Advanced Sensing Techniques

Introduction

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&

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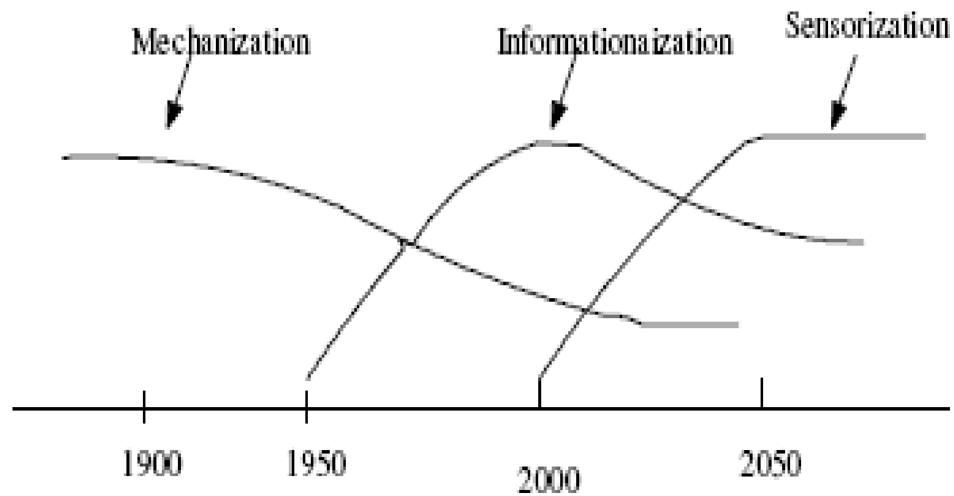
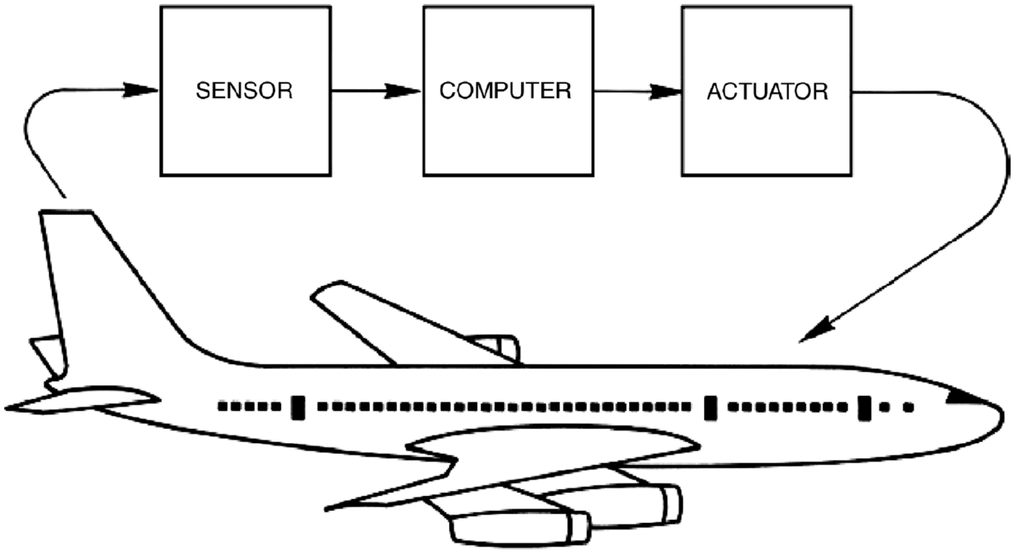
Introduction

Industrial Revolution: Automation (Three phases)

- Mechanization
- Informationization
- Sensorization





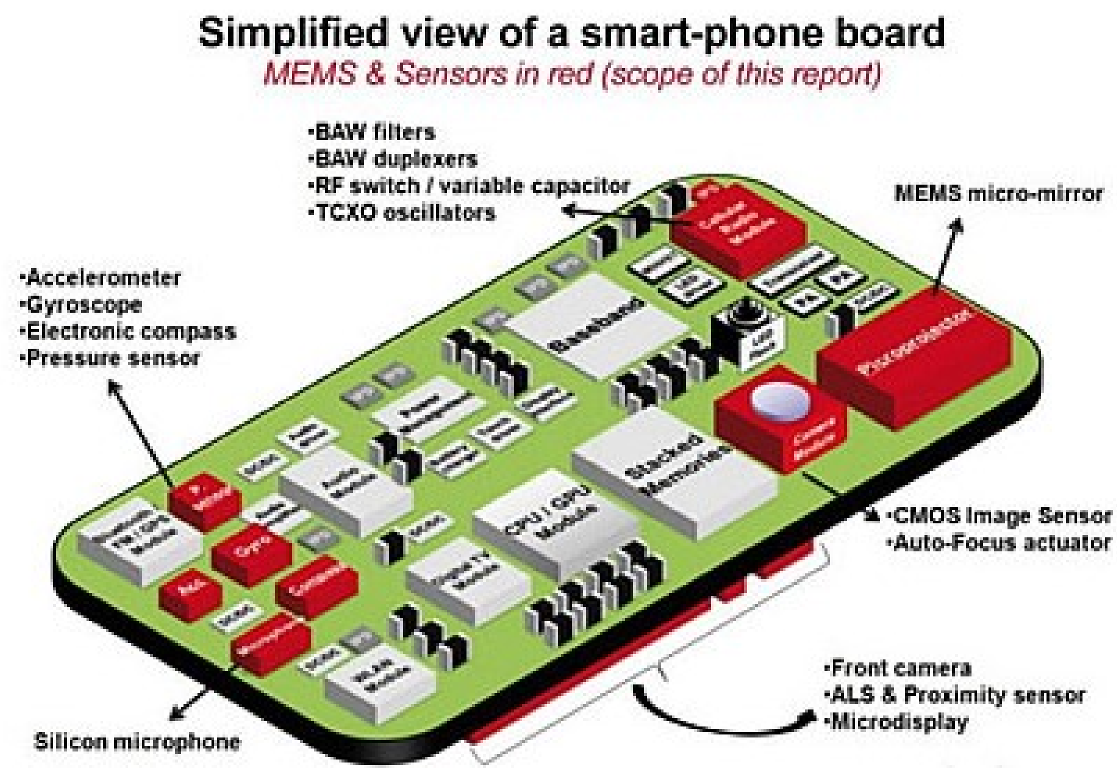
Fully automated airplane combining three phases

Ref: J.H. Huijsing: *Smart Sensor Systems: Why? Where? How?* In *Smart Sensor Systems*, edited by G.C.M. Meijer, Wiley. Sussex, 2008.

Example Illustration of Sensorization

Automatic Washing Machine

Revolution: Manual to Automatic



Revolution: Basic to Smart

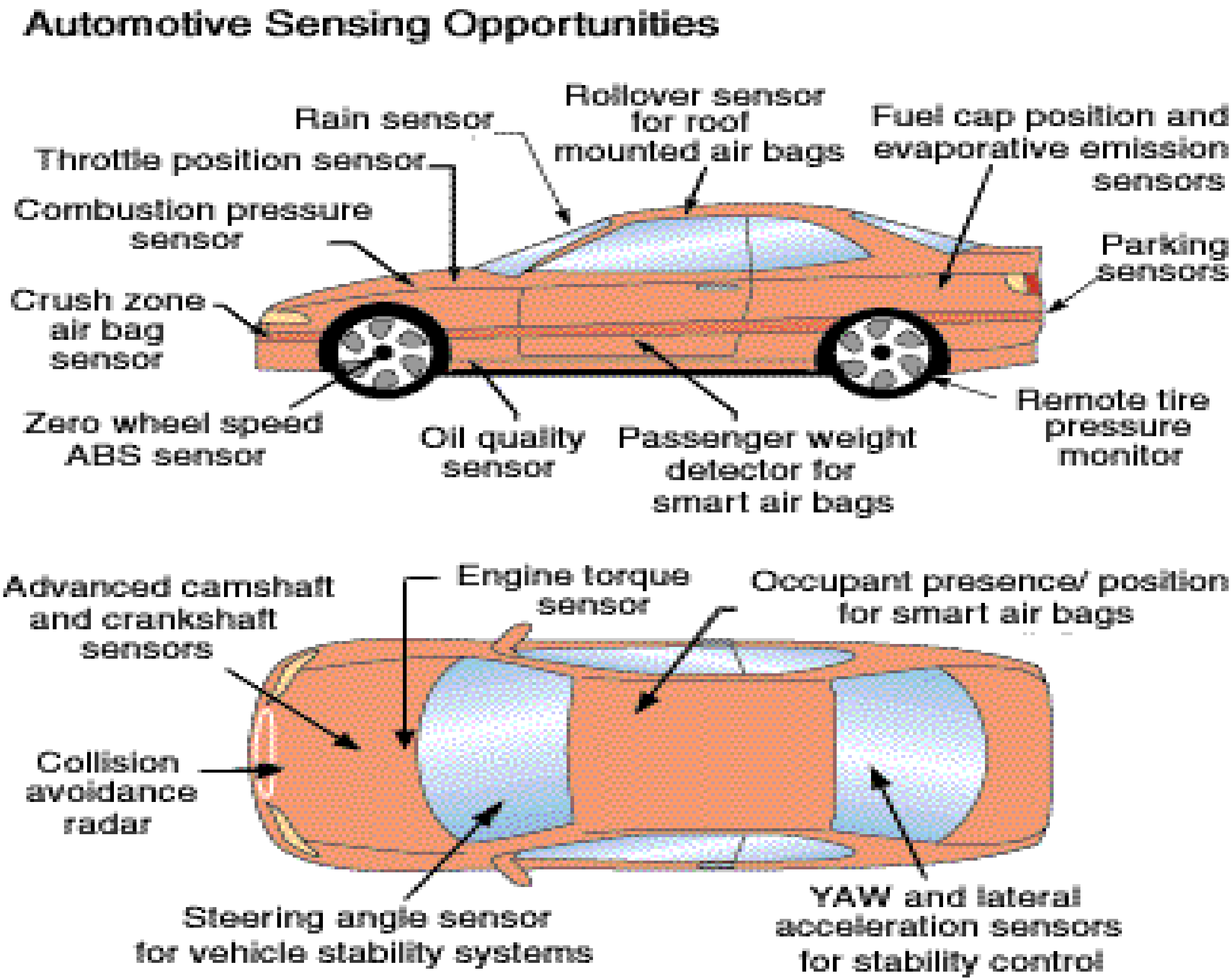
Important Sensors:

Temperature sensor, Humidity sensor
Force sensor, Proximity sensor,
Level sensor, Flow sensor,
Speed sensor, Vibration sensor etc.

Important Sensors Used:

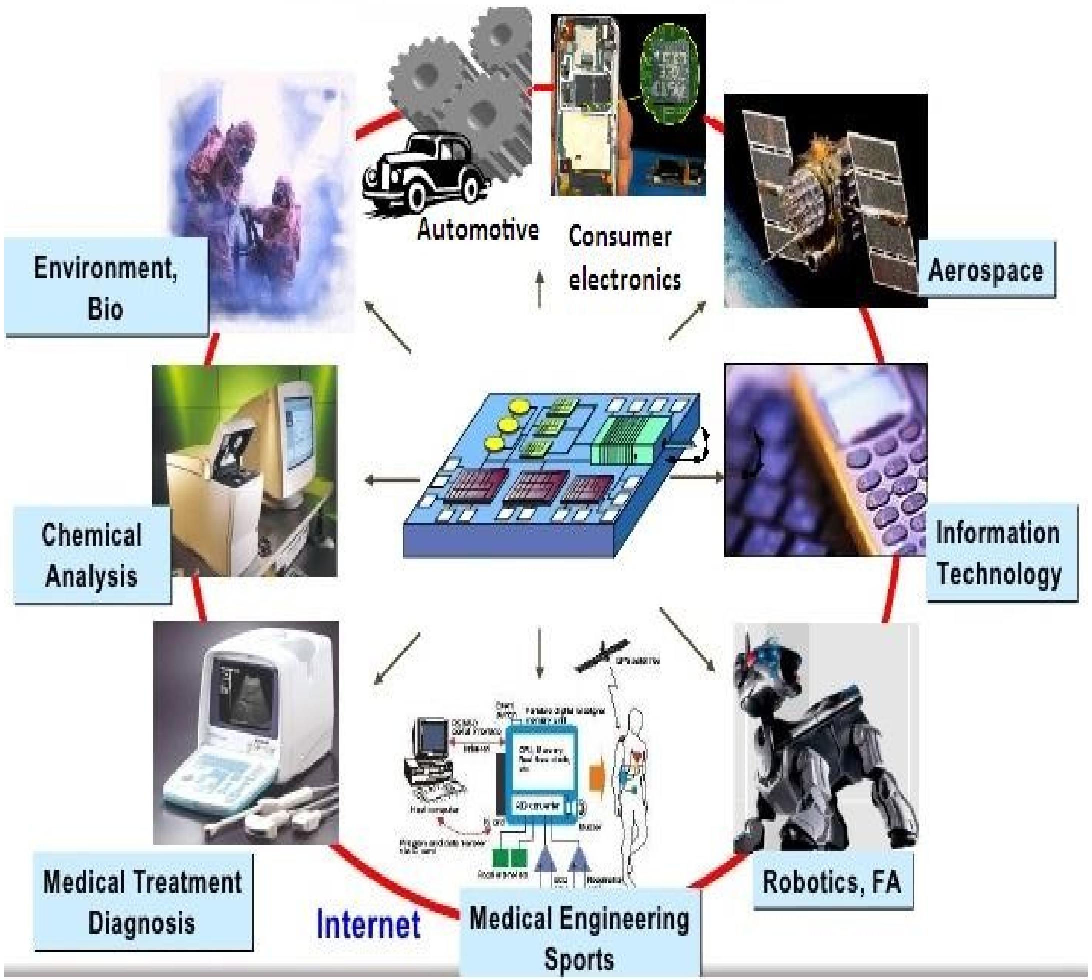
Accelerometer, Gyroscope,
Magnetometer, Proximity sensor,
Microphone, etc.

Sensors in a car



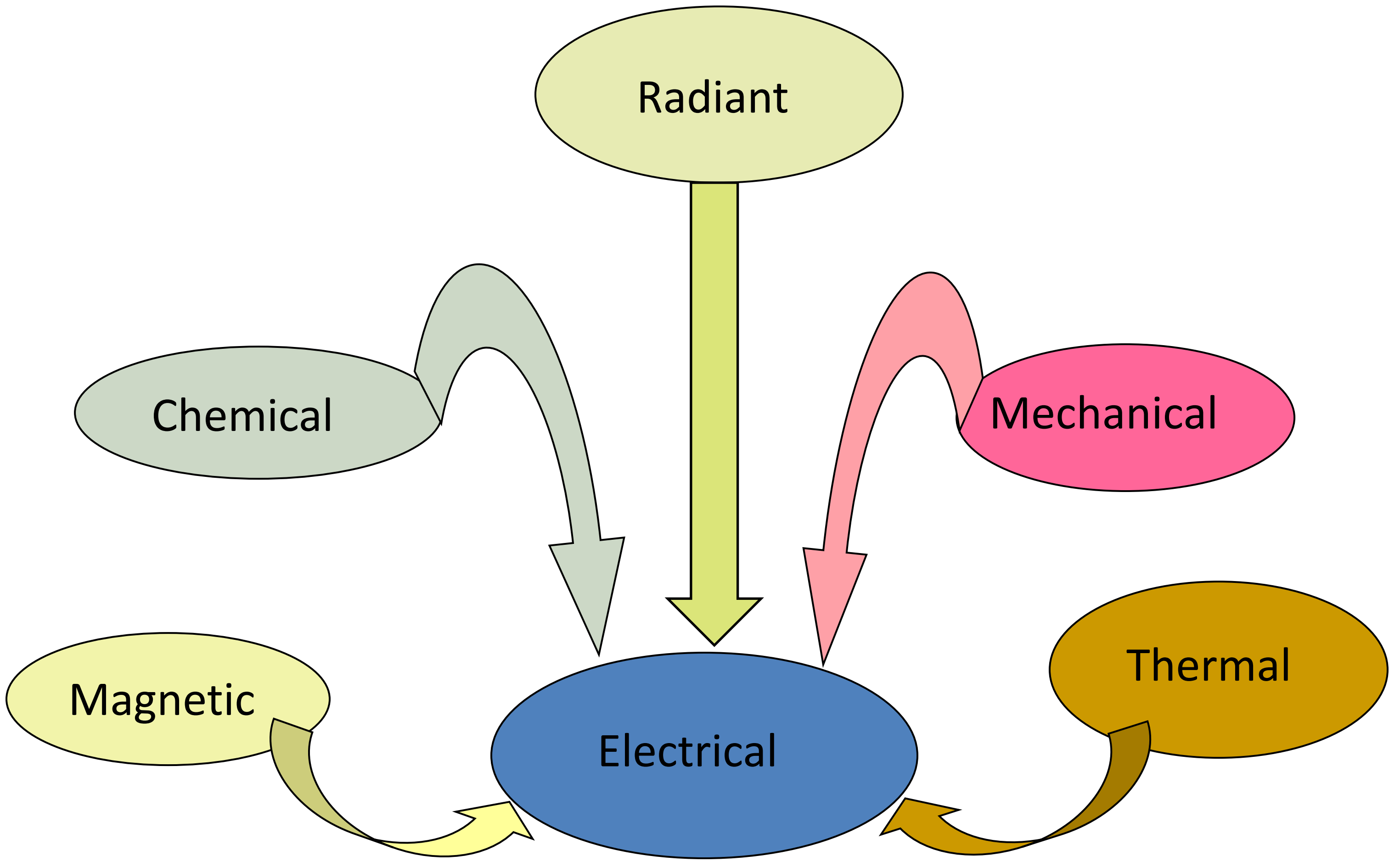
Sensorization

Applications



Popular Sensors

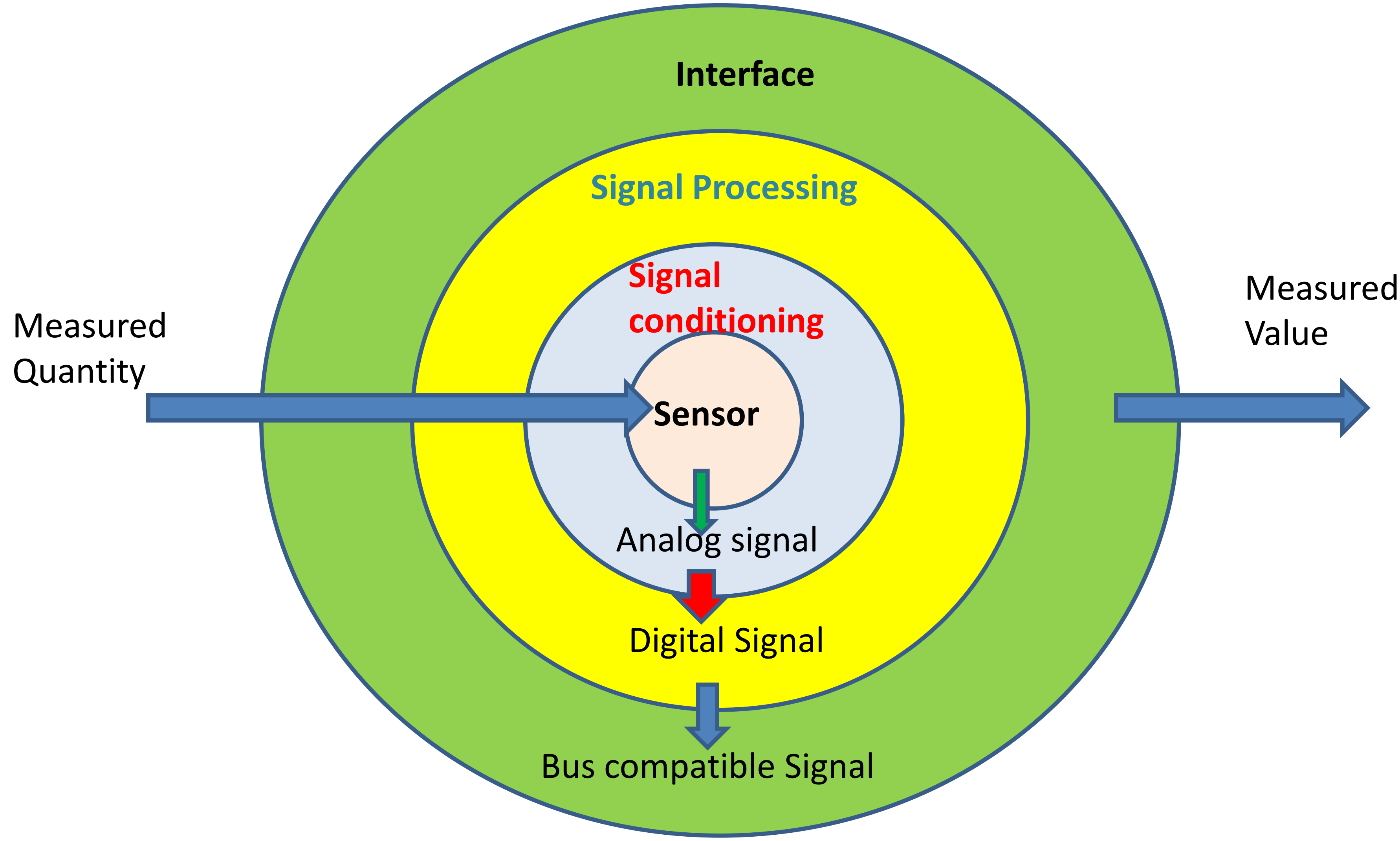
Sensor Signal Domains

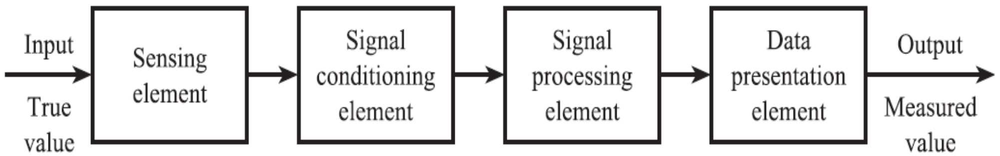


Common Measured Quantity

Domain	Quantity
Mechanical	Position/Displacement, Velocity, Acceleration, Force, Strain, Stress, Pressure, Torque etc.
Thermal	Temperature, Flux, Specific Heat, Thermal Conductivity
Electrical	Charge, Voltage, Current, Electric Field (amplitude, phase,), Conductivity
Magnetic	Magnetic Field (amplitude, phase, polarization), Flux, Permeability
Optical	Refractive Index, Reflectivity, Absorption
Chemical	Fluid Concentrations (Gas or Liquid), Biological parameters/variables

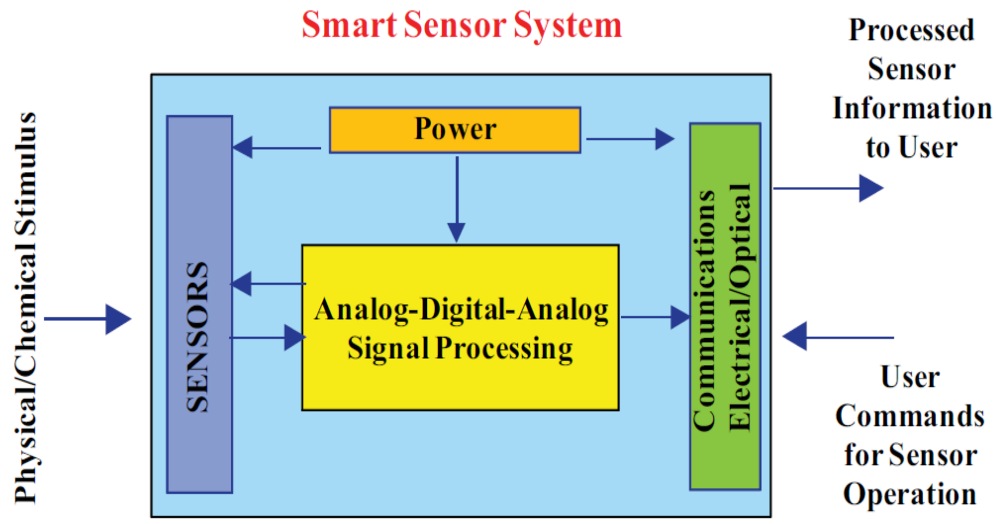
Basic Sensor Structure

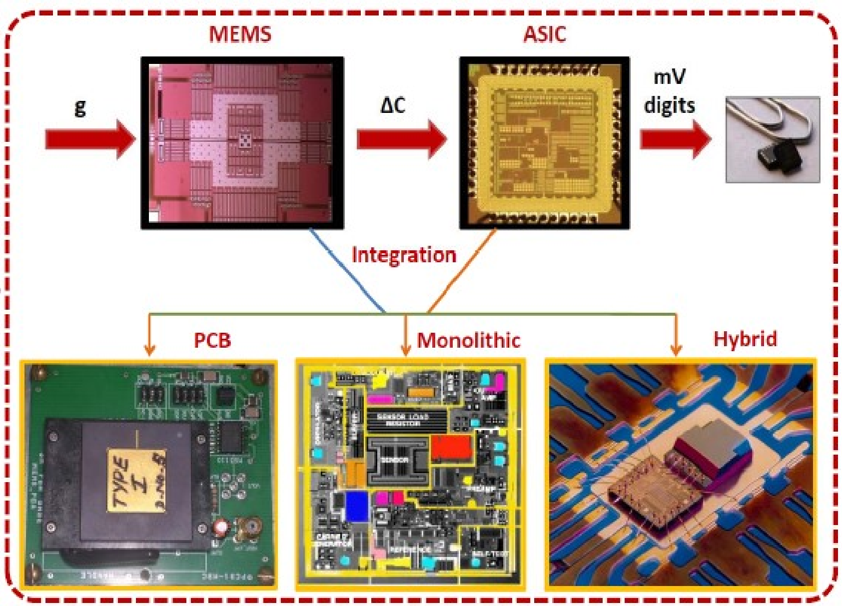




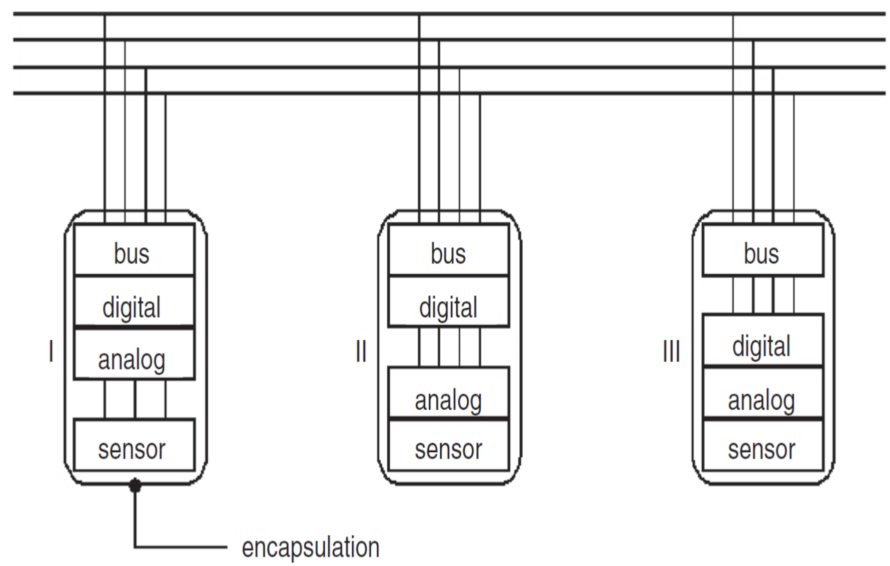
Desired features of Advanced Sensors and Systems

- Miniaturization
- Hybridization/Integration/ Packaging
- Incorporation of complex signal processing capabilities
- Improved data communication
- Enhancement of sensing domain



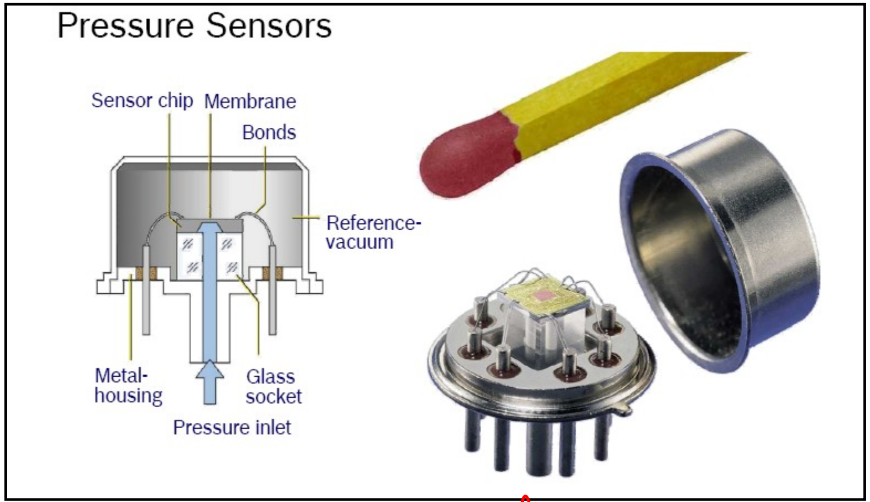


Hybrid Smart Sensor Types



Recent Developments in Sensing Elements

- Newer Sensing Materials
- Newer Sensing Methodology
- New Sensing structures
- Precision manufacturing
- Small size
- Ready integration with sensor electronics



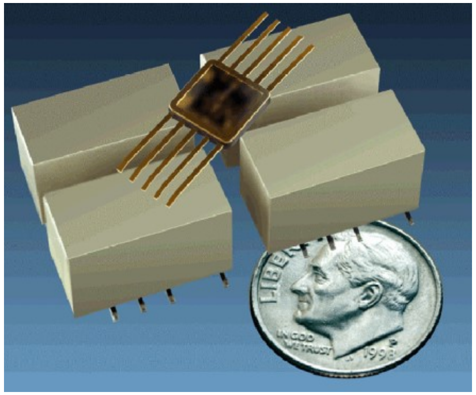
Micro Electro Mechanical Systems

- MEMS
- NEMS
- MOEMS
- Gas Sensors
- Bio Sensors

Nano

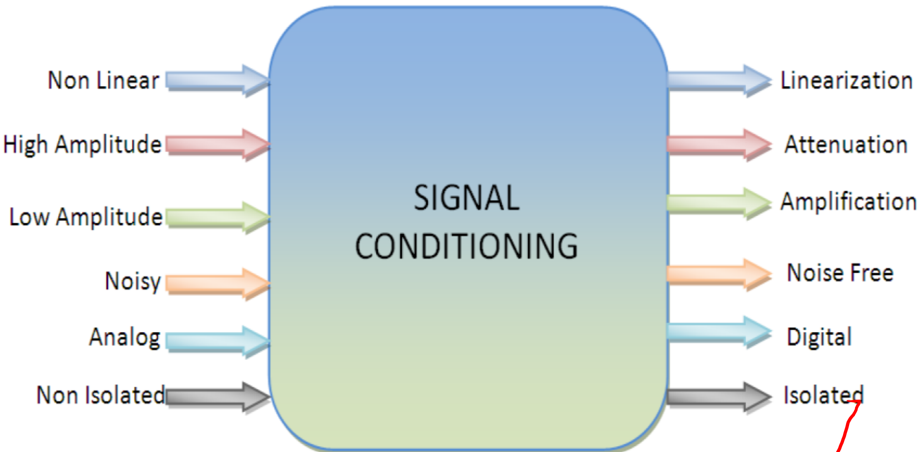
Optical

$$C = \frac{\epsilon_0 A}{d}$$



Micro-Relay - Cronos

Developments in Signal Conditioning & Processing



- **Features:**
- A/D Conversion
- Digital Filtering
- Linearization
- Self test and auto-calibration
- Provide intelligence and decision making capacity
- Provide compatibility with network interface

- Bridges, oscillators, amplifiers, rectifiers, filters etc.
- Integrated in a single IC

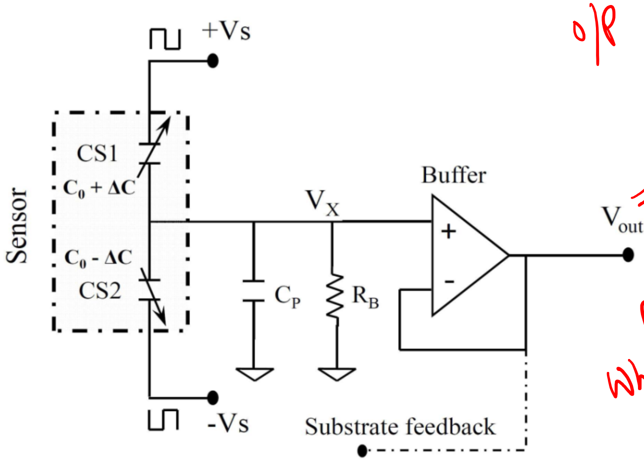
o/p

i/p

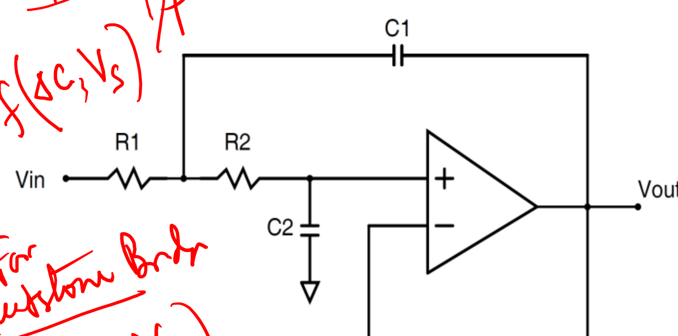
$V_{out} = f(\Delta C, V_s)$

For Wheatstone Bridge

$V_0 = f(\Delta R, V_s)$



Capacitance half bridge



Sallen Key Filter

Challenges:

- With improvement of IC technology, the operating voltage is reduced. It decreases linear operating range
- Reduction of power consumption
- Reduction of noise, interference
- Size, monolithic integration

Developments in Signal Conditioning & Processing

Digital Signal Processing:

- Flexibility in noise removal by digital filtering
- Complex and fast computation

Smartness:

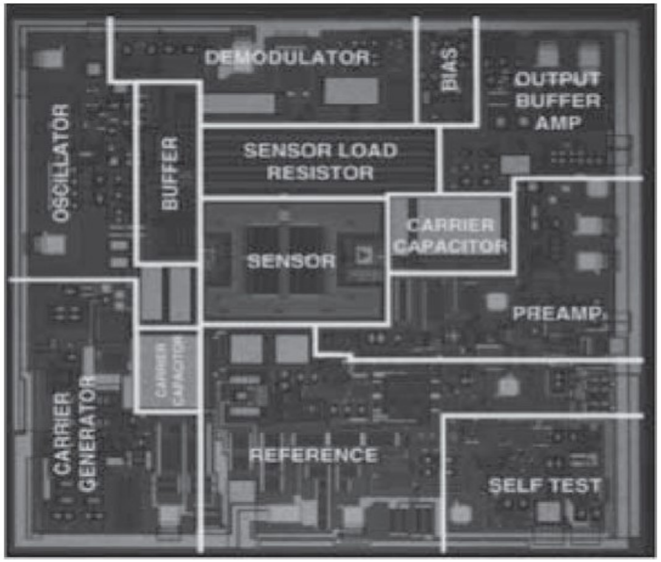
- Provides network connectivity

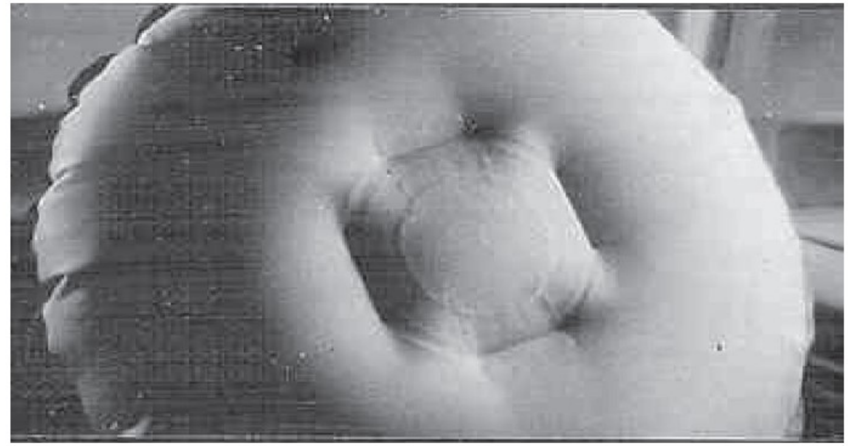
Intelligence:

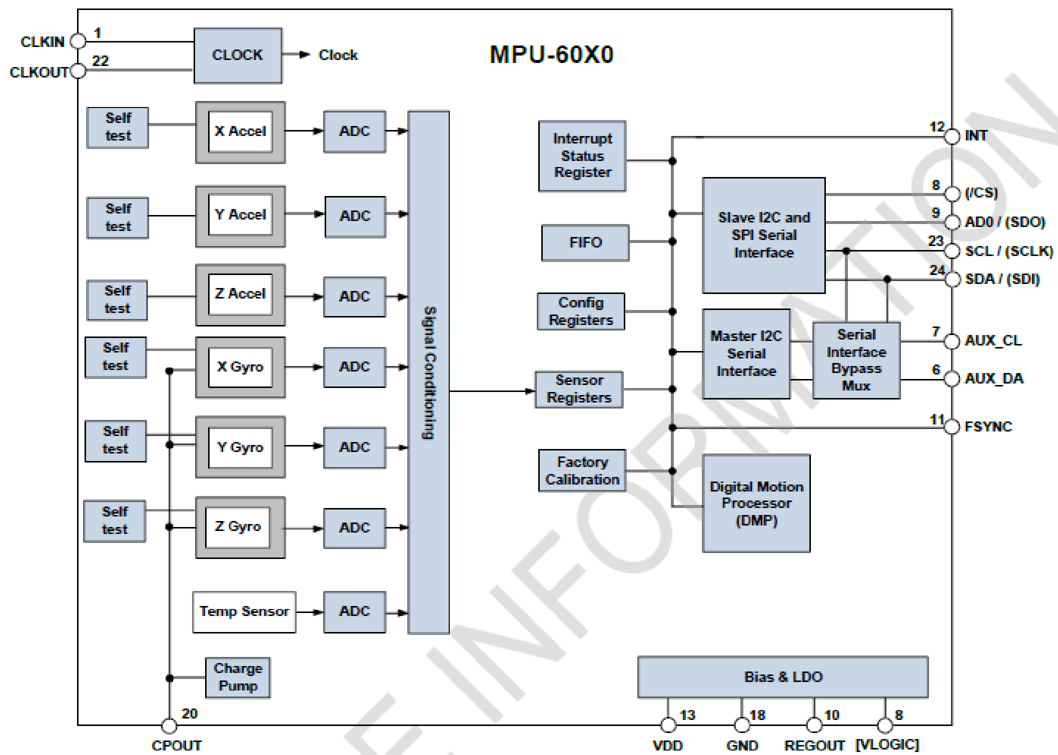
- Provides several intelligent functions, e.g. memory, self testing, self identification, self validation etc.

- Uses advanced features like Neural Network, Fuzzy logic etc.

Example: Commercial IMU SensorsADXL-50, MPU 6050







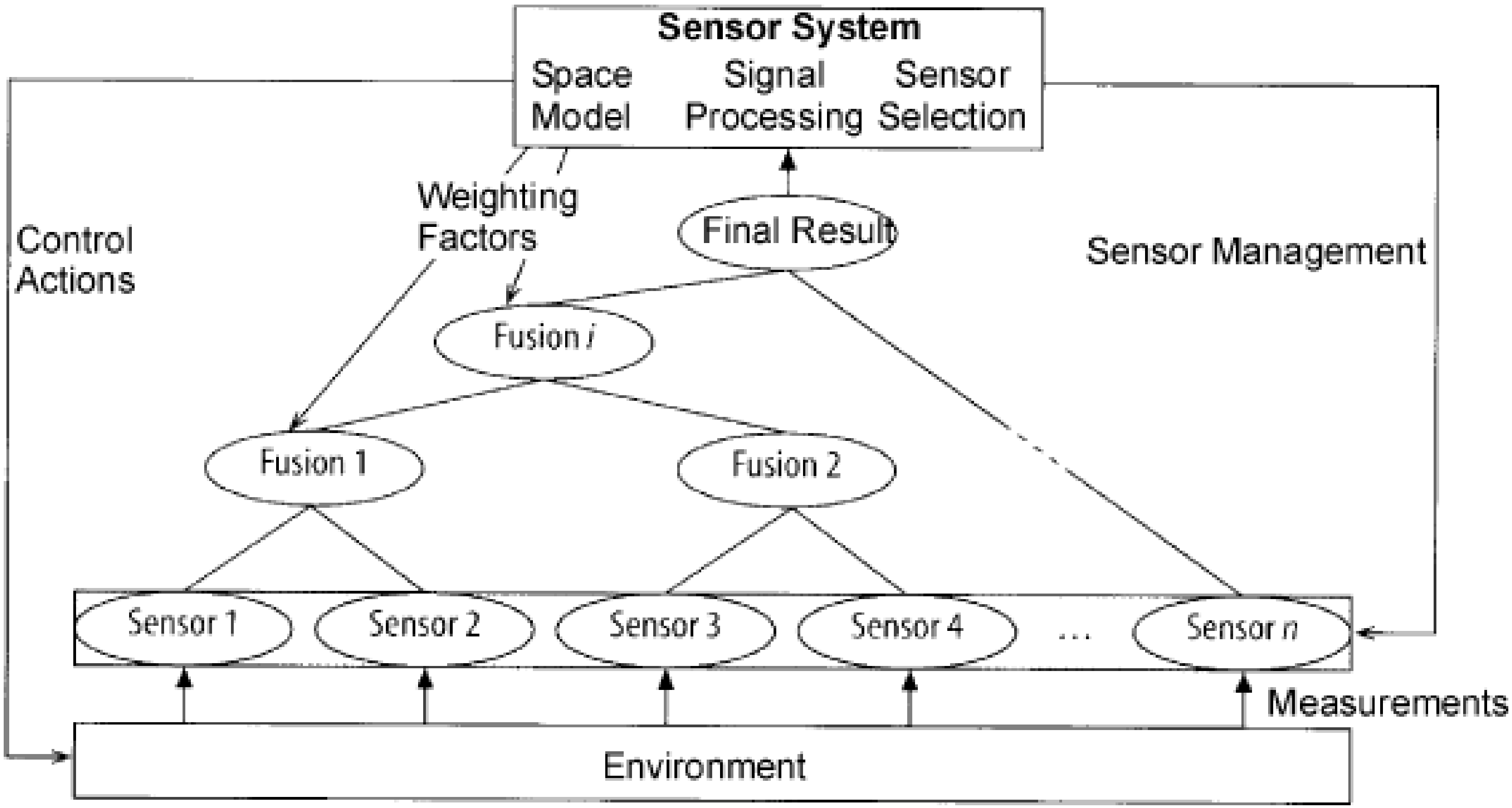
Note: Pin names in round brackets ( ) apply only to MPU-6000
Pin names in square brackets [ ] apply only to MPU-6050

Desired functionalities in a sensor to provide smartness

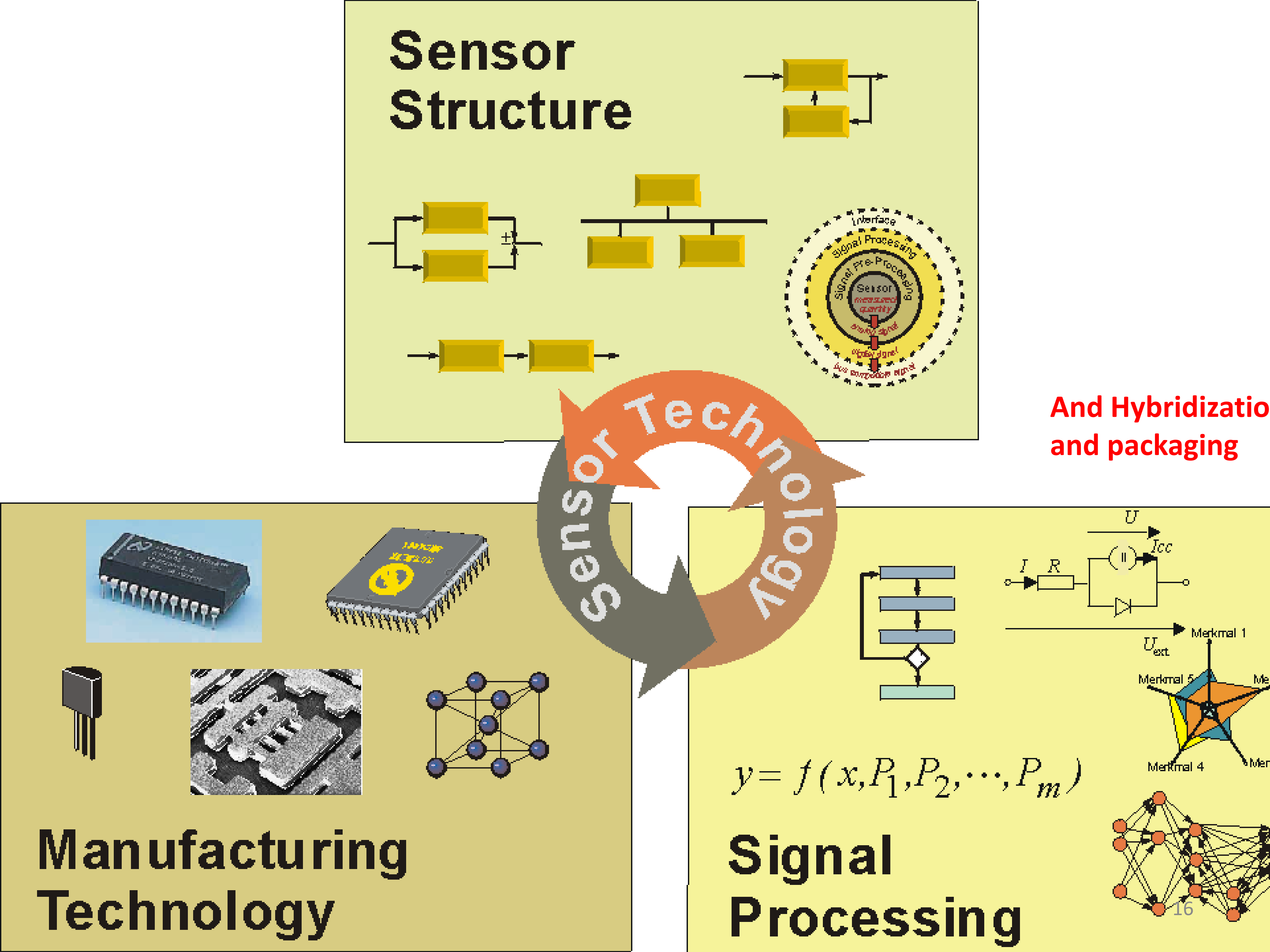
- Self test, self diagnostic
- Digital output in standard format
- Software functions like signal processing and Data logging
- Multi-channel data fusion
- Conforming to standard data transfer and control protocol.
- Security

Advanced features:

- Fault diagnostics and reconfiguration
- Sensor fusion

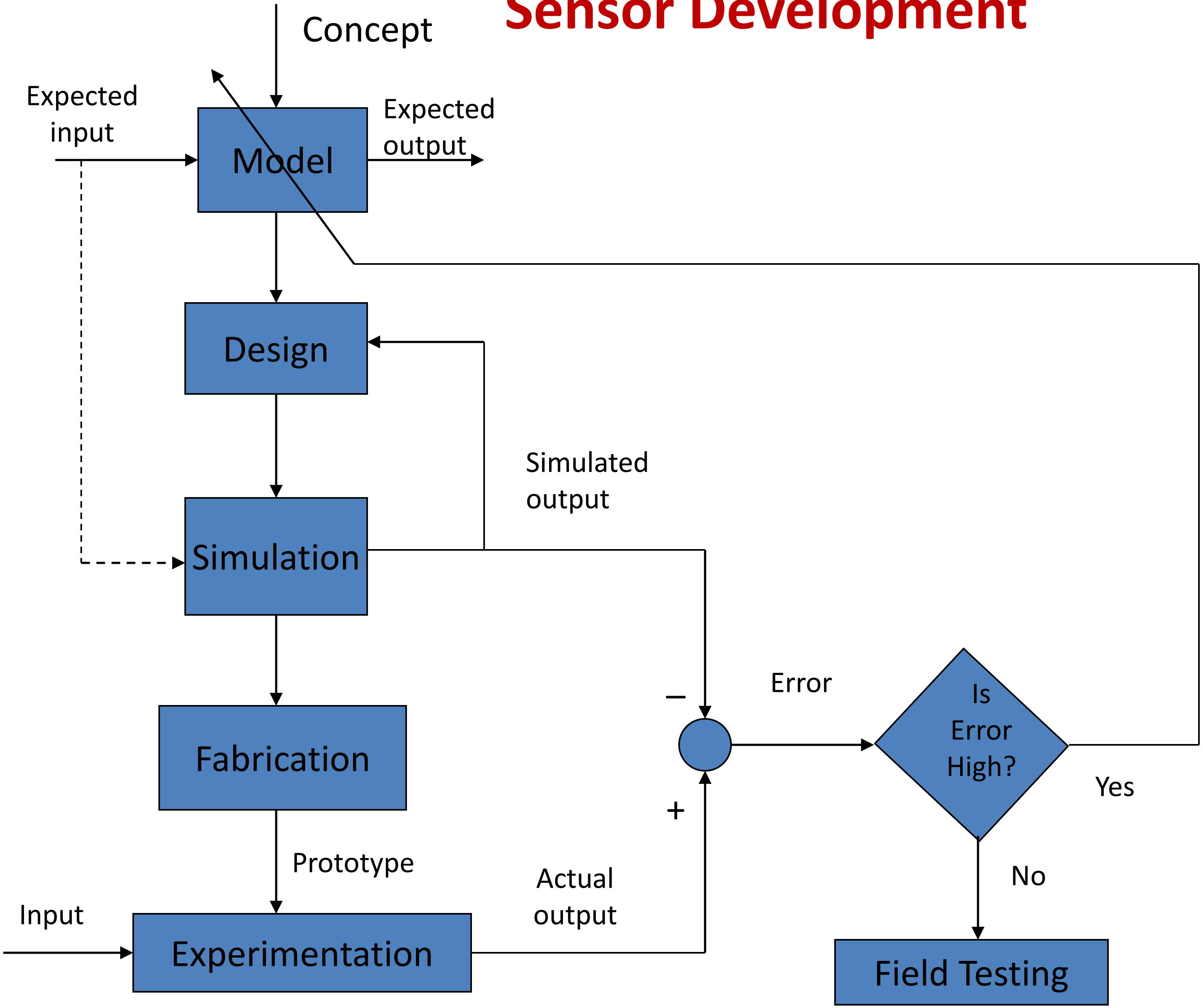


Sensor Fusion

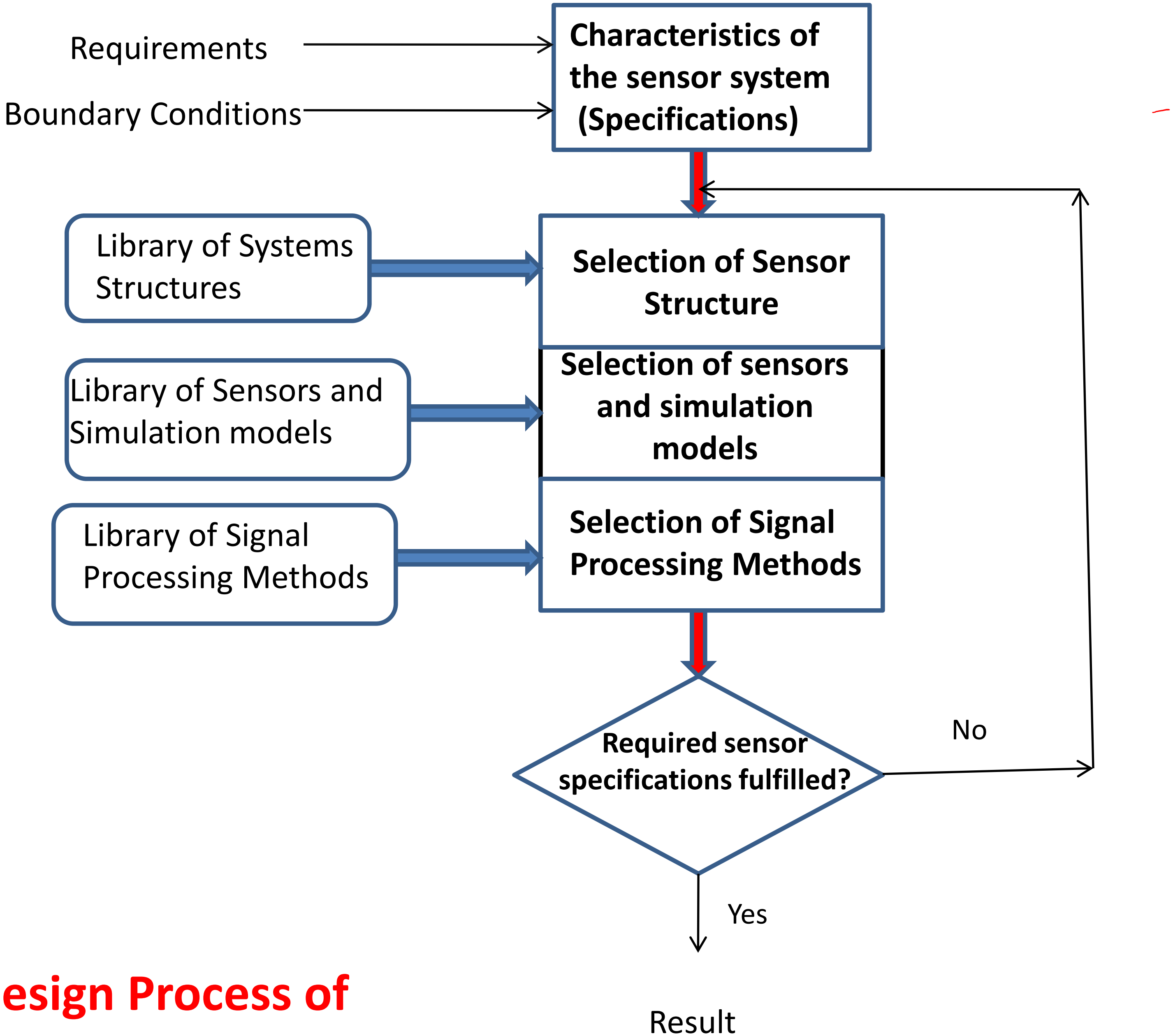


**And Hybridizatio
and packaging**

Sensor Development



Modeling, Simulation and Experimentation Cycle



Design Process of Sensor Systems

Scope for Advanced Sensing Techniques:

- **Materials**
- **Fabrication Techniques**
- **Hybridization/Integration/Packaging**
- **Mathematical Modelling**
- **Design Methodology**
- **Newer Sensing Techniques**
- **Applications**

Sensing materials

Sensing materials

A. Silicon:

Advantages:

- Versatile; Small size
- Easy for batch fabrication/microfabrication
- Can readily be integrated with signal conditioning circuits
- High young modulus (comparable to steel)
- High melting point
- Good structural stability

Physical and chemical effects of sensors on Silicon:

Signal Domain for Si	Type of Sensing
1. Radiant	Photovoltaic, Photoconductive
2. Mechanical	Pressure sensing (diaphragm), vibrations sensing (accelerometer) Piezo-resistivity
3. Thermal	IC temperature sensor
4. Magnetic	Hall effect sensor, Magneto-resistance
5. Chemical	ISFET/ChemFET

B. Ceramic materials:

- Piezoelectric effect
- Ferroelectric effect
- Pyroelectric effect

Force $\Rightarrow$ Charge

Radiation $\Rightarrow$ Charge

Materials:

- Quartz (SIO_2)
- ZnO (Piezoelectric + Pyroelectric)
- $LiNbO_3$ (Ferroelectric + Pyroelectric)
- $Pb(ZrTi)O_3$ (PZT) (Ferroelectric effect)

Since Si does not have any Piezoelectric property, such property can be added by depositing a layer of piezoelectric material on crystalline Silicon. Example: deposition of ZnO layers on Si-structures in SAW (Surface Acoustic Wave) sensors.

C. Metal oxides:

Example: ZnO, SnO_2 , Al_2O_3, TiO_2,

Used for: (i) Humidity sensing (Al_2O_3)

(ii) Gas sensing e.g. CO, CO_2 , CH_4 ,

(O_2 gas sensing using ZrO_2)

D. Polymer/ Plastics:

Examples:

1. PVDF (a polymer type ferroelectric material, used for medical imaging)
2. Electret (A plastic material that can trap electric charge- Electret microphone)
3. Polymer sensors for detection of enzymes

E. Other types of semiconductors:

Examples:

CdS, InAs, GaS etc: For radiation detection and other applications

F. Thin film and thick film materials:

- Deposition of thin layers of resistive, piezoelectric, semiconductor or magnetic materials on sensitive substrates.
- These layers often display the same effect as bulk materials and can easily be combined with electronic circuits.
- Examples: Thin film Nichrome strain gages, Thick film Thermistors, Ni-Fe head magnetic recording heads.
- Thick film: 10-50 micron
- Thin film < 10 micron
- Deposition techniques are different.

G. Optical Fiber based Sensors:

Single mode and multimode fibers for sensing (i) temperature, (ii) strain, (iii) velocity, (iv) current, (v) voltage, (vi) magnetic field.

H. Newer materials:

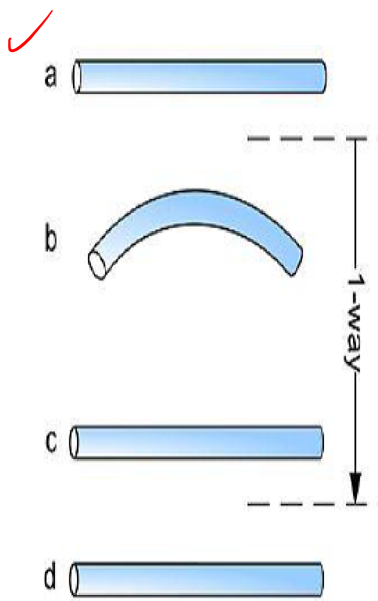
Examples: Shape Memory Alloys (SMA), Carbon Nano-tubes, Ghraphene oxides etc.

Shape memory Alloy (e.g. Ni-Ti Alloy)

SMA: An alloy that "remembers" its original shape
An alloy after deformation returns to its pre-deformed shape when heated.
An alloy that undergoes large strain & capable of recovering the initial configuration

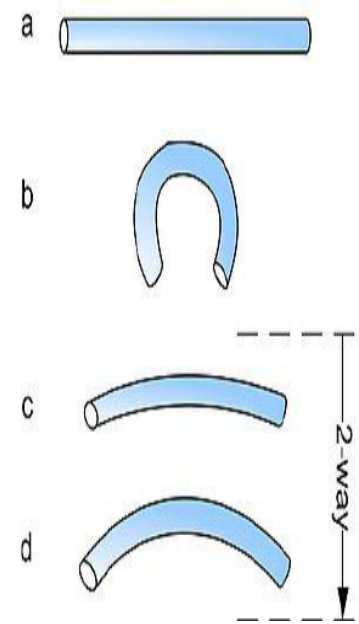
One Way Shape Memory Effect

- When a SMA is in its cold state (below As), the metal can be bent or stretched and will hold this shape until heated above the transition T.
- Upon heating, the shape changes to its original.
- When the metal cools again, it will remain in the hot shape until deformed again.
- In this case, cooling from high Tdoes not cause macroscopic shape change.



Two Way Shape Memory Effect

- The material remembers two shapes: one at high T & the other at low T.
- Shows shape memory effect during both cooling and heating.
- The metal can be trained to leave some reminders of the deformed low temp condition in the high temperature phases.
- Above a certain T, the metal loses the 2 way memory effect. This is called "amnesia"



Thank You