What is Mechatronics?

Mechatronics is the synergistic integration of mechanics, electronics, controls and computer engineering towards the development of smart products and systems.

Mechatronic engineers develop automation solutions to improve quality of life, enhance product quality and replace manual labour.

Other Definitions for Mechatronics (1)

- "The word, mechatronics is composed of mecha from mechanics and tronics from electronics. In other words, technologies and developed products will be incorporating electronics more and more into mechanisms, intimately and organically, and making it impossible to tell where one ends and the other begins."

  T. Mori, "Mechatronics," Yasakawa Internal Trademark Application Memo, 21.131.01, July 12, 1969.

- "Synergistic integration of mechanical engineering with electronics and intelligent computer control in the design and manufacturing of industrial products and processes."

  F. Harshama, M. Tomizuka, and T. Fukuda, "Mechatronics-what is it, why, and how?-and editorial," IEEE/ASME Trans. on Mechatronics, 1(1), 1-4, 1996.

Other Definitions for Mechatronics (2)

- Mechatronic engineering is concerned with the <u>design of automated machines</u>. It is strongly based on a combination of mechanical, electronics and software engineering, but is a distinctly different discipline to all three.

  Engineers Australia

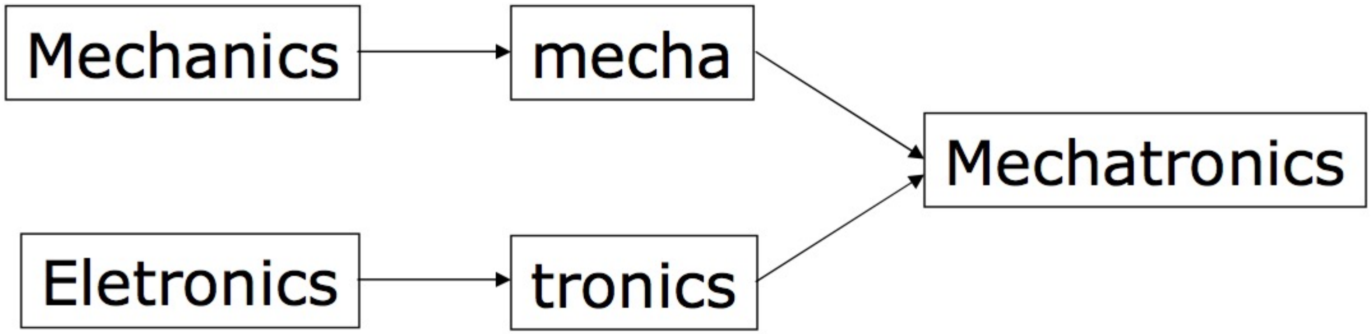
- "<u>Integration of</u> electronics, control engineering, and mechanical engineering."

  W. Bolton, Mechatronics: Electronic Control Systems in Mechanical Engineering, Longman, 1995.

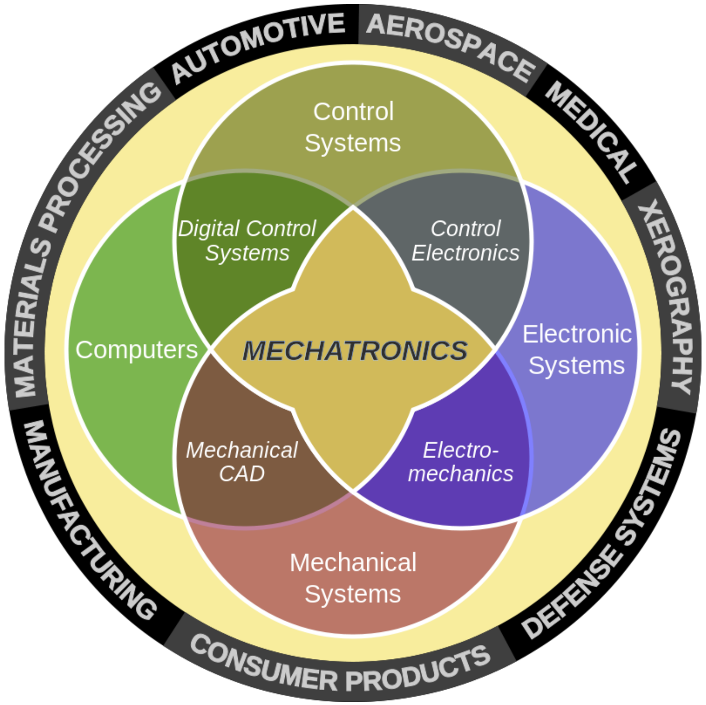
- "Field of study involving the analysis, design, synthesis, and selection of systems that combine electronics and mechanical components with modern controls and microprocessors."

  D. G. Alciatore and M. B. Histand, Introduction to Mechatronics and Measurement Systems, McGraw Hill, 1998.

What is Mechatronics? (3)



What is Mechatronics? (4)

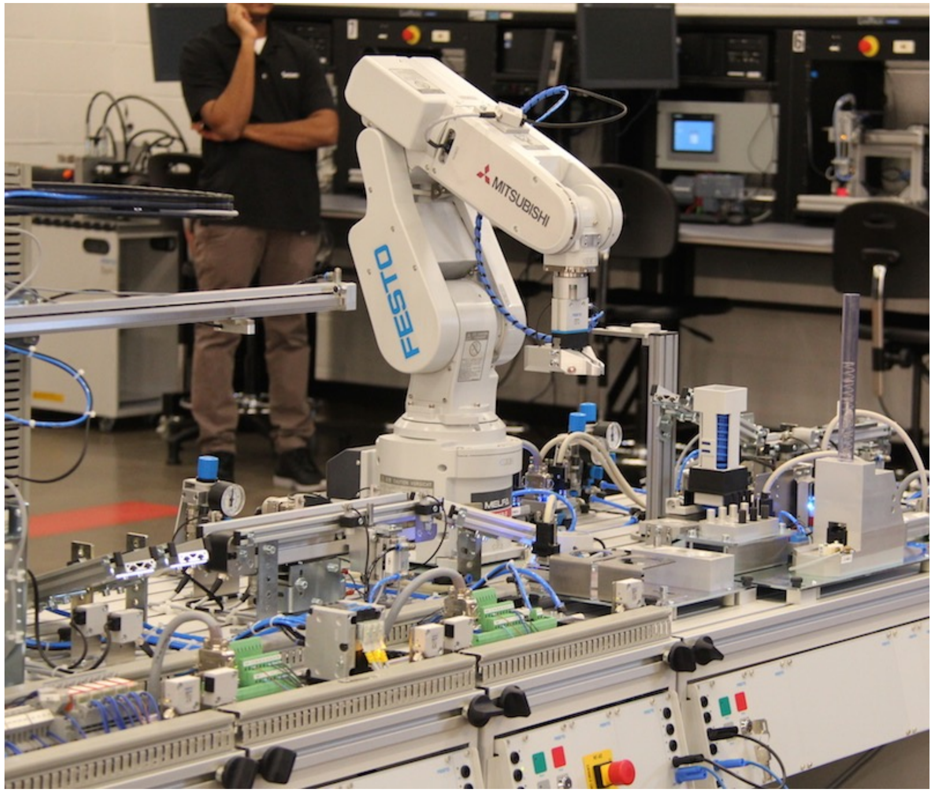


Aerial Euler diagram from Rensselaer Polytechnic Institute's website describes the s fields that make up Mechatronics

Areas in the Mechatronics Discipline

- Mechanical Engineering
  - Dynamic systems
  - Solid mechanics
  - Thermodynamics and Fluid Mechanics
- Electronic
  - Digital design
  - Sensors
  - Signal conditioning
- Control
  - Classical control systems
  - Modern control systems
- Computer
  - Software programming
  - Computer Hardware

What is Mechatronics?



Source: Seneca College/ Siemens Canada

Is this a Mechatronic Device?

1915 Ford Model T

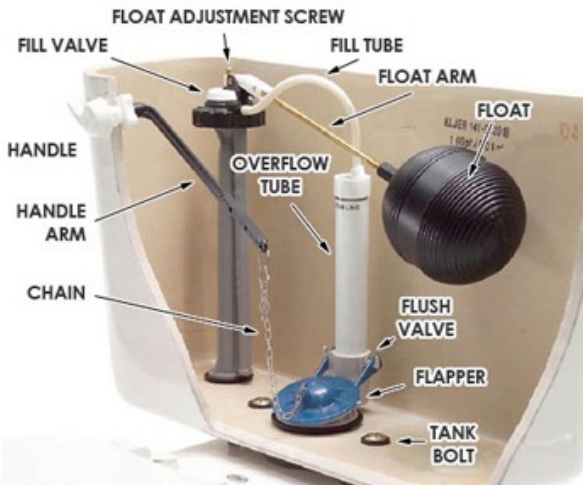
A. Yes
B. No

Is this a Mechatronic Device?

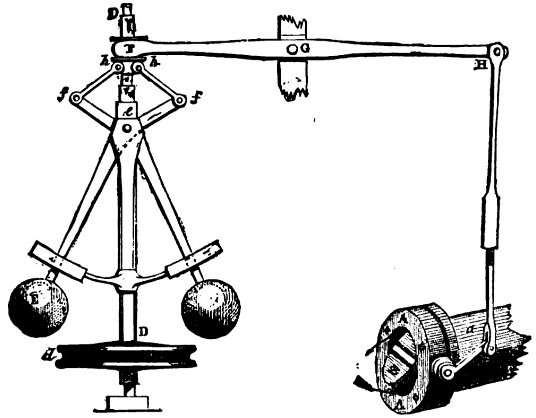
Courtesy: Tesla Motors

A. Yes
B. No

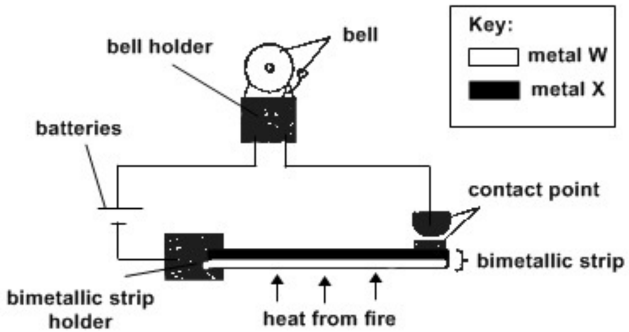
Examples of Predominantly Mechanical Designs



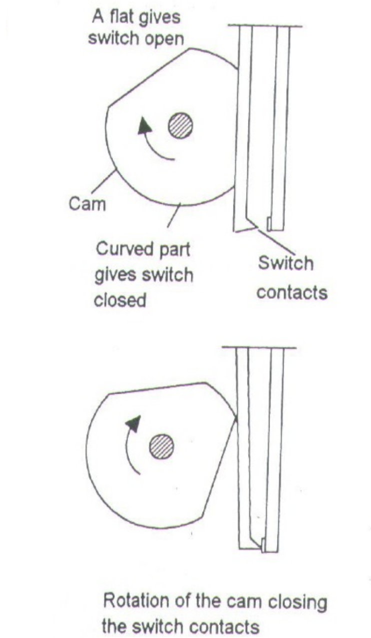
Float Valve



Governor and Throttle Valve



Bi Metallic Strip



Cam Operated Switch

A Brief History (1)

- Industrial Revolution – Mechanical (1760 - 1840)
  - Transformed from hand production methods to machines.
  - Improved efficiency of water power and increasing use of steam power.
  - Development of machine tools and the rise of the factory system.
  - Operations of motion transmission, sensing, actuation, and computation were performed using mechanical components such as cams, gears, levers, and linkages.
- Semiconductor Revolution – Electronic (1950 onwards)
  - Led to the creation of integrated circuit (IC) technology.
  - Effective, miniaturized, power electronics could amplify and deliver needed amount of power to actuators.
  - On-board, discrete analog/digital ICs provided rudimentary computational and decision-making circuits for control of mechanical devices.

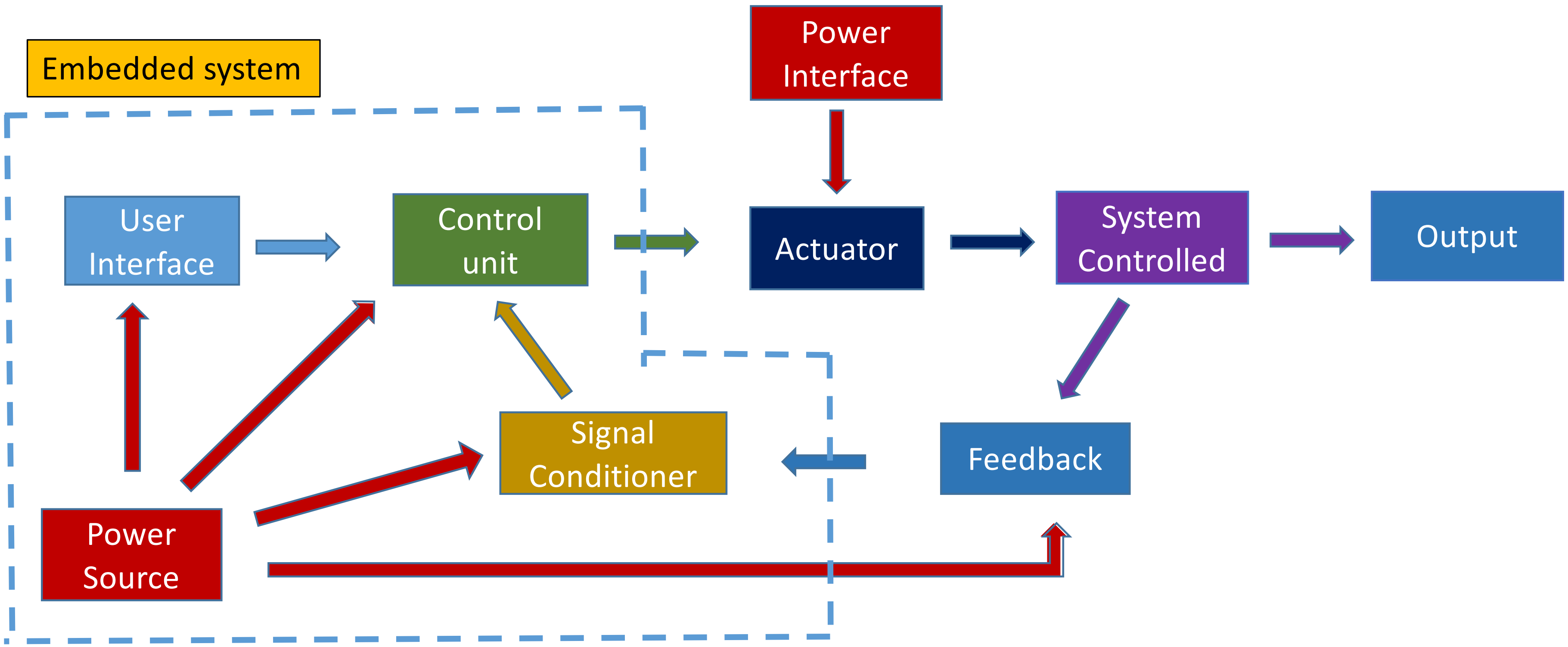
A Brief History (2)

- Information Revolution – Computer (1990 onwards)
  - VLSI technology led to the introduction of microprocessor, microcomputer, and microcontroller.
  - Computing hardware is ubiquitous, cheap, and small.
  - Thus computing hardware can be effortlessly interfaced with real world electromechanical systems.
  - Development internet and telecommunications technology enabled sharing of information and data.

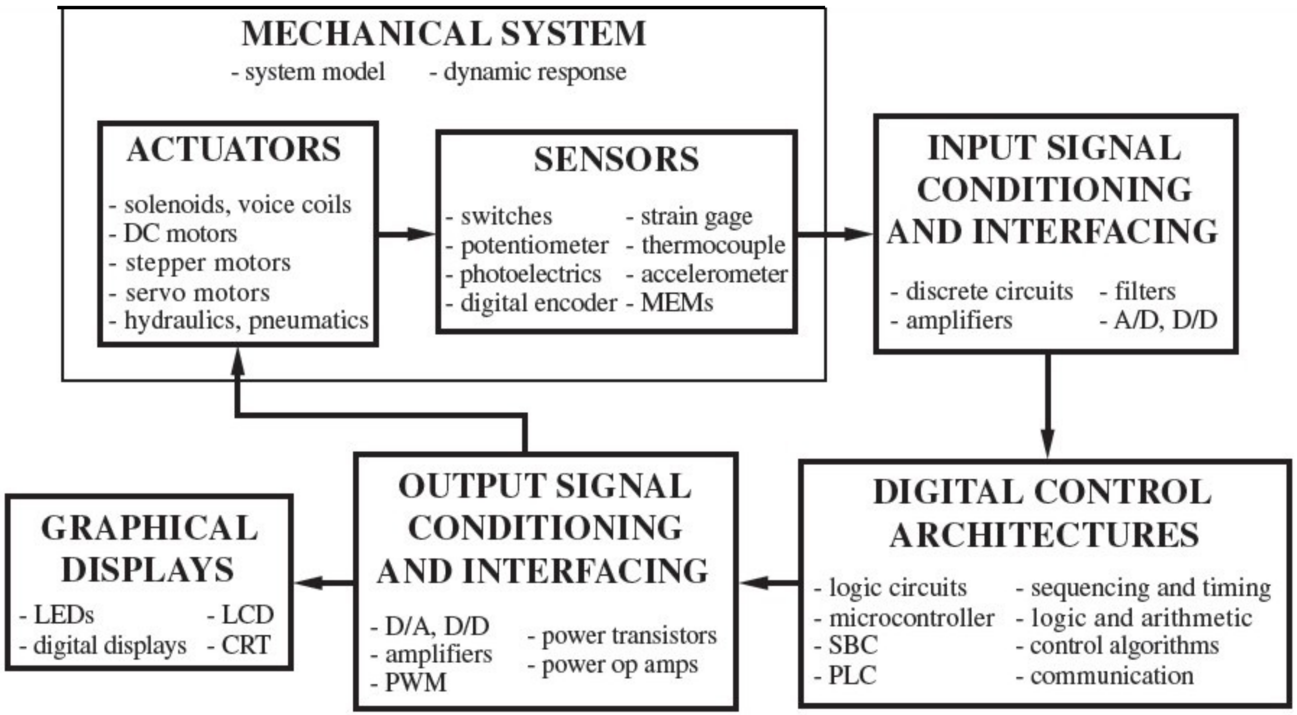
Various Mechatronics Applications

- **Consumer products:** smart phone, closed circuit camera system, microwave oven, toaster, dish washer, laundry washer-dryer, climate control units, etc.
- **Medical:** implant-devices, patient monitoring systems, assisted surgery, haptic, etc.
- **Manufacturing:** robotics, machines, processes, etc.
- **Automotive:** cruise control, temperature control, antilock brake, active suspension, air bags, engine management, safety systems, etc.
- **Defense:** unmanned ground, air and underwater vehicles, jet engines, etc.
- **Network-centric, distributed systems:** distributed robotics, tele- robotics, intelligent highways, etc.

A schematic of a mechatronic system



Components of a Mechatronic System



Embedded System

- Microcontrollers
  - Small computer (SoC) on a single integrated circuit containing a processor core, memory and other programmable input/output peripherals.
  - Eg: Arduino, PIC, ARM
- Single board computer
  - Complete computer built on a single circuit board, with microprocessor(s), memory, input/output (I/O) and other features required of a functional computer.
  - Eg: Raspberry Pi, Beaglebone
- Field programmable gate array
  - Integrated circuit designed to be configured by a customer or a designer after manufacturing.
  - The FPGA configuration is generally specified using a hardware description language (HDL), similar to that used for an application-specific integrated circuit (ASIC).
  - Eg: Altera, Xilinx

Sensors by Type/Sector

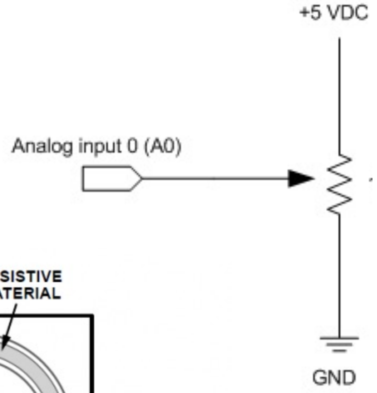
Physical Parameter	Sensor Type
Load	Strain gauge, piezoelectric sensor
Temperature	RTD, thermocouple
Angle measurement	Potentiometer, encoder
Distance	Infra red sensor, sonar sensor, camera, LIDAR
Force/Acceleration	piezoelectric sensor, inertial measurement unit (IMU)
Liquid level	Capacitive sensor, infra red sensor

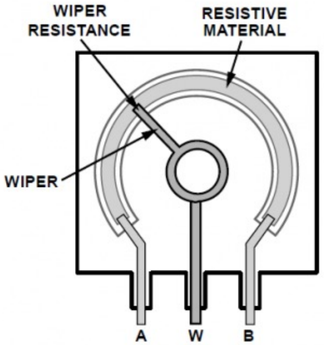
Interfacing sensors to embedded systems

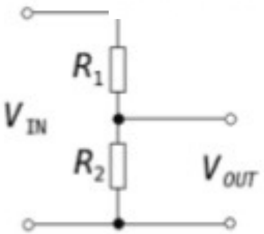
- Sensors represent any physical quantity as a voltage.
- This voltage signal could be either analog or digital.
- If the signal is analog it should be acquired through the analog to digital converters.
- Some microcontrollers have in-built analog to digital converters (ADC) while single board computers like raspberry pi don’t.
- When these are not present, signal acquisition should be carried out using external ADCs.
- When the output of these are a digital voltage signal, these could be directly interfaced with the embedded system.
- However, the communication will be carried out using various communication protocols.

Position measurement - Angular Position

Potentiometers

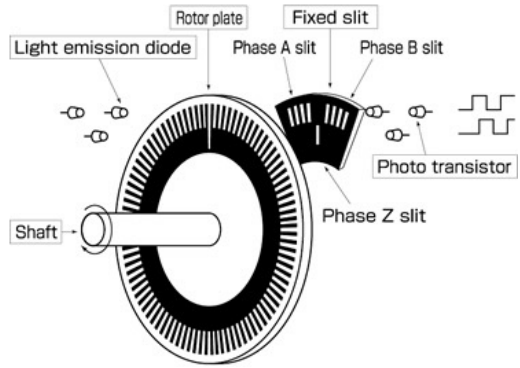






$$V_{OUT} = \left(\frac{R_1}{R_1 + R_2}\right) V_{IN}$$

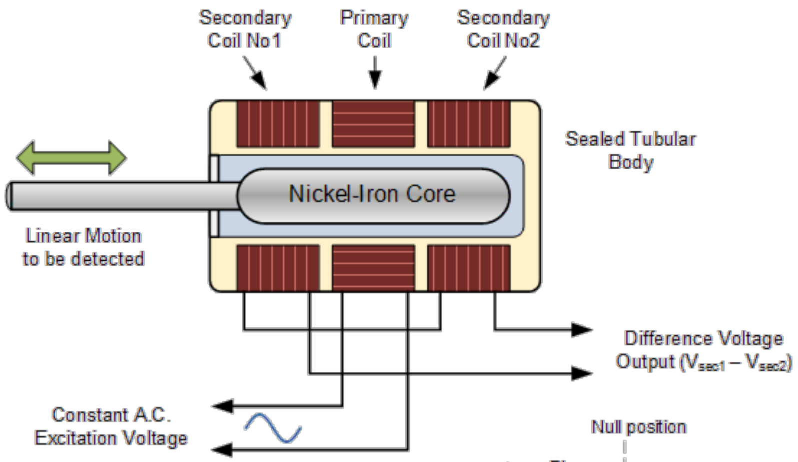
Optical encoders

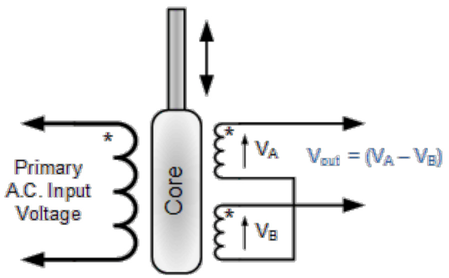


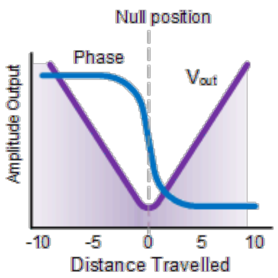
Incremental Encoder Simplified Structure

Position measurement - Linear Position

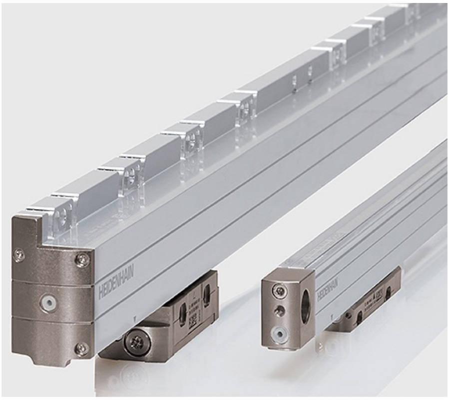
Linear variable differential transformer (LVDT)

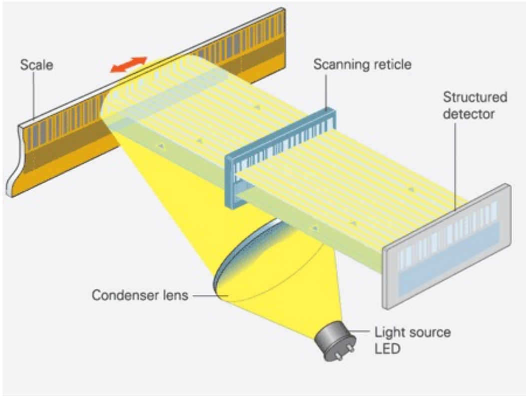






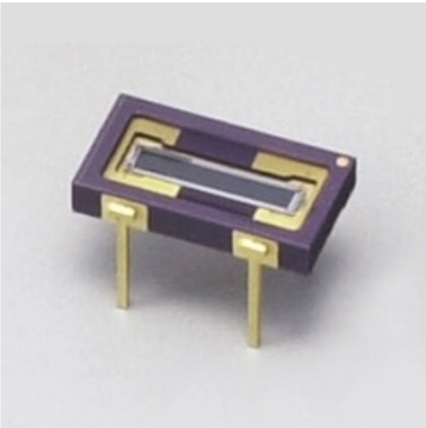
Linear scanning encoders



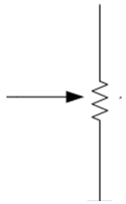


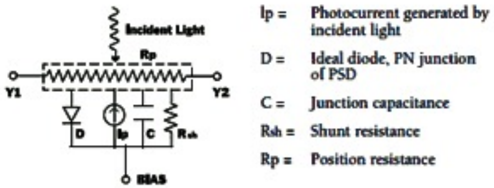
Position measurement

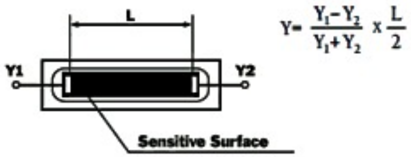
Using Position Sensitive Detectors

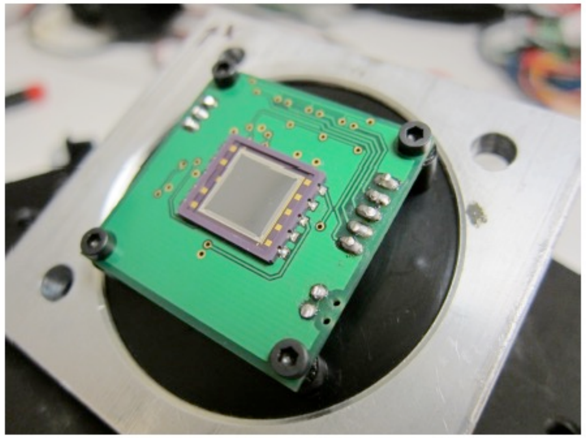


1D Measurement







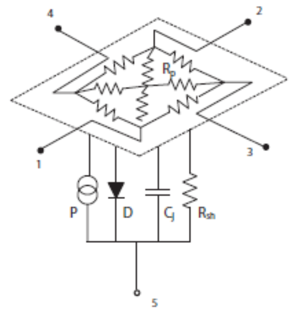


2D Measurement

Position is provided using 4 currents I_1, I_2, I_3 & I_4.

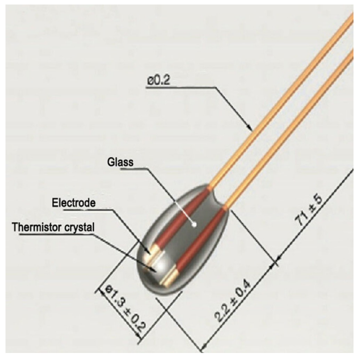
$$X_p = \frac{(I_2 + I_3) - (I_1 + I_4)}{I_1 + I_2 + I_3 + I_4}$$

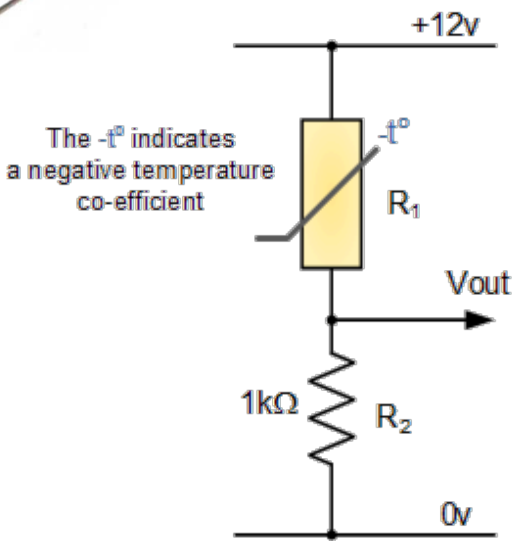
$$Y_p = \frac{(I_2 + I_4) - (I_1 + I_3)}{I_1 + I_2 + I_3 + I_4}$$

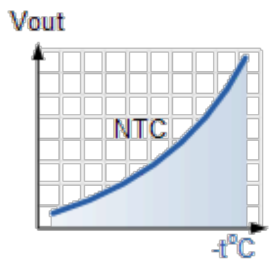


Temperature Measurement

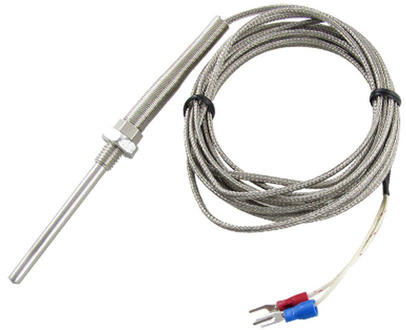
Thermistors

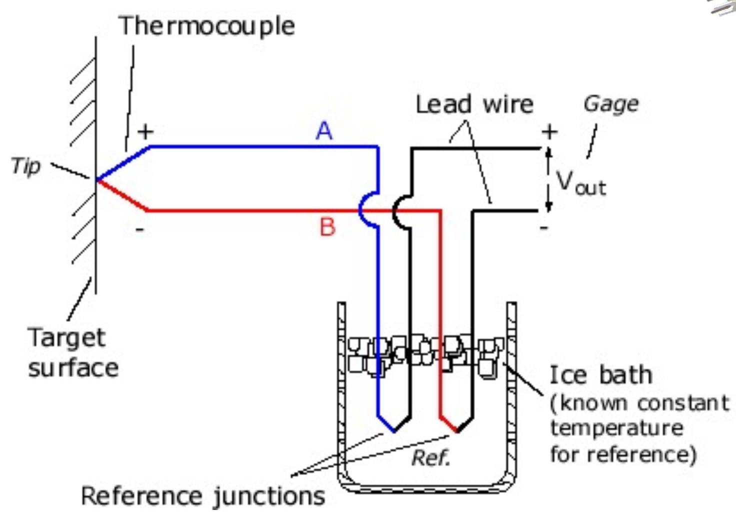






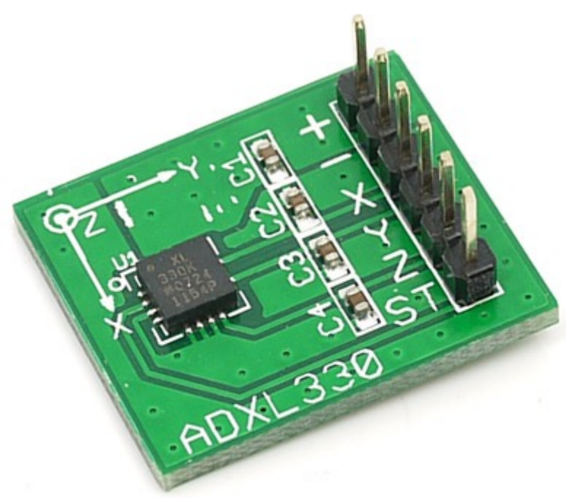
Thermocouples

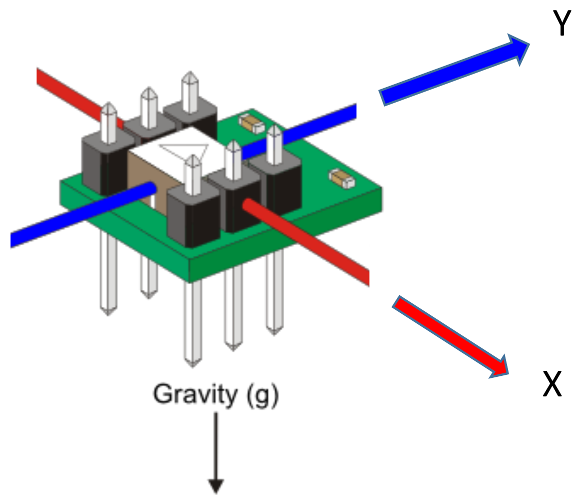




Acceleration measurement

<u>Accelerometer</u>

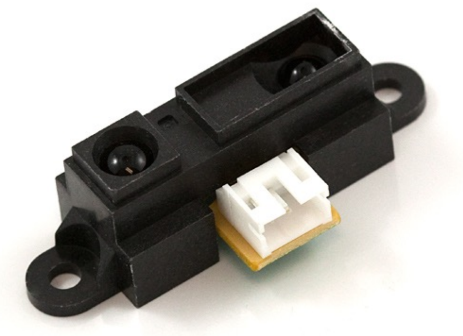


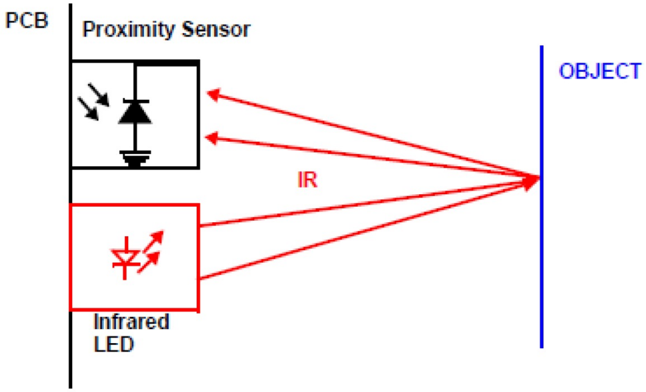


Measurement range is given in ‘g’s.

Proximity

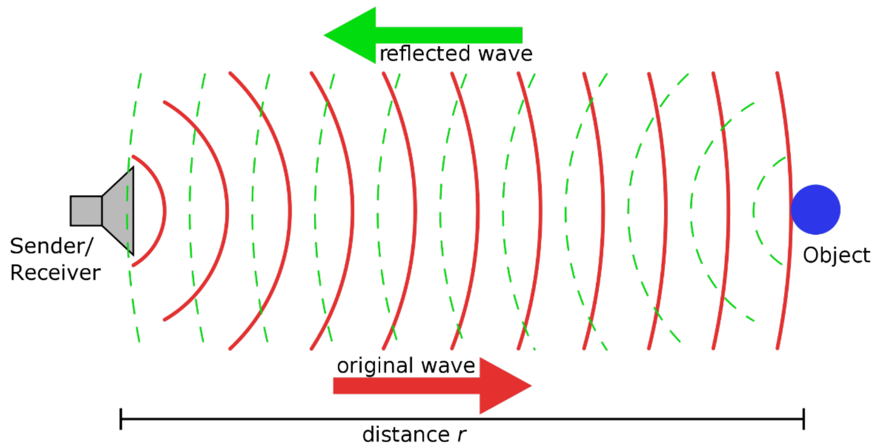
IR sensors





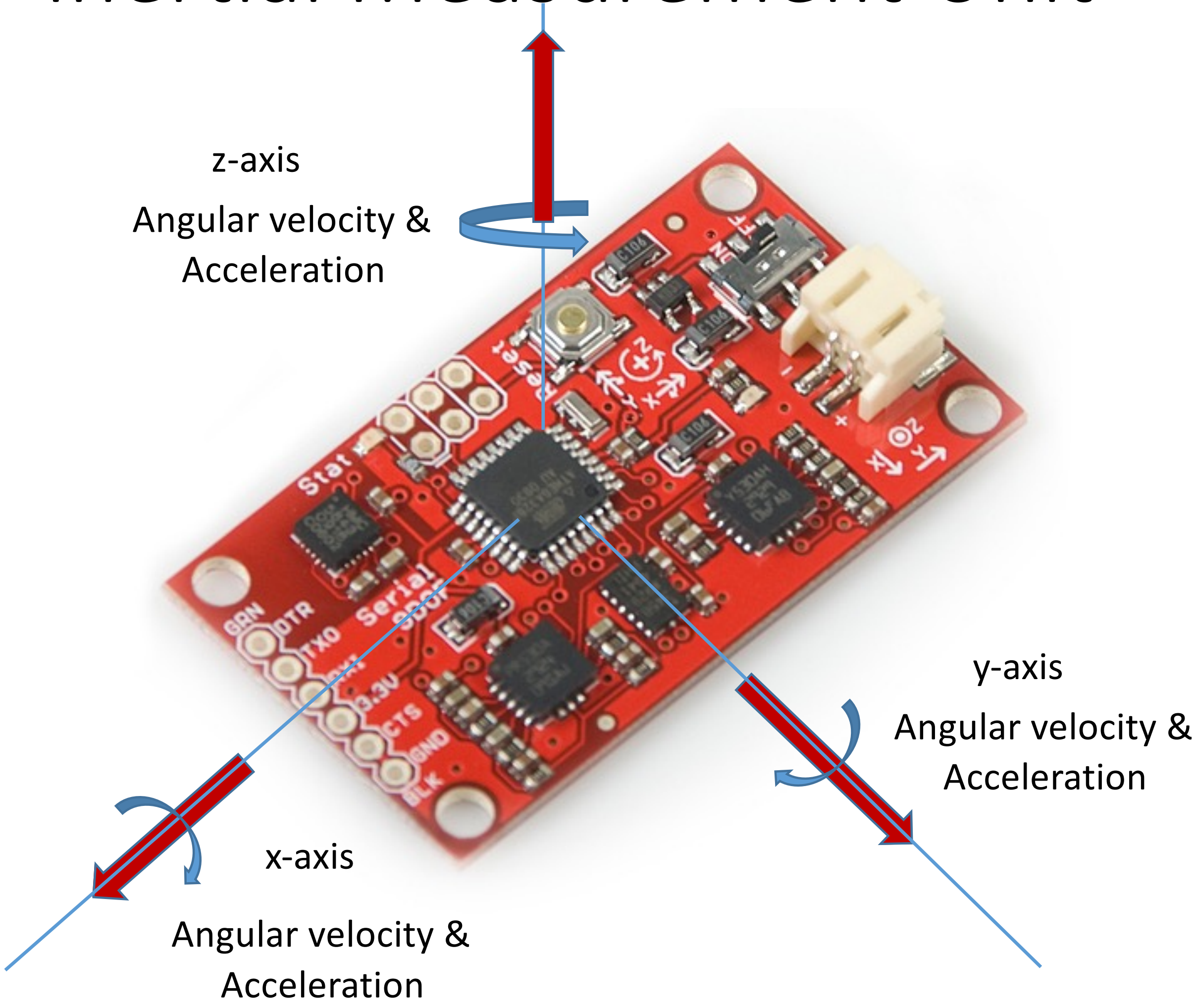
Position is given as an analog voltage signal

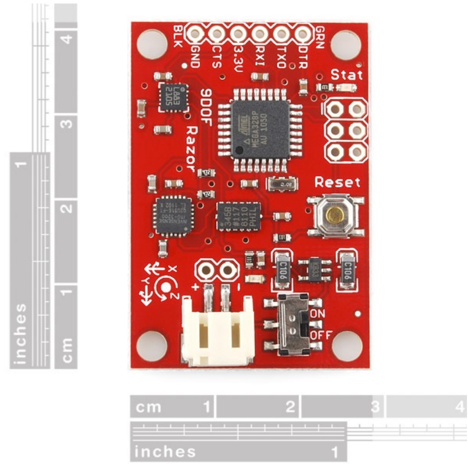
Sonar sensors



Position is obtained using time of flight measurement

Inertial Measurement Unit





$$\ddot{\theta} = \frac{\tau}{I}$$

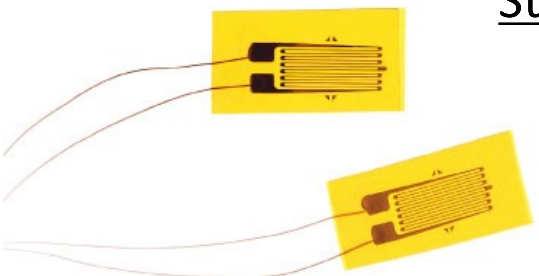
$\ddot{\theta}$ Angular acceleration

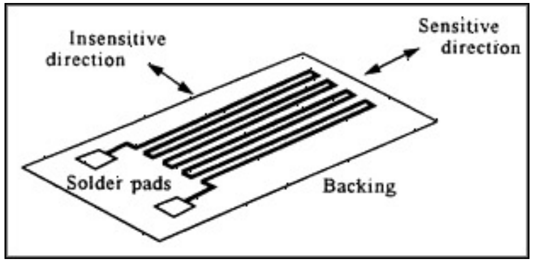
τ Torque

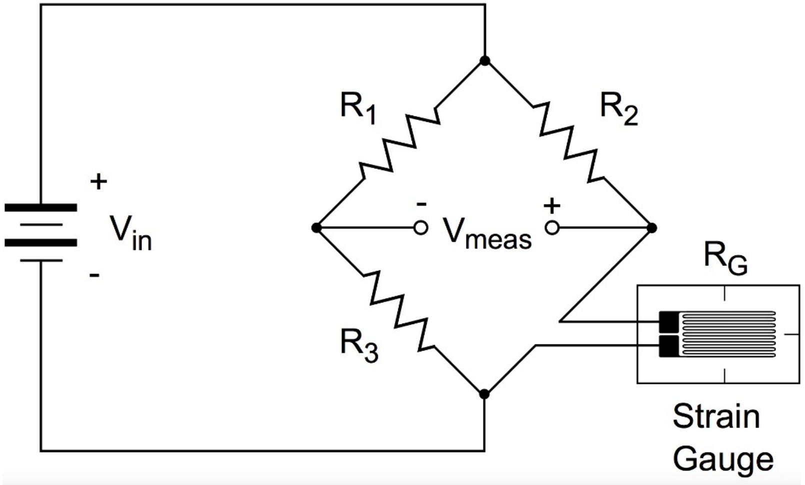
I Mass moment of inertia

Load

Strain Gauge

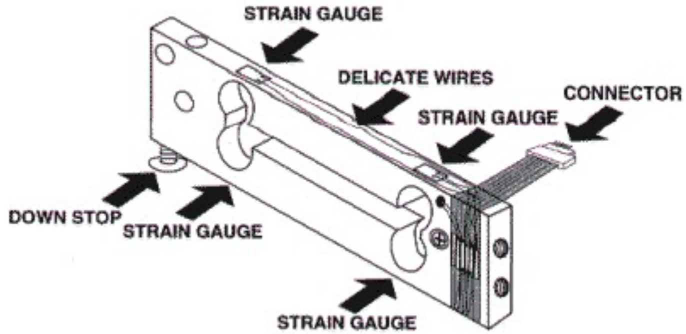






$$V_{meas} = V_{in}\left[\frac{R_G}{R_2 + R_G} - \frac{R_3}{R_1 + R_3}\right]$$

Load cell

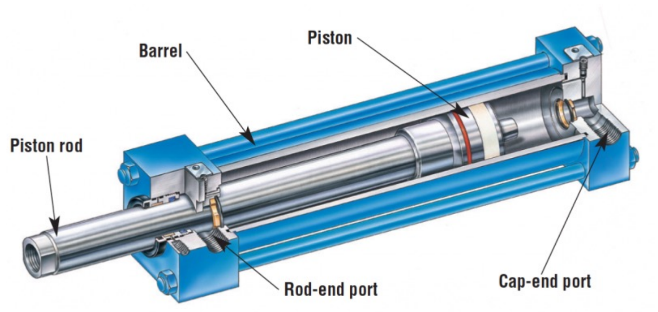


Actuators

- An **actuator** can control or move a mechanism or system.
- Actuators could produce linear or rotary motion.
- Actuators could be classified according to the type of energy used.
    - Electric
    - Pneumatic
    - Hydraulic

Hydraulic Actuators

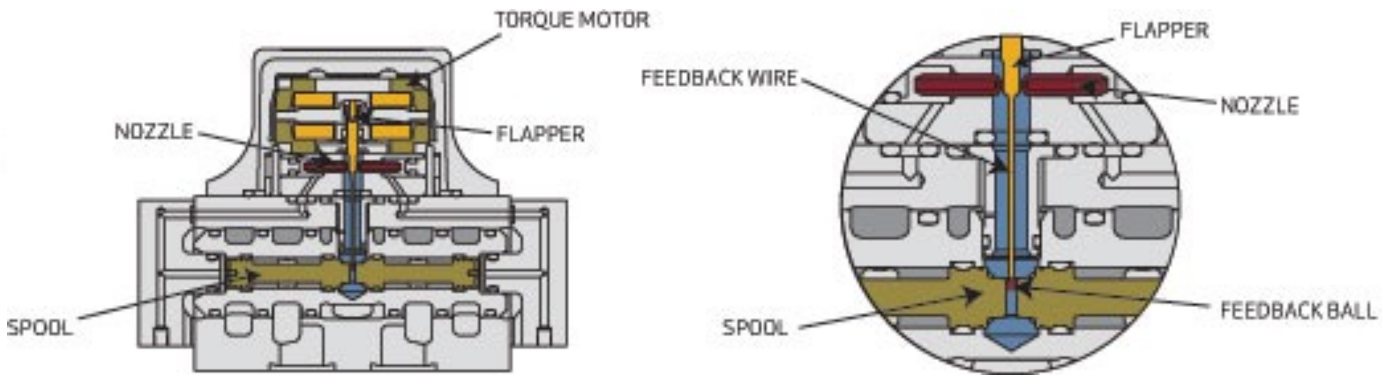
- Hydraulic valves are used for controlling the hydraulic flow into the actuator.
- These systems usually operate between 1000 – 5000 psi (550 – 690 kPa).
- There are both linear and rotary hydraulic actuators.
- Applications: Control surfaces of air crafts, backhoes, hoists.



Controlling Hydraulic Actuators

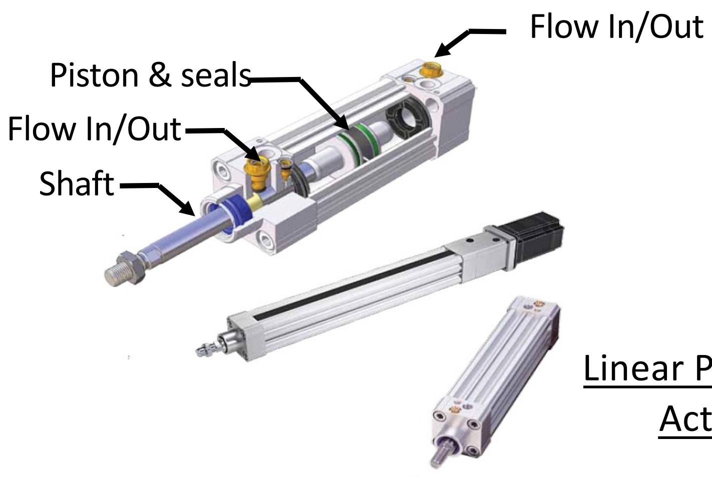
- Electro-hydraulic servo valves could be used for precise control of the actuator position.

Moog® G761 Electro-Hydraulic Servo Valve

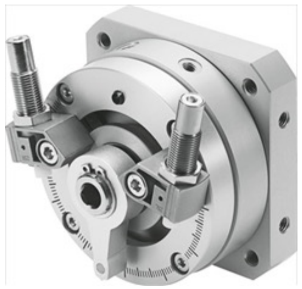


Pneumatic Actuators

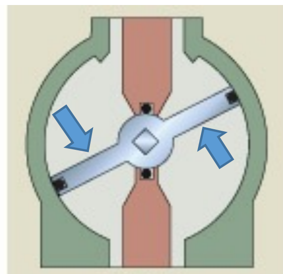
- A pneumatic actuator converts energy (typically in the form of compressed air) into mechanical motion.
- A pneumatic valve or solenoid is used for controlling the air flow into the actuator.
- These systems usually operate between 80 – 100 psi (550 – 690 kPa).
- Pneumatic actuators produce either linear or rotary motion.
- Applications: industrial labeling systems, torque wrenches, riveting units.



Linear Pneumatic Actuator



Single Vane Rotary Actuator



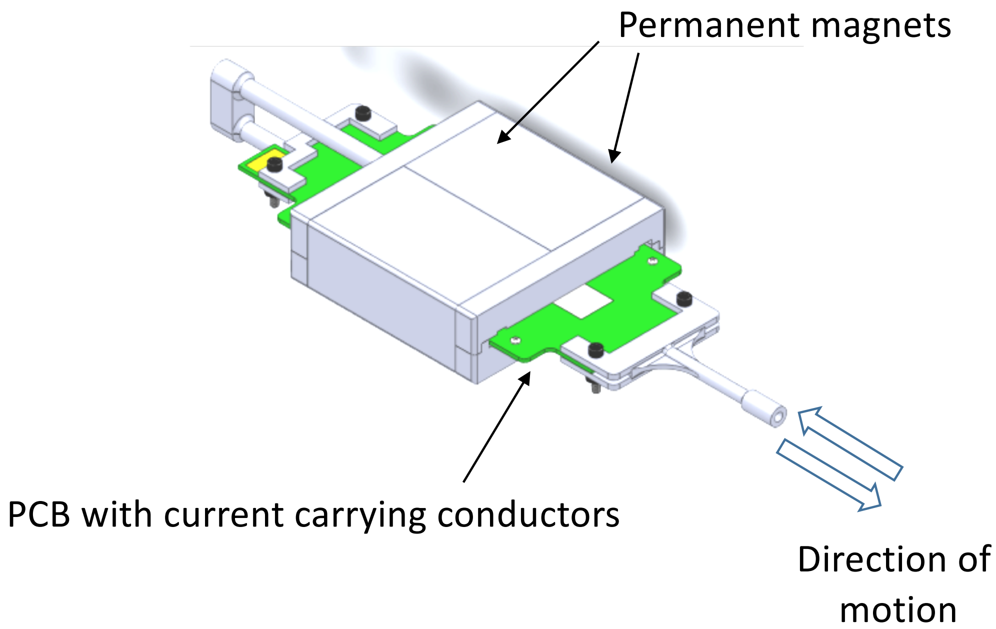
Double Vane Rotary Actuator

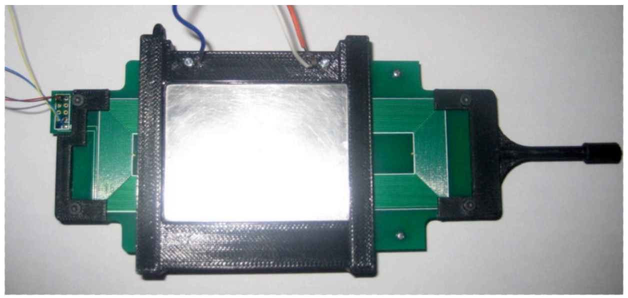
Rotary Pneumatic Actuator

Electric Actuators

- Converts electric energy into mechanical energy.
- There are both linear and rotary type electric actuators.

<u>A Linear Voice Coil (An example of a linear actuator)</u>





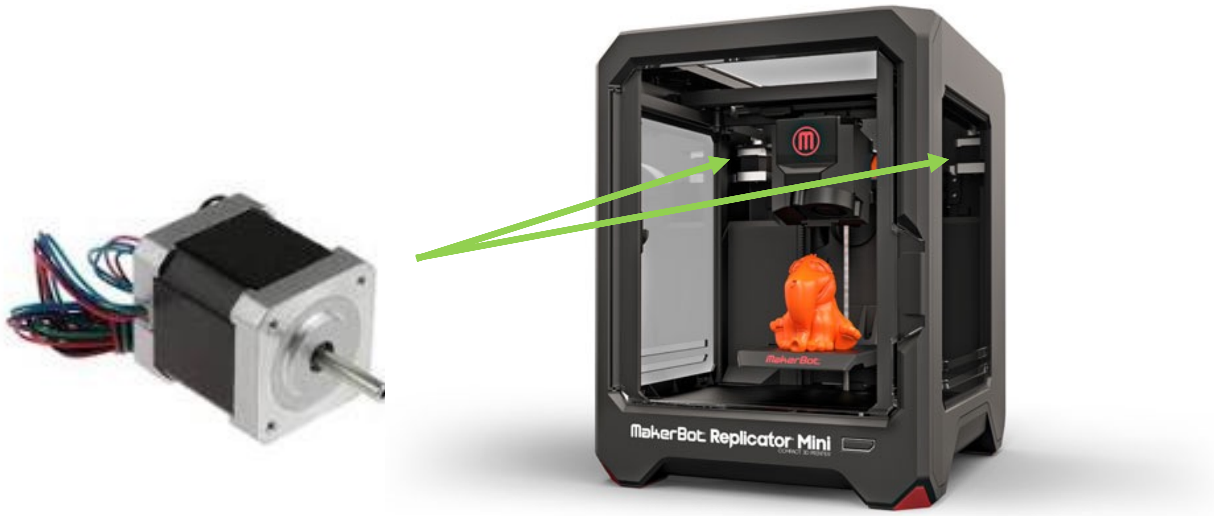
Source: www.agilesensors.com

Electric motors

- Converts electric energy into rotary motion.
- There are several types of motors.

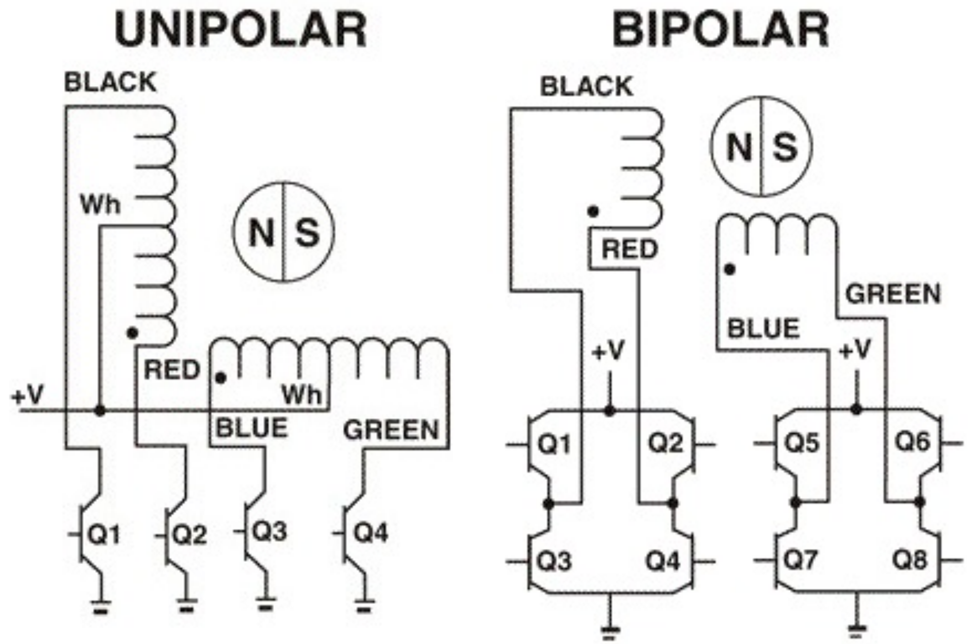
<u>Stepper motors</u>

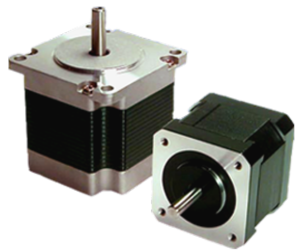
- Can divide one revolution into a number of steps.(eg: 400 steps/rev)
- Applications – 3D printers, CNC machines, precision x-y tables, miniature robots



Stepper Motors

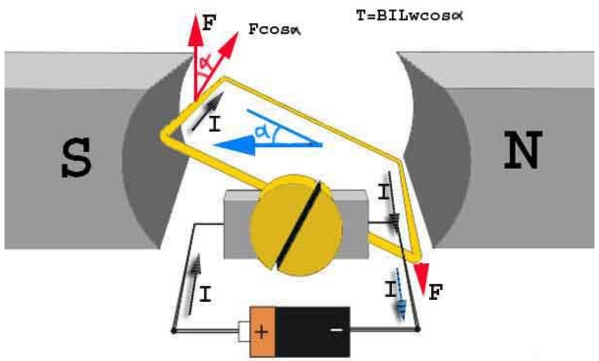
- There are two types of stepper motors based on the construction of the winding.
- These are:
  - o Unipolar stepper motors.
  - o Bipolar stepper motors.
- Bipolar stepper motors usually have four leads while unipolar stepper motors have six leads.
- For driving:
  - Unipolar stepper motors require 4 transistors
  - Bipolar stepper motors require 6 transistors

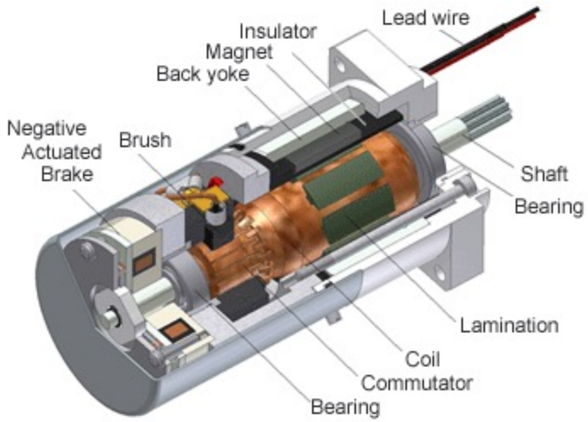




Brushed DC Motors

- These use permanent magnets as stator and armature windings as rotor.
- When current flows through armature it starts to rotate due to the magnetic field from the stator permanent magnets (Fleming's Left hand rule).
- Contact between the windings and brushes is made using commutators.
- Applications include hand drills, automatic window shutters, alternators, hydraulic pumps, forklifts.

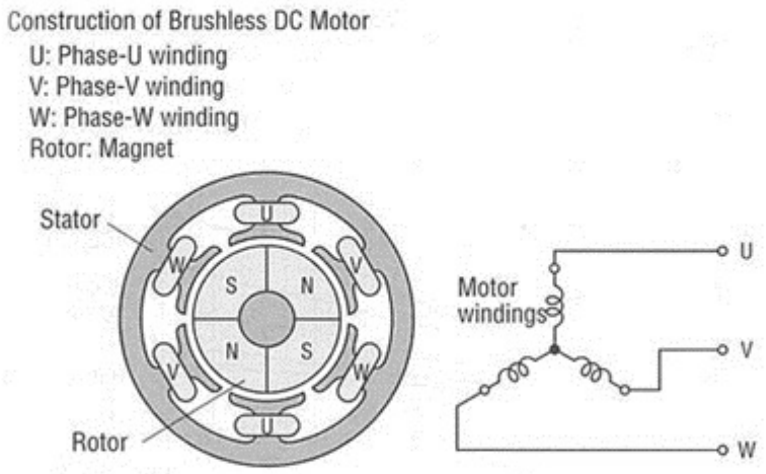


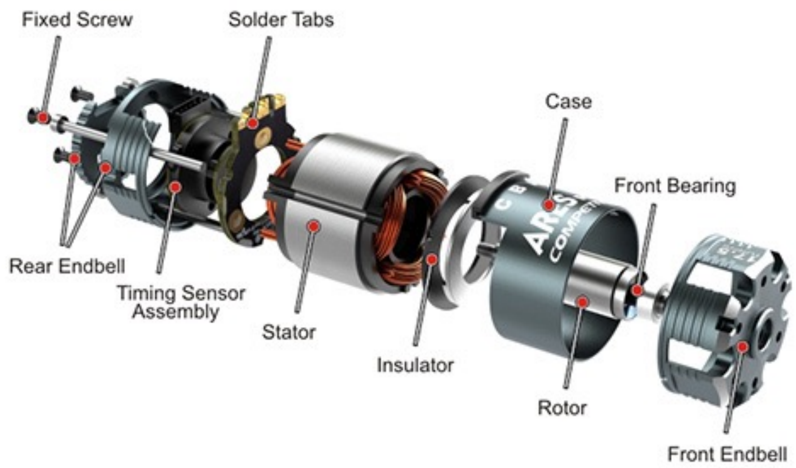


Source:
Eminebea Motors

Brushless DC Motors

- These have an armature as stator and permanent magnets as rotor.
- Rotating magnets passing the stator poles create a back EMF in the stator windings.
- These are more efficient as compared to brushed version of motors.
- Capable of producing high speeds.
- Applications – Quadcopter UAVs, fixed wing UAVs, hand drills.





Source:
ARES Motors

Methods of Signal Conditioning

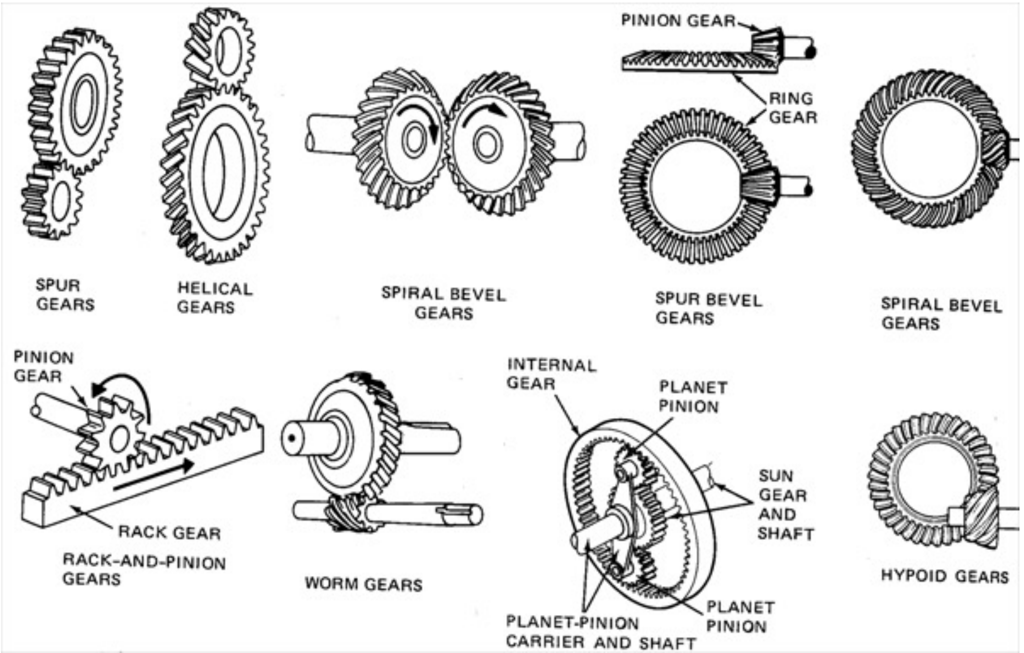
- Filtering
  - Filtering is carried out by hardware or software.
  - It includes operations such as low pass, high pass or band pass filters that could be implemented in hardware or software.
  - Computationally intensive filtering algorithms such as the Kalman filters are usually implemented in software.
- Amplification
  - Sometimes the voltage signals are too weak to be acquired from ADCs.
  - Therefore, the signals should be amplified using ICs.
  - Amplification will increase the resolution of the input signal & signal-to-noise ratio.
- Isolation
  - These embedded systems have an analog side and a digital side or a high voltage and a low voltage sides.
  - Magnetic or optic isolation is often used.

Power sources

- Sometimes the system require voltages at multiple levels (±5 V, ±12 V, ±24 V).
- When there is a high voltage side and a low voltage side sometimes the two sides need to be separated using opto-couplers.
- At times the system may need power from sources like hydraulics and pneumatics to drive actuators.
- Sometimes the system may require both high power and low power levels.
- In such cases power amplification needs to be carried.
- When different voltage levels are connected level converters have to be used. Eg. a 3.3 V side is connected with 5 V side.

Methods of Power Transmission

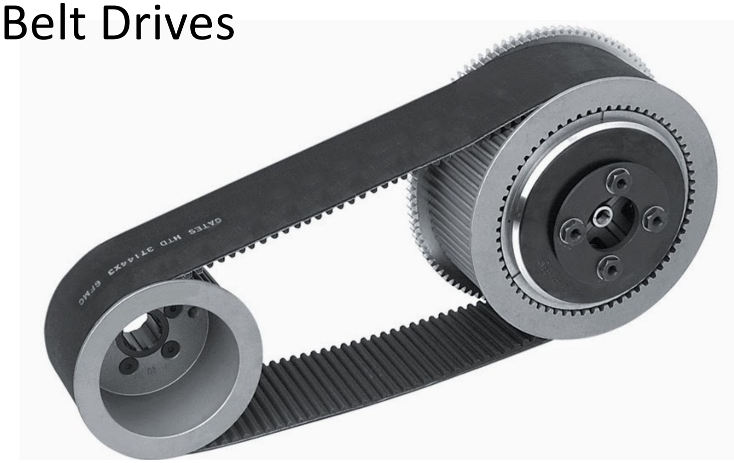
Gear Drives

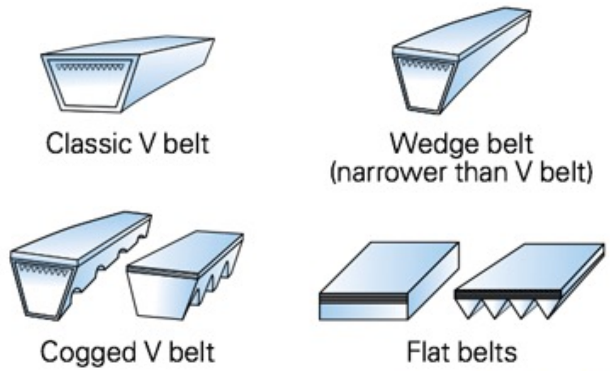


- Used when source and load is located close by.
- Large amounts of power could be transmitted.
- Higher transmission efficiency.
- Types of gears.
  - Spur
  - Helical
  - Bevel
  - Worm
  - Rach and pinion

Methods of Power Transmission

Belt Drives





Source: Carbon Trust, 2011.

- Used when source and load is located far apart.
- Lower transmission efficiency.
- Types of belt drives.
  - Flat
  - Round
  - V
  - Toothed

Ball Screws

- Converts rotary motion to linear motion.
- Transmission efficiency is as high as 85%.
- Can provide very precise motion.
- Operates at slower speeds.

Lecture Topics covered

- Modelling of Dynamic Systems
- Transient response of dynamic systems
- Frequency response analysis
- Sensors & transducers
- Electrical Actuators
  - Stepper motors
  - DC Motors
  - DC Motor Control
  - Brushless DC Motors
- Hydraulic/Pneumatic actuators
- Analog to Digital Controllers
- Serial Communication
- Case studies of Mechatronic Systems