UNIT 5 (KOE-034)

❖ Human senses and sensors:

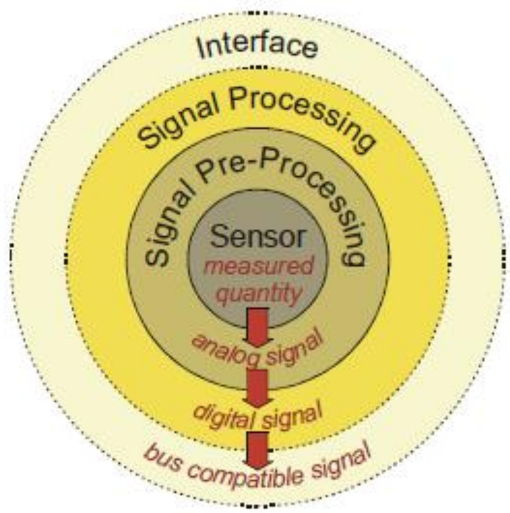
Although human senses are mainly receivers and processors of information from nature and the environment, they have restrictions naturally imposed on them. That is why practical sensors must be an extension of our senses.

An infrared sensor is required to see beyond the human color spectrum; an ultrasonic sensor to discover sounds higher than those with which the human ear can cope.

Often sensor devices need to operate in severe conditions, such as in underwater exploration, the inspection of nuclear reactors and biomedical applications. In such cases, the device often produces a poor output, which is data with a low signal-to-noise ratio (SNR), and may require amplification, filtering and processing prior to further use and/or interpretation. At this point measurement and ***control systems*** assume greater significance.

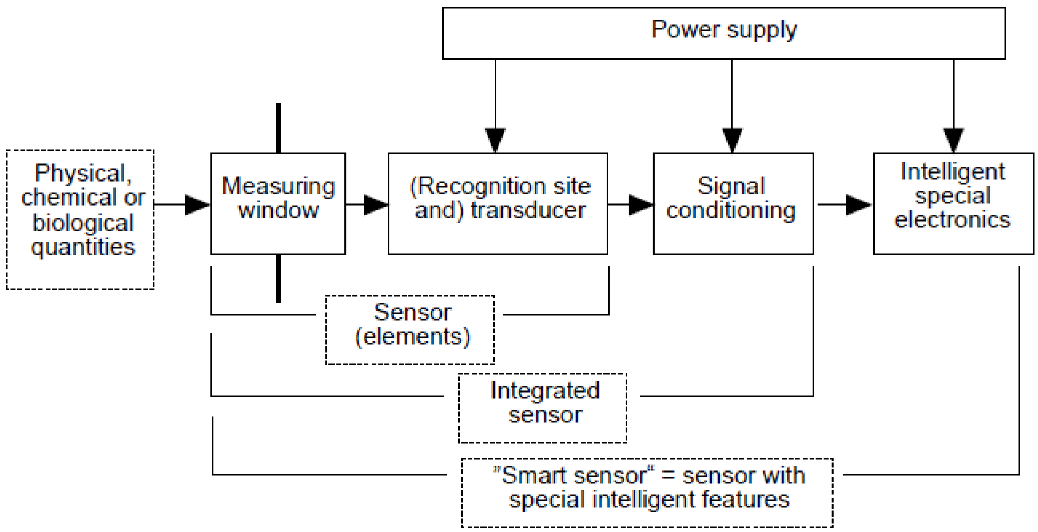
❖ Standard Sensor Vs Intelligent Sensor:

Stander Sensor is a combination of a sensing element, an analog interface circuit, an analog to digital converter (ADC) and a bus interface in single housing.



Standard Sensor structure

Smart Sensor/ Intelligent sensor is the sensor that has one or several intelligent functions such as *logical function, two-way communication, make decision, self-calibration, self-testing, self-identification, self-validation, self-adaptation*, etc.

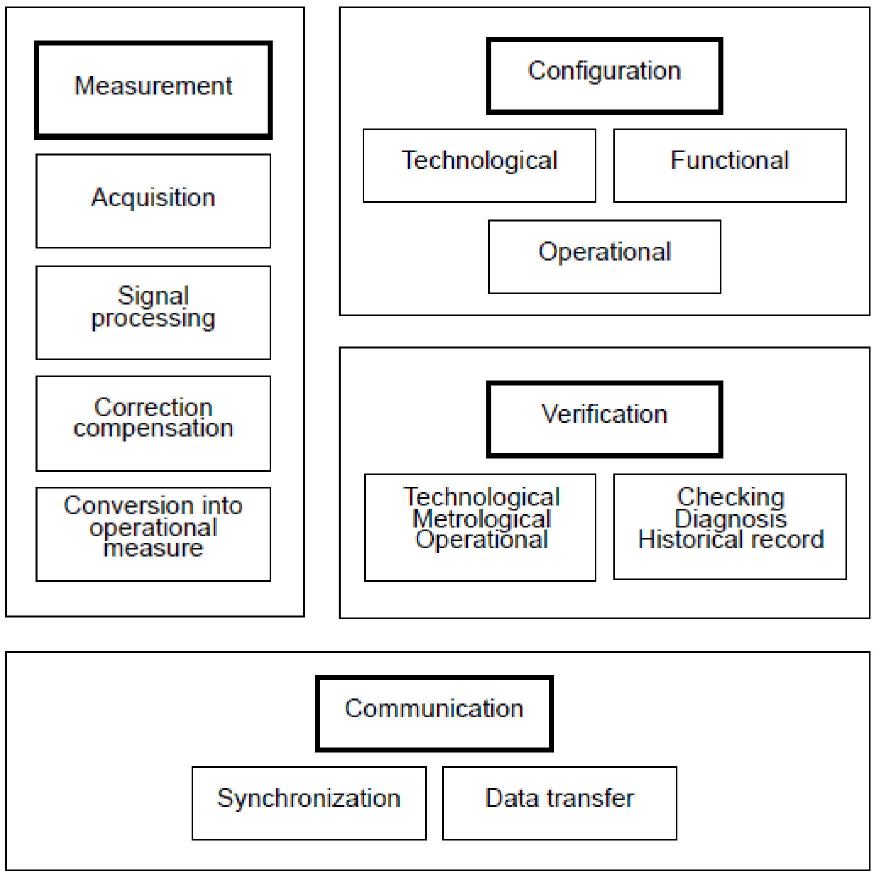


Smart / Intelligent Sensor structure

The advent of integrated circuits, which became possible because of the tremendous progress in semiconductor technology, resulted in the low cost microprocessor. Thus if it is possible to design a *low cost sensor* which is silicon based then the overall cost of the *control system* can be reduced. We can have integrated sensors which has electronics and the transduction element together on one silicon chip. This complete system can be called as *system-on-chip*. The main aim of integrating the electronics and the sensor is to make an ***intelligent sensor***, which can be called as *smart sensor*. Smart sensors then have the ability to make some decision.

Physically a smart sensor consists of ***transduction element, signal conditioning electronic and controller/processor*** that support some ***intelligence*** in a single package.

❖ Smart Sensor function:



(Smart Sensor function)

The four basic functions of smart sensors are ***measurement, configuration, verification, and communication***. Each function may have more than one sub-function as well. Although all four functions are very important and they individually play a crucial role in design of intelligent sensors, the functions which largely contribute to the smartness of the intelligent sensor are verification and measurement functions.

The ***verification function*** offers services, such as continuous supervision of the intelligent sensor's behavior using a set of supervisory equipment implemented in the intelligent sensor. *Results of continuous supervision can be stored in a database and available for maintenance purposes*. It offers the necessary services for diagnosis, allowing the user to locate faults whenever they are detected.

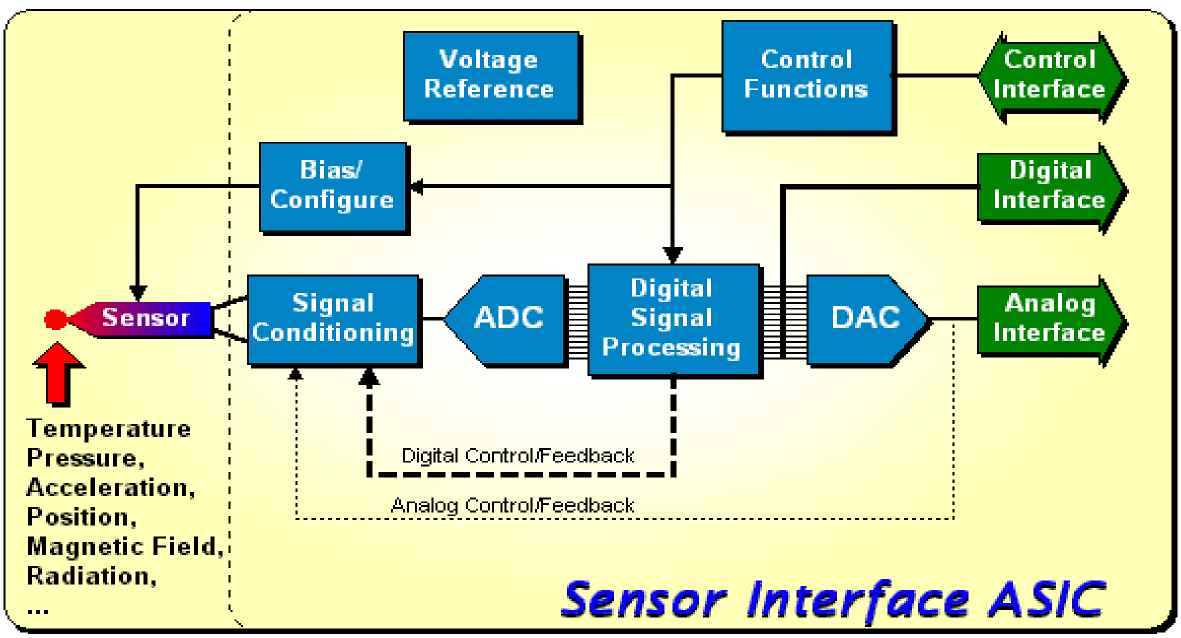
The communication function allows bidirectional communication between the intelligent sensor and other equipment to which it is connected by a field bus.

❖ General Architecture of smart sensor:

One can easily propose a general architecture of smart sensor from its definition, functions. From the definition of smart sensor it seems that it is similar to a data acquisition system, the only difference being the presence of complete system on a single silicon chip. In addition to this it has on–chip offset and temperature compensation. 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

The generalized architecture of smart sensor is shown below:



Internal Architecture of Smart Sensor

❖ Potential advantages of the smart-sensor concept include:

- ✓ lower maintenance;
- ✓ reduced down time;
- ✓ higher reliability;
- ✓ fault tolerant systems;
- ✓ adaptability for self-calibration and compensation;
- ✓ lower cost;
- ✓ lower weight;
- ✓ fewer interconnections between multiple sensors and control systems; and
- ✓ Less complex system architecture.

❖ What does the IoT expect of its sensors?

Sensors have traditionally been functionally simple devices that convert physical variables into electrical signals or changes in electrical properties. While this functionality is an essential starting point, sensors need to add the following properties to perform as IoT components:

- Low cost, so they can be economically deployed in large numbers
- Physically small, to "disappear" unobtrusively into any environment
- Wireless, as a wired connection is typically not possible
- Self-identification and self-validation
- Very low power, so it can survive for years without a battery change, or manage with energy harvesting
- Robust, to minimize or eliminate maintenance
- Self-diagnostic and self-healing
- Self-calibrating, or accepts calibration commands via wireless link
- Data pre-processing, to reduce load on gateways, PLCs, and cloud resources

❖ Sensor characteristics

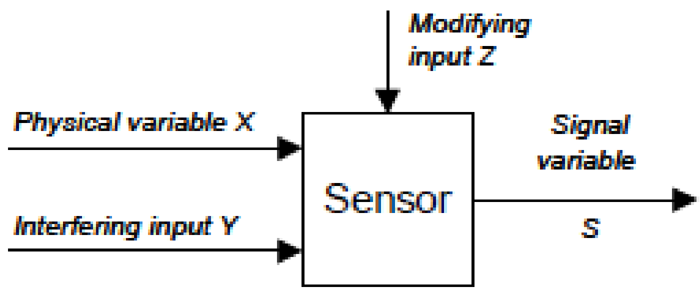
Static characteristics: The properties of the system after all transient effects have settled to their final or steady state

- ✓ Accuracy
- ✓ Discrimination
- ✓ Precision
- ✓ Errors
- ✓ Drift
- ✓ Sensitivity
- ✓ Linearity
- ✓ Hysteresis

Dynamic characteristics: The properties of the system transient response to an input

- ✓ Zero order systems
- ✓ First order systems
- ✓ Second order systems

❖ Calibration:



Interfering inputs (Y): Those that the sensor to respond as the linear superposition with the measurand variable X

Modifying inputs (Z): Those that change the behavior of the sensor and, hence, the calibration curve

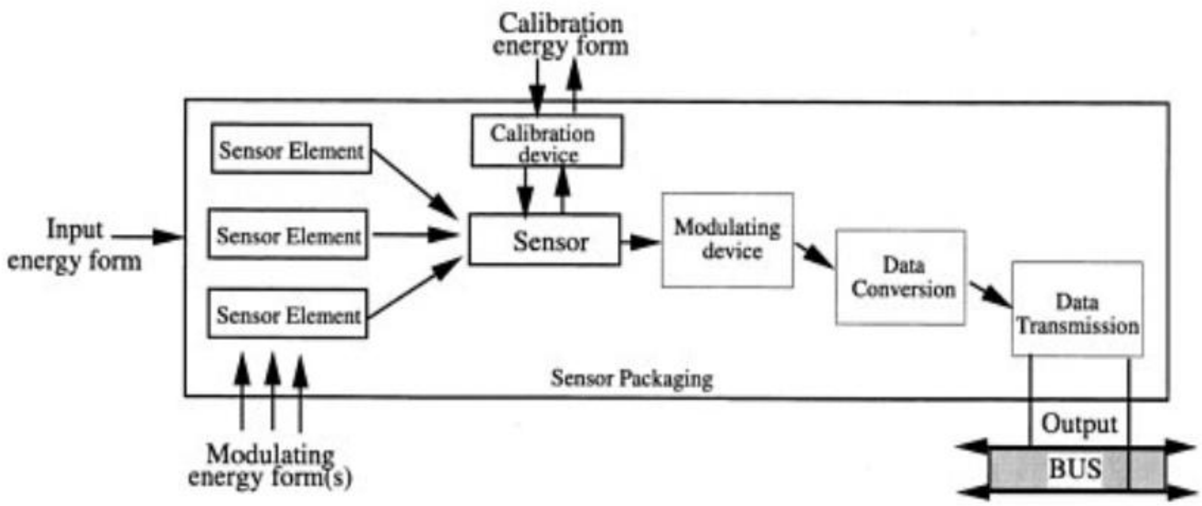
Smart sensors acquire information about a non-electrical quantity of interest (the measurand) and convert this information to a useful electrical output signal. In order to do so, they combine a sensing element and the associated interface electronics on a single chip or in a single package. The sensing element performs the conversion from the non-electrical domain of the measurand to an electrical signal, while the interface electronics further process this signal to produce an output that can readily be used in a measurement or control system.

Errors introduced in these steps affect the performance and reliability of the overall system. Therefore, it is very important to determine how large these errors are. The process of doing so is generally referred to as *calibration*.

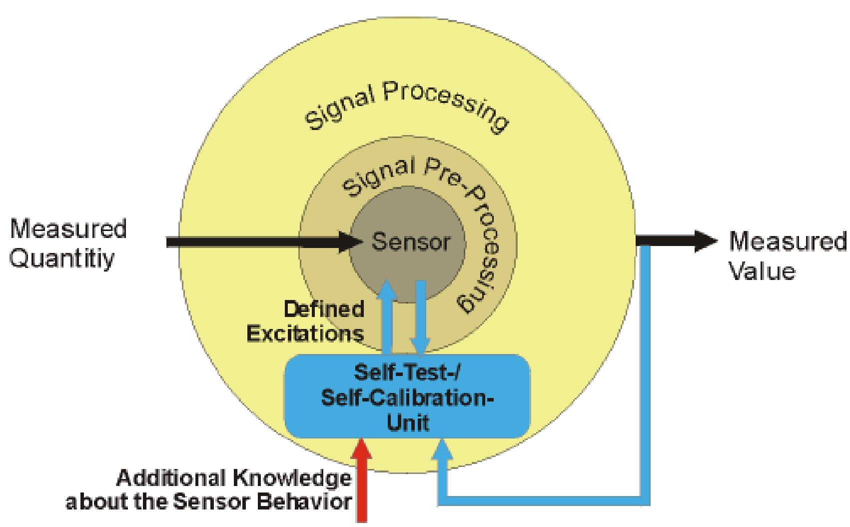
So,

An intelligent sensor should have a standard output and the ability to *compensate unwanted cross-sensitivities*. In addition, *offset, drift and nonlinearity should be minimized*. Some kind of *self-testing or calibration* should periodically be performed therefore the system will cheaply be maintained. The way to realize this concept is to combine a sensor device with a number of microelectronics components into a single sensor package often referred to as an intelligent sensor.

Calibration is, in short, the procedure of establishing the accuracy of a sensor. A proper calibration procedure ensures that readings of a sensor can be traced to international standards, and enables correction of these readings when necessary



Self-test / Self-calibration is, in short, the term that is used for a variety of techniques that improve the accuracy of a sensor by adding intelligence to it.

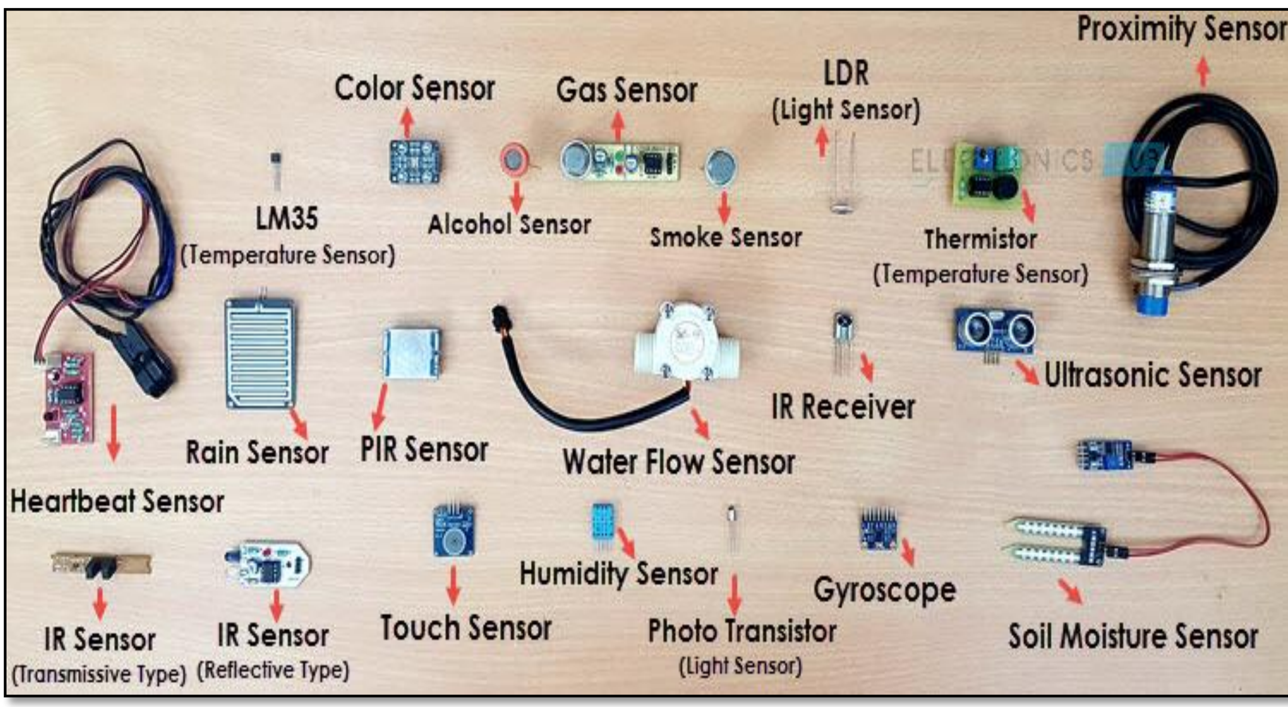


Smart Sensor structure

❖ Different Types of Sensors

The following is a list of different types of sensors that are commonly used in various applications. All these sensors are used for measuring one of the physical properties like Temperature, Resistance, Capacitance, Conduction, Heat Transfer etc.

- ✓ Temperature Sensor
- ✓ Proximity Sensor
- ✓ Accelerometer
- ✓ IR Sensor (Infrared Sensor)
- ✓ Pressure Sensor
- ✓ Light Sensor
- ✓ Ultrasonic Sensor
- ✓ Smoke, Gas and Alcohol Sensor
- ✓ Touch Sensor
- ✓ Color Sensor
- ✓ Humidity Sensor
- ✓ Tilt Sensor
- ✓ Flow and Level Sensor.



❖ Robots classification:

The following is the classification of Robots according to the Robotics Institute of America

- ✓ **Variable-Sequence Robot**: A device that performs the successive stages of a task according to a predetermined method easy to modify
- ✓ **Playback Robot** :A human operator performs the task manually by leading the Robot
- ✓ **Numerical Control Robot**: The operator supplies the movement program rather than teaching it the task manually.
- ✓ **Intelligent Robot:** A robot with the means to understand its environment and the ability to successfully complete a task despite changes to the environment.

❖ Application of sensors in automatic robot control & automobile engine control:

1. Automatic robot control: (Sensor-Driven Robot Control)

To accurately achieve a task in an intelligent environment, a robot has to be able to react dynamically to changes in its surrounding

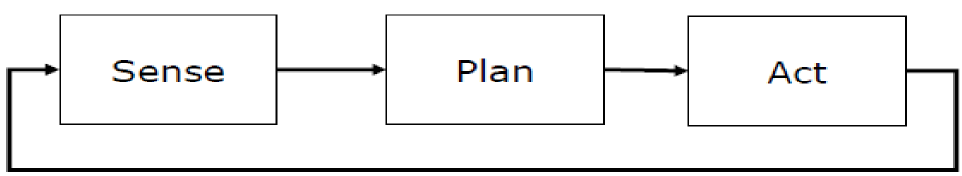
- ✓ Robots need sensors to perceive the environment
- ✓ Most robots use a set of different sensors (different sensors serve different purposes)
- ✓ Information from sensors has to be integrated into the control of the robot
- ✓ Internal sensors to measure the robot configuration
  - Encoders measure the rotation angle of a joint
  - Limit switches detect when the joint has reached the limit
- ✓ Proximity sensors are used to measure the distance or location of objects in the environment. This can then be used to determine the location of the robot.
  - Infrared sensors determine the distance to an object by measuring the amount of infrared light the object reflects back to the robot
  - Ultrasonic sensors (sonars) measure the time that an ultrasonic signal takes until it returns to the robot
  - Laser range finders determine distance by measuring either the time it takes for a laser beam to be reflected back to the robot or by measuring where the laser hits the object
- ✓ Computer Vision provides robots with the capability to passively observe the environment
  - Stereo vision systems provide complete location information using triangulation
  - However, computer vision is very complex (Correspondence problem makes stereo vision even more difficult)
  - ✓ **Robot control architecture:**

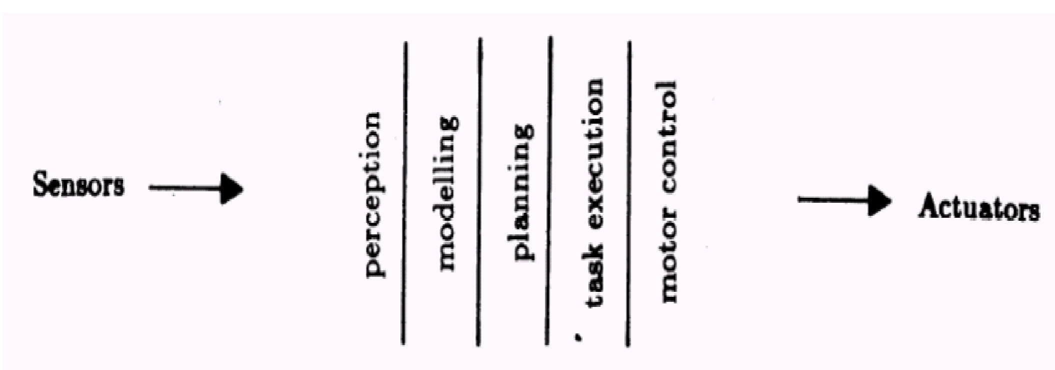
    A robotic paradigm can be described by relation between three primitives:

    Sense : Plan : Act

    - ✓ **Hierarchical / Deliberative Robot Control Architectures:**

      In a deliberative control architecture the robot first plans a solution for the task by reasoning about the outcome of its actions and then executes it (Control process goes through a sequence of sensing, model update, and planning steps)





Advantages

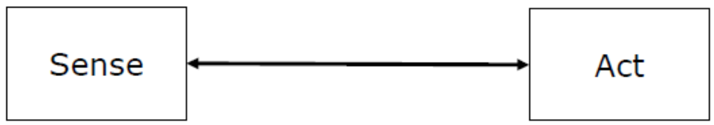
- Reasons about contingencies
- Computes solutions to the given task
- Goal-directed strategies

Problems

- Solutions tend to be fragile in the presence of uncertainty
- Requires frequent preplanning
- Reacts relatively slowly to changes and unexpected occurrences

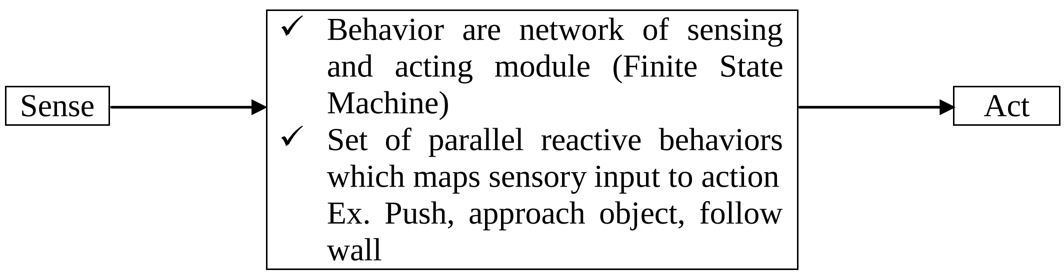
✓ **Reactive Robot Control Architectures:**

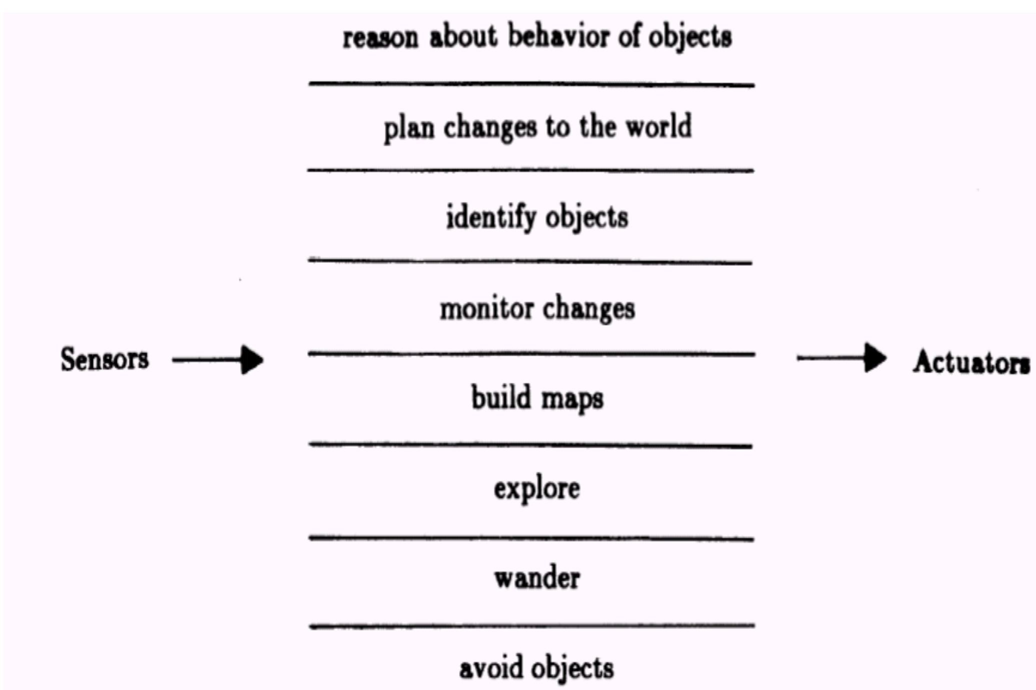
Direct mapping between sensor input and actuators output, it very reactive to changes in sensor readings.



✓ **Behavioral Based Robot Control Architectures:**

In behavior-based control architecture the robot's actions are determined by a set of parallel, reactive behaviors which map sensory input and state to actions.





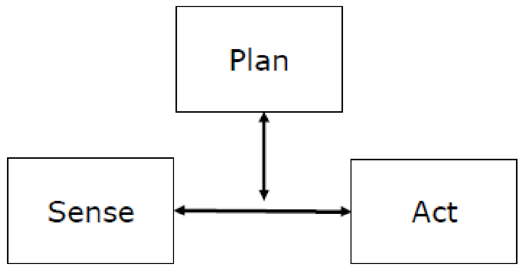
Advantages

- ✓ Reacts fast to changes
- ✓ Does not rely on accurate models ("The world is its own best model")
- ✓ No need for preplanning

Problems

- ✓ Difficult to anticipate what effect combinations of behaviors will have
- ✓ Difficult to construct strategies that will achieve complex, novel tasks
- ✓ Requires redesign of control system for new tasks

✓ **Hybrid Robot Control Architecture:**
Many architectures of today follow this paradigm



2. Sensor in automobile engine control:

Control System	Indirectly controlled variable	Directly controlled variable	Manipulated variable	Sensor	Actuator
Fuel injection system	Air-fuel ratio	Exhaust oxygen content	Quality of injection fuel	Zirconia or Titania based electro-chemical	Fuel injector
Knock control	Knock	Knock sensor output	Ignition timing	Piezo-electric accelerometer	Ignition coil switch. Transistor
Anti-lock braking system	Wheelslip limit	Wheelspeed	Brake time pressure	Magnetic reluctance	ABS solenoid valve

Examples of Automotive Closed-loop Control Systems

Measured variable	Direct/indirect measurement	Sensor technology/ reference	Sensor mounting location
Battery voltage	Direct measurement	Resistive attenuator	
Throttle position	Direct measurement	Potentiometer	Accelerator pedal
Knock (engine cylinder pressure oscillations during ignition)	Direct measurement	Piezoelectric accelerometer type.	Cylinder block or head
Oxygen concentration in exhaust gas (Lambda sensor)	Direct measurement	Zirconia or Titania based exhaust gas oxygen sensors	Exhaust manifold (normal operation above 300^0 C)

Measured variable	Direct/indirect measurement	Sensor technology/ reference	Sensor mounting location
Intake manifold absolute pressure	Indirect measurement of engine load or mass air-flow intake	Wheatstone bridge arrangement of thick film resistors bonded onto a thin alumina diaphragm	Within intake manifold
Mass airflow	Direct and indirect measurement of fuel injector basic pulse width	Various forms including 'flap' type, 'hot-wire', Karman vortex and thick-film diaphragm	Within air intake
Temperature	Direct measurement at various locations	Thermistor or thermocouple depending on temperature range	Intake air, outside air, catalytic converter, engine coolant, hydraulic oil
Engine speed and crankshft reference position	Direct measurement	Magnetic reluctance or Hall effect device	Flywheel on end of engine crankshaft

Engine Management Sensors

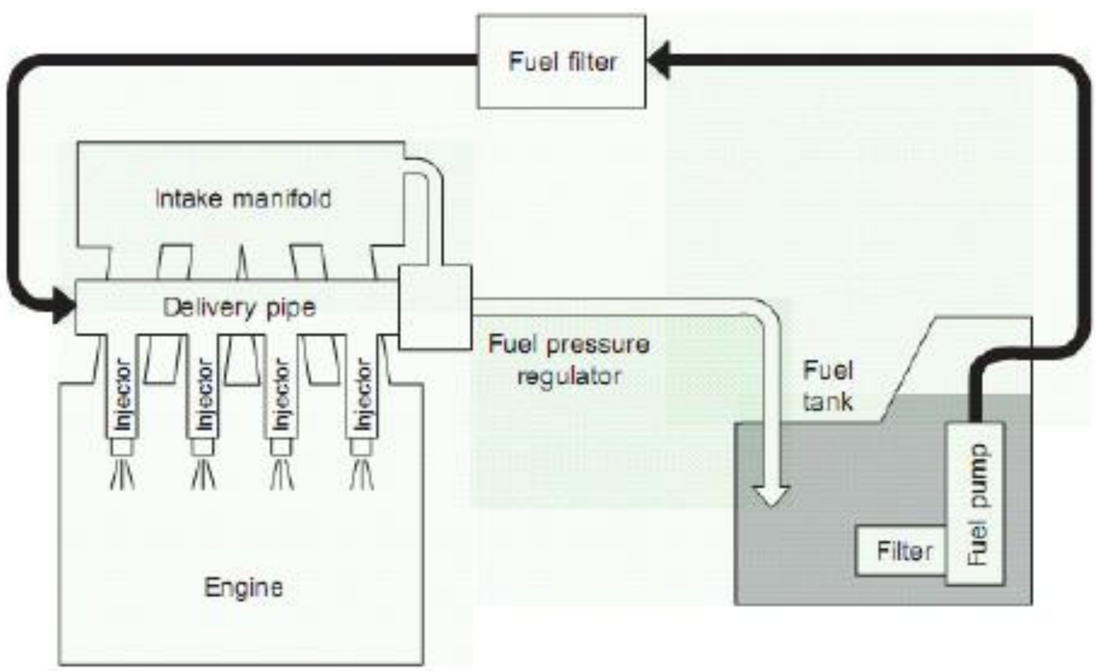
Measured variable and application	Direct/indirect measurement	Sensor technology/ reference	Sensor mounting location
Wheelspeed and engine speed, (ABS, TCS and electronic damping)	Direct measurement	Magnetic reluctance or Hall effect device	Brake assembly and crankshaft flywheel respectively
Steering wheel angle, (Electronic damping)	Direct measurement	Potentiometer or optical encoder	Steering shaft
Throttle position	Indirect measurement of vehicle accel.	Potentiometer	Accelerator pedal
Chassis and wheel acceleration, (electronic damping)	Direct	Piezo-electric accelerometer	Engine compart-ment and wheel assembly
Brake system pressure (electronic damping)	Indirect measurement of vehicle decelerat-ion	Flexing plate sensor with strain gauges mounted on plate	Brake master cylinder
Steering shaft torque (Electric power assisted steering)	Direct measurement	Optical device relying on steering shaft distortion under driver's twisting action	Steering shaft

Chassis control sensor

Measured variable	Direct/indirect measurement	Sensor technology/ reference	Sensor mounting location
Vehicle deceleration (air-bag systems)	Direct measurement	'G' sensor (Piezo-electric accelerometer)	Single-point electronic sensing, location in dashboard or steering wheel
Wheelspeed and engine speed (Vehicle nav. Systems)	Direct measurement	Magnetic reluctance or Hall effect device	Brake assembly.

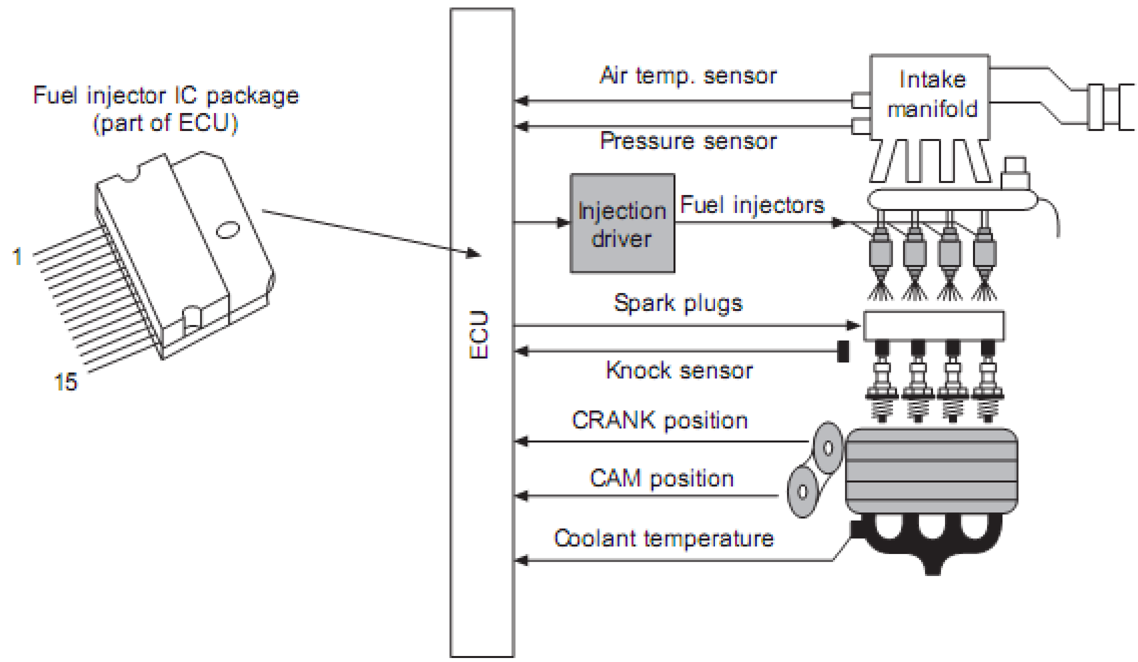
Safety and onboard navigation sensor

Electronic fuel injection (EFI):



- ✓ Allows precise and fast control of fuel injected
- ✓ By control of the 'on-time' period of the solenoid operated injectors (spray nozzle) and plunger.
- ✓ Delivery pipe fuel pressure is maintained constant by a fuel pressure regulator
- ✓ Opening and closing times of between 0.5 and 1 ms.
- ✓ Engine operating speed of 6000 rpm (10 ms revolution time)
- ✓ Injector on-time can be controlled between 1 and 10 ms.

Power driver application:

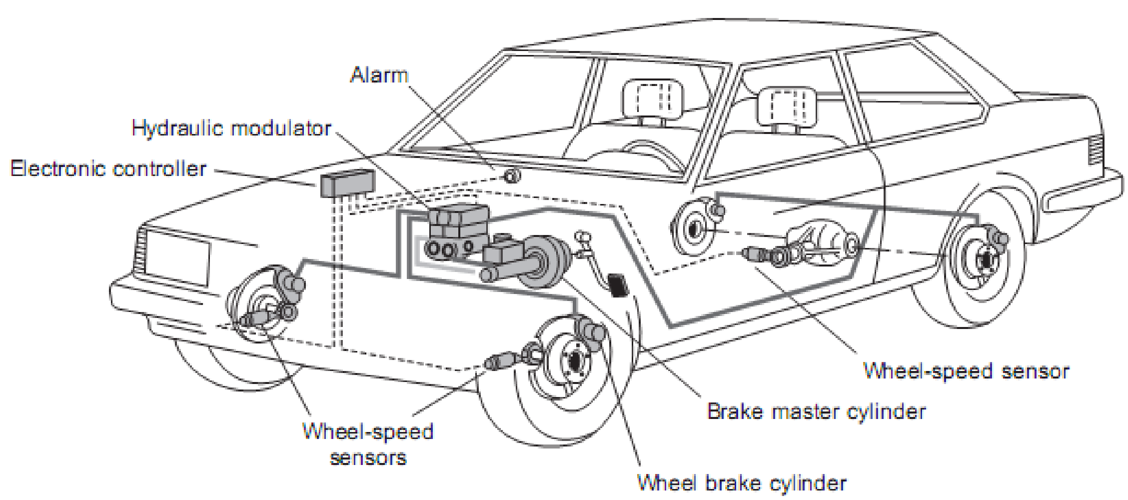


- ✓ Multi-point or sequential fuel injection, with one fuel injector near the intake valve (or valves) of each cylinder.
- ✓ At a device level, a fuel injector IC package
- ✓ Provides the high solenoid drive current required
- ✓ Incorporates both over-voltage and short-circuit protection,
- ✓ Fault reporting diagnostic routines also included

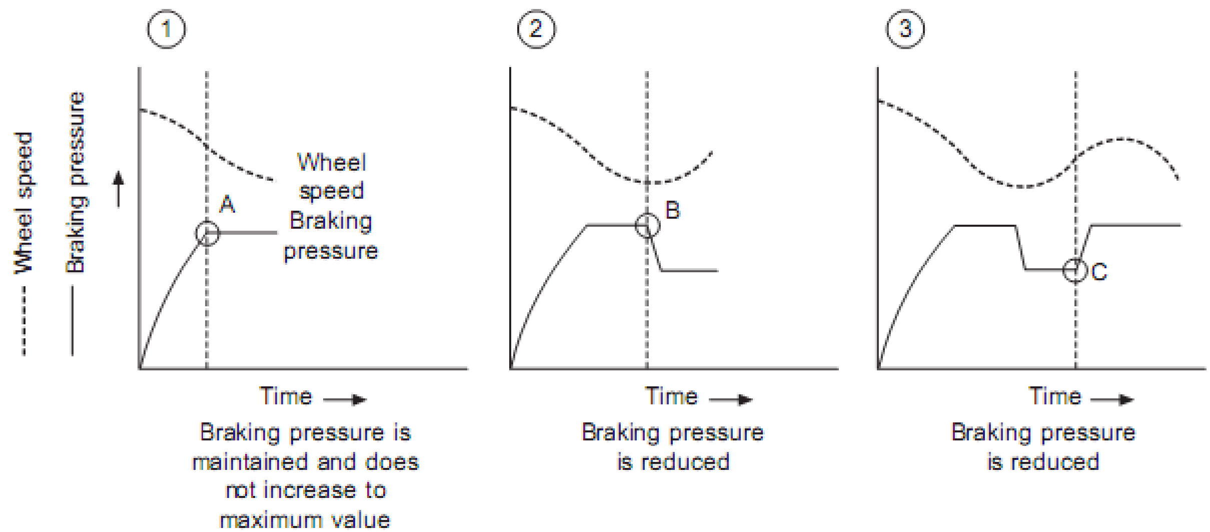
Chassis Control Systems

- ➢ Anti Lock Braking system
- ➢ Electronic Damping Control system
- ➢ Power Assisted Steering System
- ➢ Traction Control Systems

➢ Anti-lock braking systems (ABS)



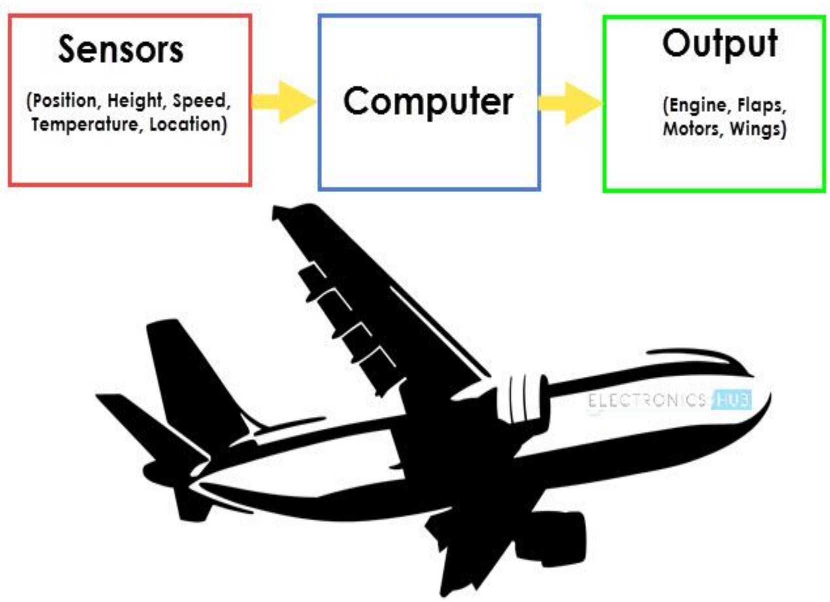
- ✓ The vehicle skids, the wheels lock and driving stability is lost so the vehicle cannot be steered
- ✓ If a trailer or caravan is being towed it may jack-knife
- ✓ The braking distance increases due to skidding
- ✓ The tyres may burst due to excessive friction and forces being concentrated at the points where the locked wheels are in contact with the road surface



Wheel-speed and braking pressure during ABS-controlled braking

- ✓ If wheel decelerates beyond a certain level, curtail brake pressure (1)
- ✓ If wheel decelerates further, reduce brake pressure further (2)
- ✓ If wheel accelerates, increase brake pressure (3)

3. Real time application of sensor:
Ex. Autopilot System in aircrafts:



- ✓ The example we are talking about here is the Autopilot System in aircrafts. Almost all civilian and military aircrafts have the feature of Automatic Flight Control system or sometimes called as Autopilot.
- ✓ An Automatic Flight Control System consists of several sensors for various tasks like speed control, height, position, doors, obstacle, fuel, maneuvering and many more. A Computer takes data from all these sensors and processes them by comparing them with pre-designed values.
- ✓ The computer then provides control signal to different parts like engines, flaps, rudders etc. that help in a smooth flight. The combination of Sensors, Computers and Mechanics makes it possible to run the plane in Autopilot Mode.
- ✓ All the parameters i.e. the Sensors (which give inputs to the Computers), the Computers (the brains of the system) and the mechanics (the outputs of the system like engines and motors) are equally important in building a successful automated system.
- ✓ But in this tutorial, we will be concentrating on the Sensors part of a system and look at different concepts associated with Sensors (like types, characteristics, classification etc.).

4. Some other application:

Smart Cities

- ✓ **Smart Parking:** Monitoring of parking spaces availability in the city.
- ✓ **Structural health:** Monitoring of vibrations and material conditions in buildings, bridges and historical monuments.
- ✓ **Noise Urban Maps:** Sound monitoring in bar areas and centric zones in real time.
- ✓ **Smartphone Detection:** Detect iPhone and Android devices and in general any device which works with WiFi or Bluetooth interfaces.
- ✓ **Electromagnetic Field Levels:** Measurement of the energy radiated by cell stations and WiFi routers.
- ✓ **Traffic Congestion:** Monitoring of vehicles and pedestrian levels to optimize driving and walking routes.
- ✓ **Smart Lighting:** Intelligent and weather adaptive lighting in street lights.
- ✓ **Waste Management:** Detection of rubbish levels in containers to optimize the trash collection routes.
- ✓ **Smart Roads:** Intelligent Highways with warning messages and diversions according to climate conditions and unexpected events like accidents or traffic jams.

Smart Environment

- ✓ **Forest Fire Detection:** Monitoring of combustion gases and preemptive fire conditions to define alert zones.
- ✓ **Air Pollution:** Control of CO_2 emissions of factories, pollution emitted by cars and toxic gases generated in farms.
- ✓ **Snow Level Monitoring:** Snow level measurement to know in real time the quality of ski tracks and allow security corps avalanche prevention.
- ✓ **Landslide and Avalanche Prevention:** Monitoring of soil moisture, vibrations and earth density to detect dangerous patterns in land conditions.
- ✓ **Earthquake Early Detection:** Distributed control in specific places of tremors.

Smart Water

- ✓ **Potable water monitoring:** Monitor the quality of tap water in cities.
- ✓ **Chemical leakage detection in rivers:** Detect leakages and wastes of factories in rivers.
- ✓ **Swimming pool remote measurement:** Control remotely the swimming pool conditions.
- ✓ **Pollution levels in the sea:** Control real-time leakages and wastes in the sea.
- ✓ **Water Leakages:** Detection of liquid presence outside tanks and pressure variations along pipes.
- ✓ **River Floods:** Monitoring of water level variations in rivers, dams and reservoirs.

Smart Metering

- ✓ **Smart Grid:** Energy consumption monitoring and management.
- ✓ **Tank level:** Monitoring of water, oil and gas levels in storage tanks and cisterns.
- ✓ **Photovoltaic Installations:** Monitoring and optimization of performance in solar energy plants.
- ✓ **Water Flow:** Measurement of water pressure in water transportation systems.
- ✓ **Silos Stock Calculation:** Measurement of emptiness level and weight of the goods.

Security & Emergencies

- ✓ **Perimeter Access Control:** Access control to restricted areas and detection of people in non-authorized areas.
- ✓ **Liquid Presence:** Liquid detection in data centers, warehouses and sensitive building grounds to prevent break downs and corrosion.
- ✓ **Radiation Levels:** Distributed measurement of radiation levels in nuclear power stations surroundings to generate leakage alerts.
- ✓ **Explosive and Hazardous Gases:** etection of gas levels and leakages in industrial environments, surroundings of chemical factories and inside mines.

Retail

- ✓ **Supply Chain Control:** Monitoring of storage conditions along the supply chain and product tracking for traceability purposes.
- ✓ **NFC Payment:** Payment processing based in location or activity duration for public transport, gyms, theme parks, etc.
- ✓ **Intelligent Shopping Applications:** Getting advices in the point of sale according to customer habits, preferences, presence of allergic components for them or expiring dates.
- ✓ **Smart Product Management:** Control of rotation of products in shelves and warehouses to automate restocking processes.

Logistics

- ✓ **Quality of Shipment Conditions:** Monitoring of vibrations, strokes, container openings or cold chain maintenance for insurance purposes.
- ✓ **Item Location:** Search of individual items in big surfaces like warehouses or harbours.
- ✓ **Storage Incompatibility Detection:** Warning emission on containers storing inflammable goods closed to others containing explosive material.
- ✓ **Fleet Tracking:** Control of routes followed for delicate goods like medical drugs, jewels or dangerous merchandises.

Industrial Control

- ✓ **M2M Applications:** Machine auto-diagnosis and assets control.
- ✓ **Indoor Air Quality:** Monitoring of toxic gas and oxygen levels inside chemical plants to ensure workers and goods safety.
- ✓ **Temperature Monitoring:** Control of temperature inside industrial and medical fridges with sensitive merchandise.
- ✓ **Ozone Presence:** Monitoring of ozone levels during the drying meat process in food factories.
- ✓ **Indoor Location:** Asset indoor location by using active (ZigBee) and passive tags (RFID/NFC).
- ✓ **Vehicle Auto-diagnosis:** Information collection from CanBus to send real time alarms to emergencies or provide advice to drivers.

Smart Agriculture

- ✓ **Wine Quality Enhancing:** Monitoring soil moisture and trunk diameter in vineyards to control the amount of sugar in grapes and grapevine health.
- ✓ **Green Houses:** Control micro-climate conditions to maximize the production of fruits and vegetables and its quality.
- ✓ **Golf Courses:** Selective irrigation in dry zones to reduce the water resources required in the green.

- ✓ **Meteorological Station Network:** Study of weather conditions in fields to forecast ice formation, rain, drought, snow or wind changes.
- ✓ **Compost:** Control of humidity and temperature levels in alfalfa, hay, straw, etc. to prevent fungus and other microbial contaminants.

Smart Animal Farming

- ✓ **Hydroponics:** Control the exact conditions of plants grown in water to get the highest efficiency crops.
- ✓ **Offspring Care:** Control of growing conditions of the offspring in animal farms to ensure its survival and health.
- ✓ **Animal Tracking:** Location and identification of animals grazing in open pastures or location in big stables.
- ✓ **Toxic Gas Levels:** Study of ventilation and air quality in farms and detection of harmful gases from excrements.

Domotic & Home Automation

- ✓ **Energy and Water Use:** Energy and water supply consumption monitoring to obtain advice on how to save cost and resources.
- ✓ **Remote Control Appliances:** Switching on and off remotely appliances to avoid accidents and save energy.
- ✓ **Intrusion Detection Systems:** Detection of windows and doors openings and violations to prevent intruders.
- ✓ **Art and Goods Preservation:** Monitoring of conditions inside museums and art warehouses.

eHealth

- ✓ **Fall Detection:** Assistance for elderly or disabled people living independent.
- ✓ **Medical Fridges:** Control of conditions inside freezers storing vaccines, medicines and organic elements.
- ✓ **Sportsmen Care:** Vital signs monitoring in high performance centers and fields.
- ✓ **Patients Surveillance:** Monitoring of conditions of patients inside hospitals and in old people's home.
- ✓ **Ultraviolet Radiation:** Measurement of UV sun rays to warn people not to be exposed in certain hour