Introduction

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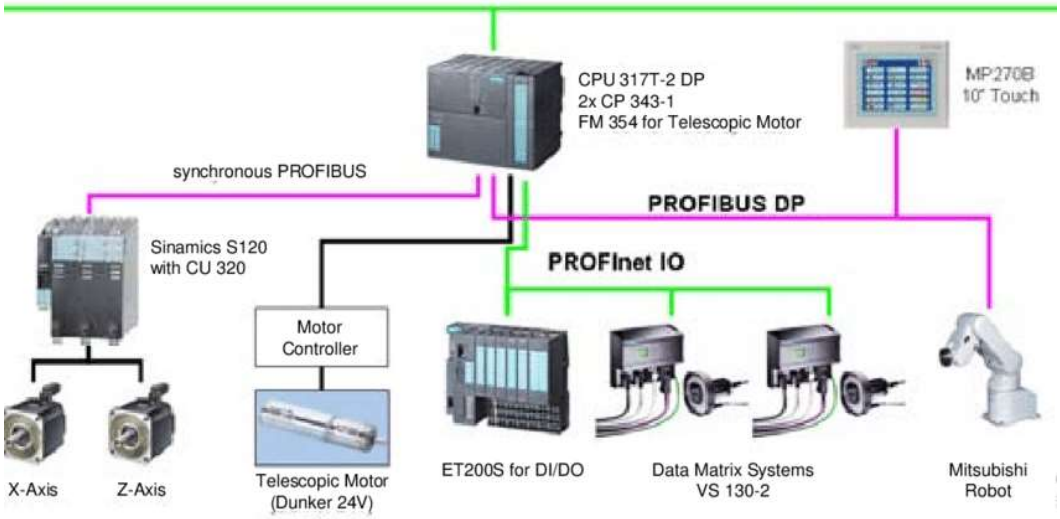
Automation system



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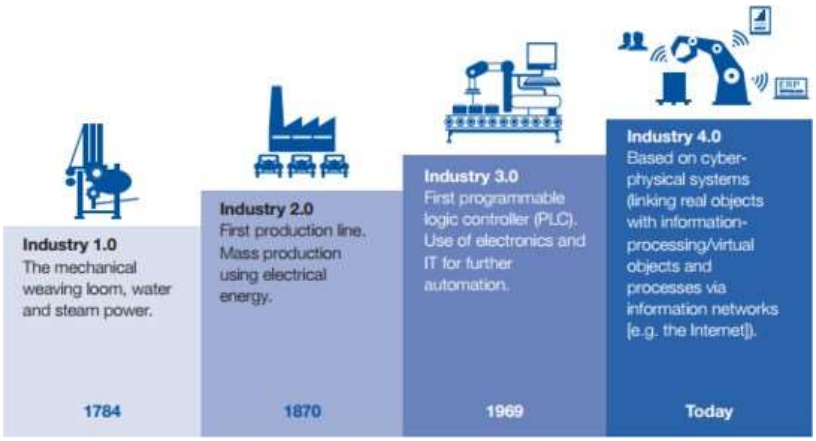
INDUSTRY 4.0



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INDUSTRY 4.0

2017: we enter Industry 4.0, in which **computers** and **automation** will come together in an entirely new way, with **robotics** connected **remotely** to computer systems equipped with **machine learning** algorithms that can learn and control the robotics with very little input from human operators.

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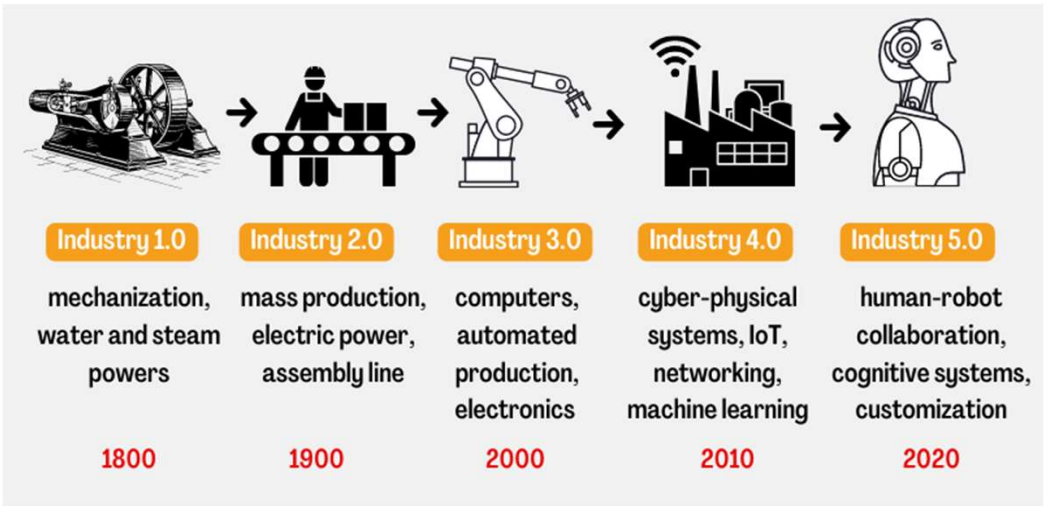
Industry 4.0 introduces what has been called the "**smart factory**," in which **cyber-physical systems monitor** the physical processes of the factory and make decentralized **decisions**. The physical systems become **Internet of Things**, communicating and **cooperating** both with each other and with **humans** in real time via the **wireless web**.

Industry 5.0

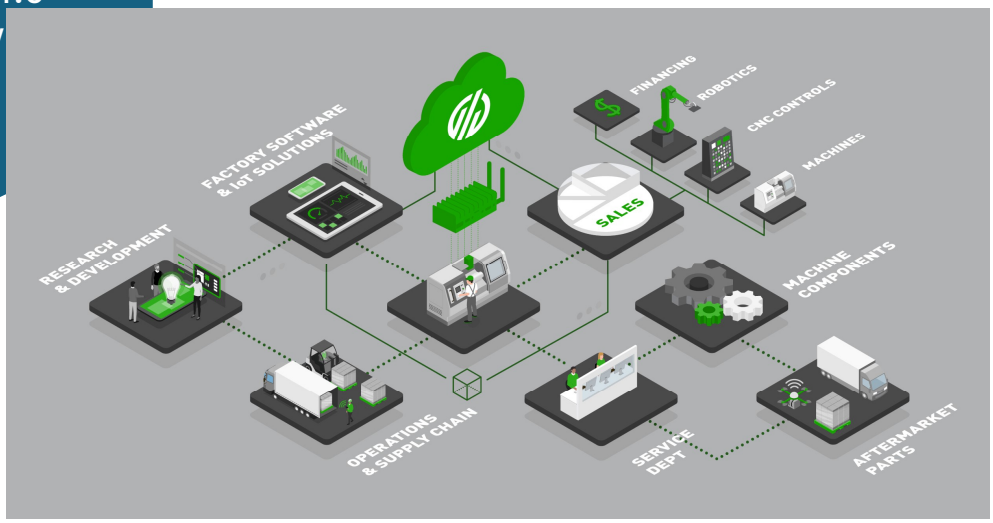


Source: https://knowhow.distrelec.com/manufacturing/is-your-business-ready-for-industry-5-0/

Industry 4.0 Overview

https://onlinelibrary.wiley.com/doi/10.1155/2022/2845446

Industry 4.0 Overview



https://www.machinemetrics.com/blog/industry-4-0-technologies

Sensors and Actuators

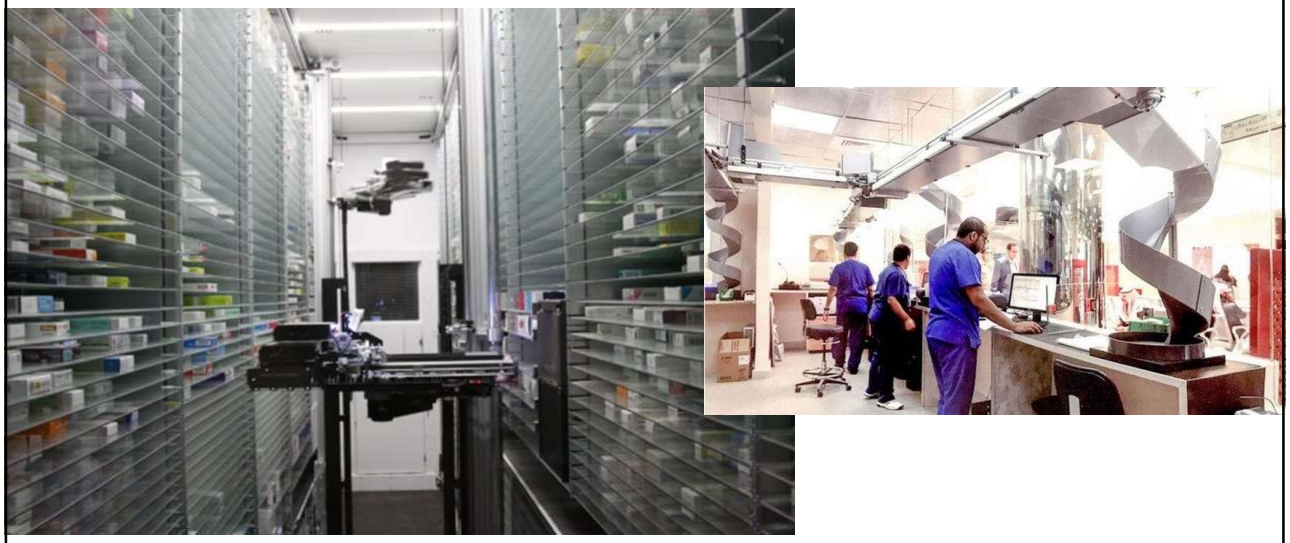
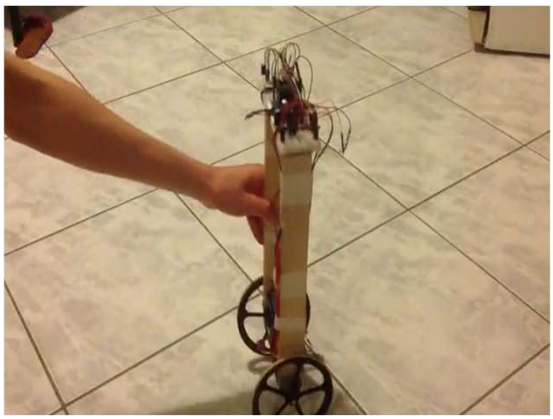


Fig: Smart Pharmacy.

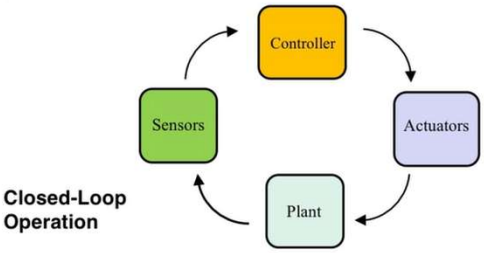
Inverted Pendulum robot



- **IMU sensor**
  - Combination of Accelerometer and Gyros
  - feedback control loop.
  - Noise

Sensor

- Sensors are critical devices in any mechatronic system that enable **feedback control**
  - Without sensors, all actuator control would need to be **open-loop**
- Sensors enable system to **respond to external stimuli**



Closed-Loop Operation

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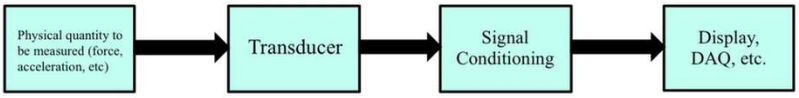
Transducers

- **Transducer** is active element of a sensor that converts **physical quantity** to **electrical signal**
  - Oftentimes requires signal conditioning for electrical signal to be useful



- Many sensors are transducers, but not all (i.e., mercury thermometer, spring scale force sensor, etc.

Spring scale force sensor

Pressure sensors (gauges)

Pressure transducers

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Sensor vs Transducer

SENSOR	TRANSDSUCER
SENSOR IS A DEVICE WHICH SENSE PHYSICAL VARIABLES LIKE TEMPERATURE / PRESSURE / LIGHT AND MANY MORE ... AND GIVES OUTPUT IN A MEASURABLE FORMAT .	TRANSDUCER IS A DEVICE WHICH CONVERTS ONE FORM OF ENERGY INTO ANOTHER FORM MAINLY OUTPUT IS IN ELECTRICAL OR ELECTRONICS FORMAT .
SENSOR CONSIST OF SENSING ELEMENT ONLY	TRANSDUCER CONSIST OF SENSING ELEMENT AND TRANSDUCTION ELEMENT WHICH HELPS IN CONVERSION OF ENRGY .
FOR EXAMPLE PRESSURE SENSOR	FOR EXAMPLE PRESSURE TRANSDUCER (STRAIN GUAGE)

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Sensors

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Analog vs Digital Sensors

- **Analog sensors** provide output as continuous quantity
  - Usually **analog voltage**, but can also be resistance, capacitance, etc.
- **Digital sensors** provide digital output data
  - Serial output (UART, RS-232, I2C, SPI, etc)

TI LM335 Analog Temperature Sensor

Output signal: Analog voltage

TI TMP117 Digital Temperature Sensor

Output signal: I2C

Courtesy of Texas Instruments

Fig: UART serial.

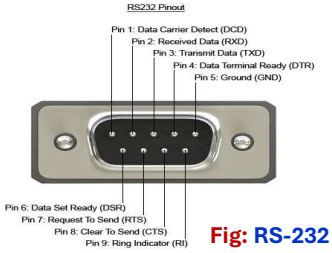


Fig: RS-232 protocol.

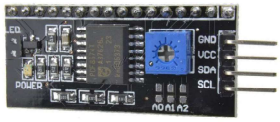


Fig: I2C module.

Scalar vs. Vector Sensors

- **Scalar Sensor:** Measures a magnitude (single value), e.g., temperature, pressure.
- **Vector Sensor:** Measures both magnitude and direction, e.g., force, velocity.

- **Scalar Sensors:** Ideal for ambient conditions and non-directional phenomena.
- **Vector Sensors:** Essential in dynamic systems requiring orientation and force analysis.

• Key Differences:

Aspect	Scalar Sensor	Vector Sensor
Nature of Data	Single-dimensional	Multi-dimensional
Examples	Thermometer, Barometer	Accelerometer, Gyroscope
Use Cases	Climate monitoring, pressure measurements	Robotics, navigation systems

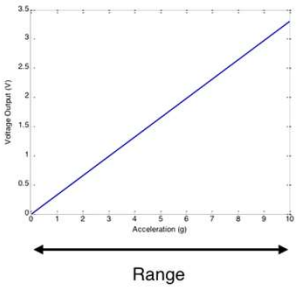
Sensor Characteristics

- Understanding **sensor characteristics** is extremely important during design of mechatronic systems
  - Selection of sensor with poor characteristics for desired application will lead to bad performance
- Key performance specifications include **range, accuracy, sensitivity, resolution, noise characteristics**

Range

- **Sensor Range:** Range of physical quantity that can be detected by sensor
  - Related to output range of sensor by **sensitivity**

Example: Accelerometer with range of 0-10 g and sensitivity of 330 mv/g.



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Accuracy

- **Sensor Accuracy:** Difference between true and measured value is sensor accuracy
  - Usually expressed as percentage of full-scale (FS) maximum value
  - Can be improved through **calibration**

Example: At 77 deg F, LM34A temperature sensor has an accuracy of ± 0.4 deg F.

Courtesy of Texas Instruments

– Range 0 to 200^{0}C, accuracy ±5%, means result is expected to lie within + or -10^{0}C

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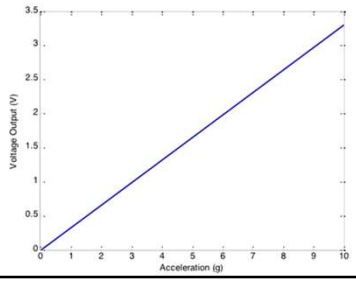
Sensitivity: It is the relationship indicating how much output there is per unit input

- **Sensor Sensitivity:** Relationship between measured input and output of sensor
  - If sensor response is *linear*, then sensitivity is slope of line relating input to output

Sensitivity of this notional accelerometer is **330 mV/g**.



- **Error:** The difference between the result of the measurement and the true value of the quantity being measured.

Error = measured value - true value

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Resolution

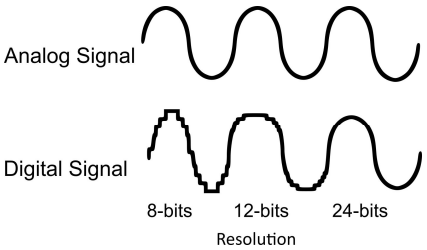
It is the smallest change that can be detected in the quantity that it is being measured.

- **Sensor Resolution**: Smallest change in input that will produce observable change in output value
  - Most analog sensors don't really have resolution. Resolution depends on configuration of analog-to-digital converter (ADC)
  - Sensors with digital outputs will always list resolution

TI TMP117 Digital Temperature Sensor

Resolution: **0.0078 deg C** (from datasheet)

Courtesy of Texas Instruments



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- **Repeatability or reproducibility:**

The terms repeatability and reproducibility of a transducer are used to describe its ability to give the same output for repeated applications of the same input value.

- Usually expressed as a percentage of the full range output

$$\text{repeatability} = \frac{\text{max.} - \text{min. values given}}{\text{full range}} \times 100$$

A transducer for the measurement of angular velocity meter has a repeatability of ± 0.01 % of the full range at a particular angular velocity.

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Noise

- **Noise** is usually a random component of the sensor signal that perturbs the signal from its true value
- Noise effects can be mitigated through **filtering**
- **Signal-to-noise ratio** is ratio of signal power to power of background noise

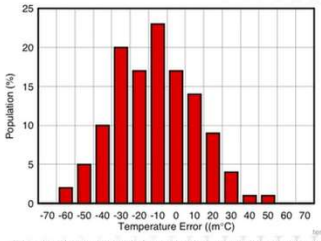
$$SNR = \frac{P_{\text{signal}}}{P_{\text{noise}}}$$

(usually measured in dB)

Poor signal-to-noise ratio from a sensor may lead to performance problems, where a system is reacting to noise rather than value signal.

TMP117 Temperature error distribution due to noise at 25 deg C

Courtesy of Texas Instruments



T_A = 25 °C. V+ = 3.3 V. One-shot mode with averaging = 8.

Figure 7. Typical Temperature Distribution Error

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Performance terminology of sensors

- **Stability:** The stability of a transducer is its ability to give the **same output** when used to measure a constant **input over a period**.

- **Drift:** Used to describe the **change in output that occurs over time**.
- **Zero drift:** used to describe the changes that occur in output when there is zero input.

- **Dead band/time:** It is the range of input values of the transducer for which there is **no output**.

  Example: **bearing friction** in a flowmeter using a rotor might mean that there is no output until the input has reached a particular velocity threshold**.**
- **Dead time:** It is the length of time from the application of an input until the output begins to respond and change.

Actuators

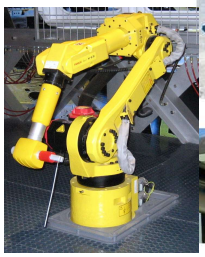
Actuators

Computers

Tools

Cars

Consumer Electronics



Stealth Bomber

High Speed Trains

Actuators are the devices that lead to the physical motion of the actuators itself, along with any attached components

- Car actuators differ from bullet train actuators.
- Robot wheelchair actuators differ from lens camera actuators.
- 3D printer actuators differ from Stewart platform actuators.

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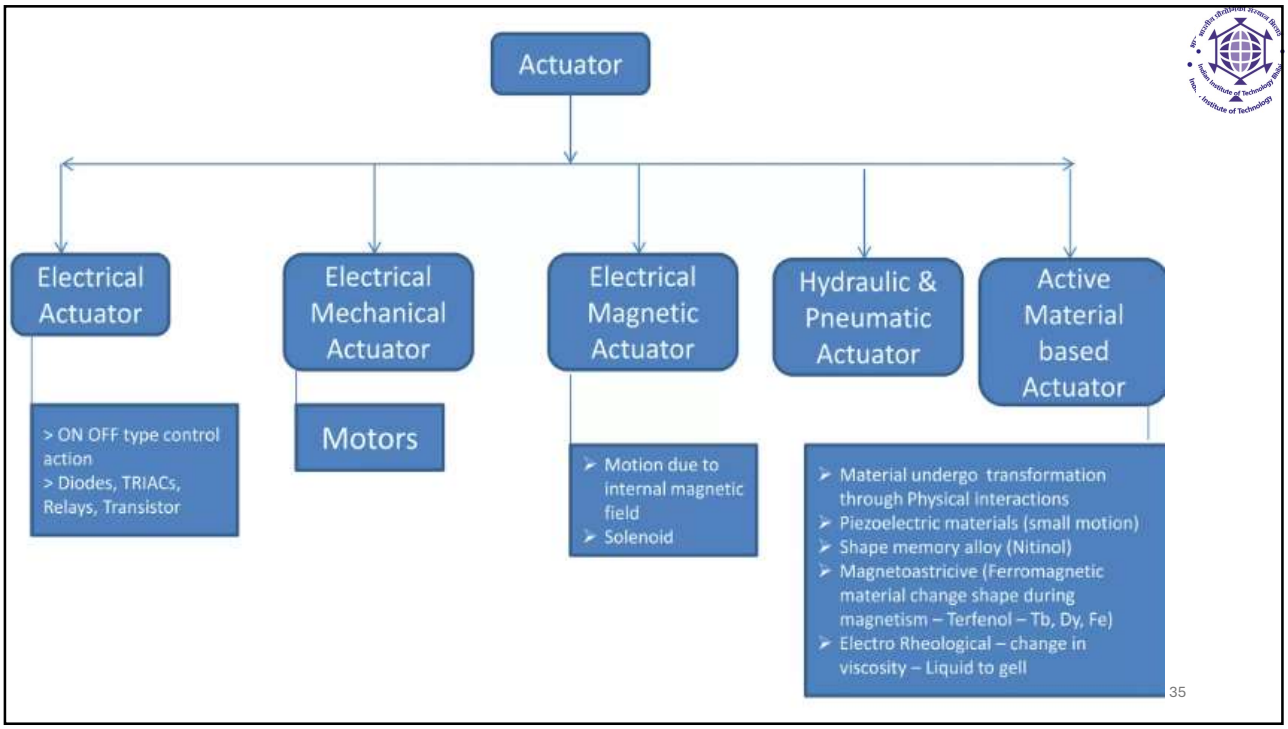

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Actuators

- The actuators used for mechatronics systems classified into two categories

Linear actuators

Linear actuators are the actuators that move in linear fashion.

Example: Roof opener, actuators of crane.

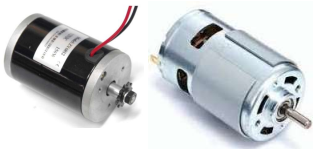
Rotary actuators

Rotary actuators are used to turn things in a circular fashion.
Example: Ceiling fan, actuators of robot arm joints.

Actuator types

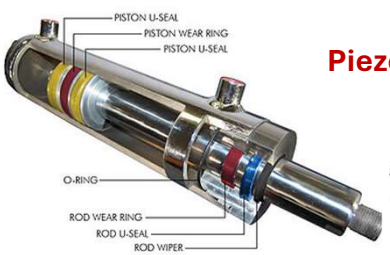
- Actuator needs to move objects.

Electric actuator: Works based on electro magnetic induction.

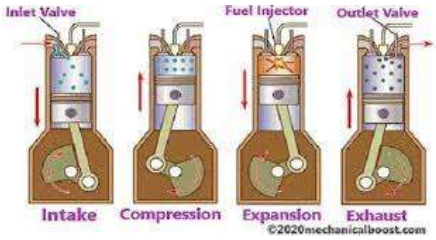


Servos, Stepper, Direct drive

Hydraulic: Pressurized fluid is used to actuate things.

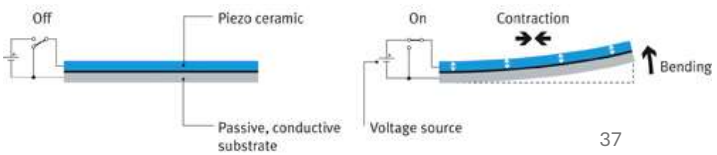


Internal Combustion: Burning of fuel is used to move the objects.

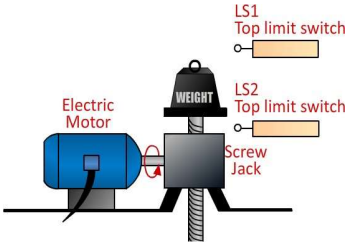


Pneumatic: Pressurized air to actuate

Piezoelectric: Piezoelectric effect is used to actuate.



Electrical Actuator



With an electrical system we have three basic choices;

- Solenoid,
- DC motor or
- AC induction motor.

Of these, the **Solenoid** produces a linear stroke directly but its stroke is normally limited to a maximum distance of around **100** mm.

Both **DC and AC motors** are rotary devices and their outputs need to be converted to linear motion by mechanical devices such as worms screws or rack and pinions.

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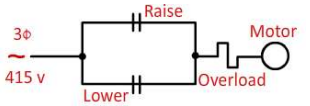
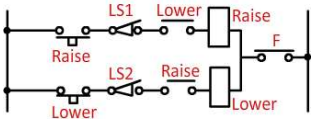
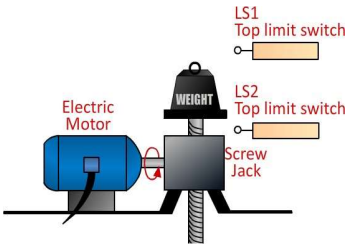
Electrical Actuator







- System shown in Figure comprising a **Mechanical Jack** driven by an AC motor controlled by a reversing starter.
- Neither type of motor can be allowed to **Stall** against an end of travel stop, so end of travel limits are needed to stop the drive.
- Auxiliary equipment comprises two **limit switches**, and a **motor overload** protection device.

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Fluid Power

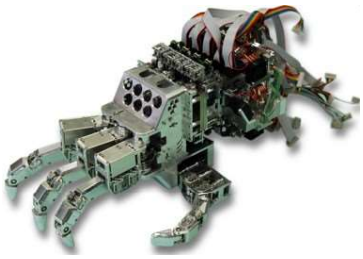
Technology that deals with

- Generation
- Control
- Transmission

} of **Power** using Pressurised fluids

Muscle that moves industry

Used to Push, Pull, Regulate, or Drive all machines of modern industry



Fluid

- **Liquid** (Hydraulics)
- **Gas** (Pneumatics)

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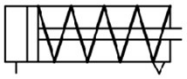
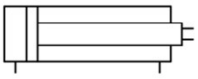
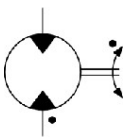
Fluid Power Actuators

Linear Actuators

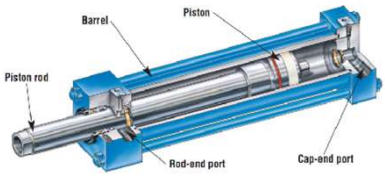
Single acting 

Double acting 

Rotary Actuators



Hydraulic / Pneumatic Cylinders



Hydraulic / Pneumatic Motors

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