Ch. 6 - The Things: Sensors

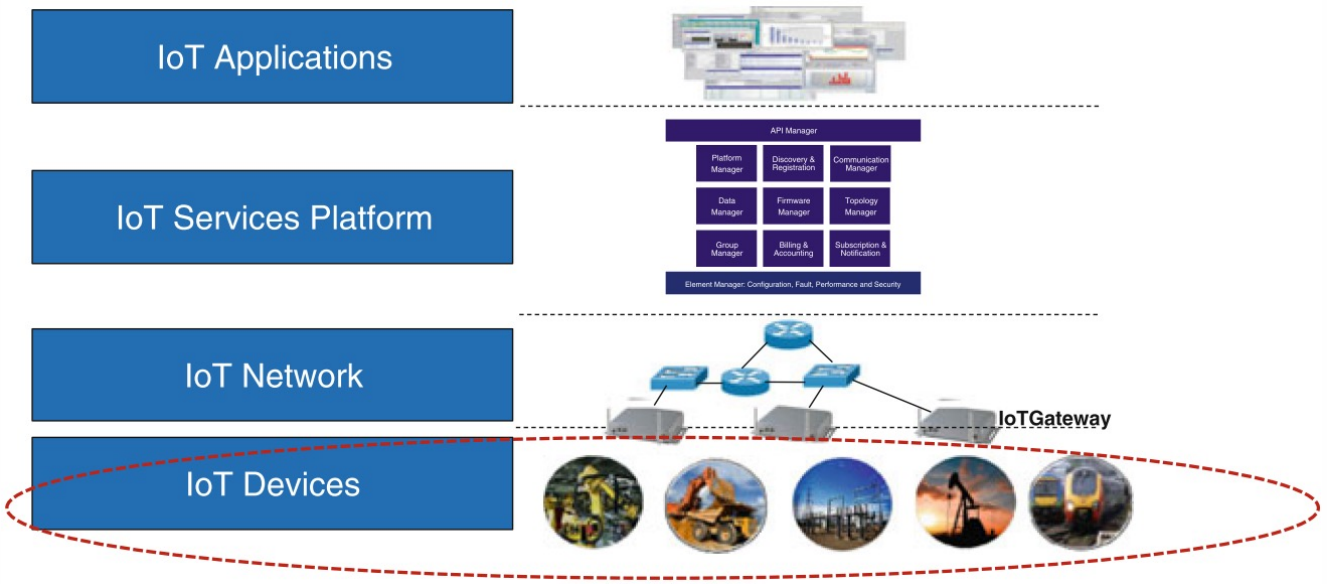
COMPSCI 147
Internet-of-Things; Software and Systems

Chapter 3 in textbook

Agenda

- **Sec 1 - Components and Categorization**
- Sec 2 – Most common Sensor Types
- Sec 3 - Sensors Market

The Things: Sensors and Actuators



Recall IoT definition

- IoT is the network of things, with device identification, **embedded intelligence**, and sensing and **acting** capabilities, **connecting people and things** over the Internet.

- Things were defined as anything and everything stretching from appliances to buildings to cars to people to animals, to trees, to plants, etc.

- Two main requirements:
  - Sensing is essential to identify and collect key parameters for analysis
  - Addressing is necessary to uniquely identify things over the Internet

- Additional requirement: Control things through actuators

What is a sensor

- A sensor is a device (typically electronic) that detects events or changes in its physical environment: e.g.
  - Temperature
  - Sound
  - Heat
  - Pressure
  - Flow
  - Magnetism
  - Motion
  - chemical and biochemical parameters
- and provides a corresponding output to adjoining devices (e.g., gateways, actuators).

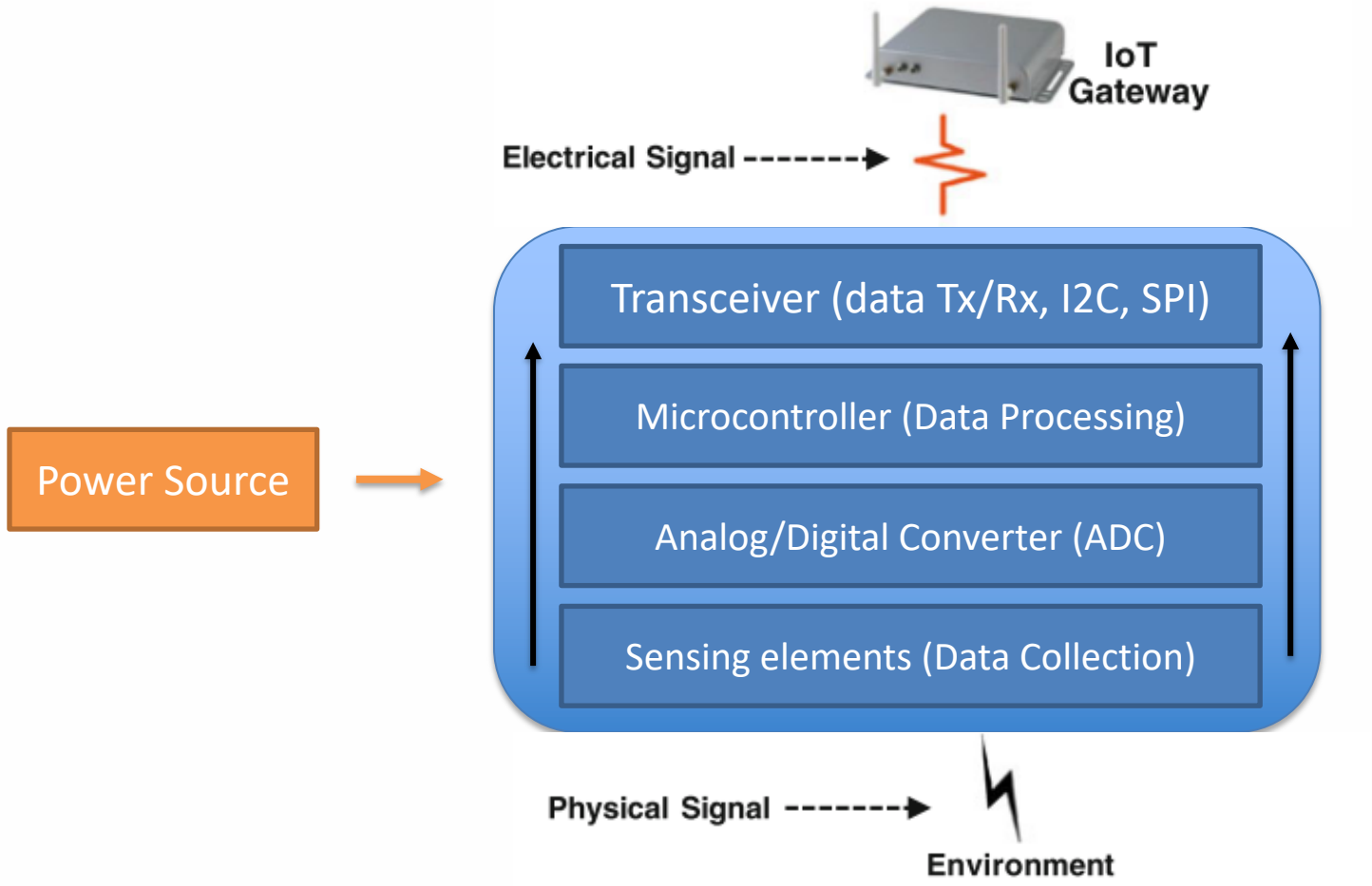
- Most sensors take analog inputs and deliver digital, often electrical, outputs.
- An analog-to-digital converter is often required

SMART SENSORS - INTRODUCTION

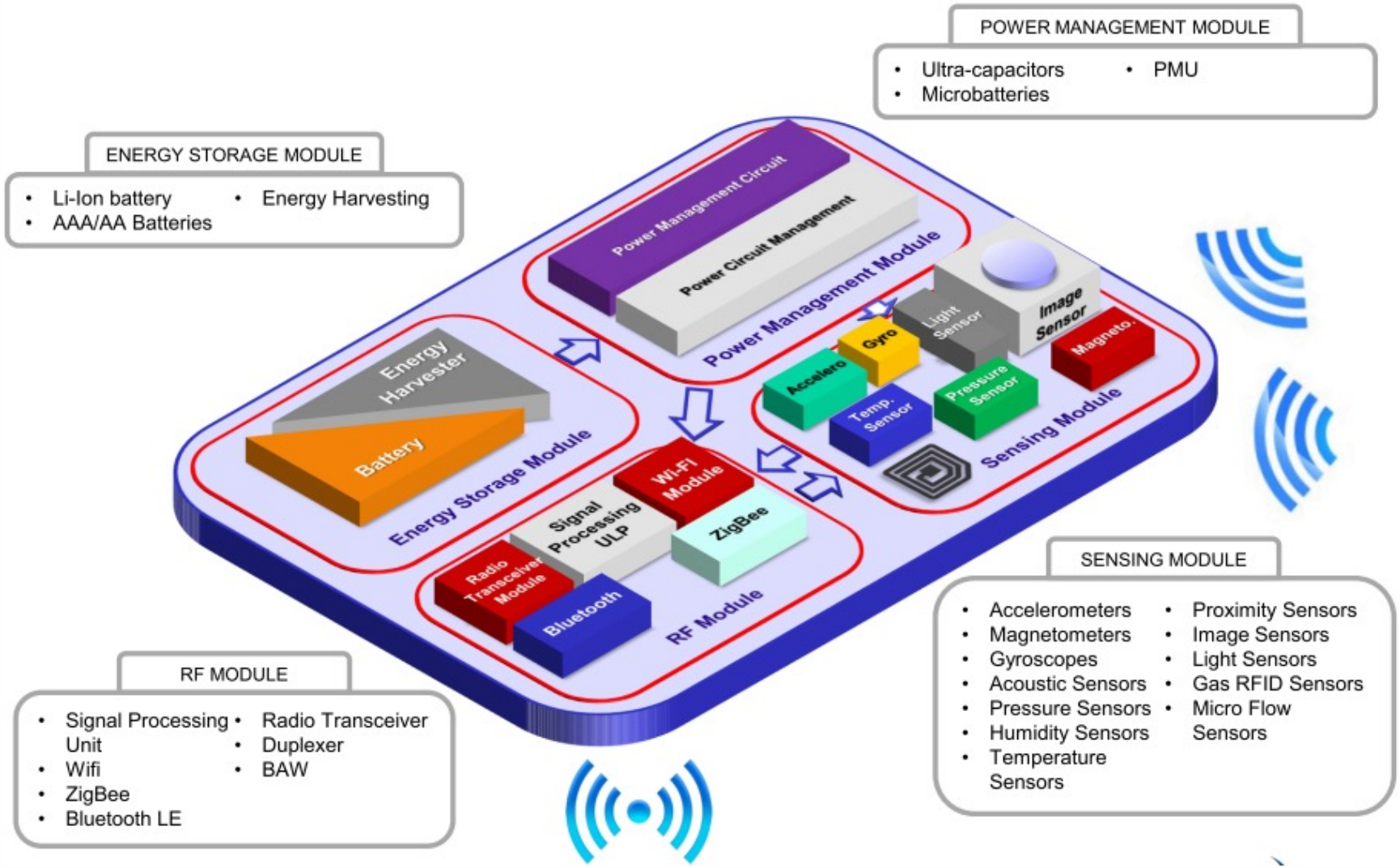
- Smart Sensor = Sensor + **Interfacing circuit**
  - Translate physical signals to electric. Smart sensors are both sensors and actuators.
  - Can communicate and compute sensor-derived data.
  - Can include logic functions (make decisions).
  - Commonly, a cost effective, small chip solution.

- Advantages:
  - Self Calibration: By adjusting deviation of sensor values.
  - Communication: Can broadcast information about its own status.
  - Computation: Can report additional metrics, like variance, average, std deviation, etc..
  - Multisensing: Several physical sensors can be integrated in one single smart sensor
    - E.g.: Smart motion sensors can integrate compass, accelerometer and GPS.

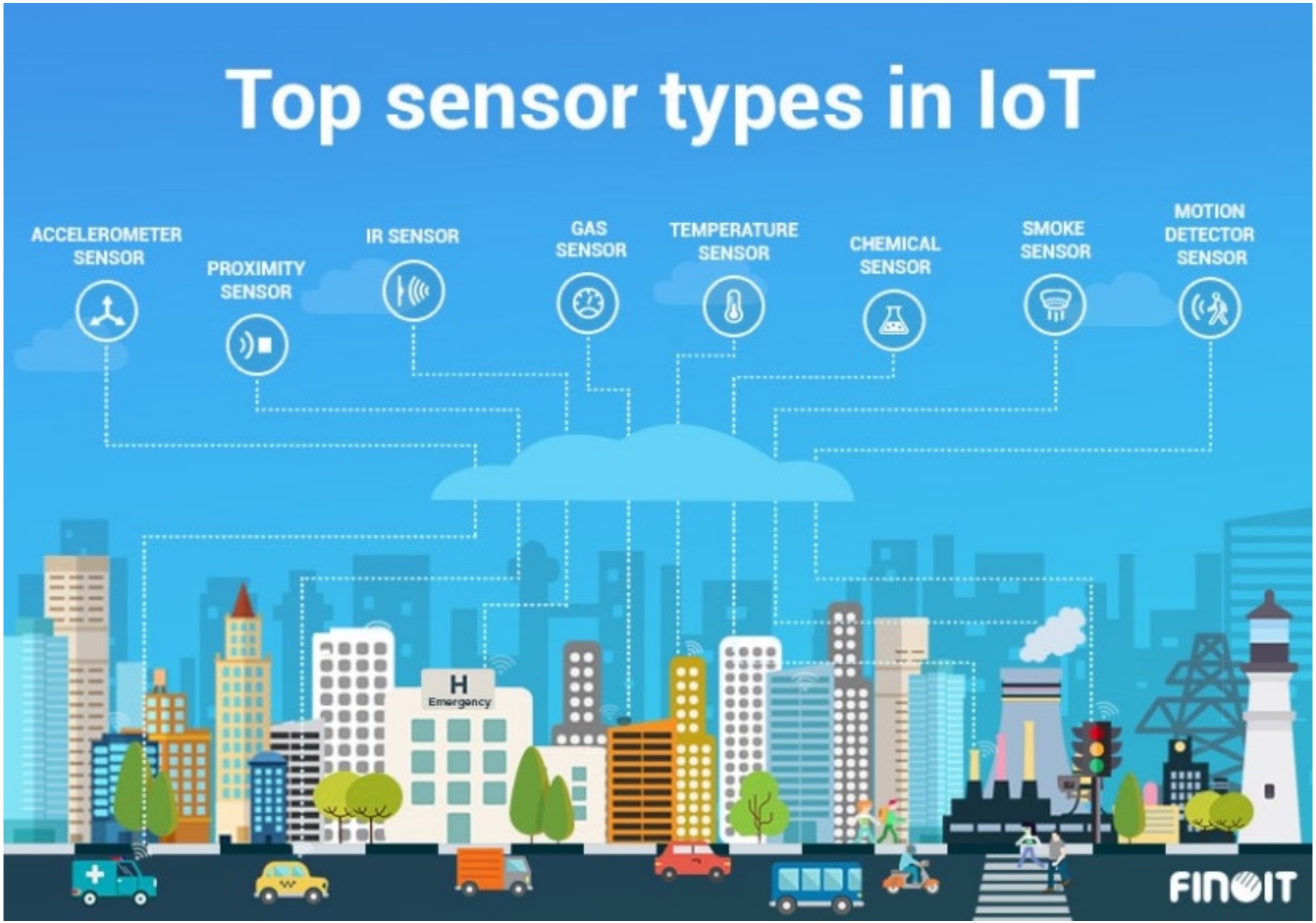
SMART SENSORS - COMPONENTS



IOT WIRELESS SENSORS MAP



Vermesan et al. (2017). Internet of Things Cognitive Transformation Technology Research Trends and Applications.


Top sensor types in IoT
ACCELEROMETER SENSOR
PROXIMITY SENSOR
IR SENSOR
GAS SENSOR
TEMPERATURE SENSOR
CHEMICAL SENSOR
SMOKE SENSOR
MOTION DETECTOR SENSOR
H
Emergency
FINOIT

SENSOR CATEGORIZATION

- Active or passive
  - Require external power supply or not?
- Invasive or non-invasive
  - Is it part of the environment it is measuring?
- Contact or no-contact
  - Require physical contact?
- Absolute or relative
  - Absolute scale or based on a difference with a fixed or variable reference value

SENSOR CATEGORIZATION II

- Area of application
  - Specific industry?
- How sensors measure
  - The physical mechanism used to measure
    - thermoelectric, electrochemical, piezo-resistive, optic, electric, fluid mechanic, photoelastic, …
- What do they measure
  - The physical variables they measure
- Material, cost, design, …

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- **Sec 2 – Most common Sensor Types**
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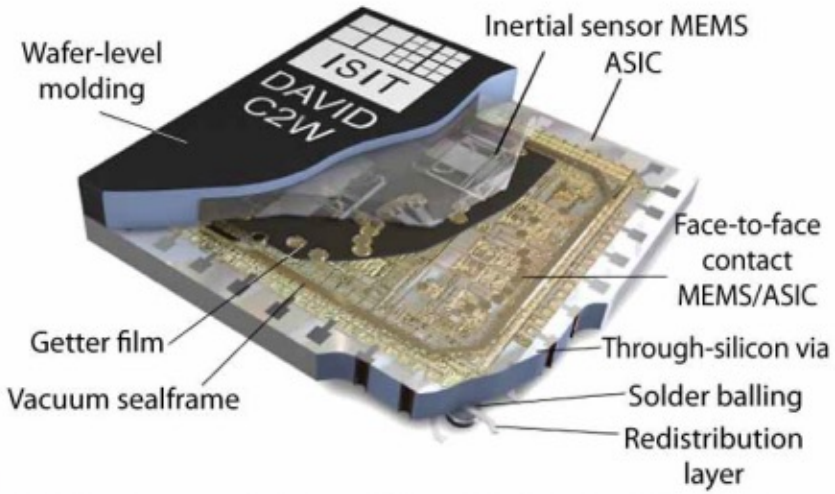
INERTIAL SENSORS

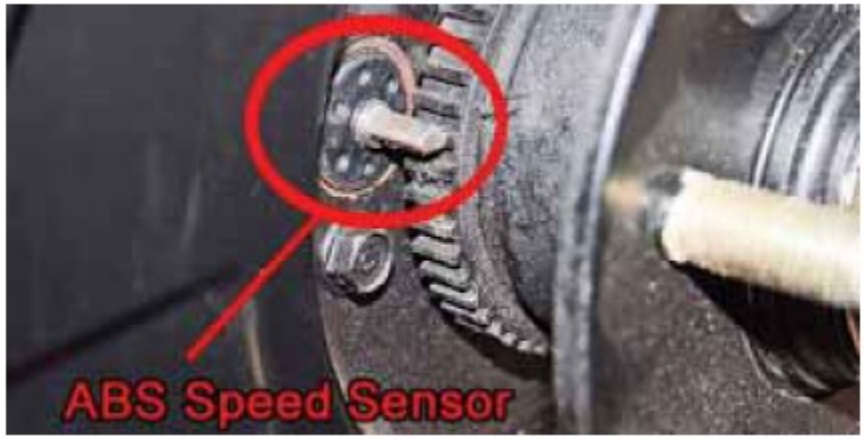
- Inertial sensors are sensors based on **inertia**
- Applications: Industrial machinery, automotive, human activity
- Technology: MEMS (Microelectromechanical systems)
- An inertial measurement unit (**IMU**) works by detecting **linear acceleration** using one or more **accelerometers** and **rotational rate** using one or more **gyroscopes**



8. The EU-funded microscopic-sized gyroscope DAVID (Downscale Assembly of Interconnected Devices) project focuses on developing an inertial sensor system with extremely high packaging density for the hybrid integration of MEMS and ASIC devices.

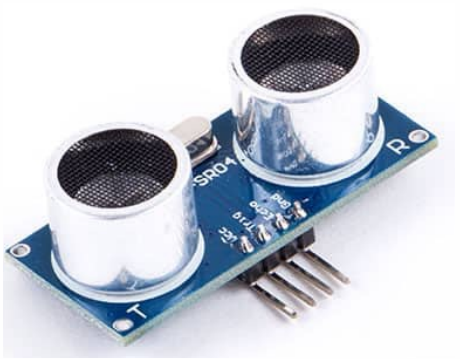
TACHOMETER SENSOR

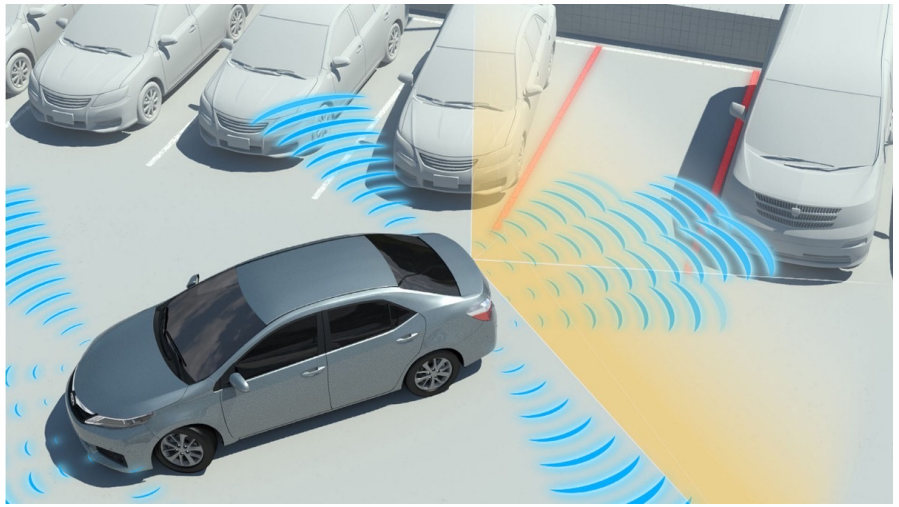
- An instrument measuring the **rotation speed** of a **shaft** or **disk**, as in a motor or other machine
- Applications: Industrial machinery, automotive, human activity
- Technology: Magnetic, light



PROXIMITY SENSOR

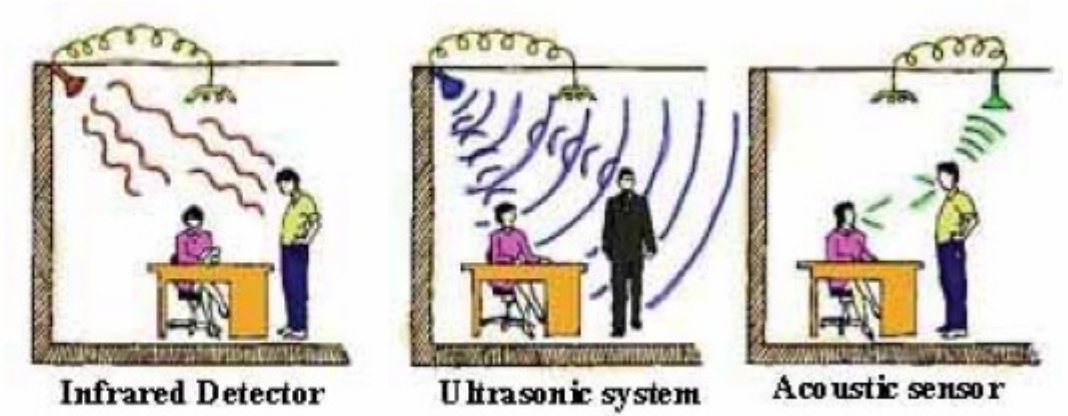
- A sensor able to detect the **presence of nearby objects without any physical contact**
  - Often emits an **electromagnetic field** or a **beam** of electromagnetic radiation (e.g., **infrared**), and looks for **changes** in the **field** or **return** signal.
- Applications: Industrial machinery, automotive, human activity
- Technology: Capacitive, Inductive, Magnetic, Light, Ultrasound





OCCUPANCY SENSOR

- A **descriptive** term for various **indoor motion detecting** devices used to **notice the presence** of a person in a room or space
- Application: Home/office monitoring
- Technology: Passive IR, Ultrasound most common



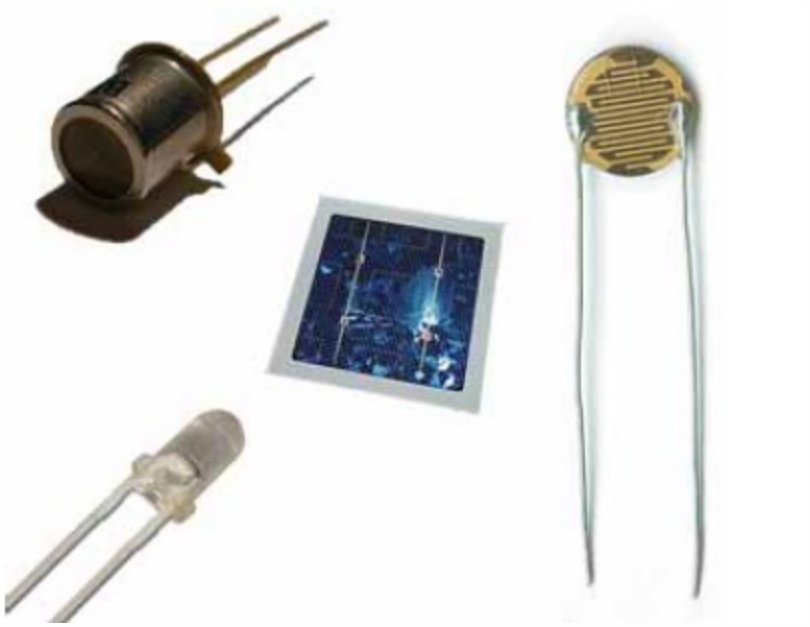
Occupancy Sensor Technologies

TEMPERATURE/HUMIDITY SENSOR

- One of the most common sensors (esp. temperature).
- Applications: Home/office HVAC control, automotive, industrial
- Technology: Thermocouple, Resistance Temperature Detectors (RTD), Thermistor, Solid state..
  - For instance, **thermistor** is a type of resistor whose resistance is dependent on temperature.
    E.g., DHT 11

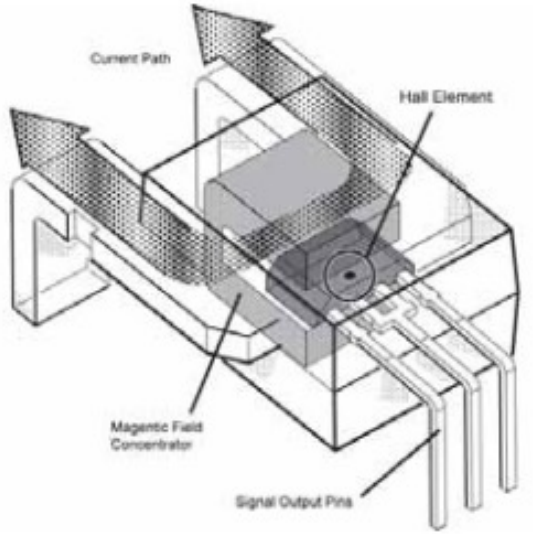
LIGHT SENSOR

- Used to detect the current ambient **light** level
- Applications: Home/office/industrial lighting control
- Technology: Solid state, photocell, photoresistor, photodiode
  - For instance, the **resistance** of a **photoresistor decreases** with **increasing** incident **light** intensity



POWER (CURRENT) SENSOR

- A device that detects **electric current** (AC or DC) in a wire
- Applications: Home/office/industrial power monitoring/control
- Technology: Coil (Faraday's law), Hall effect

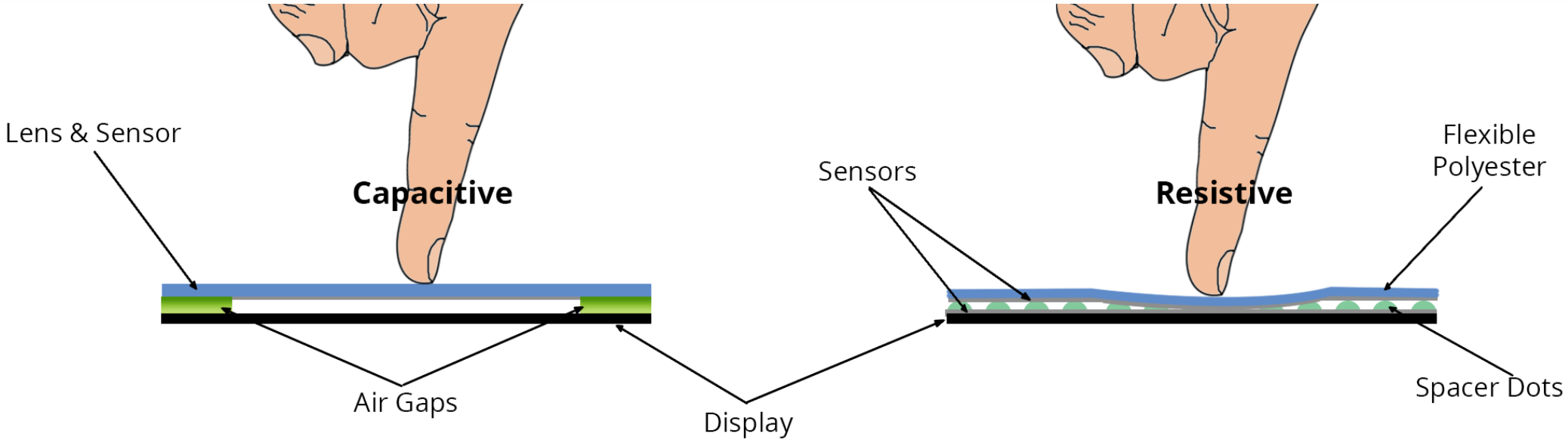


MOISTURE SENSOR

- Soil moisture sensors measure the **volumetric water content** in soil.
- Applications: Agricultural irrigation monitoring/control
- Technology: Capacitive, RF pulse, (also: thermal, resistive)

TOUCH SENSOR

- Applications: Human interface
- Technology: **Resistive , Capacitive**, Inductive

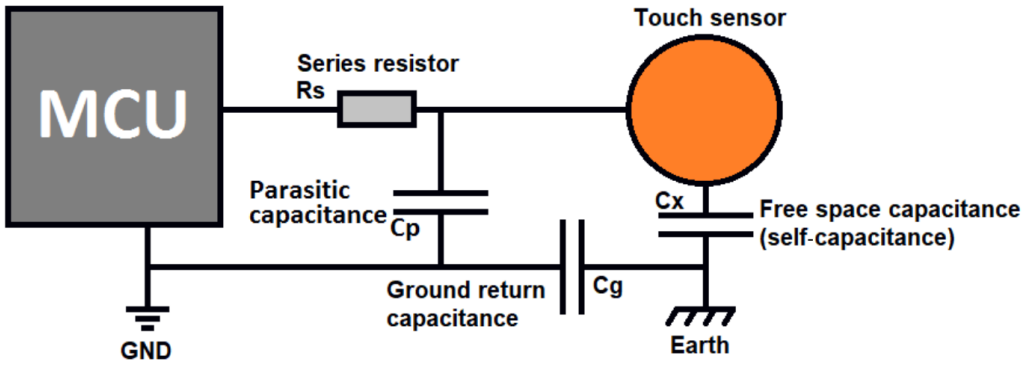


TOUCH SENSOR : Capacitive touch button example

Self-Capacitance Measurement

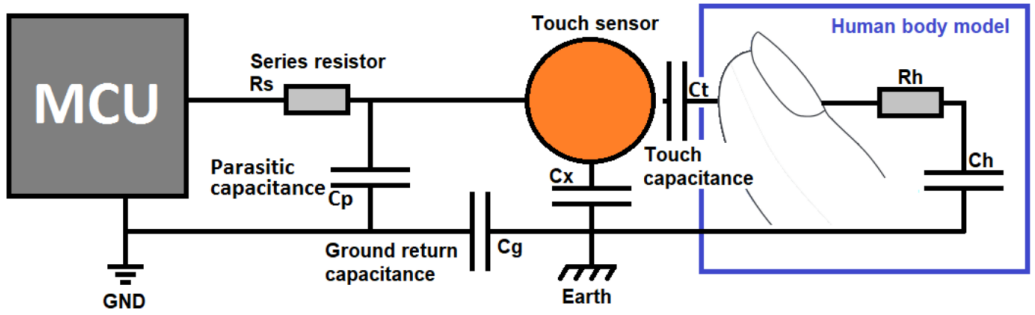
Self-capacitance touch sensors use a single sensor electrode to measure the apparent capacitance between the electrode and the ground of the touch sensor circuit.

Figure 1-1. Self-Capacitance Sensor Model



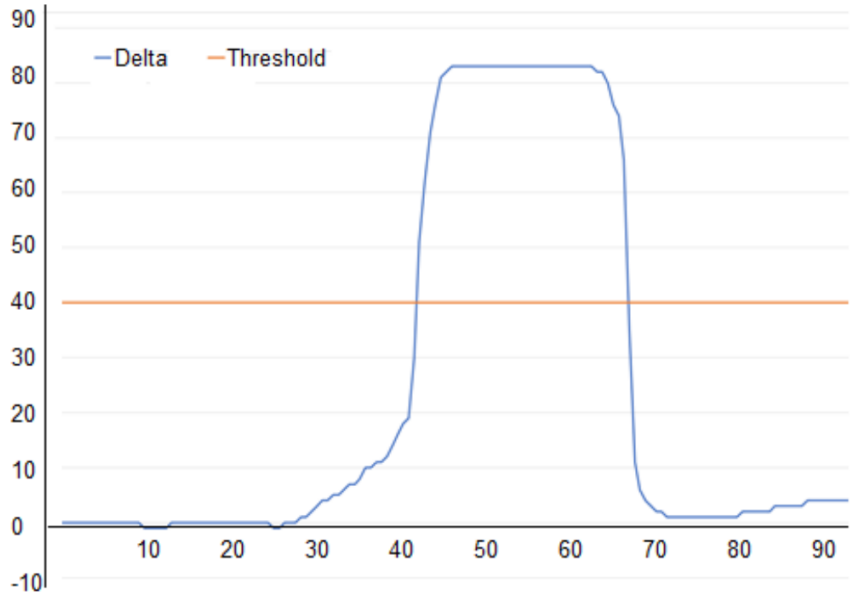
The base capacitance is formed by the combination of parasitic, sensor, and ground return capacitance. In combination, these form the 'untouched' or default capacitance that is measured during calibration and is used as a reference to detect a capacitance change indicating touch contact.

Figure 1-2. Self-Capacitance Model with Touch Contact



When a touch contact is applied, the apparent sensor capacitance is increased by the introduction of a parallel path to earth through the 'Human Body Model' (HBM). The touch capacitance C_t forms a series combination with the HBM capacitance C_h and ground to earth capacitance C_g. This increase is referred to as the touch 'delta'.

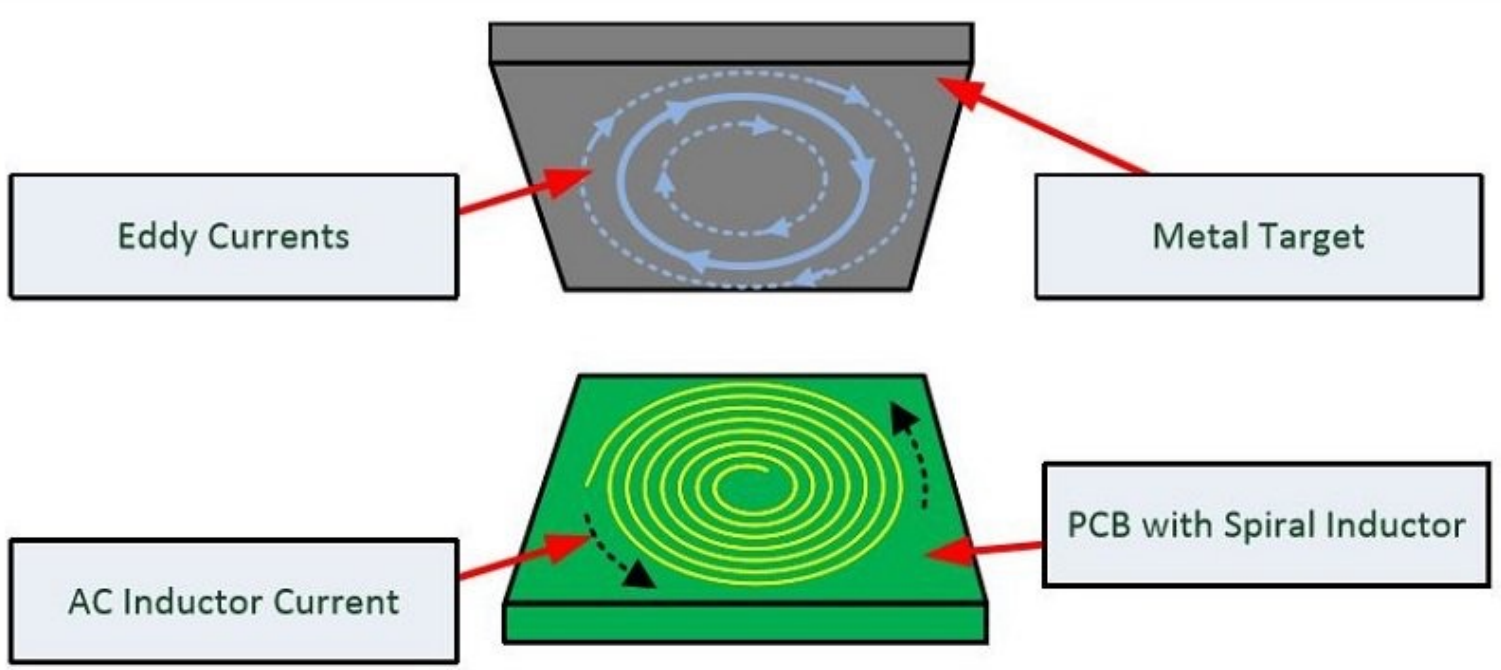
Figure 1-3. Button Sensor Delta and Threshold



Microchip AN2934: Capacitive Touch Sensor Design Guide

TOUCH SENSOR

- Applications: Human interface
- Technology: Resistive , Capacitive, **Inductive**



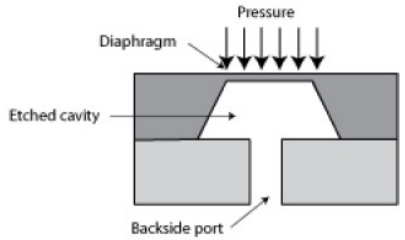
- A controller circuit drives AC current through the inductor.
- This generates an AC magnetic field, which creates eddy currents in the conductive plate.
- If a finger press causes the metal plate to deflect, the reduced distance between plate and inductor leads to a measurable change in inductance.

PRESSURE PAD SENSOR

- Applications: Human interface/monitoring, industrial
- Technology: Piezoresistive, capacitive

AIR/FLUID PRESSURE SENSOR

- A device for pressure measurement of gases or liquids including water level, flow, speed, and altitude.
- Applications: **Industrial**. Also widely used in **automotive applications** to measure fluid level, airbag, and antilock braking system, in **biomedical applications** to sense blood pressure, in **aviation** to maintain a balance between the atmospheric pressure and the control systems of the airplanes, and in **submarines** to estimate depth and ensure proper operation of electronic systems and other components
- Technology: Diaphragm, condenser



ACOUSTIC SENSOR

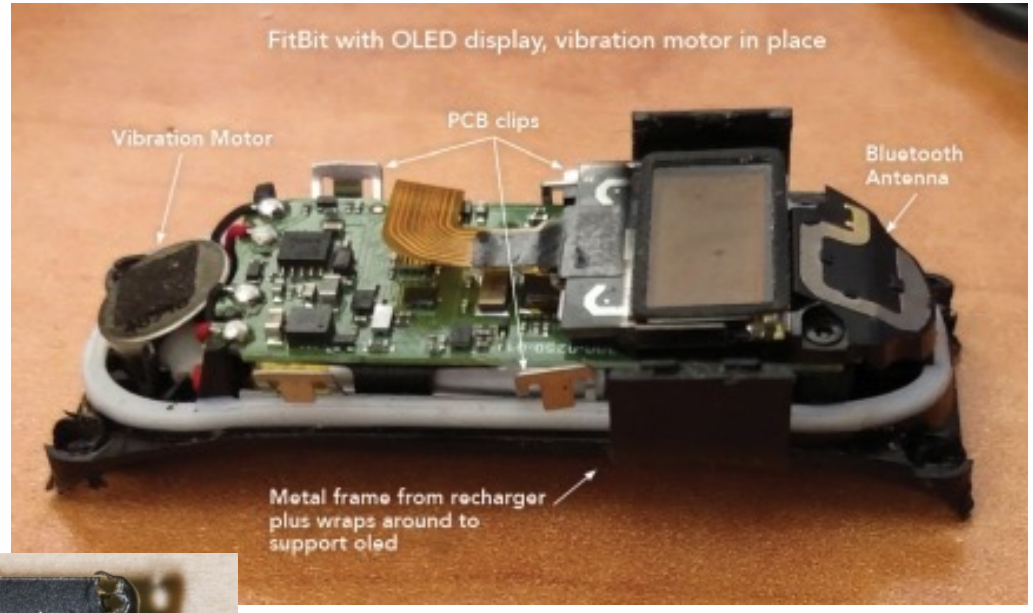
- Applications: Industrial monitoring/control, human interface, nautical
- Technology: Diaphragm condenser, Surface Acoustic Wave (SAW - MEMS)

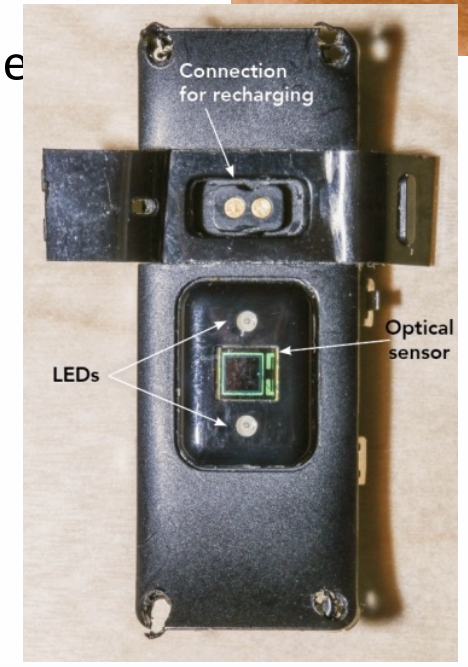
STRAIN SENSOR

- Used to measure strain on an object
- Applications: Industrial monitoring/control, civil infrastructure
- Technology: **Resistive thin films**

Teardown: Fitbit

- 3-axis accelerometer, which tracks motion patterns
- Gyroscope
- Altimeter, which tracks altitude changes
- Built-in GPS receiver + GLONASS, which tracks your location during a workout
- Multi-path optical heart rate tracker
- Multipurpose electrical sensors compatible with the ECG app and EDA Scan app
- On-wrist skin temperature sensor
- Ambient light sensor
- Microphone
- Speaker
- Vibration motor





https://www.microcontrollertips.com/inside-fitbit-charge/

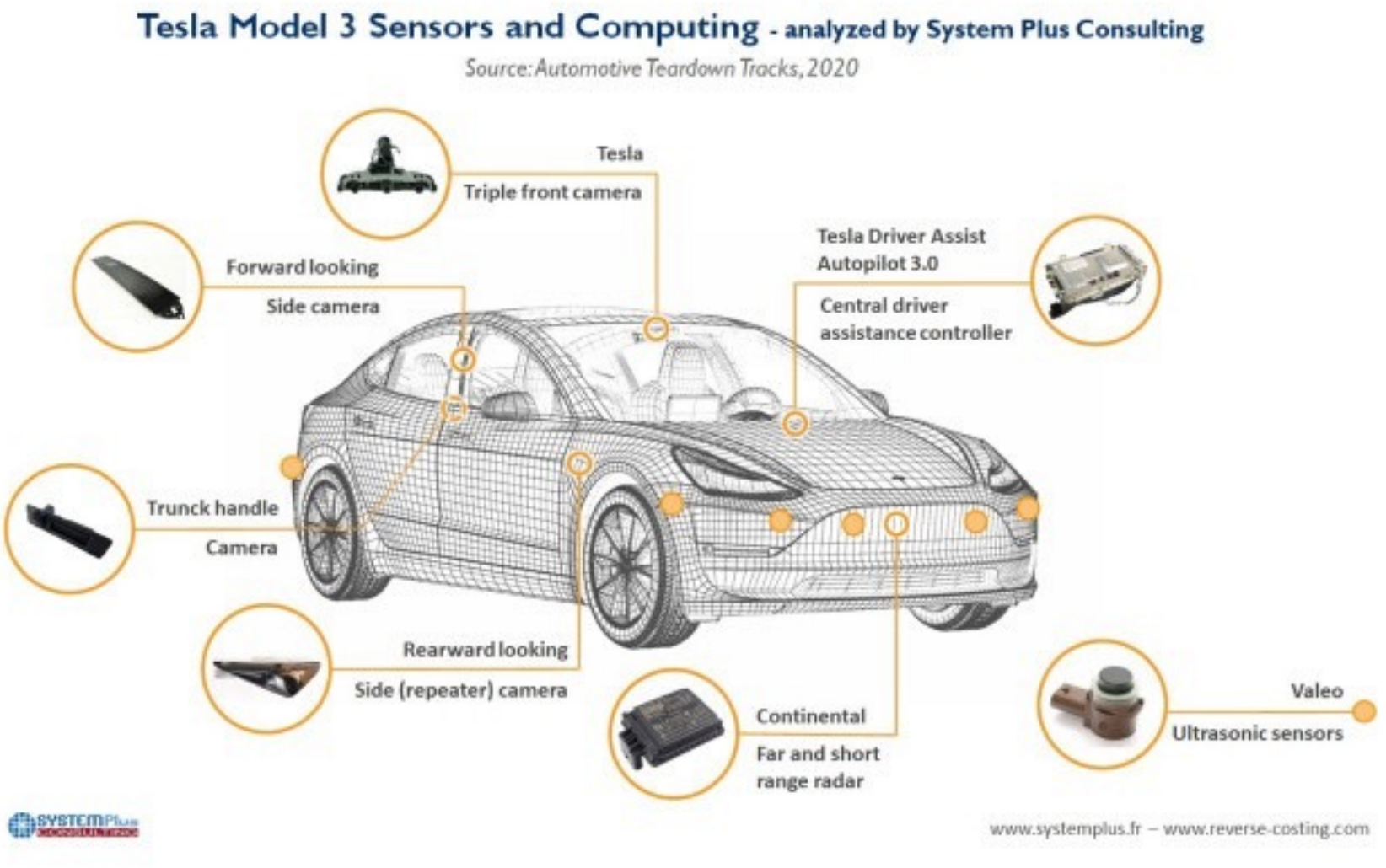
Teardown: iPhone

Sensors inside iPhone (11)

- Face ID
- Barometer
- Three-axis gyro
- Accelerometer
- Proximity sensor
- Ambient light sensor

https://support.apple.com/kb/SP804?locale=en_US

Teardown


Tesla Model 3 Sensors and Computing - analyzed by System Plus Consulting
Source: Automotive Teardown Tracks, 2020
Tesla
Triple front camera
Forward looking
Side camera
Tesla Driver Assist
Autopilot 3.0
Central driver
assistance controller
Trunck handle
Camera
Rearward looking
Side (repeater) camera
Continental
Far and short
range radar
Valeo
Ultrasonic sensors
www.systemplus.fr – www.reverse-costing.com

Sensors inside Tesla Model 3

- 9 cameras
- Radar
- 12 ultrasonic sensors
- Wheel tick sensors
- Wheel pitch sensor
- Microphone
- Accelerometer
- Ambient lighting sensor (may be part of the 9th camera) for Model 3
- Torque and position sensor on the steering wheel
- Seat occupancy sensors (5). Passenger weight is used in controlling deployment of the air bag.
- Seat position sensor (position is saved in driver profile). Seat position is used in adjusting deployment of the air bag.
- Seat belt latch sensors
- Door open sensor s (4)
- Trunk open sensors (2),
- Charge port open sensor
- External temperature sensor
- Cabin temperature sensor
- Battery temperature sensors (multiple)
- Battery voltage sensors
- Accelerator pedal position sensors (2)
- Brake pedal position sensor
- Tire pressure sensors - TPMS (4)
- Glare sensor for automatic mirror dimming
- Key card sensor/reader
- Charging handle button press sensor
- Windshield washer fluid fill level sensor

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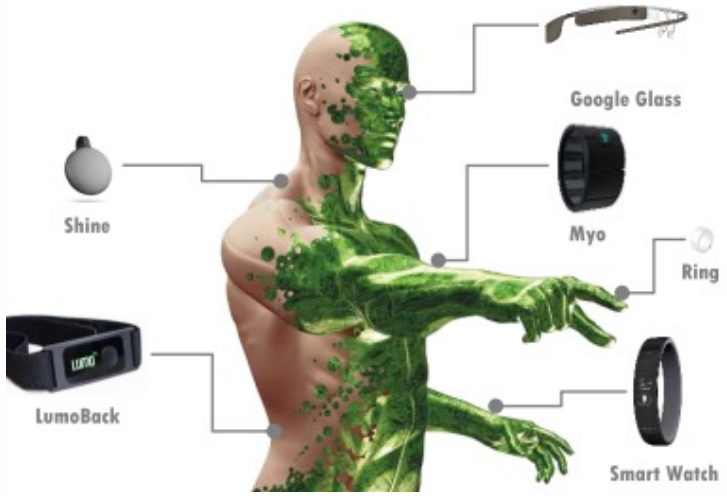
SENSOR TYPES - SUMMARY

Sensor Types	Description	Examples
Position	A position sensor measures the position of an object; the position measurement can be either in absolute terms (absolute position sensor) or in relative terms (displacement sensor). Position sensors can be linear, angular, or multi-axis.	Potentiometer, inclinometer, proximity sensor
Occupancy and motion	Occupancy sensors detect the presence of people and animals in a surveillance area, while motion sensors detect movement of people and objects. The difference between the two is that occupancy sensors generate a signal even when a person is stationary, whereas motion sensors do not.	Electric eye, radar
Velocity and acceleration	Velocity (speed of motion) sensors may be linear or angular, indicating how fast an object moves along a straight line or how fast it rotates. Acceleration sensors measure changes in velocity.	Accelerometer, gyroscope
Force	Force sensors detect whether a physical force is applied and whether the magnitude of force is beyond a threshold.	Force gauge, viscometer, tactile sensor (touch sensor)
Pressure	Pressure sensors are related to force sensors, measuring force applied by liquids or gases. Pressure is measured in terms of force per unit area.	Barometer, Bourdon gauge, piezometer
Flow	Flow sensors detect the rate of fluid flow. They measure the volume (mass flow) or rate (flow velocity) of fluid that has passed through a system in a given period of time.	Anemometer, mass flow sensor, water meter

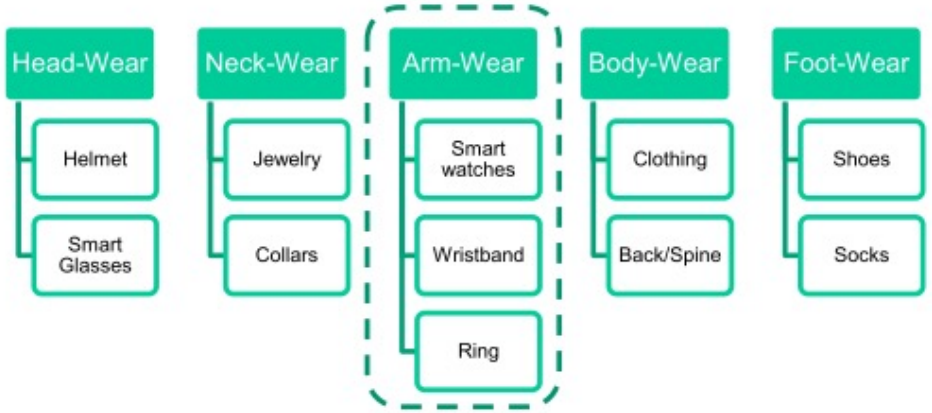
Sensor Types	Description	Examples
Acoustic	Acoustic sensors measure sound levels and convert that information into digital or analog data signals.	Microphone, geophone, hydrophone
Humidity	Humidity sensors detect humidity (amount of water vapor) in the air or a mass. Humidity levels can be measured in various ways: absolute humidity, relative humidity, mass ratio, and so on.	Hygrometer, humistor, soil moisture sensor
Light	Light sensors detect the presence of light (visible or invisible).	Infrared sensor, photodetector, flame detector
Radiation	Radiation sensors detect radiation in the environment. Radiation can be sensed by scintillating or ionization detection.	Geiger-Müller counter, scintillator, neutron detector
Temperature	Temperature sensors measure the amount of heat or cold that is present in a system. They can be broadly of two types: contact and non-contact. Contact temperature sensors need to be in physical contact with the object being sensed. Non-contact sensors do not need physical contact, as they measure temperature through convection and radiation.	Thermometer, calorimeter, temperature gauge
Chemical	Chemical sensors measure the concentration of chemicals in a system. When subjected to a mix of chemicals, chemical sensors are typically selective for a target type of chemical (for example, a CO_2 sensor senses only carbon dioxide).	Breathalyzer, olfactometer, smoke detector
Biosensors	Biosensors detect various biological elements, such as organisms, tissues, cells, enzymes, antibodies, and nucleic acid.	Blood glucose biosensor, pulse oximetry, electrocardiograph

WEARABLE ELECTRONIC MARKET

- The global wearable electronics market can be segmented in 5 categories:
  - Head-Wear category includes helmet product and vision aid
  - Neck-Wear, with collars and necklace products that cover up electronics with jewels
  - Arm-Wear category is **the most burgeoning category** with multiples devices expected wristband, smart watches, ring, armband, etc.
  - Body-Wear products include **smart clothing**, and devices monitoring **back/spine position**.
  - Foot-Wear



Wearable Electronic Market Segmentation:



Arm-Wear market is one of the most promising market and many actors are targeting it.

YOLE Développement

WEARABLE ELECTRONIC

- Wearable electronics is a new big **opportunity for sensors**
  - Fitness / activity monitoring, healthcare, sports applications
  - In many cases the sensor **acts as a hub**
- Basic calculations can be done at the device level
- After transmission (enabled by low energy Bluetooth) : advanced software / fusion can be done by the smartphone
  - Below are many examples of such developments:

Garmin Venu 3

Samsung Galaxy Watch Series 6

Apple Watch Series 9

Google Pixel Watch Series 2

WEARABLE ELECTRONIC / CONNECTED DEVICES

BodyMedia

(Acquired by Jawbone in 2013)

- Integrates MEMS accelerometer (from Kionix and STMicroelectronics) in its systems for fitness application
- We note that no gyroscopes are used presently. This would enable more precise monitoring and new sport applications, however power consumption would be too high. It could be part of larger systems in the future.

MYO by ThalmicLabs

- Proprietary EMG muscle activity sensors
- Nine-axis IMU containing:
  - three-axis gyroscope
  - three-axis accelerometer
  - three-axis magnetometer

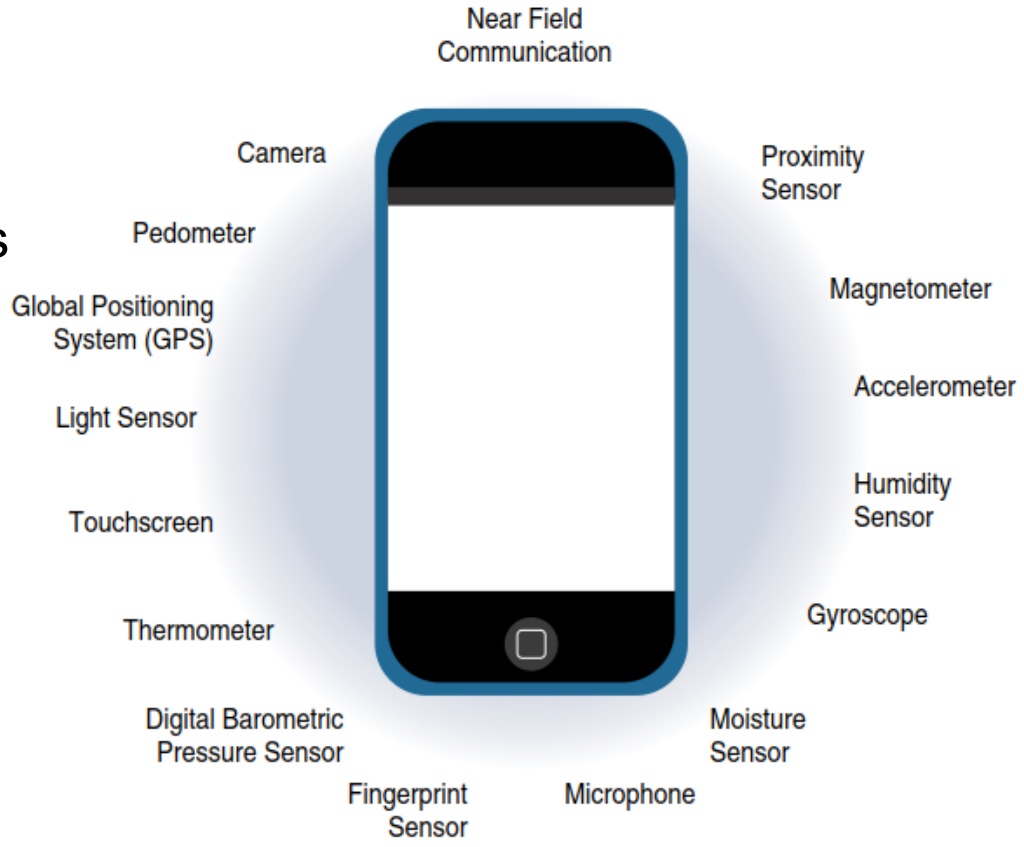
Cell Phone as a Hub

Jawbone Up24

NodeKore from Variable Technologies

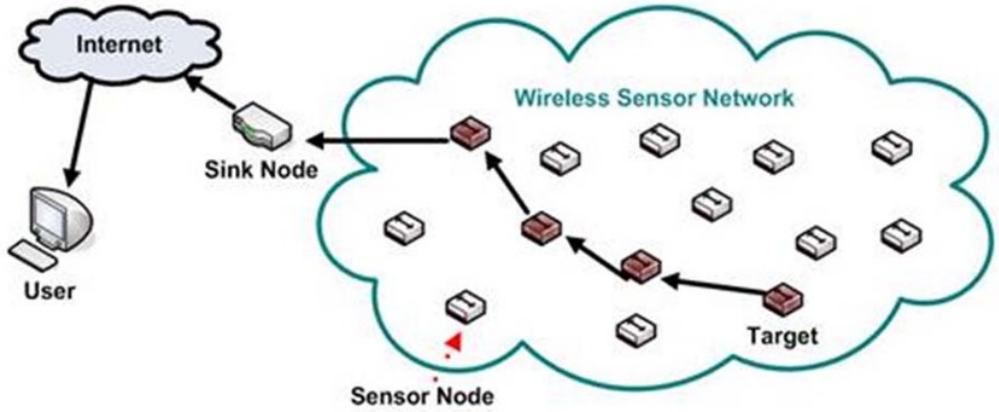
GROWTH IN THE NUMBER OF SENSORS

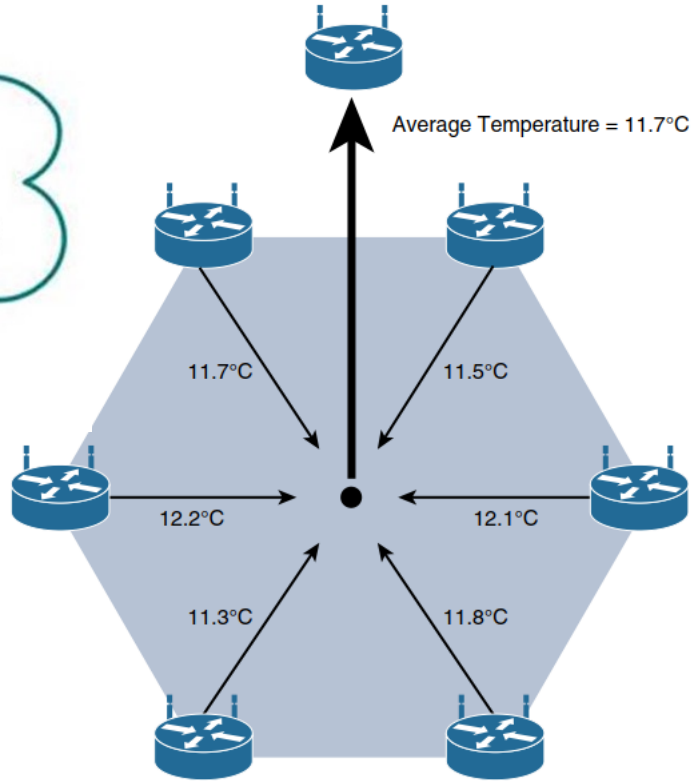
- **A billion smart phones are sold each year!**
  - Over a dozen sensors inside each
- **Smart homes** with potentially hundreds of sensors
- **Intelligent vehicles** with 100+ sensors each
- **Connected cities** with thousands upon thousands of connected sensors



WIRELESS SENSOR NETWORKS (WSN)

- Made up of wirelessly connected smart objects, which are sometimes referred to as **motes**





Data Aggregation in Wireless Sensor Networks

GROWTH AND PREDICTIONS IN THE NUMBER OF SENSORS

- **A trillion-sensor economy is around the corner!**