Sensors - II

Calibration

Sensor calibration is an adjustment or set of adjustments performed on a sensor or instrument to make that sensor / instrument function as accurately, or error free, as possible.

Advantages of Calibration

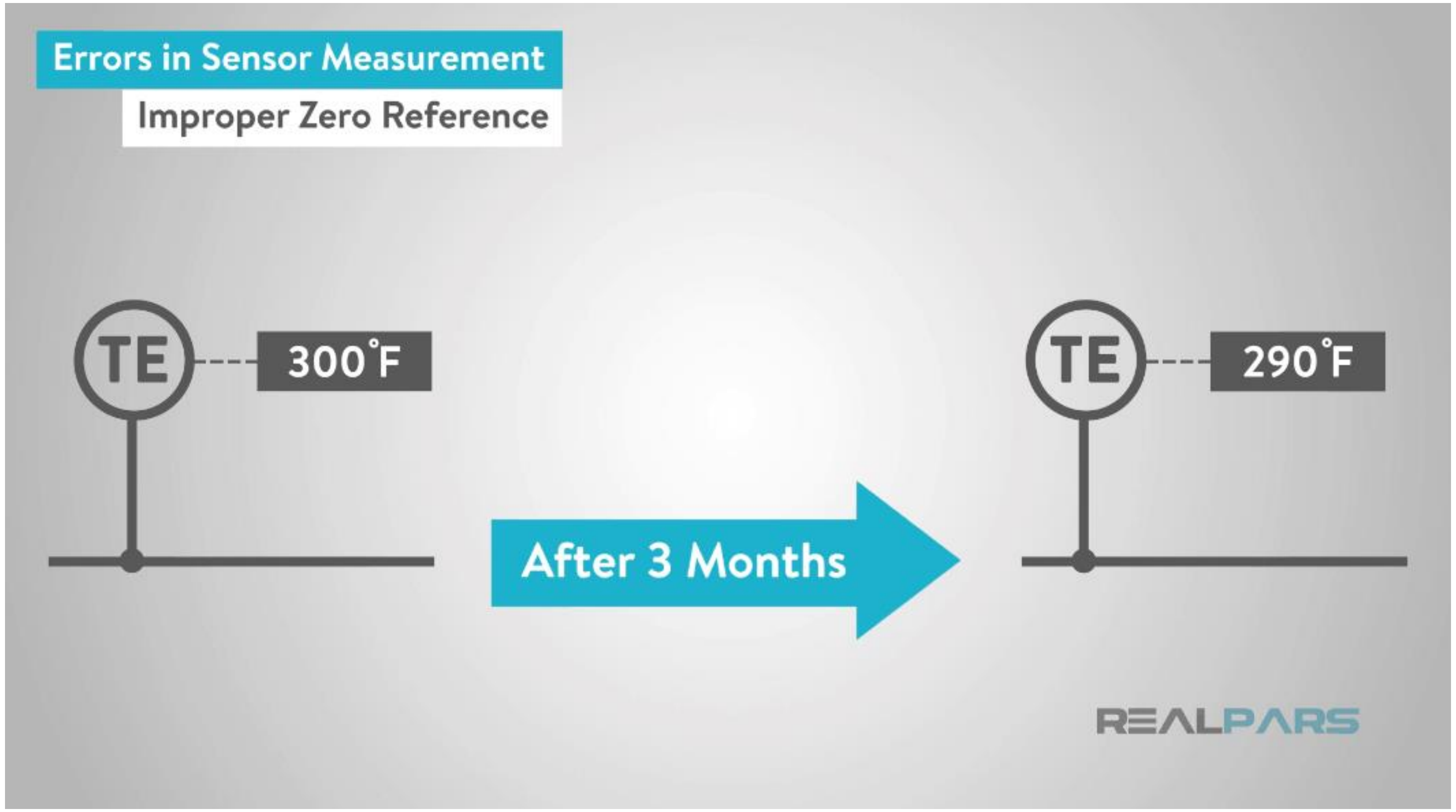
Errors in Sensor Measurement

Error is simply the algebraic difference between the indication and the actual value of the measured variable. Errors in sensor measurement can be caused by many factors.

Error due to Improper Zero Reference

First, the instrument may not have a proper zero reference.

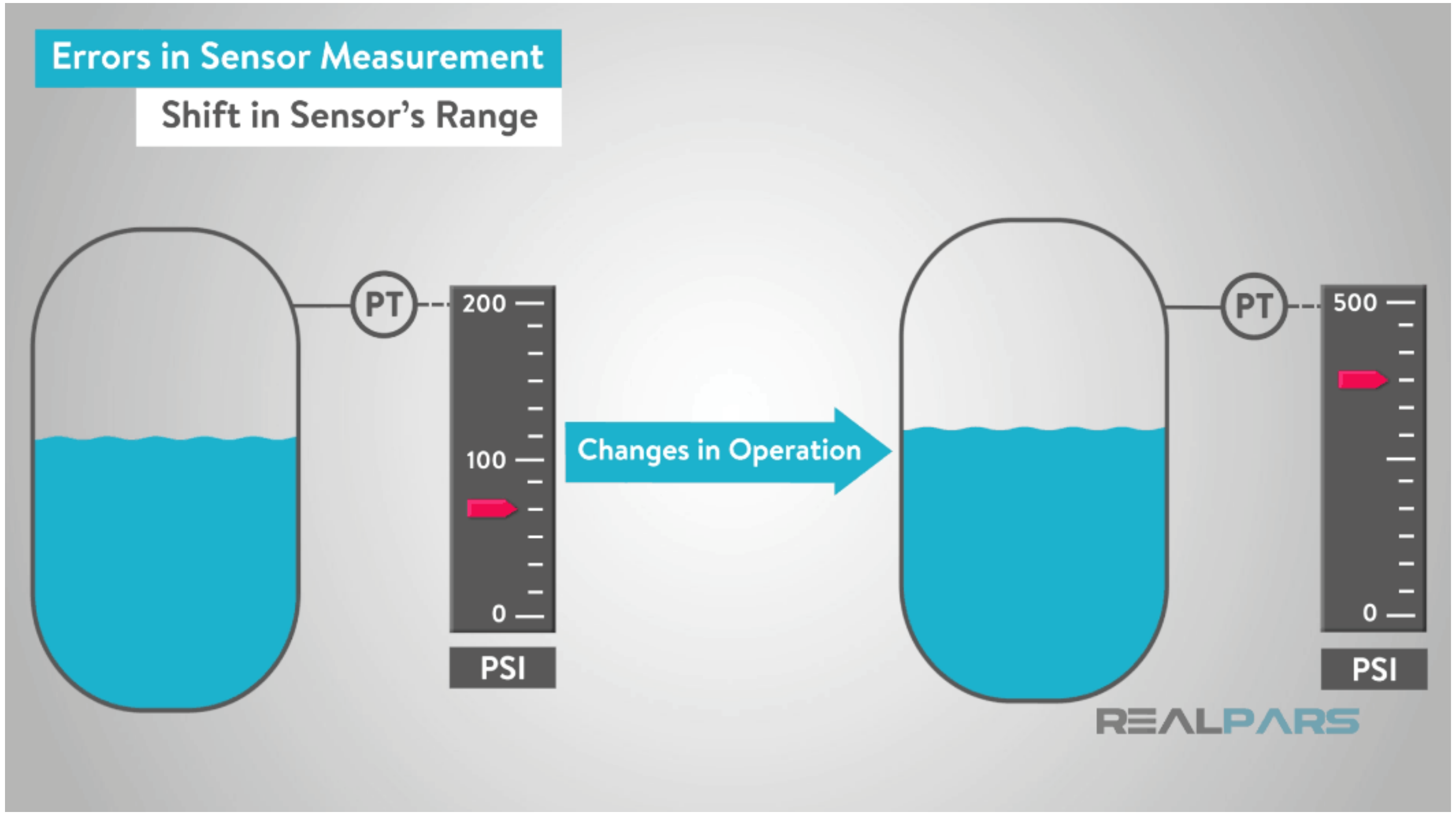
Modern sensors and transmitters are electronic devices, and the reference voltage, or signal, may drift over time due to temperature, pressure, or change in ambient conditions.



Error due to Shift in Sensor's Range

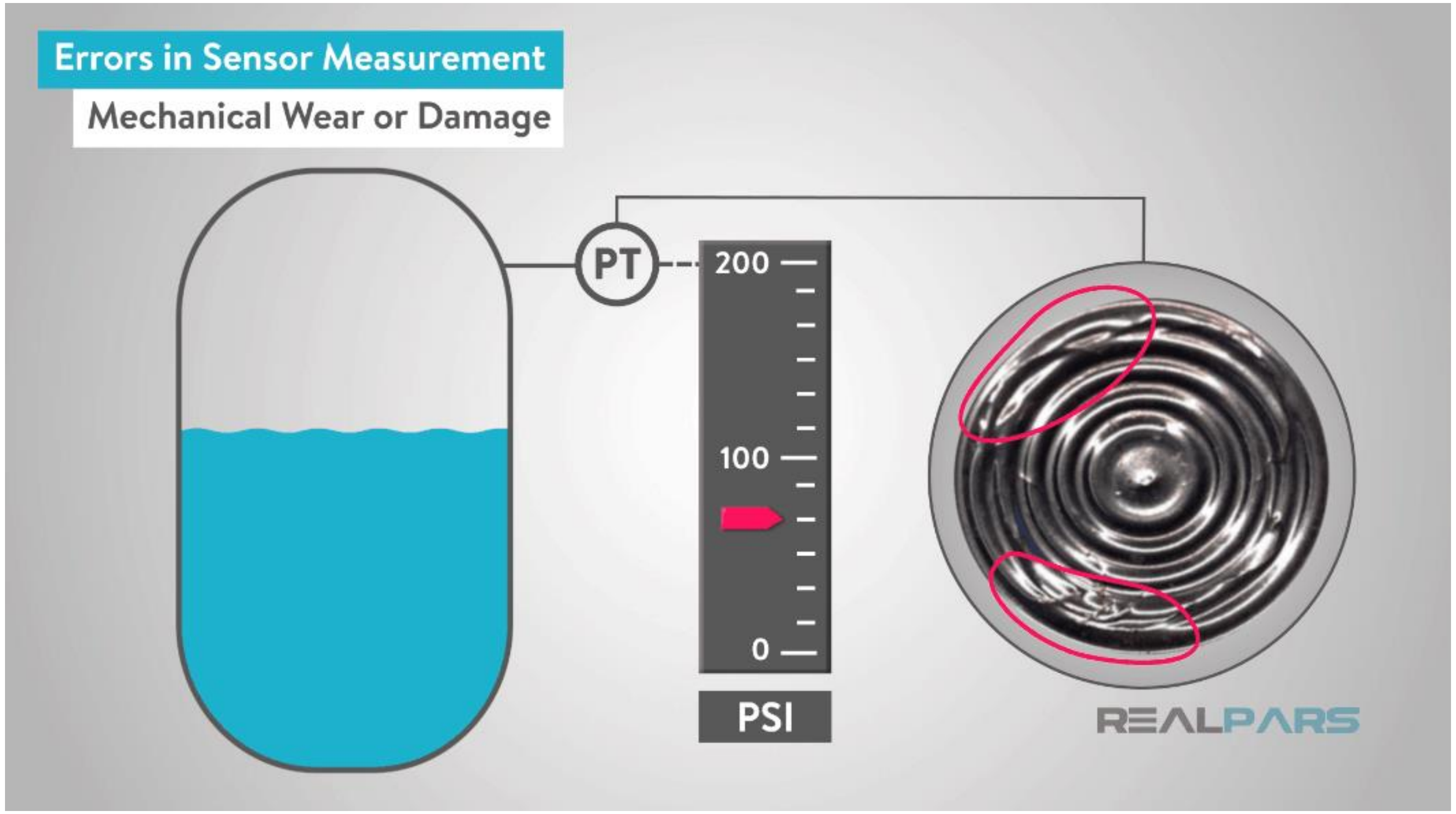
Second, the "sensor's range" may shift due the same conditions just noted, or perhaps the operating range of the process has changed.

For example, a process may currently operate in the range of 0 to 200 pounds per square inch (PSI), but changes in operation will require it to run in the range of 0 to 500 pounds per square inch (PSI).



Error due to Mechanical Wear or Damage

Third, error in sensor measurement may occur because of mechanical wear, or damage. Usually, this type of error will require repair or replacement of the device.

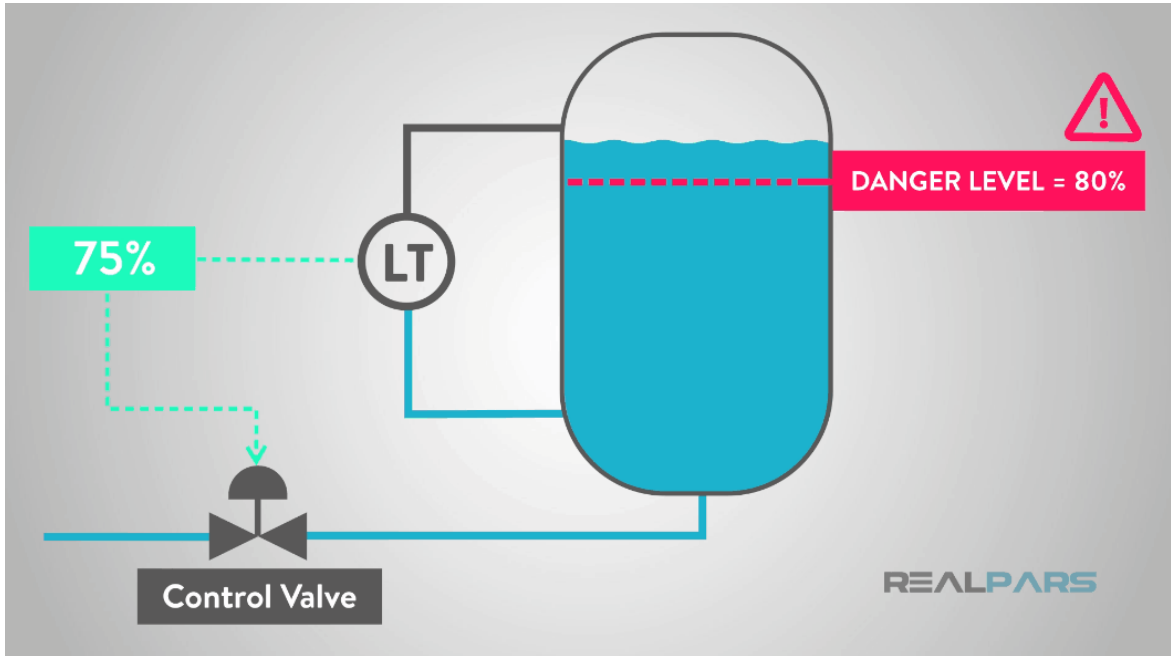


Errors are not desirable, since the control system will not have accurate data from which to make control decisions, such as adjusting the output of a control valve or setting the speed of a feed pump.

If the calibration is too far from the accurate process conditions, process safety may be jeopardized.

Every instrument to have a proper calibration.

Proper calibration will yield accurate measurements, which in turn, makes good control of the process possible.



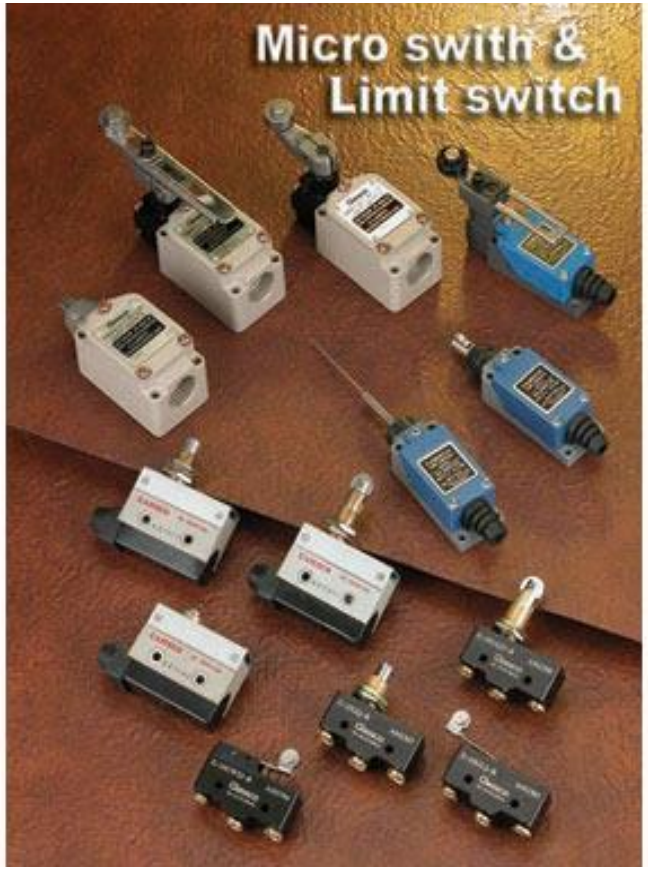
When good control is realized, then the process has the best chance of running efficiently and safely.

Sensor Calibration

Most modern process plants have sensor calibration programs, which require instruments to be calibrated periodically.

Calibration can take a considerable period of time, especially if the device is hard to reach or requires special tools.

Limit Switches



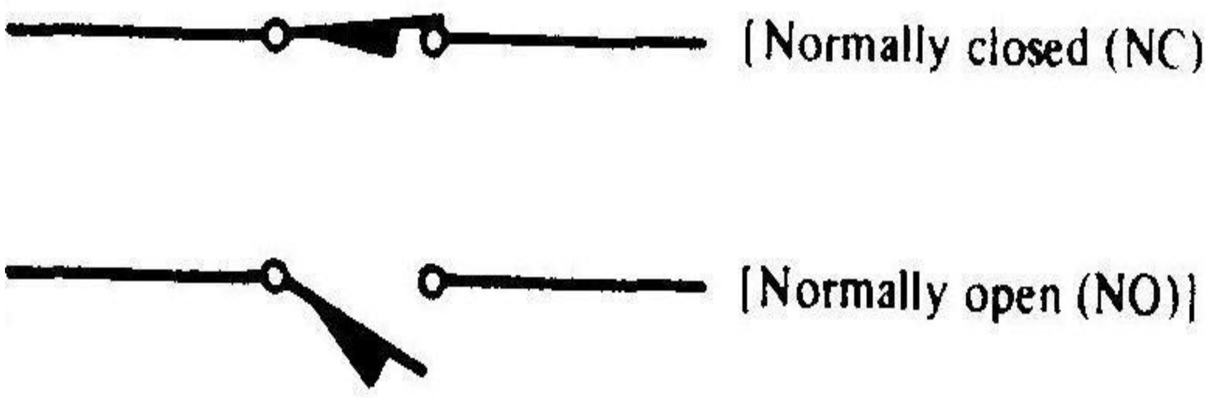
A limit switch has the same ON/OFF characteristics.

The limit switch usually has a pressure-sensitive mechanical arm.

When an object applies pressure on the mechanical arm, the switch circuit is energized.

An object might have a magnet attached that causes a contact to rise and close when the object passes over the arm.

Limit Switches



Limit switches can be either
- Normally open (NO) or
- Normally closed (NC)

Limit switches are mechanical devices

Advantages:

Simplicity, robustness, and repeatability to processes.

Easy to maintain

Reliability is another benefit

They will not be affected by electromagnetic interferences (EMI)

Limitations:

They are subject to mechanical failure.

Their speed of operation is relatively low

Proximity Sensors

Proximity sensing is the technique of detecting the presence or absence of an object with an electronic non-contact sensor. There are three types of proximity sensors:

1. Inductive,
2. Capacitive
3. Magnetic

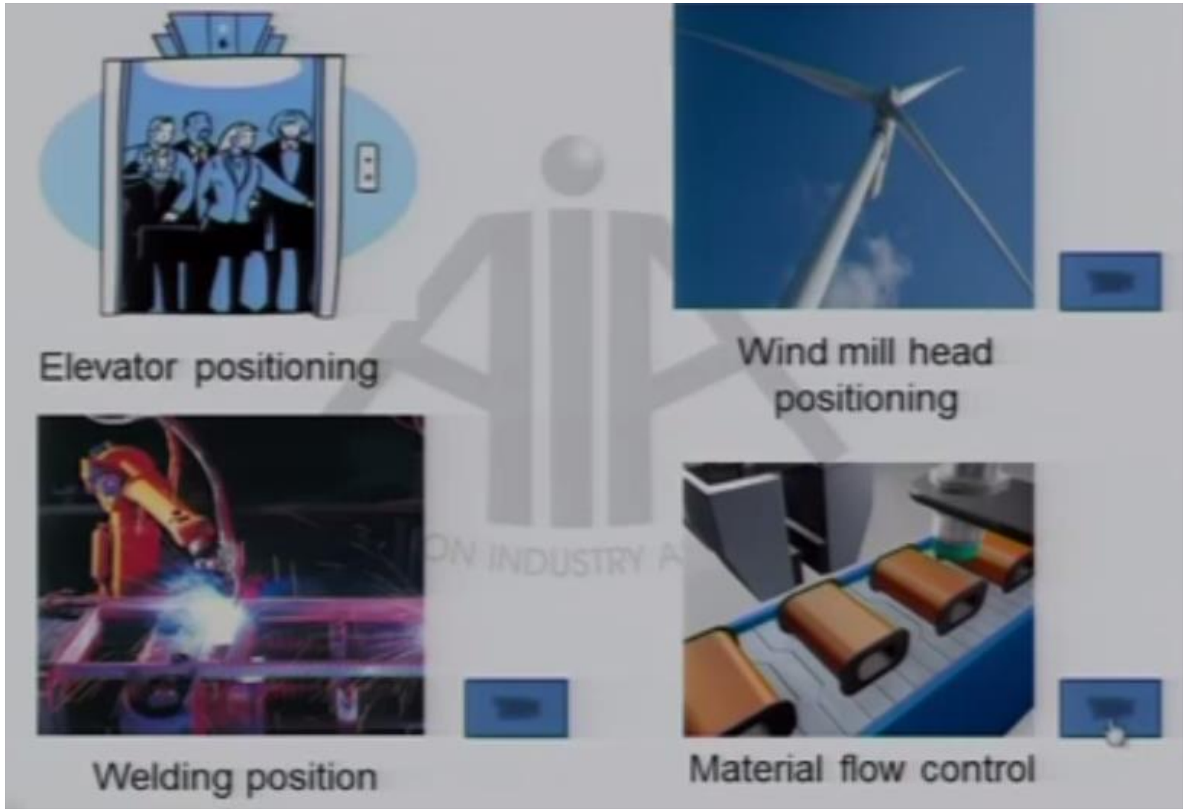
- Mechanical limit switches are the first devices to detect objects in industrial applications.
- Inductive proximity sensors are used in place of limit switches for non-contact sensing of metallic objects.
- Capacitive proximity switches can also detect non-metallic objects.
- Both inductive and capacitive sensors are limit switches with ranges up to 100mm.

Inductive Proximity Sensors

Inductive sensors are used to detect the presence of metallic objects.

These sensors require DC or AC voltage for the power to drive circuitry to generate the fields and to produce output signal.

Inductive Proximity Sensors - Applications



Typical applications of inductive proximity sensors in control systems:

- Motion position detection
- Motion control
- Conveyor system control
- Process control
- Machine control
- Verification and counting

Capacitive Proximity Sensors

The capacitance between two plates is determined by three things

Size of plates
Gap size
Material bet the plates

C = (Area x Dielectric)/Distance

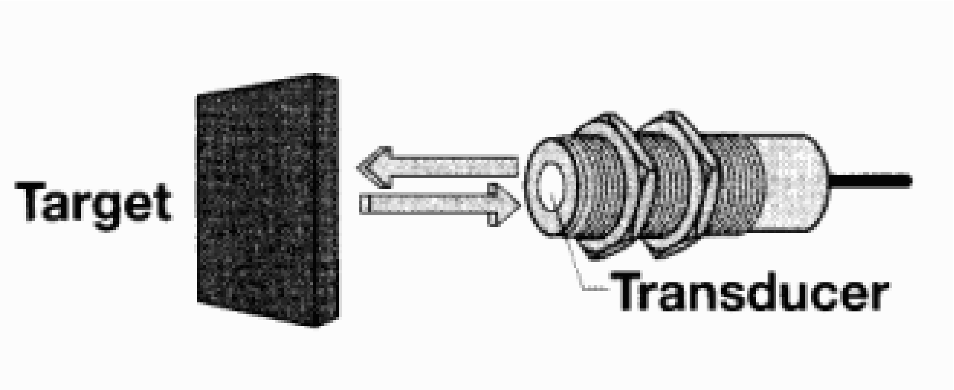
Typical applications of capacitive proximity sensors in control systems:

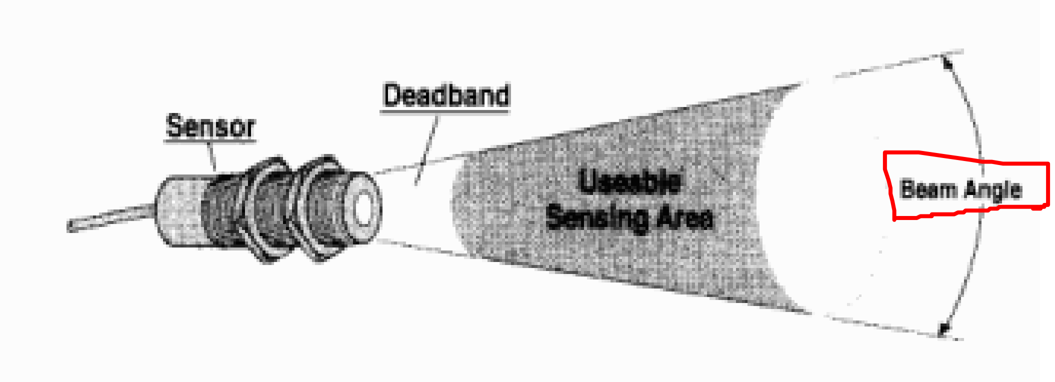
- Liquid level detection
- Bulk material level control
- Process control

Ultrasonic Sensors

Ultrasonic sensors **are used in non-contact material monitoring applications including level control, positioning, flow monitoring and conveyor transfer.**

Ultrasonic sensors use the propagation time of sound pulse to calculate the distance of a target. Sound pulses are emitted and received by a diaphragm in the face of the transducer as illustrated in the diagram below.





Beam Angle: The beam angle is the angle formed by sound waves as they emanate from an ultrasonic sensor. The beam angle defines the usable area in which target detection is possible.

Ultrasonic Sensors - Applications

- Object/Target detection
- Distance
- Level
- Content level
- Missing material
- Double sheet detection
- SONAR
- Flow meters
- Medical field

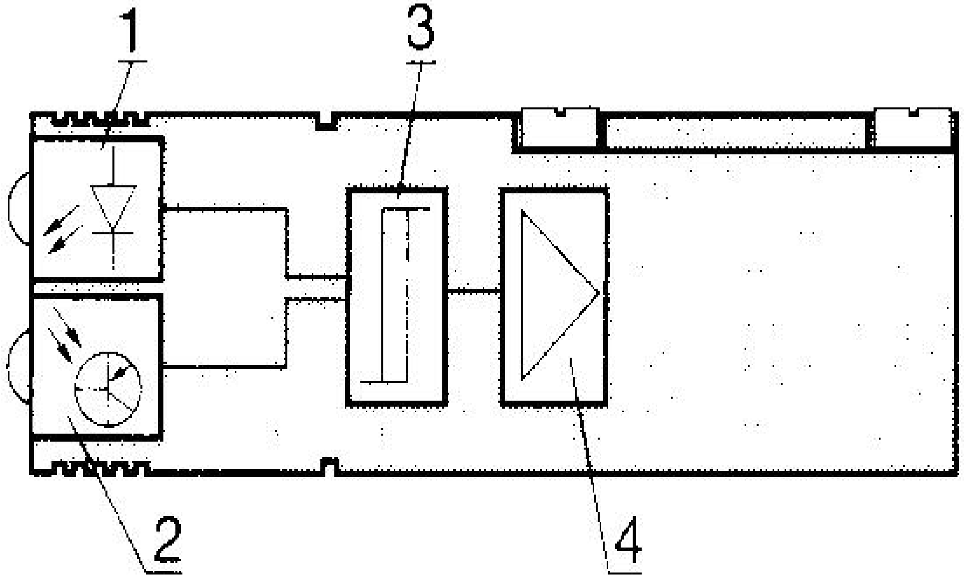
Photoelectric Sensors

- A photoelectric sensor is a semiconductor component that reacts to light or emits light. The light may be either in visible range or the invisible infrared range.
- Infrared sensors may be active or passive. The active sensors send out an infrared beam and respond to the reflection of the beam against a target.
- The distinct advantage of photoelectric sensors over inductive or capacitive sensors is their increased range.
- Dirt, oil mist and other environmental factors will hinder operation of photoelectric sensors during manufacturing process.

Photoelectric Sensors

- Photoelectric sensors are comprised of the following components :

1. Light Source (LED)
2. Receiver (phototransistor)
3. Signal Converter
4. Amplifier



Proximity Sensors Comparision

Proximity sensor comparison

Technology	Sensing range	Applications	Target materials
Inductive 	<4-40 mm	Any close-range detection of ferrous material	Iron Steel Aluminum Copper etc. 
Capacitative 	<3-60 mm	Close-range detection of non-ferrous material	Liquids Wood Granulates Plastic Glass etc. 
Photoelectric 	<1mm- 60 mm	Long-range, smalll or large target detection	Silicon Plastic Paper Metal etc. 
Ultrasonic 	<30 mm- 3 mm	Long-range detection of targets with difficult surface properites. Color/reflectivity insensitive.	Cellophane Foam Glass Liquid Powder etc. 

Displacement and Speed Measurement

- Range of few μm to few cm
- Measurement may be of contact type or noncontact type
- Linear or angular (rotary).
- Measurement principles
  - Electrical sensing - passive electrical sensors are used, variation of resistance, inductance or capacitance with displacement is measured
  - Optical sensing - intensity variation of light with distance

Displacement and Speed Measurement

Techniques

- Potentiometers
- LVDT
- Inductive type
- Capacitive type
- Optical sensors

Flow Measurement

The common types of flow-meters that find industrial applications

- Obstruction type (differential pressure or variable area)
- Inferential (turbine type),
- Electromagnetic,
- Positive displacement (integrating),
- Fluid dynamic (vortex shedding),
- Anemometer,
- ultrasonic and
- Mass flowmeter (Coriolis).

Pressure and Force Measurement

Pressure = Force/Area

Units

- 1 Pascal = N/m^2
- 1Bar = 10^5 N/m^2
- 1psi = 6895 N/m^2

Pressure measurement

- Static
- Dynamic

All pressure measured is a relative term

- Absolute pressure
- Gauge pressure
- Differential pressure

Barometer ,Manometer

Pressure Transducers

Mechanical

- **Bourdon Tube**
- **Bellows**

Electrical

- **Strain Gauge**
- **Capacitance**
- **Piezoelectric**

Temperature Measurement

We associate the concept of temperature with how hot or cold an object feels. Our senses provide us with a qualitative indication of temperature.

Temperature can be thought of as the property that determines whether an object is in **thermal equilibrium** with other objects.

Two objects in thermal equilibrium with each other are at the same temperature.

If two objects have different temperatures, they are not in thermal equilibrium with each other.

Temperature is something that determines whether or not energy will transfer between two objects in thermal contact

Temperature Measurement

- When a substance receives heat the following effects are observed.
- Change in volume
- Change in pressure
- Change in electric resistance
- Change in radiation
- Change in thermo electric e.m.f., and
- Change in color.

Any of these changes can be used for the measurement of temperature.

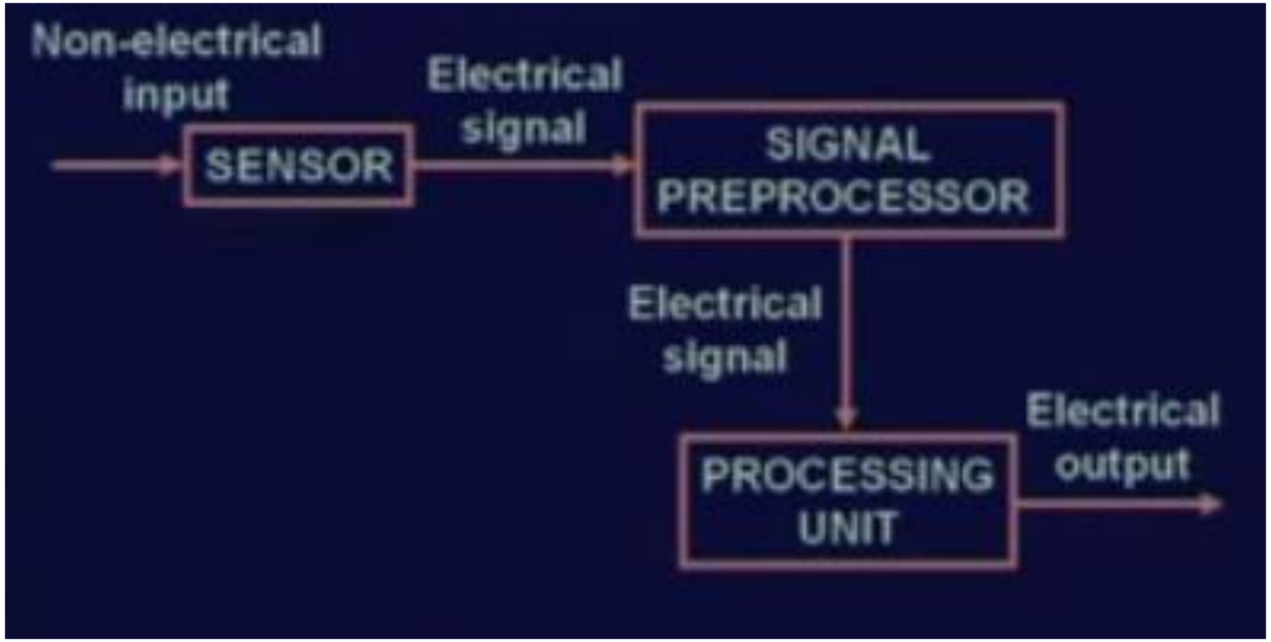
Temperature Sensors

- Liquid and gas thermometer
- Bimetallic strip
- Resistance thermometers (RTD and Thermistors)
- Thermocouple
- Junction semiconductor sensor
- Radiation pyrometer

Smart Sensor

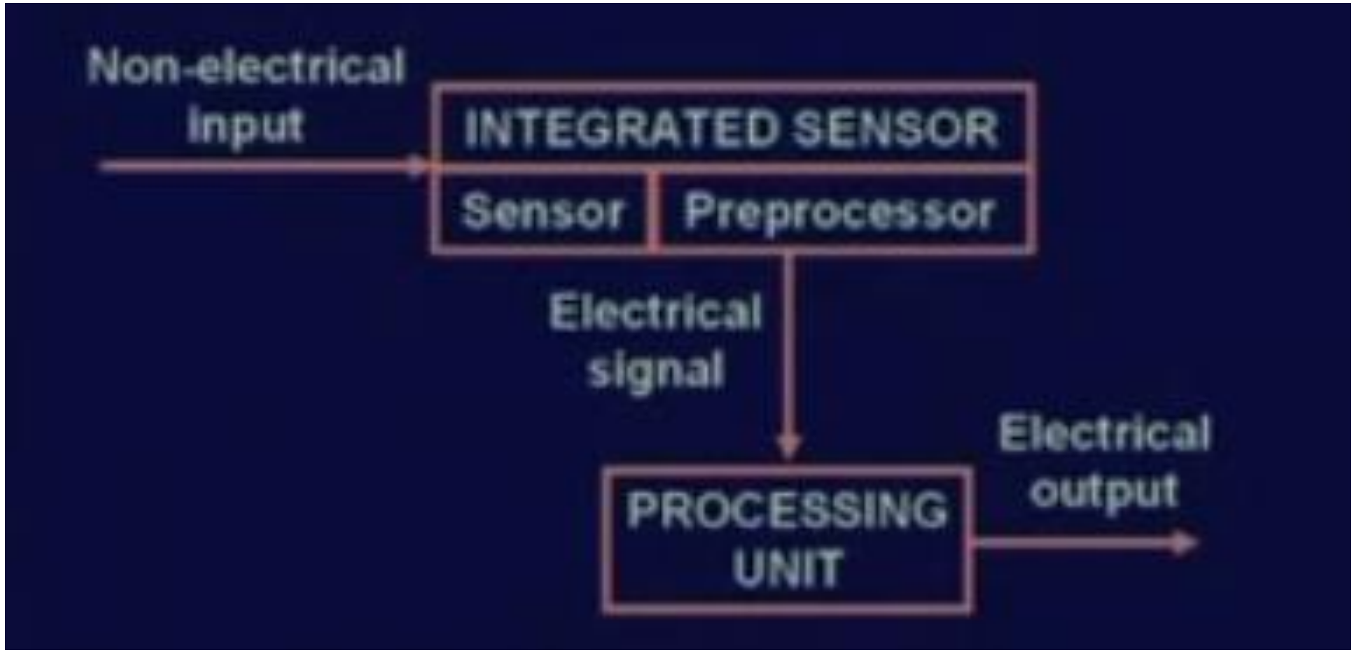
- Sensors are devices used to provide information on the presence or absence of an object.
- Sensors such as photoelectric, inductive, capacitive, and ultrasonic change their output when an object is present without touching the sensor.
- Sensors are capable of manipulation and computation of the sensor-derived data.
- Sensors simply take physical, biological or chemical input & convert it to the measured value into a digital format.
- The successful applications of many type of solid state sensors has stimulated the market but led to demand either a low unit cost or an enhanced functionality to improve the market value.
- Both of these may be achieved through a higher level of device integration – system on chip (SOC)
- More difficult sensing problems are now being studied which require higher level of processing power (more intelligence) than is achievable from today's sensors
- There are different views at present over the precise definition of smart sensors

A typical sensor



4 – 20 MA Pressure sensor

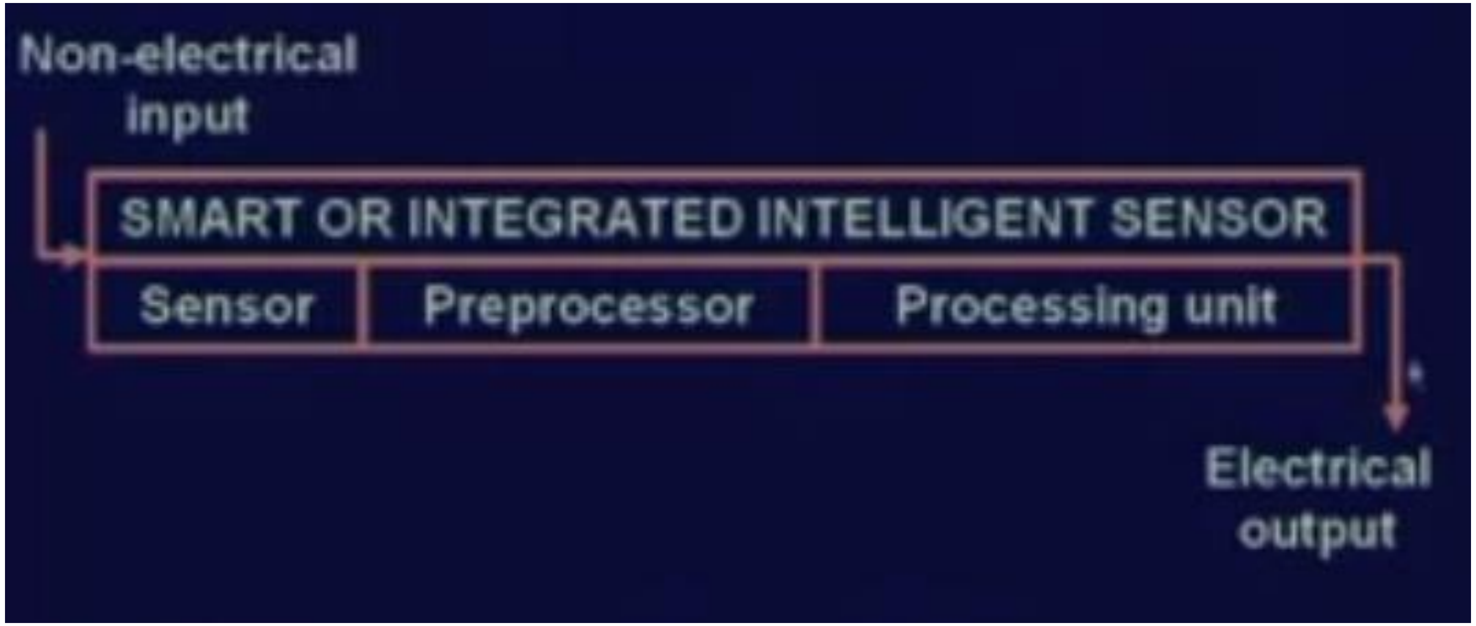
An integrated sensor in a sensor system



A device onto which at least one sensing element and signal processing circuit has been integrated is a smart sensor

A low level smart sensor

Smart sensor or Integrated intelligent sensor



All smart sensors must be integrated and intelligent , while any sensor that has significant intelligence which has not been integrated can be called as intelligent sensor

Smart Sensor

- ***sensors are capable of manipulation and computation of the sensor-derived data***
- ***Sensor + interfacing circuit = smart sensor***
- ***Capable of***
  - **** logic functions,***
  - **** two-way communication,***
  - **** make decisions.***
- *A sensor producing an electrical output when combined with interfacing electronic circuits is known as Smart Sensor*
- *It simply physical, biological or chemical input & converts it to the measured value into a digital format.*

WHY SMART SENSOR ?

- ***Self calibration:*** Adjust deviation of output of sensor from desired value.
- ***Communication:*** Broadcast information about its own status.
- ***Computation:*** Allows one to obtain the average, variance and standard deviation for the set of measurements.
- ***Multisensing:*** A single smart sensor can measure pressure, temperature, humidity, gas flow and infrared chemical réaction surface acoustic vapour etc.
- ***Cost improvement:*** less hardware and reduction of repetitive testing make smart sensor cost effective. Reduced cost of bulk cables and connectors
- ***Enhancement of application***

Reference : Stanford University. Stanford online

- ***Remote Diagnostics***
- ***System Reliability:*** *System reliability is significantly improved due to the utilization of smart sensors. One is due to the reduction in system wiring and second is the ability of the sensor to diagnose its own faults and their effect.*
- ***Better Signal to Noise Ratio:*** *The electrical output of most of the sensors is very weak and if this transmitted through long wires at lot of noise may get coupled. But by employing smart sensor this problem can be avoided.*
- ***Improvement in characteristics***
  - ***Non-linearity***
  - ***Cross-sensitivity***
  - ***Offset/drift***

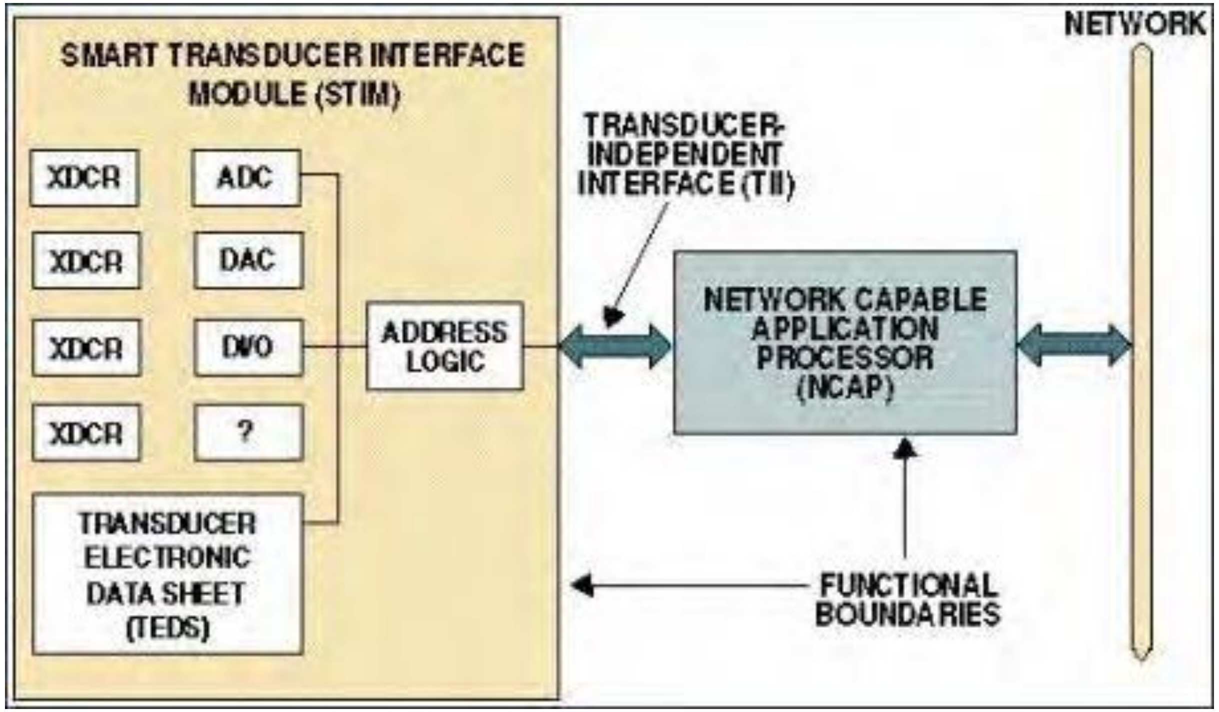
Advantages

- *Minimum Interconnecting Cables*
- *High Reliability*
- *High Performance*
- *Easy to Design, Use and Maintain*
- *Scalable -Flexible System*
- *Small Rugged Packaging*
- *Minimum Cost*

Components of Smart sensors

There are two main components of a functional smart sensor:

1) ***Transducer interface module (TIM)***
2) ***Network capable application processor (NCAP)***



Transducer Interface Module

- ***Transducer interface module (TIM):*** *A TIM is a module that contains the interface, signal conditioning, Analog-to-Digital and/or Digital-to-Analog conversion and in many cases, it also contains the transducer. A TIM can range in complexity from a single sensor or actuator to a module containing many transducers including both sensors and actuators.*
- **This TIM provides the following functions-**
  - *Analog Signal Conditioning*
  - *Triggering*
  - *Analog to Digital Conversion*
  - *Command Processing*
  - *TEDS Storage*
  - *Data Transfer Communications*

Network Capable Application Processor

- ***Network capable application processor (NCAP):*** *An NCAP is the hardware and software that provides the gateway function between the TIMs and the user network or host processor (the transducer channel).*
- *The IEEE 1451 standard defines the communications interface between an NCAP or host processor and one or more TIMs. Three types of transducers are recognized by the IEEE 1451 standard; sensors, event sensors and actuators.*

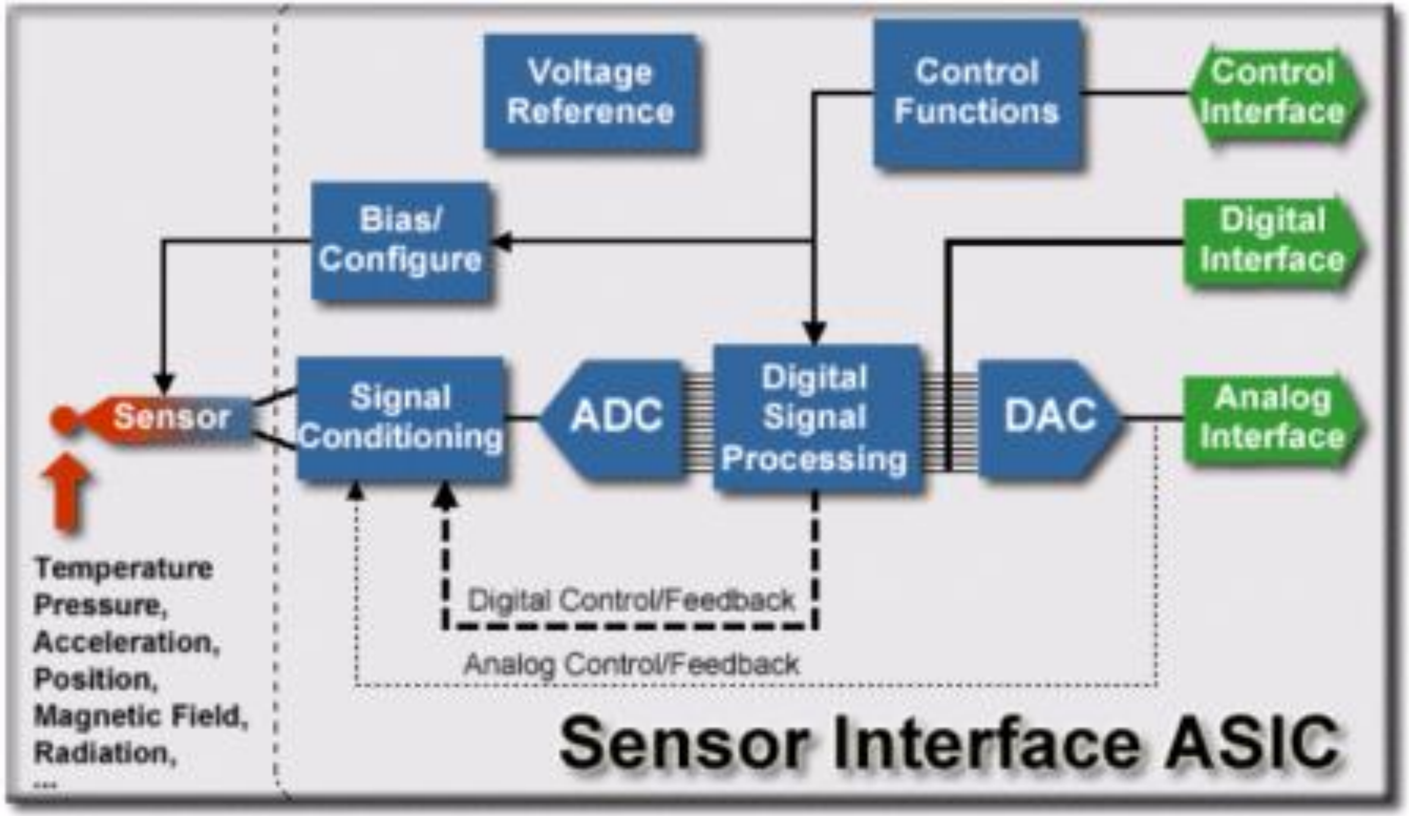
This NCAP provides the following functions-

- *Communications*
- *Interface Control*
- *Message Routing*
- *TIM Discovery and Control*
- *Data Correction Interpretation of TEDS Data*
- *Message Encoding and Decoding*

General Architecture of smart sensor

A general architecture of smart sensor consists of following important components:

- *Sensing element/transduction element,*
- *Amplifier,*
- *Sample and hold,*
- *Analog multiplexer,*
- *Analog to digital converter (ADC),*
- *Offset and temperature compensation,*
- *Digital to analog converter (DAC),*
- *Memory,*
- *Serial communication and*
- *Processor*



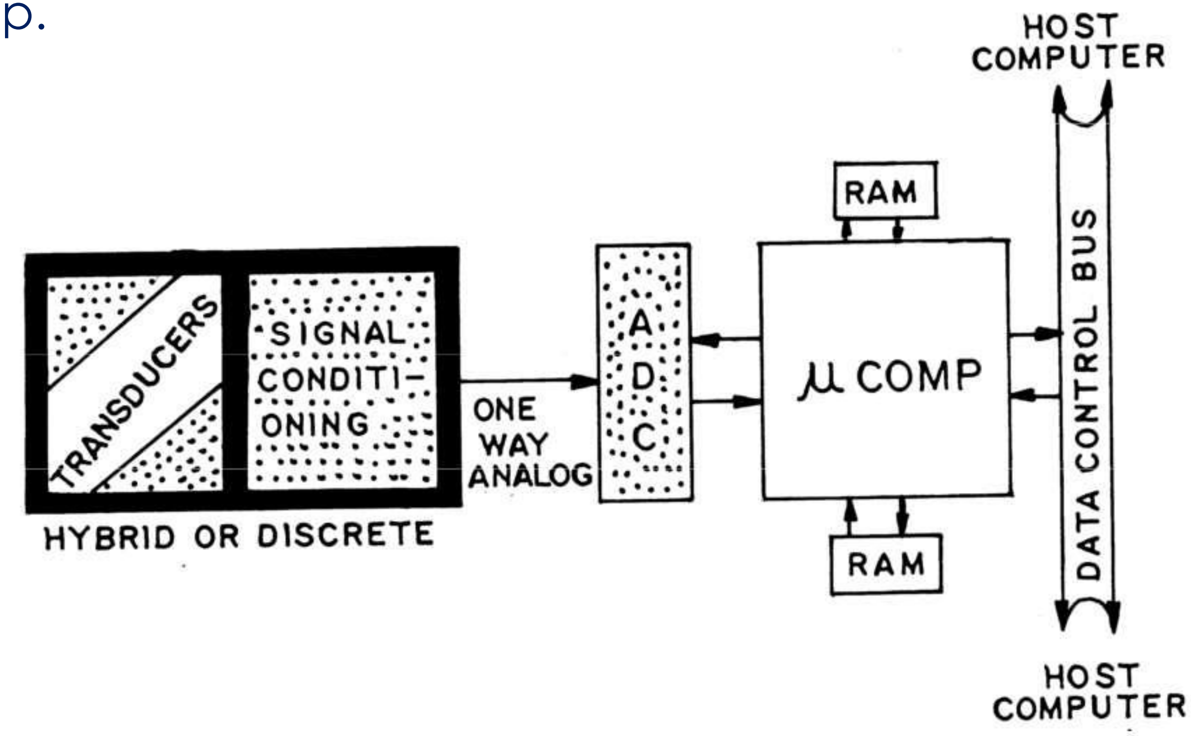
EVOLUTION- SMART SENSORS

- **First generation** devices had little, if any, electronics associated with them. Had MEMS sensor element (mostly based on a silicon structure) and sometimes combined with analog amplification on a micro chip.

- **Second generation** sensors were part of purely analog systems with virtually all of the electronics remote from the sensor. Had MEMS sensor element combined with analog amplification and analog-to-digital converter on one micro chip.

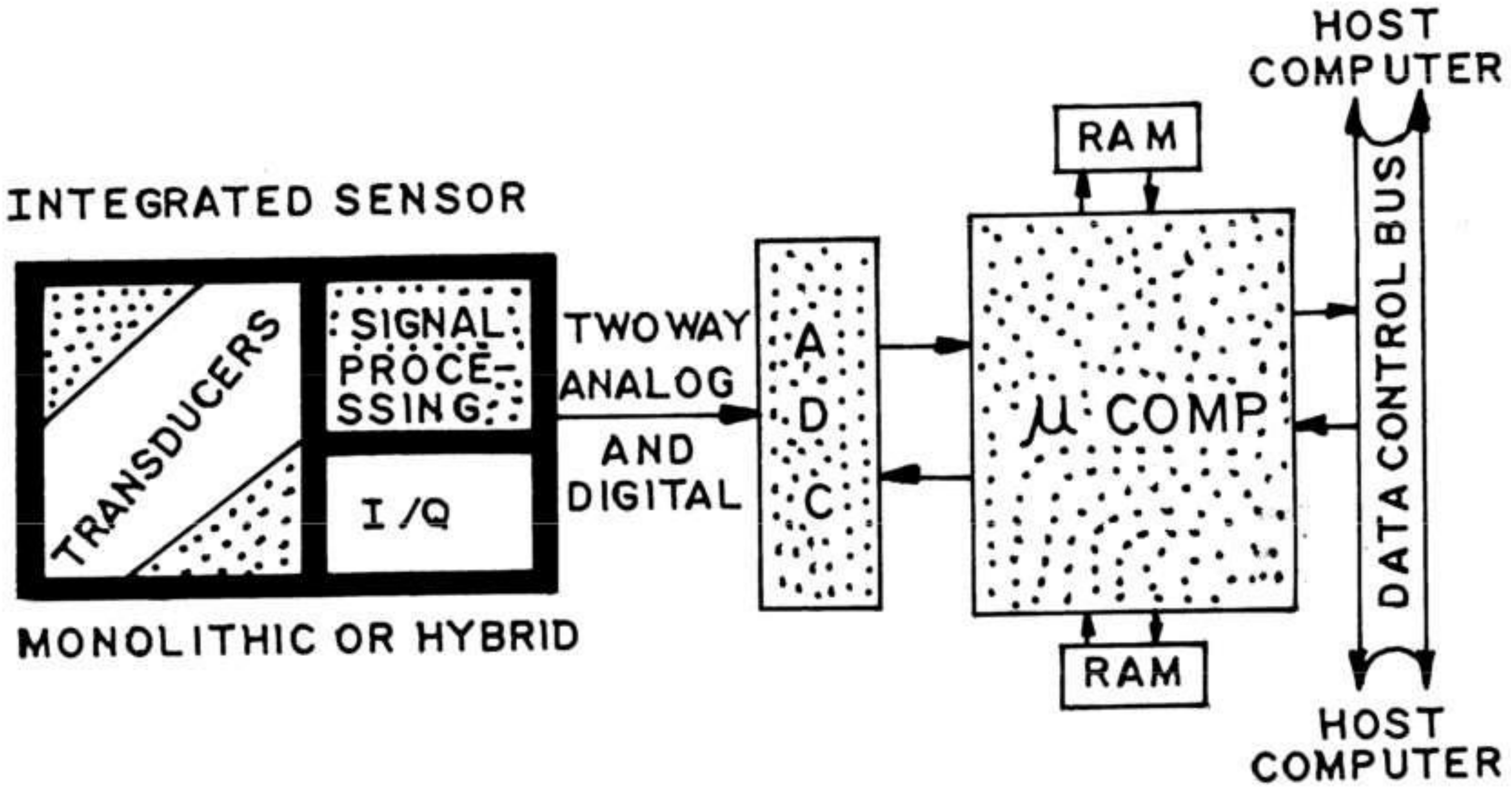
THIRD GENERATION SENSORS

- **THIRD GENERATION SENSORS :** Fusion of the sensor element with analog amplification, analog-to-digital converter and digital intelligence for linearization and temperature compensation on the same micro chip.



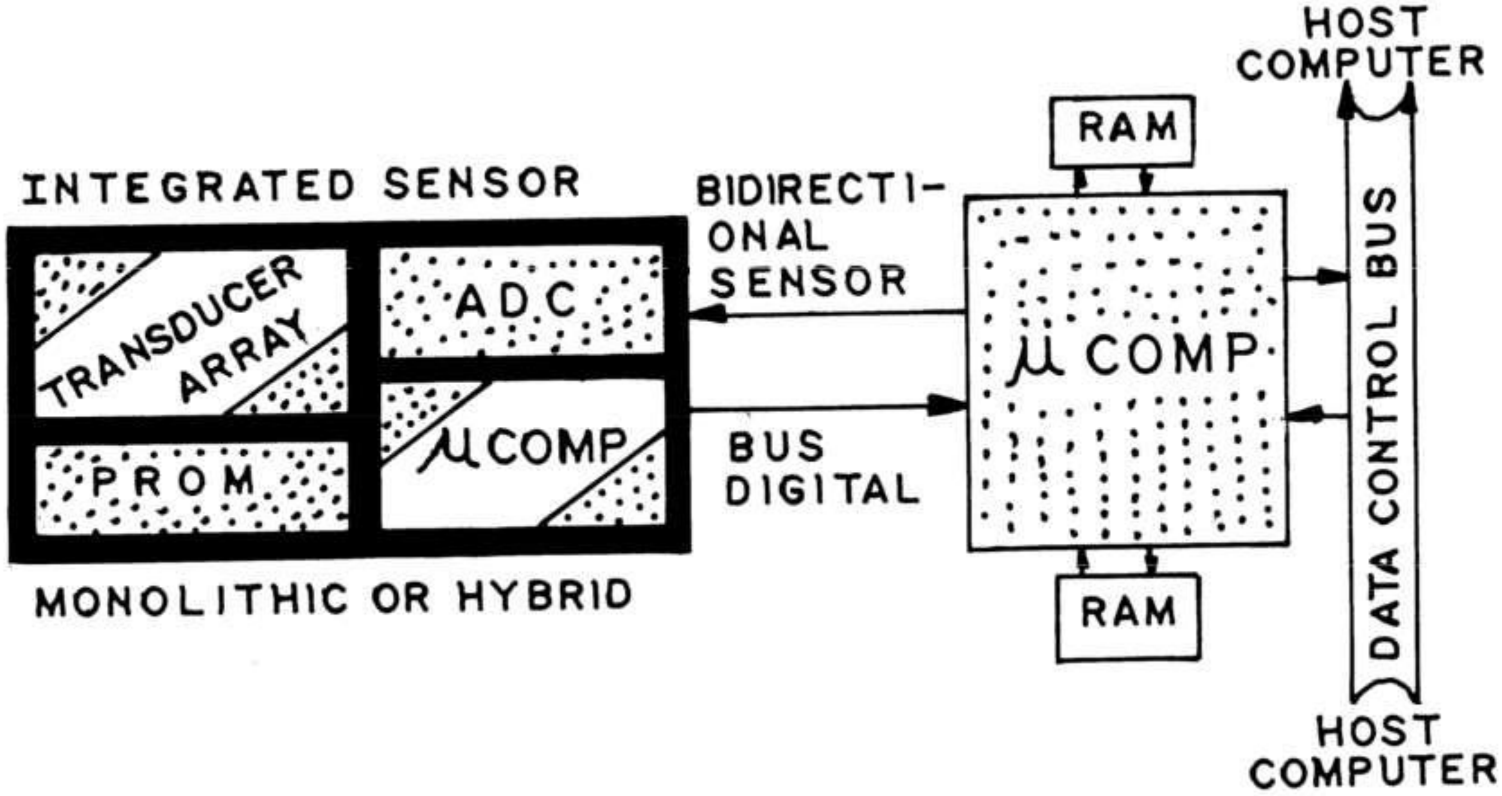
FOURTH GENERATION SENSORS

- **FOURTH GENERATION SENSORS:** Memory cells for calibration and temperature compensation data are added to the elements of the 3rd MEMS sensor generation.



FIFTH GENERATION SENSORS

- **FIFTH GENERATION SENSORS :** This generation sensors are equivalent to intelligent sensors.



APPLICATIONS OF SMART SENSORS

- ***Accelerometer*:**

It consists of the sensing element and electronics on silicon. The accelerometer itself is a metal-coated SiO_2 cantilever beam that is fabricated on silicon chip where the capacitance between the beam and the substrate provides the output signal.

- ***Optical sensor:***

Optical sensor is one of the examples of smart sensor, which are used for measuring exposure in cameras, optical angle encoders and optical arrays. Similar examples are load cells silicon based pressure sensors.

- ***Infrared detector array:***

It is developed at solid laboratory of university of Michigan. Here infrared sensing element is developed using polysilicon.

Disadvantages

- The smart sensor consists of both actuators & sensors, so it is more complex than other simple sensors.
- The complexity is much higher in the wired smart sensors, as a consequence the costs are also higher.
- Sensor calibration has to be managed by an external processor.
- Predefined embedded functions have to be given during the design of the smart sensor.

Thank you!