casting
  mechanical strength, transparency

Others: sterilisability, biocompatibility, weight, machinability, cost

Design of innovative testing systems



Esercitazione LAB1

Immaginando di dover progettare un sistema di testing meccanico per tessuti molli (sensore deformazione/forza + attuatore + trasmissione):

- identificare sensori e motori adeguati (considerando almeno un dispositivo basato su materiali intelligenti) per l'applicazione e riassumerne le proprietà rilevanti (range lavoro, risoluzione, ingombro, *marca & modello, fornitore & codice fornitore, costo, disponibilità*)
- Calcolare coppia motrice (considerando ad esempio una vite a ricircolo di sfere come trasmissione)
- Identificare materiali/tecniche prototipazione e per il prodotto finito (per la struttura di supporto del sistema)

Esercitazioni

Gruppo	1	2	3	4	5	6	7	8	9	10	11
1.03 Proprietà Materiali	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
8.03 Polymers&Hydrogels	ok	ok	ok	ok	ok	ok	ok+	ok	ok+	ok	ok
15.03 Piezoelectrics	ok+	ok	ok	ok	ok	ok	ok	ok+	ok	ok	ok+
28.03 MR	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
29.03 SMA	ok	ok	ok?	ok	ok	ok	ok	ok	ok	ok	ok

Legenda: ok+ ok ok-