Self Calibration -

Process in which smart sensor automatically compensates for errors or deviations by adjusting its internal parameters based on pre-defined standards or known reference values.

Importance -

- Long term accuracy • Improved reliability
- Reduced maintainence - no manual calibration needed
- Consistency in harsh environment

Mechanism -

a.) Internal Reference standards -

Can contain built-in reference standards or internal calibration circuits. These references are periodically compared with sensor's output. If output deviates from ref. sensor ~~with~~ will adjust its internal parameters to match ref.

Example - temp. sensor might include a known stable temp. ref. point. The sensor compares its o/p to this ref. periodically & recalibrates if required

b.) Algorithmic compensation -

Use embedded μPs & algo to compensate for drift & errors. These algos are designed to recognize specific patterns of deviation, such as linear or non-linear drift & apply correction factors.

Ex - pressure sensor experiences drift due to temp. changes hence pre-programmed temp. compensation models are used to adjust sensor readings.

c.) Environmental sensing -

Can ~~sno~~ include additional sensors to monitor environmental conditions

d.) Feedback loops -
In this sensor continuously monitors its own performance & automatically correct any errors.

Types of errors corrected -

- Offset drift - baseline or zero point may shift due to aging or environmental factors.
- Sensitivity drift - response to change in i/p may degrade over time
- Non - linearity - sensors o/p may become non - linear

Self testing -
sensor's Capability to monitor its internal components & operation, verify the accuracy of its o/p & diagnose potential issues. Checks system health periodically or continuously & informs user when ~~sor~~ sensor requires maintenance.

Importance -

- ↑ reliability & safety
- Fault detection
- ↓ downtime
- Cost efficiency for maintenance

Mechanism -

a.) Built - In ~~Sof~~ self Test (BIST) -
Here sensor incorporates additional circuitry or software routines to test its own components Can be done periodically, at startup or on demand.
Sensor generates test signals or known ref. i/p & compares sensor's actual o/p. If deviation is there then identify the issue.
Ex- accelerometer might initiate a self test by

applying a small, known stimulus (an electrical signal that stimulates a motion) & checking whether its o/p matches the expected response.

b.) Redundancy & cross-checking -

Redundant components (multiple sensing elements) provide duplicate measurements which are compared to detect anomalies. significant deviation can be flagged as fault.

Ex- In IMU, multiple sensing elements can measure same axis. If one sensor drifts or fails, the other can provide correct readings & notify the user the problem.

c.) Signal Integrity Monitoring -

Tracks the quality of signal being processed by sensor. Checks for abnormalities such as noise, interference, or signal degradation, which could indicate a malfunction.

Monitors sensor's internal signal paths ensuring that all components like ADC, amp are working

d.) Health monitoring -

Evaluate ~~own~~ own performance based on historical data, environmental conditions & expected behaviour.

e.) Self calibration as part of self testing.

Types of faults detected -

- Component failures - sensing element failure.
- Signal path issues - malfunction in ADC, amp, filters
- Degradation of sensor performance.
- Electrical & mechanical faults - broken wires, short circuits, issues in power supply

Self Communicating-
Embedded comm. interfaces that allow sensors to automatically send data, alerts & diagnostics to other devices or systems.

Importance-
- Real time data sharing
- Eliminates need for manual data collection i.e. autonomous system operation
- Integration with IoT
- ↑ efficiency • Remote access & control • Better decision making
- Scalability

Key functions-
a.) Data transmission - transmit data to a designated system like PLC, SCADA or cloud.

b.) self diagnostics & health reporting

c.) Inter sensor communication

d.) Networked system integration - integrated to larger networks like IoT, industrial networks or cloud based monitoring.

Ex- agri IoT system, has moisture sensors placed in soil comm their readings to central cloud platform, where data analytics can determine optimal irrigation schedule.

Communication Protocols used-
a.) Wired - ethernet - fast, reliable transmission over LAN
RS 232/RS 485 - serial comm. for transmission in short range
Modbus - used in SCADA

b.) Wireless - Wi-fi, Zigbee, Bluetooth, ~~LoRa~~
LoRa (Long Range) - Low power WAN

c.) IoT specific - MQTT (Message Queuing Telemetry Transport)
CoAP (Constrained Application Protocol)

Case study

Automatic Robot Control -

Robot is designed to navigate through industrial warehouse. transporting goods from one location to another.

Smart sensors used-

- LIDAR - 3D mapping of environment. emit LASER pulses, which bounce back when they hit an object
- Ultrasonic sensor - object detection
- IMU - provide data about robot's acceleration, orientation & angular velocity. Helps robot maintain balance & stabilize its movement in uneven terrains or during sharp turns.
- Vision sensors (camera) - to recognize the objects it needs to pick up.
- Force/Torque sensors - for lifting, gripping

Main modules-

- Machine Vision module
- Path planning —"—
- Robot control module

Machine Vision module-

To provide robot with sensory attributes. Based on optical (vision) cameras. acquiring frames in real time.

3 stages-

Frame acquisition - camera used for this stating frame rate, resolution & related parameters.

Image processing - perform obstacle detection based on color & filtering done via size

Data comm. - extract obstacle location & sent to path planning module.

Automobile Engine Control

Engine - device that converts fuel energy into mechanical energy

Moving part - piston moves in hollow cylinder.
2 Valves to let air & fuel mixture in & allow burned fuel to escape
Spark plug - located at top of cylinder to set fuel on fire.
Cam shaft - controls the opening & closing of valves
4 stroke -
Intake - valve opens, mixture of fuel & air fills the cylinder. Piston moves down.
Compression - Piston comes up by compressing fuel & air & keeping valves closed, producing pressure.
When piston reaches its max height, fuel burns by a electric spark from spark plug.
Combustion - piston moves down, Also known as power stroke, due to explosion of fuel burning
Exhaust - 2^{nd} valve opens causing the piston to rise & pushing hot gases from burned fuel out.

Piston connected to crank shaft to produce mechanical movement (rotary)
Supporting systems -
- Cooling system - to prevent overheating
- Lubrication system - to reduce friction b/w moving parts
- Fuel injection system - to control amount & timing of fuel
- Exhaust system - to ↓ harmful emissions

To enhance fuel efficiency, ↓ emissions & improve overall performance to meet regulatory standards & customer demands, company uses smart sensors with Engine Control Unit (ECU) to achieve control over combustion, emissions & energy efficiency.

Sensors -

O_2 sensors - monitors amount of oxygen in exhaust gases. ensuring engine runs at ideal fuel-air ratio. ECU uses this info to adjust fuel injection in real time

Mass Air Flow (MAF) sensor - measures the amount of air entering the engine intake. Helps ECU determine the appropriate amount of fuel

Manifold Absolute Pressure (MAP) sensor - measures the pressure in intake manifold, which is directly related to engine load. Helps ECU calculate air density & adjust fuel delivery

Knock sensor - detects abnormal combustion, known as engine knocking or detonation. It can damage engine if left unchecked.

Crankshaft & Camshaft position sensors - provides data on position & rotational speeds of shafts. ECU uses this info to synchronize fuel injection & ignition timing.

Exhaust gas recirculation (EGR) valve position sensor - Monitors position of EGR valve which recirculates a portion of exhaust gas back into combustion chamber. This process ↓ combustion temp., reducing NOx emissions

Integration -

Closed loop system - driven by O_2, MAF & MAP sensor

Fuel Injection & ignition timing control - during cold starts, more fuel is injected to ensure proper combustion. Under heavy load (acceleration) ECU ↑ fuel supply to boost power. Prevent knocking.