SENSORS & ACTUATORS

Robotics Club & HUMANOID IIT KANPUR

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AIM OF THE LECTURE

- WHY SENSORS AND ACTUATORS ?
- BASIC OF SYSTEM HARDWARE and DATA HANDLING SYSTEM
- WHAT ARE SENSORS? (Brief Only)
- TYPES OF SENSORS
- SAMPLING AND QUANTISATION
- WHY ACTUATORS?
- TYPE OF ACTUATIONS(Brief Only)

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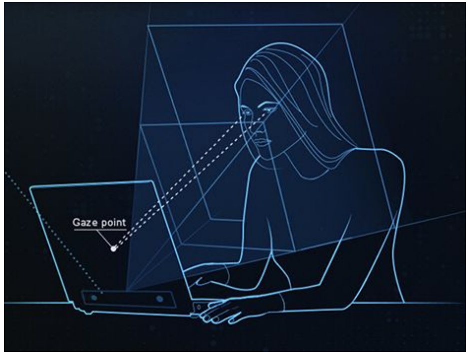
WHY SENSORS AND ACTUATORS ?

Q1 HOW WILL YOU ABLE TO INTERACT WITH THE SURROUNDING?

Q2 HOW WILL YOU ABLE TO MAKE CHANGES IN THE SURROUNDINGS?

SENSOR



ACTUATOR

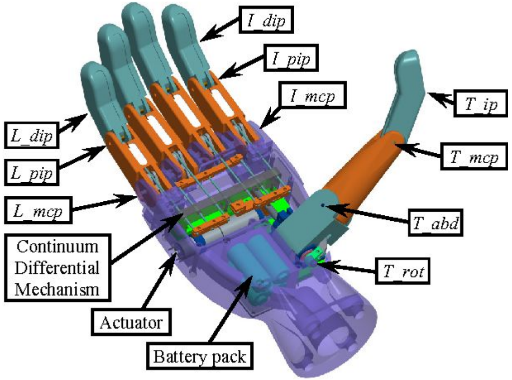
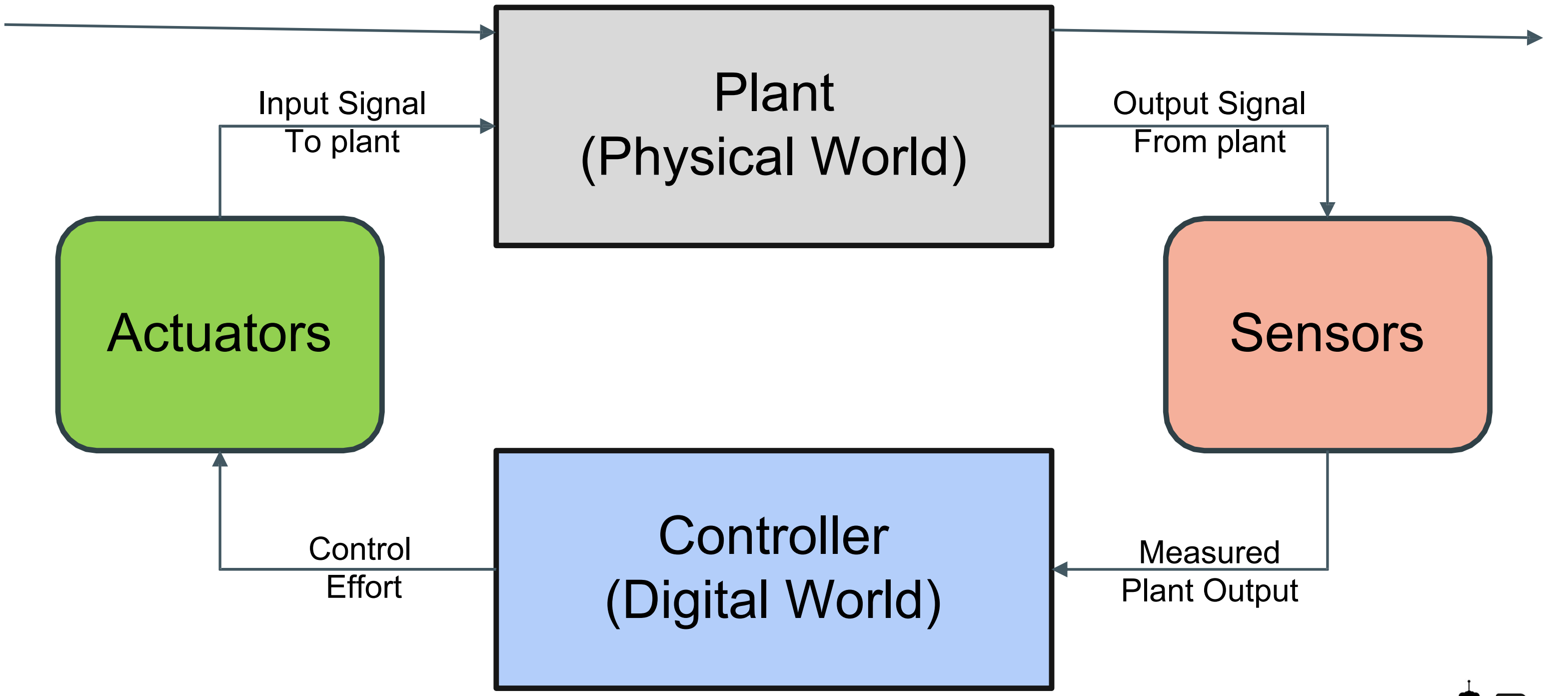


Fig. 3. The single-actuator prosthetic hand

Components of a System Hardware

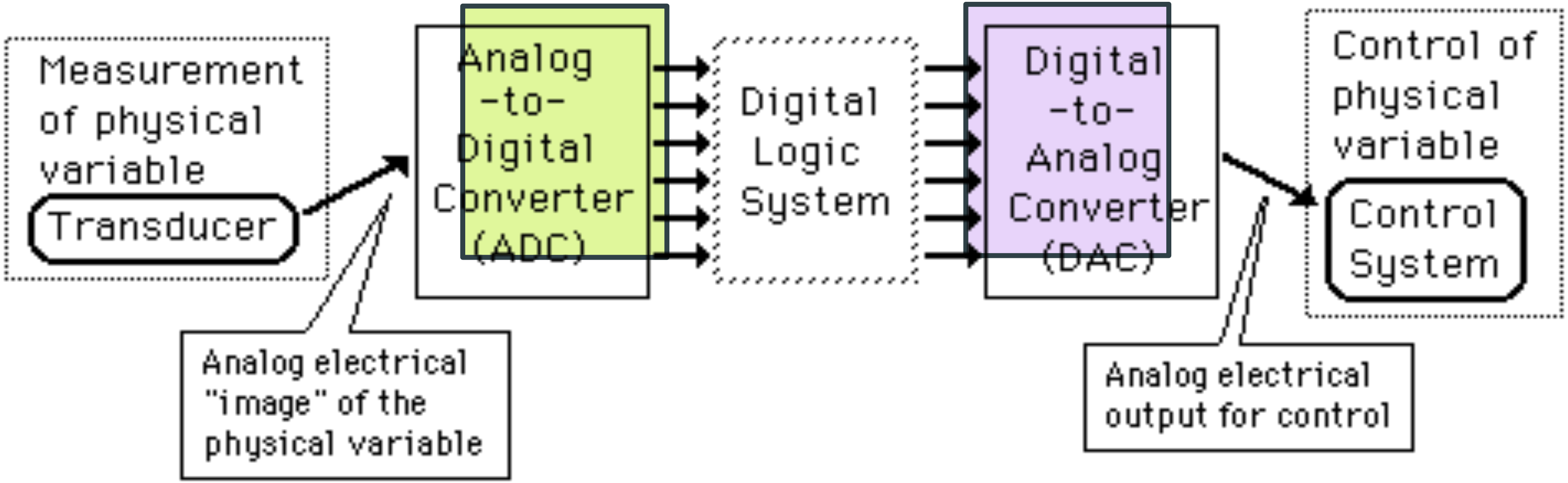


Data Handling Systems

Both data about the physical world and control signals sent to interact with the physical world are typically "analog" or continuously varying quantities.

In order to use the power of digital electronics, one must convert from analog to digital form on the experimental measurement end and convert from digital to analog form on the control or output end of a laboratory system.

Data Collection and Control

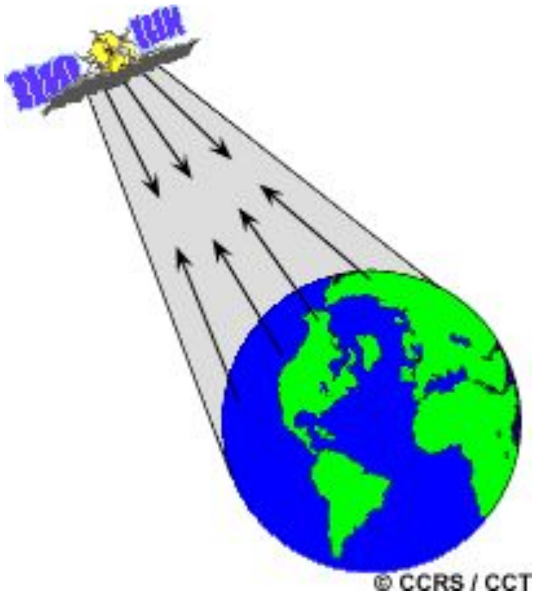


Source: http://hyperphysics.phy-astr.gsu.edu/hbase/hph.html

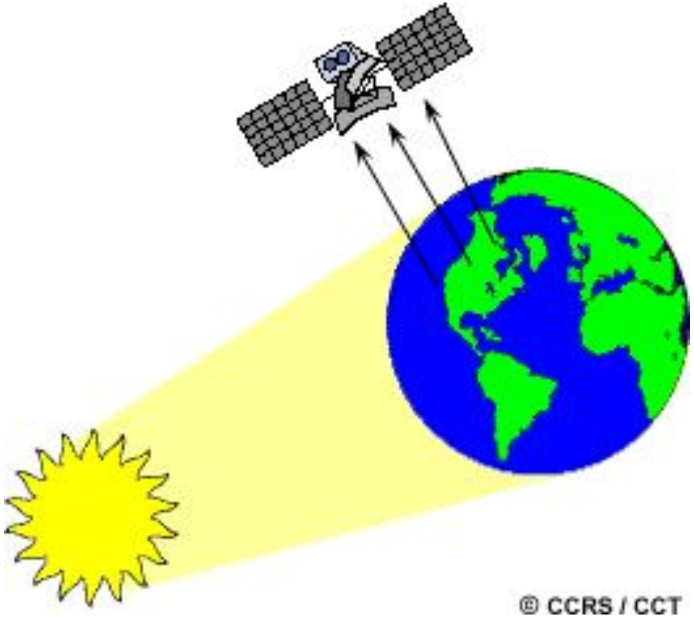
SENSORS

Classification of Sensors

Active - Passive Sensors



Active Sensor



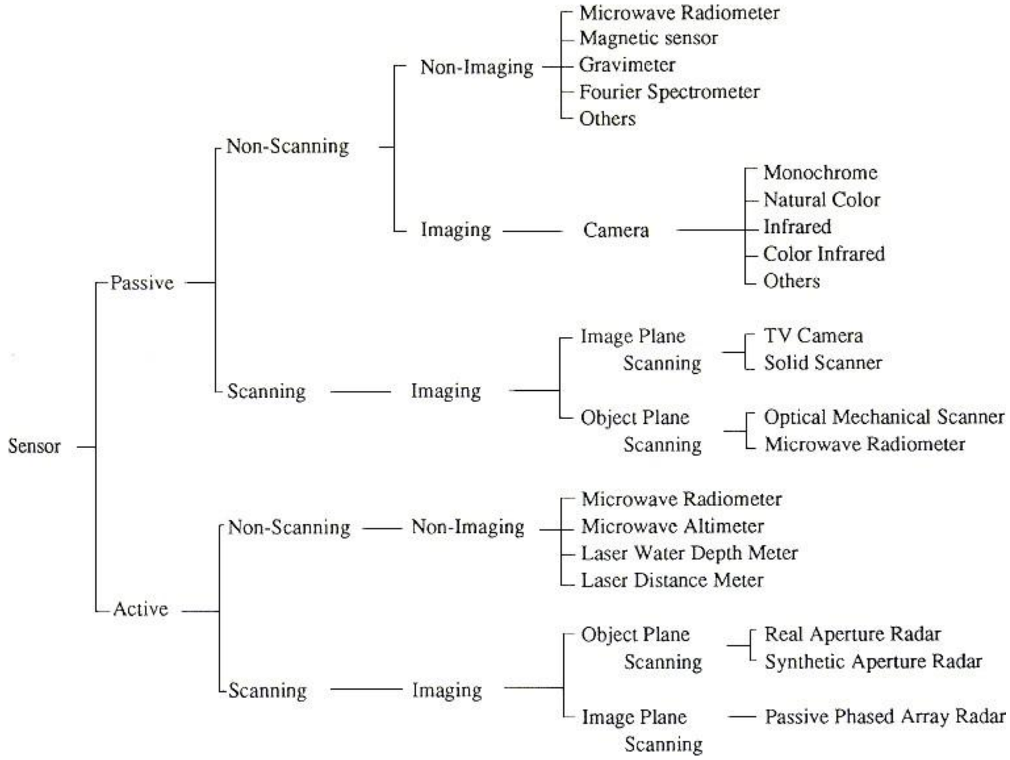
Passive Sensor

Classification of Sensors

In **passive sensing**, sensor measures the energy that is naturally available, such as thermal infrared, surface emissions.

In **active sensing,** sensors provides energy on their own as a source of illumination. The energy reflected by the target is detected and measured.

Note: The above two terms are used with the perspective of remote sensing.



Source: http://wtlab.iis.u-tokyo.ac.jp/~wataru/lecture/rsgis/rsnote/cp2/cp2-1.htm

VARIETIES OF SENSORS

Acoustic Sensors
Geophone
Hydrophone
Microphone

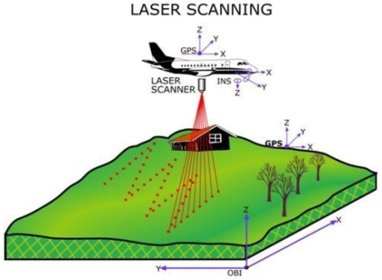
Automotive Sensors
Air flow meter
Speedometer
Hall-Effect Sensor
Air- Fuel Ratio meter

Proximity Sensor
Alarm sensor
Doppler Radar
Motion Detector

Optical Sensor
Photodiode
Infrared sensor
Camera

Electric Current Sensors
Hall Probe
Magnetometer
Current sensor
Voltage Detector

Navigation Instruments
LIDAR
Gyroscope Rotary
Encoder Odometer
Tachometer



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1. Camera

Vision processing requires a lot of RAM, and even low resolution cameras may give lots of data, parsing through which can be difficult.

Cameras draw in around 0.1 A current, the current rating of the USB hub to which they are attached must be checked.

Raspberry Pi Camera

Advamotion

Image Processing vs. Computer Vision

Image Processing

- Research area associated with signal processing
- Transforms raw images into ‘better’ images through filtering, compression and enhancement techniques

image   image

Computer Vision

- Research area used in artificial intelligence
- Concerned with extracting useful data from an image and using it for making some further logical computation

Source: http://www.cc.gatech.edu/~hays/research/obj_detect_teaser.jpg

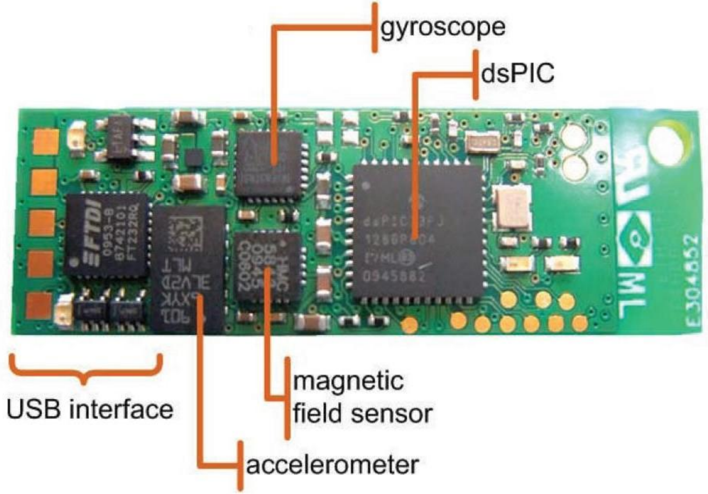
2. Inertial Measurement Unit

Consists of three sensors

- **Accelerometer :** Used to measure inertial acceleration

- **Gyroscope :** Measures angular velocity about defined axis

- **Magnetometer :** Can be used along with gyroscope to get better estimates of robot's orientation (i.e. roll, pitch, yaw)



Miniaturized IMU developed at [ETH Zurich]

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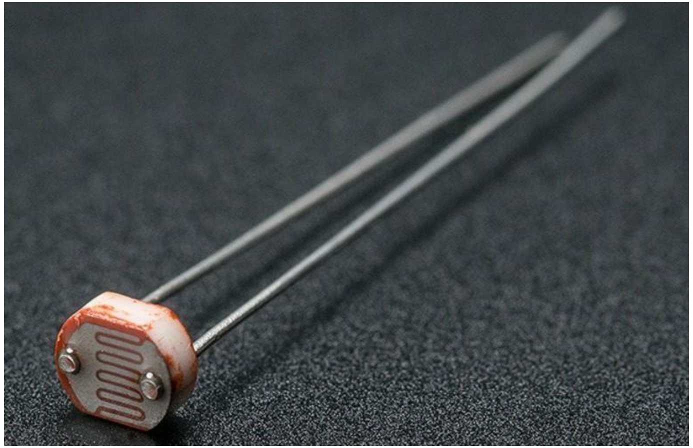
3. Photo-Resistors

Light sensitive resistors whose **resistance decreases as the intensity of light they are exposed to increases.** They are made of high resistance semiconductor material.



WORKING - When light hits the device, the photons give electrons energy. This makes them jump into the conductive band and thereby conduct electricity.

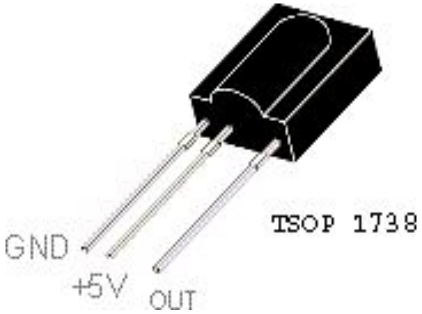
4. Infrared Sensor

The TSOP 17XX is the most commonly used IR receiver. The last two digits indicate the frequency of the modulated IR signals that it responds to so that other signals in the environment do not interfere.

A photodiode can also be used as a receiver, but it doesn't have response only for some specific frequency.

The TSOP gives an active low output.

It can also be used for colour detection.

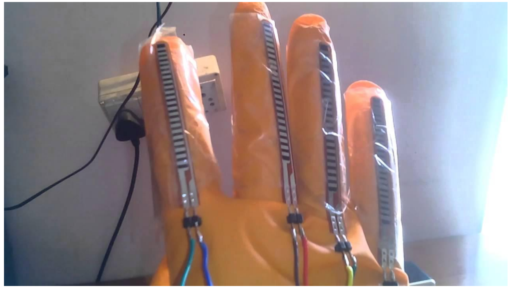


HEAT SENSING

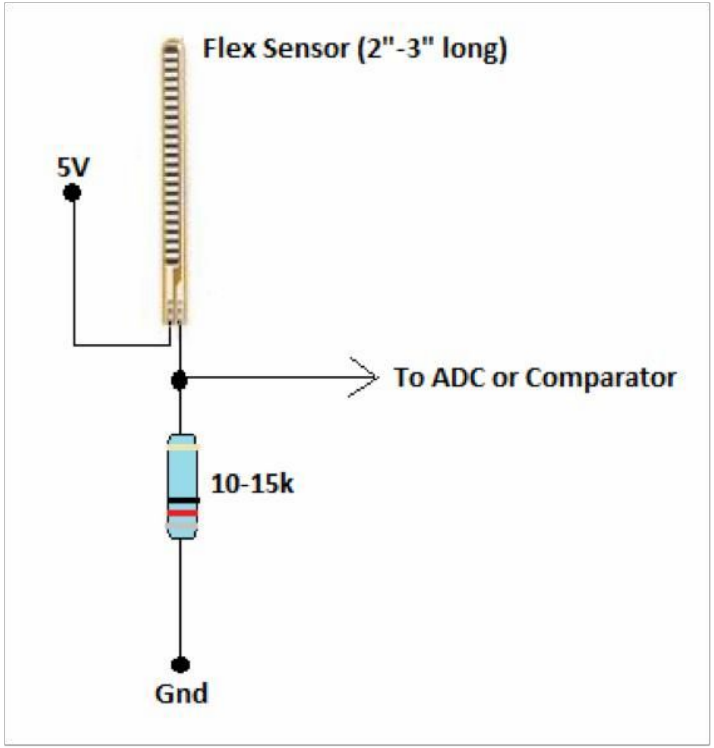
5. Flex Sensors

Measure the amount of deflection caused by bending, also called bend sensors.

The bending must occur around a radius of curvature, as by some angle at a point isn't effective and if done by more than 90 deg., may permanently damage the sensor.



HAND GESTURE SENSING



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6. Ultrasonic Sensor

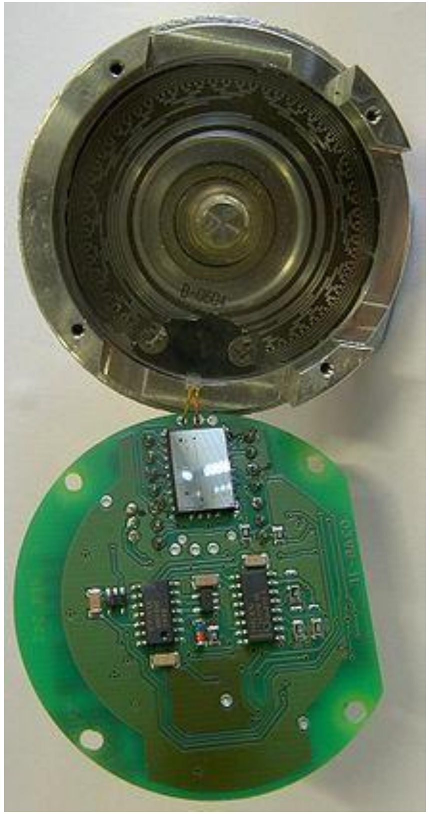
These are commonly used for obstacle detection.

Works on the Principle which is similar to that of SONAR systems, which consists of **time of flight**, the **Doppler effect** and the **attenuation of sound waves.**

7. Rotary Encoder

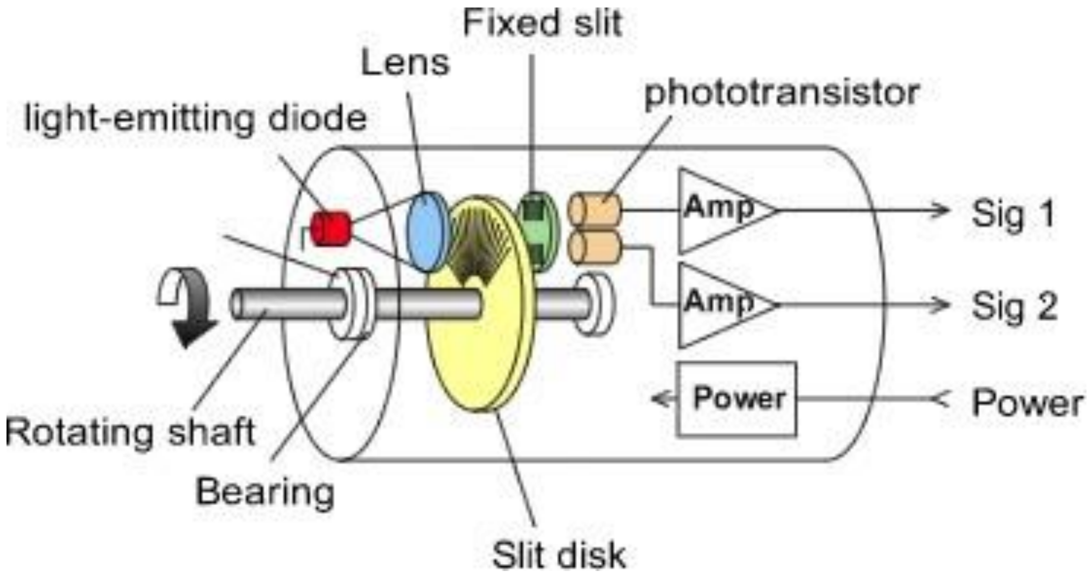
They convert the angular position of a shaft or axle to a analog / digital code.

They may represent the value in **absolute** or **incremental terms**. The advantage of absolute encoders is that they maintain the information of the position even when power is removed, and this is available immediately on its application.



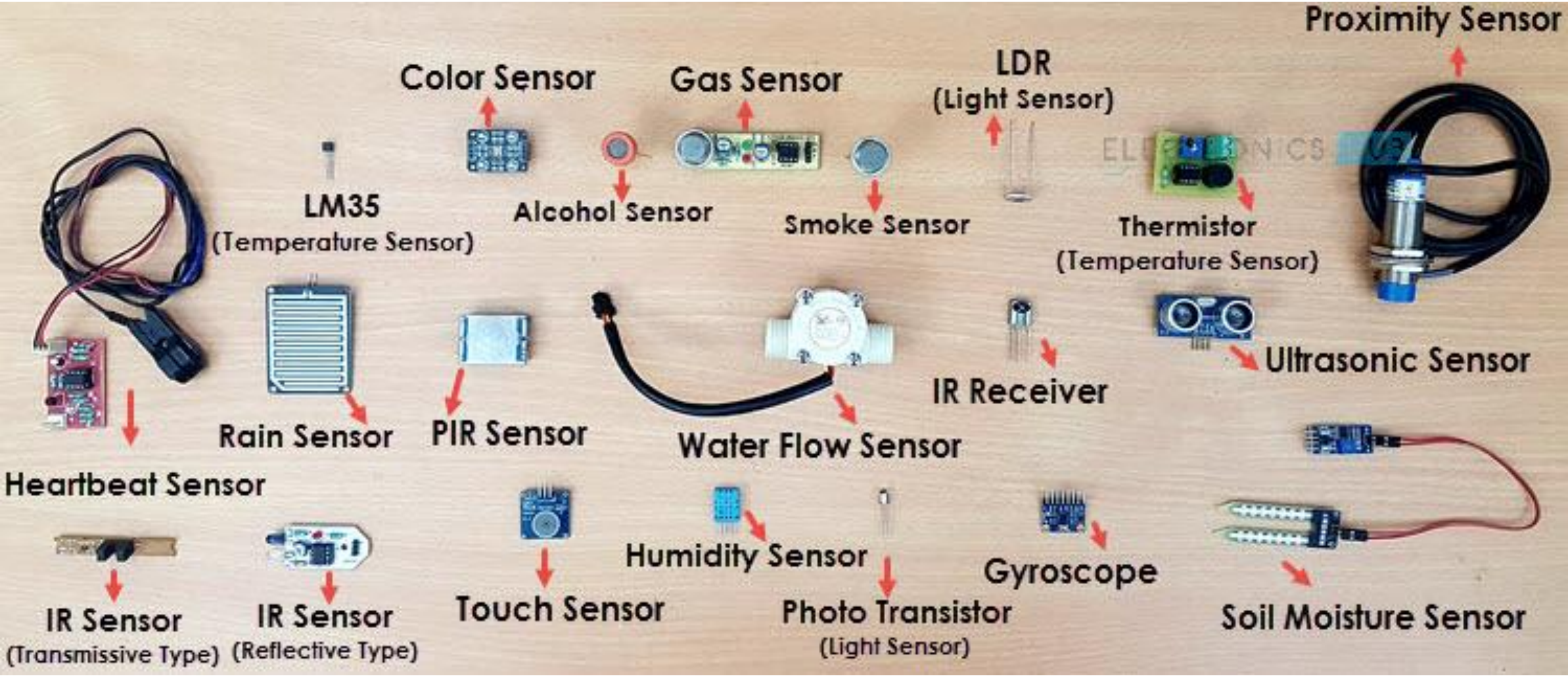
Incremental Rotary Encoder

It provides cyclical outputs (only) when the encoder is rotated.



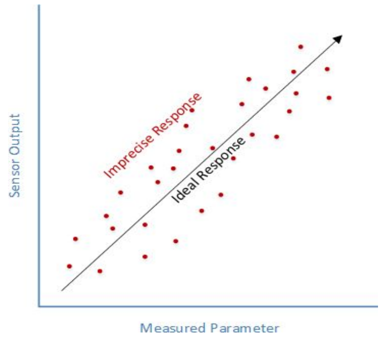
Source: https://www.onosokki.co.jp/English/hp_e/products/category/images/rp_principle_e.gif

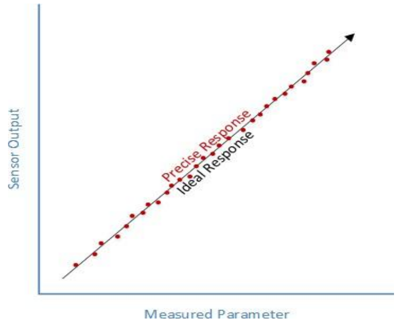
REAL MODEL OF SOME SENSORS



What makes a good sensor?

- **Precision:** An ideal sensor produces same output for same input. It is affected by noise and hysteresis.
- **Resolution:** The ability to detect small changes in the measuring parameter
- **Accuracy:** ‘It is the combination of precision, resolution and calibration.’





Source: https://learn.adafruit.com/calibrating-sensors/why-calibrate

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Calibration of Sensors

Most sensors are **not ideal** and are often affected by **surrounding noise**. For a color sensor, this could be ambient light, and specular distributions.

If a sensor is known to be accurate, it can be used to make comparison with reference readings. This is usually done with respect to certain standard physical references, such as for a rangefinder we may use a ruler for calibration.

Each sensor has a 'characteristic curve' that defines the sensor's response to an input. The **calibration process** maps the sensor's response to an ideal linear response

Characteristic Curve of Sensor

Suppose the output of a sensor for some physical quantity *x(t)* is given by *f(x(t))*:

- Linear Model

$$f(x(t)) = ax(t) \quad \text{, where} \quad a \in \mathbb{R}$$

- Affine Model

$$f(x(t)) = ax(t) + b \quad \text{, where} \quad , a \in \mathbb{R} \quad b \in \mathbb{R}$$

Often, 'a' is called the **proportionality constant**, which gives an idea of the sensitivity of the sensor, and 'b' denotes the **bias**.

Note: The sensitivity of a sensor is ratio of output value to measured quantity.

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Sensor’s Operating Range

If the operating range of a sensor is *(L, H)*,

$$f(x(t)) = \begin{cases} ax(t) + b & \text{if } L \leq x(t) \leq H \\ aH + b & \text{if } x(t) > H \\ aL + b & \text{if } x(t) < L, \end{cases}$$

To get an idea of how precise the measurements of a sensor can be, one defines its **precision ‘p’** as the smallest difference between two distinguishable sensor readings of the physical quantity.

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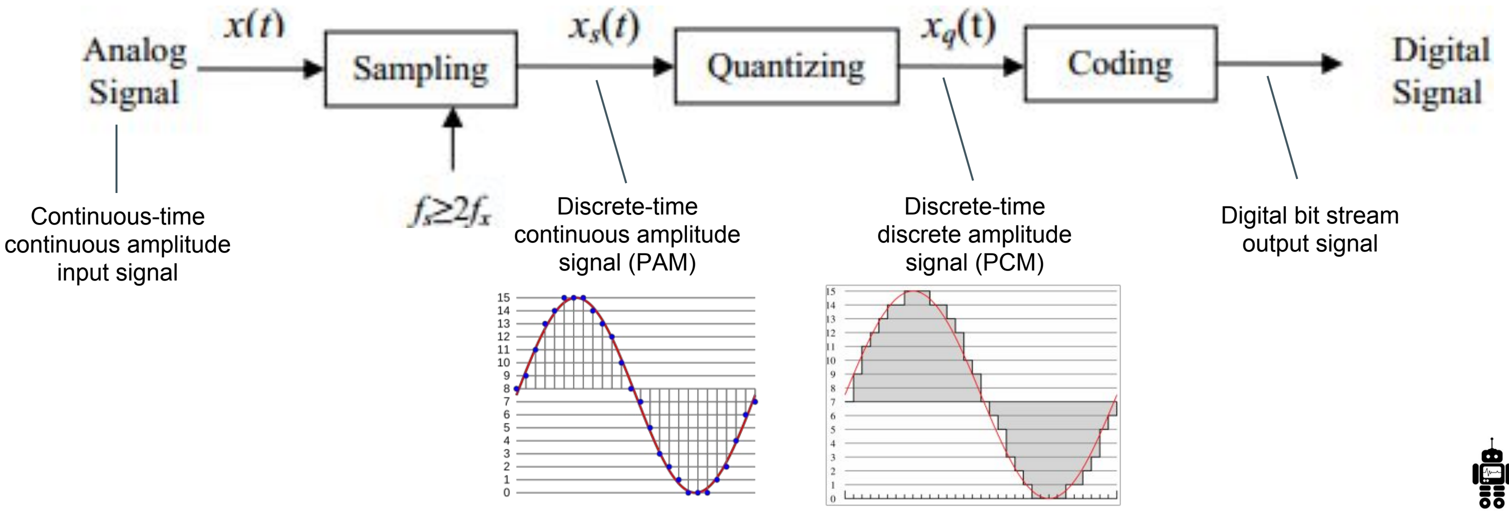
Sampling and Quantisation

The **process of the discretization** of the domain of the signal being measured is called sampling, whereas quantization refers to the **discretisation of the range**.

Pulse Code Modulator

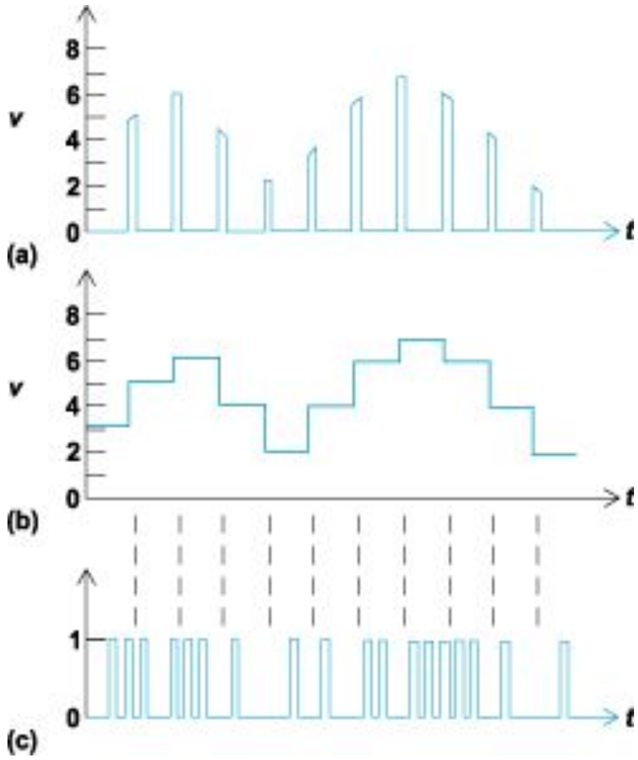


Sampling and Quantisation

SAMPLING: Evaluating the input signal at discrete units of time, say *0, T, 2T, ... nT.*

QUANTIZING: Provides discretized values to the input on basis of a finite number of thresholding conditions

ENCODING: Transforms the digital data into a digital signal, comprising of bits 0111011…, on basis of various schemes.



Manchester Line code

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Sampling and Quantisation

- If the **sampling rate** isn't high, one can end up with different signals(aliases) during reconstruction, that fit the same set of sample points. This is called aliasing, and is undesirable. For best sampling, the sampling rate must be >= 2 times the frequency of the signal. **(Nyquist Shannon Sampling Theorem)**
- In the case of quantisation, selection of fewer **levels of discretisation** can lead to progressive loss of spatial detail. Also, contours(artificial boundaries) can start appearing due to sudden changes in intensity. For audio signals, this can be heard as noise/distortions.

ACTUATORS

TYPES OF ACTUATORS

In a robot, actuators are used in order to produce some mechanical movement.

Electric

Electro-mechanical devices which allow movement through use of electrically controlled systems of gears

DC Motor

Hydraulic

Transforms energy stored in reservoirs into mechanical energy by means of suitable pumps

Water Pump by Tefulong Ltd.

Pneumatic

Uses pneumatic energy provided by air compressor and transforms it into mechanical energy by means of pistons or turbines

Pneumatic cylinder by Janatics Ltd.

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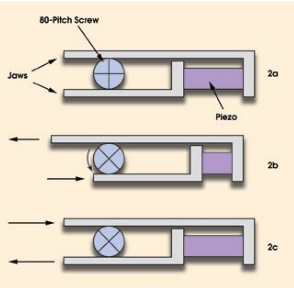
TYPES OF ACTUATORS

In a robot, actuators are used in order to produce some mechanical movement.

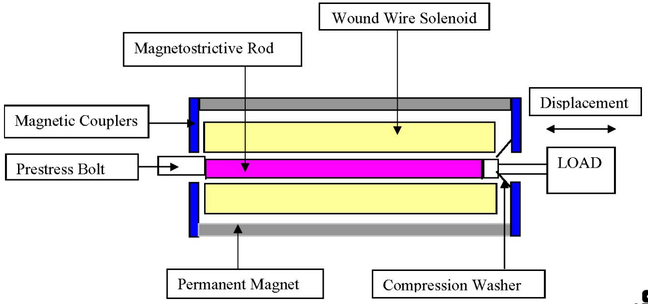
Piezoelectric

A piezoelectric motor is a type of electric motor based on the change in shape of a piezoelectric material when an electric field is applied.



Magnetostrictive

The Magnetostrictive Actuators are solid state magnetic actuators. A current driven coil surrounding the magnetostrictive rod generates the expansion of the rod.



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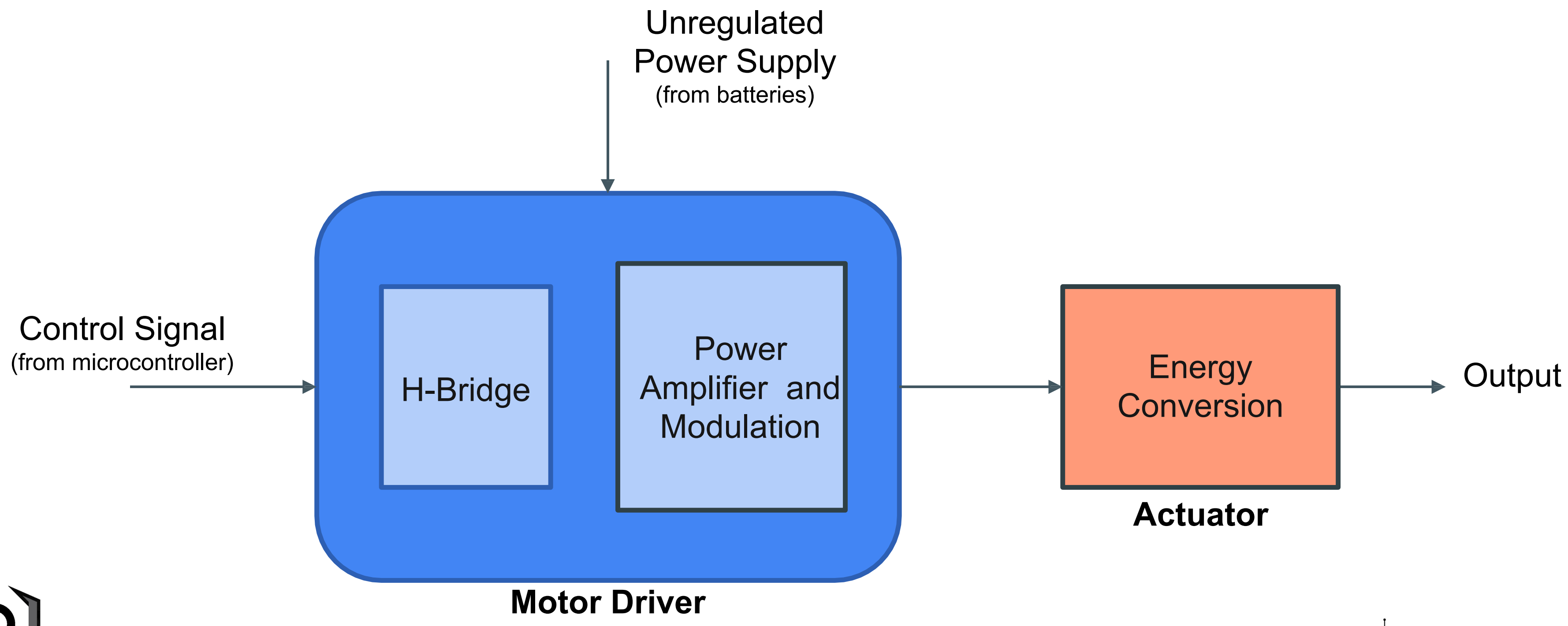
ACTUATOR FUNCTIONAL DIAGRAM

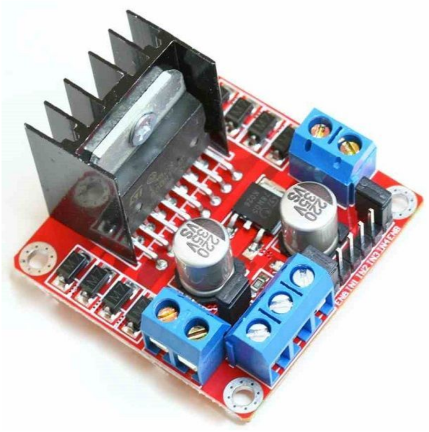


MOTOR DRIVER

- Microcontrollers, typically, have current rating of 5-10 mA, while motors draw a supply of 150mA. This means motors can’t be directly connected to microcontroller.

- For electromechanical actuators, following motor drivers are often used:

  - **Simple DC Motors:** L298, L293
  - **Servo Motors:** Already have power cable and different control cable
  - **Stepper Motors:** L/R Driver Circuit, Chopper Drive



L298N Stepper Motor Driver Controller

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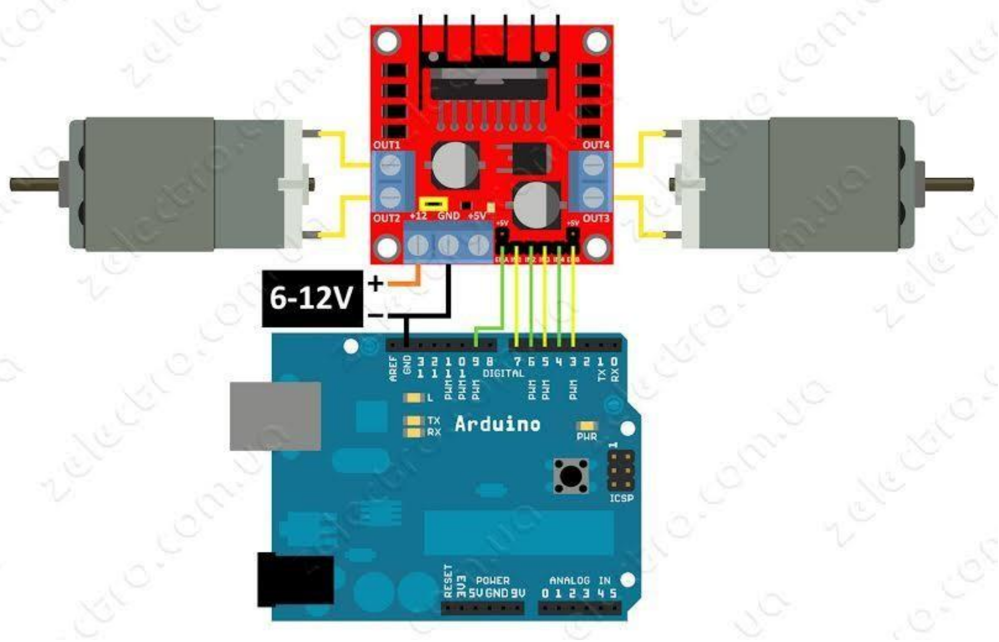
Lft98 DUAL H-BRIDGE IC

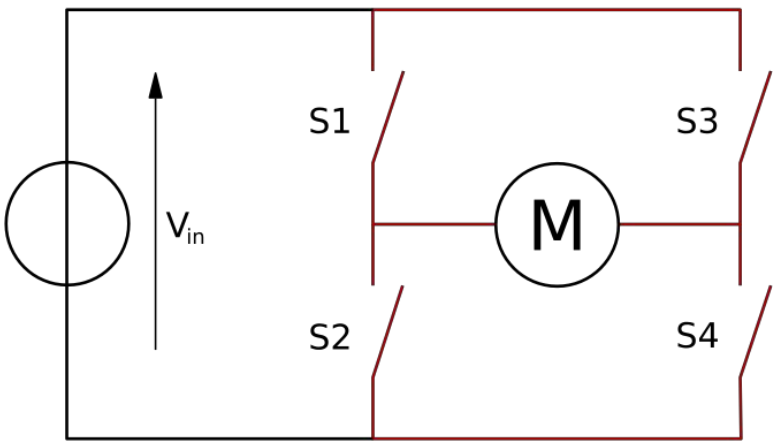
- Allowsto independentlycontrol two DC motors up to 2 A each in both directions.
- Power consumption for logical part 0-36 mA
- Requires protective diodes against back e.m.f. externally



Connections to L298 Dual H-Bridge 2A

H- BRIDGE

It is an electronic circuit used to apply voltage across a load in either direction on basis of input from a microcontroller



S1	S2	S3	S4	Result
1	0	0	1	Motor moves right
0	1	1	0	Motor moves left
0	0	0	0	Motor coasts
0	1	0	1	Motor brakes
1	0	1	0	Motor brakes
1	1	0	0	Short circuit
0	0	1	1	Short circuit
1	1	1	1	Short circuit

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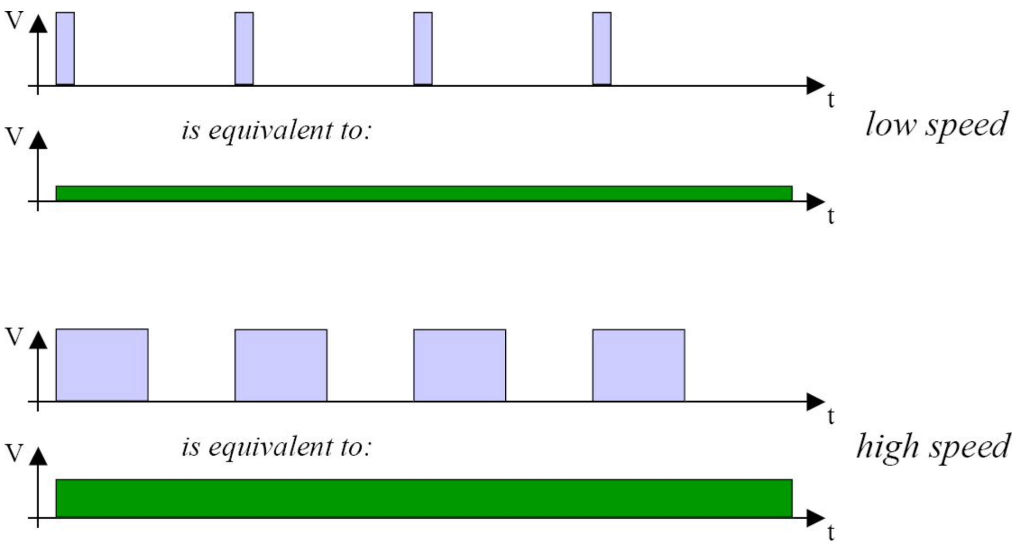
SPEED CONTROL USING PWM

- Pulse Width Modulation (PWM) is scheme in which duty cycle of square wave output fromthe microcontroller is varied by providing a varying average DC output
- Voltage seen by the load is directly proportional to the unregulated source voltage

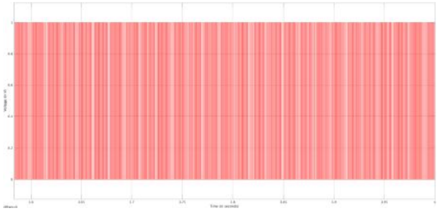


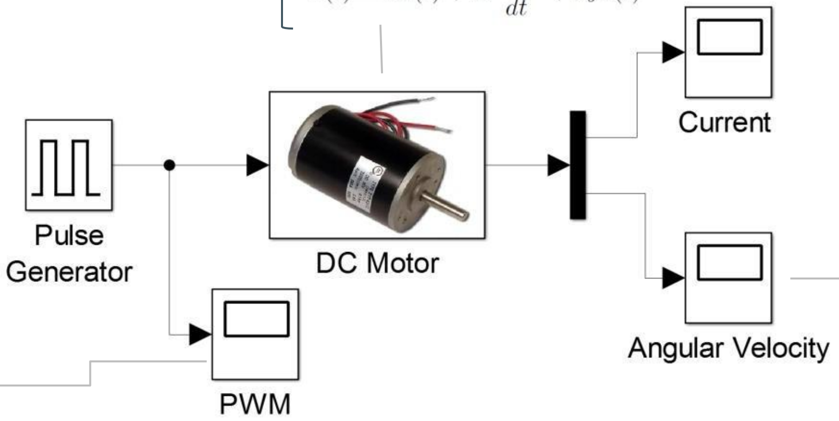
MATLAB SIMULATION

Model Equations:

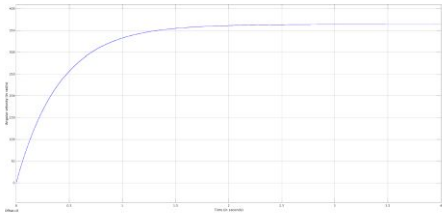
$$\begin{cases} I\dfrac{d\omega(t)}{dt} = k_T i(t) \\[2ex] v(t) = Ri(t) + L\dfrac{di(t)}{dt} + k_b\omega(t) \end{cases}$$

Duty Cycle: 10%
Amplitude: 1V
Frequency: 1kHz





Saturates at angular velocity of 370 rpm



More information: http://ctms.engin.umich.edu/CTMS/index.php?example=MotorSpeed&section=SystemModeling

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