Sri Venkateswara College of Engineering

MECHANICAL ENGINEERING DEPARTMENT

ME 18703 MECHATRONICS

UNIT – I SENSORS, TRANSDUCERS AND ACTUATORS 10 hrs

Static Characteristics of Sensor

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UNIT - I SENSORS, TRANSDUCERS AND ACTUATORS 10

- **Static Characteristics of Sensor**
- Dynamic Characteristics of Sensor
- Potentiometers
- LVDT – Capacitance sensors
- Strain gauges – Load cell
- Eddy current sensor – Hall effect sensor
- Temperature sensors – Light sensors
- Types of Stepper motors – Construction – Working Principle – Advantages and Disadvantages.
- Types of Servo motors – Construction – Working Principle – Advantages and Disadvantages.

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Contents : Sensors and Transducers

Static Characteristics

- Range and span
- Error
- Accuracy
- Precision
- Sensitivity
- Hysteresis error
- Non-linearity error
- Repeatability / reproducibility
- Stability
- Drift
- Dead band/time
- Resolution
- Output impedance
- Threshold

Dynamic Characteristics

- Response time
- Time constant
- Rise time
- Settling time
- Fidelity
- Lag

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Sensors and Transducers

- **Sensor** is an element which produces a signal relating to the quantity being measured.
- Ex: electrical resistance temperature element, the quantity being measured is temperature and the sensor transforms an input of temperature into a change in resistance.
- **Transducer** is the term often used in place of the term sensor.
- Transducers are defined as elements that when subject to some physical change experience a related change. (Convert signals from one form to another form of energy)
- A sensor/transducer is said to be analogue if it gives an output which is analogue and so changes in a continuous way and typically has an output whose size is proportional to the size of the variable being measured.
- The term digital is used if the systems give outputs which are digital in nature, i.e. a sequence of on/off signals whose value is related to the size of the variable being measured.

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Sensors and Transducers

- **Smart sensors** where the sensor and signal conditioning combined with a microprocessor in the same package.
- A smart sensor have the ability to compensate for random errors.
- To adapt to changes in the environment: an automatic calculation of measurement accuracy, adjust for non-linearities to give a linear output, self-calibrate and give self-diagnosis of faults.
- Such sensors have their own standard, IEEE 1451, can be used in a 'plug-and-play' manner, holding and communicating data in a standard way.
- Information is stored in the form of a TEDS (Transducer Electronic Data Sheet), generally in EEPROM, and identifies each device and gives calibration data.

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Static and Dynamic Characteristics:

- **The static characteristics** are the values given when steady-state conditions occur, i.e. the values given when the transducer has settled down after having received some input.
- **The dynamic characteristics** refer to the behavior between the time that the input value changes and the time that the value given by the transducer settles down to the steady-state value.

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- **Dynamic characteristics** are stated in terms of the response of the transducer to inputs in particular forms.
- For example –
  - a step input when the input is suddenly changed from zero to a constant value, or
  - a ramp input when the input is changed at a steady rate, or
  - a sinusoidal input of a specified frequency.

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Sensors and Transducers – Static Characteristics

1. **Range and span:** It defines the limits between with in which the input can vary.
   - The span is the maximum value of the i/p minus the minimum value. (Max-Min)
   - Example, a load cell for the measurement of forces have a range of 0 to 50 kN and a span of 50 kN .
2. **Error:** Error is the difference between the result of the measurement and the true value of the quantity being measured: error = measured value - true value
   - Ex: if a measurement system gives a temperature reading of 25°C when the actual temperature is 24°C, then the error is +1°C.
   - If the actual temperature had been 26°C then the error would have been -1°C.
   - A sensor might give a resistance change of 10.2Ω when the true change should have been 10.5Ω. The error is -0.3Ω.

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3. Accuracy:

- ❖ Accuracy is the extent to which the value indicated by a measurement system might be wrong.
- ❖ The summation of all the possible errors that are likely to occur, as well as the accuracy to which the transducer has been calibrated.
- ❖ Ex: A temperature-measuring instrument specified as having an accuracy of ±2°C. the reading is expected to lie within plus or minus 2°C of the true value.
- ❖ Accuracy is often expressed as a percentage of the full range output or full-scale deflection.
- ❖ The percentage of full-scale deflection term results from when the outputs of measuring systems were displayed almost exclusively on a circular or linear scale.
- ❖ Ex: An accuracy of ±5% of full range output. If the range of the sensor, say, 0 to 200°C, then the reading given can be expected to be within ± 10°C of the true reading.

Precision

- ❖ An equipment which is precise is not necessarily accurate.
- ❖ Defined as the capability of an instrument to show the same reading when used each time (reproducibility of the instrument).

Darts on a dartboard illustrate the difference between accuracy and precision.

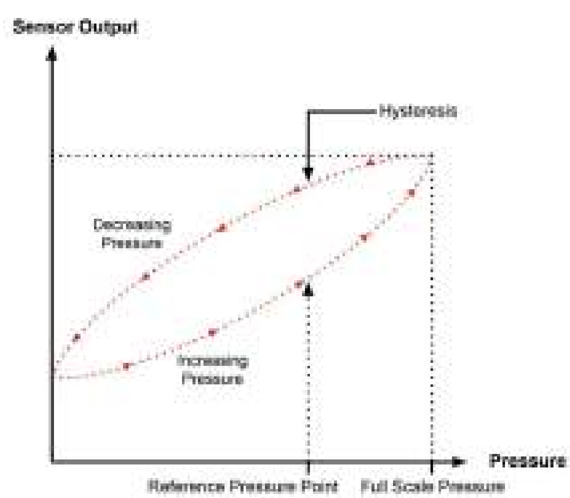
Good Accuracy, Good Precision | Poor Accuracy, Good Precision | Poor Accuracy, Poor Precision

4 Sensitivity:

- It is the relationship indicating how much output there is per **unit** input, i.e. output/input. Minimum input of physical parameter that will create a detectable output change.
- For example, a resistance thermometer may have a sensitivity of 0.5Ω/°C. indicates the sensitivity to inputs other than that measured, i.e. environmental changes.
- A transducer for the measurement of pressure is having a temperature sensitivity of ±0.1 % of the reading per °C change in temperature.

5. Hysteresis error

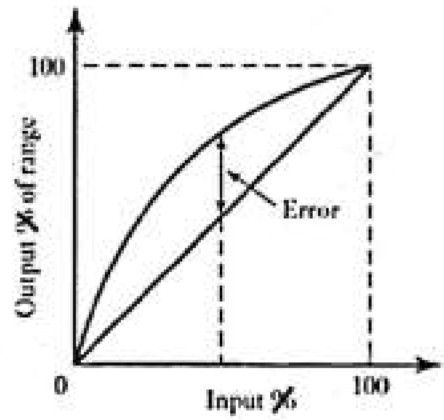
- Transducers can give different outputs from the same value of quantity being measured according to whether that value has been reached by a continuously increasing change or a continuously decreasing change.
- Figure shows such an output with the hysteresis error as the maximum difference in output for increasing and decreasing values.



6 Non-linearity error

Figure: Non-linearity error using: (a) end-range values

- Linear relationship (Straight line) between the input and output is assumed over the working range.
- The error is defined as the maximum difference from the straight line.
- The error is generally quoted as a percentage of the full range output.
- For example, a transducer for the measurement of pressure might be quoted as having a non-linearity error of ±0.5% of the full range.



- In (a) method, the error shown the straight line joining the output values at the end points of the range

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Figure: Non-linearity error using: (b) best straight line for all values

- In (b) method, to find the straight line by using the method of least squares to determine the best fit line when all data values are considered equally likely to be in error

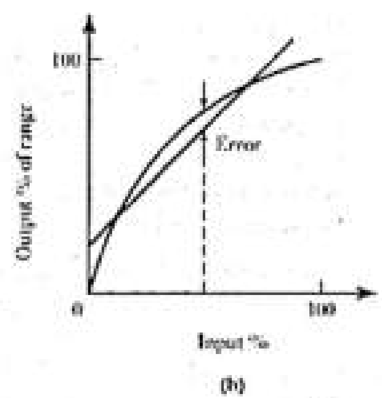

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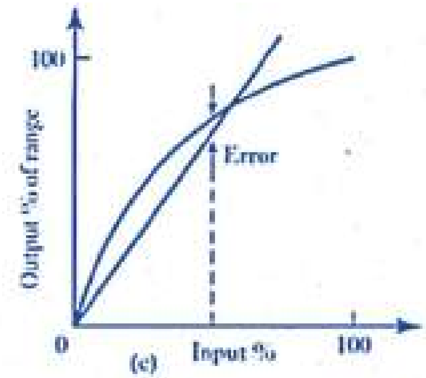
Figure: Non-linearity error using (c) best straight line through zero point.

- In (c) method, to find the straight line by using the method of least squares to determine the best fit line which passes through the zero point:



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7 Repeatability / 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.
- The error resulting from the same output not being given with repeated applications is 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 typically might be quoted as having a repeatability of ±0.01% of the full range at a particular angular velocity.

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8 Stability

- The stability of a transducer is its ability to give the same output when used to measure a constant input over a period of time.
- The term drift is often used to describe the change in output that occurs over time.
- The drift may be expressed as a percentage of the full range output.
- The term zero drift is used for the changes that occur in output when there is zero input.

9 Dead band/time

- The dead band or dead space of a transducer is the range of input values for which there is no output.
- For example, bearing friction in a flow meter using a rotor might mean that there is no output until the input has reached a particular velocity threshold.
- The dead time is the length of time from the application of an input until the output begins to respond and change.

10 Resolution

- When the input varies continuously over the range, the output signals for some sensors may change in small steps.
- A wire-wound potentiometer is an example of such a sensor, the output going up in steps as the potentiometer slider moves from one wire turn to the next.
- The resolution is the smallest change in the input value that will produce an observable change in the output.
- For a wire-wound potentiometer the resolution might be specified as, say, 0.5° or perhaps a percentage of the full-scale deflection.
- For a sensor giving a digital output the smallest change in output signal is 1 bit. Thus for a sensor giving a data word of N bits, i.e. a total of 2N bits, the resolution is generally expressed as 1/2N.

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11 Output impedance

- When a sensor giving an electrical output is interfaced with an electronic circuit it is necessary to know the output impedance since this impedance is being connected in either series or parallel with that circuit.
- The inclusion of the sensor can thus significantly modify the behavior of the system to which it is connected.
- Example: Specification of a strain gauge pressure transducer:
- Ranges: 70 to 1000 kPa, 2000 to 70000 kPa
- Supply voltage: 10V d.c. or a.c. r.m.s.
- Thermal zero shift: 0.030% full range output/°C
- Full range output: 40 mV
- Non-linearity and hysteresis: ±0.5% full range output
- Temperature range: -54°C to +120°C when operating

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12 Drift

- Drift is a variation in the instrument output which is not caused by any change of input, it may be caused by internal temperature changes and component instability.
- The drift is a gradual shift of the instrument indication.
- Many environmental factors are cause of drift such as - stray electric and magnetic field, temperature changes, change in atomic structure, mechanical vibration, wear and tear, corrosion, aging of components.
- The drift becomes significant when an instrument is used for long time.
- Zero drift is the change in output from its set zero value over a period of time. The whole instrument calibration may gradually shift by same amount.

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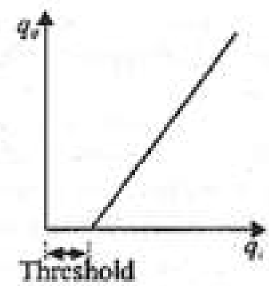
13 Threshold

- Suppose an instrument is in its zero position, i.e. there is no input to it.
- If now an input is gradually applied to it, the instrument will require some minimum value of input before it shows any output.
- This minimum input which is necessary to activate an instrument to produce an output is termed its threshold.



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Dynamic Characteristics

- If a measuring device is used for measuring any rapidly varying quantity, the relation between output and input is different than in case of static inputs.
- This is called as dynamic response of the device. The dynamic response of the system can be expressed by differential equations. (Zero order, First order, Second order etc...)
- The dynamic characteristics of a device depends on the order of differential equations, When it is a linear differential equation, the device is dynamically linear.

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First order instrument

- First order instruments are characterized by one parameter called time constant (τ) of system. The first order system is represented by

$$\tau \dot{y} + y = x(t)$$

where, $x(t) \rightarrow$ Time function of input

and $y \rightarrow$ Output of system

- Lower time constant represents fast response and minimum error.

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Second order instrument

- A second order instrument is characterized by two constants natural response (ω_n) and damping ratio (ζ) of the instrument. The second order system is represented by -

$$\frac{1}{\omega_n^2}\ddot{y} + \frac{2\zeta}{\omega_n}\dot{y} + y = x(t)$$

where, ω_n is expressed in rad/sec.

ζ is a non dimensional quantity. This indicates the relative stability of the system

- Second order system is either poorly damped system. i.e. oscillatory output for transient input or highly damped system. i.e. sluggish response, it takes considerable time to reach to steady state.

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Types of Inputs

- To study dynamic behaviour of a measuring device, some standard inputs are applied, these are,
    - 1. Step input
    - 2. Ramp input
    - 3. Impulse input
    - 4. Parabolic input
    - 5. Sinusoidal input
- Examples of dynamic characteristics are - speed of response, fidelity, lag and dynamic error.

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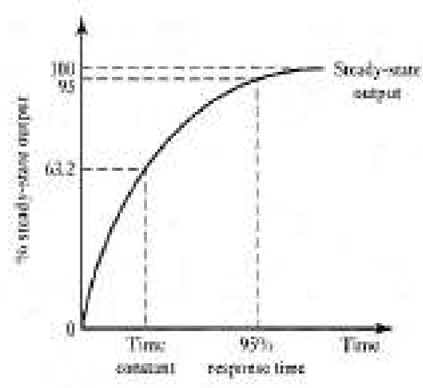
Dynamic Characteristics

1. Response time

- This is the time which elapses after a constant input, a step input, is applied to the transducer up to the point at which the transducer gives an output corresponding to some specified percentage, e.g. 95%, of the value of the input (Figure).
- For example, if a mercury-in-glass thermometer is put into a hot liquid there could be an appreciable time lapse, perhaps as much as 100 s or more, before the thermometer indicates 95% of the actual temperature of the liquid.

Figure: Response to a step input:



2 Time constant

- This is the 63.2% response time.
- A thermocouple in air might have a time constant of perhaps 40 to 100 s.
- The time constant is a measure of the inertia of the sensor and so how fast it will react to changes in its input.
- The bigger the time constant, the slower the reaction to a changing input signal.

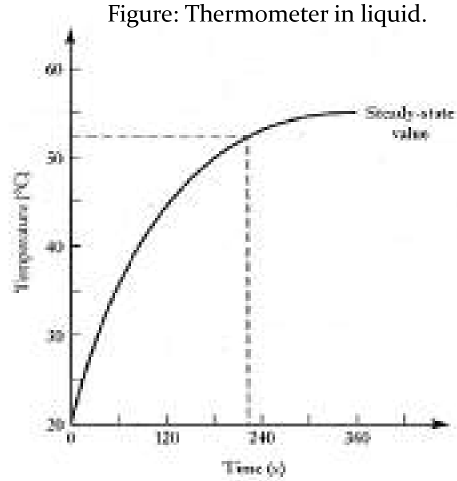
3 Rise time

- This is the time taken for the output to rise to some specified percentage of the steady-state output.
- Often the rise time refers to the time taken for the output to rise from 10% of the steady-state value to 90% or 95% of the steady-state value.

4. Settling time

- This is the time taken for the output to settle to within some percentage, e.g. 2%, of the steady-state value.
- The graph indicates an instrument reading changed with time, being obtained from a thermometer plunged into a liquid at time t = 0.
- The steady-state value is 55°C and so, since 95% of 55 is 52.25°C, the 95% response time is about 228 s.

Figure: Thermometer in liquid.



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5 Fidelity

- Fidelity is the ability to reproduce the changes in input signal faithfully.
- It is defined as the degree to which an instrument indicates the changes in the measured variable without dynamic error.
- Poor fidelity indicates non linearity of the measuring device or instrument.

6 Lag

- The delay in response of a device for a change in input is called as lag. Every measuring device has some definite delay.
- Because of lag the output response along the time axis may be delayed.

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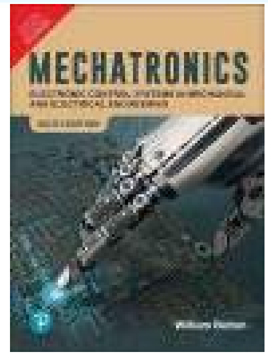

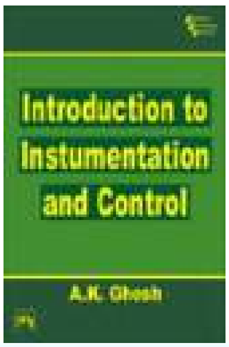

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MECHANICAL ENGINEERING DEPARTMENT

ME 18703 MECHATRONICS

UNIT – I SENSORS, TRANSDUCERS AND ACTUATORS 10 hrs

Potentiometers

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UNIT - I SENSORS, TRANSDUCERS AND ACTUATORS 10

- Static Characteristics of Sensor
- Dynamic Characteristics of Sensor
- **Potentiometers**
- LVDT – Capacitance sensors
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- Eddy current sensor – Hall effect sensor
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Contents :

Displacement and Position Sensors

Variable Resistance Device: Potentiometer [POT]

- Linear potentiometer
- Rotary potentiometer

Linear Variable Differential Transformer (LVDT)

Rotary Variable Differential Transformer (RVDT)

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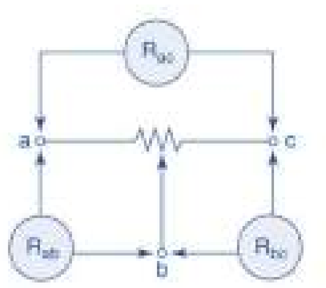
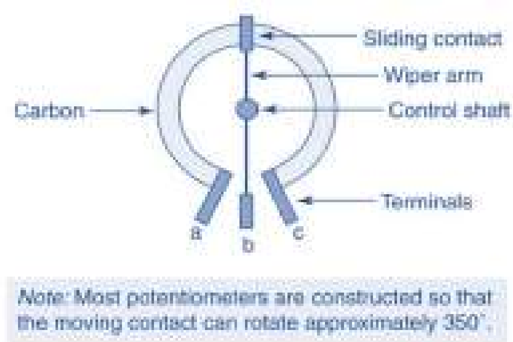
Displacement and Position Sensors

- Displacement sensors: used for the measurement of movement of an object.
- Position sensors: used to determine the position of an object in relation to some reference point.
- Proximity sensors: a type of position sensor and are used to trace when an object has moved with in particular critical distance of a transducer.
- An electrical circuit consists basically of three variable passive components, namely resistance, inductance and capacitance.
- All three of them can be utilized to construct devices for transducting displacement.

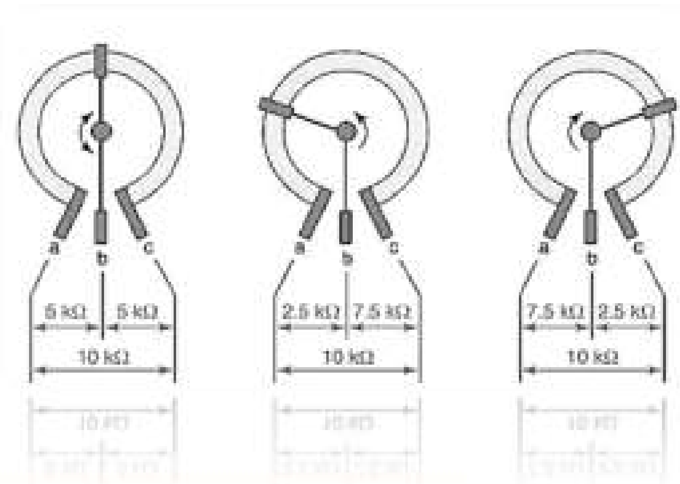
Variable Resistors - Potentiometers

- Potentiometer – a three-terminal resistor whose value can be adjusted (within set limits) with a movable contact by the user
- $R_{ac} = R_{ab} + R_{bc}$





Setting the Value of Resistance



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Potentiometers - POT

- The motion of the contact can be translational, rotational, or helical which is a combination of the two former motions
- A potentiometer can be used to convert rotary or linear displacement into a voltage.
- The potentiometers can be classified into following two types
  - 1. Linear potentiometer
  - 2. Rotary potentiometer

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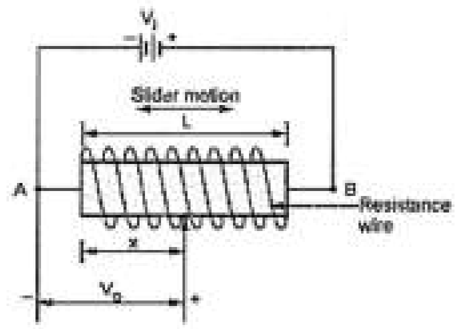
- A potentiometer is the most common position sensor.
- Has a fixed resistor with a movable tap that allows the amount of resistance between the tap and either end of resistor of a total resistance [0 to 100 %].
- Consists of a resistance element with number of turns of wire wound around non-conducting bar together with a sliding contact.
- The linear displacement of the wiper contact is directly converted into proportional output voltage.
- The linear potentiometer is usable in applications where the linear movement must be measured accurately e.g. pressure measurement using diaphragm.

Linear Potentiometer



$V_o = \frac{x}{L} V_i$ or $x = \frac{V_o}{V_i} \cdot L$

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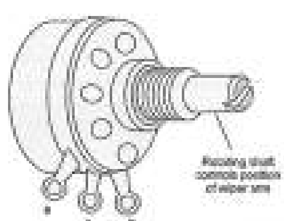
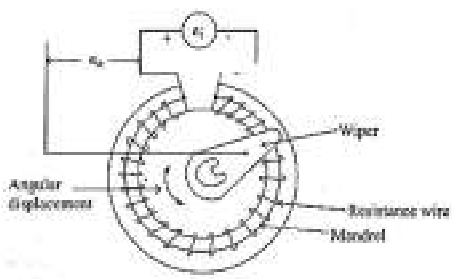
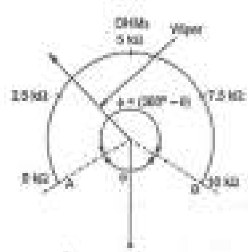
Rotary Potentiometer

- The operation of linear and rotary potentiometer operation is same.
- The main difference is that the shaft of the rotary potentiometer converts rotary motion into the change in resistance.







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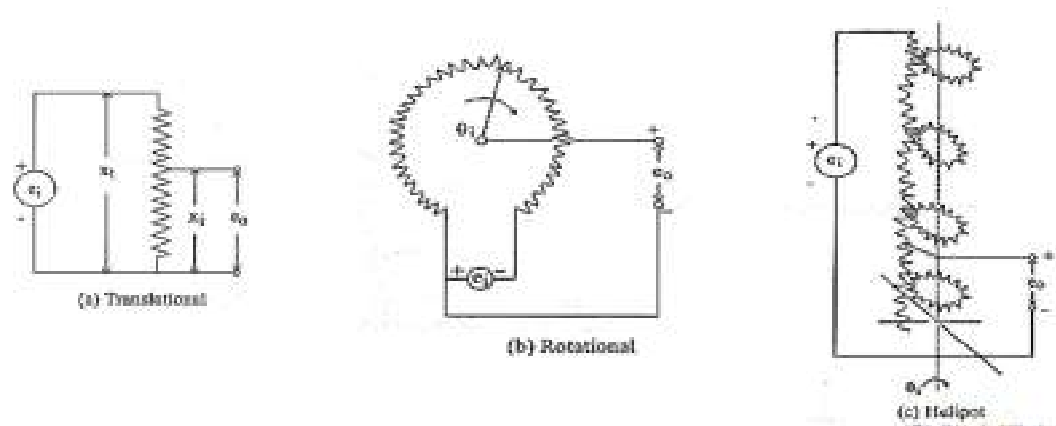
Potentiometer configuration

- Translational, single turn rotational, and multi-turn helix potentiometers.



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$$e_o = \left(\frac{\text{resistance at the output terminals}}{\text{resistance at the input terminals}}\right) X \text{ input voltage} = \left[\frac{R_p\left(\frac{x_i}{x_t}\right)}{R_p}\right] e_i = \frac{x_i}{x_t} \times e_i$$

For the translational potentiometer,

Let, e_i and e_o be the input and output voltage respectively (v)

x_t be the total length of translational pot (m)

x_i be the displacement of wiper from its zero position (m)

R_p be the total resistance of the potentiometer (Ω)

$$\text{Sensitivity } S = \frac{Output}{Input} = \frac{e_o}{x_i} = \frac{e_i}{x_t}$$

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POT Materials

- **Wire wound potentiometers** are platinum, nickel chromium, nickel copper or some other precious resistance elements.
- **Non wire potentiometers** are also called **continuous potentiometers**.
- The materials used for non-wire wound (or continuous) potentiometers are cermet, Hot moulded carbon, carbon and thin metal film.

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Advantages of Resistance Potentiometers

- (i) Inexpensive
- (ii) Simple to operate and very useful for simple applications.
- (iii) Very useful for measurement of large amplitudes of displacement
- (iv) Their electrical efficiency is very high.
- (v) In wire wound potentiometers the resolution is limited, while in cermet metal film potentiometers, the resolution is infinite.

Disadvantages of Resistance Potentiometers

- (i) They require a large force to move their wipers (sliding contacts)
- (ii) The sliding contacts can be contaminated, can wear out, become misaligned and generate noise so that the life of the transducer is limited

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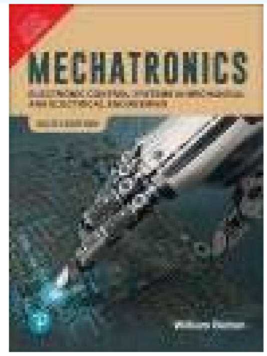
References



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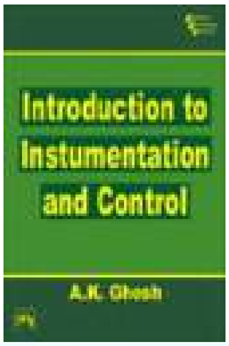

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LVDT

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Rotary Variable Differential Transformer (RVDT)

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Linear Variable Differential Transformer (LVDT) – A Passive Transducer

- The (LVDT) is an inductive transducer to translate the linear motion into electrical signals.
- The transformer consists of a single primary winding P and two secondary windings S1 and S2 wound on a cylindrical former.
- The secondary windings have equal number of turns and are identically placed on either side the primary winding.
- The primary winding is connected to an alternating current source.
- A movable soft iron core is placed inside the former. The displacement to be measured is applied to the arm attached to the soft iron core.
- In practice the core is made of high permeability, nickel iron which is hydrogen annealed.
- This gives low harmonics, low null voltage and a high sensitivity.
- This is slotted longitudinally to reduce eddy current losses.
- The assembly is placed in a stainless steel housing and the end lids provide electrostatic and electromagnetic shielding.
- The frequency of a.c applied to primary windings may be between 50HZ to 20KHZ.

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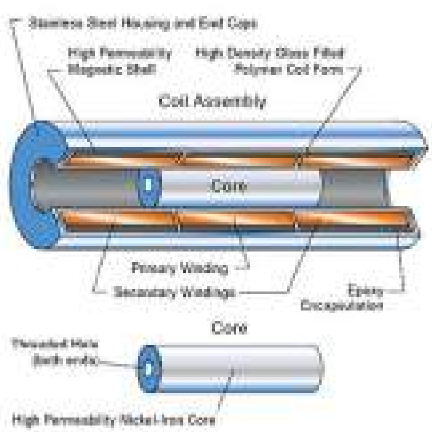
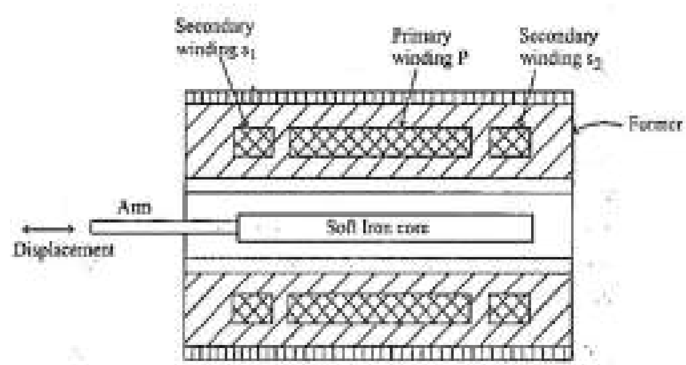
- Since the primary is excited by an alternating current source, it produces an alternating magnetic field which in turn induces alternating current voltages in the two secondary windings.





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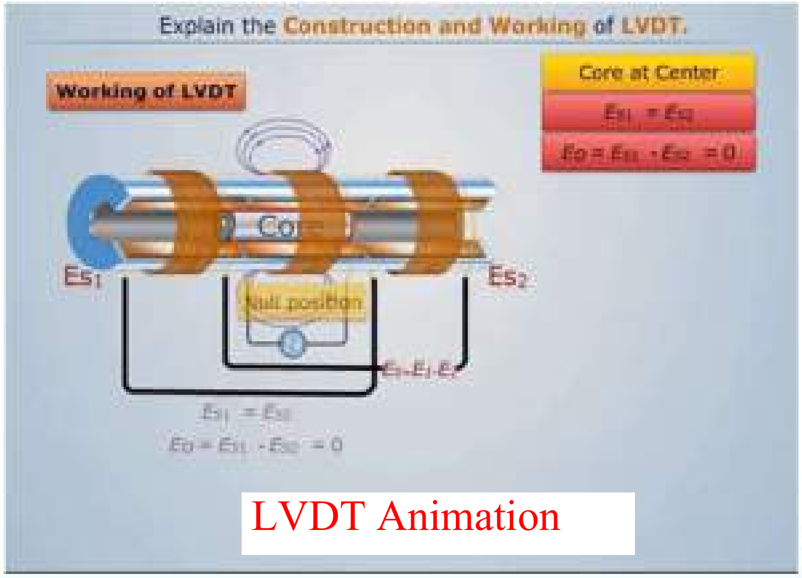
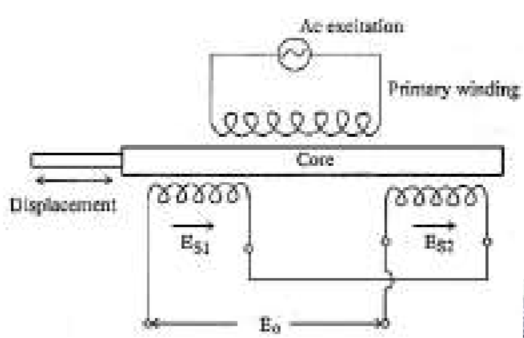


LVDT Animation

- The output voltage of secondary s1 is Es1 and that of secondary s2 is Es2,
- In order to convert the outputs from s1 and s2 into a single voltage signal, the two secondaries s1, and s2 are connected in series opposition .
- The output voltage of the transducer is the difference of the two voltages
- Differential output voltage $E_o = E_{s1} - E_{s2}$
- Thus at null position, $E_{s1}=E_{s2}$



- If the core is moved to the left of the NULL position, more flux links with windings S1 and less with windings S2.
- Accordingly output voltage Es1, of the secondary windings S2 is more than Es2, the output voltage of secondary winding S2.
- The magnitude of output voltage is, thus. Eo = Es1 – Es2 and the output voltage is in phase with say, the primary voltage.
- Similarly if the core is moved to the right of the null position,
- Eo = Es2 – Es1 and is 180° out of phase with the primary voltage.
- Therefore, the two differential voltages are 180° out phase with each other.

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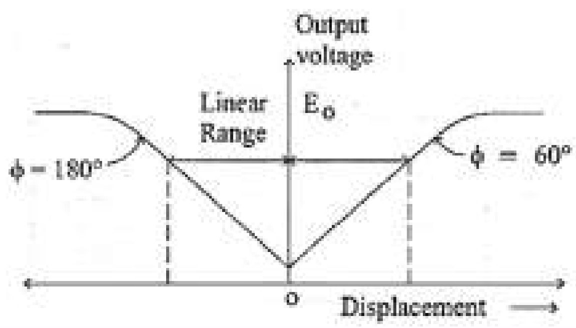
Variation of Output Voltage with Linear Displacement for an LVDT

- The curve is practically linear for a limited range of displacement from the null position. Beyond this range of displacement, the curve starts to deviate from a straight line.



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RVDT (Rotary Variable Differential Transformer)

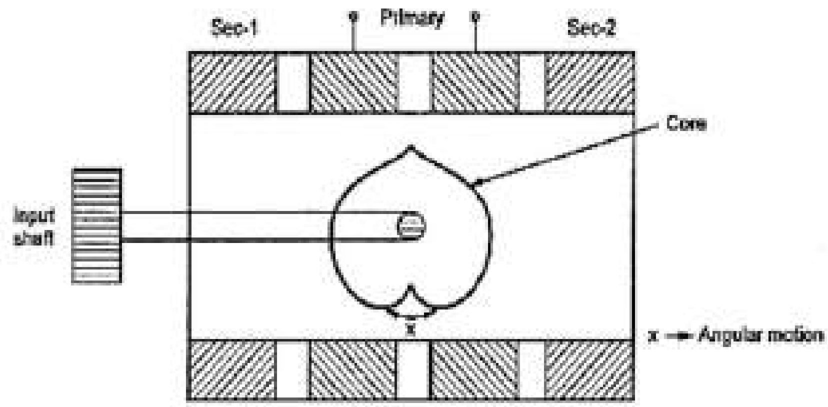

Fig. Rotary variable differential transformer

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Advantages of LVDT

- High range for measurement of displacement ranging from 1.25 mm to 250 mm.
- The absence of friction between coil and core of an LVDT - no wear out - infinite mechanical life.
- The separation between LVDT core and LVDT coils permits the isolation of media
- The LVDT gives a high output and many a times there is no need for amplification.
- High sensitivity which is typically about 40 v/mm.
- These transducers can usually tolerate high degree of shock and vibrations especially when the core is spring loaded without any adverse effects.
- LVDT show a low hysteresis and hence repeatability is excellent under all conditions.
- Low power consumption of LVDT is very less then 1w.

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Disadvantages of LVDT

- Relatively large displacements are required for appreciable differential output
- They are sensitive to stag magnetic fields but shielding is possible.
- The transducer performance is affected by vibrations.
- The receiving instrument must be selected to operate on a.c. signals or a demodulator network must be used if d.c. output is required.
- The dynamic response is limited mechanically by the mass of the core and electrically by the frequency of applied voltage.
- The frequency of the carrier should be at least ten times the highest-frequency component to be measured.
- Temperature affects the performance of the transducers.

Uses of LVDT

- Used to-measure displacement, force, weight, pressures, thickness, etc .

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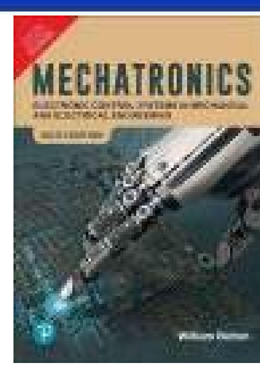

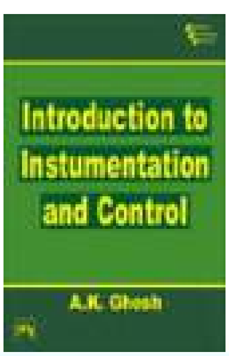

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MECHANICAL ENGINEERING DEPARTMENT

ME 18703 MECHATRONICS

UNIT – I SENSORS, TRANSDUCERS AND ACTUATORS 10 hrs

Capacitance Sensors

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UNIT - I SENSORS, TRANSDUCERS AND ACTUATORS 10

- Static Characteristics of Sensor
- Dynamic Characteristics of Sensor
- Potentiometers
- LVDT
- **Capacitance sensors**
- Strain gauges – Load cell
- Eddy current sensor – Hall effect sensor
- Temperature sensors – Light sensors
- Types of Stepper motors – Construction – Working Principle – Advantages and Disadvantages.
- Types of Servo motors – Construction – Working Principle – Advantages and Disadvantages.

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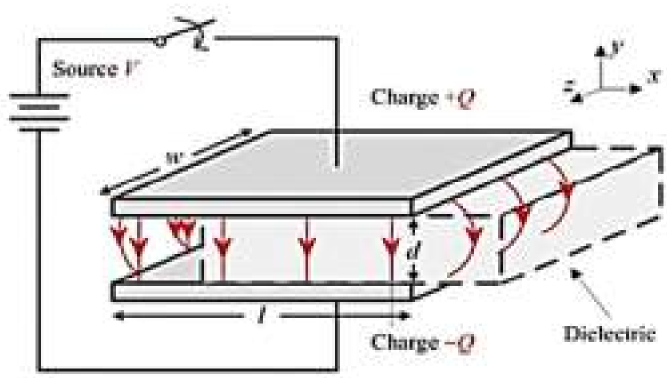
Parallel Plates capacitor



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Capacitive Sensor

- It is used for measuring, displacement, velocity, force etc.
- It is passive type sensor in which *equal* and *opposite* charges are generated on the plates due to voltage applied across the plate which is *separated* by dielectric material.
- A combination of plates which can hold an electric charge is called a capacitor.
- The capacitor may be characterized by q, the magnitude of charge on either conductors, and by V, the positive potential difference between the conductors
- The ratio of charge to voltage is constant for each capacitor, and is called the capacitance (C) of the capacitor.
- The capacitance 'C' of a parallel plate capacitor is given by C = $\frac{\varepsilon_r \varepsilon_0}{d} A$
  - Where ε_r = Permittivity of the dielectric between the plates [= 1 for air]
  - ε_0 = Permittivity of free space [= 8.854×10^{-12} F/m for air]
  - A = Area of overlap between two plates in m^2
  - d = Distance between two plates in m.

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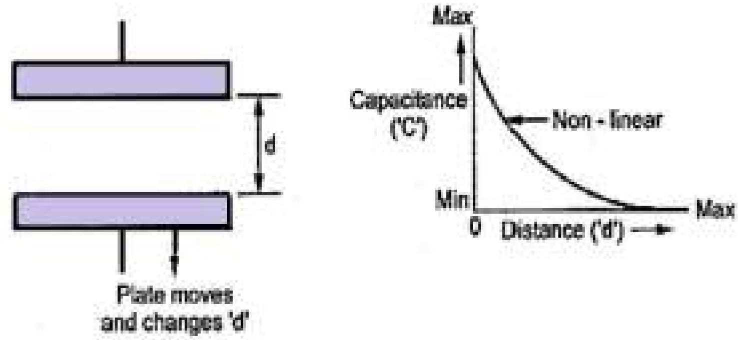
By Changing the distance between two plates:

- The displacement is measured due to the change in capacitance



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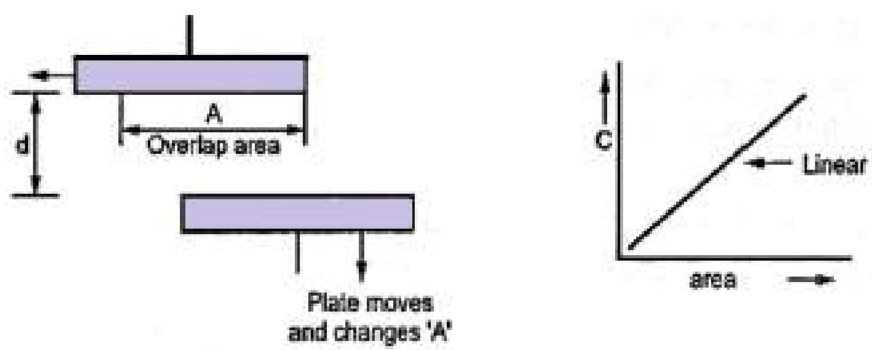
By varying the area of overlap:

- The displacement causes the area of overlap to vary.
- The capacitance is directly proportional to the area of the plates and varies linearly with changes in the displacement between the plates.



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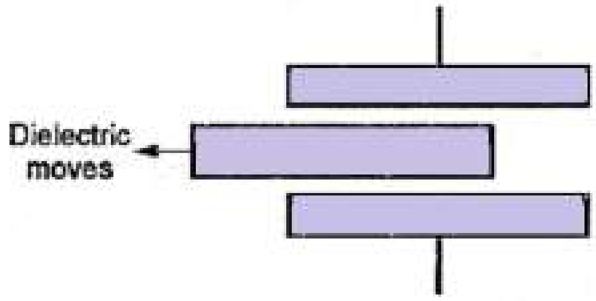
By varying the dielectric constant:

- The change in capacitance can be measured due to change in dielectric constant as a result of displacement.
- When the dielectric material is moved due to the displacement, the material causes the dielectric constant to vary in the region where the two electrodes are separated that results in a charge in capacitance.



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Advantages of Capacitive Sensor

1. It is non-contact type sensor and can be used with any material with resistivity less than 100 Ω/cm²
2. The sensor is extremely rugged and be subjected to high shock loads.
3. Even at high temperature performance of the transducer is very good. (since ε_r is constant for a wide temperature range).
4. Sensitivity is better in different environmental conditions.
5. Linearity is better.

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Disadvantages of capacitive sensors

1. The metallic parts must be insulated from each other, in order to reduce the effect of stray capacitances, the frames must be earthed.
2. It show nonlinear behavior many a times on account of edge effects. Therefore guard rings must be used to eliminate this effect.
3. The output impedance tends to be high on account to their small capacitance value. This leads to loading effect.
4. The cable connecting the sensor to the measuring point is also a source of error.

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Applications of Capacitive Sensor

1. Insulation layer measurement can be carried out by variable area capacitive transducers.
2. Moisture measurement in wood is carried out by variable permittivity type capacitive transducer.
3. Dynamic measurement of force can be carried out by variable distance capacitive transducer.

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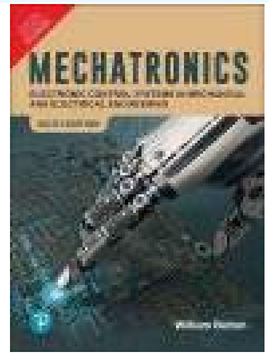

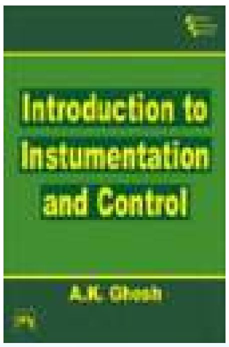

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MECHANICAL ENGINEERING DEPARTMENT

ME 18703 MECHATRONICS

UNIT – I SENSORS, TRANSDUCERS AND ACTUATORS 10 hrs

Strain Gauges

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- Static Characteristics of Sensor
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Strain Gauge

- Resistance changes under the application of **force** or **strain.**
- Used for measurement of force, strain, stress, pressure, displacement, acceleration etc.
- It consists of a foil of resistive characteristics, which is safely mounted on a backing material.
- When a known amount of stress is subjected on the resistive foil, the resistance of the foil changes accordingly.
- Establishes a relation between the change in the resistance and the strain applied.
- This relation is known by a quantity called **gauge factor**.
- The change in the resistance can be calculated with the help of a **Wheatstone bridge**.

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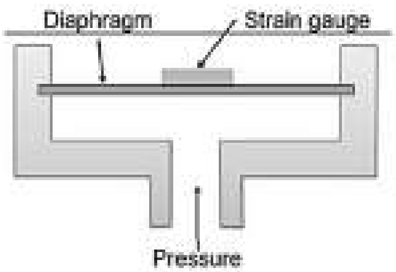
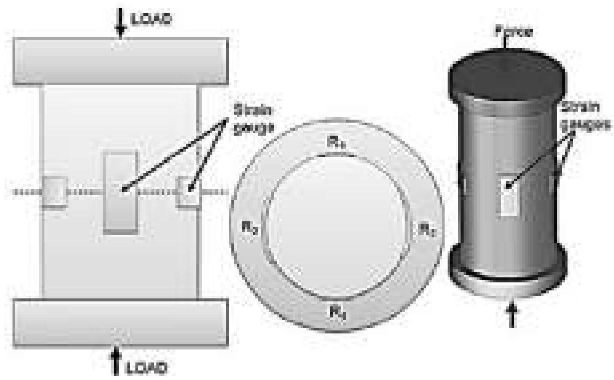
Strain Gauge Application



DIAPHRAGM PRESSURE GAUGE



STRAIN GAUGE LOAD CELL

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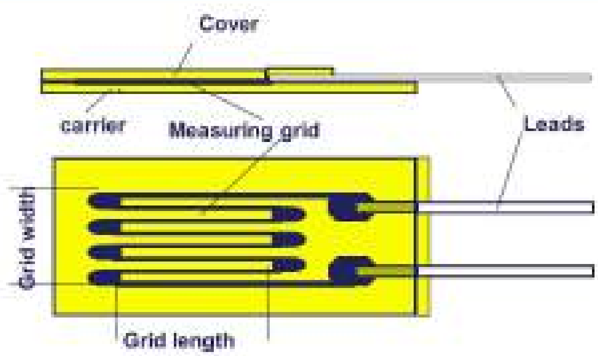
Strain Gauge Construction



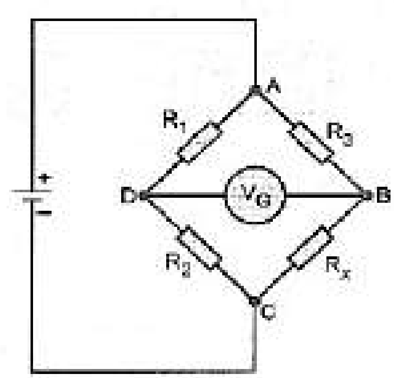


Fig. Wheatstone bridge

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Strain Gauge

- There are four resistances connected as a bridge circuit.
- The three resistors R1, R2 and R3 will have known values.
- The value of the resistance R_X will be unknown and has to be calculated.
- The value of resistance R2 is adjustable.
- A galvanometer has to be set between the points B and D.
- The property of the strain gauge depends on the size, shape and electrical conductivity of the conductor used.

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Types of Strain Gauges

- Depending on principle of operation and constructional features, strain gauges can be classified as
- a) Mechanical gauges
- b) Optical gauges
- c) Electrical gauges

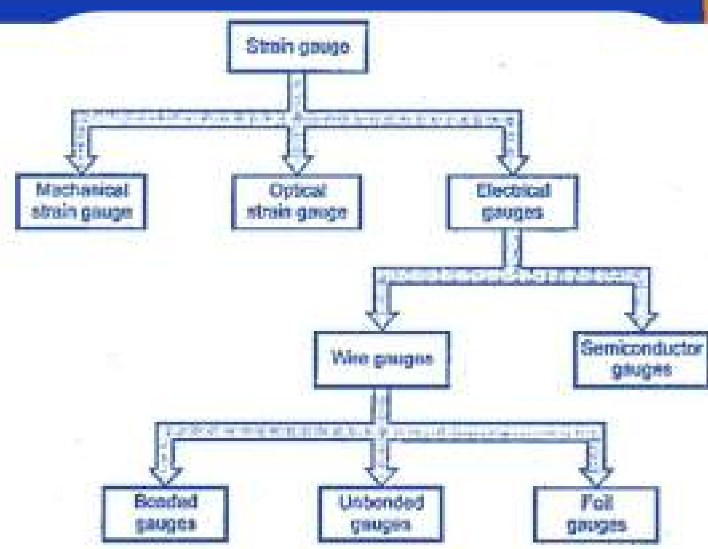

Fig Types of strain gauges

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Mechanical Strain Gauges

- It use levers and gears to magnify change in length (ΔL).
- Huggenberger type of extensometer is commonly used for magnification by using rack and pinion arrangement.
- Mechanical strain gauges are much larger in size.
- The accuracy of mechanical strain gauge is poor.
- Mechanical gauges are suitable for specific cases only such as,
  - Where sufficient space is available.
  - Additional mass of mechanical mass does not cause any error.
  - Point of measurement is accessible for visual inspection.

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Optical Strain Gauges

- Optical strain gauge uses multiple reflectors using mirrors or prisms for magnification of incremental length.
- Morfin's mirror extensometer is commonly used for measurement.
- The accuracy of optical strain gauges is high and independent of temperature variations.

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Electrical Strain Gauges

- Electrical strain gauge uses principle of measuring change in resistance, capacitance or inductance proportional to the strain.
- Bonded resistance type strain gauge is most popularly used while capacitance and inductance type strain gauge are used for special applications only.
- The electrical resistance of the wire changes as a function of strain.
- This change in resistance can be measured by using proper signal conditioning circuits.
- Sensitivity is dependent on the type of material used.

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Theory of Strain Gauge

- The principle: the electrical resistance of the conductor changes, when it is subjected to mechanical deformation.
- Resistance of conductor $R = \rho \frac{L}{A}$

  where, L is length of conductor, A is cross sectional area of conductor, ρ is resistivity of material
- Differentiating the equation $\frac{\partial R}{R} = \frac{\partial \rho}{\rho} + \frac{\partial L}{L} - \frac{\partial A}{A}$
- The area is related to the square of some transverse dimension (diameter) denoted by D, $\frac{\partial A}{A} = 2\frac{\partial D}{D}$

  Therefore $\frac{\partial R}{R} = \frac{\partial \rho}{\rho} + \frac{\partial L}{L} - 2\frac{\partial D}{D}$

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Gauge factor is defined as the ratio of per unit change in resistance to per unit change in length.

Gauge factor $G = \frac{\Delta R/R}{\Delta L/L} = \frac{\Delta R/R}{Axial\ Strain}$

Since $\frac{\partial L}{L} = \varepsilon a$ (axial strain) , $\frac{\partial D}{D} = \varepsilon l$ (Lateral strain), and Poison's Ratio $v = -\frac{\frac{\partial D}{D}}{\frac{\partial L}{L}}$

After solving for gauge factor, while $G = 1 + 2V + \frac{\partial \rho/\rho}{\partial L/L}$ or

$$G = \underbrace{1}_{\text{Resistance change due to change in length}} + \underbrace{2v}_{\text{Resistance change due to change in area}} + \underbrace{\frac{\partial \rho/\rho}{\varepsilon a}}_{\text{Resistance change due to change in resistivity or piezoresistance effect}}$$

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Gauge factor

- The value of the resistance of the gauge and its gauge factor is specified by the manufacturer.
- If resistivity ρ does not vary with strain (neglected) for a typical value of v = 0.5, gauge factor G = 2.
- The strain e usually measured in microstrain. (1 microstrain = 1 μm/m)

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Resistance Wire Strain Gauge

- Bonded Strain Gauge
- Unbonded Strain Gauge
- Foil Strain Gauge

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Bonded Strain Gauge

- The strain gauge is bonded on the surface of specimen being tested by using thin adhesive cement.
- The strain gauge is a grid of fine resistance wire.
- The wire grid may have shape of square, rectangle, circle or rosette type.
- The surface area of the wire section is kept larger than its cross sectional area to avoid stress relaxation and slippage.
- The wire gauges may be fabricated in four basic varieties i.e. flat-gird, wrap around, single wire or woven type.
- The wire grid is mounted on a backing paper.

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Unbonded Strain Gauge

- Unbonded strain gauge is a free filament sensing element where strain is transferred to the resistance wire directly without any backing.
- Number of loops of high tensile strength resistance wire is wound so that winding experiences an increase or decrease of stress for a given force input.

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Unbonded Strain Gauge

Advantages

- Because of its radial symmery spurious transverse forces are cancelled.
- Very low hysteresis and creep.
- Force summing and force sensing components can be integrated.

Disadvantage

- Problem of fixing at the place of measurement.

Applications

- Unbonded strain gauges are used in displacement transducer, pressure transducer and accelerometers.

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Foil Strain Gauge

- Foil gauge uses very thin metal foil of larger area compared to its cross section.
- The foil is used as sensing element. Foil can be easily fabricated in different shapes such as circular gauges, diaphragm gauges, spiral gauges, rosettes by using photoetching process.

Advantages

- Higher heat dissipation capability because of large surface area.
- Better thermal stability.
- Excellent strain reproducibility because of photoetching process.
- More flexible as foil is very thin.
- Available in different shapes and sizes, convenient for measurement of localized strains.

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Characteristics of typical foil and wire strain gauges	
Gauge factor	Approximately 2. Exact value supplied with gauge
Gauge resistance	Standardized values: 120 Ω, 350 Ω, 600 Ω, and 1000 Ω are employed
Linearity	Usually with ± 0.1 % upto 4000 $\mu\varepsilon$ and within ±1% upto 10000 $\mu\varepsilon$ ($\mu\varepsilon$ denotes micro strain, 1 $\mu\varepsilon$ = 0.0001 % strain)
Breaking Strain	About 25,000 $\mu\varepsilon$
Fatigue life	Upto 10 million strain reversals
Temperature compensation	Gauges may be obtained with coefficients of thermal expansion that match general purpose steels, stainless steels and aluminium alloys. Compensation for thermal effects may also be obtained by the use of bridge circuit.

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Temperature Compensation

- Strain measurements are to be carried over a long period of time therefore the gauges are subjected to changes in ambient temperature.
- The variation in temperature cause change in resistivity and apparent strain.
- The effect of change in ambient temperature (Δt) is given by expression:

$$\left(\frac{\Delta R}{R}\right)_{\Delta t} = [(\alpha_s - \alpha_g)\, G + \beta]\, \Delta t$$

where, α_g is the coefficient of linear expansion of gauge material,

α_s is coefficient of linear expansion of specimen

β is coefficient of resistivity of gauge material

Δt is change in ambient temperature

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Temperature compensated gauges

- Temperature compensated gauge consists of elements of two different materials.
- The dimensions of each material are so chosen that the change in resistance of one gauge due to temperature, is compensated by other gauge.
- This results in a minimum apparent strain due to change in temperature.
- The temperature compensation using to different gauge material is useful for limited range of temperature and strain levels.

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Compensation through bridge arrangement

- Temperature compensation can also be achieved by placing strain gauges properly in a wheatstone bridge.
- An identical strain gauge is exposed to the same temperature variations by placing it in the adjacent arm of bridge, better compensation can be achieved.
- Such compensation technique is widely employed in strain gauge instrumentation

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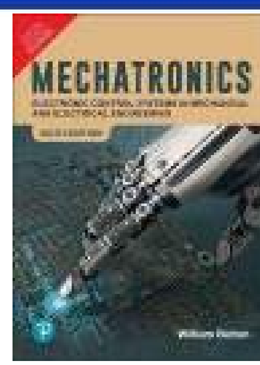

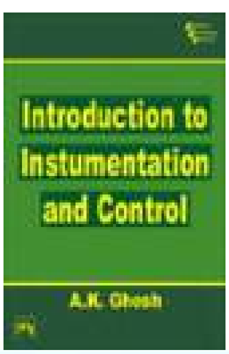

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MECHANICAL ENGINEERING DEPARTMENT

Sri Venkateswara College of Engineering

ME 18703 MECHATRONICS

UNIT – I SENSORS, TRANSDUCERS AND ACTUATORS 10 hrs

Eddy Current Sensor – Hall Effect Sensor

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UNIT I

- Static Characteristics of Sensor
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Eddy Current Sensor

- Eddy-Current sensors are non-contact devices capable of high-resolution measurement of the position and/or change of position of any conductive target.
- Eddy-Current sensors are also called inductive sensors, but generally "eddy current" refers to precision displacement instruments (or non-destructive testing probes) and "inductive" refers to inexpensive proximity switches.
- High resolution and tolerance of dirty environments make eddy-current sensors indispensable in today's modern industrial operations.

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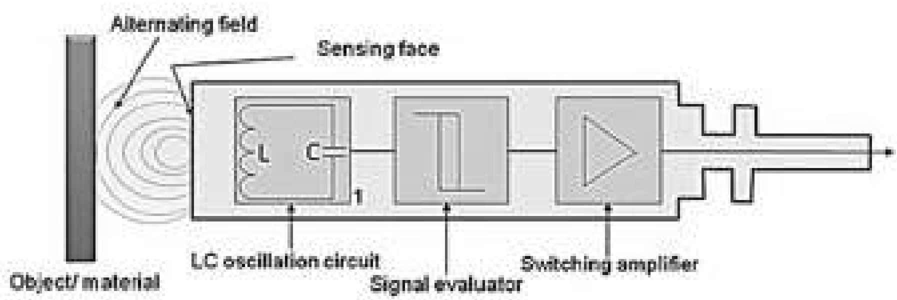
Eddy Current Sensor

Eddy current: A localized electric current induced in a conductor by a varying high frequency magnetic field.



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Eddy Current Sensor

- Eddy current sensors are used to detect conductive materials.
- They comprise of a coil, an oscillator, a detector and a triggering circuit.
- When an a.c is passed through this coil, an alternative magnetic field is generated.
- If a metal object comes in the close with the coil, then eddy currents are induced in the object due to the magnetic field.
- These eddy currents create their own magnetic field which distorts the magnetic field responsible for their generation.
- Impedance of the coil changes and so the amplitude of alternating current.
- This is used to trigger a switch at some pre-determined level of change in current.
- Eddy current sensors are relatively inexpensive, available in small in size, highly reliable and have high sensitivity for small displacements.

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Advantages of Eddy Current Sensor

- Tolerance of dirty environments
- Not sensitive to material in the gap between the probe and target
- Less expensive and much smaller than laser interferometers
- Less expensive than capacitive sensor

Disadvantages of Eddy Current Sensor:

Not a good choice in these conditions:

- Extremely high resolution (capacitive sensors are ideal)
- Large gap between sensor and target is required (optical and laser are better)

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Applications of Eddy Current Sensors

- Automation requiring precise location
- Machine tool monitoring
- Final assembly of precision equipment such as disk drives
- Drive shaft monitoring
- Vibration measurements

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Hall Effect Sensor

- A device which converts magnetic or magnetically encoded information into electrical signals
- A Hall Effect device is a solid state device, and is a passive transducer.
- Magnetic field has two important characteristics: flux density and polarity (North and South Poles).
- The output signal from a Hall effect sensor is the function of magnetic field density around the device.
- When the magnetic flux density around the sensor exceeds a certain pre-set threshold, the sensor detects it and generates an output voltage called the Hall Voltage, V_H.

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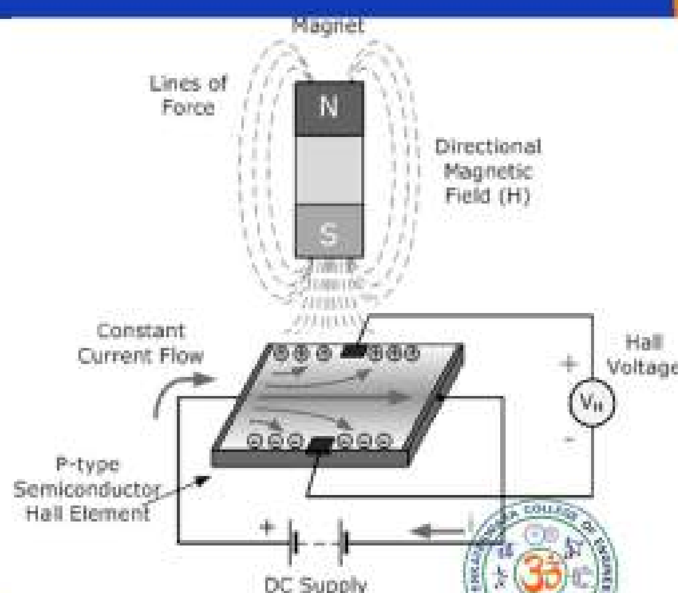
Hall effect

A potential difference caused across an electrical conductor when a magnetic field is applied in a direction perpendicular to that of the flow of current.



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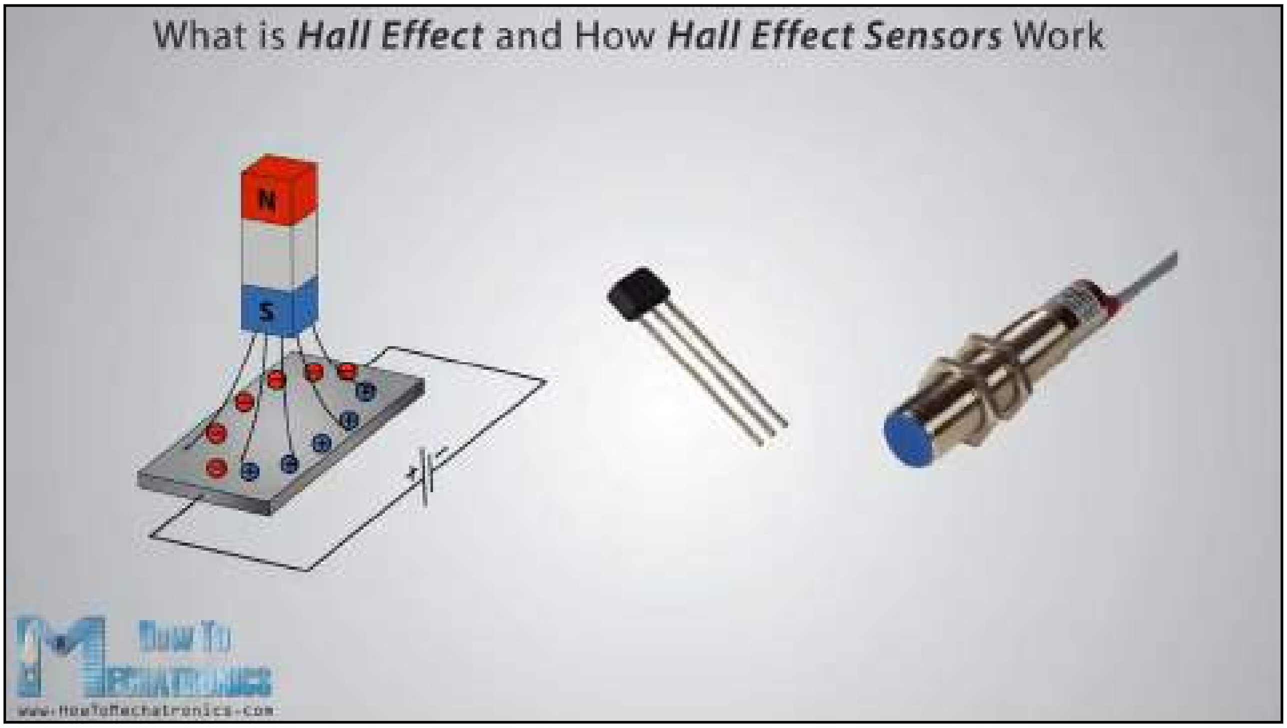

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- Hall Effect Sensors consist of a thin piece of rectangular p-type semiconductor material such as gallium arsenide (GaAs), indium antimonide (InSb) or indium arsenide (InAs) passing a continuous current through itself.
- When the device is placed within a magnetic field, the magnetic flux lines exert a force on the semiconductor material which deflects the charge carriers, electrons and holes, to either side of the semiconductor slab.
- This movement of charge carriers is a result of the magnetic force they experience passing through the semiconductor material.

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Advantages of Hall Effect Sensors

- Production of an output voltage signal independent of the rate of the detected field.
- Hall Effect sensors display low carrier density, hence conductivity is smaller and their voltage is larger.
- A high speed operation is possible.
- Hall sensors can measure zero speed.

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Disadvantages of Hall Effect Sensors

- The Hall Effect sensor is not capable of measuring a current flow at a distance greater than 10 cm.
- Possible for external magnetic fields to interfere with magnetic field and bias the measurement of current flow.
- Temperature affects the electrical resistance of the element and the mobility of majority carriers and also the sensitivity of Hall Effect sensors.
- The offset voltage exist as an output voltage in the absence of a magnetic field.

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Applications of Hall Effect Sensors

- Current sensing
- Variable speed drives
- Motor control protection/indicators
- Power supply sensing
- Motion sensing
- Diaphragm pressure gauge
- Flow meters

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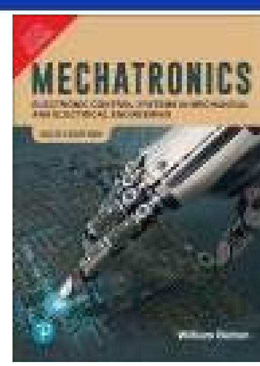

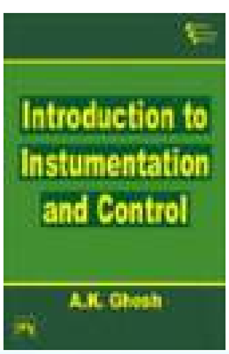

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MECHANICAL ENGINEERING DEPARTMENT

SVCE | Sri Venkateswara College of Engineering

ME 18703 MECHATRONICS

UNIT – I SENSORS, TRANSDUCERS AND ACTUATORS 10 hrs

Temperature Sensors – Light sensors

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UNIT I - SENSORS, TRANSDUCERS AND ACTUATORS 10

- Static Characteristics of Sensor
- Dynamic Characteristics of Sensor
- Potentiometers
- LVDT
- Capacitance sensors
- Strain gauges – Load cell
- Eddy current sensor – Hall effect sensor
- **Temperature sensors – Light sensors**
- Types of Stepper motors – Construction – Working Principle – Advantages and Disadvantages.
- Types of Servo motors – Construction – Working Principle – Advantages and Disadvantages.

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Temperature Sensors

- Temperature: A condition of a body by virtue of which heat is transferred to or from other body.
- Temperature is a fundamental unit like mass, length and time.
- Temperature is measured in ^{o}C or K or ^{o}F.
- Four most widely used temperature detectors are,
  - i) Thermocouples
  - ii) Resistance Temperature Detectors (RTD)
  - iii) Thermistors
  - iv) Bimetallic Strips

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Thermocouples

- Thermocouples are most widely used temperature detectors in industry.
- The working principle of thermocouple is based on thermo e.m.f.
- The three basic laws of thermo e.m.f. are,
  - **i) Seebeck effect**
  - **ii) Peltier effect**
  - **iii) Thomson effect**

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Seebeck effect

- If two dissimilar metals or alloy wires A and B are joined together to form a loop and a difference of temperature exists between the two ends, a potential difference across the junction will set up resulting in thermos electric e.m.f.
- The magnitude of this e.m.f. will be dependent upon temperature difference between two junction and the materials used for two wires.

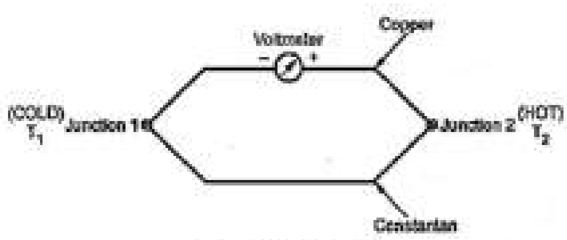

Fig. Thermo e.m.f.

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Peltier effect

- When a electric current crosses a junction between two dissimilar metals, one junction get heated up and another will evolve the heat (cold junction).

Thomson effect

- If a conductor is subjected to temperature gradient, then a corresponding voltage gradient will be generated along the conductor. The current will flow from cold junction to hot junction.

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Thermocouple construction

- It consists of a pair of dissimilar metal wires joined together at one end, forming the sensing or hot junction; and terminated at the other end a reference or cold junction, which is maintained at a known constant temperature (reference temperature).
- When a temperature difference exists between the sensing junction and the reference junction, an e.m.f. is produced.
- The magnitude of this voltage depends on the material used for the wires and the temperature difference between the two junctions.
- When the reference junction is terminated by a meter or recording instruments, the meter indication is proportional to the temperature difference between the hot junction and the reference junction. This thermoelectric effect, caused by contact potentials at the junctions, is known as the Seebeck effect.

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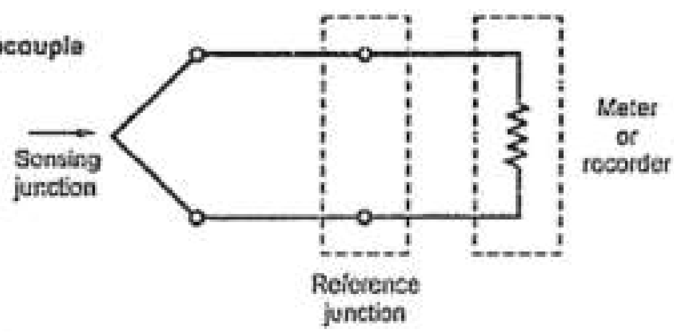
Thermocouple construction

Fig. Thermocouple



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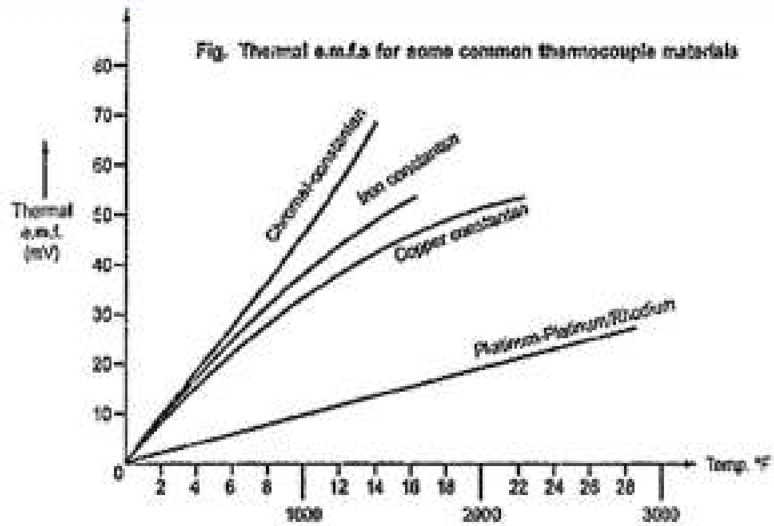
Thermocouple Material:

- ❖ Metals including copper-constantan, iron-constantan, chromel-constantan, chromel-Alumel, platinum-platinum/Rhodium.
- ❖ They cover wide range of temperature, going as high as 2700° C.



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Thermopile : The series of thermocouples connected together is called as thermopile.

Advantages of thermocouples:

- ❖ Rugged construction
- ❖ Comparatively cheap
- ❖ Temperature range - 250° C to 2500° C
- ❖ Easy calibration
- ❖ Good reproducibility
- ❖ Good accuracy
- ❖ Bridge circuit for sensing is not required because output is available directly in millivolts.

Limitations of thermocouples

- ❖ For accurate measurement cold junction compensation is necessary.
- ❖ E.M.F. versus temperature characteristic is non-linear.
- ❖ Very small voltage is obtained as output.

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Resistance Temperature Detectors (RTD)

- The change in temperature is detected by the change in resistance of the wire.
- There are two types of RTDs, having positive and negative thermal coefficients of resistivity (resistance increases or decreases with the increase in temperature respectively).
- RTDs are constructed using bridge circuits.
- The change in temperature causes considerable resistance change which gives a voltage drop in accordance with the thermal coefficient of resistance of the wire.
- This voltage is further amplified and the temperature is read thus.

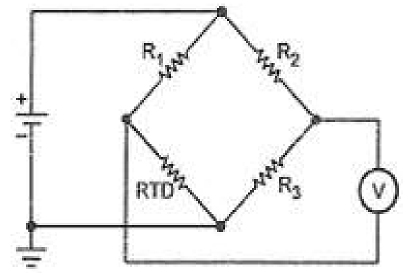

Fig. Resistance Temperature Detectors (RTD)

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Advantages of RTD

- Linearity over a wide operating range
- Wide operating range
- Higher temperature operation
- Better stability at high temperature

Disadvantages of RTD

- Low sensitivity
- It can be affected by contact resistance, shock and vibration
- Requires no point sensing
- Higher cost than other temperature transducers

Applications of RTD

- It is widely used in furnaces for automatic temperature measurement.
- Used in medical and chemical laboratories to detect very low temperatures (like dry ice and liquid nitrogen).

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Thermistors (Thermal resistor)

- A thermistor is a type of resistor whose resistance strongly depends on temperature.
- A thermistor is a temperature-sensing element composed of sintered semiconductor material and sometimes mixture of metallic oxides such as Mn, Ni, Co, Cu and Fe, which exhibits a large change in resistance proportional to a small change in temperature.
- Pure metals have positive temperature coefficient of resistance, alloys have nearly equal zero temperature coefficient of resistance and semiconductors have negative temperature coefficient of resistance.
- Thermistors can be classified into two types :
- **Positive Temperature Coefficient (PTC) thermistor**: resistance increase with increase in temperature.
- **Negative Temperature Coefficient (NTC) thermistor**: resistance decrease with increase in temperature.

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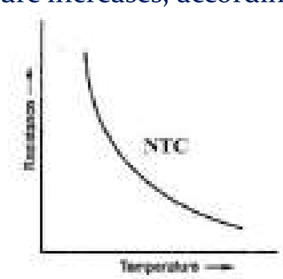
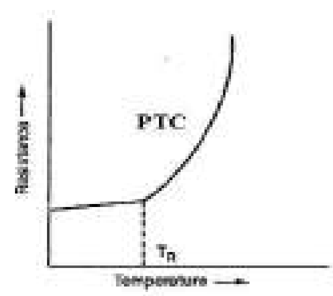
Characteristics of thermistors:

In NTC thermistor, the resistance decreases as the temperature increases, according to the following expression. $R_T = R_0 e^{\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)}$

- Where, R_T is the resistance at temperature T(K)
- R_o is the resistance at temperature T_o (K)
- T_o is the reference temperature, normally 25°C
- β is a constant, its value is decided by the characteristics of the material.
- If the value of β is high, then the resistor - temperature relationship will be very good.
- Then the sensitivity of the thermistor also increases.





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Advantages of Thermistors

- They are simple and easy to owing to their small sizes.
- Their cost is low.
- They are highly sensitive.
- They can be adapted to various electrical readouts. With the help of computers thermistors can be easily used for accurate temperature measurement.

Disadvantages of Thermistors

- The temperature vs resistance curves of thermistors are highly nonlinear.
- It is not rugged and requires delicate handling which limits its application.
- They are susceptible to self-heating errors.
- Their range is limited to few hundred degrees Celsius.
- Thermistors use semiconductors which are prone to permanent de-calibration.

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Applications of Thermistors

- Thermistors are used in automotive applications
- Instrumentation and Communication
- Consumer electronics
- Food handling and processing
- Defense and aerospace

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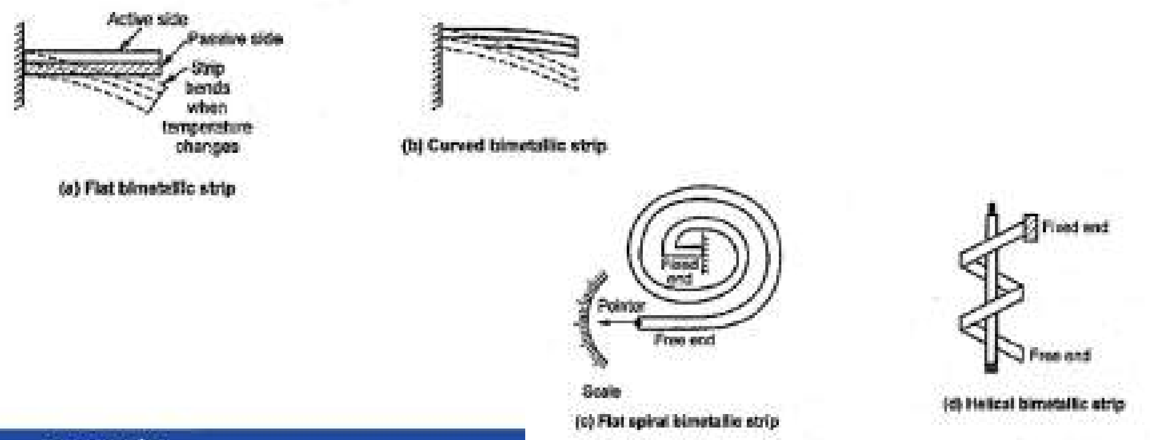
Bimetallic Strips

- It is used to convert a temperature change into mechanical displacement and thus acts as a temperature sensor
- The strip consists of two strips of different metals which expand at different rates as they are heated, usually steel and copper.



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Bimetallic thermometer:

- All metals change in dimension, that is expand or contract when there is a change in temperature.
- The rate at which this expansion or contraction takes place depend on the temperature co-efficient of expansion of the metal and this temperature coefficient of expansion is different for different metals.
- Hence the difference in thermal expansion rates is used to produce deflections which is proportional to temperature changes.

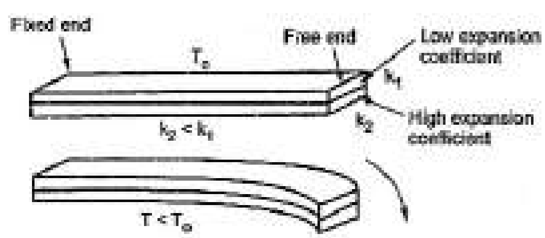

Fig. Bimetallic thermometer

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- The bimetallic thermometer consists of a bimetallic strip
- The two metal strips are joined together by brazing, welding or riveting so that the relative motion between them is arrested.
- The bimetallic strip is in the form of a cantilever beam. An increase in temperature will result in the deflection of the free end of the strip as shown in diagram.
- This deflection is linear and can be related to temperature changes. The radius of the curvature of the bimetallic strip which was initially flat is determined using the following relationship.

Where, R = Radius of the curvature at the temperature T2.

T = Total thickness of the bimetallic strip = (t_1+t_2)

m = t_1/t_2 =Thickness of lower expansion metal/thickness of higher expansion metal.

$\propto l$ = Coefficient of expansion of lower expansion metal,

αh = Coefficient of expansion of higher expansion metal.

T1 = Initial temperature.

T2 = Temperature.

$$R = t\{3(1+m)^2 + (1+mn)[m^2 + 1/mn]\} / 6(\alpha h - \alpha l)(T_2 - T_1)(1+m)^2$$

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Advantages of bimetallic thermometers

- They are simple, robust and inexpensive.
- Their accuracy is between + or - 2 % to 5 % of the scale.
- They can with stand 50 % over range in temperatures.
- They can be used where ever a mercury in glass thermometer is used.

Limitations of bimetallic thermometer:

- They are not recommended for temperature above 400 "C.
- On regular usage, bimetallic may permanently deform, which will introduce errors.

Application of bimetallic strips and thermometers

- The bimetallic strip is used in control devices.
- The spiral strip is used in air conditioning thermostats.
- The helix strip is used for process application such as refineries, oil burners, tyre vulcanisers etc.

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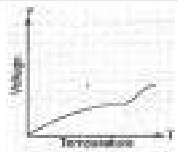
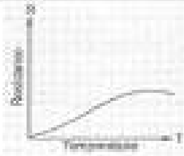
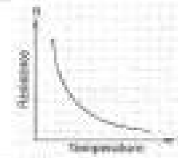
Comparison of Thermocouple, RTD and Thermistor

	Thermocouple	RTD	Thermistor
Symbol			
Characteristics			
Advantages	• Self powered • Simple and Rugged • Cheaper • More flexible • Wide temperature range	• Most Stable • Most Accurate • More Linear than thermocouple	• High output • Fast • Two wire resistance measurement
Disadvantages	• Non Linear • Low voltage • Reference required • Least Stable • Least Sensitive	• Expensive • Power supply required • Small change in resistance • Self heating	• Non Linear • Limited temperature range • Fragile • Power supply required • Self heating

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Light Sensor

- A Light Sensor is something that a robot can use to detect the current ambient light level i.e. how bright / dark it is.
- There are a range of different types of light sensors:
  - i) Photoresistor
  - ii) Photodiodes
  - iii) Phototransistors

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Photoresistor

- A Photoresistor is a variable resistor that let current flow easy when it is exposed to light. It's most used as a sensor to detect changes in brightness.
- Streetlights often use a photoresistor to detect when it should turn on.
- Photoresistors, also known as Light Dependent Resistor (LDR), Cadmium Sulfide cells (CDS cells).
- Photoconductor and sometimes simply Photocells are a type of transducer which converts energy from one form to another where one of the known forms is electrical energy.

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Photoresistor

- Resistance in a Photoresistor inversely varies with the amount of light it is exposed to
  Bright light = Less resistance   Low light = more resistance.
- These sensors are used to make light sensitive devices and are more often found in street lights, cheap toys, outdoor clocks etc.
- If you have ever wondered how a street light turns on in the night and switches off in the day, you will be surprised to find a cheap photoresistor circuitry inside it.

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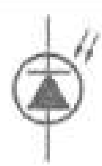
Advantages

1. Cheaper (very nominal)
2. Commonly found in most robot hobby shops.
3. Available in different sizes with different specifications.
4. Easy to design and implement them in a circuitry.

Disadvantages

1. Highly inaccurate. Each one behaves differently than the other. If the first one has a resistance of 150 Ω in bright light, second one can have 500 Ω of resistance in the same light
2. They cannot be used to determine precise light levels
3. Very slow for sensitive applications.

Photodiode



- A photodiode is a semiconductor device that converts light into current.
- The current is generated when photons are absorbed in the photodiode.
- Photodiodes are used to detect light and feature wide, transparent junctions.
- Generally, these diodes operate in reverse bias, where in even small amounts of current flow, resulting from the light, can be detected with ease.
- Photodiodes can also be used to generate electricity, used as solar cells and even in photometry.

Principle of operation

- A photo diode is biased against its easy flow of direction of current, i.e. it is reverse biased so that a very low leakage current flows.
- If a photon of sufficient energy is incident on the diode at its junction, an electron is freed and if it possesses enough energy, it may pass over the energy barrier causing a small leakage current to flow.
- The amount of current is proportional to the amount of illumination of the junction.

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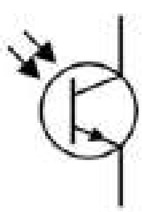
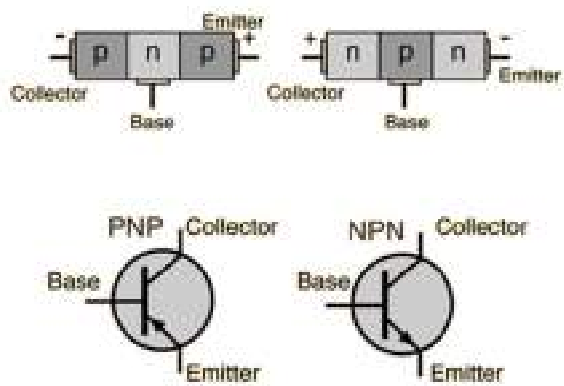
Phototransistor





- The phototransistor is a semiconductor light sensor formed from a basic transistor with a transparent cover that provides much better sensitivity than a photodiode.
- A phototransistor is a light-sensitive transistor.

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Principal of operation:

- Photo transistors are active type sensors.
- The base connection is left open circuit or disconnected because it is not required, only be used to bias the transistor
- For operation the bias conditions are simple. The collector of an n-p-n transistor is made positive with respect to the emitter or negative for a p-n-p transistor.
- The light enters the base region of the phototransistor where it causes hole electron pairs to be generated.
- This mainly occurs in the reverse biased base-collector junction. The hole-electron pairs move under the influence of the electric field and provide the base current, causing electrons to be injected into the emitter.

Applications

- Punch-card readers, Security systems, Encoders - measure speed and direction, IR photo detectors etc

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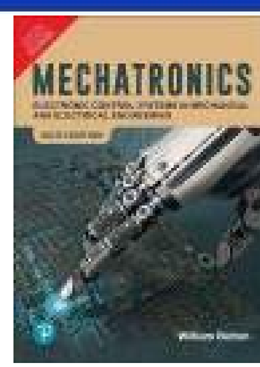

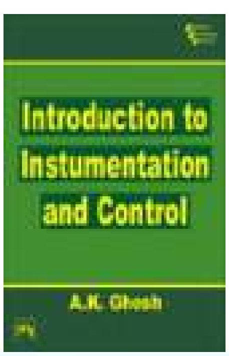

A.K.Ghosh, "Introduction to instrumentation and control" PHI Publishing 2018.

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Sri Venkateswara College of Engineering

MECHANICAL ENGINEERING DEPARTMENT

ME 18703 MECHATRONICS

UNIT – I SENSORS, TRANSDUCERS AND ACTUATORS 10 hrs

Servo Motors

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UNIT I - SENSORS, TRANSDUCERS AND ACTUATORS 10

- Static Characteristics of Sensor
- Dynamic Characteristics of Sensor
- Potentiometers
- LVDT
- Capacitance sensors
- Strain gauges – Load cell
- Eddy current sensor – Hall effect sensor
- Temperature sensors – Light sensors
- **Types of Stepper motors – Construction – Working Principle – Advantages and Disadvantages.**
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Actuators

- In a control system, the element which transforms the output of a controller into a controlling action/motion is called as **actuators.**
- Actuators produce physical changes such as linear and angular displacements.
- Examples of actuators are - solenoids, electric motors, hydraulic cylinders, pneumatic cylinders and motors.
- Actuators can handle the static or dynamic loads placed on it by control valve.
- The important aspects of actuators are proper selection and sizing.

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Functions of an actuator - two major functions.

1. To respond an external signal directed to it causing inner valve to move accordingly
   - Hence to control flow rate of fluid by positioning the control valve.
2. To provide support for valve accessories e.g. limit switches, solenoid valves.

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Classification of Actuators

- Actuators are available in various forms to suit the particular requirement of process control. These can be classified into three main categories.
  1. Pneumatic actuators
  2. Hydraulic actuators
  3. Electrical actuators

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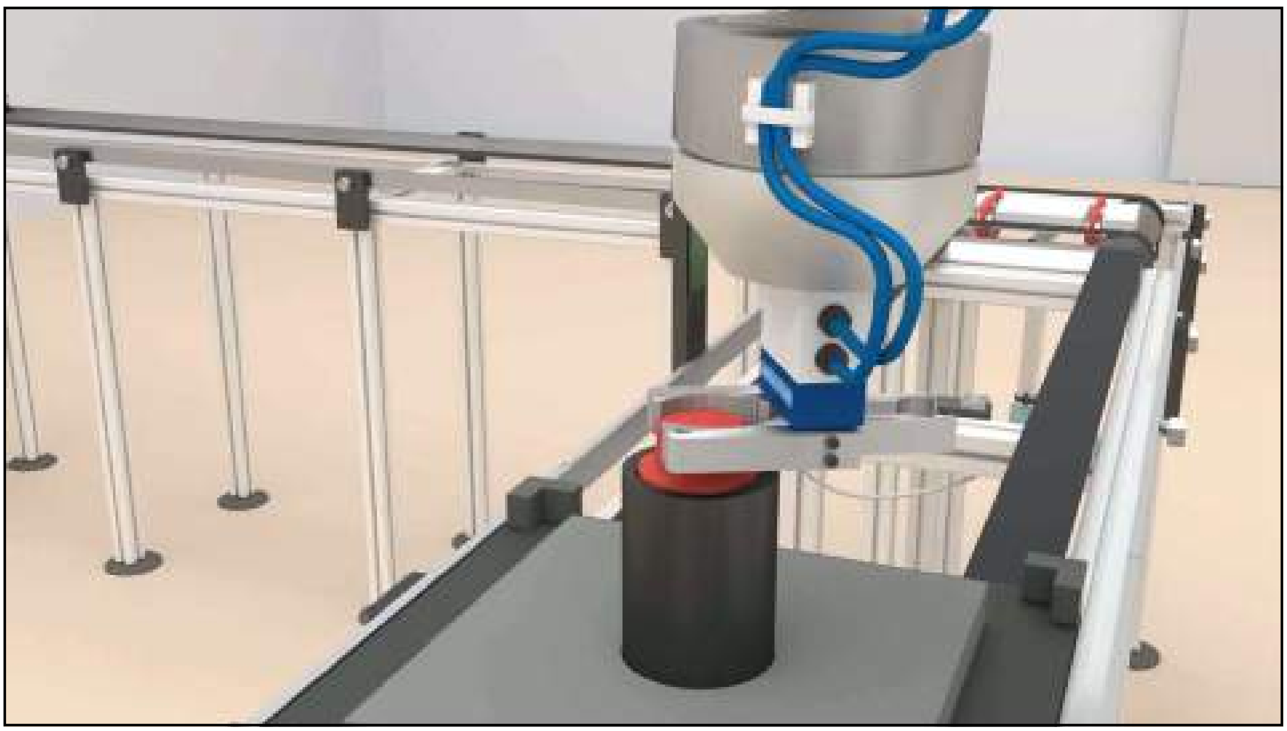

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Stepper Motor

- A stepper motor is an electromechanical device which converts electrical pulses into discrete mechanical movements.
- These motors rotate a specific number of degrees as a respond to each input electric pulse.
- Typical types of stepper motors can rotate 2°, 2.5°, 5°, 7.5°, and 15° per input electrical pulse.
- Feed back element: Rotor position sensor or sensor less feedback based techniques.
- The speed of the motor shafts rotation is directly related to the frequency of the input pulses
- The length of rotation is directly related to the number of input pulses applied.

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Stepper Motor Types

There are three basic stepper motor types.

- Variable-reluctance
- Permanent-magnet
- Hybrid

Stepper motor offers important features such as :

1. Available resolutions ranging from several steps up to 400 steps (or higher) per revolution.
2. Several horse power ratings.
3. Ability to track signals as fast as 1200 pulses per second.

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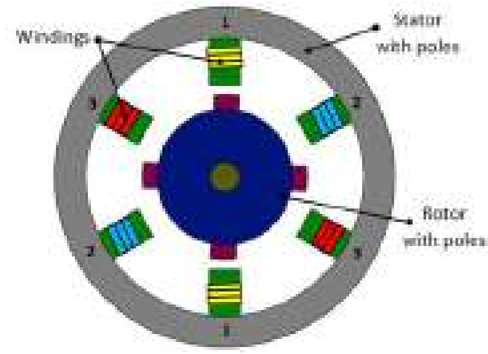
Varibale- Reluctance (VR) Stepper Motor

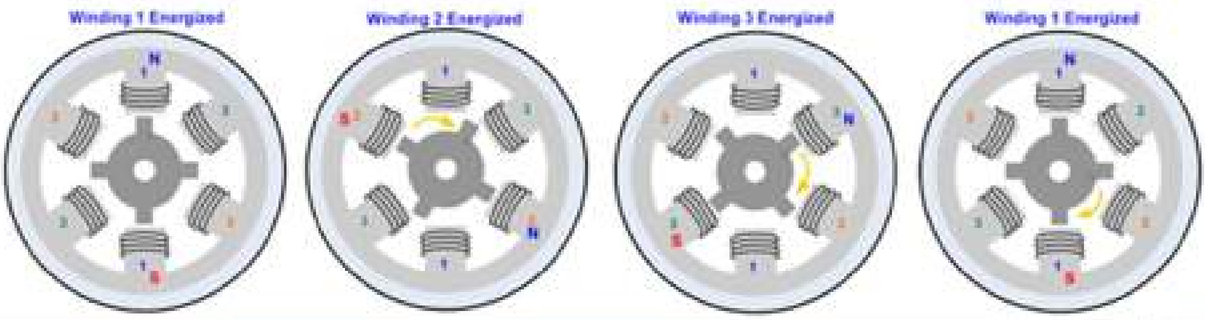
- This type of stepper motor has been around for a long time.
- It is the easiest to understand from a structural point of view.
- It has three to five windings and a common terminal connection, creating several phases on the stator.
- The rotor is toothed and made of metal, but is not permanently magnetized.
- The rotor has four teeth and the stator has three independent windings (six phases), creating 30 degree steps.



Varibale- Reluctance (VR) Stepper Motor

- The rotation of a variable reluctance stepping motor is produced by energizing individual windings.
- When a winding is energized, current flows and magnetic poles are created, which attracts the metal teeth of the rotor.
- The rotor moves one step to align the offset teeth to the energized winding.
- At this position, the next adjacent windings can be energized to continue rotation to another step, or the current winding can remain energized to hold the motor at its current position.
- When the phases are turned on sequentially, the rotor rotates continuously.

- The three steps shown in Fig. move the rotor a quarter turn.
- A full rotation requires 12 steps for a variable reluctance stepper motor.
- Typical variable reluctance motors have more teeth and use a tooth pole along with a toothed rotor to produce step angles near one degree.



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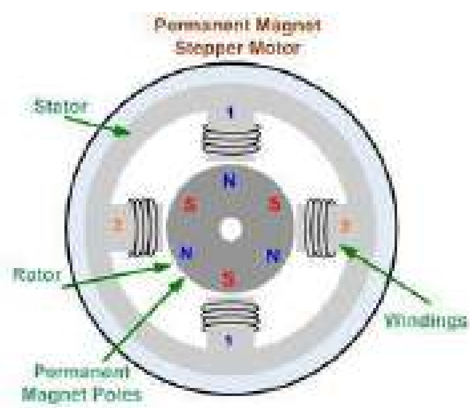
Permanent Magnet Stepper Motor

- These are similar in construction to that of variable reluctance stepper motors except that the rotor is made of permanent magnet.
- It consists of a stator with windings and a rotor with permanent magnet poles.
- Alternate rotor poles have rectilinear forms parallel to the motor axis.
- Stepping motors with magnetized rotors provide greater flux and torque than motors with variable reluctance.
- The motor has three rotor pole pairs and two independent stator winding creating 30 degree steps.



- Motors with permanent magnets are subjected to influence from the back-EMF of the rotor, which limits the maximum speed.
- Therefore, when high speeds are required, motors with variable reluctance are preferred over motors with permanent magnets.

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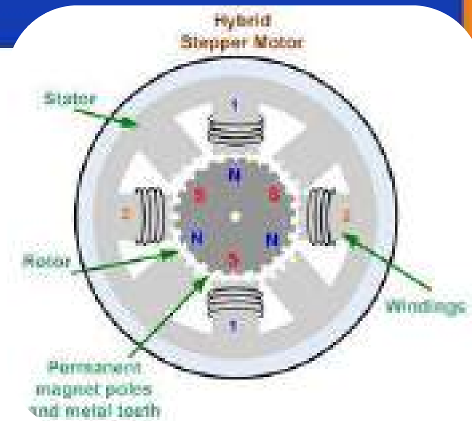
Hybrid Stepper Motor

- The hybrid stepper motors have the combination of the best properties of variable reluctance and permanent magnet steppers, so they are more expensive than the PM stepper motor.
- This motors provide better performance with respect to step resolution, torque and speed.
- The rotor of a hybrid stepper is multi-toothed like the variable reluctance steppers and it contains an axially magnetized concentric magnet around its shaft.



- The teeth on the rotor provide an even better path which helps guide the magnetic flux to preferred locations in the air gap.
- The most commonly used types of stepper motors are the hybrid and permanent magnet.
- The designers prefer permanent magnets unless their project requires the hybrid steppers, since the cost of permanent magnet are less than of hybrids.

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Advantages of Stepper Motor

1. The rotation angle of the motor is proportional to the input pulse.
2. The motor has full torque at standstill.
3. Precise positioning and repeatability of movement with an accuracy of 3 - 5 % of a step
4. The error is non cumulative from one step to the next.
5. Excellent response to starting, stopping and reversing.
6. Very reliable and good life since there are no contact brushes in the motor.
7. The life is only dependent on the life of the bearing.
8. The motors response to digital input pulses provides open-loop control, making the motor simpler and less costly to control.
9. It is possible to achieve very low speed synchronous rotation with a load that is directly coupled to the shaft.
10. A wide range of rotational speeds can be realized as the speed is proportional to the frequency of the input pulses.

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Disadvantages of Stepper Motor

1. They have low torque capacity (typically less than 500 N-m) compared to DC motors.
2. They have limited speed (limited by torque capacity and by pulse-missing problems due to faulty switching systems and drive circuits).

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Stepper Motor Specification

1. Pull-in torque: Represents maximum torque load at the shaft, at which the motor can start without losing steps
2. Step angle: Represents angular displacement of the rotor for one control impulse.
3. Maximum no load start frequency: Represents the maximum control impulse frequency at which the unloaded motor can start, stop or reverse without losing steps.
4. Limit start frequency: Represents the maximum impulse frequency at which the motor can start without losing steps, when a given moment of inertia and torque load are presented at the shaft.
5. Maximum no load frequency: Represents the maximum impulse frequency that the motor can follow without losing synchronization.

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Stepper Motor Specification

6. Maximum frequency: Maximum frequency of impulses at which a motor keeps its timing for given torque load and inertia
7. Pull-out torque: Maximum torque that can be maintained by the motor at a certain speed, without losing steps
8. Detent torque: Represents the value of the holding torque presented by at the motor shaft when it is not electrically energized.
9. Angular speed: Is calculated as a product between the stepping angle and the control frequency.
10. Slew range: The range of switching rates between pull-in and pull-out in which a motor will run in synchronism but cannot start or reverse.

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Stepper Angle

$$\beta = \frac{N_s - N_r}{N_s \times N_r} \times 360^\circ$$

Where,

N_s = No. of stator teeth

N_r = No. of rotor teeth

N=TR/β

Where,

N-Total steps or Pulses,

TR-Total Revolutions,

β=Step angle

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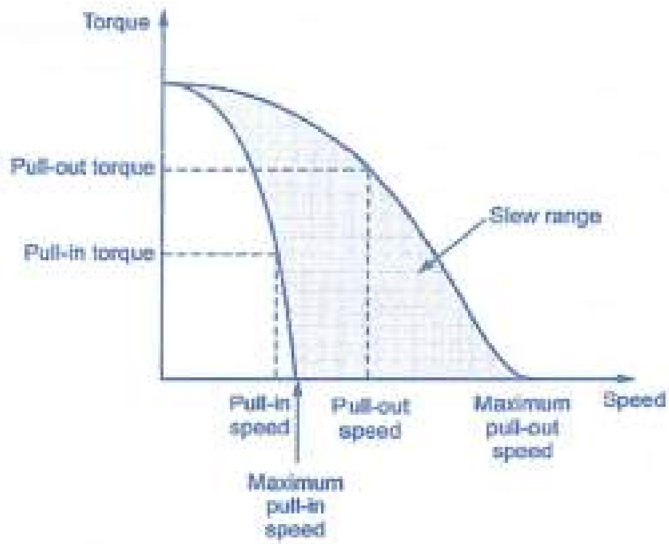
Fig. General characteristics of a stepper motor



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Application of Stepper Motor

1. Industrial Machines : Automotive gauges and machine tooling automated production equipments.
2. Security : New surveillance products for the security industry.
3. Medical : Inside medical scanners, samplers, and also found inside digital dental photography, fluid pumps, respirators and blood analysis machinery.
4. Consumer Electronics : In cameras for automatic digital camera focus and zoom functions. And also have business machines applications, computer peripherals applications

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Servo Motor

- A servo motor is a simple electrical motor, controlled with the help of servo mechanism.
- Servo motor is a special type of motor which is automatically operated up to certain limit for a given command with help of error-sensing feedback to correct the performance.
- If the motor as controlled device, associated with servo mechanism is DC motor, then it is commonly known DC Servo Motor.
- If the controlled motor is operated by AC, it is called AC Servo Motor.

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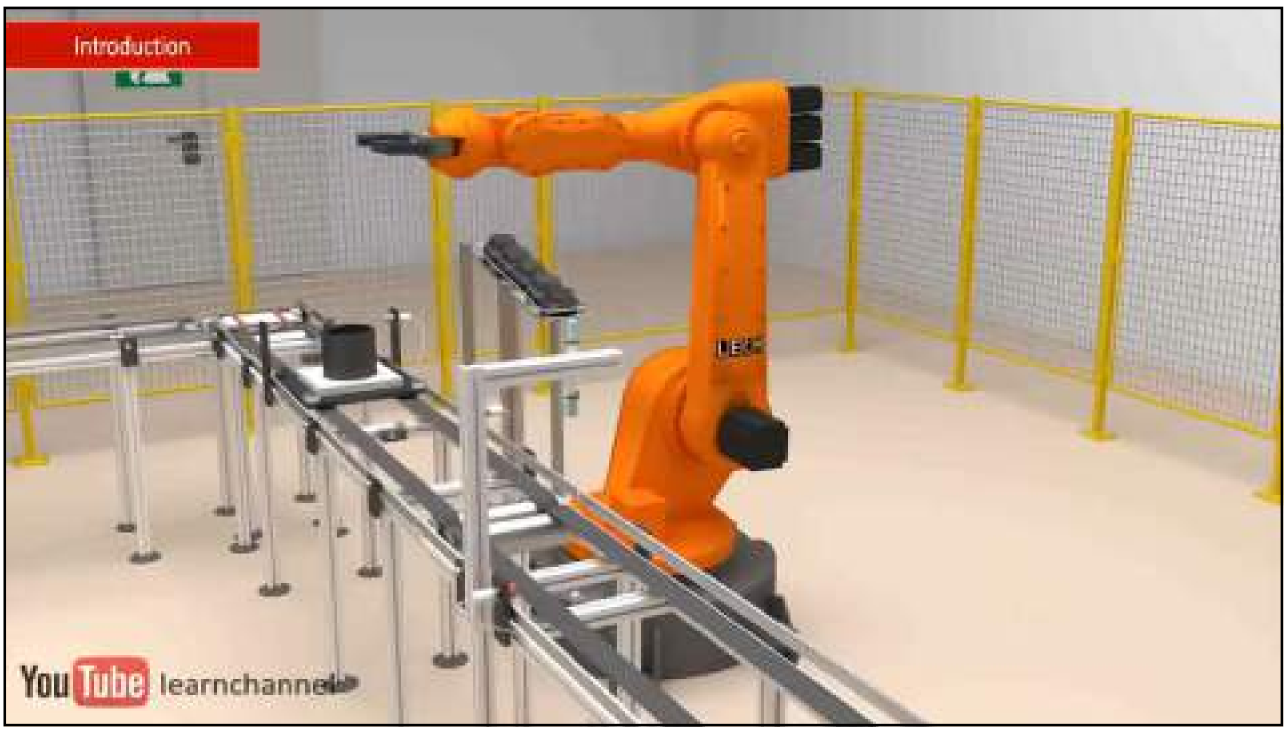

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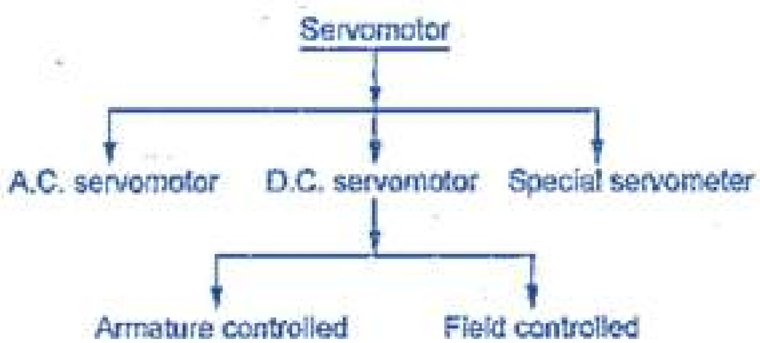
Types of Servo Motors

- Classified depending upon the nature of the electricity supply to be used for it's operation.



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DC Servo Motors

Servomotor features:

- Linear relationship between the speed and electric control signal.
- Steady state stability.
- Wide range of speed control.
- Linearity of mechanical characteristics throughout the entire speed range.
- Low mechanical and electrical inertia.
- Fast response.

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DC Servo Motors Construction:

- A DC servo motor consists of a small DC motor, feedback potentiometer, gearbox, motor drive electronic circuit and electronic feedback control loop.
- It is more or less similar to the normal DC motor.
- The stator of the motor consists of a cylindrical frame and the magnet is attached to the inside of the frame.
- The rotor consists of brush and shaft.
- A commutator and a rotor metal supporting frame are attached to the outside of the shaft and the armature winding is coiled in the rotor metal supporting frame.

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DC Servo Motors Construction

- A brush is built with an armature coil that supplies the current to the commutator.
- At the back of the shaft, a detector is built into the rotor in order to detect the rotation speed.
- With this construction. it is simple to design a controller using simple circuitry because the torque is proportional to the amount of current through the armature.

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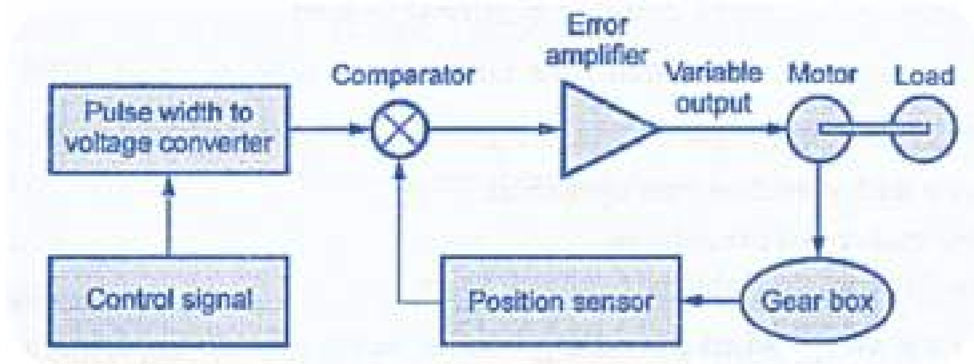
Block Diagram of a Servo Motor



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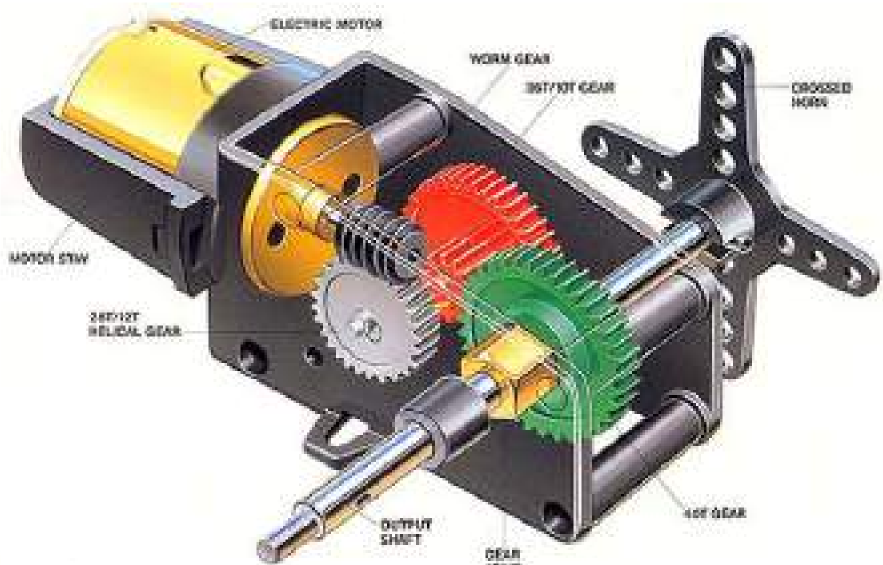

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Working Principle of DC Servo Motor

- A DC reference voltage is set to the value corresponding to the desired output.
- This voltage can be applied by using another potentiometer, control pulse width to voltage converter, or through timers depending on the control circuitry.
- The dial on the potentiometer produces a corresponding voltage which is then applied as one of the inputs to error amplifier.
- In some circuits, a control pulse is used to produce DC reference voltage corresponding to desired position or speed of the motor and it is applied to a pulse width to voltage converter.
- In digital control, microprocessor or microcontroller are used for generating the PWM pluses in terms of duty cycles to produce more accurate control signals.
- The feedback signal corresponding to the present position of the load is obtained by using a position sensor.
- This sensor is normally a potentiometer that produces the voltage corresponding to the absolute angle of the motor shaft through gear mechanism.

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Working Principle of DC Servo Motor contd...

- Then the feedback voltage value is applied at the input of error amplifier (comparator).
- The error amplifier is a negative feedback amplifier, and it reduces the difference between its inputs.
- It compares the voltage related to current position of the motor (obtained by potentiometer) with desired voltage related to desired position of the motor (obtained by pulse width to voltage converter), and produces the error either a positive or negative voltage.
- This error voltage is applied to the armature of the motor.
- If the error is more, the more output is applied to the motor armature.
- As long as error exists, the amplifier amplifies the error voltage and correspondingly powers the armature.
- The motor rotates till the error becomes zero.
- If the error is negative, the armature voltage reverses and hence the armature rotates in the opposite direction.

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DC Servo motor Advantages

1. High output power relative to motor size and weight.
2. Encoder determines accuracy and resolution.
3. High efficiency. It can approach 90% at light loads.
4. High torque to inertia ratio. It can rapidly accelerate loads.
5. Has "reserve" power. 2-3 times continuous power for short periods.
6. Has "reserve" torque. 5-10 times rated torque for short periods.
7. Motor stays cool. Current draw proportional to load.
8. Usable high speed torque. Maintains rated torque to 90 % of NL RPM
9. Audibly quiet at high speeds.
10. Resonance and vibration free operation.

DC Servo motor Disadvantages

1. Requires "tuning" to stabilize feedback loop.
2. Motor "runs away" when something breaks. Safety circuits are required.
3. Complex. Requires encoder.
4. Brush wear out limits life to 2,000 hrs. Service is then required.
5. Peak torque is limited to a 1% duty cycle.
6. Motor can be damaged by sustained overload.
7. Bewildering choice of motors, encoders, and servodrives.
8. Power supply current 10 times average to use peak torque.
9. Motor develops peak power at higher speeds. Gearing often required.
10. Poor motor cooling. Ventilated motors are easily contaminated.

AC Servo Motor

- Most of the servomotors used in the low power servomechanism are a.c. servomotors.
- The a.c. servomotor is basically two phase induction motor.
- The output power of A.C servomotor varies from fraction of watts to few hundred of watts.
- The operating frequency is 50 Hz to 400 Hz.

Features of A.C. Servomotor

- 1. Light in weight for quick response.
- 2. Robust in construction.
- 3. It is reliable and its operation is stable in nature.
- 4. Smooth and noise free operation.
- 5. Large torque to weight ratio.
- 6. Large resistance to reactance ratio.

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Construction

- The A.C servomotor is basically consists of a stator and a rotor.
- The stator carries two windings, uniformly distributed and displaced by 90° in space, from each other.
- On winding is called as main winding or fixed winding or reference winding. The reference winding is excited by a constant voltage a.c. supply.
- The other winding is called as control winding.
- It is excited by variable control voltage, which is obtained from a servo amplifier.
- The winding are 90° away from each other and control voltage is 90° out of phase with respect to the voltage applied to the reference winding. This is necessary to obtain rotating magnetic field.

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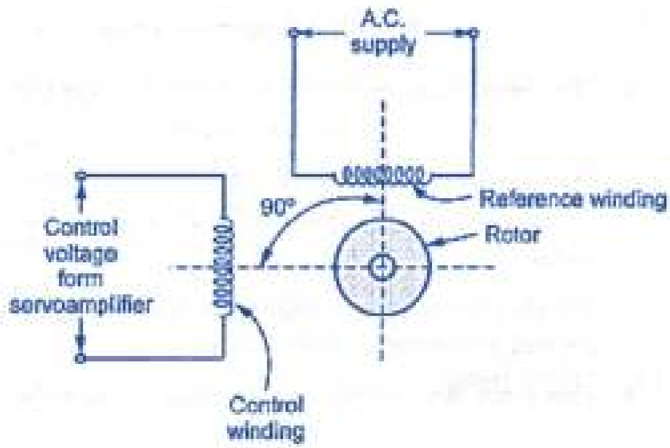
- To reduce the loading on the amplifier, the input impedance i.e. the impedance of the control winding in increased by using a tuning capacitor in parallel with the control winding.
- The rotor is generally of two types :
- 1. Squirrel cage rotor
- 2. Drag cup type rotor



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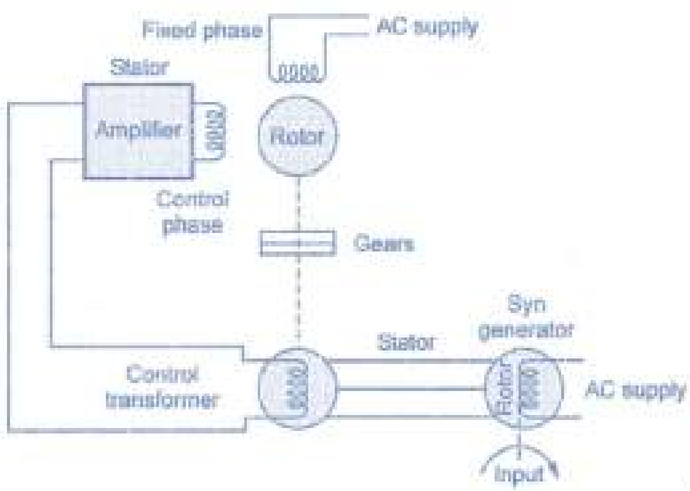
Working Principle of AC Servo Motor

- The schematic diagram of servo system for AC two-phase induction motor is shown in the figure below.



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Working Principle of AC Servo Motor

- In this, the reference input at which the motor shaft has to maintain at a certain position is given to the rotor of synchro generator as mechanical input theta.
- This rotor is connected to the electrical input at rated voltage at a fixed frequency.
- The three stator terminals of a synchro generator are connected correspondingly to the terminals of control transformer.
- The angular position of the two-phase motor is transmitted to the rotor of control transformer through gear train arrangement and it represents the control condition alpha.
- Initially, there exist a difference between the synchro generator shaft position and control transformer shaft position.
- This error is reflected as the voltage across the control transformer.

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Working Principle of AC Servo Motor

- This error voltage is applied to the servo amplifier and then to the control phase of the motor. With the control voltage, the rotor of the motor rotates in required direction till the error becomes zero.
- This is how the desired shaft position is ensured in AC servo motors. Alternatively, modern AC servo drives are embedded controllers like PLCs, microprocessors and microcontrollers to achieve variable frequency and variable voltage in order to drive the motor.
- Mostly, pulse width modulation and Proportional-Integral-Derivative (PID) techniques are used to control the desired frequency and voltage.

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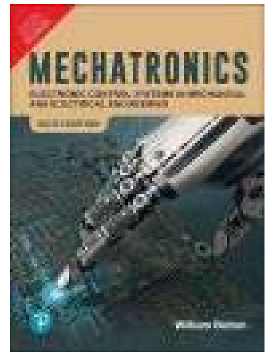

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UNIT II - MICROPROCESSOR AND MICROCONTROLLER 14

Concepts of 8255 PPI - Block diagram

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UNIT II - MICROPROCESSOR AND MICROCONTROLLER 14

1. Introduction
2. Architecture of 8085
3. Pin Configuration
4. Addressing Modes
5. Instruction set
6. Programming
7. Timing diagram of 8085
8. Concepts of 8051 microcontroller
9. Block diagram
10. Concepts of 8255 PPI
11. Block diagram.

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Features of 8255

- The 8255 is a widely used, programmable parallel I/O device or parallel communication interface.
- It can be programmed to transfer data under various conditions, from simple I/O to interrupt I/O.
- It is flexible, versatile and economical (when multiple I/O ports are required).
- It has three 8 bit ports port A, Port B and Port C.
- It is a 40 pin DIP chip.
- It is completely TTL compatible.
- All I/O Pins of 8255 has 2.5 mA d.c driving capacity.
- The 8255 can operate in three I/O modes:
  - Mode 0 : Simple input/ output
  - Mode 1 : Input/ output with handshake
  - Mode 2 : Bi-directional I/O data transfer

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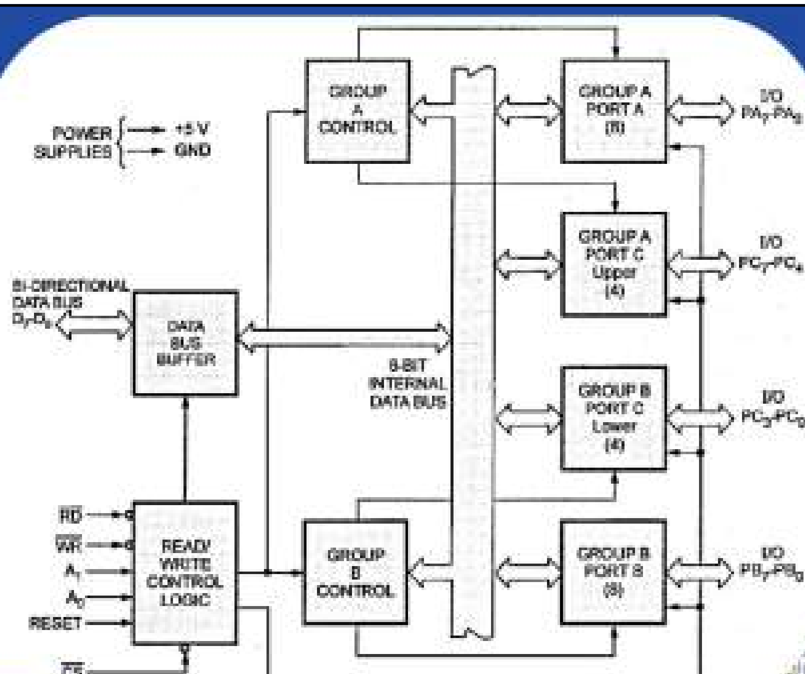
Block Diagram of 8255



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Block Diagram of 8255

It consist of **data bus buffer**, **control logic**, **Group A** and **Group B Controls**.

Data Bus Buffer

- This three-state bi-directional 8-bit buffer is used to interface the 82C55A to the system data bus.
- Data is transmitted or received by the buffer upon execution of input or output instructions by the CPU.
- Control words and status information are also transferred through the data bus buffer.

Read / write and Control Logic

- The function of this block is to manage all of the internal and external transfers of both Data and Control or Status words.
- It accepts inputs from the CPU Address and Control busses accepts inputs from the CPU Address and Control busses and in turn, issues commands to both of the Control Groups.

i. **(A0 and A1) Port Select 0 and Port Select 1 :**

- These input signals, in conjunction with the RD and WR inputs, control the selection of one of the three ports or the control word register.
- They are normally connected to the least significant bits of the address bus (A0 and A1).

ii. (CS) Chip Select :

- A "low" on this input pin enables the communication between the 82C55A and the CPU.

iii. (RD) Read :

- A "low" on this input pin enables 82C55A to send the data or status information to the CPU on the data bus.
- In essence, it allows the CPU to "read from" the 82C55A.

iv. (WR) Write :

- A "low" on this input pin enables the CPU to write data or control words into the 82C55A.

v. (RESET) Reset :

- A "high" on this input initializes the control register to 9BH and all ports (A, B, C)are set to the input mode.
- "Bus hold" devices internal to the 82C55A will hold the I/O port inputs to a logic "1" state with a maximum hold current of 400 mA.

3. Group A and Group B Controls

- The functional configuration of each port is programmed by the systems software.
- In essence, the CPU "output" a control word to the 8255A.
- The control word contains information such as mode, bit set, bit reset, etc. that initializes the functional configuration of the 8255A.
- Each of the Control blocks (Group A and Group B) accepts commands from the Read/Write Control Logic, receives control words from the internal data bus and issues the proper commands to its associated ports.

Port A : One 8 bit data output latch/buffer and one 8-bit data input latch.

Port B : One 8-bit data output latch/buffer and one 8-bit data input buffer.

Port C : One 8-bit data output latch/buffer and one 8-bit data input buffer (no latch for input).

This port can be divided into two 4-bit ports under the mode control.

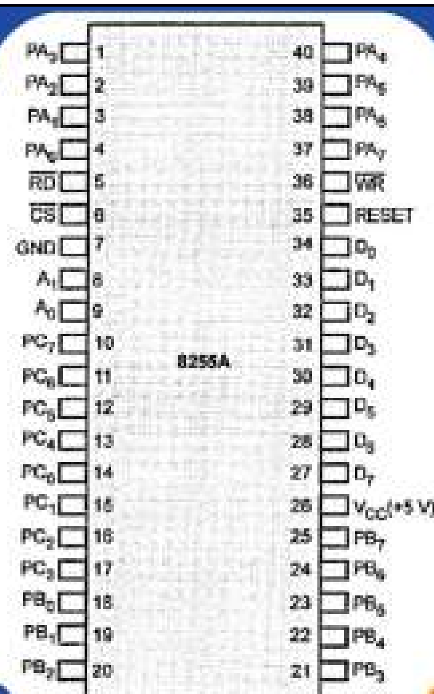
Each 4-bit port contains a 4-bit latch and it can be used for the controls signal outputs and status signal inputs in conjunction with ports A and B.

Pin Diagram of 8255

1. PA7-PA0 : These are eight port A lines that acts as either latched output or buffered input lines depending upon the control word loaded into the control word register.

2. PC7-PC4 :: Upper nibble of port C lines. They may act as either output latches or input buffers lines. This port also can be used for generation of handshake lines in mode 1 or mode 2.

3. PC3-PC0: These are the lower port C lines, other details are the same as *PC7-PC4* lines.



4. PB0-PB7: These are the eight port B lines which are used as latched output lines or buffered input lines in the same way as port A.

5. RD: This is the input line driven by the microprocessor and should be low to indicate read operation to 8255.

6. WR: This is an input line driven by the microprocessor. A low on this line indicates write operation.

7. CS: This is a chip select line. If this line goes low, it enables the 8255 to respond to RD and WR signals, otherwise RD and WR signal are neglected

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9. A1-A0:

- These are the address input lines and are driven by the microprocessor.
- These lines A1-A0 with RD, WR and CS from the following operations for 8255.
- These address lines are used for addressing anyone of the four registers, i.e. three ports and a control word register as given in table (next slide)

10. D0 - D7: These are the data bus lines those carry data or control word to/from the Microprocessor.

11. RESET : A logic high on this line clears the control word register of 8255. All ports are set as input ports by default after reset.

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Control Word Register

❖ In case of 8086 systems, if the 8255 is to be interfaced with lower order data bus, the Ao and A1 pins of 8255 are connected with A1 and A2 respectively.

$\overline{RD}$	$\overline{WR}$	$\overline{CS}$	A_1	A_0	Input (Read) cycle
0	1	0	0	0	Port A to Data bus
0	1	0	0	1	Port B to Data bus
0	1	0	1	0	Port C to Data bus
0	1	0	1	1	CWR to Data bus

$\overline{RD}$	$\overline{WR}$	$\overline{CS}$	A_1	A_0	Output (Write) cycle
1	0	0	0	0	Data bus to Port A
1	0	0	0	1	Data bus to Port B
1	0	0	1	0	Data bus to Port C
1	0	0	1	1	Data bus to CWR

$\overline{RD}$	$\overline{WR}$	$\overline{CS}$	A_1	A_0	Function
X	X	1	X	X	Data bus tristated
1	1	0	X	X	Data bus tristated

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Control word:

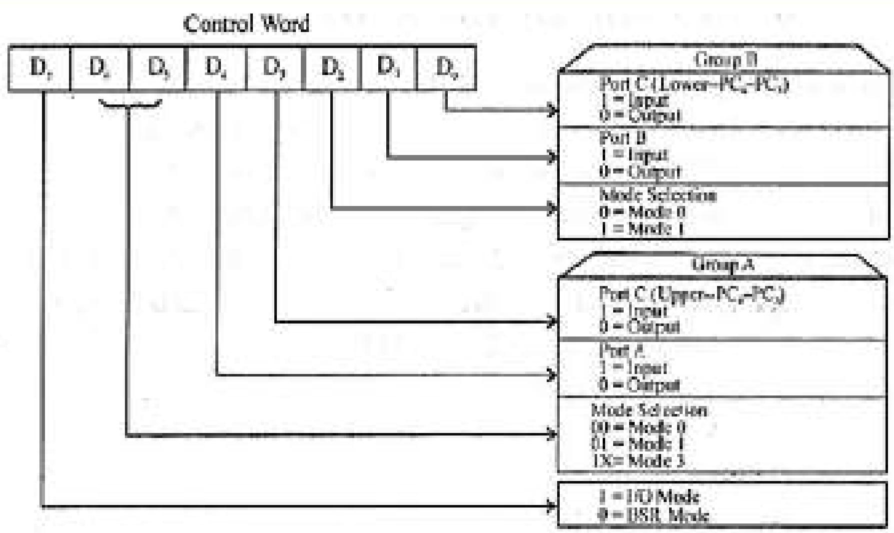

Figure .8255A Control Word Format for I/O Mode

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Modes of Operation of 8255

These are two basic modes of operation of 8255.

- ❖ I/O-mode
- ❖ Bit Set-Reset mode (BSR).

- ❖ In I/O mode, the 8255 ports work as programmable I/O ports,
- ❖ While in BSR mode only port C (PC0-PC7) can be used to set or reset its individual port bits.
- ❖ Under the I/O mode of operation, further there are three modes of operation of 8255, so as to support different types of applications,
  - **mode 0, mode 1 and mode 2.**

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1. Bit Set-Reset (BSR) Mode :

- ❖ In this mode any of the 8-bits of port C can be set or reset depending on D0 of the control word.
- ❖ The bit to be set or reset is selected by bit select flags D3, D2 and D1 of the CWR as given in following table.

Fig. BSR mode : CWR format

D_3	D_2	D_1	Selected bits of port C
0	0	0	D_0
0	0	1	D_1
0	1	0	D_2
0	1	1	D_3
1	0	0	D_4
1	0	1	D_5
1	1	0	D_6
1	1	1	D_7

Table : BSR mode

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2. I/O Modes

Mode 0 : Simple Input or Output

- In this mode, Port A and Port B are used as two simple 8-bit I/O ports and Port C as two 4-bit I/O ports.
- Each port (or half-port, in case of Port C) can be programmed to function as simply an input port or an output port.
- The input/output features in mode 0 are :
  1. Outputs are latched,
  2. Inputs are not latched
  3. Ports do not have handshake or interrupt capability.

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The salient features of this mode are,

- Two 8-bit ports (port A and port B) and two 4-bit ports (port C upper and lower) are available. The two 4-bit ports can be combined used as a third 8-bit port.
- Any port can be used as an input or output port.
- Output ports are latched. Input ports are not latched.
- A maximum of four ports are available so that overall 16 I/O configurations are possible.

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Mode 1 : Input or Output with handshake

- In mode 1, handshake signals are exchanged between the microprocessor and peripherals prior to data transfer.
- The ports (A and B) function as 8-bit I/O ports.
- They can be configured either as input or output ports. Each port (Port A and Port B) uses 3 lines from port C as handshake signals.
- The remaining two lines of port C can be used for simple I/O functions.
- Input and output data are latched and Interrupt logic is supported.

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The salient features of mode 1 are listed as follows :

- Two groups - group A and group B are available for strobed data transfer.
- Each group contains one 8-bit data I/O port and one 4-bit control/data port.
- The 8-bit data port can be either used as input and output port. The inputs and outputs both are latched.
- Out of 8-bit port C, PC0-PC2 are used to generate control signals for port B and PC3-PC5 are used to generate control signals for port A. The lines PC6 - PC7 may be used as independent data lines.

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Mode 2 (Strobed bidirectional I/O) :

- This mode of operation of 8255 is also called as strobed bidirectional I/O.
- This mode of operation provides 8255 with additional features for communicating with a peripheral device on an 8-bit data bus.
- Handshaking signals are provided to maintain proper data flow and synchronization between the data transmitter and receiver.
- The interrupt generation and other functions are similar to mode 1.
- In this mode, 8255 is a bidirectional 8-bit port with handshake signals.

The Salient features of Mode 2 of 8255 are listed as follows :

- The single 8-bit port in group A is available.
- The 8-bit port is bidirectional and additionally a 5-bit control port is available.
- Three I/O lines are available at port C. (PC2 - PC0)
- Inputs and outputs are both latched.

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UNIT-IV

PROGRAMMING LOGIC CONTROLLERS

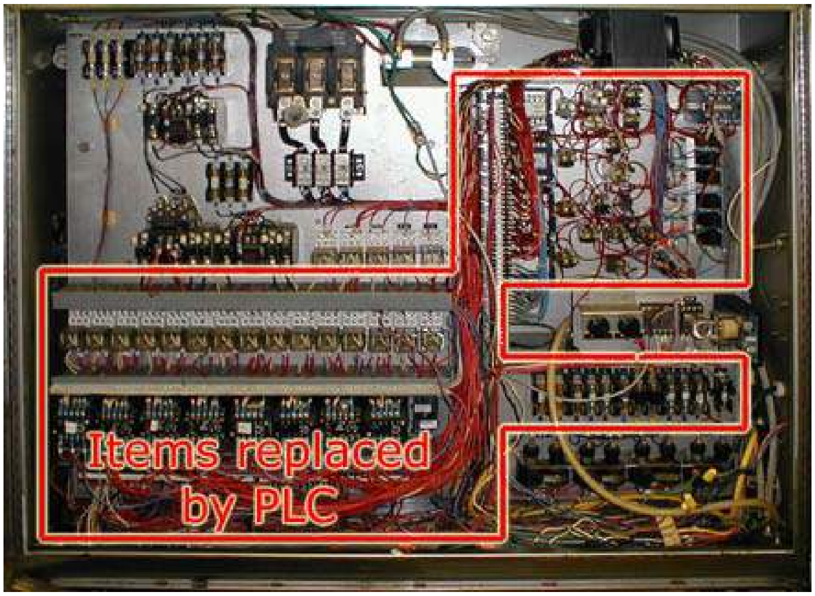
Programmable Logic Controllers – Basic Structure – Input / Output Processing – Programming – Mnemonics – Timers, Internal relays and counters – Shift Registers – Master and Jump Controls – Data Handling – Analogs Input / Output – Selection of a PLC.

Programmable Logic Controller (PLC)

Definition:

A programmable logic controller (PLC) is a digital electronic device that uses a programmable memory to store instructions and to implement functions such as logic, sequencing, timing, counting and arithmetic in order to control machines and processes

Relay Panel for logic control



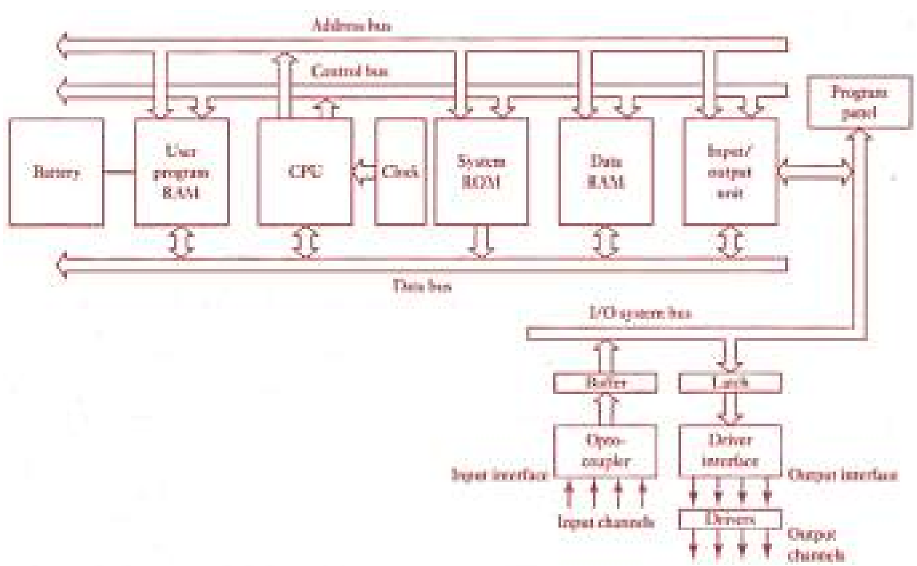
A.KUMARASWAMY. AP, MECH

PLC Replacement

PLC Specific Advantages

- They are rugged and designed to withstand vibrations, temperature, humidity and noise.
- The interfacing for inputs and outputs is inside the controller.
- They are easily programmed.

Basic Structure - Architecture of a PLC.



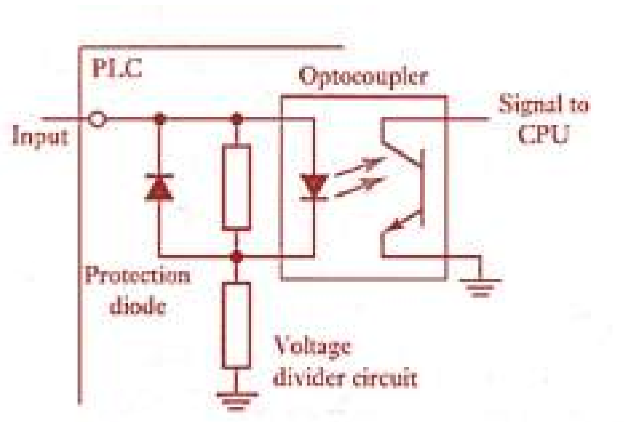
Internal structure of a PLC.

- Central processing unit (CPU) - controls and processes all the operations within the PLC
- A clock with a frequency of typically between 1 and 8 MHz,
  - Determines the operating speed of the PLC
  - Provides the timing and synchronization for all elements in the system memory and input/output interfaces.
- A bus system carries information and data to and from the CPU, memory and input/output units.
- Memory elements:
  - A system ROM –permanent storage for the operating system and fixed data,
  - RAM for the user's program,
  - Temporary buffer stores for the input/output channels.

Input/output

- The i/o units provide the interface between the system and the outside world.
- The i/o interfaces provide isolation and signal conditioning functions so that sensors and actuators can often be directly connected to them without the need for other circuitry.
- Inputs might be from limit switches which are activated when some event occurs, or other sensors such as temperature sensors, or flow sensors.
- The outputs might be to motor starter coils, solenoid valves, etc.
- Electrical isolation from the external world is usually by means of optoisolators

Input channel

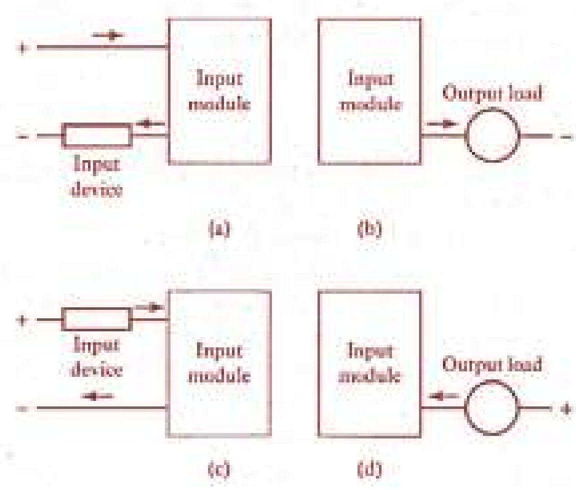


- Possible input voltages of 5 V, 24 V, 110 V and 240 V.
- The output to the output unit will be digital with a level of 5 V.
- Outputs are of relay type, transistor type or triac type.
- Relays:
  - The signal from the PLC output is used to operate a relay and so is able to switch currents of the order of a few amperes in an external circuit.
  - The relay isolates the PLC from the external circuit and can be used for both d.c. and a.c. switching.
  - Relays are, however, relatively slow to operate.
- The transistor used to switch current through the external circuit.
  - This gives a faster switching action.
  - The transistor output is only for d.c. switching.
- Optoisolators are used with transistor switches to provide isolation between the external circuit and the PLC.
- Triac outputs can be used to control external loads which are connected to the a.c. power supply.

- Optoisolators are used to provide isolation.
  - might be a 24 V, 100 mA switching signal,
  - a d.c. voltage of 110 V, I A or perhaps 240 V,
  - 1 A a.c., or 240V, 2 A a.c., from a triac output channel.
- With a small PLC, all the outputs might be of one type, e.g. 240 V a.c., 1 A.
- With modular PLCs, however, a range of outputs can be accommodated by selection of the modules to be used.

Sourcing and sinking

(a), (b) Sourcing, and (c), (d) sinking.



Sourcing and sinking

- Used to describe the way in which d.c. devices are connected to a PLC.
- With **sourcing**, using the conventional current flow direction as from positive to negative, an input device receives current from the input module (Figure (a).
- If the current flows from the output module to an output load then the output module is referred to as sourcing (Figure (b)).
- With **sinking**, an input device supplies current to the input module (Figure (c).
- If the current flows to the output module from an output load then the output module is referred to as sinking (Figure (d).

- The input/output unit provides the interface between the system and the outside world.
- allowing for connections to be made through input/output channels to input devices such as sensors and output devices such as motors and solenoids.
- It is also through the input/output unit that programs are entered from a program panel.
- Every input/output point has a unique address which can be used by the CPU.
- It is like a row of houses along a road: number 10 might be the 'house' to be used for an input from a particular sensor while number '45' might be the 'house' to be used for the output to a particular motor

Inputting programs

- Programs are entered into the input/output unit from small hand-held programming devices, desktop consoles with a visual display unit (VDU), keyboard and screen display, or by means of a link to a personal computer (PC) which is loaded with an appropriate software package.
- Only when the program has been designed on the programming device and is ready is it transferred to the memory unit of the PLC.
- The programs in RAM can be changed by the user.
- To prevent the loss of these programs when the power supply is switched off, a battery is likely to be used in the PLC to maintain the RAM contents for a period of time.
- After a program has been developed in RAM it may be loaded into an EPROM chip and so made permanent.

- Specifications for small PLCs often specify the program memory size in terms of the number of program steps that can be stored.
- A program step is an instruction for some event to occur.
- A program task might consist of a number of steps and could be, for example: examine the state of switch A, examine the state of switch B, if A and B are closed then energise solenoid P which then might result in the operation of some actuator. When this happens another task might then be started.
- Typically the number of steps that can be handled by a small PLC is of the order of 300 to 1000, which is generally adequate for most control situations.

Forms of PLCs

- PLCs were first conceived in 1968.
- They are now widely used and extend from small self-contained units, i.e. single boxes, for use with perhaps 20 digital input/outputs to rack-mounted systems which can be used for large numbers of inputs/outputs, handle digital or analogue inputs/outputs, and also carry out PID control modes.
- The single-box type is commonly used for small programmable controllers and is supplied as an integral compact package complete with power supply, processor, memory and input/output units.
- Typically such a PLC might have 6, 8, 12 or 24 inputs and 4, 8 or 16 outputs and a memory which can store some 300 to 1000 instructions.
- For example, the MELSEC FX3U has models which can have 6, 8, 12 or 24 inputs and 4, 8 or 16 relay outputs and a memory which can store some 300 to 1000 instructions.
- Some systems are able to be extended to cope with more inputs and outputs by linking input/output boxes to them.

- Systems with larger numbers of inputs and outputs are likely to be modular and designed to fit in racks.
- These consist of separate modules for power supply, processor, input/output, etc., and are mounted on rails within a metal cabinet.
- The rack type can be used for all sizes of programmable controllers and has the various functional units packaged in individual modules which can be plugged into sockets in a base rack. The mix of modules required for a particular purpose is decided by the user and the appropriate ones then plugged into the rack.
- So the number of input/output connections can be increased by just adding more input/output modules.
- For example, the SIMATIC S7-300/400 PLC is rack mounted with components for the power supply, the CPU, input/output interface modules, signal modules which can be used to provide signal conditioning for inputs or outputs and communication modules which can be used to connect PLCs to each other or to other systems.

Input/output processing

- Cycle: A PLC is continuously running through its program and updating it as a result of the input signals(loop).
- Two methods:
  - Continuous updating
  - Mass input/output copying.

Continuous updating

- Continuous updating involves the CPU scanning the input channels as they occur in the program instructions.
- Each input point is examined individually and its effect on the program determined.
- There will be a built-in delay, typically about 3 ms, when each input is examined in order to ensure that only valid input signals are read by the microprocessor.
- This delay enables the microprocessor to avoid counting an input signal twice, or, more frequently, if there is contact bounce at a switch.
- A number of inputs may have to be scanned, each with a 3 ms delay, before the program has the instruction for a logic operation to be executed and an output to occur.
- The outputs are latched so that they retain their status until the next updating.

Mass input/output copying

- Because, with continuous updating, there has to be a 3 ms delay on each input, the time taken to examine several hundred input/output points can become comparatively long.
- To allow a more rapid execution of a program, a specific area of RAM is used as a buffer store between the control logic and the input/output unit.
- Each input/output has an address in this memory.
- At the start of each program cycle the CPU scans all the inputs and copies their status into the input/output addresses in RAM.
- As the program is executed the stored, input data is read, as required, from RAM and the logic operations carried out.
- The resulting output signals are stored in the reserved input/output section of RAM.
- At the end of each program cycle all the outputs are transferred from RAM to the output channels.
- The outputs are latched so that they retain their status until the next updating.

The sequence is:

- Scan all the inputs and copy into RAM.
- Fetch and decode and execute all program instructions in sequence, copying output instructions to RAM.
- Update all outputs.
- Repeat the sequence.

- A PLC takes time to complete a cycle of scanning inputs and updating outputs according to the program instructions and so the inputs are not watched all the time but only examined periodically.
- A typical PLC cycle time is of the order of 10 to 50 ms and so the inputs and outputs are updated every 10 to 50 ms.
- This means that if a very brief input appears at the wrong moment in the cycle, it could be missed.
- Thus for a PLC with a cycle time of 40 ms, the maximum frequency of digital impulses that can be detected will be if one pulse occurs every 40 ms.
- The Mitsubishi compact PLC, MELSEC FX3U, has a quoted program cycle time of 0.065μS per logical instruction and so the more complex the program, the longer the cycle time.

I/O addresses

- The PLC has to be able to identify each particular input and output and it does this by assigning addresses to each, rather like houses in a town have addresses to enable post to be delivered to the right families.
- With a small PLC the addresses are likely to be just a number preceded by a letter to indicate whether it is an input or output.
- For example, Mitsubishi and Toshiba have inputs identified as X400, X401, X402, etc., and outputs as Y430, Y431, etc.
- With larger PLCs having several racks of input and output channels and a number of modules in each rack, the racks and modules are numbered and so an input or output is identified by its rack number followed by the number of the module in that rack and then a number to show its terminal number in the module.
- For example, the Allen-Bradley PCL-5 has 1:012103 to indicate an input in rack 01 at module 2 and terminal 03.

PLC Programming

- Mnemonics
- Ladder Diagrams

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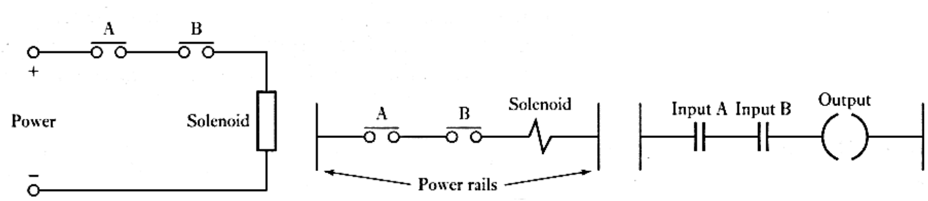
Ladder programming

- The form of programming commonly used with PLCs is ladder programming.
- This involves each program task being specified as though a rung of a ladder.
- Thus such a rung could specify that the state of switches A and B, the inputs, be examined and if A and B are both closed then a solenoid, the output, is energised.
- Figure below illustrates this idea by comparing it with an electric circuit.

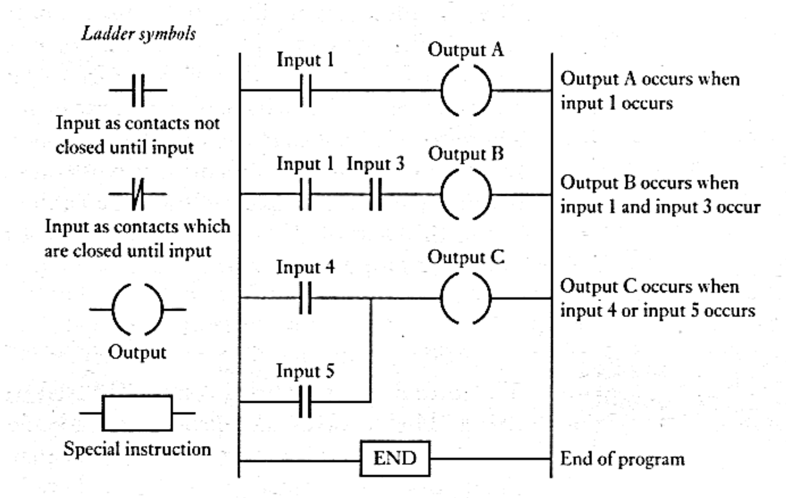


(a) (b) (c)

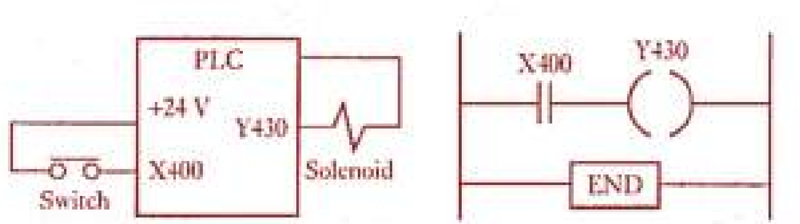
- The sequence followed by a PLC when carrying out a program can be summarised as:
  - 1 Scan the inputs associated with one rung of the ladder program.
  - 2 Solve the logic operation involving those inputs.
  - 3 Set/reset the outputs for that rung.
  - 4 Move on to the next rung and repeat operations 1,2,3.
  - 5 Move on to the next rung and repeat operations 1,2,3.
  - 6 Move on to the next rung and repeat operations 1,2,3.
  - 7 And so on until the end of the program with each rung of the ladder program scanned in turn.
- The PLC then goes back to the beginning of the program and starts again.

- PLC programming based on the use of ladder diagrams involves writing a program in a similar manner to drawing a switching circuit.
- The ladder diagram consists of two vertical lines representing the power rails.
- Circuits are connected as horizontal lines, i.e. the rungs of the ladder, between these two verticals.
- Figure below shows the basic standard symbols that are used and an example of rungs in a ladder diagram.
- In drawing the circuit line for a rung, inputs must always precede outputs and there must be at least one output on each line.
- Each rung must start with an input or a series of inputs and end with an output.

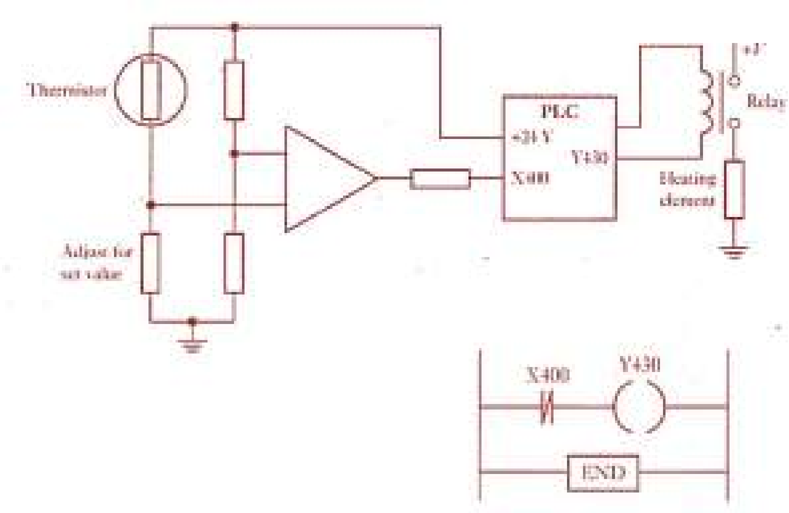
Ladder program



Switch controlling a solenoid



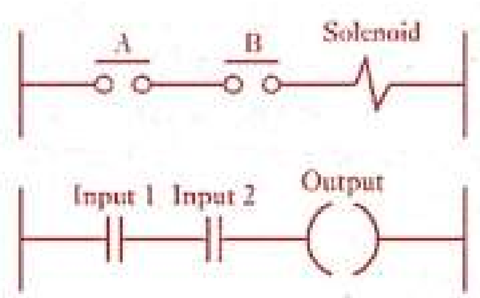
Temperature control system.



Logic functions

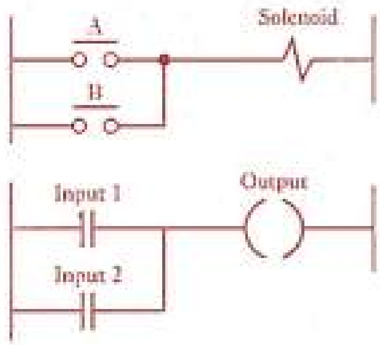
AND Logic

- where a coil is not energised unless two, normally open, switches are both closed.



OR Logic

- where a coil is not energised until either, normally open, switch A or B is closed.



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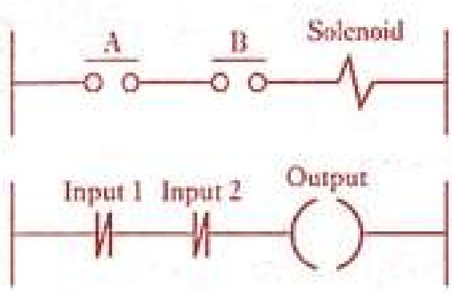
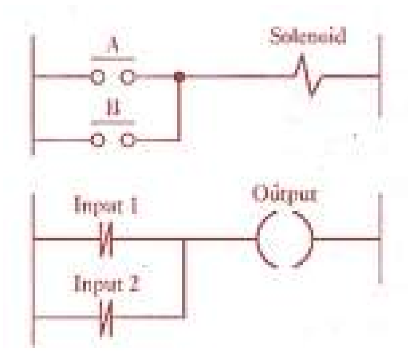
NOR Logic

- Since there has to be an output when neither A nor B have an input, and when there is an input to A or B the output ceases, the ladder program shows Input I in parallel with Input 2, with both being represented by normally closed contacts.



NAND Logic

There is no output when both A and B have an input. Thus for the ladder program line to obtain an output we require no inputs to Input 1 and to Input 2.



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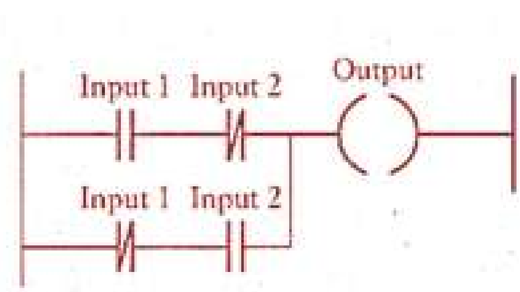
EXCLUSIVE-OR (XOR)

There being no output when there is no input to Input 1 and Input 2 and when there is an input to both Input 1 and Input 2. Note that we have represented each input by two sets of contacts, one normally open and one normally closed.



Draw ladder for the truthtable

Inputs			
A	B	C	Output
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	1
1	1	0	1
1	1	1	1

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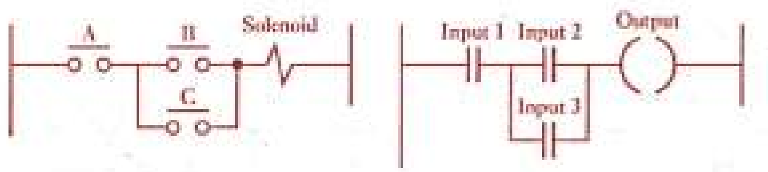
Answer:

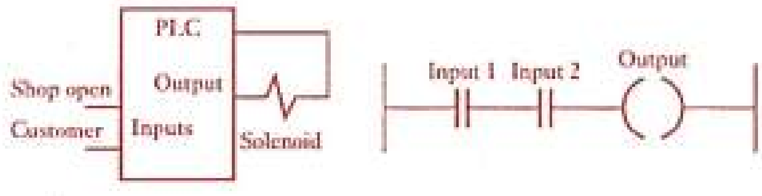


(a) (b)

Draw ladder for the situation

Shop open switch	Customer approaching sensor	Solenoid output
Off	Off	Off
Off	On	Off
On	Off	Off
On	On	On

Answer:



Mnemonics

- It is an alternative way of entering a program
- That is to translate the ladder program into an instruction list and then enter this into the programming panel or computer.
- Instruction lists consist of a series of instructions with each instruction being on a separate line.
- An instruction consists of an operator followed by one or more operands, i.e. the subjects of the operator.
- In terms of ladder programs, each operator in a program may be regarded as a ladder element.
- Thus we might have for the equivalent of an input to a ladder program:

LD A (*Load input A *)

- The mnemonic codes used by different PLC manufacturers differ but an international standard (IEC 1131-3) has been proposed and is widely used.
- Table below shows common core mnemonics.

IEC 1131-3	Mitsubishi	OMRON	Siemens	Operation	Ladder diagram
LD	LD	LD	A	Load operand into result register	Start a rung with open contacts
LDN	LDI	LD NOT	AN	Load negative operand into result register	Start a rung with closed contacts
AND	AND	AND	A	Boolean AND	A series element with open contacts
ANDN	ANI	AND NOT	AN	Boolean AND with negative operand	A series element with closed contacts
OR	OR	OR	O	Boolean OR	A parallel element with open contacts
ORN	ORI	OR NOT	ON	Boolean OR with negative operand	A parallel element with closed contacts
ST	OUT	OUT	=	Store result register into operand	An output from a rung

Instruction lists and logic functions

AND Logic

LD X400 ("Input at address X400")
AND X401 ("ADD input at address X401")
OUT Y430 ("Output to address Y430")

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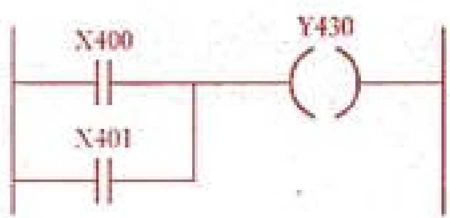
OR Logic



LD X400 ("Input at address X400")
OR X401 ("OR input at address X401")
OUT Y430 ("Output to address Y430")

NOR Logic

LDI X400 (*NOT input at address X400*)
ANI X401 (*AND NOT input at address X401*)
OUT Y430 (*Output to address Y430*)

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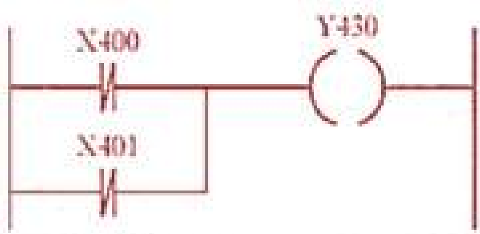
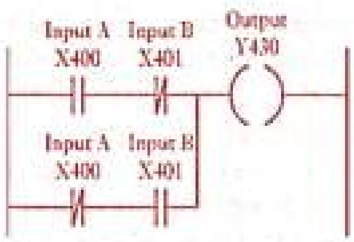
NAND Logic



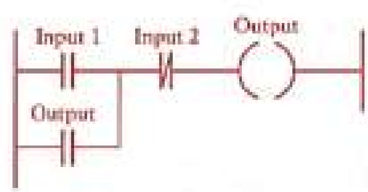
LDI X400 (*NOT input at address X400*)
ORI X401 (*OR NOT input at address X401*)
OUT Y430 (*Output to address Y430*)

X-OR Logic



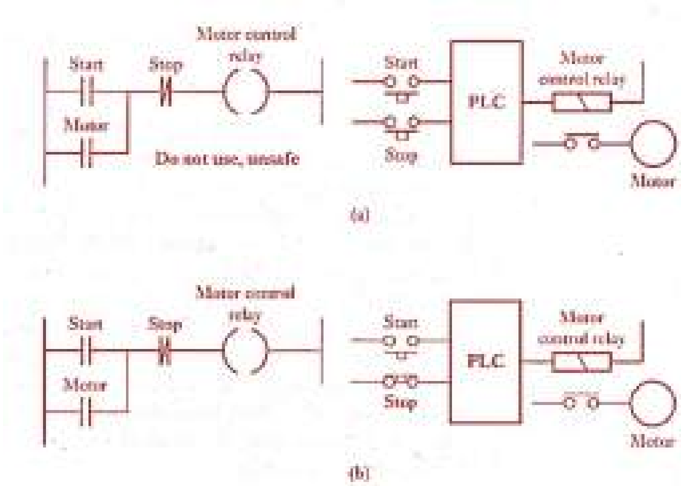
LD X400 ("Load input at address X400")
ANI X401 ("AND NOT input at address X401")
LDI X400 ("Load NOT input at address X401")
AND X401 ("AND input at address X401")
ORB
OUT Y430 ("Output to address Y430")

Latching



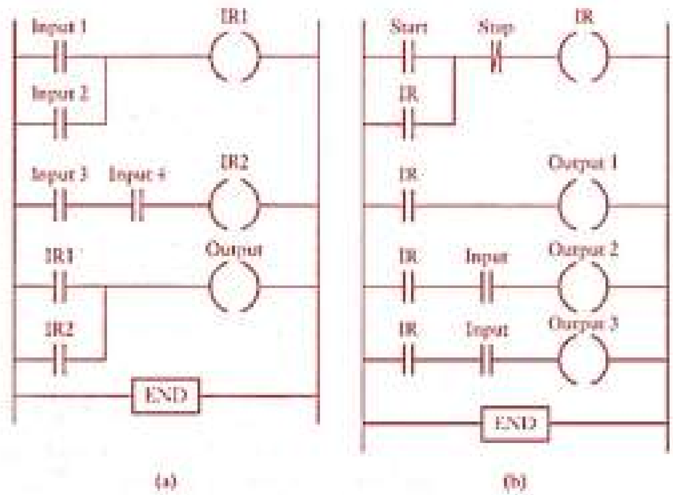
- It holds a coil energised, even when the input which energised it ceases.
- It is a self-maintaining circuit in that, after being energised, it maintains that state until another input is received. It remembers its last state.
- When there is an output, a set of contacts associated with the output is energised and closes. These contacts OR the Input 1 contacts.
- Even if Input 1 contacts open, the circuit will still maintain the output energised.
- The only way to release the output is by operating the normally closed contact Input 2.

Stop system: (a) unsafe, (b) safe



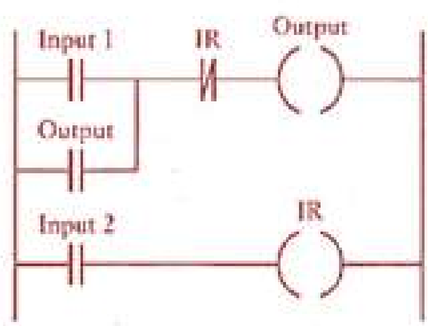
Internal relays or auxiliary relay or marker

- Software relays
- Some have battery back-up - used in circuits to ensure a safe shut-down of plant in the event of a power failure.
- Internal relays can be very useful aids in the implementation of switching sequences.
- Internal relays are often used when there are programs with multiple input conditions.

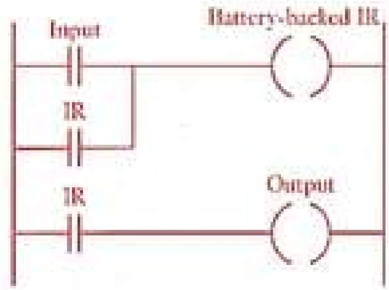


- (a) An output controlled by two input arrangements,
- (b) starting of multiple outputs

Resetting a Latch

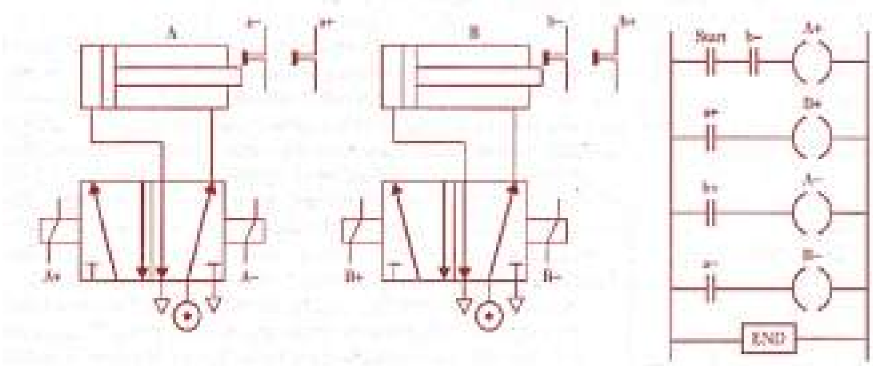


Use of a battery-backed internal relay



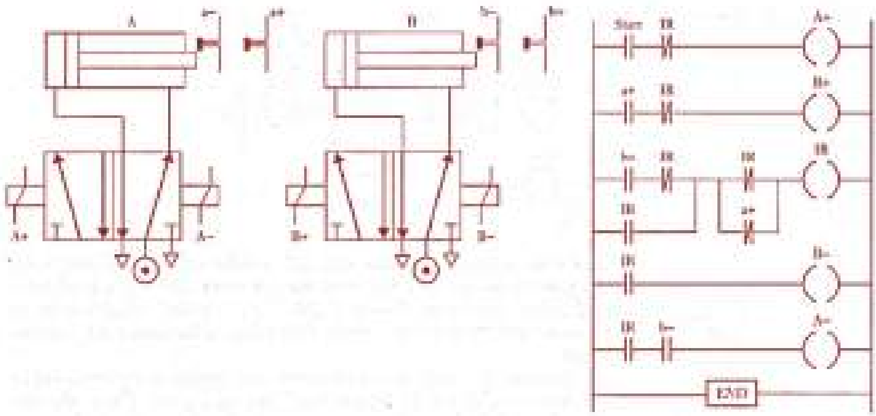
Sequencing

A+ B+ A- B-



Cascade Sequence

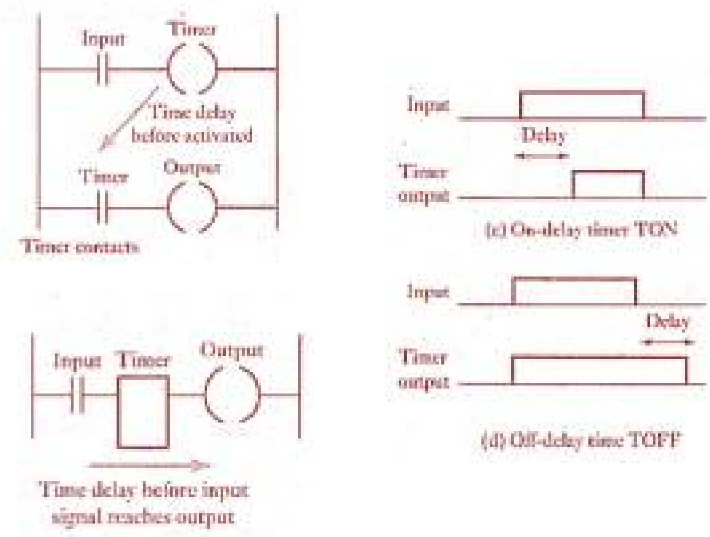
A+ B+ B- A-



Timers

- Timers behave like relays with coils which when energised result in the closure or opening of contacts after some preset time.
- The timer can be treated as an output for a rung with control being exercised over pairs of contacts.
- Otherwise consider a timer as a delay block in a rung which delays signals in that rung reaching the output

Timers



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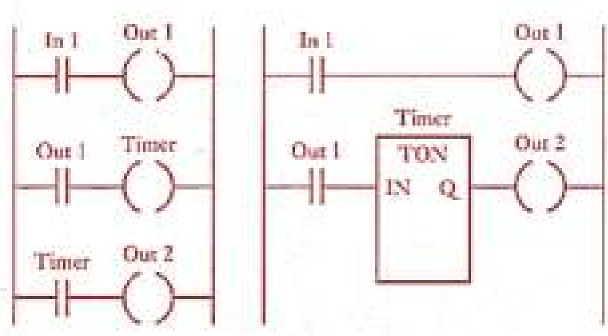
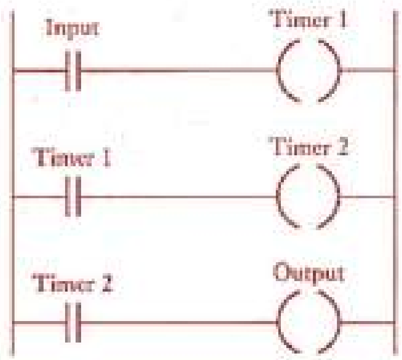
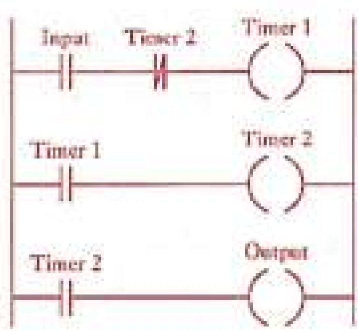
Timed sequence



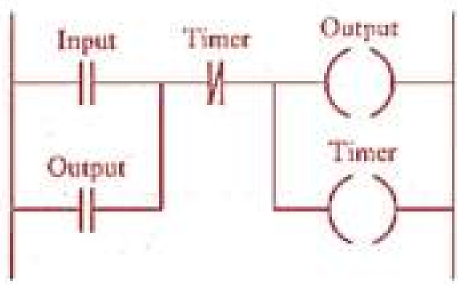
Cascaded timers



On/off cyclic timer.



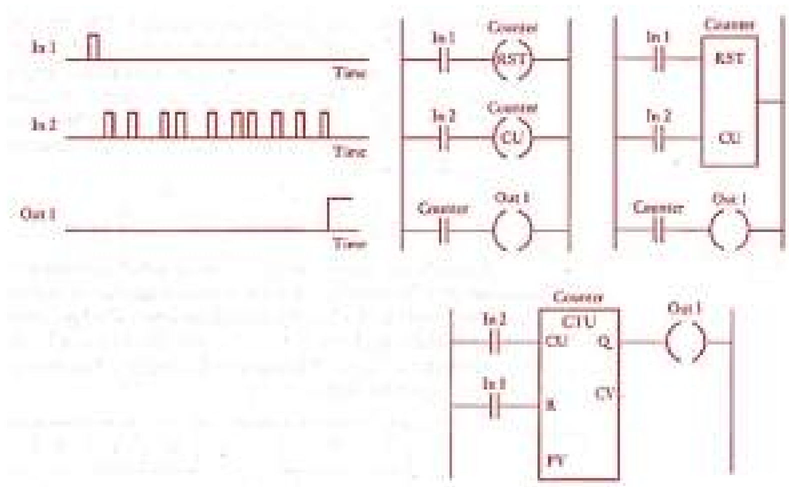
Delay-off timer.



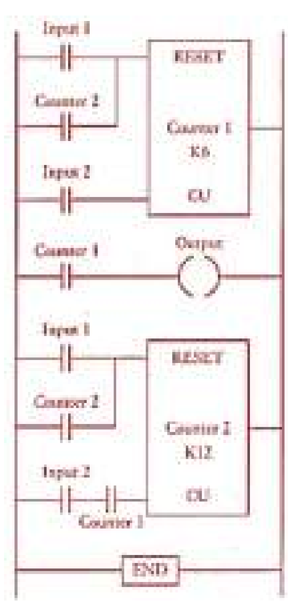
Counters

- Counters are used to count a specified number of contact operations,
- e.g. where items pass along a conveyor into boxes, and when the specified number of items has passed into a box, the next item is diverted into another box.
- **Down-counter.** the counter counts down from the present value to zero, i.e. events are subtracted from the set value. When zero is reached the counter's contact changes state.
- **An up-counter** would count up to the preset value, i.e. events are added until the number reaches the set value. When the set value is reached the counter's contact changes state.

The inputs and output for a counter and various ways of representing the same program

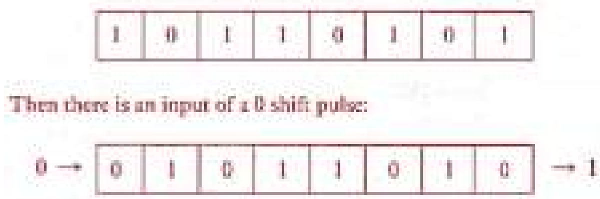


- As an illustration of the use of a counter, consider the problem of the control for a machine which is required to direct 6 items along one path for packaging in a box, and then 12 items along another path for packaging in another box.
- It involves two counters, one preset to count 6 and the other to count 12.
- Input 1 momentarily closes its contacts to start the counting cycle, resetting both counters.
- Input 2 contacts could be activated by a microswitch which is activated every time an item passes up to the junction in the paths. Counter 1 counts 6 items and then closes its contact.
- This activates the output, which might be a solenoid used to activate a flap which closes one path and opens another. Counter 1 also has contacts which close and enables Counter 2 to start counting.
- When Counter 2 has counted 12 items it resets both the counters and opens the Counter 1 contacts, which then results in the output becoming deactivated and items no longer directed towards the box to contain 12 items.



Shift registers

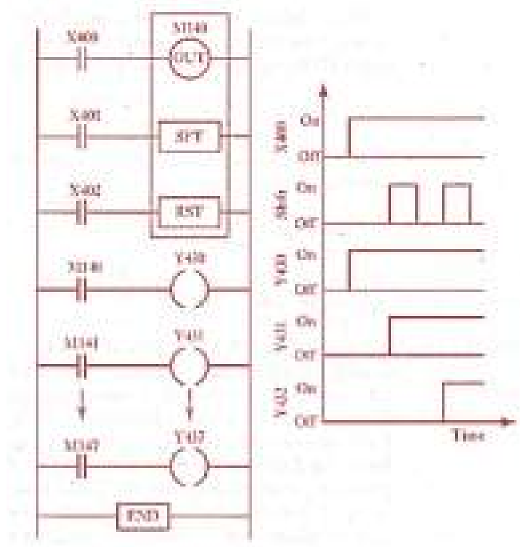
- A number of internal relays can be grouped together to form a register.
- Which can provide a storage area for a series sequence of individual bits.
- A 4-bit register would be formed by using four internal relays, an 8-bit using eight.
- The term shift register is used because the bits can be shifted along by 1 bit when there is a suitable input to the register.
- For example, with an 8-bit register we might initially have:



- With the result that all the bits shift along one place and the last bit overflows

- The grouping together of a number of auxiliary registers to form a shift register is done automatically by a PLC when the shift register function is selected at the control panel.
- With the Mitsubishi PLC, this is done by using the programming function SFT (shift) against the auxiliary relay number that is to be the first in the register array.
- This then causes the block of relays, starting from that initial number, to be reserved for the shift register.
- Thus, if we select MI40 to be the first relay then the shift register will consist of Ml40, M141, Ml42, M143, MI44, M145, MI46 and M147
- Shift registers have three inputs: one to load data into the first element of the register (OUT), one as the shift command (SFT) and one for resetting (RST).
- With OUT, a logic level 0 or 1 is loaded into the first element of the shift register.
- With SFT, a pulse moves the contents of the register along 1 bit at a time, the final bit overflowing and being lost.
- With RST, a pulse of the closure of a contact resets the register contents to all zeros

Shift register



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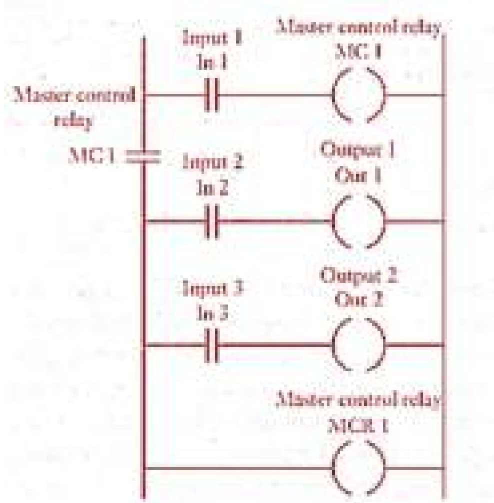
Master and jump controls

- A whole block of outputs can be simultaneously turned off or on by using the same internal relay contacts in each output rung so that switching it on or off affects everyone of the rungs.
- An alternative way of programming to achieve the same effect is to use a master relay.
- Controlling the power to a length of the vertical rails of theladder. When there is an input to close Input 1 contacts, master relay MC1 is activated and then the block of program rungs controlled by that relay follows.
- The end of a master-relay-controlled section is indicated by the reset MCR. It is thus a branching program in that if there is Input 1 then branch to follow the MC1 controlled path; if not, follow the rest of the program and ignore the branch.
- The program instruction is: MC M100
- To indicate the end of the section controlled by a master control relay, the program instruction is: MCR M100

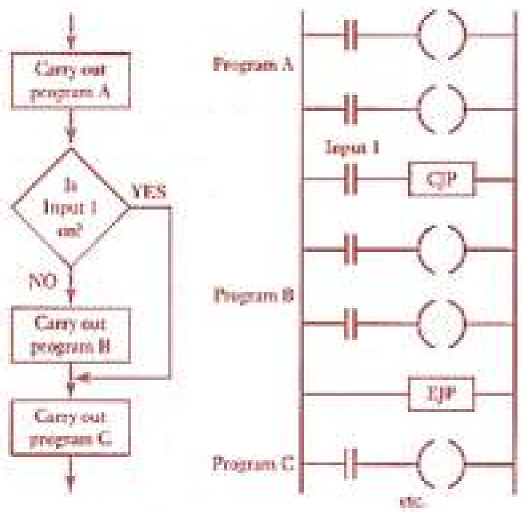
Master control relay



Jumps

- A function which is often provided with PLCs is the conditional jump function. Such a function enables programs to be designed so that if a certain condition exists then a section of the program is jumped.
- Following a section of program, A, the program rung is encountered with Input 1 and the conditional jump relay CJP.
- If Input 1 occurs then the program jumps to the rung with the end of jump relay coil EJP and so continues with that section of the program labelled as C, otherwise it continues with the program rungs labelled as program B

Jump.

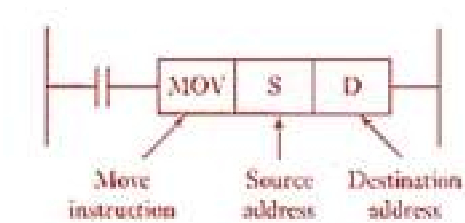


Data handling

1. With the exception of the shift register, we have been concerned with the handling of individual bits of information, e.g. a switch being closed or not.
2. There are, some control tasks where it is useful to deal with related groups of bits, e.g. a block of eight inputs, and so operate on them as a data word. Such a situation can arise when a sensor supplies an analogue signal which is converted to, say, an 8-bit word before becoming an input to a PLC.
3. The operations that may be carried out with a PLC on data words normally include:
    1. Moving data.
    2. Comparison of magnitudes of data, i.e. greater than, equal to, or less than.
    3. Arithmetic operations such as addition and subtraction.
    4. Conversions between binary-coded decimal (BCD), binary and octal.

Data movement

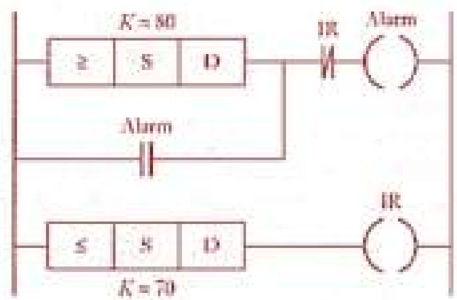
- For data movement the instruction will contain the move data instruction, the source address of the data and the destination address of the data.
- Such data transfers might be to move a constant into a data register, a time or count value to a data register, data from a data register to a timer or counter, data from a data register to an output, input data to a data register, etc



Data comparison

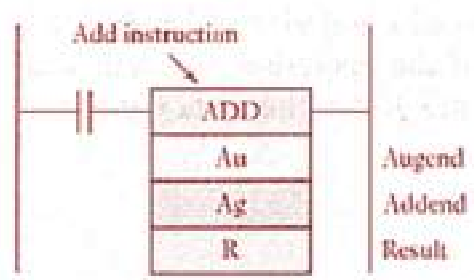
- Data comparisons - less than (usually denoted by < or LES), equal to (= or EQU), less than or equal to (≤ or <= or LEQ), greater than (> or GRT), greater than or equal to (≥, >= or GEQ) and not equal to (≠ or < > or NEQ).
- To compare data, the program instruction will contain the comparison instruction, the source address of the data and the destination address.
- Thus to compare the data in data register D1 to see if it is greater than data in data register D2. Such a comparison might be used when the signals from two sensors are to be compared by the PLC before action is taken.
- For example, an alarm might be required to be sounded if a sensor indicates a temperature above 80°C and remain sounding until the temperature falls below 70°C.
- The input temperature data is inputted to the source address and the destination address contains the set value.

- When the temperature rises to 80°C, or higher, the data value in the source address becomes ≥ the destination address value and there is an output to the alarm which latches the input.
- When the temperature falls to 70°C, or lower, the data value in the source address becomes ≤ the destination address value and there is an output to the relay which then opens its contacts and so switches the alarm of(



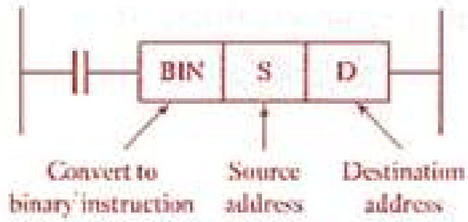
Arithmetic operations

- Addition or subtraction might be used to alter the value of some sensor input value, perhaps a correction or offset term, or alter the preset values of timers or counters.



Code conversions

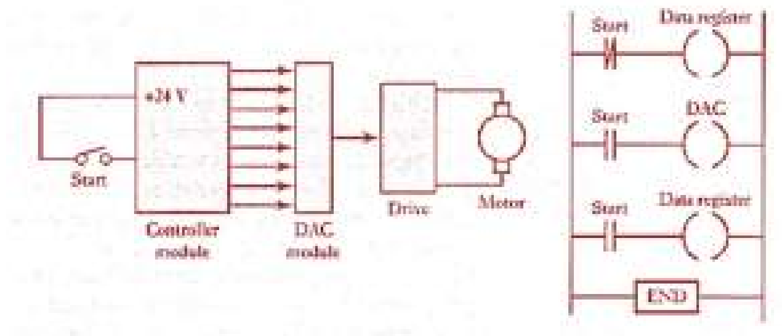
- All the internal operations in the CPU of a PLC are carried out using binary numbers. Thus, when the input is a signal which is decimal, conversion to BCD is used. Likewise, where a decimal output is required, conversion to decimal is required. Such conversions are provided with most PLCs.
- For example, with Mitsubishi, the ladder rung to convert BCD to binary.
- The data at the source address is in BCD and converted to binary and placed at the destination address.



Analogue input/output.

- Many sensors generate analogue signals and many actuators require analogue signals.
- Thus, some PLCs may have an analogue-to-digital converter module fitted to input channels and a digital-to-analogue converter module fitted to output channels.
- An example of where such an item might be used is for the control of the speed of a motor so that its speed moves up to its steady value at a steady rate.
- The input is an on/off switch to start the operation. This opens the contacts for the data register and so it stores zero. Thus the output from the controller is zero and the analogue signal from the DAC is zero and hence motor speed is zero.
- The closing of the start contacts gives outputs to the DAC and the data register. Each time the program cycles through these rungs on the program, the data register is incremented by 1 and so the analogue signal is increased and hence the motor speed.
- Full speed is realised when the output from the data register is the word 11111111. The timer function of a PLC can be used to incorporate a delay between each of the output bit signals.

Ramping the speed of a motor



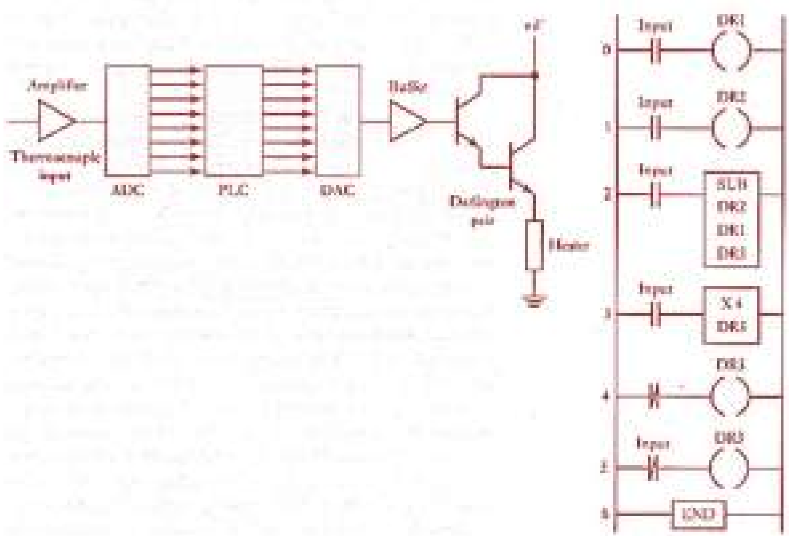
- A PLC equipped with analogue input channels can be used to carry out a continuous control function, i.e. PID control.
- Thus, for example, to carry out proportional control on an analogue input the following set of operations can be used:

1. Convert the sensor output to a digital signal.
2. Compare the converted actual sensor output with the required sensor value, i.e. the set point, and obtain the difference. This difference is the error.
3. Multiply the error by the proportional constant Kp.
4. Move this result to the DAC output and use the result as the correction signal to the actuator.

Proportional control of temperature.

- An example of where such a control action might be used is with a temperature controller.
- The input could be from a thermocouple, which after amplification is fed through an ADC into the PLC.
- The PLC is programmed to give an output proportional to the error between the input from the sensor and the required temperature.
- The output word is then fed through a DAC to the actuator, a heater, in order to reduce the error.

Proportional control of temperature.



- With the ladder program shown, rung 0 reads the ADC and stores the temperature value in data register DR1.
- With rung 1, the data register DR2 is used to store the set point temperature.
- Rung 2 uses the subtract function to subtract the values held in data registers DR1 and DR2 and store the result in data register DR3, i.e. this data register holds the error value.
- With rung 3 a multiply function is used, in this case to multiply the value in data register DR3 by the proportional gain of 4.
- Rung 4 uses an internal relay which can be programmed to switch off DR3 if it takes a negative value.
- With rung 5 the data register DR3 is reset to zero when the input is switched off.
- Some PLCs have add-on modules which more easily enable PLC control to be used, without the need to write lists of instructions in the way outlined above.

SELECTION OF A PLC:

The factors to be considered in selecting a PLC for a particular task are:

1. Input/output capacity and its expansion capability for future needs.
2. Types of inputs/outputs required, i.e. isolation, on-board power supply for I/o, signal conditioning, etc.
3. The size of memory required.
4. The speed and power of the CPU. This is related to the number of instructions that can be handled by a PLC. As the types of I/o increases or/and the number of I/o increases, the faster CPU is required

Reference

- Bolton,W, "Mechatronics", Pearson education, second edition, fifth Indian Reprint, 2003

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MECHANICAL ENGINEERING DEPARTMENT

ME 18703 MECHATRONICS

UNIT IV - MECHATRONICS SYSTEM DESIGN

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UNIT IV - MECHATRONICS SYSTEM DESIGN

12

- Mechatronics
- Key elements of mechatronic systems
- Stages in design
- Traditional and mechatronic design approaches
- Data acquisition systems
- Overview of I/O process
- Virtual instrumentation software
- Condition monitoring
- Adaptive control
- SCADA systems.
- Possible Design Solutions

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Mechatronics Definition:

"Mechatronics is the synergistic integration of precision mechanical engineering and intelligent control systems engineering comprises of electrical and information technology which in turn produces smart products and processes."

The term mechatronics was 'invented' by a Japanese engineer Tetsuro Mori in the year 1969.

Mechatronics

Mechatronics design process follows **concurrent approach** instead of **sequential approach.**

Example : Autonomous vehicles, flight control and navigation systems, engine management system, washing machines, cameras, microwave devises (oven), robots, traffic light control systems, Numerically controlled machine tools, etc....

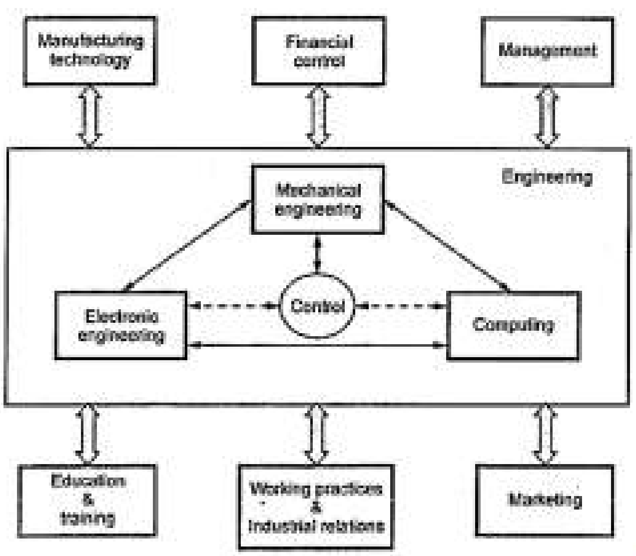
Goal of Mechatronics Design

- Smarter products/processes
- Cheaper products/processes
- Relaiable products/processes
- Flexible products/processes

Mechatronic System –Elements - A smart system

- Mechanical System
  - Frame work
- Actuators
  - Mechanical Actuators
  - Electronic actuators
- Sensors and transducers
  - Measuring system
- Electronic System
  - Driving system
- Control system
  - Microcontrollers
  - PLC
- Knowledge base (Information Technology)

Scope and Importance of Mechatronics



- Synergistic (interaction with cooperation) integration of electronics and computing technologies – the key success of manufacturing industries in world market today

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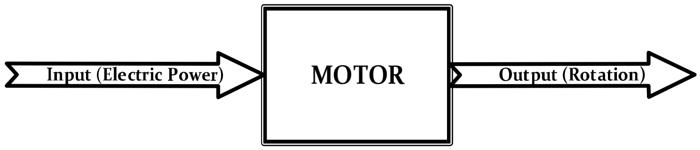
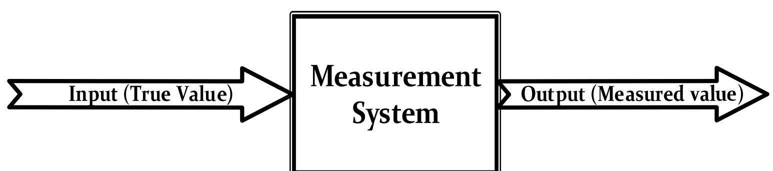
System



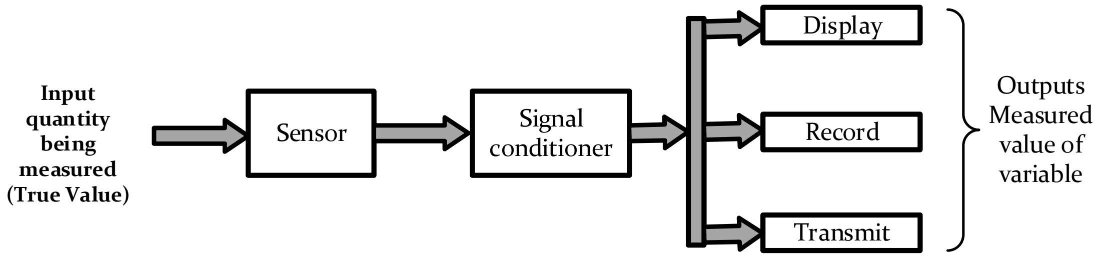
- A system may be represented as a **black box** which has **an input** and **an output.**
- A **system** is an orderly combination or arrangement of components connected to form a single unit for performing a defined function.
- System concerned only with the relationship between the input and output and not on the process going inside the box.
- Here, The system is motor. The input is the electric power and the output after processed by the system is rotation.

Measurement System



- A basic system in mechatronics design
- Measurement is the operation of determining the value of a quantity.
- The objective is to give user a numerical value corresponding to the variable being measured
- The input is a **true value** of a variable to measure and output is a measured value of that variable.
- Examples of measurement system are - thermometer for measuring temperature, weighing system for measuring weights.

Elements of a Measurement System



- Sensor
- Signal conditioner
- Data representation / Display

Elements of a Measurement System contd..

Sensor or Transducer :

- Sensor is continuously in contact with the process for which variable is being measured and gives output correspondingly.
- Sensor receives information from variable and changes this information into suitable form that can be measured and displayed.

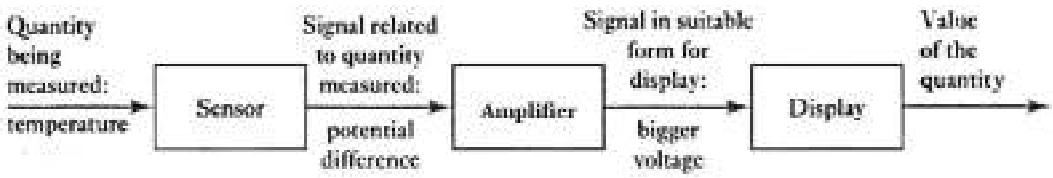
Signal conditioner :

- The signal conditioner changes the information received from sensor into suitable form Examples of signal conditioners are, - wheat stone bridge, that converts change in resistance into change in voltage, amplifier that transforms the signal magnitude, oscillator that converts an impedance change into a variable frequency. Etc.
- Signal processing elements such as analog-to-digital converters, filters are also used.

Data representation / Display :

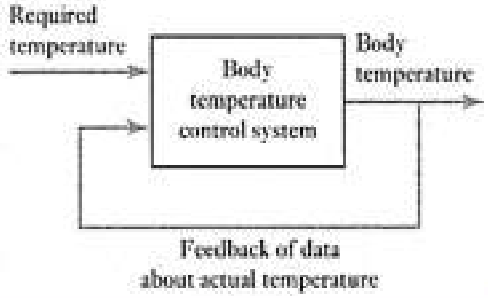
- The measured value must be displayed so that observer can recognize it. This is done by display e.g. pointer, recorder or digital read out. Also the output may be transmitted into other control system so that it can be compared with required value.

A Measurement System - Example



Control System – A system

- Control system
  - To control a variable – temperature control
  - To control a sequence of operations/events – washing cycle in a washing machine
  - Control whether an event occurs or not, e.g. a safety lock

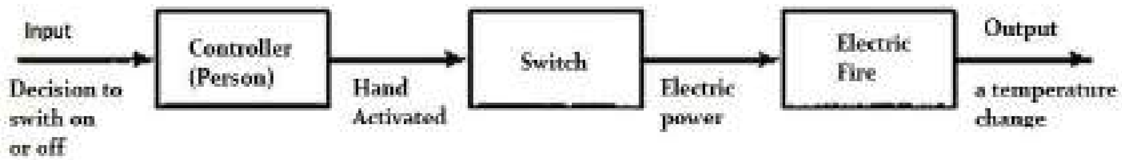


Control Systems – Types

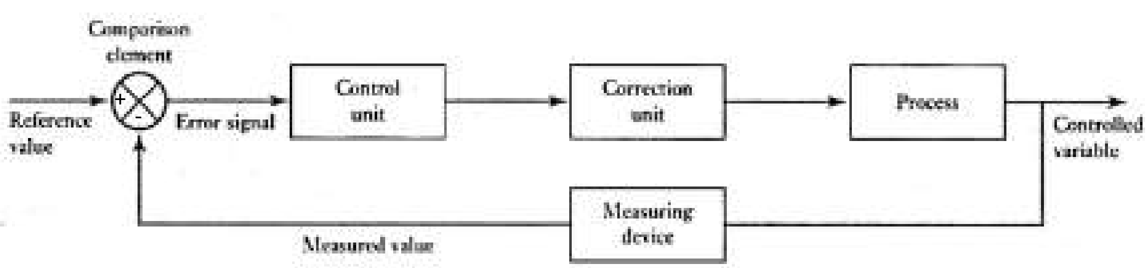
Open loop system

Closed loop system

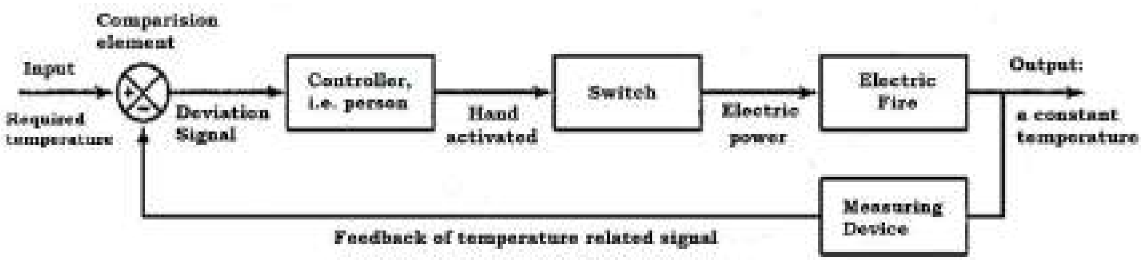
Elements of an Open loop system



Basic elements of a closed-loop system

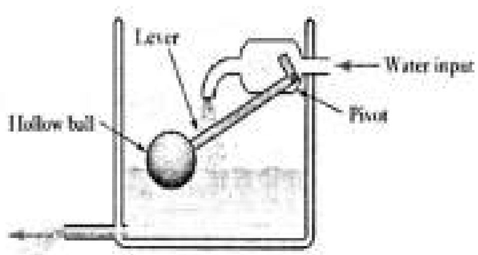


The automatic temperature control – A closed loop system

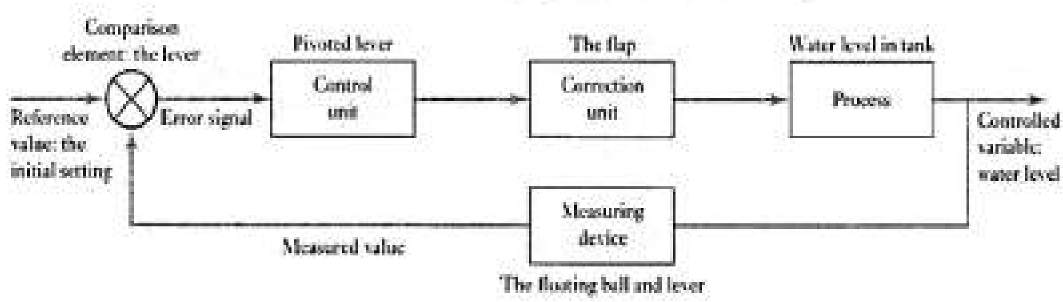


Controlled variable	–	the room temperature
Reference value	–	the required room temperature
Comparison element	–	the person comparing the measured value with the required value of temperature
Error signal	–	the difference between the measured and required temperatures
Control unit	–	the person
Correction unit	–	the switch on the fire
Process	–	the heating by the fire
Measuring device	–	a thermometer

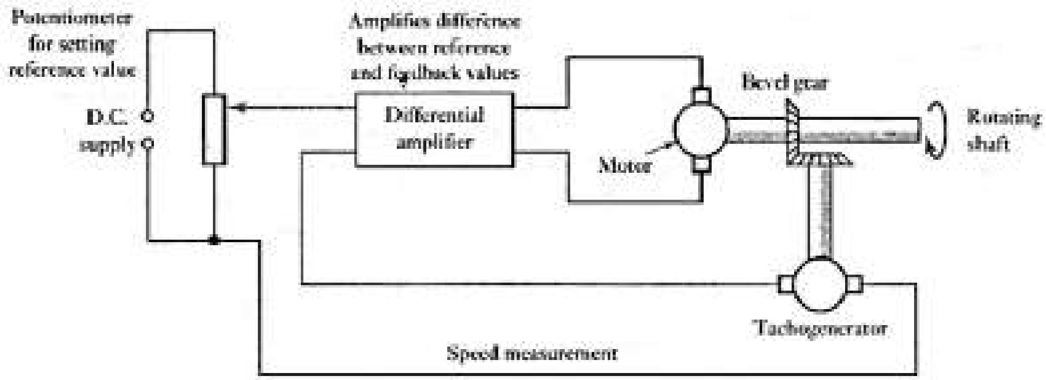
The automatic control of water level – A closed loop system



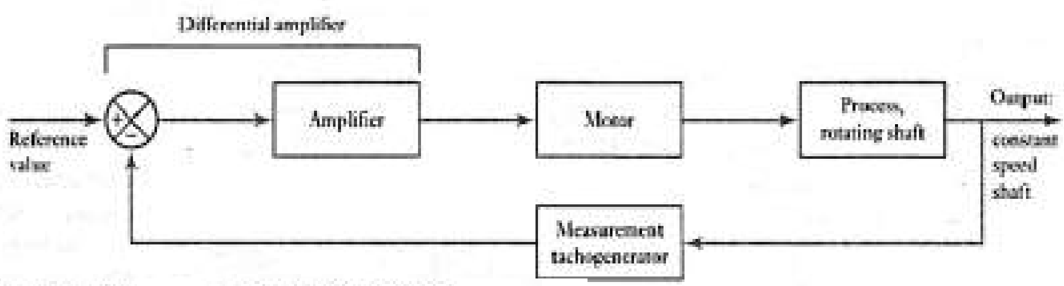
Controlled variable	–	water level in tank
Reference value	–	initial setting of the float and lever position
Comparison element	–	the lever
Error signal	–	the difference between the actual and initial settings of the lever positions
Control unit	–	the pivoted lever
Correction unit	–	the flap opening or closing the water supply
Process	–	the water level in the tank
Measuring device	–	the floating ball and lever



Shaft speed control – A Closed loop system

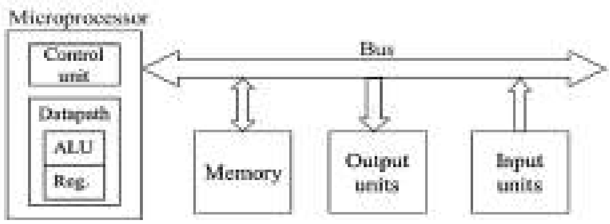


Shaft speed control – A Closed loop system



Controlled variable	–	speed of rotation of shaft
Reference value	–	setting of slider on potentiometer
Comparison element	–	differential amplifier
Error signal	–	the difference between the output from the potentiometer and that from the tachogenerator system
Control unit	–	the differential amplifier
Correction unit	–	the motor
Process	–	the rotating shaft
Measuring device	–	the tachogenerator

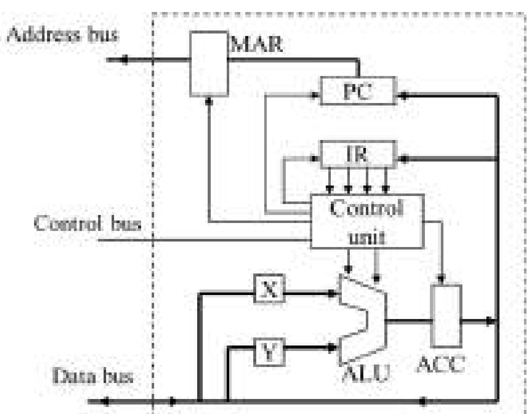
Microprocessor-Based Control Systems



Microprocessor-based systems are electrical systems consisting of microprocessors, memories, I/O units, and other peripherals.

- Microprocessors are the brains of the systems
- Microprocessors access memories and other units through buses
- The operations of microprocessors are controlled by instructions stored in memories

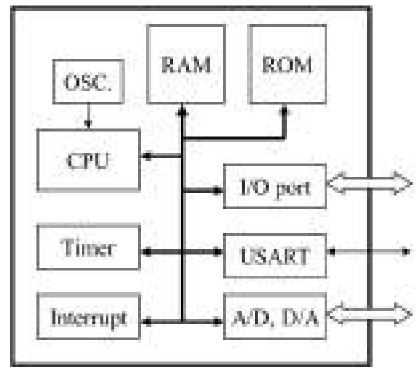
A simple microprocessor architecture



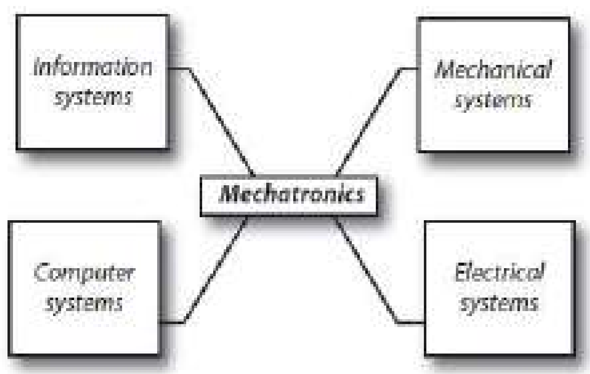
A microprocessor is a processor (or Central Processing Unit, CPU) fabricated on a single integrated circuit.

Microcontrollers

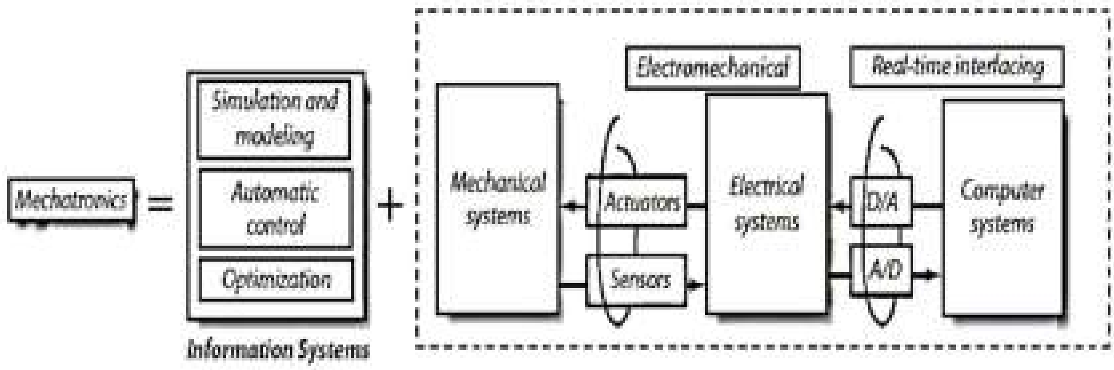
- A microcontroller is a simple computer implemented in a single VLSI chip.
- In general, microcontrollers are cheap and have low performance
- Microcontrollers are widely used in industrial control, automobile and home applications



Mechatonics Constituents



Building Blocks of Mechatronics System (Key Elements)



Mechatronic System

- System Modeling (mathematical equations) for desired response or behavior when inputs occur.
- Models involve drawing block diagrams to represent systems.
- A system can be thought of as a box or block diagram which has an input and an output
- For example, a spring - an input of a force F and an output of an extension x.
  - The equation might be $F = kx$, where k is a constant.
- As another example, a motor which has as its input electric power and as output the rotation of a shaft .
- A measurement system can be thought of as a box which is used for making measurements. It has as its input the quantity being measured and its output the value of that quantity.
- For example, a temperature measurement system, i.e. a thermometer, has an input of temperature and an output of a number on a scale.

The Design Process – Stages

1. The need

The design process begins with a need from, a customer or client. This may be identified by market research being used to establish the needs of potential customers.

2. Analysis of the problem

The first stage in developing a design is to find out the true nature of the problem, i.e. analysing it. This is an important stage in that not defining the problem accurately can lead to wasted time on designs that will not fulfil the need.

3. Preparation of a specification

Following the analysis, a specification of the requirements can be prepared. This will state the problem, any constraints placed on the solution, and the criteria which may be used to judge the quality of the design. In stating the problem, all the functions required of the design, together with any desirable features, should be specified. Thus there might be a statement of mass, dimensions, types and range of motion required, accuracy, input and output requirements of elements, interfaces, power requirements, operating environment, relevant standards and codes of practice, etc.

4. Generation of possible solutions

This is often termed the conceptual stage. Outline solutions are prepared which are worked out in sufficient detail to indicate the means of obtaining each of the required functions, e.g. approximate sizes, shapes, materials and costs. It also means finding out what has been done before for similar problems; there is no sense in reinventing the wheel.

5. Selections of a suitable solution

The various solutions are evaluated and the most suitable one selected. Evaluation will often involve the representation of a system by a model and then simulation to establish how it might react to inputs.

The Design Process – Stages

6. Production of a detailed design

The detail of the selected design has now to be worked out. This might require the production of prototypes or mock-ups in order to determine the optimum details of a design.

7. Production of working drawings

The selected design is then translated into working drawings, circuit diagrams, etc., so that the item can be made.

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Traditional and Mechatronics Designs

- Engineering design is a complex process involving interactions between many skills and disciplines.
- With traditional design - sequential approach , the approach was for the mechanical engineer to design the mechanical elements, then the control engineer to come along and design the control system.
- The basis of the mechatronics approach is considered to lie in the concurrent inclusion of the disciplines of mechanical engineering, electronics, computer technology and control engineering in the approach to design.
- The inherent concurrency of this approach depends very much on system modelling and then simulation of how the model reacts to inputs and hence how the actual system might react to inputs.

An illustration - the design of bathroom scales.

- Such scales might be considered only in terms of the compression of springs and a mechanism used to convert the motion into rotation of a shaft and hence movement of a pointer across a scale; a problem that has to be taken into account in the design is that the weight indicated should not depend on the person's position on the scales.
- However, other possibilities can be considered if we look beyond a purely mechanical design. For example, the springs might be replaced by load cells with strain gauges and the output from them used with a microprocessor to provide a digital readout of the weight on an LED display.
- The resulting scales might be mechanically simpler, involving fewer components and moving parts. The complexity has, however, been transferred to the software.

- Another illustration, the traditional design of the temperature control for a domestic central heating system has been the bimetallic thermostat in a closed-loop control system.
- The bending of the bimetallic strip changes as the temperature changes and is used to operate an on/off switch for the heating system.
- However, a multidisciplinary solution to the problem might be to use a microprocessor-controlled system employing, a thermodiode as the sensor. Such a system has many advantages over the bimetallic thermostat system.
- The bimetallic thermostat is comparatively crude and the temperature is not accurately controlled; also devising a method for having different temperatures at different times of the day is complex and not easily achieved.
- The microprocessor-controlled system can, however, cope easily with giving precision and programmed control. The system is much more flexible. This improvement in flexibility is a common characteristic of mechatronics systems when compared with traditional systems.

Possible Solutions to Design Problems

- **Timed switch**
- **Windscreen-wiper motion**
- **Bathroom scales**

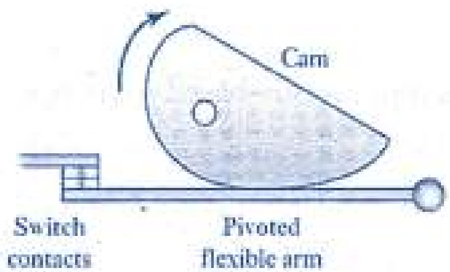
Timed switch

- Consider a simple requirement for a device which switches on some actuator, e.g. a motor, for some prescribed time.
- Possible solutions might involve:
  - ✓1 A rotating cam
  - ✓2 A PLC
  - ✓3 A microprocessor
  - ✓4 A microcontroller
  - ✓5 A timer, e.g. 555

Timed switch

A rotating cam – mechanical solution

- A mechanical solution could involve a rotating the cam would be rotated at a constant rate and the cam follower used to actuate a switch.
- The length of time for which the switch is closed depending on the shape of the cam.
- This is a solution that has widely been used in the past.



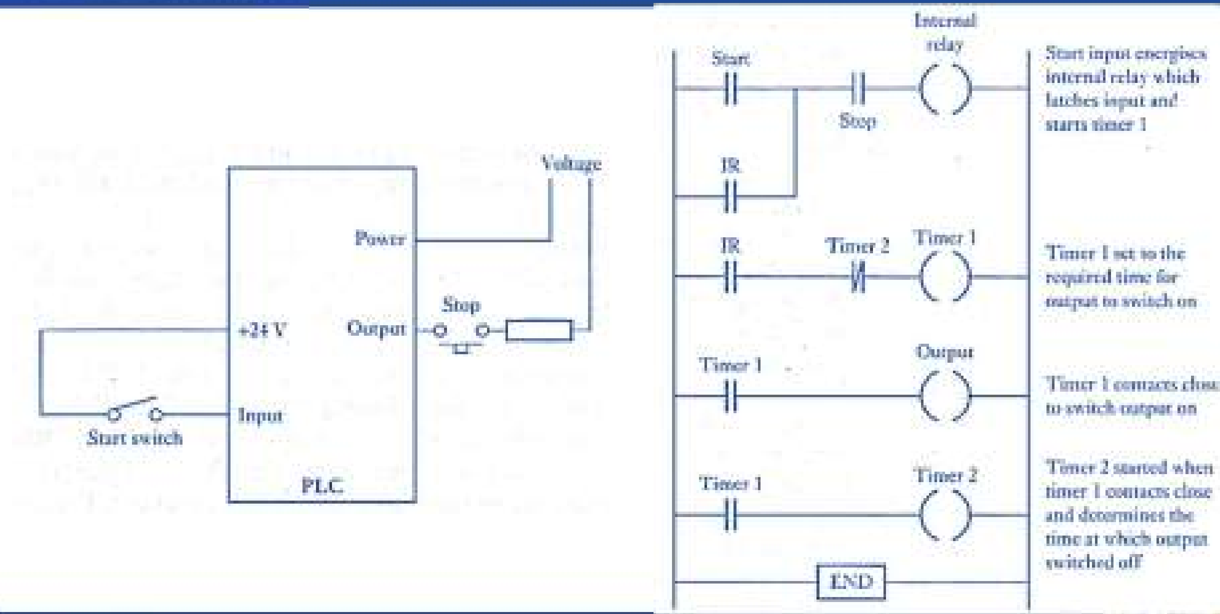
Timed switch

A PLC solution

- A PLC solution could involve the arrangement shown in Figure with the given ladder program.
- This would have the advantage over the rotating cam of having off and on times which can be adjusted by purely changing the timer preset values in the program, whereas a different cam is needed if the times have to be changed with the mechanical solution.
- The software solution is much easier to implement than the hardware one.

A PLC solution

Timed switch



Timed switch

Microprocessor-based solution

- A microprocessor-based solution could involve a microprocessor combined with a memory chip and input/output interfaces.
- The program is then used to switch an output on and then off after some time delay, with the time delay being produced by a block of program in which there is a timing loop.
- This generates a time delay by branching round a loop the number of cycles required to generate the requisite time. Thus, in assembly language we might have:

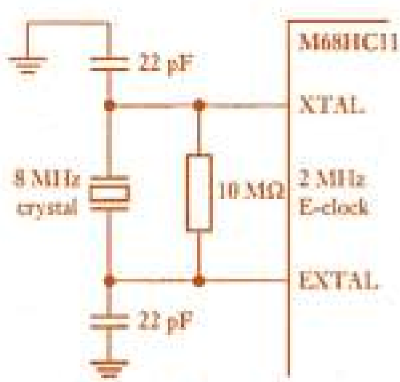
```
DELAY   LDX   #F424   ; F424 is number of loops
LOOP    DEX
        BNE   LOOP
        RTS
```

- DEX decrements the index register and BNE, branch if not equal, each take 4 clock cycles. The loop thus takes 8 cycles and there will be n such loops until 8n + 3 + 5 gives the number F424 (LDX takes 3 cycles and RTS takes 5 cycles).
- In C we could write the program lines using the while function.

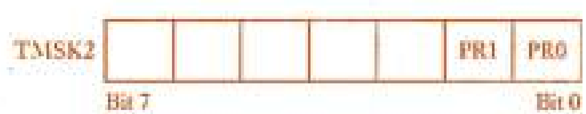
Microcontroller Solution

- Another possibility is to use the timer system in a microcontroller such as MC68HC11.
- This is based on a 16-bit counter TCNT operating from the system E-clock signal.
- The system E-clock can be prescaled by setting bits in the timer interrupt mask register 2 (TMSK2), address $1024
- The TCNT register starts at $0000 when the processor is reset and counts continuously until it reaches the maximum count of $FFFF.
- On the next pulse it overflows and reads $0000 again . When it overflows, it sets the timer overflow flag TOF (bit 7 in miscellaneous timer interrupt flag register 2, TFLG2 at address $1025). Thus with a prescale factor of 1 and an E-clock of 2 MHz, overflow occurs after 32.768 ms.

(a) Generating 2 MHz internal clock, (b) prescale factor



(a)



PR1	PR0	Prescale factor
0	0	1
0	1	4
1	0	8
1	1	16

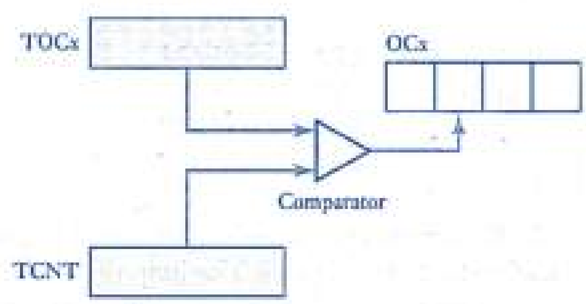
(b)

Timed switch

- One way of using this for timing is for the TOF flag to be watched by polling. When the flag is set, the program increments its counter.
- The program then resets the flag, by writing a 1 to bit 7 in the TFLG2 register. Thus the timing operation just consists of the program waiting for the required number of over flag settings.
- A better way of timing involves the use of the output-compare function.
- Port A of the microcontroller can be used for general inputs or outputs or for timing functions. The timer has output pins, OC1, OC2, OC3, OC4 and OC5, with internal registers TOC1, TOC2, TOC3, TOC4 and TOC5.
- We can use the output-compare function to compare the values in the TOC1 to TOC5 registers with the value in the free-running counter TCNT.
- This counter starts at 0000 when the CPU is reset and then runs continuously. When a match occurs between a register and the counter, then the corresponding OC_x flag bit is set and output occurs through the relevant output pin.
- Thus by programming the TOC_x registers, so the times at which outputs occur can be set. The output-compare function can generate timing delays with much higher accuracy than the timer overflow flag.

Timed switch

Output compare.



- The following program illustrates how output compare can be used to produce a time delay.
- The longest delay that can be generated in one output compare operation is 32.7 ms when the E-clock is 2 MHz.
- In order to generate longer delays, multiple output-compare operations are required. Thus we might have each output-compare operation producing a delay of 25 ms and repeating this 40 times to give a total delay of 1

```
REGBAS   EQU   $1000    ; Base address of registers
TOC2     EQU   $18      ; Offset of TOC2 from REGBAS
TCNT     EQU   $0E      ; Offset of TCNT from REGBAS
TFLG1    EQU   $23      ; Offset of TFLGI from REGBAS
OC1      EQU   $40      ; Mask to clear OC1 pin and OC1F flag
CLEAR    EQU   $40      ; Clear OC2F flag
D25MS    EQU   50000    ; Number of E-clock cycles to generate a 25 ms delay
NTIMES   EQU   40       ; Number of output-compare operations needed to give 1 s delay
         ORG   $1000
COUNT    RMB   1        ; Memory location to keep track of the number of
                        ; output-compare operations still to be carried out
```

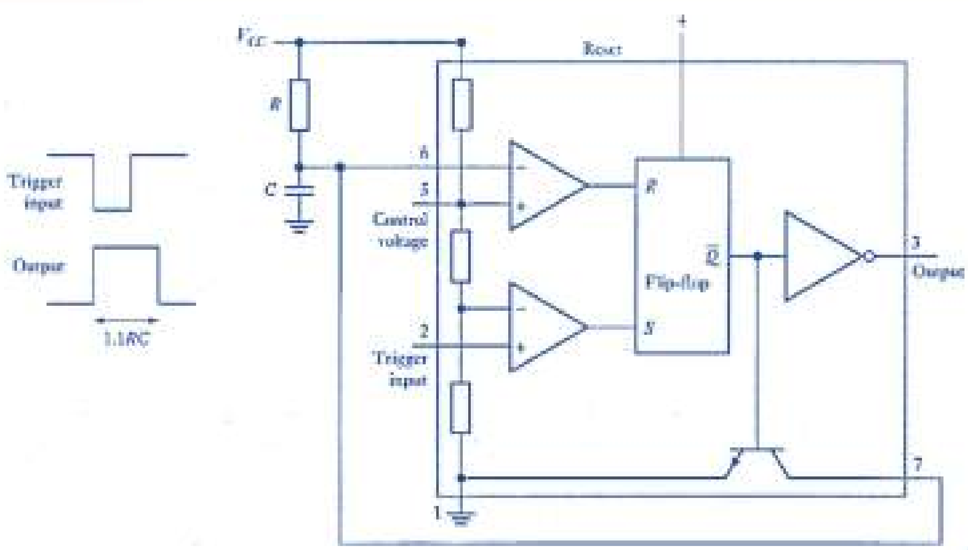

Timed switch

```
         ORG    $C000          ; Starting address of the program
         LDX    #REGBAS
         LDAA   #OC1           ; Clear OC1 flag
         STAA   TFLG1,X
         LDAA   #NTIMES        ; Initialise the output-compare count
         STAA   COUNT
         LDD    TCNT,X
WAIT     ADDD   #D25MS         ; Add 25 ms delay
         STD    TOC2,X         ; Start the output-compare operation
         BRCLR  TFLG1,X OC1    ; Wait until the OC1F flag is set
         LDAA   #OC1           ; Clear the OC1F flag
         STAA   TFLG1,X
         DEC    COUNT          ; Decrement the output-compare counter
         BEQ    OTHER          ; Branch to OTHER if 1 s elapsed
         LDD    TOC2,X         ; Prepare to start the next compare operation
         BRA    WAIT
OTHER                          ; The other operations of the program which occur after the 1 s
                               ; delay
```

A timer, e.g. 555

- Another possible method of producing a timed output signal is to use a timer module, e.g. 555.
- With the 555 timer, the timing intervals are set by external resistors and capacitors.
- The timer and the external circuitry needed to give an on output when triggered, the duration of the on output being 1.1RC.
- Large times need large values of R and C. R is limited to about 1MΩ, otherwise leakage becomes a problem, and C is limited to about 10μF if electrolytic capacitors with the problems of leakage and low accuracy are to be avoided.
- Thus the circuit shown is limited to times less than about 10 s. The lower limit is about R = 1 kΩ and C = 100 pF, i.e. times of a fraction of a millisecond. For longer times, from 16 ms to days, an alternative timer such as the ZN1034E can be used.

The 555 timer.



Possible solutions for Windscreen-wiper motion

- Consider a requirement for a device which will oscillate an arm back and forth in an arc like a windscreen wiper.
- Possible solutions might be:
  - ✓1 Mechanical linkage and a d.c. motor
  - ✓2 A stepper motor

Mechanical solution

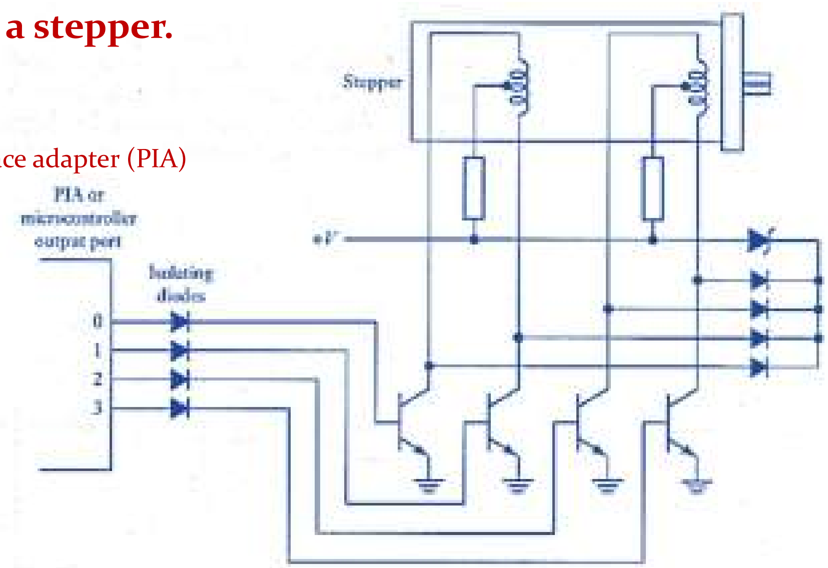
- A mechanical solution is shown below. Rotation of arm 1 by a motor causes arm 2 to impart an oscillatory motion to arm 3.
- Car windscreen wipers generally use such a mechanism with a d.c. permanent magnet motor.

Stepper motor solution

- An alternative solution is to use a stepper motor
- A microprocessor with a PIA, or a microcontroller, might be used with a stepper.
- The input to the stepper is required to cause it to rotate a number of steps in one direction and then reverse to rotate the same number of steps in the other direction.

Interfacing a stepper.

peripheral interface adapter (PIA)



Windscreen-wiper motion

- If the stepper is to be in the **'full-step'** configuration then the outputs need to be as shown in Table.
- Thus to start and rotate the motor in a forward direction involves the sequence A, 9,5,6 and then back to the beginning with 1 again.
- To reverse we would use the sequence 6, 5, 9, A and then back to begin with 6 again.

Step	Bit 3	Bit 2	Bit 1	Bit 0	Code
1	1	0	1	0	A
2	1	0	0	1	9
3	0	1	0	1	5
4	0	1	1	0	6
1	1	0	1	0	A

Windscreen-wiper motion

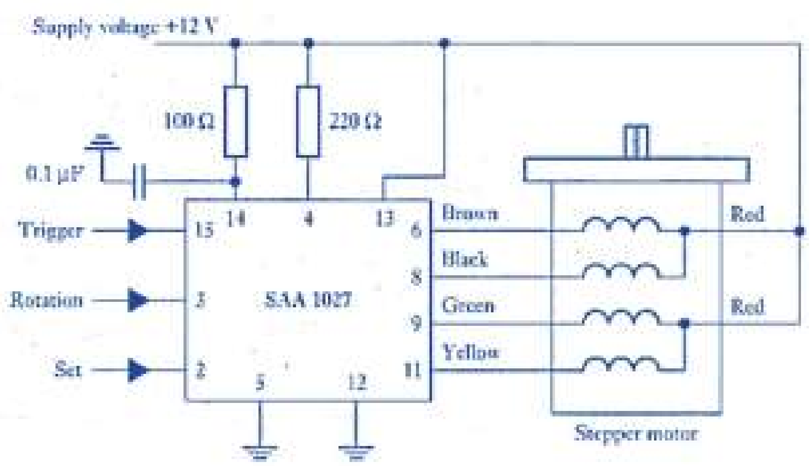
- If **'half-step'** configuration is used then the outputs need to be as shown in Table. Forward motion then involves the sequence A, 8, 9, 1,5,4,6,2 and then back to A, with reverse requiring 2,6, 4, 5, 1, 9, 8, A and back to 2.

Step	Bit 3	Bit 2	Bit 1	Bit 0
1	1	0	1	0
2	1	0	0	0
3	1	0	0	1
4	0	0	0	1
5	0	1	0	1
6	0	1	0	0
7	0	1	1	0
8	0	0	1	0
1	1	0	1	0

USING IC's

- Integrated circuits are available for step motor control and their use can simplify the interfacing and the software.
- All that is then needed is the requisite number of input pulses to the trigger, the motor stepping on the low-to-high transition of a high-low-high pulse.
- A high on the rotation input causes the motor to step anti-clockwise, while a low gives clockwise rotation.
- Thus we just need one output from the microcontroller for output pulses to the trigger and one output to rotation.
- An output to set is used to reset the motor back to its original position.

Integrated circuit SAA 1027 for stepper motor.

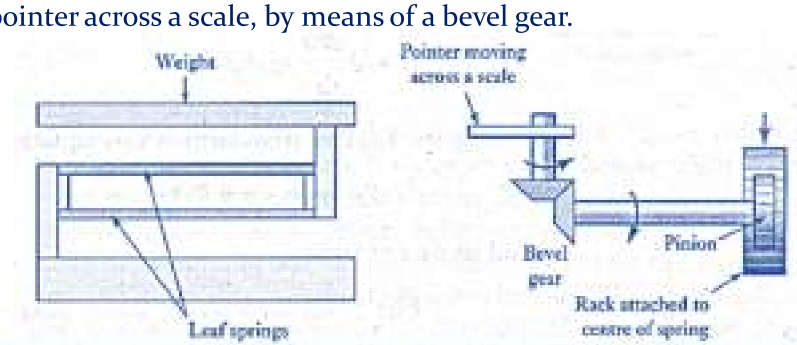


Bathroom scales

- A simple weighing machine - bathroom scales.
- The main requirements are that a person can stand on a platform and the weight of that person will be displayed on some form of readout.
- The weight should be given with reasonable speed and accuracy and be independent of where on the platform the person stands.
- Possible solutions can involve:
  - 1 A purely mechanical system based on a spring and gearing.
  - 2 A load cell and a microprocessor/microcontroller system.

Mechanical Solution

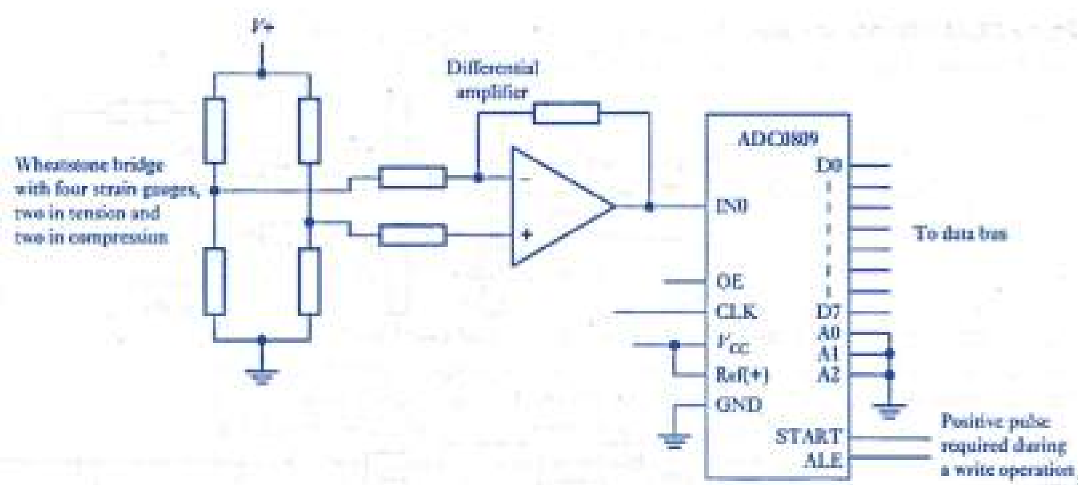
- One possible solution is to use the weight of the person on the platform to deflect an arrangement of two parallel leaf springs.
- With such an arrangement the deflection is virtually independent of where on the platform the person stands. The deflection can be transformed into movement of a pointer across a scale by using the arrangement shown in Figure.
- A rack-and-pinion is used to transform the linear motion into a circular motion about a horizontal axis. This is then transformed into a rotation about a vertical axis, and hence movement of a pointer across a scale, by means of a bevel gear.



Microprocessor Solution

- Another possible solution involves the use of a microprocessor. The platform can be mounted on load cells employing electrical resistance strain gauges.
- When the person stands on the platform the gauges suffer strain and change resistance. If the gauges are mounted in a four-active-arm Wheatstone bridge then the out-of-balance voltage output from the bridge is a measure of the weight of the person.
- This can be amplified by a differential operational amplifier. The resulting analogue signal can then be fed through a latched analogue-to-digital converter for inputting to the microprocessor, e.g. the Motorola 6820. Figure follows shows the input interface. There will also be a need to provide a non-erasable memory and this can be provided by an EPROM chip, e.g. Motorola 2716. The output to the display can then be taken through a PIA, e.g. Motorola 6821

Microprocessor Input interface



- However, if a micro controller is used then memory is present within the single microprocessor chip, and. by a suitable choice of microcontroller, e.g. M68HCII, we can obtain analogue-to-digital conversion for the inputs.
- The system then becomes: strain gauges feeding through an operational amplifier a voltage to the port E (the ADC input) of the microcontroller, with the output passing through suitable drives to output through ports B and C to a decoder and hence an LED display.
- The program structure might be:
- Initialisation by clearing LED displays and memory

  Start

  Is someone on the scales? If not display ooo

  If yes

    input data

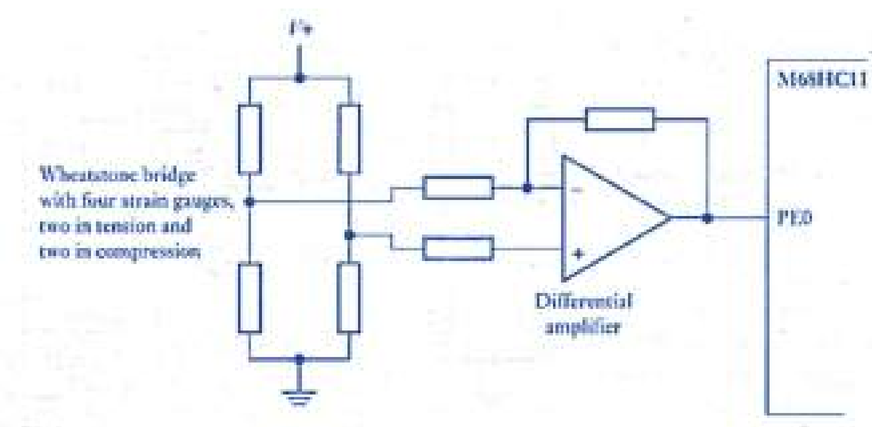
    convert weight data into suitable output form

    output to decoder and LED display

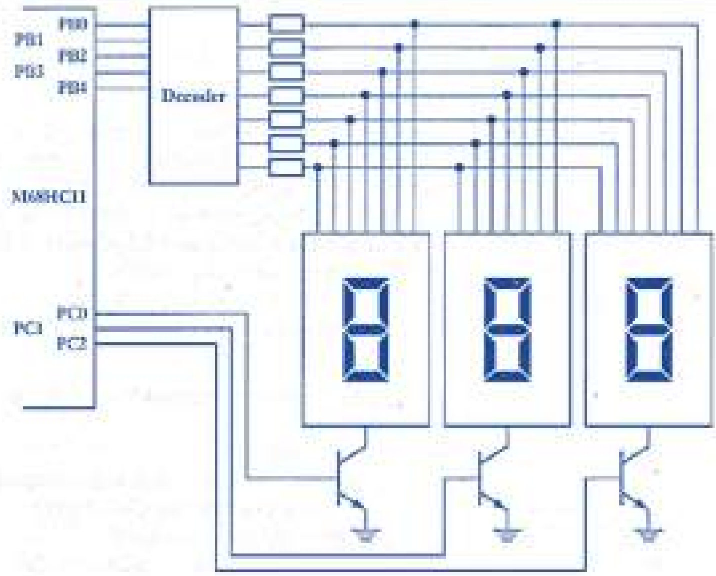
    time delay to retain display

  Repeat from start again to get new weight

Microcontroller Interfacing



LED Display



- In considering the design of the mechanical parts of the bathroom scales
- we need to consider what will happen when someone stands on the scales. We have a spring-dam per-mass system comparable with that describe its behaviour by

$$m\frac{d^2x}{dt^2} + c\frac{dx}{dt} + kx = F$$

Taking the Laplace transform gives

$$ms^2 X(s) + cs\,X(s) + kX(s) = F(s)$$

and so the system can be described by a transfer function of the form

$$G(s) = \frac{X(s)}{F(s)} = \frac{1}{ms^2 + cs + k}$$

$$s^2 + 2\zeta\omega_n s + \omega_n^2$$

natural frequency ω_n of $\sqrt{(k/m)}$

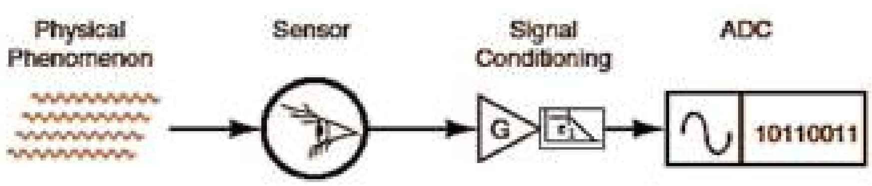
ζ of $c/(2\sqrt{(mk)})$.

- The quadratic term is of the form damping factor

Data Acquisition Process

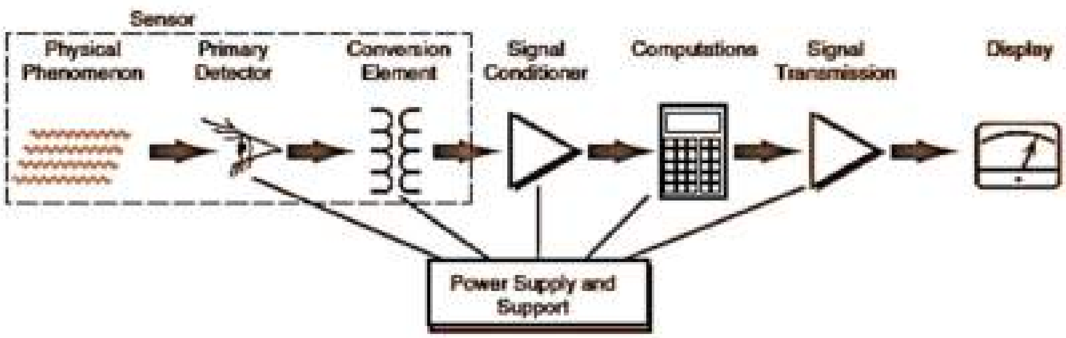
- To automate a process, first thing will have to tackle is data acquisition—the process of making measurements of physical phenomena and storing them in some coherent fashion.
- It's a vast technical field with thousands of practitioners, most of whom are hackers as we are.
- The practical aspects of sensors and signals plays a major role.

Elements of the data acquisition process.



- The physical phenomenon may be electrical, optical, mechanical, or something else that you need to measure.
- The sensor changes that phenomenon into a signal that is easier to transmit, record, and analyze—usually a voltage or current.
- Signal conditioning amplifies and filters the raw signal to prepare it for analog-to-digital conversion (ADC), which transforms the signal into a digital pattern suitable for use by your computer.

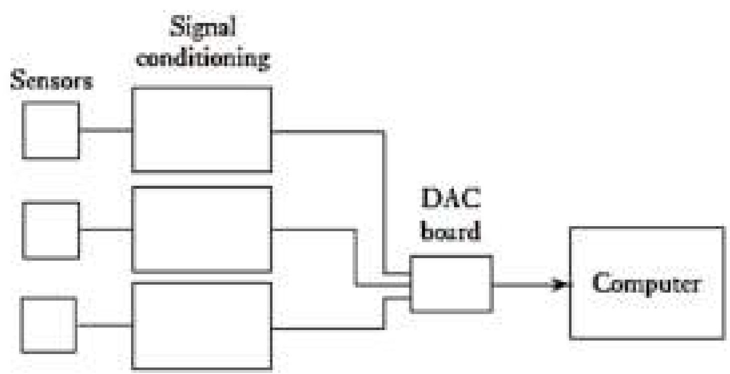
A complete sensor model



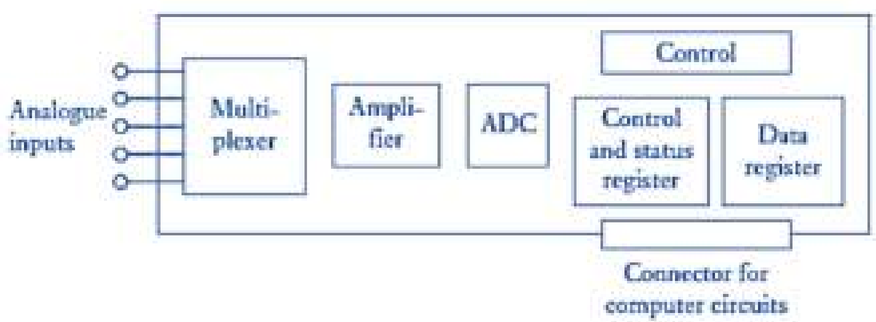
Data Acquisition

- The term data acquisition, or DAQ, is used for the process of taking data from sensors and inputting that data into a computer for processing.
- The sensors are connected, generally via some signal conditioning, to a data acquisition board which is plugged into the back of a computer.
- The DAQ board is a printed circuit board that, for analogue inputs, basically provides a multiplexer, amplification, analogue-to-digital conversion, registers and control circuitry so that sampled digital signals are applied to the computer system. Figure shows the basic elements of such a board.

Data Acquisition



Data Acquisition – DAQ Board



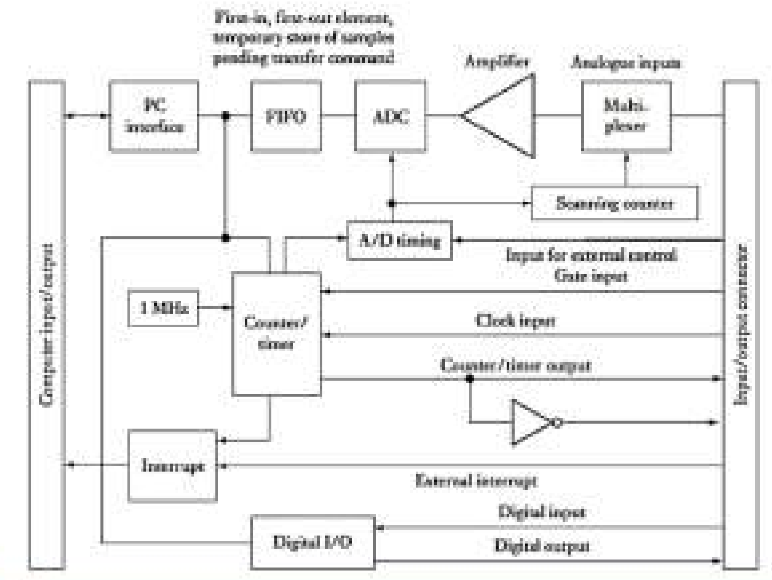
Data Acquisition

- Computer software is used to control the acquisition of data via the DAQ board. When the program requires an input from a particular sensor, it activates the board by sending a control word to the control and status register.
- Such a word indicates the type of operation that the board has to carry out.
- As a consequence the board switches the multiplexer to the appropriate input channel. The input from the sensor connected to that input channel is then passed via an amplifier to the ADC.
- After conversion the resulting digital signal is passed to the data register and the word in the control and status register changes to indicate that the signal has arrived.
- Following that signal, the computer then issues a signal for the data to be read and taken into the computer for processing.
- This signal is necessary to ensure that the computer does not wait doing nothing while the board carries out its acquisition of data, but uses this to signal to the computer when the acquisition is complete and then the computer can interrupt any program it is implementing, read the data from the DAQ and then continue with its program.

Data Acquisition

- A faster system does not involve the computer in the transfer of the data into memory but transfers the acquired data directly from the board to memory without involving the computer, this being termed direct memory address (DMA).
- The specifications for a DAQ board include the sampling rate for analogue inputs, which might be 100 kS/s (100 000 samples per second).
- The Nyquist criteria for sampling indicate that the maximum frequency of analogue signal that can be sampled with such a board is 50 kHz, the sample rate having to be twice the maximum frequency component.
- In addition to the above basic functions of a DAQ board, it may also supply analogue outputs, timers and counters which can be used to provide triggers for the sensor system.
- As an example of a low-cost multifunction board for use with an IBM computer, Figure shows the basic structure of the National Instruments DAQ board PC-LPM-16. This board has 16 analogue input channels, a sampling rate of 50 kS/s, an 8-bit digital input and an 8-bit digital output, and a counter/timer which can give an output. Channels can be scanned in sequence, taking one reading from each channel in turn, or there can be continuous scanning of a single channel.

PC-LPM-16 DAQ board

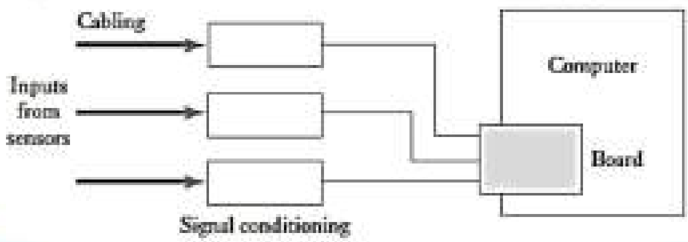


Data Acquisition

- The term data acquisition (DAQ) tends to be frequently used for systems in which inputs from sensors are converted into a digital form for processing, analysis and display by a computer.
- The systems thus contain: sensors, wiring to connect the sensors to signal conditioning to carry out perhaps filtering and amplification, DAQ hardware to carry out such functions as conversion of input to digital format and conversion of output signals to analogue format for control systems, the computer and DAQ software.
- The software carries out analysis of the digital input signals. Such systems are also often designed to exercise control functions as well.

Computer with plug-in boards

- Figure, shows the basic elements of a DAQ system using plug-in boards with a computer for the DAQ hardware. The signal conditioning prior to the inputs to the board depends on the sensors concerned, e.g. it might be for thermocouples: amplification, cold junction compensation and linearisation; for strain gauges: Wheatstone bridge, voltage supply for bridge and linearisation; for resistance temperature detectors (RTDs): current supply, circuitry and linearisation.

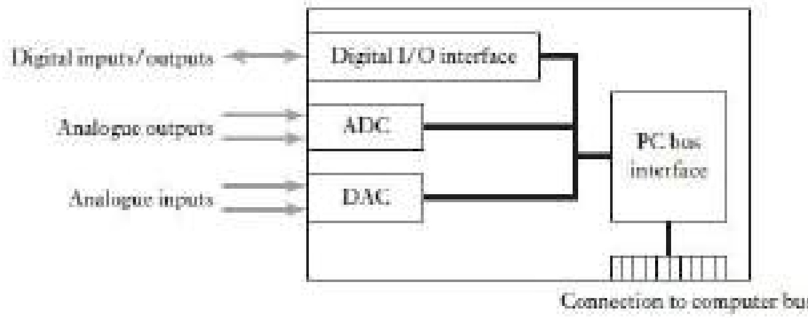


Computer with plug-in boards

- In selecting the DAQ board to be used the following criteria have to be considered:
- What type of computer software system is being used, e.g. Windows, MacOS?
- What type of connector is the board to be plugged into, e.g. PCMCIA for laptops, NuBus for MacOS, PCI?
- How many analogue inputs will be required and what are their ranges?
- How many digital inputs will be required?
- What resolution will be required?
- What is the minimum sampling rate required?
- Are any timing or counting signals required?

DAQ Board Elements.

- Figure shows the basic elements of a DAQ board. Some boards will be designed only to handle analogue inputs/outputs and others digital inputs/outputs.



DAQ Board Elements.

- All DAQ boards use drivers, software generally supplied by the board manufacturer with a board, to communicate with the computer and tell it what has been inserted and how the computer can communicate with the board. Before a board can be used, three parameters have to be set.
- These are the addresses of the input and output channels, the interrupt level and the channel to be used for direct memory access. With 'plug-and-play' boards for use with Windows software, these parameters are set by the software; otherwise microswitches have to be set on the card in accordance with the instructions in the manual supplied with the board.
- Application software can be used to assist in the designing of measurement systems and the analysis of the data. As an illustration of the type of application software available, LabVIEW is a graphical programming software package that has been developed by National Instruments for DAQ and instrument control.

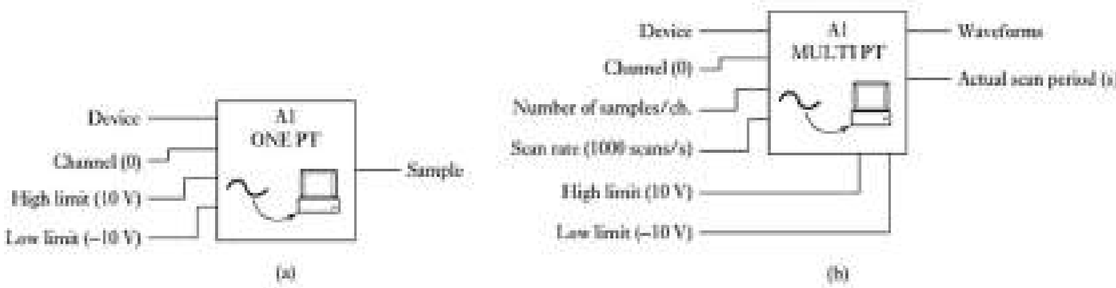
DAQ Board Elements.

- LabVIEW programs are called virtual instruments because in appearance and operation they imitate actual instruments. A virtual instrument has three parts: a front panel which is the interactive user interface and simulates the front panel of an instrument by containing control knobs, push-buttons and graphical displays; a block diagram which is the source code for the program with the programming being done graphically by drawing lines between connection points on selected icons on the computer screen; and representation as an icon and connector which can provide a graphical representation of the virtual instrument if it is wanted for use in other block diagrams.
- Figure 6.24(a) shows the icon selected for a virtual instrument where one analogue sample is obtained from a specified input channel, the icon having been selected from the Analog Input palette. The 'Device' is the device number assigned to the DAQ board, the 'Channel' is the source of the data, a 'Sample' is one analogue-to-digital conversion, and 'High limit' and 'Low limit' are the voltage limits expected for the signal (the default is 110 V and 210 V and changing these values automatically changes the gain of the amplifier on the DAQ board).

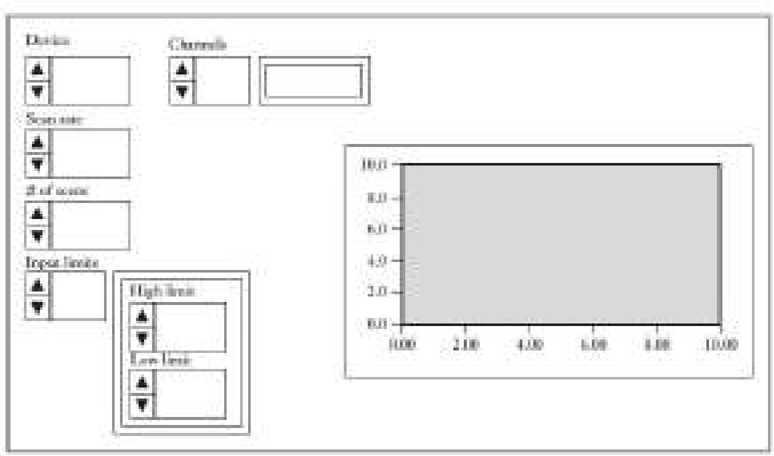
DAQ Board Elements.

- If we want a waveform from each channel in a designated channel string then the icon shown in Figure (b) can be selected. For each input channel a set of samples is acquired over a period of time, at a specified sampling rate, and gives a waveform output showing how the analogue quantity varies with time.
- By connecting other icons to, say, the above icon, a block diagram can be built up which might take the inputs from a number of analogue channels, sample them in sequence and display the results as a sequence of graphs. The type of front panel display we might have for a simple DAQ acquisition of samples and display is shown in Figure. By using the up and down arrows the parameters can be changed and the resulting display viewed.
- Virtual instruments have a great advantage over traditional instruments in that the vendor of a traditional instrument determines its characteristics and interface while with a virtual instrument these can all be defined by the user and readily changed.

Analogue input icon: (a) single input, (b) for sampling from a number of channels



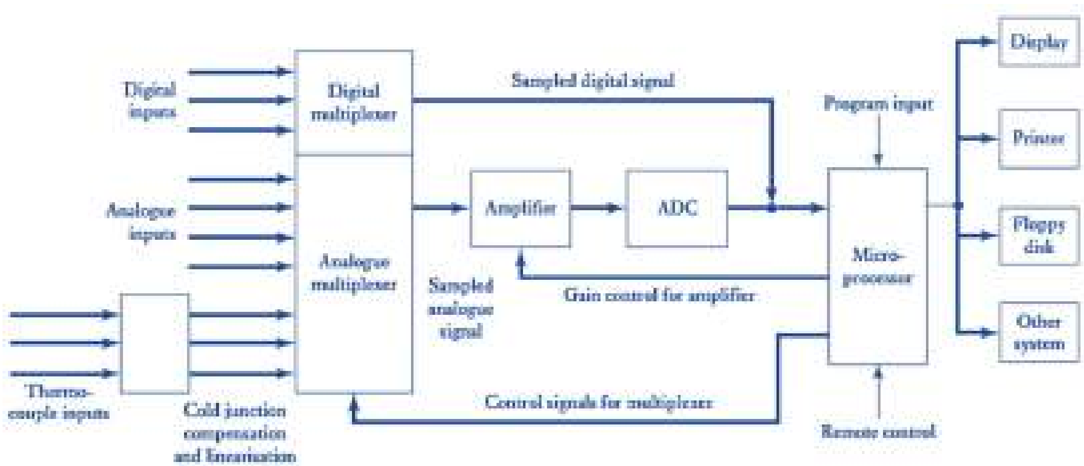
Front Panel.



Data loggers

- The term data logger is used for DAQ systems which are able to be used away from a computer. Once the program has been set by a computer, it can be put onto a memory card which can be inserted into the logger or have the program downloaded to it from a computer, so enabling it to carry out the required DAQ functions.
- Figure 6.26 shows the basic elements of a data logger. Such a unit can monitor the inputs from a large number of sensors. Inputs from individual sensors, after suitable signal conditioning, are fed into the multiplexer.
- The multiplexer is used to select one signal which is then fed, after amplification, to the ADC. The digital signal is then processed by a microprocessor. The microprocessor is able to carry out simple arithmetic operations, perhaps taking the average of a number of measurements. The output from the system might be displayed on a digital meter that indicates the output and channel number, used to give a permanent record with a printer, stored on a floppy disk or transferred to perhaps a computer for analysis.

Data Logger System.



Data loggers

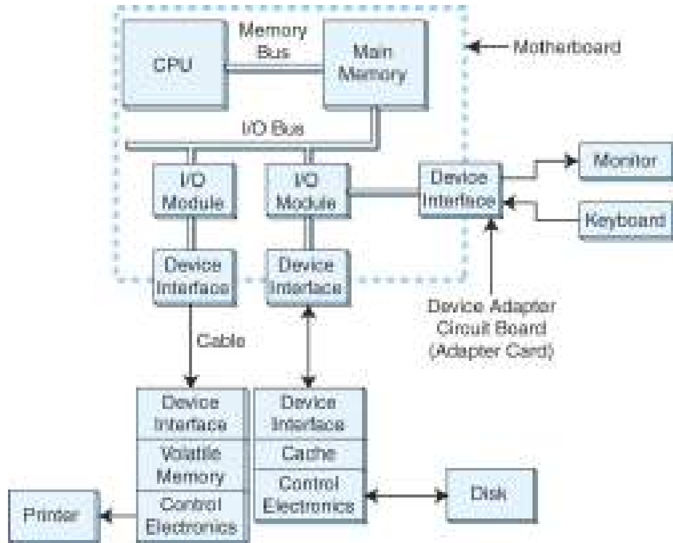
- Because data loggers are often used with thermocouples, there are often special inputs for thermocouples, these providing cold junction compensation and linearisation. The multiplexer can be switched to each sensor in turn and so the output consists of a sequence of samples. Scanning of the inputs can be selected by programming the microprocessor to switch the multiplexer to sample just a single channel, carry out a single scan of all channels, a continuous scan of all channels, or perhaps a periodic scan of all channels, say every 1, 5, 15, 30 or 60 minutes.
- Typically a data logger may handle 20 to 100 inputs, though some may handle considerably more, perhaps 1000. It might have a sample and conversion time of 10 μs and be used to make perhaps 1000 readings per second. The accuracy is typically about 0.01% of full-scale input and linearity is about 60.005% of full-scale input. Cross-talk is typically 0.01% of full-scale input on any one input. The term cross-talk is used to describe the interference that can occur when one sensor is being sampled as a result of signals from other sensors.

I/O System

- The I/O subsystem is treated as an independent unit in the computer
  - The CPU initiates I/O commands generically
    - Read, write, scan, etc
    - This simplifies the CPU
  - I/O modules are components that connect an I/O device to the I/O bus
    - The I/O module is an intermediary between CPU and the I/O device, and possibly between memory and the I/O device
  - This allows us to tailor I/O devices to specific uses without having to worry about how the CPU might be able to handle that new type of device
  - In addition, while the CPU may initiate an I/O operation, once begun, the I/O module takes over so that the CPU can get back to doing whatever it was doing
    - There are 4 general forms of I/O control, we will cover each

I/O Architectures

- I/O subsystem will typically include
  - Blocks of memory dedicated to I/O buffering
  - I/O bus(es)
  - I/O devices
  - Specialized interfaces (for instance for keyboard and monitor) and interface cards
  - Possibly other connections (network, cable, etc)



Programmed I/O

- Programmed I/O
  - The CPU monitors the I/O module so that the CPU is not free to work on other things
    - This is an inefficient form of I/O, and the oldest form, it is typically not used today unless the program directly calls for input from keyboard or other device
  - The process:
    - I/O instruction in the program causes CPU to examine I/O module's control register's ready bit – if it is ready, then the CPU issues the I/O command by setting the proper bits in this register
    - the I/O module issues the command to the I/O device and watches over device
    - when the I/O device has completed the task the I/O module sets the proper bits in its control register
    - the CPU, which has been watching this register, then cleans up the operation (on input, moves the input datum from the I/O module's data register to the CPU register or memory location)

Interrupt-Driven I/O

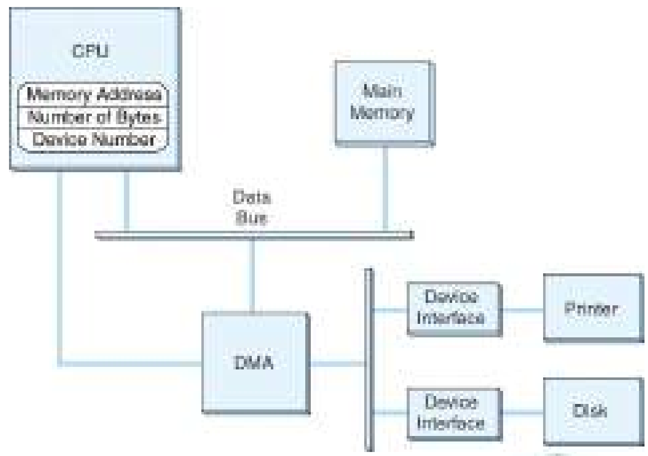
- Here, the Interrupt system is used so that the CPU does not have to watch and wait for the I/O module
  - The process:
    - The CPU issues the command to the I/O module
    - The CPU then continues with what it was doing
    - The I/O module, like before, issues the command to the I/O device and waits for the I/O to complete
    - Upon completion of one byte input or output, the I/O module sends an interrupt signal to the CPU
    - The CPU finishes what it was doing, then handles the interrupt
      - This will involve moving the resulting datum to its proper location on input
    - Once done with the interrupt, the CPU resumes execution of the program
  - This is much more efficient than Programmed I/O as the CPU is not waiting during the (time-consuming) I/O process
    - However, if the I/O itself takes more than 1 input or output (that is, if the amount being transferred is greater than 1 byte), then this interrupts the CPU often, so instead…

Handling Interrupts

- Device raises the interrupt (sends interrupt signal)
- At the end of the current fetch execute cycle, CPU checks for interrupt, if there is one, it saves its status (register values)
- CPU identifies interrupting device (we talk about how this is done later)
- Given the interrupting device number, use this to map into the Interrupt vector table
  - For instance, interrupt 15 would be at location 15 in memory, this entry stores the location of interrupt 15's handler in operating system memory
- Move this address into the PC
- Execute interrupt handler
- Upon completion, restore saved register values

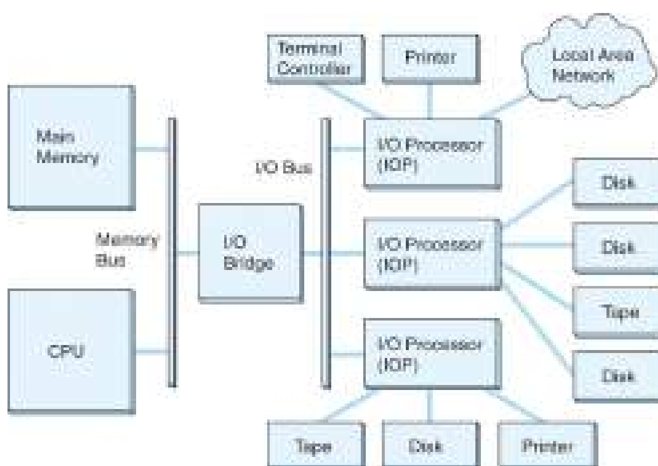
DMA I/O

- Direct memory access allows an I/O module to communicate directly with memory so that the CPU does not have to be interrupted for each data movement
  - In any large transfer, DMA I/O is preferable to Interrupt-driven I/O
  - The DMA controller only interrupts the CPU once, once the entire data transfer is complete
  - Note: memory is a slave device so it cannot initiate bus transfers, the DMA controller then acts as a memory master
  - The DMA controller includes a count register set by the CPU to count the number of bytes still to be transferred
  - The DMA controller acts as an interface between I/O device and memory



Channel I/O

- In DMA I/O, if there is a failure of the I/O device, the I/O module interrupts the CPU to handle the problem
- A more sophisticated I/O module is known as an I/O channel
  - this is an I/O module with its own mini-processor (known as an I/O processor)
  - these processors contain their own ALUs and control units so that they can perform comparisons and make branches in their own mini-programs
- Channel I/O can handle any problem without having to interrupt the CPU



I/O architecture with I/O Channels

I/O Accessing and Addressing

- I/O accesses use the Expansion bus and System bus
  - as multiple devices might need access at the same time, bus access must be governed
  - three approaches are:
    - bus arbiter, a controller to select the device that next gets to use the bus based on a priority scheme
    - an I/O monitor checks for bus traffic and if it is busy, waits
    - use the CPU as an arbiter
- To determine which device is to handle a CPU command, the CPU sends the device's address on the address bus (along with the control command of read or write)
- There are two forms of addressing used in computers:
  - Isolated I/O – every device has a unique address and so device j watches for address j over the address bus, and the CPU uses two sets of control lines, one to memory, one to the I/O subsystem
  - Memory-mapped I/O – some memory addresses are reserved for I/O module registers, and communication from the CPU to memory & I/O is generic
  - Memory-mapped while being cheaper because of the need for fewer control lines takes away some memory addresses so those memory locations are never used

Forms of I/O

- Character versus block
  - We differentiate between whether we expect a single datum (byte or word size) or a block of data
    - Character: keyboard, mouse, monitor, printer, modem
    - Block: storage device (disk drive, tape drive)
  - Notice that block devices are usually much higher speed than character
  - Also, block devices tend to use DMA while character uses interrupt-driven
- Synchronous vs asynchronous
  - Synchronous devices use the system clock to regular usage (note that a transfer may not occur at every clock cycle but it will start with a clock pulse)
  - Asynchronous devices are not regulated by the clock and the device may start or stop communicating at any time (think of a network message coming in, or a response from the printer)

Virtual Instrumentation Software

- Modelling, analysis, design, data acquisition, and control are important activities within the field of Mechatronics.
- Computer software tools and environments are available for effectively carrying out, both at the learning level and at the professional application level.
- MATLAB is an interactive computer environment with a high-level language and tools for scientific and technical computation, modelling and simulation, design, and control of dynamic systems.
- SIMULINK is a graphical environment for modelling, simulation, and analysis of dynamic systems, and is available as an extension to MATLAB.
- LabVIEW is graphical programming language and a program development environment for data acquisition, processing, display, and instrument control.
- Simulink provides a graphical environment for modeling, simulating, and analyzing linear and nonlinear dynamic systems. First a suitable block diagram model of the system is developed on the computer screen, and stored.
- The SIMULINK environment provides almost any block that is used in a typical block diagram. These include transfer functions, integrators, gains, summing junctions, inputs (i.e., source blocks), and outputs (i.e., graph blocks or scope blocks).

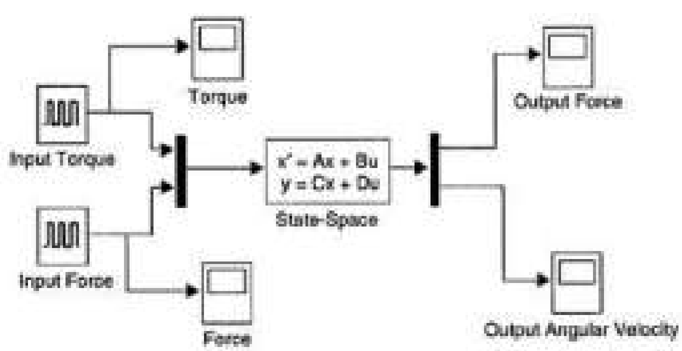
Virtual Instrumentation Software

- Such a block may be selected and inserted into the workspace as many times as needed, by clicking and dragging using the mouse. These blocks may be connected as required, using directed lines.
- A block may be opened by clicking on it, and the parameter values and text may be inserted or modified as needed. Once the simulation block diagram is generated in this manner, it may be run and the response may be observed through an output block (graph block or scope block).
- There are two types of elements in SIMULINK: blocks and lines. Blocks are used to generate (or input), modify, combine, output, and display signals. Lines are used to transfer signals from one block to another.

Starting Simulink

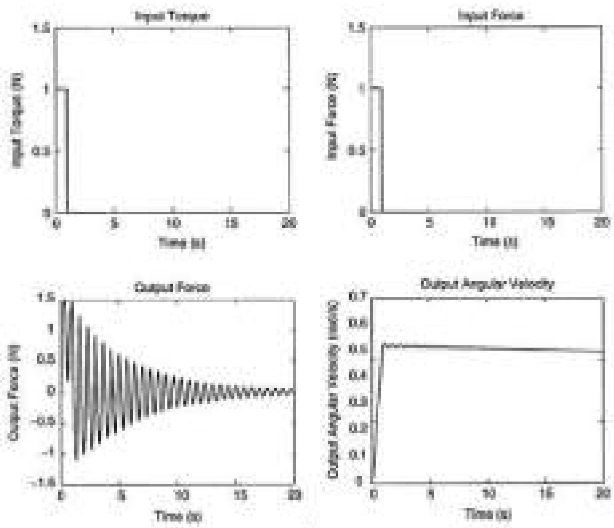
- First enter the MATLAB environment. You will see the MATLAB command prompt >>. To start SIMULINK, enter the command: simulink. Alternatively, you may click on the "Simulink" button at the top of the MATLAB command window.
- Basic Elements:-
- There are two types of elements in SIMULINK: blocks and lines. Blocks are used to generate (or input), modify, combine, output, and display signals. Lines are used to transfer signals from one block to another.
- Blocks:-
- The subfolders below the SIMULINK folder show the general classes of blocks available for use. They are
- Continuous: Linear, continuous-time system elements (integrators, transfer functions, state-space models, etc.)
- A signal can be either a scalar signal (single signal) or a vector signal (several signals in parallel). The lines used to transmit scalar signals and vector signals are identical; whether it is a scalar or vector is determined by the blocks connected by the line.

SIMULINK model of a robotic sewing machine



(a)

SIMULINK model of a robotic sewing machine – Simulation Results



(b)

MATLAB:

- MATLAB interactive computer environment is very useful in computational activities in Mechatronics.
- Computations involving scalars, vectors, and matrices can be carried out and the results can be graphically displayed and printed.
- MATLAB toolboxes are available for performing specific tasks in a particular area of study such as control systems, fuzzy logic, neural network, data acquisition, image processing, signal processing, system identification, optimization, model predictive control, robust control, and statistics.
- Mathematical computations can be done by using the MATLAB command window. Simply type in the computations against the MATLAB prompt “>>” as illustrated next.
- An example of a simple computation using MATLAB is given below.
    - >> x=2; y=-3;
    - >> z=x^2-x*y+4
    - z=-14

MATLAB:

- MATLAB Arithmetic Operations

Symbol	Operation
+	Addition
-	Subtraction
*	Multiplication
/	Division
^	Power

Useful Mathematical Functions in MATLAB

abs()	Absolute value/magnitude
acos()	Arc-cosine (inverse cosine)
acosh()	Arc-hyperbolic-cosine
asin()	Arc-sine
atan()	Arc-tan
cos()	Cosine
cosh()	Hyperbolic cosine
exp()	Exponential function
log()	Natural logarithm
log10()	Log to base 10 (common log)
real()	Real part of a complex number
imag()	Imaginary part of a complex number
sign()	Signum function
sin()	Sine
sqrt()	Positive square root
tan()	Tan function

Some Relational Operations

Operator	Description
<	Less than
<=	Less than or equal to
>	Greater than
>=	Greater than or equal to
= =	Equal to
~=	Not equal to

Basic Logical Operations

Operator	Description
&	AND
|	OR
~	NOT

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LABVIEW

- LabVIEW or Laboratory Virtual Engineering Workbench is a product of National Instruments. It is a software development environment for data acquisition, instrument control, image acquisition, motion control, and presentation.
- LabVIEW is a complied graphical environment, which allows the user to create programs graphically through wired icons similar to creating a flowchart.

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Working with LabVIEW:-

- As a software centered system, LabVIEW resides in a desktop computer, laptop or PXI as an application where it acts as a set of virtual instruments (VIs), providing the functionality of traditional hardware instruments such as oscilloscopes.
- Comparing to physical instruments with fixed functions, LabVIEW Vis are flexible and can easily be reconfigured to different applications.
- It is able to interface with various hardware devices such as GPIB (General Purpose Interface Bus), data acquisition modules, distributed I/O, image acquisition, and motion control, making it a modular solution.

Condition Monitoring

- Improve industrial plant performance
- Provide early warning of potential failure
- Continuous drive for improved efficiencies
- Reducing unexpected plant downtime
- Removing need for routine maintenance

Need of CM

- Maintenance performed on a 'just-in-time' principle rather than on a routine basis
  - Reduction in replacement-parts holding
- Reduces or eliminates unscheduled shut-down of plant or equipment
  - lead to additional costs, usually out of all proportion to the cost of the repairs subsequently found to be necessary

Condition Monitoring

- Dynamic systems (electrical, hydraulic, mechanical or thermal) possesses a normal characteristic 'signature' when operating in the desired state
- Changes in this signature may indicate the onset of a failure
- Small differences between normal and abnormal signatures may be hidden by 'noise' in the system
- Modern transducers and associated signal-analysis techniques can now discriminate between truly random variations and significant trends which, with knowledge of the system parameters and normal characteristics, can be used to predict time to failure

Condition Monitoring

- Need to identify changes in the condition of a machine that will indicate some potential failure
- Physical characteristics are identified that collectively indicate the current condition of the machine
- Each of these characteristics is measured, analysed, and recorded so that trends can be recognised
- Over a period of time, the progress of these trends represents the deterioration of machine condition and can be used to determine maintenance actions.

Where is it done?

- Originally developed to anticipate failure in high-speed gearboxes in the aerospace industry
- Now being applied to an ever-growing range of industries
- If process variables such as vibration, speed, pressure, temperature, voltage, current etc. can be measured, then it is likely that a process signature can be identified which can lead in turn to the application of Condition Monitoring techniques

Example

- Different types of monitoring systems are used according to the criticality and condition of the individual asset
- Data: Body Temperature 99°F
- Diagnosis: Appendicitis
- Prognosis: Bad
- Action: Appendectomy tomorrow

Technologies Applied

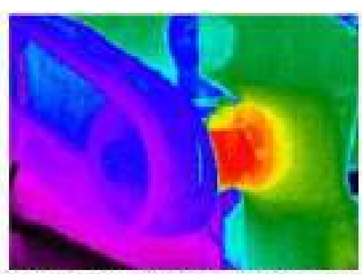
1. **Vibration analysis**
2. **Thermographic analysis**
3. **Oil analysis**
4. **Ultrasonic analysis**
5. **Motor current signature analysis (MCSA)**
6. **Performance trending/visual observations**

1. Vibration Analysis

- Involves measuring the forces created from vibrations.
- 50 to 70% of rotating component failures are attributable to misalignment
- Non-intrusive.
- Foundation of rotating machinery predictive maintenance.
- Limited analysis on reciprocating machinery now possible.

2. Thermographic Analysis

- Involves the use of infrared scanners to detect differences in surface temperatures.
- Based on the principle that machinery failures will be preceded by changes in temperature.
- Foundation of electrical component predictive maintenance
- Can be used to analyze patterns of heat loss or gain
- Non-intrusive
- Non-contact



Pulley-bearing combinations like this can be investigated with thermography

3. Oil Analysis

- Identifies the condition of the hydraulic fluid or lubricant
  - Viscosity analysis
  - Contamination analysis
  - Acid/Base number
  - Oil additive analysis
- Identifies the condition of the machine.
  - Wear particle analysis

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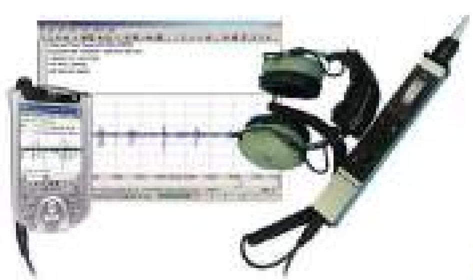
4. Ultrasonic Analysis

- Measures the sonic sound patterns of machines being monitored
- Airborne ultrasounds (20 kHz - 100kHz)
  - Cannot penetrate solid surfaces
  - Can penetrate cracks
  - Radiate in a straight line therefore the source is easy to locate
  - Travel a short distance



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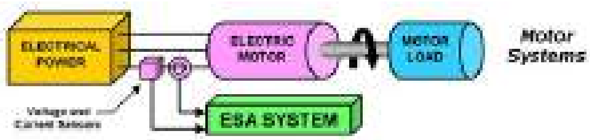
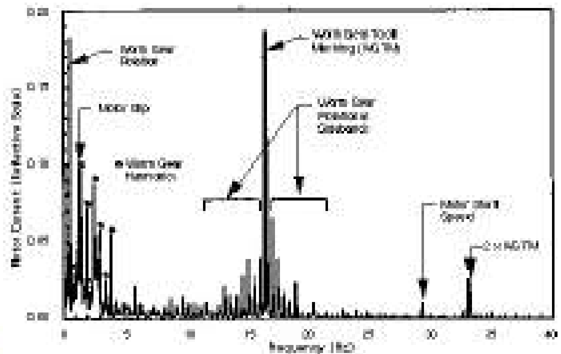
5. Motor Current Signature Analysis

- Detects mechanical and electrical problems in motor driven rotating equipment.
- Based on the concept that an electrical motor driving a mechanical load acts as an efficient transducer.
  - Motor senses mechanical load conditions and translates variations in these conditions into variations in electrical current conditions.





6. Performance Trending

- Monitoring the performance of a machine through the trending of process data.
  - Pressure
  - Temperature
  - Flow
  - Amperage

Visual Observations

- Oldest and most common technique
- Involves looking, listening, touching
- Virtually all equipment

Benefits

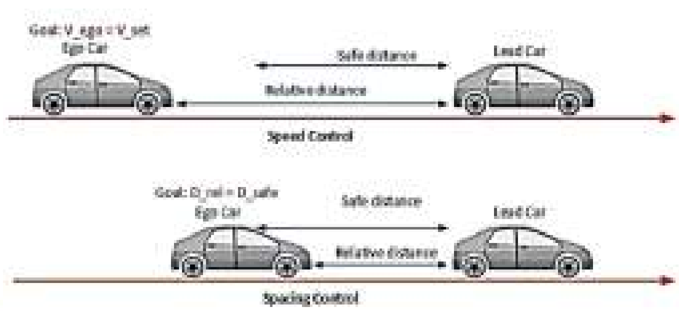
- Opportunity to organising avoidance strategies to minimise lost time and unexpected costs
- Provides information on
  - presence of a fault condition
  - indication of fault type
  - diagnosis of the cause of a fault
  - level of severity of fault
  - prediction of time-to-failure

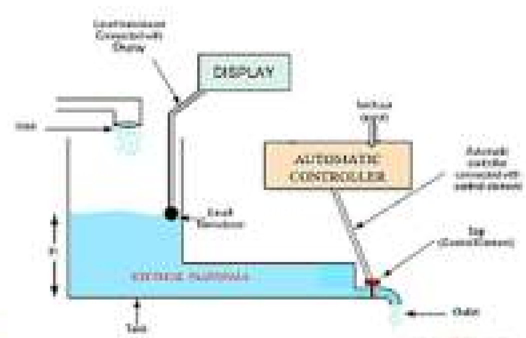
Adaptive Control

- The control systems in which the system parameters are automatically adjusted to keep the system at an optimum level are called adaptive control systems. Such type of control systems itself detects changes in the plant parameters and make essential adjustments in the controller parameters to maintain optimum level or performance.
- Adaptive control system adapts the parameters of the controller to changes in the parameters or structure of the controlled system in such a way that the entire system maintains optimal behavior according to the given criteria, independent of any changes that might have occurred.
- Adaptive control is the control method used by a controller which must adapt to a controlled system with parameters which vary, or are initially uncertain
- For example, as an aircraft flies, its mass will slowly decrease as a result of fuel consumption a control law is needed that adapts itself to such changing conditions

Adaptive Control

- Adaptive control is different from robust control in that it does not need a priori information about the bounds on these uncertain or time varying parameters robust control guarantees that if the changes are within given bounds the control law need not be changed, while adaptive control is concerned with control law changing itself



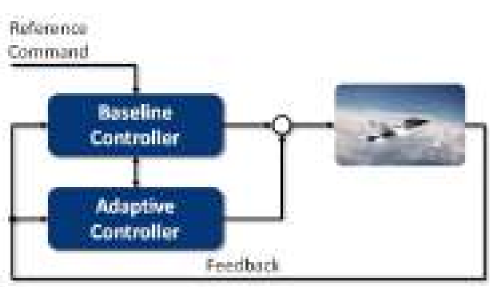


ADAPTIVE CONTROL AND ITS APPLICATIONS IN THE INDUSTRY

- Adaptive control has been increasing its use in different sectors and industries since its beginnings in the aerospace going through the control of vibrations until the use of autonomous Systems and Unmanned Aerial Systems (UAS). This is possible because its features permit to optimize the automations that are under its control, that is very attractive for industry
- **EVOLUTION OF THE ADAPTIVE CONTROL**
- Adaptive control was originated in 1950 when designing the automatic control of an aircraft whose dynamic was variable in the desired range of operations For this reason, conventional control was not capable to cover the range of operation and it is created a gain scheduling technique.
- Since then, adaptive control has been extended to new applications such as drying ovens, active control of vibrations, efficient conditioning, robotics permitting to control the process or even improve the efficiency that was performed with conventional controls

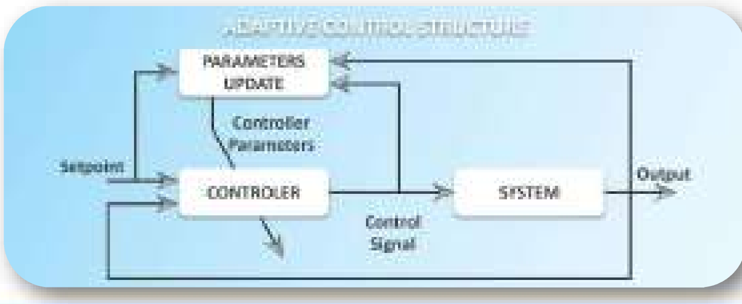
ADAPTIVE CONTROL AND ITS APPLICATIONS IN THE INDUSTRY

- Nowadays, one of the most important applications if the flight control of unmanned aircrafts, due to the changes in the flight dynamic



Adaptive Control System

- Adaptive control is a set of techniques that permit to adjust the value of control parameters in real time, permitting to monitor controlled variables even if plant parameters are unknown or if they change over time. This control is a special kind of non lineal control, and the process can be split in two timelines rapid time (feedback loop) and slow time (variation of control parameters, which affects to automations)

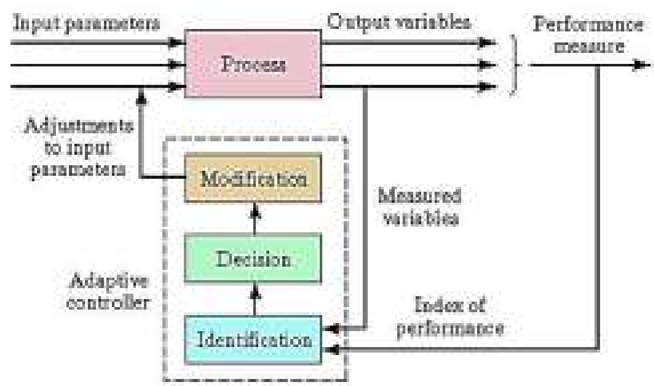


Adaptive Control System

- WHY AND ADAPTIVE CONTROL AND NOT A CONVENTIONAL ONE?
- Conventional controllers are designed to adjust linear and non variable systems over time (LTI). This approach is true for fixed points of operations with small perturbations When this approximation stops being true, conventional controllers performance stops being good enough
- Adaptive control is capable to adapt itself changing control parameters, keeping a good control along the process
- In the UAS industry it should be preference to implement adaptive controls instead of conventional controls, since it permits to configure the controllers in a way that it can be automatically adapted to changing flight conditions
- For instance, during an UAS flight, its plant dynamic may change for different ranges of speed in order to optimize the plant control, it is necessary a control rule capable to be adapted to this change in the system that some UAS autopilot can already manage

Adaptive Control System

- Because steady-state optimization is open-loop, it cannot compensate for disturbances
- Adaptive control is a self-correcting form of optimal control that includes feedback control
- Measures the relevant process variables during operation (feedback control)
- Uses a control algorithm that attempts to optimize some index of performance (optimal control)



Three Functions in Adaptive Control

- 1. Identification function - current value of IP is determined based on measurements of process variables. This involves determining the current performance of the process or system. The identification function is concerned with determining the current value of this performance measure by making use of the feedback data from the process.
- 2. Decision function - decide what changes should be made to improve system performance
  - Change one or more input parameters
  - Alter some internal function of the controller
  - Once the system performance is determined, the next function is to decide how the control mechanism should be adjusted to improve process performance.
  - The decision process is carried out by means of a pre-programmed logic provided by the designer.

Three Functions in Adaptive Control

3. Modification function - implement the decision function

- Concerned with physical changes (hardware rather than software)
- The third AC function is to implement the decision.
- While the decision function is a logic function, modification is concerned with a physical or mechanical change in then system.
- The modification involves changing the system parameters or variables so as to drive the process towards a more optimal state.

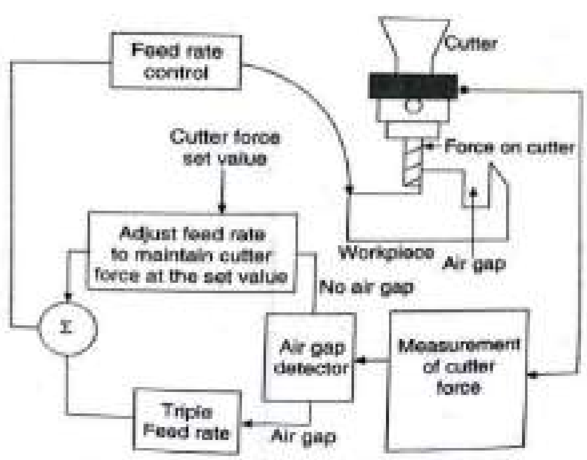
Adaptive Control Operates in a Time-Varying Environment

- The environment changes over time and the changes have a potential effect on system performance
- Example: Supersonic aircraft operates differently in subsonic flight than in supersonic flight
- If the control algorithm is fixed, the system may perform quite differently in one environment than in another
- An adaptive control system is designed to compensate for its changing environment by altering some aspect of its control algorithm to achieve optimal performance

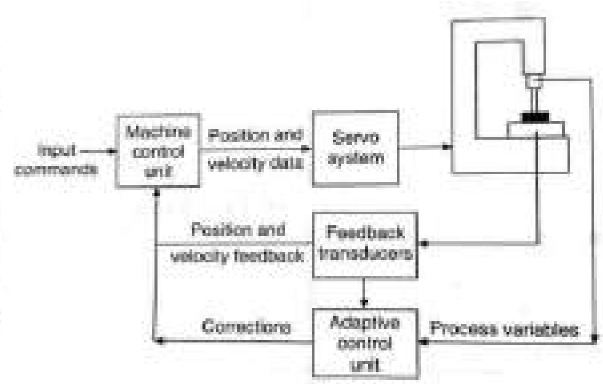
Adaptive Control System

- Adaptive control (AC) machining originated out of research in early 1970's sponsored by U.S Air Force.
- The initial adaptive control systems were based on analog devices, representing the technology at that time.
- Today adaptive control uses microprocessor based controls and is typically integrated with an existing CNC system.
- Adaptive control system is a logical extension of the CNC mechanism.
- In CNC mechanism the cutting speed and feed rates are prescribed by the part programmer.
- The determination of these operating parameters depends on the Knowledge and experience of programmer regarding the work piece, tool materials, coolant conditions and other factors.
- By contrast in adaptive control machining there is improvement in the production rate ana reduction in the machining cost as a result of calculating and setting of optimal parameters during machining.

Adaptive Control System



A typical adaptive control machining system.



Adaptive control machining system.

Adaptive Control System

- The adaptive control is basically a feedback system that treats the CNC as an internal unit and in which the machining variables automatically adapt themselves to the actual conditions of the machining process.
- Note:- IP (Performance Index) is usually an economic function such as max production rate or minimum machining cost.
- The main idea of AC is the improvement of the cutting process by automatic on line determination of speed and/ or cutting.
- The AC is basically a feedback system in which cutting speed and feed automatically adapt themselves to the actual condition of the process and are varied accordingly to the changes in the work conditions as work progresses.

WHERE TO USE ADAPTIVE CONTROL

- Adaptive control is not suitable for every machining situation.
- In general, the following characteristics can be used to identify situations where adaptive control can be beneficially applied.
- The in-process time consumes a significant portion of the machining cycle time.
- There are significant sources of variability in the job for which AC can compensate.
  - The cost of operating the machine tool is high.
  - The typical jobs involve steels, titanium and high strength alloys.

In practice the AC system of machine tools can be classified into two types:

- AC with optimization (ACO)
- AC with constrains (ACC)
- Geometric Adaptive Control (GAC)

Adaptive Control System

- ACC are systems in which machining conditions such as spindle speed or feed rate are maximized within the prescribed limits of machines and tool constrains such as maximum torque, force or horse power.
- In AC system the correct feed and speed are automatically found and it is not necessary to spend efforts on calculations of optimum feeds and speeds.
- ACC systems do not utilize a performance index and are based on maximizing a machining variable (e.g., feed rate) subject to process and machine constraints (e.g., allowable cutting force on the tool, or maximum power of the machine).
- The objective of most ACC types of systems is to increase the MRR during rough cutting operations.

Adaptive Control System

- For example, to maximize the machining feedrate while maintaining a constant load on the cutter, despite variations in width and depth of cut.
- In a normal CNC system, the feedrate is programmed to accommodate the largest width and depth in a particular cut, and this small feedrate is maintained along the entire cut. As a result the machining rate is reduced.
- By contrast, with the ACC system, the maximum allowable load (e.g., cutting force) on the cutter is programmed.
- As a result, when the width or depth of cut are small the feed rate is high; when either the width or depth of cut (or both) are increased, the feedrate is automatically reduced, and consequently the allowable load on the cutter is not exceeded.
- The result is, the average feed with ACC is much larger than its programmed counterpart.

Benefits of AC

- Increased production rates.
- Increased tool life.
- Greater part protection.
- Less operator intervention.

Drawbacks of AC

- The main problem is that is require on-line measurement of tool wear.
- So far there have been no industrially acceptable methods developed for the direct measurement of tool wear.
- Indirect measurement assumes that tool wear is proportional to other measurable variables such as cutting forces and temperatures.
- The drawback of using these indirect measurements is that variations in their values can be caused by process variations other than tool wear, such as workpiece hardness or cutting conditions.
- Thus making it difficult to identify the tool wear effect from the effect of the other parameter variations on the measurements.
- Another problem is the interface of an AC system with CNC units. As yet, manufacturers have not standardized interfaces

GEOMETRIC ADAPTIVE CONTROL

- GAC are typically used in finish machining operations.
- In GACs the part quality is maintained in real time by compensating for the deflection and wear of cutting tools.
- The objective of GAC is to achieve:-
- (1) the required dimensional accuracy and
- (2) a consistency of surface finish of machined parts despite tool wear or tool deflection

Drawback of GAC

- Both the dimensional accuracy and the surface finish are affected by the flank wear and the crater wear of the tools which deteriorate during cutting.
- These variables cannot be measured in real time; neither can they be accurately predicted from off-line tool testing.

Need for Adaptive Control

- 1. The key reason is that most of the processes are nonlinear The control loops are generally designed to maintain the controlled variable at its set point by compensating for all disturbance occurring in the process The controller performance is optimum only for a particular range in which the process is linearized Once the process starts to operate beyond the linearized range, the controller fails to produce desired performance It is because of the fact that the parameters of the controller is not suitable for the current operating conditions
- 2. The changes in transfer function of process which occurs due to parameter variations or variation in the coefficients or wear and tear of important components
- 3. The nature and magnitude of disturbances vary with time There may be an occurrence of an unpredictable and unknown disturbance in the process
- 4. There may be a change in nature of inputs to the process and the properties of raw materials
- In all the above cases, a conventional controller cannot perform at a satisfactory level
- This demands the need for a special type of controller that adapt in accordance with the uncertainties in the process and in turn Adaptive Control

Types of Adaptive Control

- There are two major approaches to determine the controller parameters adaptation They are,
- **1. Programmed or Gain Scheduled Adaptive Control**
- The Programmed Adaptive Control is compared to feed forward compensation because it adjust the controller parameters based on the measurement of an auxiliary variable and the knowledge of operating conditions of process. Also, there is no feedback to check the correctness of adaptation
- **2 Self Adaptive Control**
- The Self Adaptive Control is comparable to feedback compensation because the adaptation of controller parameters is based on the measurement of closed loop performance and aim to optimize it Model Reference Adaptive Control (MRAC) and Self Tuning Regulator (STR) are two mechanisms that come under self adaptive control

Applications of Adaptive Control

1. Adaptive control is used in the robotic manipulators of robotic systems which demands high positioning accuracy
2. Adaptive control is used for altitude control of satellites. The observation satellites should be operated at lower altitudes where the air drag makes the quick reorientation of satellite is necessary to increase the observation time.
3. Adaptive control is used in the autopilot of air crafts and steering control of ships.
4. Adaptive control is used in the control of strip temperature for the continuous annealing and processing in metallurgical processes.

5. Adaptive control is used in distillation columns to provide high product quality and a considerable reduction of thermal energy usage.
6. Adaptive control is used to stabilize PID based pH control system in chemical industries. Without adaptive control, the process gain (Kp) increases as the pH value becomes neutral and it leads to change in total loop gain and finally to instability of loop. The adaptive control keeps the total loop gain at the desired value (usually 0.5) by lowering the controller gain (Kc).

Supervisory Control and Data Acquisition - SCADA System

- SCADA stands for **S**upervisory **C**ontrol **A**nd **D**ata **A**cquisition.
- It is a type of software application program for process control. SCADA is a central control system which consists of controllers network interfaces, input/output, communication equipment, and software.
- SCADA systems are used to monitor and control the equipment in the industrial process which includes manufacturing, production, development, and fabrication.
- The infrastructural processes include gas and oil distribution, electrical power, water distribution. Public utilities include bus traffic system, airport.
- The SCADA system takes the reading of the meters and checks the status of sensors in regular intervals so that it requires minimal interference of humans.

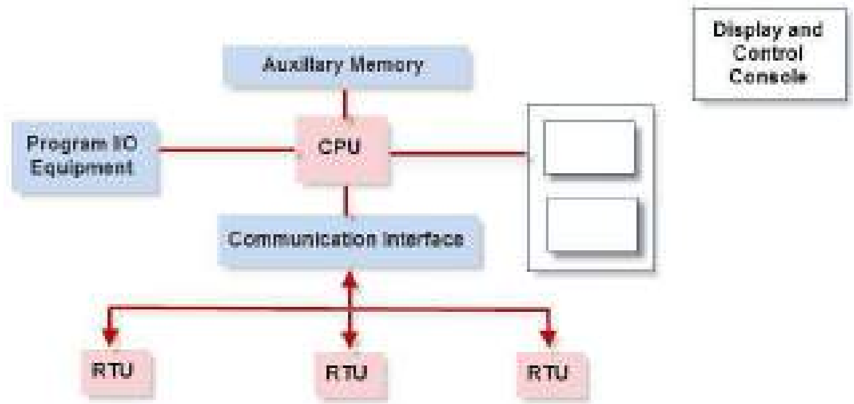
SCADA System

- A large number of processes occur in large industrial establishments. Every process you need to monitor is very complex because each machine gives a different output.
- The SCADA system used to gather data from sensors and instruments located in remote areas. The computer then processes this data and presents it promptly.
- The SCADA system gathers the information (like a leak on a pipeline occurred) and transfers the information back to the system while giving the alerts that leakage has occurred and displays the information in a logical and organized fashion.
- The SCADA system used to run on DOS and UNIX operating systems.

SCADA System

- Generally, the SCADA system is a centralized system that monitors and controls the entire area. It is a pure software package that is positioned on top of the hardware.
- A supervisory system gathers data on the process and sends the commands control to the process. The SCADA is a remote terminal unit which is also known as RTU. Most control actions are automatically performed by RTUs or PLCs.
- The RTUs consists of the programmable logic converter which can be set to specific requirement. For example, in the thermal power plant, the water flow can be set to a specific value or it can be changed according to the requirement.
- The SCADA system allows operators to change the set point for the flow, and enable alarm conditions in case of loss of flow and high temperature, and the condition is displayed and recorded. The SCADA system monitors the overall performance of the loop. The SCADA system is a centralized system to communicate with both wired and wireless technology to Clint devices. The SCADA system controls can run completely all kinds of the industrial process.

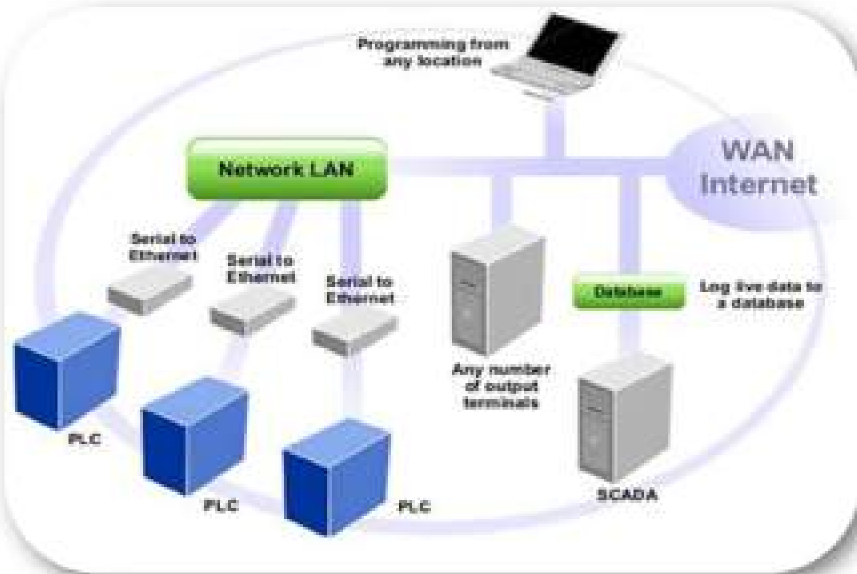
SCADA System



SCADA - Hardware Architecture:

- The generally SCADA system can be classified into two parts:
  - The Clint layer which caters for the man-machine interaction.
  - The data server layer which handles most of the process data activities.
- The SCADA station refers to the servers and it is composed of a single PC. The data servers communicate with devices in the field through process controllers like PLCs or RTUs. The PLCs are connected to the data servers either directly or via networks or buses.
- The SCADA system utilizes a WAN and LAN networks, the WAN and LAN consist of internet protocols used for communication between the master station and devices.
- The physical equipment like sensors connected to the PLCs or RTUs. The RTUs convert the sensor signals to digital data and sends digital data to the master. According to the master feedback received by the RTU, it applies the electrical signal to relays. Most of the monitoring and control operations are performed by RTUs or PLCs as we can see in the figure.

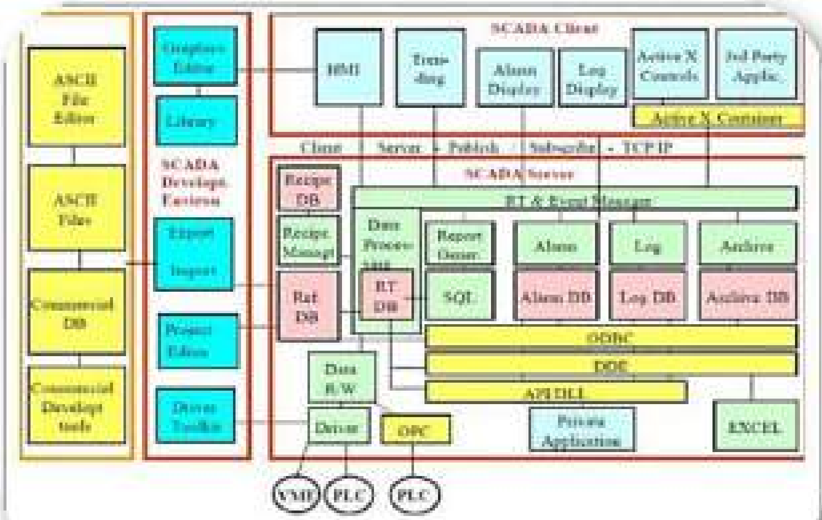
SCADA - Hardware Architecture:



SCADA - Software Architecture

- Most of the servers are used for multitasking and real-time database. The servers are responsible for data gathering and handling. The SCADA system consists of a software program to provide trending, diagnostic data, and manage information such as scheduled maintenance procedures, logistic information, detailed schematics for a particular sensor or machine, and expert-system troubleshooting guides. This means the operator can see a schematic representation of the plant being controlled.
- EX: alarm checking, calculations, logging, and archiving; polling controllers on a set of parameters, those are typically connected to the server.

SCADA - Software Architecture



Typical generic software architecture of SCADA systems

Working Procedure of SCADAsystem

- The SCADA system performs the following functions:
  - Data Acquisitions
  - Data Communication
  - Information/Data presentation
  - Monitoring/Control
- These functions are performed by sensors, RTUs, controller, a communication network. The sensors are used to collect the important information and RTUs are used to send this information to the controller and display the status of the system.
- According to the status of the system, the user can give the command to other system components. This operation is done by the communication network.

Working Procedure of SCADAsystem

- Data Acquisitions:
- The real-time system consists of thousands of components and sensors. It is very important to know the status of particular components and sensors. For example, some sensors measure the water flow from the reservoir to the water tank and some sensors measure the value pressure as the water is a release from the reservoir.
- Data Communication:
- The SCADA system uses a wired network to communicate between users and devices. Real-time applications use a lot of sensors and components which should be controlled remotely. The SCADA system uses internet communications. All information is transmitted through the internet using specific protocols. Sensor and relays are not able to communicate with the network protocols so RTUs used to communicate sensors and network interfaces.

Working Procedure of SCADAsystem

- Information/Data presentation:
- The normal circuit networks have some indicators which can be visible to control but in the real-time SCADA system, there are thousands of sensors and alarm which are impossible to be handled simultaneously. The SCADA system uses the human-machine interface (HMI) to provide all of the information gathered from the various sensors.
- Human-machine interface:
- The SCADA system uses the human-machine interface. The information is displayed and monitored to be processed by a human. HMI provides access to multiple control units which can be PLCs and RTUs. The HMI provides the graphical presentation of the system. For example, it provides a graphical picture of the pump connected to the tank. The user can see the flow of the water and the pressure of the water. The important part of the HMI is an alarm system that is activated according to the predefined values.

Working Procedure of SCADAsystem

- Monitoring/Control:
- The SCADA system uses different switches to operate each device and displays the status of the control area. Any part of the process can be turned ON/OFF from the control station using these switches. SCADA system is implemented to work automatically without human intervention but in critical situations, it is handled by manpower.
- SCADA for Remote Industrial plant:
- In large industrial establishments, many processes occur simultaneously and each needs to be monitored, which is a complex task. The SCADA systems are used to monitor and control the equipment in the industrial processes which include water distribution, oil distribution, and power distribution. The main aim of this project is to process the real-time data and control the large scale remote industrial environment. In the real-time scenario, a temperature logging system for a remote plant operation is taken.

Working Procedure of SCADAsystem

- The temperature sensors are connected to the microcontroller, which is connected to the PC at the front end, and software is loaded on the computer. The data is collected from the temperature sensors. The temperature sensors continuously send the signal to the microcontroller which accordingly displays these values on its front panel. One can set the parameters like low limit and high limit on the computer screen. When the temperature of a sensor goes above-set point the microcontroller sends a command to the corresponding relay. The heaters connected through relay contacts are turned OFF and ON.
- This is a temperature logging system. Here 8 temperature sensors in multiplexing mode are connected to the microcontroller through ADC 0808. Then the values of all the sensors are sent serially by the microcontroller through Max 32 to the com port of the PC. A Software "DAQ System" loaded on the PC takes these values and show them on its front panel, and also logs them to the database "daq.mdb". One can set by the interactive way some parameters like a set point, low limit, and high limit on the computer screen.

Working Procedure of SCADA system

- When the temperature of some sensor increases beyond the set point, the microcontroller sends commands to relay driver IC. The heaters connected through relay contacts are (specific for that sensor) turned OFF (or ON in opposite case). High limit and low limits are for alarm. When the temperature goes above the high limit or below low limit the alarm will be turned on.

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SCADA - Applications:

- Power generation, transmission, and distribution
- Water distribution and reservoir system
- Public buildings like electrical heating and cooling system.
- Generators and turbines
- Traffic light control system
- **Advantages:**
- The SCADA system provides onboard mechanical and graphical information
- The SCADA system is easily expandable. We can add a set of control units and sensors according to the requirement.
- The SCADA system ability to operate critical situations.

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TEXT BOOKS:

- Bolton, “Mechatronics”, Prentice Hall, 2019
- Mechatronics System Design - Devdas Shetty
- Web resources

MECHANICAL ENGINEERING
DEPARTMENT

UNIT V - MECHATRONICS APPLICATIONS 10

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UNIT V - MECHATRONICS APPLICATIONS 10

- Mechatronic control in automated manufacturing
- Artificial intelligence in Mechatronics
- Fuzzy logic applications in Mechatronics
- Microsensors in Mechatronics
- Case studies - pick and place robot
- Case studies - engine management system
- Case studies - consumer mechatronic products

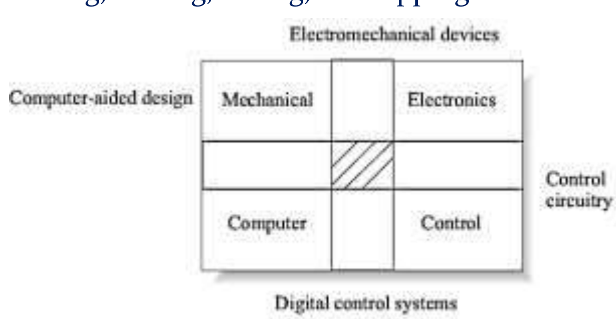
2

Mechatronics in Manufacturing

- Until the 1970's, machine tools were largely mechanical systems with very limited electrical or electronic content.
- However, since then there has been a dramatic change in technology with an increase in the content of electrical and electronic systems integrated with mechanical parts through mechatronics.
- Machine tools incorporating computer numerical control, electric servodrives, electronic measuring systems, and precision mechanical parts such as ball screws and antifriction guideways are examples of the application of mechatronic technology.
- The Japanese machine tool industry has flourished because Japanese have mastered electronics and have been able to combine precision mechanics and informatics in design.
- Computer and control system units are widely used in machine tools. Figure shows how the Japanese have incorporated mechatronics in manufacturing. Computer aided design (CAD), electromechanical devices, control circuitry, and digital control systems are widely used in mechatronic systems in the manufacturing environment.
- The development of computer numerically controlled (CNC) machines is an outstanding contribution to manufacturing industries.

Mechatronics in Manufacturing

- It has made possible the automation of the machining processes with flexibility to handle small to medium batch qualities in part production. Initially, the CNC technology was applied on basic metal cutting machines such as lathes and milling machines.
- Later, to increase the flexibility of machines handling a variety of components and to incorporate them in a single set-up in the same machine, CNC machines with material handling systems were developed. CNC machines are capable of performing multiple operations such as milling, drilling, boring, and tapping.



Control Terminology

- Controlled variables - these are the variables which quantify the performance or quality of the final product, which are also called output variables.
- Manipulated variables - these input variables are adjusted dynamically to keep the controlled variables at their set-points.
- Disturbance variables - these are also called "load" variables and represent input variables that can cause the controlled variables to deviate from their respective set points.
- Set-point change - implementing a change in the operating conditions. The set-point signal is changed and the manipulated variable is adjusted appropriately to achieve the new operating conditions. Also called servomechanism (or "servo") control.
- Disturbance change - the process transient behavior when a disturbance enters, also called regulatory control or load change. A control system should be able to return each controlled variable back to its set-point.

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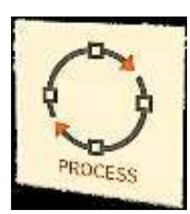
Process

- A sequence of interdependent and linked procedures
- At every stage it consume one or more type of resources (employee time, energy, machines, money etc.) into outputs
- These outputs then serve as inputs for the next stage until a known goal or end result is reached



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Control

- Control in process industries refers to the regulation of all aspects of the process.
- TYPES OF PROCESS
  - CONTINUOUS PROCESS
  - BATCH PRODUCTION
  - INDIVIDUAL OR DISCRETE PRODUCTS PRODUCTION

TYPES OF PROCESS CONTROL IN MANUFACTURING

1.Continuous process

- Process itself runs continuously and uninterrupted in time. Example: Production of chemicals, plastics

2.Batch process

- Operation is performed on the batch to produce a finished product. Example: Production of adhesive and glues

3.Individual or discrete process

- A series of operations produces a useful output product. Example: involves the production of discrete pieces of product such as metal stamping.

PROCESS CONTROL IN MANUFACTURING

- An engineering discipline that deals with architectures, mechanism and algorithms for maintaining the output of a specific process within a desired range's extensively used in industry
- Enables mass production of consistent products from continuously operated processes such as oil refining, paper manufacturing etc.
- Enables automation by which a small staff of operating personnel can operate a complex process from a central control room.
- Manufacturers control the production process for three reasons:
  - a) Reduce variability b) Increase efficiency c) Ensure safety

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Specific Objectives of Control

- Increased product throughput
- Increased yield of higher valued products
- Decreased energy consumption
- Decreased pollution
- Decreased off-spec product
- Increased Safety
- Extended life of equipment
- Improved Operability
- Decreased production labor

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Process Control System

- A process control system an be defined as the functions and operations necessary to change material either physically or chemically.
- Process control normally refers to the manufacturing or processing of products in industry.

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PROCESS VARIABLES

- A condition of the process fluid (a liquid or gas) that can change the manufacturing process in some way. Common process variables include:
- Pressure
- Flow
- Level
- Temperature
- Density
- Liquid interface
- Mass
- Conductivity

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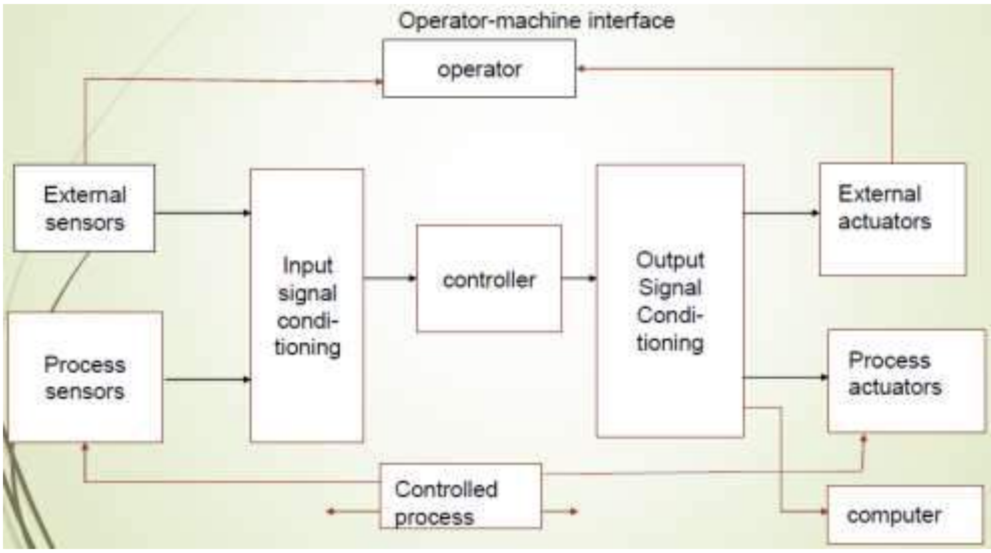
Components of process control system



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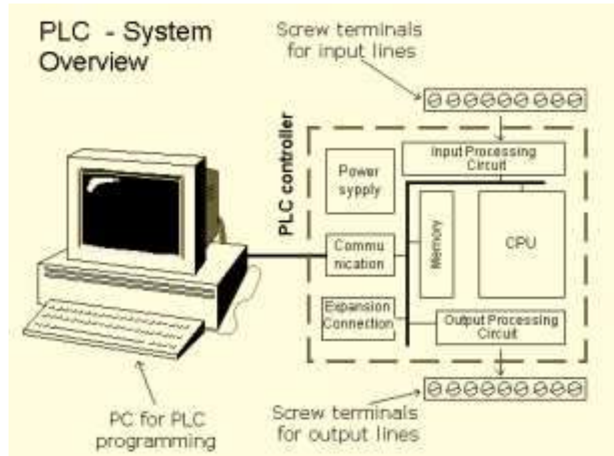
Primary Elements of PCS

- 1.Programmable Control Logic
- Best for controlling machines with several discrete devices such as motor starters, limit switches, etc
- Uses a programmable memory to store instructions and execute specific functions that include on/off control, timing, counting, sequencing, etc
- It is equipped with special input/output interfaces and a control programming language.



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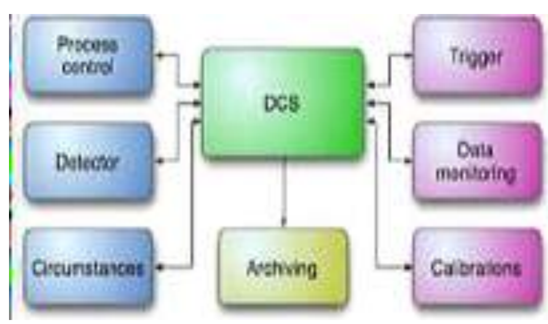
Primary Elements of PCS

- 2. DISTRIBUTED CONTROL SYSTEM
- Central control systems which are good at controlling analog devices.
- In this control elements are distributed throughout the system.
- A hierarchy of controllers is connected by communications networks for command and monitoring.
- Dedicated systems used to control manufacturing processes that are continuous or batch-oriented such as oil refining, petrochemicals, central station power generation, fertilizers etc.



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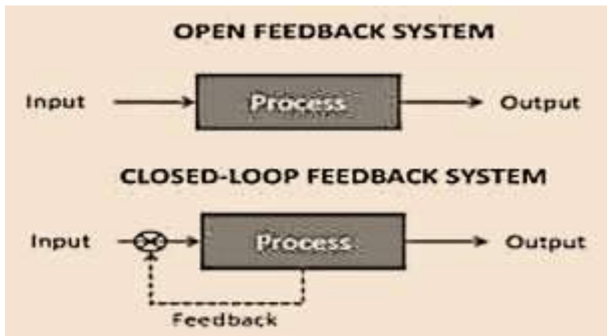
TYPES OF PROCESS CONTROL SYSTEM

- 1. open-loop control system
- 2. closed loop control system



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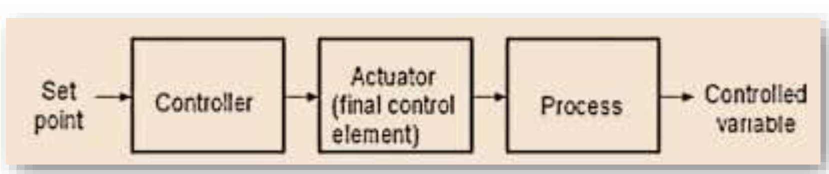
1.Open loop system

- A control action is applied on the output of the system
- It does not receive any feedback signal to control or alter the output status
- Set Point
- Controller
- Actuators
- Process
- Disturbance



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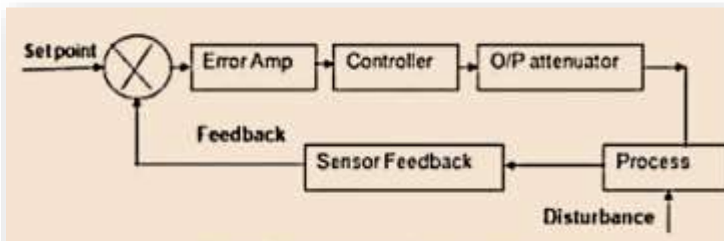
2.Closed loop system

- The output of the process affects the input control signal.
- The system measures the actual output of the process and compares it to the desired output.
- 1. Comparator
- 2. Error Amplifier
- 3. Controller
- 4. Output attenuator
- 5. Sensor Feedback



Block Diagram of the Closed Loop System

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APPLICATIONS AREAS

- Food Production
- Telecommunication and IT sector
- Car wheel manufacturing process
- Waste water treatment
- Continuous filling operation

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FUTURE SCOPE

- Improved process modelling technique, more capable performance monitoring tools will produce the "next" generation of PCS with greater economic benefits and improved reliability.
- Many automation projects will be implemented within the so called SMART CITY.
- In transportation, buildings, and health care will have closer proximity to process control system.

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REFERENCES:

Bequette, B.W., "Process Control Modeling, Design and Simulation", PHI, 2005

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What is meant by artificial intelligence?

- What constitutes an intelligent machine? A dictionary definition of intelligent might be 'endowed with the ability to reason'.
- **The more intelligent we think a person is, the more we consider he or she is able to learn, generalise from this acquired knowledge, be capable of reasoning and able to make predictions by considering what is possible, learning from any mistakes.**
- We can apply the same criteria to a machine: an intelligent machine is one endowed with the ability to reason.
- A central heating system makes decisions about its actions. For example, should the boiler switch on or off as a result of information from a thermostat?, however, considered to be intelligent because it is not capable of reasoning and making decisions under a wide range of conditions. For example, it cannot recognise a pattern in inputs from a thermostat and so make predictions about whether to switch the boiler on or off. It just does what it is told to do. It does not 'think for itself'.

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Self-regulation

- We can consider the closed-loop feedback systems as being self-regulation systems in that they regulate the output of a system to a required value.
- Thus a thermostatically controlled central heating system is used to maintain the room temperature at the value set for the thermostat.
- Such systems cannot, however, be considered intelligent; they merely do what they were told to do

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Perception

- Perception with an intelligent system is the collecting of information using sensors and the organising of the gathered information so that decisions can be made.
- For example, a control system used with a production line might have a video camera to observe components on a conveyor belt.
- The signals received from the camera enable a computed representation of the components to be made so that features can be identified.
- This will contain information about critical elements of the components.
- These can then be compared with representations of the components so that decisions can be made by the control system as to whether the component is correctly assembled or perhaps which component it is.

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Perception

- Then action can be taken by the control system perhaps to reject faulty components or divert particular components to particular boxes.
- Thus, with a mechatronics system, perception involves sensors gathering appropriate information about a system and its environment, decoding it and processing it to give useful information which can be used elsewhere in the system to make decisions.

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Cognition

- Once a machine has collected and organised information, it has to make decisions about what to do as a consequence of the information gathered. This is termed **cognition.**
- Vital to this perception and cognition is pattern recognition. What are the patterns in the data gathered? Humans are very good at pattern recognition.
- Think of a security guard observing television monitors.
- He or she is able to look at the monitors and recognise unusual patterns, e.g. a person where there should be no person, an object having been moved, etc.
- This is the facility required of intelligent machines.
- An autopilot system on an aircraft monitors a lot of information and, on the basis of the patterns perceived in that data, makes decisions as to how to adjust the aircraft controls.

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Cognition

- Machine pattern recognition can be achieved by the machine having a set of patterns in its memory and gathered patterns are then compared with these and a match sought.
- The patterns in its memory may arise from models or a process of training in which data is gathered for a range of objects or situations and these given identification codes.
- For example, for recognizing coins, information may be gathered about diameter and colour.
- Thus a particular one-pound coin might be classified as having a diameter of 2.25 cm and a colour which is a particular degree of redness (it is a bronze coin).
- However, an intelligent machine will need to take account of worn and dirty coins and still be able to recognise the one-pound coin.

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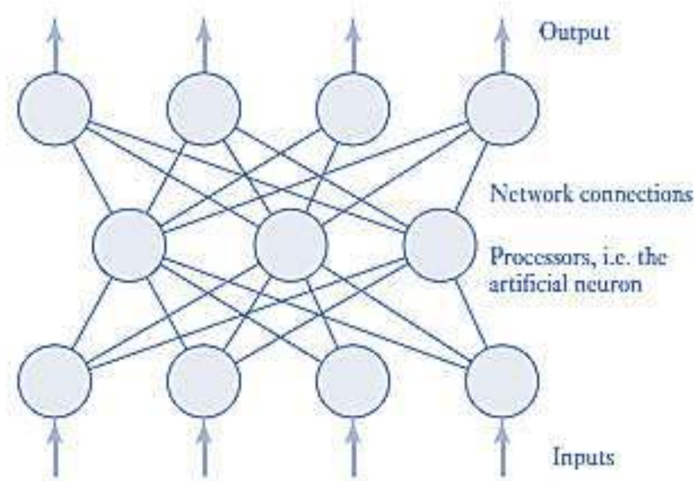
- In the above example of the coins, only two dimensions were considered, namely diameter and colour. In more complex situations there may be many more dimensions.
- The human brain is faced with sorting and classifying multidimensional information and does this using neural networks.
- Artificial neural networks are now being used with intelligent machines. Such networks do not need to be programmed but can learn and generalise from examples and training.
- A neural network is composed of a large number of interconnected processing units, the outputs from some units being inputs to others. Each processor in the network receives information at its inputs, and multiplies each by a weighting factor.

Neural networks

- If operating as AND, it then sums these weighted inputs and gives an output of a 1 if the sum exceeds a certain value or is positive.
- For example, we might have an input of 1 with a weighting factor of -1.5 to give -1.5, another input of 1 with a weighting factor of 1.0 to give 1.0 and a third input of 1 with a weighting factor of 1.0 to give 1.0. The sum of these weighted inputs is thus -1.5 + 1.0 + 1.0 = 0.5 and so an output of 1 if the values are to be positive for an output.
- With these inputs as 1 X -1.5, 0 X 1.0 and 0 X 1.0, the weighted sum is -1.5 and so an output of 0.
- The network can be programmed by learning from examples and so be capable of learning.

Neural networks



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Reasoning

- Reasoning is the process of going from what is known to what is not known. There are a number of mechanisms for carrying out reasoning.

Reasoning mechanisms

- An example of deterministic reasoning is to use the *'if–then'* rule. Thus, we might deduce that *if* a coin has a diameter of 1.25 cm *then* it is a pound coin.
- If the first part of the statement is true then the second part of the statement is true; if it is false then the second part is not true.
- In this form of reasoning we have a true–false situation and it is assumed that there is no default knowledge so that when the deduction is made there are no exceptions.
- Thus, in the above example, we cannot take account of there being a coin from another country with the same diameter.

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Reasoning

- *Non-deterministic reasoning* allows us to make predictions based on probability.
- If you toss a coin, there are two ways it can land: face upwards or face downwards.
- Out of the two ways there is just one way which will give face upwards. Hence, the probability of its landing face upwards is 1 in 2 or 1/2.
- An alternative way of arriving at this value is to toss a coin repeatedly and, in the long run, in 1/2 of the times it will end up with face upwards. Figure (a) shows how we can represent this as a probability tree.
- If we throw a six-sided die then the probability of its landing with a six uppermost is 1/6. Figure (b) shows how we can represent this as a probability tree. On each limb of the tree the probability is written. The chance of a coin landing with either heads or tails is 1. Thus, for a tree, the total probability will be 1.

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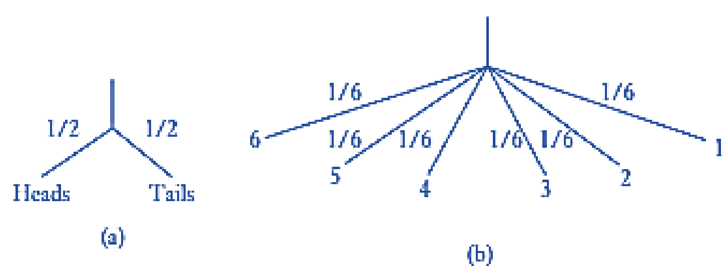
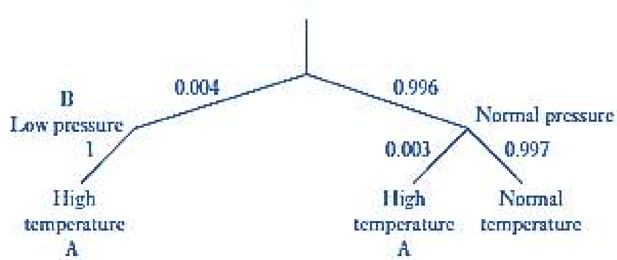
Probability trees: (a) a coin, (b) a die.



A conditional probability tree.



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Reasoning

- Thus in the example of the pound coin we might want to consider that there is a probability of 0.9 of a coin with diameter 1.25 cm being a pound coin.
- In the case of a mechatronics system we might monitor it for, say, 1000 hours and during that time the number of hours that the temperature has been high was found to be 3 hours.
- We can then say that the probability of the temperature being high is 3 /1000 = 0.003.
- Sometimes we might know the probability of an event occurring and want to establish the probability that it will result in some other event.
- Thus, in a mechatronics system we might want to know what are the chances of, say, when a sensor detects a low pressure that the system will overheat, bearing in mind that there could be other reasons for a high temperature.
- We might represent this as the tree shown in Figure..

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Reasoning

- Bayes' rule can be used to solve this problem. This can be stated as

$$p(A|B) = \frac{p(B|A) \times p(A)}{p(B)}$$

- p(AIB) is the probability of A happening given that B has happened, p(BIA) is the probability of B happening given that A has happened, pIAI is the probability of A happening, pIBI is the probability of B happening.
- Thus, if the probability for the system of a high temperature occurring pIAI is 0.003, i.e. in 3 times in 1000 a high temperature occurs, and the probability of there being a low pressure pIBI is 0.004, i.e. in 4 times in 1000 a low pressure occurs, then as we might be certain that the system will overheat if the pressure is low, i.e. p(BIA) is 1, we must have a conditional probability of (1 X 0.0032) /0.004 = 0.75 that the system will overheat when a low pressure is detected.

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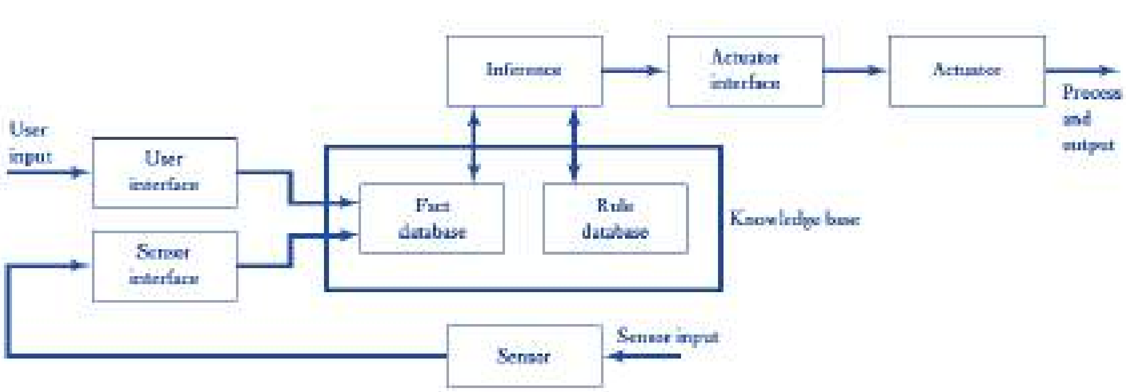
Rule-based reasoning

- At the heart of a rule-based system are a *set of rules*. These, when combined with facts, i.e. in mechatronics this could be inputs from sensors and users, enable inferences to be made which are then used to actuate actuators and control outputs.
- Figure illustrates this sequence. The combination of fact and rule databases is known as the knowledge base for a machine.
- Inference is where the reasoning takes place as a result of the input facts being combined with the rules and decisions made which are then fed to actuators.
- The rules used are often in the form of 'if–then' statements. Thus we might have a group of rules for a central heating system of the form,
- If boiler on; Then pump is on
- If pump on AND room temperature less than 20°C; Then open valve
- If boiler not on; Then pump not on etc.

Rule-based system.

- The fact database with such a system would contain the facts:
- Room temperature , 20°C
- Timer On, Valve Open, Boiler On and Pump On



Fuzzy logic

- The rules can also be in the form of propositions involving probability statements or fuzzy logic.
- Lotfi Zadeh proposed in 1965 a form of reasoning which has become known as fuzzy logic.
- One of its main ideas is that propositions need not be classified as true or false, but their truth or falsehood can be weighted so that it can be classified between the two on a scale.
- A membership function is defined for a value as being whether it is a member of a particular set.
- Thus we might define one set of temperature values as being 0 to 20°C and another as 20 to 40°C. If the temperature is, say, 18°C then membership of the 0 to 20°C set is 1 and that of the 20 to 40°C set 0.

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Fuzzy logic

- However, with fuzzy logic we define overlapping sets, e.g. cold 0 to 20°C, warm 10 to 30°C and hot 20 to 40°C.
- A temperature of 18°C is thus a member of two sets. If the fuzzy set membership functions are defined as shown in Figure, then 18°C has a cold membership of 0.2, a warm membership of 0.8 and a hot membership of 0.
- On the basis of data such as this, rules can be devised to trigger appropriate action. For example, a cold membership of 0.2 might have heating switched on low, but a cold membership of 0.6 might have it switched on high.
- Fuzzy logic is now being used in many commonly encountered products. For example, domestic washing machines can sense the fabric type, dirtiness and load size and adjust the wash cycle accordingly.

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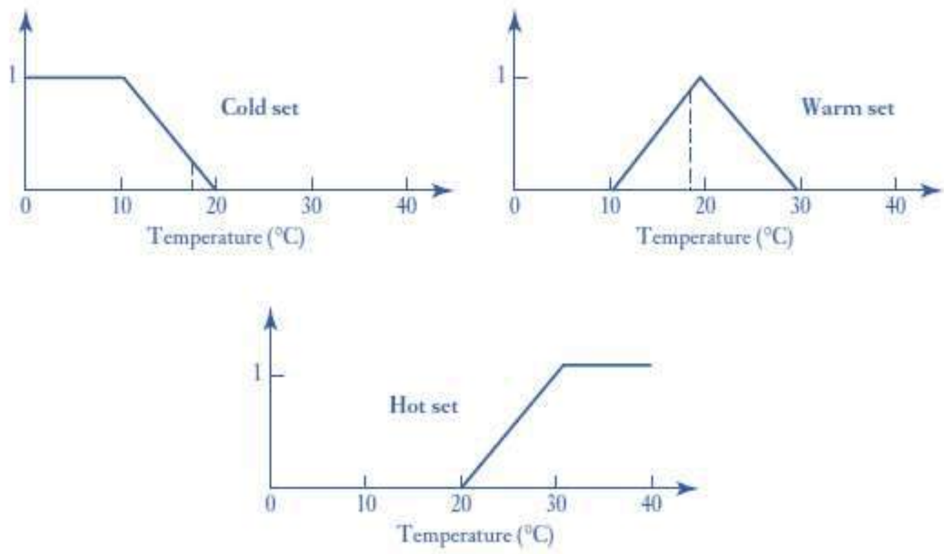
Fuzzy set membership functions.



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Learning

- Machines that can learn and extend their knowledge base have great advantages compared with machines that cannot learn. Learning can be thought of as adapting to the environment based on experience. With machines, learning can be accomplished in a number of ways.
- A simple method of learning is by new data being inputted and accumulated in memory. Machines can also learn by the data they receive being used to modify parameters in the machine.
- Another method of learning that can be used is when reasoning is defined in terms of probabilities and that is to update the probabilities used in the light of what happens. A simple example: Say we have a bag containing 10 coloured balls, all being red apart from one black one. When we first draw a ball from the bag, the probability of pulling the black ball out is 1/10. If we find it is a red ball, then the next time we draw a ball out the probability that it will be a black ball is 1/9. Our 'machine' can learn from the first ball being red by adjusting its probability value for a black ball being drawn. Bayes' rule can be used to update a machine, being now written as

$$p(H|E) = \frac{p(E|H) \times p(H)}{p(E)}$$

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Learning

- where H is the hypothesis that we start with and E the example now encountered. Then p(HIE) is the probability of the hypothesis H being true given that the example E has happened, p(EIH) is the probability of the example E happening given that the hypothesis H is true, p(E) is the probability of an example E happening, p(H) is the probability of the hypothesis H being true. This allows the machine to update the probability of H every time new information comes in.
- Yet another method a machine can learn is from examples. This is when a machine generalises from a set of examples. These may be the result of training with examples being supplied to the machine so that is can build up its rules or as a consequence of events it has encountered.
- Pattern recognition generally involves this form of learning. Thus, given an example of the number 2 in an array of pixels, the machine can learn to recognise the number 2. Neural networks also involve learning by example.
- A machine may also learn by drawing analogies between a problem it has solved before and a new problem.

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At a glance

- An intelligent machine is one endowed with the ability to reason.
- Perception with an intelligent system is the collecting of information using sensors and the organising of the gathered information so that decisions can be made.
- Reasoning is the process of going from what is known to what is not known.
- An example of deterministic reasoning is to use the 'if–then' rule. Non-deterministic reasoning allows us to make predictions based on probability.
- With fuzzy logic propositions need not be classified as true or false, but their truth or falsehood can be weighted so that it can be classified between the two on a scale.
- Learning can be thought of as adapting to the environment based on experience.

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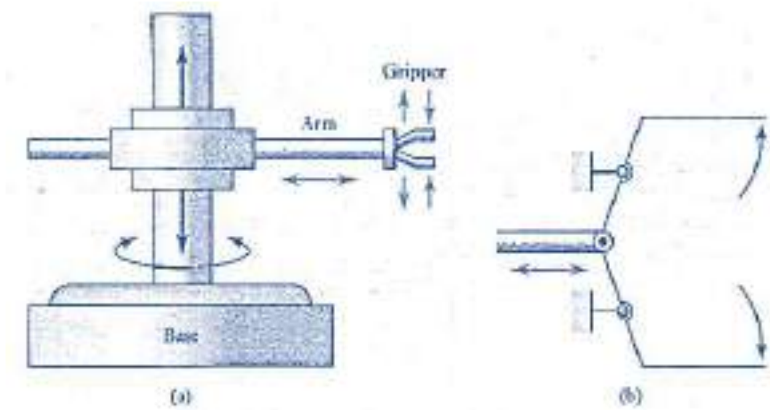
Case studies of mechatronic systems

- Pick and place Robot
- Engine Management system
- Automatic car park barrier

Robot control - A pick-and-place robot

- The robot has three axes about which motion can occur: rotation in a clockwise or anti-clockwise direction of the unit on its base, arm extension or contraction and arm up or down; also the gripper can open or close.
- These movements can be actuated by the use of pneumatic cylinders operated by solenoid-controlled valves with limit switches to indicate when a motion is completed.
- The clockwise rotation of the unit might result from the piston in a cylinder being extended and the anti-clockwise direction by its retraction.
- Likewise the upward movement of the arm might result from the piston in a linear cylinder being extended and the downward motion from it retracting; the extension of the arm by the piston in another cylinder extending and its return movement by the piston retracting.
- The gripper can be opened or closed by the piston in a linear cylinder extending or retracting

(a) Pick-and-place, (b) a gripper.



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A typical program for such a robot might be:

1. Close an upright gripper on a component hanging from an overhead feeder.
2. Contract the arm so that the component is withdrawn from the feeder.
3. Rotate the arm in a horizontal plane so that it points in the direction of the work piece.
4. Extend the arm so that the gripper is over the work piece.
5. Rotate the wrist so that the component hangs downwards from the gripper.
6. Release the gripper so that the component falls into the required position.
7. Rotate the gripper into an upright position.
8. Contract the arm.
9. Rotate the arm to point towards the feeder.
10. Repeat the sequence for the next component.

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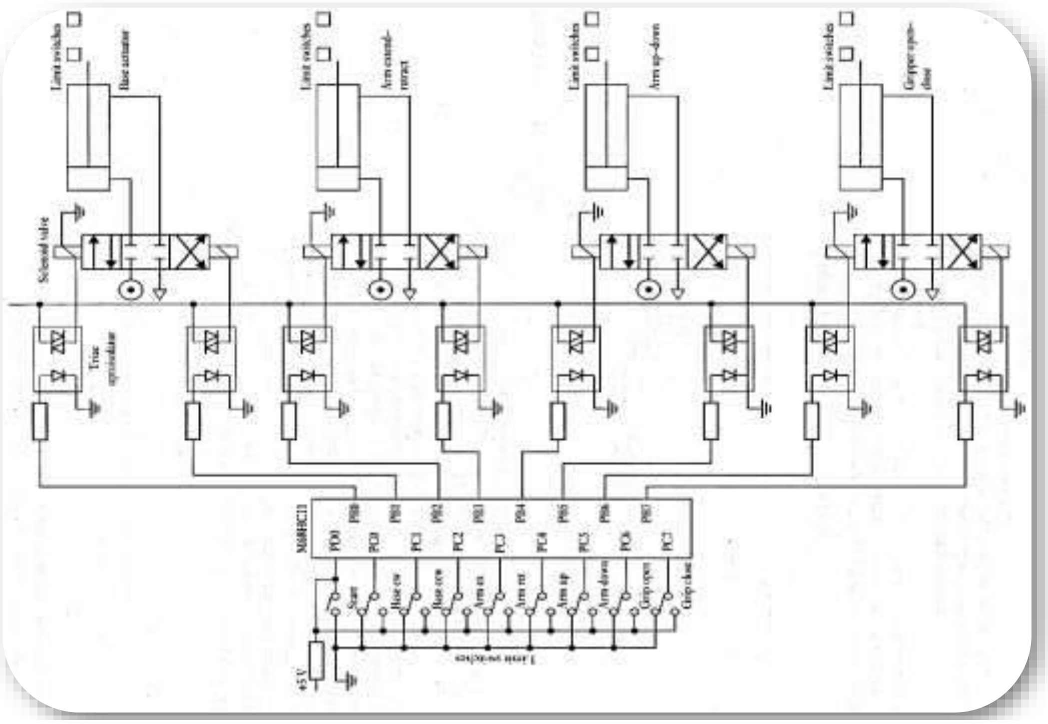

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- Hydraulic and pneumatic rams are widely used to drive robot arms since they can easily be controlled to move limbs at a relatively slow speed, while electric motors would need to operate through a gearbox.
- The positions of the arm and gripper are determined by limit switches. This means that only two positions can be accurately attained with each actuator and the positions cannot be readily changed without physically moving the positions of the switches.
- The arrangement is an open-loop control system. In some applications this may not be a problem.
- However, it is more common to use closed-loop control with the positions of an arm and gripper being monitored by sensors and fed back to be compared in the controller with the positions required.
- When there is a difference from the required positions, the controller operates actuators to reduce the error.
- The angular position of a joint is often monitored by using an encoder, this being capable of high precision.

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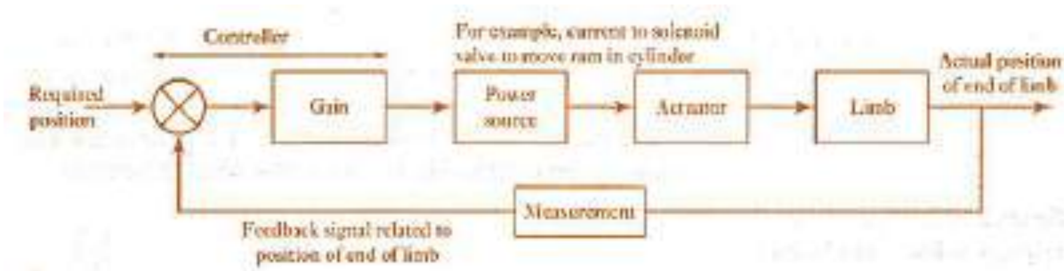
❖ A closed-loop arrangement that might be used for linear motion of a robot arm.



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Autonomous Mobile Robot

- Robots are machines, which perform tasks similar to the human form.
- There basically two types of robot: mobile and stationary.
- Mobile robots have the capability to move around in their environment and are not fixed to one physical location.
- Stationary robots are fixed in one place (such as a robotic arm).
- Mobile robots can be defined as the machines that can roll, walk, climb, and fly under their own automatic control.
- Mobile robots are the focus of a great deal of current research and almost every major university has one or more labs that focus on mobile robot research.
- Mobile robots are also found in industry, military and security environments.
- They also appear as consumer products, for entertainment to perform certain tasks like vacuum cleaning.

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Typical applications of mobile robots are:

- Automated guided vehicles (AGV) in manufacturing factories
- Nuclear accident cleanup
- Planetary exploration
- Mail delivery

- Autonomous robots are robots that can perform desired tasks in unstructured environments without continuous human guidance.
- An autonomous mobile robot knows at least some information about where it is and how to reach various goals and or waypoints along the way. Many kinds of robots have some degree of autonomy.
- Different robots can be autonomous in different ways. A high degree of autonomy is particularly desirable in fields such as space exploration, cleaning floors, mowing lawns, and waste water treatment. "Localization" or knowledge of its current location is calculated by one or more means, using sensors such motor encoders, vision, Stereopsis, lasers and global positioning systems.
- Positioning systems often use triangulation, relative position and/or Monte-Carlo/Markov localization to determine the location and orientation of the platform, from which it can plan a path to its next waypoint or goal.
- One important area of robotics research is to enable the robot to cope with its environment whether this is on land, underwater, in the air, underground, or in space.

- An autonomous mobile robot may also learn or gain new capabilities like adjusting strategies for accomplishing its tasks or adapting to changing surroundings.
- Autonomous robots still require regular maintenance, as do other machines.
- A fully autonomous mobile robot has the ability to:
  - gain information about the environment
  - work for an extended period without human intervention
  - move either all or part of itself throughout its operating environment without human assistance
  - avoid situations that are harmful to people, property, or itself unless those are part of its design specifications.

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Elements of autonomous mobile robot

- There are many components that come together to create a fully autonomous mobile robot.
- These elements are fundamental for autonomous mobile robot, regardless of the application domain.

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Locomotion

- At the lowest level is the locomotion capability of the robot's physical platform. Locomotion is the act of moving from place to place.
- Locomotion relies on the physical interaction between vehicle and its environment.
- It is concerned with the interaction forces, along with the mechanisms and actuators that generate them.
- The different types of locomotion are:
  - 1. Legged Locomotion
  - 2. Snake Locomotion
  - 3. Free-Floating Motion
  - 4. Wheeled Locomotion

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Sensory perception

- The next higher level is sensory perception.
- The robots have to sense what is in their environment in order to navigate in it, detect hazards, and identify goals such as exits and simulated victims.
- Sensor fusion is an important capability, as no single sensor will be able to identify or classify all aspects of the arenas.
- The simulated victims, analogous to the cheese for the mouse in a maze, provide incentive for the robots to investigate every corner of the arena.
- These simulated victims are represented by a collection of different sensory signatures.
- They have shape and colour characteristics that look like human figures and clothing. They emit a consistent heat signature, just as humans do.
- Some simulated victims have motions such as waving, and some emit sounds such as low moans, calls for help, or simple tapping.
- Any or all of these signs of life should be detected, identified, investigated further, and if confirmed as a victim, the location should be mapped.

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- For obstacle detection, the sensors need to see far and only a logic response is required.
- Common sensors used in mobile robots for detecting obstacles are the digital infrared (IR) sensor.
- Line tracing is normally required to distinguish between a white surface and a black one in order to provide guidance by the demarcation.
- For direction monitoring, the obvious sensor to use is a compass, which echoes the bearing of the mobile robot in real time.
- Proximity sensors are used to sense the presence of an object close to a mechatronics device.

- The arenas are designed to pose challenges to typical robotic navigation sensors.
- For example, acoustic-absorbing materials confuse sonar sensors.
- Laser sensors have difficulty with clear materials such as windows.
- Highly regular stripped wallpaper and other types of materials pose challenges to stereo vision algorithms.
- Compliant objects that may visually look like obstacles require the robots to apply tactile sensors or other means of verifying that they can indeed push them aside e.g. curtains in doorways

Knowledge representation

- The knowledge representation is the next level.
- It encompasses the robot's ability to model the world, using both a priori information (such as might be needed to recognize certain objects in an environment) and newly acquired information (obtained through sensing the environment as it explores).
- In the mobile robot applications, the robots are expected to communicate to humans the location of victims and hazards.
- Ideally, they would be providing humans with a map of the environment they have explored, with the simulated victim and hazard location clearly identified.
- The environment that the robots operate in is three-dimensions, hence they should be able to map in three-dimensions. The arenas may change dynamically during operation time (as a building may further collapse while rescuers are searching victims).
- Therefore, the ability to create, maintain, and use, maps to find alternate routes is important.

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Planning

- The planning or behavior generation elements of the robots build on the knowledge representation and the sensing elements.
- The robots must be able to navigate around obstacles, make progress in their mission (that is to explore as much possible of the arenas and find simulated victims), take into account time as a limiting resource, and make time critical decisions and tradeoffs.
- The planner should make use of an internal map generated by the robot and find alternative routes to exit the arenas that may be quicker or avoid areas that have become no longer traversable.

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Autonomy

- The overall autonomy of the robot is the next element to be evaluated. The robots are designed to operate with humans.
- The level of interaction may vary significantly, depending on the robot's design and capabilities, or on the circumstances.
- The intent is to allow for "mixed initiative" modes to limit human interaction and maximize the effectiveness and efficiency of the collaboration between robot and humans.
- Robots may communicate back to humans to request decisions, but should provide the human with meaningful communication of the situation.
- Pure tele-operation is not a desirable mode for the robot's operation. The human should provide the robot with high level commands, such as "go to the room on the left" rather that joystick the robot in that direction.

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Collaboration

- The final element to be evaluated in the robot's overall capabilities is collaboration among teams of robots.
- Multiple robots, either homogeneous or heterogeneous in design and capabilities, should be able to more quickly explore the arenas and find victims.
- The issues to be examined are how effectively they maximize coverage given multiple robots, whether redundancy is an advantage, and whether or how they communicate among themselves to assign responsibilities.
- The human may make the decisions about assignments for each robot a priori, but that would not be as desirable as seeing the robots jointly decide how to attack the problem when confronted in the field.

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Factors to be considered while designing a mobile robot

1. Objects to be handled
- Part dimensions
- Mass
- Pre- and post-processing geometry
- Geometrical tolerances
- Potential for part damage

2. Actuators
- Mechanical
- Vacuum
- Magnet

3. Power source
- Electrical
- Pneumatic
- Hydraulic
- Mechanical

4. Range of gripping force
- Object mass
- Friction or nested grip
- Coefficient of friction between gripper and part
- Maximum accelerations during motion

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5. Positioning
- Gripper Length
- Robot Accuracy And Repeatability
- Part Tolerances

6. Maintenance
- Number Of Cycles Required
- Use Of Separate Wear Components
- Design For Maintainability

7. Environment
- Temperature
- Humidity
- Dirt, Corrosives, Etc

8. Temperature Protection
- Heat Shields
- Longer Fingers
- Separate Cooling System
- Heat Resistant Materials

9. Materials
- Strong, Rigid, Durable
- Fatigue Strength
- Cost And Ease Of Fabrication
- Coefficient Of Friction
- Suitable For Environment

10. Other points
- Interchangeable fingers
- Design standards
- Use of mounting plate on robot
- Gripper flexible enough to accommodate
- Product design change

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Case Study 2: Engine Management System [EMS]

- Engine management system is, now-a-days, used in many of the modern cars such as Benz, Mitsubishi, and Toyota etc.
- This system uses many electronic control system involving micro controllers.
- The objective of the system being to ensure that the engine is operated at its optimum settings.
- The system consists of many sensors for observing vehicle speed, engine temperature, oil and fuel pressure, airflow etc.
- These sensors are supplying input signals to the micro controller after suitable signal conditioning and providing output signals via drivers to actuate corresponding actuators.
- A single cylinder engine consists of some of these elements in relation to an engine. The engine sensor is an inductive type. It consists of a coil and sensor wheel.

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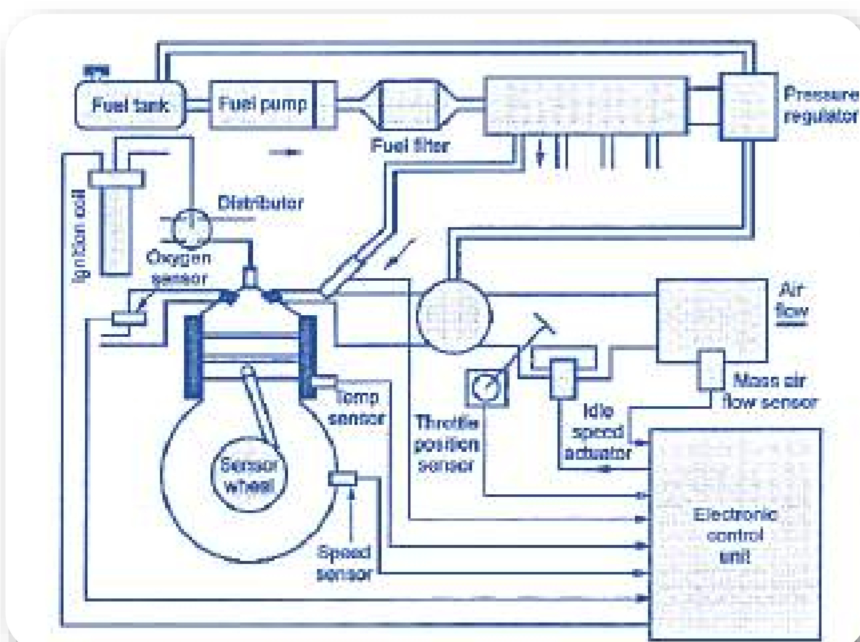
Engine Management System with sensors and Actuators



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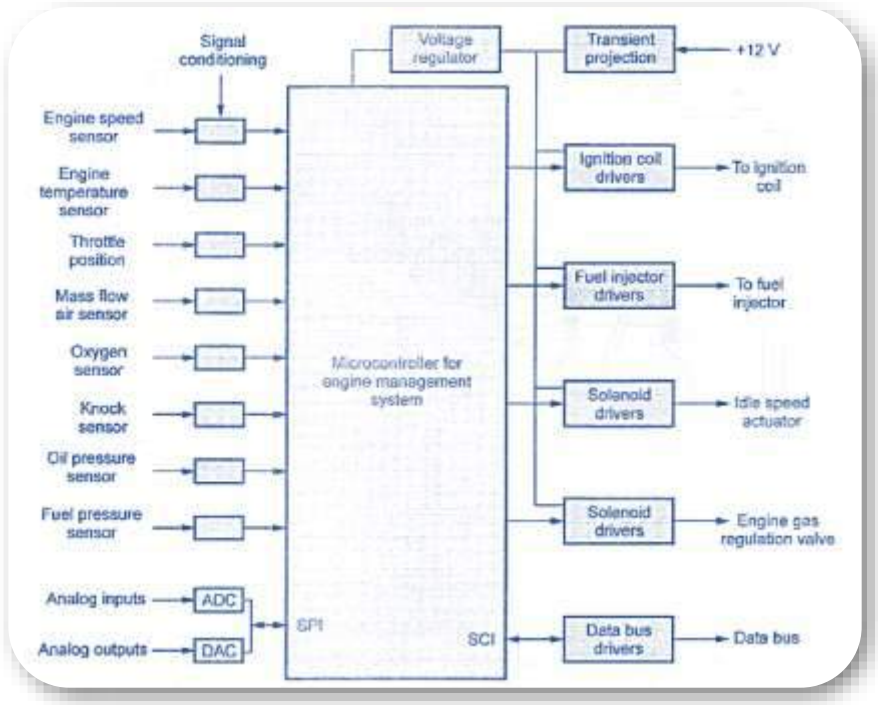
Block Diagram of Engine Management System [EMS]



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Engine Management System [EMS] contd...

- The inductance of the coil changes as the teeth of the sensor wheel pass it and so results in an oscillating voltage.
- The engine temperature sensor is generally thermocouple which is made of bimetallic strip or a thermistor.
- The resistance of the thermistor changes with change in engine temperature this results in voltage variation.
- Hot wire anemometer is used as a sensor for measuring mass airflow rate.
- The basic principle is that the heated wire will be cooled as air passes over it.
- The amount of cooling is depending on the mass rate of flow.
- The oil and pressure sensors are diaphragm type sensors.

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Engine Management System [EMS] contd...

- According to the pressure variation, the diaphragm may contract or expand and activates strain gauges which produce voltage variation in the circuit.
- The oxygen sensor is usually a close end tube which is made of Zirconium oxide with porous platinum electrode on the inner and outer Surfaces
- The sensor becomes permeable to oxygen ions at about 300°C.
- This results in generation of voltage between the electrodes.
- The various drivers such as fuel injector drivers, ignition coil drivers.
- Solenoid drivers and used to actuate actuation according to the signal by various sensors.
- Analog signals given by sensors are converted into digital signal by using analog to digital converters (ADC) and sent it to micro controllers.
- The various output digital signals are converted into analog signals by DAC (i.e., Digital to Analog Converter) and shown in various recorders or meters

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Case Study 3 : Automatic Car Park System

- Consider an automatic car park system with barriers operated by coin inserts.
- The system uses a PLC for its operation.
- There are two barriers used namely in barrier and out barrier.
- In barrier is used to open when the coin is inserted while out barrier open when the car is detected in front of it.
- It consists of a barrier which is pivoted at one end, two Solenoid valves A and B and a piston cylinder arrangement.
- A connecting rod connects piston and barrier
- Solenoid valves are used to control the movement of the piston.
- Solenoid A is used to move the piston upward in turn barrier where as solenoid B is used to move the piston downward.
- Limit switches are used to detect the foremost position of the barrier.
- When current flows through solenoid A, the, piston in the cylinder moves upward and causes the barrier to rotate about its pivot and raises to let a car through.
- When the barrier hits the limit switch, it will turns on the timer 1 give a required time delay.
- After that time delay, the solenoid B activated which brings the barrier downward by operating piston in the cylinder.
- This principle is used for both the barriers.

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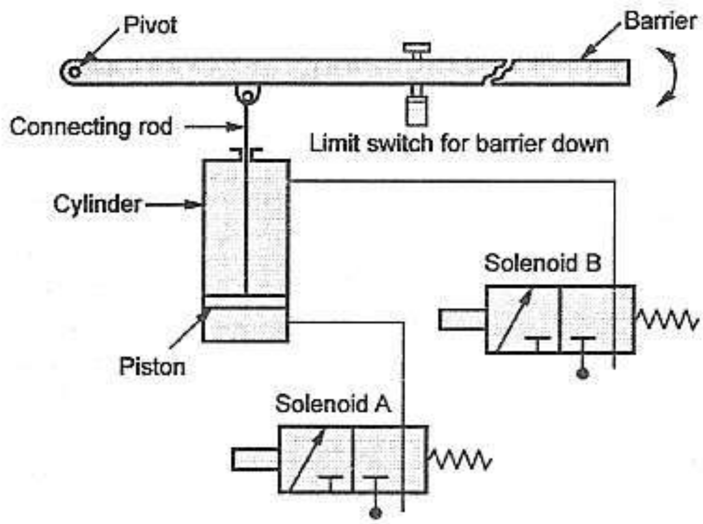
Automatic Car Park Barrier System



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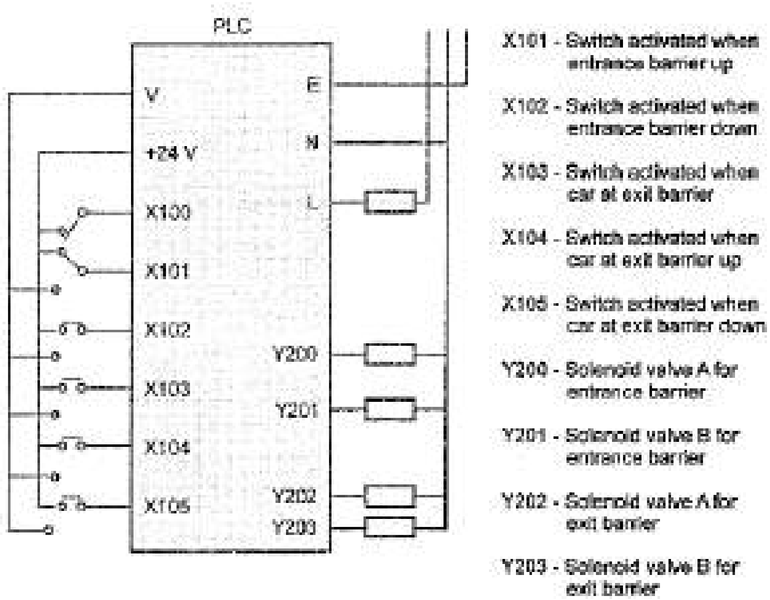
PLC arrangement for Automatic Car Park Barrier System



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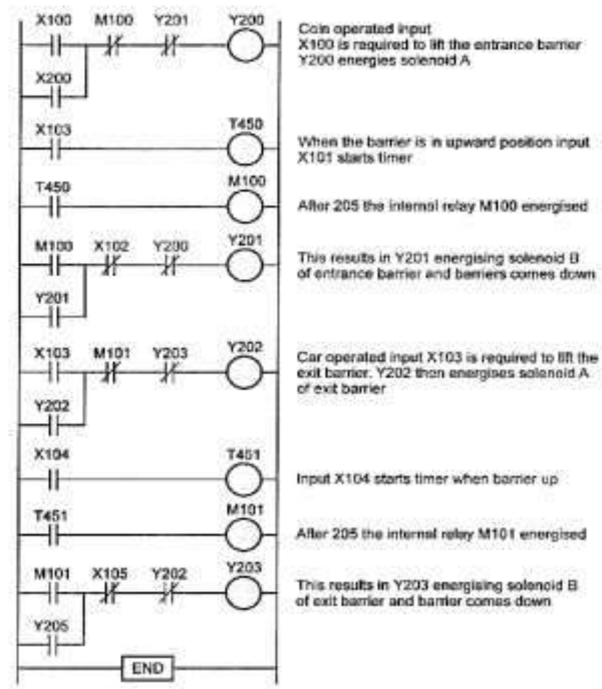
PLC Ladder for Automatic Car Park Barrier System



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MICRO SENSORS

- Presently, there is a trend to make sensors smaller and smaller. Initial stages show an evolution from a single sensor element to an intelligent sensor system with extremely small dimensions.
- The so-called smart (or integrated) sensing devices can be developed by integrating sensor components with those for signal processing.
- This integration also decreases the noise that is often created by the transmission of signals to an external data processing unit.
- Thus it will be possible to measure and evaluate for a certain task all interesting parameters at one place and at one time.

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MICRO SENSORS

- An important step toward the further development of micro sensors is the conception and design of intelligent electronic signal processors.
- This will lead to advanced distributed sensor systems in which noisy sensor signals, resulting from cross-talk or insufficient selectivity, can be successfully evaluated.
- The signal processing system of humans is very advanced; sensor signals are received over the nervous system and transferred to the brain which reliably evaluates them by a natural parallel computing system

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MICRO SENSORS

- Sensor & microsensor
- Force and pressure microsensors
- Position and speed microsensors
- Acceleration microsensors
- Chemical microsensors
- Biosensors
- Temperature sensors

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Force and Pressure Micro sensors

- Due to their simple construction and wide applicability, mechanical sensors play the most important part in miniaturization.
- Pressure micro sensors were the first ones developed and used by industry. Miniaturized pressure sensors must be inexpensive and have a high resolution, accuracy, linearity and stability.
- Presently, silicon-based pressure sensors are most often used; they can easily be integrated with their signal processing electronics on one chip.
- Their advantages include low production costs, high sensitivity and low hysteresis.

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Force and Pressure Micro sensors

- Pressure is most often measured via a thin membrane which deflects when pressure is applied.
- Either the deflection of the membrane or its change in resonance frequency is measured; both of these values are proportional to the pressure applied.
- These mechanical changes are transformed into electric signals.
- Membranes can be manufactured by bulk micromachining of a (100) silicon substrate, whereby the membrane is produced with one of the etch stop techniques.
- Pressure sensors usually employ capacitive or piezo resistive measuring principles.

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Classification of sensors

Form of signal	Measurands
Thermal	Temperature, heat, heat flow, entropy, heat capacity etc.
Radiation	Gamma rays, X-rays, ultra-violet, visible and infrared light, micro-waves, radio waves etc.
Mechanical	Displacement, velocity, acceleration, force, pressure, mass flow, acoustic wavelength and amplitude etc.
Magnetic	Magnetic field, flux, magnetic moment, magnetisation, magnetic permeability etc.
Chemical	Humidity, pH level and ions, gas concentration, toxic and flammable materials, concentration of vapours and odours, pollutants etc.
Biological	Sugars, proteins, hormones, antigens etc.

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Trends in sensor technology

- Miniaturization
- Integration (sensor, signal processing and actuator)
  - sensor with signal processing circuits for linearising sensor output, etc.
  - sensor with built-in actuator for automatic calibration, change of sensitivity etc.
- Sensor arrays
  - one-function units (to improve reliability)
  - multiple-function units

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Microsensors

- 1995 global sensor market 6 billion 25 % from MEMS based devices
- Annual increase in the market volume 20%
- Why microsensors
  - lower manufacturing cost (mass-production, less materials)
  - wider exploitation of IC technology (integration)
  - wider applicability to sensor arrays
  - lower weight (greater portability)

Applications

- Automotive industry
  - average electronics content of a car is today 20%
  - to increase safety (air bag control, ABS), reduce fuel consumption and pollution
- Medical applications
  - measurement of physical/chemical parameters of blood (temperature, pressure, pH)
  - integrated sensors in catheters
- Consumer electronics
- Environmental applications
  - determination of concentration of substances (carbon monoxide, heavy metals, etc.)
- Food industry - contaminants and impurities
- Process industry
- Robotics - distance, acceleration, force, pressure, temperature

Pressure sensors

- First microsensors developed and used by industry
  - piezoresistive pressure sensor to reduce fuel consumption by a tight control of the ratio between air and fuel
  - disposable blood-pressure sensor to monitor the status of the patient during operation
- Low production costs, high sensitivity and low hysteresis
- Commercial products are usually either piezoresistive or capacitive

Pressure sensors: operation principles

- Membrane sensors
  - deflection of the membrane
  - change in the resonance frequency
- Planar comb structures
- Optical methods (Mach-Zehnder interferometer)

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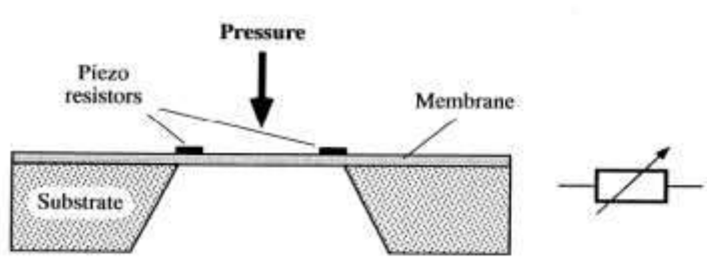
Piezoresistive pressure sensor

- Piezoresistors integrated in the membrane
- Pressure deflects the membrane
- Resistance changes proportional to deflection and thus to pressure
- Resistance change measured with Wheatstone bridge



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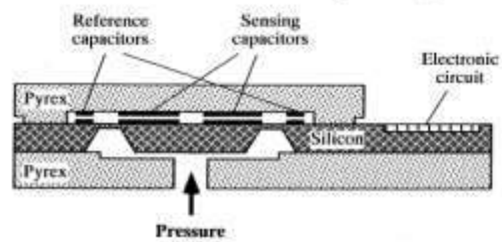
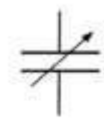
Capacitive membrane pressure sensor

- Membrane deflects when pressure is applied
  - Distance between the electrodes changes
  - Capacitance changes
- Capacitive sensors have no hysteresis
  - better long-term stability and
  - higher sensitivity but
  - higher production costs

Chip dimensions: 8.4 mm x 6.2 mm
Fabrication: anisotropic etching





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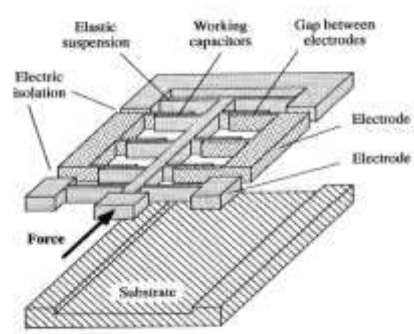
Capacitive pressure sensor, based on comb structure

- Utilizes parallel comb structure
- Force is applied parallel to the sensor surface
- Force is transformed into displacement => change in capacitance
- On one side capacitance increases and on the other side decreases => higher linearity and sensitivity



$$V_O = V_I \frac{C_1 - C_2}{C_1 + C_2}$$

Fabrication: anisotropic etching

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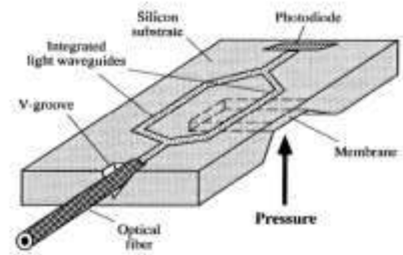
Mach-Zehnder interferometer

- Laser light brought into the sensor by optical fiber
- Light is split to two beams
- One light beam crosses a micromembrane which is deformed by pressure
- The deformation changes light properties
- The beams are combined and brought a photodiode
- Different propagation speeds result in phase shift



Chip size: 0.3 mm x 5 mm
Output: 14 µV/mbar

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Position and speed microsensors

- Applications
  - Automobiles
  - Robots
- Medical instruments
  - Contact-free optical and magnetic methods

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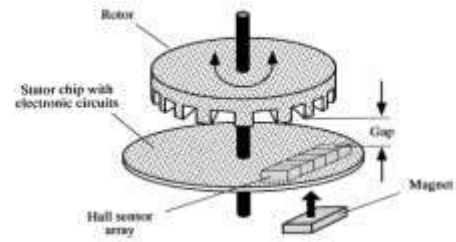
Magnetic sensor to measure angular displacement

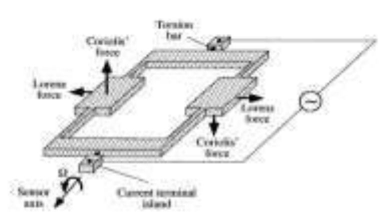
- Measurement of joint angle in robotics
- Hall sensor based measurement of angular displacement
  - Rotor with a row of teeth
  - Stator contains Hall sensors
  - Permanent magnet located under the sensors
  - Teeth passing by a Hall sensor change magnetic field



Length: 4 mm
Resolution: 0.028 degrees

Capacitive angular speed sensor

- The fork arrangement is used as a resonator
- The resonator starts to oscillate when magnetic field and alternating current are applied (Lorentz force)
- The amplitude of the swing angle is detected by the capacitance change between movable and fixed electrodes



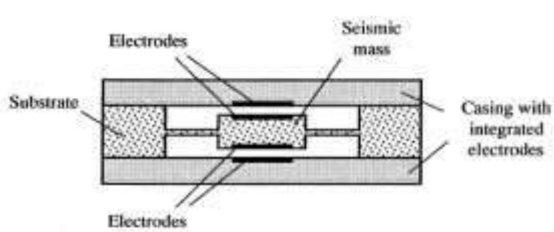
Size: 20 mm x 20 mm
Sensitivity: 0.5 mV s/deg

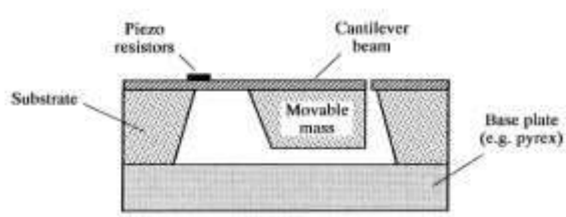
Acceleration microsensors

- Have mostly been used in automotive industry
- Usually detected with capacitive and piezoresistive methods
- An elastic cantilever where a mass is attached is mostly used
- Under acceleration mass displaces the cantilever
- Deflection of the cantilever is detected
- By increasing the mass sensitivity can be increased

Acceleration microsensors

Examples of piezoresistive and capacitive principles





A capacitive accelerometer by Analog Devices

- A mass-produced capacitive accelerometer was presented in 1991
- Microelectronic circuits for signal preamplification, temperature compensation and system self-test were integrated into the sensor
- One of the first successful commercial accelerometers
- Currently used in airbag systems
- Range ±5 g, resolution 0.005 g

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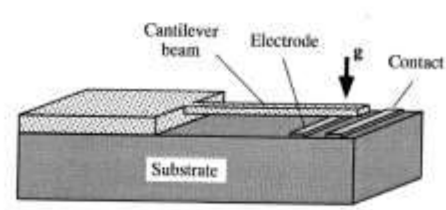
Capacitive cantilever microsensor

- Sensor consists of cantilevers acting as one electrode, an electrode strip and a contact strip
- Sawtooth voltage applied to gradually increase the electrostatic force
- Finally cantilever touches the contact strip
- Acceleration affects the magnitude of the voltage that is required for



Cantilever length: 120 - 500 μm
Sensitivity: 0.6 - 100 mV/g
Fabrication: dry etching

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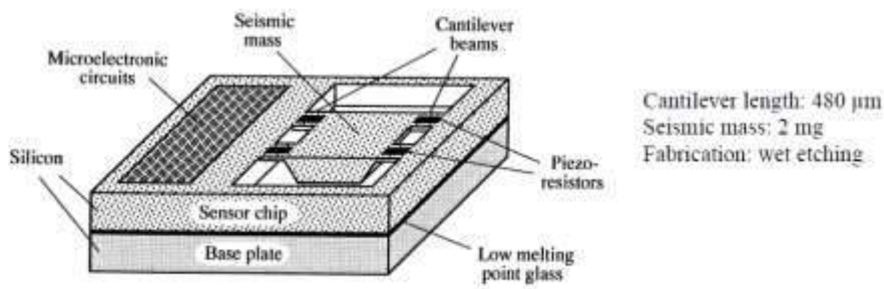
Piezoresistive microsensor with oil damping

- Sensor consists of cantilever beams, a seismic mass and oil.
- Oil dampens the resonance of the suspended mass



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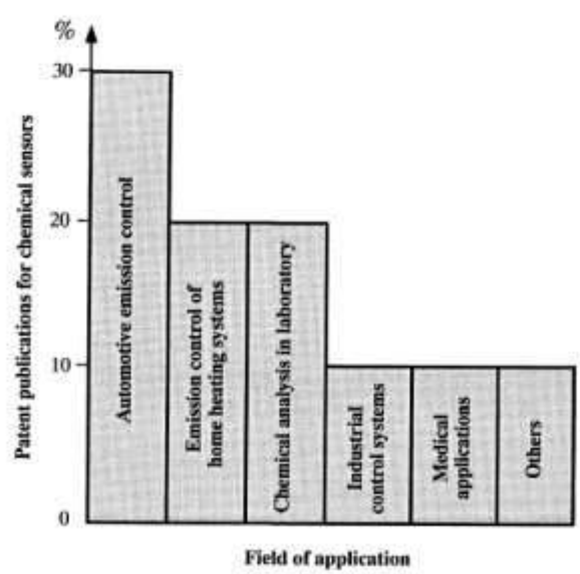
Chemical sensors

- Detect presence or concentration of a chemical substance
- Applications
  - medical diagnostics
  - nutritional science
  - environmental protection
  - automobile industry
- About 60 % of chemical sensors are gas sensors



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Chemical sensors

- Research trends (in addition to the development of sensor units):
  - integration of sensors into measurement systems (signal processing)
  - integration of several types of sensors (to test n concentrations)
  - microsystems with several identical sensors (local analysis of a substance, distribution of a parameter over a certain domain)
- Sensor principles
  - potentiometer principle in connection with FET
  - acoustic sensors
  - optical sensors

Objectives of microsensors:
- small and inexpensive
- mass-produced
- accurate and robust
- use only small amount of reagents
- short response times

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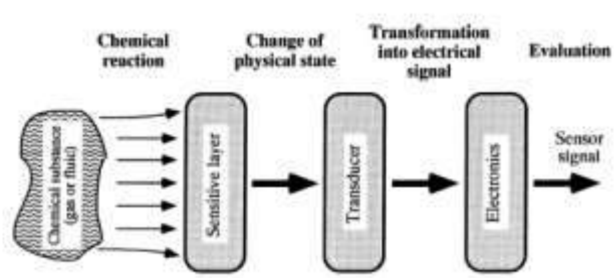
Structure of a chemical sensor system

- A sensitive layer is in contact with the substance
- Chemical reaction occurs on the sensitive layer
- Due to the reaction physical, optical, acoustic or dielectric properties are changed
- Transducer transforms the signal into electrical form

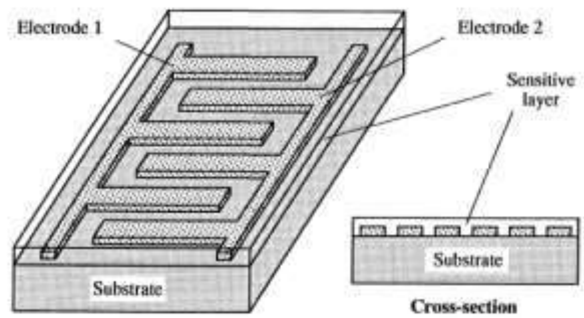


100

Operation principle of interdigital transducer sensors

- Interdigital transducers using capacitive measurement are often used in chemical sensors
- The capacitance can be adjusted by changing the dielectric properties of the sensitive layer
- E.g. resistance of SnO_2 sensitive layer changes when it interacts with certain substances

$$F_y = \frac{1}{2}\varepsilon A\left(\frac{U}{d}\right)^2$$



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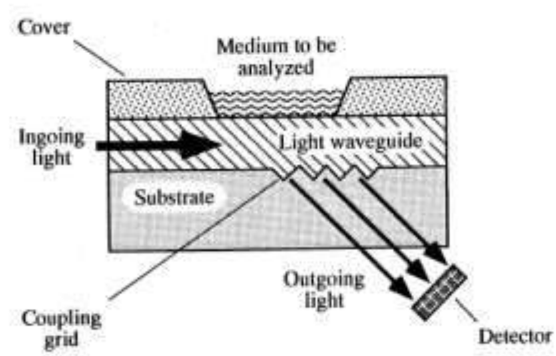
Optical sensor principle

- Optical sensors are inexpensive, easy to sterilize, can handle small samples and are highly sensitive
- Coupling grid detector
  - substance to be analyzed is in direct contact with the waveguide
  - depending on the concentration of the substance its index of refraction varies => amount of light striking the sensor depends on the concentration



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Biosensors

- Measurement principle is similar as with chemical sensors
- Sensitive layer is biologically sensitive, containing e.g. enzymes or antibodies
- Interaction between the molecules of the bioelement and the molecules of the substance changes a physical or chemical parameter
- Parameter change is converted into electrical signal
- Signal represents concentration to be measured
- **Applications**
- Biological and nutritional research to detect e.g. heavy metals or allergens
- Medical applications - patient data recording for correct and quick diagnosis during surgery
- Integration of biosensors with microfluidic components => very small analyzers
- **Difficulties**
- immobilization of proteins
- proteins are not stable for a very long time

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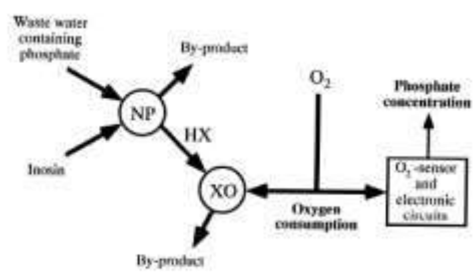
Metabolism sensors

- Uses biosensitive enzymes to catalyze a chemical reaction
- Phosphate measurement
  - enzyme NP detects phosphate and triggers chemical reaction
  - one product of the reaction HX is transformed into XO in another chemical reaction after consuming oxygen
  - amount of oxygen can be measured using a chemical sensor
  - phosphate concentration is proportional to the amount of consumed oxygen



Nucleoside phosphorylase (NP)
hypoxanthine (XP)
xanthine oxidase (XO)

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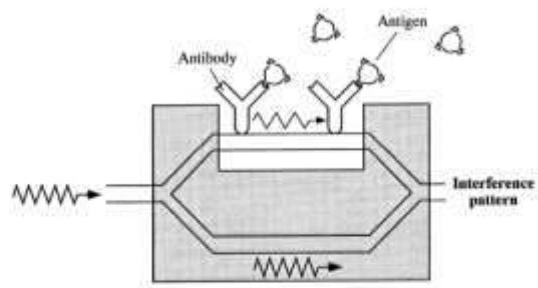
Immuno-sensors

- Antibody is the biosensitive element
- Immobilized antibody molecules bond with antigen molecules in the substance (lock and key)
- The concentration of antigens can be measured using for example interferometric method (light intensity changes)



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Temperature sensors

- Important role in monitoring systems
  - process industry
  - medicine
  - environmental protection
- Heating and air conditioning systems
- Indirect measurement of other parameters, e.g. in flow sensors
- Error compensation for temperature dependent sensors and actuators

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Wireless Surveillance Balloon

- Surveillance generally refers to monitoring or observing a person or a group of people from a certain distance, frequently, although not necessarily comprising the use of electronic equipment and / or other technological devices.
- Surveillance equipment is typically used in warfare and / or in counter - insurgency operations to monitor the activities of an enemy from a distance, thereby reducing the risk of confrontations which may result in injury, and possible death, to friendly personnel.
- Surveillance equipment may also be used to monitor hazardous situations from a distance, such as for example, as may be associated with chemical hazards, explosive hazards, and the like, so as to provide advance information to personnel responsible for controlling the hazards.
- Other applications may include search and rescue missions, police operations, and homeland security activities.

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Wireless Surveillance Balloon

- With the ever growing threat of terrorism the needs for a more economic method of surveillance to constantly monitor large areas of concern keeps on growing.
- Conventional surveillance systems, both wired and wireless, becomes uneconomical when the subject area is a large open land mass where an overall broad perspective view is important. It is in such domains of surveillance that wireless surveillance balloon becomes both necessary and economical.
- Wireless surveillance balloon is an Aerostats or Tethered balloons which carry surveillance cameras high-up in the air to obtain a broader perspective view of the target area. It is useful for both military and civil operation.
- These surveillance balloons are essentially robots capable of operating on their own when necessary. They also are able to operate in an intelligent cluster where together they can accomplish a goal by coordinating their efforts thus they become a socially interactive multiple robot system.

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Wireless Surveillance Balloon

- Aerostats, also sometimes referred to as captive balloons are tethered lighter-than air (LTA) platforms filled with either Helium or Hydrogen which helps them stay aloft in air due to buoyancy.
- Their relative cheapness and ease of maintenance makes them an attractive option to be considered as a platform for carrying surveillance camera.

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Need for wireless surveillance balloon:

- As the threat of terrorism grows, a common prevailing need of surveillance is to monitor large area of concern in the civil sector with a general overall perspective rather than acquiring pin-point detail.
- Take for example the Indo - pak border which is one of the longest high - tension border in the world. The border stretching 3323 km is constantly under vigil and major sectors like the Jammu sector in kashmir and Gujarat sector have already been fenced.
- However, despite the fencing, the infiltration still continues, Any attempt to have a round-the -clock constant video surveillance through cameras mounted on poles is unfeasible because of elaborate wiring and network requirements.
- On the other hand, cameras mounted aerostats can cover a much larger area making the whole idea feasible.

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Need for wireless surveillance balloon:

- The major advantage of aerial surveillance using wireless surveillance balloon is to provide a broad perspective view of the area from air, which leads to increased situational awareness and hence faster and more efficient surveillance.
- The concept of broader perspective becomes obvious in some situations like border and coastal surveillance.
- Another military use of wireless surveillance balloon is during battles, where an aerostat system can provide increased situational awareness and battle field knowledge allowing them to properly plan their moves with respect to their enemy.
- Such a system needs to be cheap and take less time for deployment.

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Elements of wireless surveillance balloon:

- Today's surveillance balloons are relatively small in comparison, and typically may include a payload with a video camera, a thermal imager, a laser range finder and or other sophisticated equipment adapted to record video images, and sometimes audio, and to transmit the image (and audio) back to a monitoring station.
- Furthermore, in some cases the surveillance balloons may be robotic adapted to operate, including move, without receiving control input from the monitoring station.
- Balloons may act individually or alternately clusters may act robotically without command input at times. Video surveillance information is preprocessed and then sent via wireless communications links.
- Batteries and / or gas cylinders may be selectively jettisoned to facilitate vertical movement.
- Balloons may optionally have thruster mechanisms to facilitate lateral movement which may in some embodiments be powered by a source of combustible gas which is also used for providing lift.

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Elements of wireless surveillance balloon:

- Various essential elements of a wireless surveillance balloon are listed below:
- One or more sensor assemblies which may one or more sensors selected from the group consisting of:
  - a) Image sensors
  - b) Thermal sensors
  - c) Audio sensors
  - d) Location sensors
  - e) Altitude sensors
  - f) Compass and
  - g) Motion sensors.

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Elements of wireless surveillance balloon:

- One or more communication modules, located in the housing and/or the surveillance payload, which communication modules may be adapted to transmit data collected by the sensors to one or more user interfaces and/or one or more remote monitoring stations;
- An illumination source, which illumination source may reside in the surveillance payload and/or the housing;
- An anchor line which may be adapted to anchor the deployable surveillance balloon to the housing after deployment;
- A lighter-then-air (LTA) gas source which may be adapted to provide lighter-than air gas for inflation of the surveillance balloon during and/or after deployment;
- Ancillary components which may facilitate the operation of the system, such as power source, gaslines, wires, control circuitry, databases, displays, regulators, latches, springs, levels, gaskets, etc.

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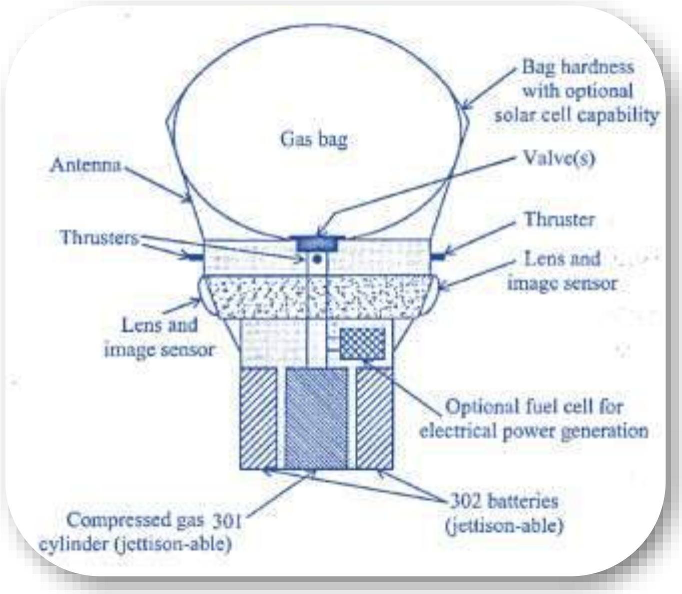
Elements of wireless surveillance balloon:



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Applications of wireless surveillance balloon:

- Border security in military,
- Enhancing battlefield situational awareness,
- Coastal surveillance,
- Platform for mounting telecommunication, television, radio transmitters and broadband equipment.
- Aerial platform for scientific instrument testing,
- Aerial platform for weather prediction instruments,
- Terrestrial mapping
- For holding up large-array radio - telescopes.

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Advantages of wireless surveillance balloon:

- Certain key advantages that wireless surveillance balloon enjoy are:
- Cheaper
- Safe
- Rapid deployment in rural or non - urban areas allows for quick and inexpensive establishment of communication networks.
- Easy to deploy and maintain.
- Require minimum crew - training for handling making it easier to incorporate into the already established surveillance infrastructure.
- Provides a broad perspective / view of target area for video surveillance.
- Aerostats can be used as a platform for radars, IR / optical sensors, and other sensor equipments.
- Can be used as cheap low - altitude telecommunication relay platforms for purposes like broadband communication and wide area networks (WAN). Bigger more sophisticated aerostats flying at an altitude of 1500 m can be used as cheap low maintenance geostationary satellites.

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Factors to be considered while choosing a wireless surveillance balloon:

- Unlike many countries, India's extreme and diversified tropical climate presents many challenges to aerostat envelop design.
- The extremely high May - June temperatures produce highly turbulent wheather at low altitudes, which makes it essential to evaluate which the stability of the design in high turbulence.
- Besides, since the Indian Market is very price - conscious which makes it apparent that cost - reduction becomes imperative, certain key issues that will have to be kept in mind while choosing a wireless surveillance balloon for the Indian Market:
  - Economy
  - Durability of envelope in tropical continental weather .
  - Durability of envelop against the severe monsoons.

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Factors to be considered while choosing a wireless surveillance balloon:

- The tropical weather generates strong turbulent gusts during noon - time and so the aerostat should be designed to withstand such gusts.
- Good stability in high - wind conditions and the ability to not lose altitude in such winds .
- The balloon itself should be easy to manage and replace when required.
- The eletronic equipment should be weather proof, and the global system to mount these electronics should be gyro - stabilized.
- It is very essential that the parts should be easily accessible as unavailability of spare parts can be major setback.

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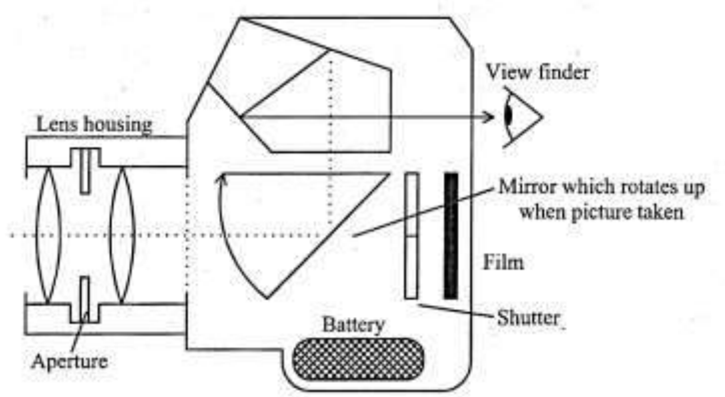
Automatic camera

- Figure shows the basic features of the canon Electro-Optical System (EOS) model, automatic, auto focus, reflex cameras. The cameras have interchangeable lenses.
- There is a main microcontroller M68HC11 in the camera body and another microcontroller in the lens housing, the two communicating with each other when a lens is attached to the camera body.

Figure (a) Reflex Camera



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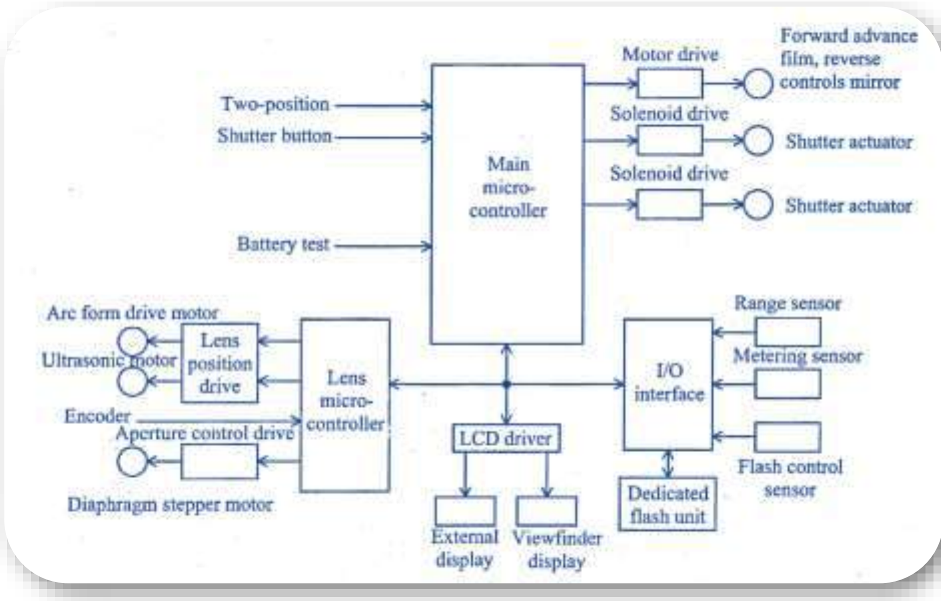
Automatic camera

Block Diagram of Electronic System

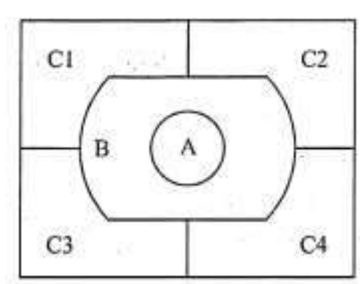


121

Automatic camera

Light Sensors

- When the photograph presses the shutter button to its first position, that of being partially depressed, the main microcontroller calculates the shutter speed and aperture settings from the input from the metering sensor and displays them in the viewfinder and an external LCD display.
- At the same time, the main microcontroller processes the input from the range sensor and sends signals to adjust the focusing of the lens.
- When the photographer presses the shutter button to its second position, that of being fully depressed, the main microcontroller issues signals to drive the mirror up, change the aperture to that required, open the shutter for the required exposure time, and then, when the shutter has closed, advance the film ready for the next photograph.



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Atomatic camera

Light Sensors

- The metering sensor has six light sensors arranged as shown in Figure
- Signal conditioning is used to obtain the average value of C 1, C2, C3 and C4 ; the A, B and average C value are then analysed to find the required exposure value. This, for example, reveals whether the scene is a scene with a relatively constant luminosity or perhaps a close up of a person so that there is a bright control zone surrounded by a dark background.
- The type of program that is used is :
- If B is equal to A and C minus B is less than 0, then exposure set on value of A.
- If B is equal to A and C minus B is 0, then exposure set on value of C.
- This information is translated by the microcontroller into an appropriate shutter speed and aperture value. If the camera is operated with the shutter speed preselected by the photographer, then only the aperture value is supplied; similarly, if the aperture is preselected then only the shutter speed is supplied.

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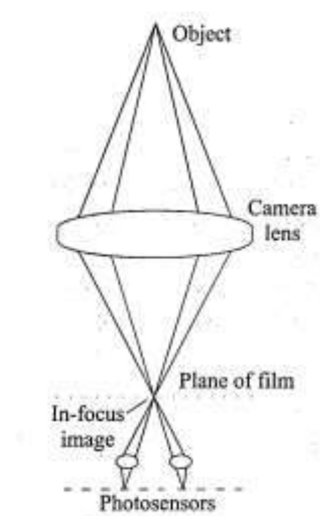
Automatic camera

Automatic Focusing

- The range sensor has two 48 - bit linear arrays of photo detectors. The light from the object, after passing through the camera lens, falls on this array.
- When the image is in focus the spacing of the images on the detector array is a particular value, the spacing deviating from this when the image is out of focus.
- The amount of this deviation is used to give an error signal which is fed to the lens microcontroller and used to give an output to adjust the focusing of the lens. An encoder is used to provide feedback of this adjustment so that the micro controller known when the focusing has been completed.
- The program is thus of the form:



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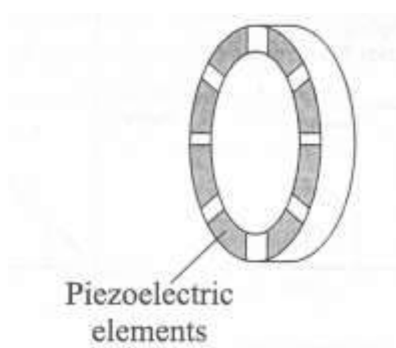
Automatic camera

Automatic Focusing

- For the main micro controller send start command to lens microcontroller take input from range sensor calculate lens movement required send lens movement data to lens microcontroller wait for verification of lens movement from microcontroller send in-focus signal to view finder display.
- For the lens microcontroller wait for start command from main microcontroller determine initial lens position wait for lens movement data from main microcontroller read lens movement data calculate new lens position while lens is not in new position drive the motor send verification signal ofin-focus to main micro controller.
- The diaphagm drive system is a stepper motor which opens or closes a set of diaphragm blades. The focusing involves two forms of drive, the arc form drive and the ultrasonic motor.
- The arc form drive uses a brushless permanent magnet d.c. motor, Hall sensors being used to detect the position of the rotor. The drive from the motor is transmitted through gears to move the focusing lens along the optical axis.

Automatic camera

- The ultrasonic motor has a series of piezoelectric elements in the form of a ring. When a current is supplied to a piezoelectric element it expands or contracts according to the polarity of the current.
- By switching the current to the piezoelectric elements in the appropriate sequence a displacement wave can be made to travel around-the piezoelectric ring of the elements in either a clockwise or counter-clockwise direction and consequently rotate a rotor which is in contact with its surface, hence driving the focusing element.



Bar Code Reader

- The familiar scene at the check out of a supermarket is of the purchases being passed in front of a light beam or a hand-held band being passed over the goods so that the bar code can be read and the nature of the purchase and hence its price automatically determined.
- The code consists of a series of black and white bars of varying widths. For example, there is such a bar code on the back of any book or product.

ISBN 0–582–25634–8

9 7 8 0 5 8 2 2 5 6 3 4 7

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Bar Code Reader

- Figure shows the basic form of the bar code used in the retail trade. The bar code represents a series of numbers. There is a prefix which identifies the coding scheme being used; this is a single digit for the regular universal product coding (UPC) scheme used in the united states and two digits for the European Article Number (EAN) scheme used in Europe. The UPC uses a 0, prefix for grocery and a 3 for pharmaceuticals.
- The EAN prefix is from 0 to 9 and is such that the UPC code can be read within the EAN code. This is followed by five digits to represent the manufacturer; each manufacturer having been assigned a unique number.
- This brings up the centre of the code pattern which is identified by two taller bar pattern. The five digit number that then follows represents the product.
- The final number is a check digit which is used to check that the code has been correctly read.
- A guard pattern of two taller bars at the start and end of the bar pattern is used to frame the bars.

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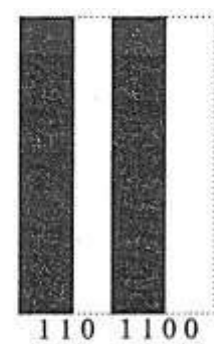
Bar Code Reader

UPC and EAN codings

- Each 1 is entered as a dark bar and thus the right-hand character 2 would be represented 1101100 and, with the adjacent dark bars run together, it appears as a double-width dark bar followed by a narrow space and then another double-width dark wide bar followed by a double-width space.
- The guard pattern at the ends of the code represent 101
- The bar code uses the EAN code and has the prefix 97 to identify it as a publication, 80582 to identify the publisher of the book, 25634 to identify the particular book and a check digit of 7.
- Note that the bar code contains the relevant parts of ISBN number, this also being a number to identify the publisher and the book concerned.



Bar Codefor Right-Hand 2

Bar Code Reader

- The procedure for using the check code digit is :
  1. Starting at the left, sum all the characters, excluding the check digit, in the odd positions, i.e first; third, fifth, etc and then multiply the sum by 3.
  2. Starting at the left, sum all the characters in the even positions.
  3. Add the results of step 1 and 2. The check character is the smallest number which when added-to this sum produced a multiple of 10.
- As an illustration of the use of the check digit, consider the bar code for the book where we have. 9780582256347.
- For the odd characters we have 9 + 8 + 5 + 2 + 5 + 3 = 32 and when multiplied by 3 we have 96. For the even characters we have 7 + 0 + 8 + 2 + 6 + 4 = 27. The sum is 123 and thus the check digit should be 7.

Bar Code Reader

- Reading the bar code involves determining the widths of the dark and light bands.
- This can involve a solid-state laser being used to direct an intense, narrow, beam of light at the code and detecting the reflected light by means of a photocell.
- Usually with the supermarket version the scanner is fixed, and a spinning mirror is used to direct the light across the bar code and so scan all the bars.
- Signal conditioning involves amplification of the output of the photocell using operational amplifiers and then using an operational amplifier circuit as a comparator in order to give a high, i.e, 1, output when a black bar is scanned and a low, i.e, 0, output when a white space is scanned.

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Bar Code Reader

- This sequence of 0's and 1s can he an input to say. a PIA connected to a motorola 6800 microprocessor. The overall form of the microprocessor program is.
  1. Initialisation to clear the various memory locations.
  2. Recovering the data from the input. This involves continually testing the input to determine whether it is 0 or 1 .
  3. Processing thedata to obtain the characters in binary format. The input is a serial signal consisting of different duration 0's and 1s depending on the width of the spaces of black bars. The microprocessor system is programmed to find the module time width by dividing the time of scan between the end marker bars by the number of modules, a module being. a light or dark band to represent a single 0 or 1. The program can the determine whether a dark or light band is a single digit or more than one and hence interpret the scanner signal.
  4. Process the binary outcome into a statement of the itempurchased and cost.

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