

Mobile Based Sensors

Modern smartphones integrate a rich array of miniaturized MEMS (Micro-Electro-Mechanical Systems) sensors, transforming them into powerful, portable IoT edge devices capable of context-aware sensing, navigation, health tracking, and augmented reality.

Major Sensors in a Smartphone

Sensor	Measures	Working Principle	Application
Accelerometer	Linear acceleration / tilt	MEMS capacitive change due to inertial mass displacement	Screen rotation, step counting, gaming
Gyroscope	Angular velocity/orientation	MEMS Coriolis-effect vibrating structure	Image stabilization, gesture, AR/VR
Magnetometer	Magnetic field/heading	Hall-effect or magnetoresistive sensing	Digital compass, navigation
Proximity Sensor	Nearby object distance	Infrared emitter–receiver pair	Auto screen-off during calls
Ambient Light Sensor	Light intensity	Photodiode/phototransistor	Automatic brightness control
GPS/GNSS Receiver	Geographic location	Satellite trilateration using time-of-flight signals	Navigation, location-based services
Barometer	Atmospheric pressure	MEMS piezoresistive pressure sensing	Altitude estimation, weather
Fingerprint Sensor	Fingerprint pattern	Capacitive or optical scanning	Biometric authentication
Camera (image sensor)	Light intensity/color (image)	CMOS photodiode array	Photography, face recognition, AR
Microphone	Sound pressure	MEMS diaphragm capacitive transduction	Voice assistants, calls

Integration with IoT

Smartphones act as mobile gateways or edge nodes: their built-in sensors, combined with Bluetooth/Wi-Fi connectivity, allow them to collect environmental and physiological data, run mobile applications for real-time analytics, and relay data to cloud IoT platforms, enabling crowd-sensing applications such as participatory air-quality mapping and traffic monitoring.

Applications

- Fitness and activity tracking (step count, calories, sleep monitoring)
- Indoor/outdoor navigation and location-based services
- Augmented reality (AR) and virtual reality (VR) applications
- Gaming and motion-controlled applications
- Health monitoring through connected wearables
- Participatory sensing (crowdsourced environmental data)

Medical Sensor

Medical (biomedical) sensors detect physiological signals from the human body and convert them into electrical signals for diagnosis, monitoring, and treatment. They form the foundation of wearable health devices and the Internet of Medical Things (IoMT), enabling continuous remote patient monitoring.

Types of Medical Sensors

(a) ECG (Electrocardiogram) Sensor

Measures the electrical activity of the heart using surface electrodes placed on the skin. It detects the depolarization and repolarization waveforms (P, QRS, T waves) of cardiac muscle, used to diagnose arrhythmia and other cardiac conditions.

(b) Pulse Oximeter (SpO2 Sensor)

Uses photoplethysmography (PPG): red and infrared LEDs pass light through tissue (typically a fingertip), and a photodetector measures differential absorption by oxygenated versus deoxygenated hemoglobin to estimate blood oxygen saturation and heart rate.

(c) Body Temperature Sensor

Uses thermistors, infrared sensors, or thermocouples to continuously monitor body temperature, useful in fever detection and post-surgical monitoring.

(d) Blood Pressure Sensor

Typically based on oscillometric or piezoresistive pressure-sensing techniques within a cuff to measure systolic and diastolic blood pressure.

(e) Blood Glucose Sensor

Electrochemical biosensors use enzymes (e.g., glucose oxidase) that react with glucose to generate a measurable current proportional to glucose concentration; used in continuous glucose monitoring (CGM) systems for diabetic patients.

(f) EMG (Electromyography) Sensor

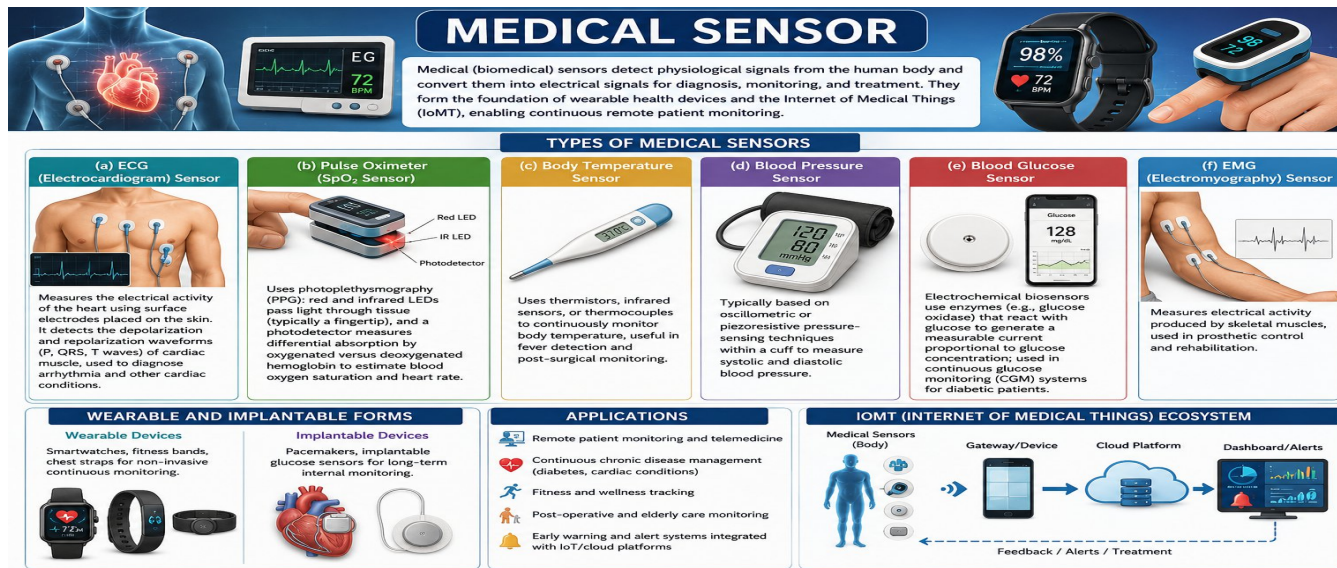
Measures electrical activity produced by skeletal muscles, used in prosthetic control and rehabilitation.

Wearable and Implantable Forms

- Wearable devices – smartwatches, fitness bands, chest straps for non-invasive continuous monitoring.
- Implantable devices – pacemakers, implantable glucose sensors for long-term internal monitoring.

Applications

- Remote patient monitoring and telemedicine
- Continuous chronic disease management (diabetes, cardiac conditions)
- Fitness and wellness tracking
- Post-operative and elderly care monitoring
- Early warning and alert systems integrated with IoT/cloud platforms



Neural Sensor

A neural sensor detects the bioelectrical activity generated by neurons in the nervous system, primarily the small electrical potentials (action potentials/local field potentials) produced during neural signaling. Neural sensors form the sensing interface of Brain-Computer Interfaces (BCIs).

Types of Neural Sensors

- **EEG (Electroencephalography) Electrodes** – non-invasive scalp electrodes that record aggregate electrical activity of large populations of neurons in the cortex; low spatial resolution but safe and easy to apply.
- **ECoG (Electrocorticography) Electrodes** – semi-invasive electrodes placed directly on the exposed brain surface (under the skull), offering higher spatial resolution and signal quality than EEG.
- **Intracortical Microelectrode Arrays** – invasive needle-like electrode arrays (e.g., Utah array) implanted directly into brain tissue to record activity of individual or small groups of neurons with very high resolution.
- **Peripheral Nerve Sensors** – electrodes that record signals from peripheral nerves for prosthetic control.

Working Principle

Neurons communicate through electrochemical signals; when a neuron fires, ionic currents flow across the cell membrane, generating a small extracellular voltage change (in the microvolt to millivolt range). Neural sensors use conductive electrodes to pick up these potentials, which are then amplified (typically requiring high-gain, low-noise amplifiers), filtered to remove artifacts, and digitized for processing by pattern-recognition or machine-learning algorithms to decode intent or diagnose abnormal neural activity.

Applications

- **Brain-Computer Interfaces (BCI)** for controlling prosthetic limbs, wheelchairs, and computer cursors
- **Diagnosis of neurological disorders** such as epilepsy (via EEG) and sleep disorders

- Neurofeedback and cognitive-state monitoring
- Neuroprosthetics and deep brain stimulation feedback systems
- Research into brain function and neural decoding

Motion Sensor

A motion sensor detects physical movement of an object or a person within its field of detection and converts this into an electrical signal, commonly used for security, automation, and human–machine interaction.

Types of Motion Sensors

Type	Working Principle	Application
Accelerometer	Measures linear acceleration using MEMS capacitive/piezoelectric elements	Wearables, vehicle crash detection, gaming
Gyroscope	Measures angular velocity using Coriolis-effect vibrating structures	Orientation sensing, drones, robotics
PIR (Passive Infrared)	Detects infrared radiation emitted by warm bodies	Security alarms, automatic lighting
Ultrasonic Sensor	Emits ultrasonic waves and measures reflected echo time	Obstacle detection, parking sensors
Microwave/Radar Sensor	Emits microwave signal and detects Doppler shift from moving objects	Long-range motion detection, traffic radar
Tomographic Sensor	Uses a mesh of radio waves across a space to detect disturbance	Large-area motion detection

Comparison: Passive vs Active Motion Sensors

- Passive sensors (e.g., PIR) detect energy emitted naturally by objects (infrared heat) without emitting their own signal – low power, but limited to line-of-sight and thermal contrast.
- Active sensors (e.g., ultrasonic, microwave/radar) emit a signal and analyze the reflection – can detect motion through obstacles or in poor thermal contrast conditions but consume more power.

Applications

- Intrusion detection and home/office security systems
- Automatic lighting and energy-saving control
- Gesture recognition and touchless interfaces
- Robotics navigation and obstacle avoidance
- Automotive safety (airbag deployment, collision avoidance)
- Fitness tracking and step counting in wearables

PIR (Passive Infrared) Sensor

A PIR sensor is a passive electronic sensor that measures infrared (IR) light radiating from objects within its field of view. All objects with a temperature above absolute zero emit thermal radiation in

the infrared spectrum; the PIR sensor detects changes in this radiation caused by movement of warm bodies such as humans or animals, without emitting any signal of its own.

Construction

- Pyroelectric Sensing Element – typically made of crystalline material (e.g., lithium tantalate or lead zirconate titanate) that generates a small electric charge when exposed to varying infrared radiation.
- Fresnel Lens – placed in front of the sensor to focus infrared radiation from a wide field of view onto the pyroelectric element and to divide the field of view into multiple zones.
- Two Sensing Elements – most PIR sensors contain two adjacent pyroelectric elements wired in opposite polarity so that ambient IR changes (common to both) cancel out, while motion (which affects one element before the other) produces a net differential signal.
- Amplifier and Comparator Circuit – amplifies the small pyroelectric signal and compares it against a threshold to generate a digital output.
- BISS0001/ IC Control Chip – common in modules (e.g., HC-SR501) to control sensitivity, delay time, and trigger mode.

Working Principle

When a warm body (such as a person) moves across the sensor's field of view, the amount of infrared radiation falling on the two pyroelectric elements changes at different times, producing a differential voltage pulse. This pulse is amplified and compared with a threshold voltage; when it exceeds the threshold, the output pin goes HIGH, indicating motion detection. If no relative motion occurs, the infrared levels on both elements remain balanced and no output is triggered.

Key Specifications (typical HC-SR501 module)

- Detection range: 3 – 7 metres (adjustable)
- Detection angle: up to 110° – 120°
- Operating voltage: 4.5 V – 20 V DC
- Output: digital HIGH/LOW (TTL compatible)
- Adjustable sensitivity and time delay (retriggerable)

Advantages and Limitations

Advantages

- Low power consumption (passive operation)
- Low cost and simple interfacing
- No emitted radiation – safe and covert operation

Limitations

- Cannot detect stationary objects (requires relative motion)
- Performance affected by ambient temperature close to body temperature
- Limited range and line-of-sight requirement
- False triggers due to sunlight, air currents, or small animals

Applications

- Intruder/security alarm systems

- Automatic door openers
- Energy-saving automatic lighting systems
- Occupancy sensing in smart buildings
- Automatic hand sanitizer/soap dispensers

Air Quality Sensor – CO2 Sensor

Air quality sensors measure the concentration of pollutant gases and particulate matter in the surrounding air, such as CO₂, CO, NO_x, SO₂, VOCs, and PM_{2.5}/PM₁₀ particulates. They are essential in environmental monitoring, indoor air quality control, and industrial safety.

Types of Air Quality Sensing Technologies

- Electrochemical Sensors – gas diffuses through a membrane and reacts at an electrode, generating a current proportional to gas concentration (used for CO, NO₂, SO₂).
- Metal Oxide Semiconductor (MOS) Sensors – gas adsorption on a heated metal-oxide surface (e.g., SnO₂) changes its electrical resistance, correlating with gas concentration (used for VOCs, CO).
- Non-Dispersive Infrared (NDIR) Sensors – measure gas concentration based on infrared absorption at a characteristic wavelength; primarily used for CO₂ sensing.
- Photoionization Detectors (PID) – ionize gas molecules with UV light to detect VOCs.
- Optical/Laser Scattering Sensors – measure light scattering by particulate matter to estimate PM_{2.5}/PM₁₀ levels.

CO2 Sensor – NDIR Working Principle

The most common and accurate CO₂ sensors use the NDIR (Non-Dispersive Infrared) technique, based on the principle that CO₂ molecules absorb infrared light strongly at a specific wavelength of approximately 4.26 micrometres.

- An infrared source emits broadband IR light into a sample chamber containing the air sample.
- The IR light passes through the gas chamber, where CO₂ molecules absorb radiation at the characteristic 4.26 μm wavelength.
- An optical filter allows only this specific wavelength to pass to the IR detector, while a reference channel (unabsorbed wavelength) provides a baseline for comparison.
- The detector measures the intensity of the transmitted IR light; a greater reduction in intensity indicates a higher CO₂ concentration (following the Beer–Lambert law).
- Signal-conditioning circuitry converts the detector output into a CO₂ concentration reading, typically expressed in parts per million (ppm).

Common CO2 Sensor Modules

- MG-811 – electrochemical CO₂ sensor (older/analog type)
- MH-Z19 / MH-Z14 – widely used NDIR CO₂ sensor modules with UART/PWM/analog output
- SCD30/SCD40 (Sensirion) – integrated NDIR/photoacoustic CO₂ sensors with digital I2C output

Applications

- Indoor air quality monitoring in offices, schools, and homes

- HVAC (Heating, Ventilation, Air-Conditioning) demand-controlled ventilation
- Greenhouse and agricultural CO₂ monitoring for plant growth optimization
- Industrial safety monitoring in confined spaces
- Environmental pollution monitoring and smart city air-quality networks
- Fermentation and food-storage monitoring

RFID Sensor

Radio Frequency Identification (RFID) is a wireless sensing and identification technology that uses electromagnetic fields to automatically identify and track tags attached to objects. Unlike barcodes, RFID does not require line-of-sight and can read multiple tags simultaneously.

Components of an RFID System

- RFID Tag (Transponder) – contains a microchip storing a unique identifier and an antenna; attached to the object being tracked.
- RFID Reader (Interrogator) – emits radio waves to communicate with and power the tag, and receives the returned data.
- Antenna – transmits and receives RF signals between the reader and the tag.
- Middleware/Backend System – processes the collected tag data and integrates it with databases or IoT platforms.

Types of RFID Tags

- Passive Tags – have no internal power source; they draw energy from the electromagnetic field of the reader to transmit data. Low cost, shorter range (a few cm to ~10 m).
- Active Tags – contain their own battery and can transmit signals independently over longer ranges (up to 100 m), at higher cost.
- Semi-Passive (Battery-Assisted Passive) Tags – use a battery to power the chip's circuitry but rely on the reader's field for communication.

Frequency Bands

Band	Frequency	Typical Range	Applications
LF (Low Frequency)	125 – 134 kHz	Up to 10 cm	Animal tracking, access control
HF (High Frequency)	13.56 MHz	Up to 1 m	Smart cards, NFC, library systems
UHF (Ultra High Frequency)	860 – 960 MHz	Up to 12 m (passive)	Supply chain, inventory, toll collection

Working Principle

The RFID reader generates an electromagnetic field through its antenna. When a passive tag enters this field, its antenna coil couples with the reader's field (via inductive coupling at LF/HF, or backscatter coupling at UHF), inducing a voltage that powers the tag's microchip. The chip then modulates the signal to transmit its stored identification data back to the reader, which decodes and forwards the information to the backend system.

Applications

- Inventory management and supply chain tracking
- Access control and personnel identification (smart cards)
- Automated toll collection systems (e.g., FASTag)
- Livestock and asset tracking
- Retail anti-theft (Electronic Article Surveillance)
- Library book tracking and healthcare asset management