Physiological sensors are biomedical devices that measure various biological signals and physiological parameters of the human body. These sensors convert physical, electrical, optical, or chemical changes into electrical signals that can be processed and displayed. They play a vital role in healthcare by enabling continuous monitoring, early disease detection, diagnosis, and treatment. Physiological sensors are widely used in hospitals, intensive care units (ICUs), wearable devices, telemedicine, fitness trackers, and home healthcare systems. Common physiological sensors include ECG, PPG, SpO_2, temperature, respiration, and sweat sensors.

ECG Sensor (Electrocardiogram Sensor)

An Electrocardiogram (ECG) sensor is a biomedical sensor used to measure the electrical activity of the heart. The heart generates electrical impulses during each heartbeat, and these impulses can be detected using electrodes placed on the surface of the skin. The electrical signals are amplified, filtered, and displayed as an ECG waveform consisting of the P wave, QRS complex, and T wave. The P wave represents atrial depolarization, the QRS complex represents ventricular depolarization, and the T wave represents ventricular repolarization. ECG sensors are commonly used to measure heart rate, detect arrhythmias, diagnose myocardial infarction, and monitor cardiac conditions in hospitals and wearable devices. A normal resting heart rate measured using ECG ranges from **60 to 100 beats per minute**. The major advantages of ECG sensors are their high accuracy, non-invasive nature, and ability to provide continuous cardiac monitoring. However, motion artifacts, improper electrode placement, and electrical interference may affect signal quality.

Principle of ECG Sensor

The ECG sensor operates on the principle that every heartbeat is initiated by an electrical impulse generated from the **Sinoatrial (SA) node**, which is the natural pacemaker of the heart. The electrical impulse spreads through the atria, reaches the **Atrioventricular (AV) node**, and then travels through the **Bundle of His**, bundle branches, and **Purkinje fibers** to stimulate ventricular contraction. These electrical activities create tiny voltage differences (approximately **0.5–4 mV**) on the skin surface, which are detected by electrodes and converted into an ECG waveform.

Construction of ECG Sensor

The ECG sensor consists of the following components:

1. Electrodes

Silver/Silver Chloride (Ag/AgCl) electrodes are attached to the patient's skin to detect the heart's electrical signals. They provide good electrical conductivity and minimize skin-electrode impedance. Standard ECG systems may use 3, 5, or 12 leads depending on the application.

2. Lead Wires

Lead wires connect the electrodes to the ECG acquisition system. They carry the very small bioelectric signals from the body to the amplifier.

3. Instrumentation Amplifier

Since ECG signals are very weak (0.5–4 mV), an instrumentation amplifier amplifies these signals while rejecting common-mode noise such as power-line interference.

4. Filters

Filters remove unwanted noise and artifacts.

- **High-pass filter:** Removes baseline drift caused by breathing and body movement.
- **Low-pass filter:** Removes high-frequency noise such as muscle activity.
- **Notch filter (50/60 Hz):** Eliminates electrical interference from power lines.

5. Analog-to-Digital Converter (ADC)

The amplified analog ECG signal is converted into a digital signal so that it can be processed by a microcontroller or computer.

6. Microcontroller/Processor

The processor analyzes the ECG signal, calculates heart rate, detects abnormalities, stores patient data, and communicates with external devices if required.

7. Display/Computer

The processed ECG waveform is displayed on a monitor or transmitted to a computer, smartphone, or cloud-based monitoring system.

Working of ECG Sensor

The working of the ECG sensor involves the following steps:

Step 1: Generation of Electrical Impulse

The heartbeat begins at the **Sinoatrial (SA) node**, located in the right atrium. The SA node generates an electrical impulse that initiates the cardiac cycle.

Step 2: Detection of Electrical Signals

The electrical impulse travels through the atria and ventricles, producing voltage differences on the body surface. Ag/AgCl electrodes placed on the skin detect these tiny electrical potentials.

Step 3: Signal Amplification

The detected ECG signal is extremely weak (typically **0.5–4 mV**). An instrumentation amplifier increases the signal amplitude while rejecting common-mode noise.

Step 4: Signal Filtering

The amplified signal passes through high-pass, low-pass, and notch filters to remove baseline drift, muscle noise, and power-line interference.

Step 5: Analog-to-Digital Conversion

The clean analog ECG signal is converted into digital form by the ADC.

Step 6: Signal Processing

The microcontroller processes the digital ECG signal to calculate heart rate, identify ECG waves, detect arrhythmias, and store or transmit the data.

Step 7: Display

Finally, the ECG waveform is displayed on a monitor, computer, or wearable device for diagnosis by healthcare professionals.

The ECG waveform consists of the following components:

1. P Wave

- Represents **atrial depolarization**.
- Indicates electrical activation and contraction of the atria.
- Normal duration: **0.08–0.10 seconds**.
- Normal amplitude: **≤0.25 mV**.

2. PR Interval

- Time taken for the electrical impulse to travel from the atria to the ventricles through the AV node.
- Normal duration: **0.12–0.20 seconds**.

3. QRS Complex

- Represents **ventricular depolarization**.
- Indicates contraction of the ventricles.
- Largest waveform in the ECG.
- Normal duration: **0.06–0.10 seconds**.

4. ST Segment

- Represents the period between ventricular depolarization and repolarization.
- Normally lies on the baseline (isoelectric line).

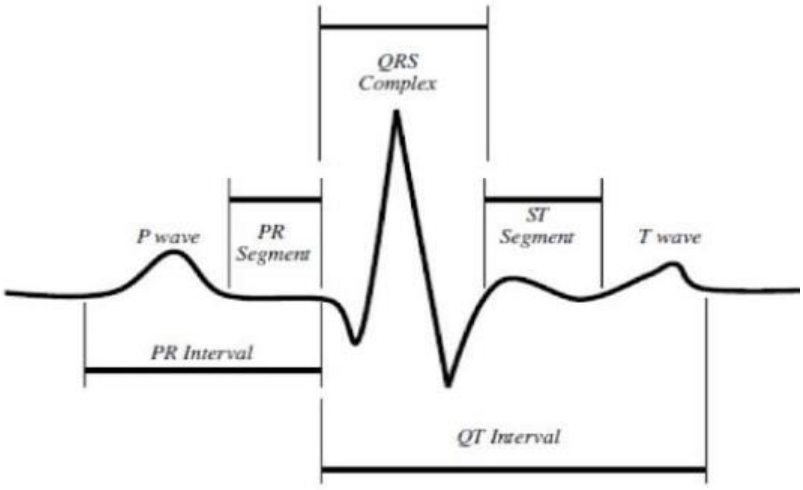
5. T Wave

- Represents **ventricular repolarization**.

- Indicates recovery of the ventricles after contraction.
- Usually upright and rounded.

6. QT Interval

- Represents the total time for ventricular depolarization and repolarization.
- Depends on heart rate.
- Normal QT interval: approximately **0.35–0.44 seconds**.



Normal ECG Parameters

Parameter	**Normal Value**
Heart Rate	60–100 beats/min
ECG Amplitude	0.5–4 mV
P Wave Duration	0.08–0.10 s
PR Interval	0.12–0.20 s
QRS Duration	0.06–0.10 s
QT Interval	0.35–0.44 s

PPG Sensor (Photoplethysmography Sensor)

Photoplethysmography (PPG) is a non-invasive optical sensing technique used to measure changes in blood volume within peripheral blood vessels. A PPG sensor consists of a light-emitting diode (LED) and a photodetector. The LED emits red, infrared, or green light into the skin, and the photodetector measures the amount of light reflected or transmitted through the tissue. As blood volume changes with each heartbeat, the intensity of the reflected light also changes, producing a pulse waveform. PPG sensors are widely used to determine heart rate, pulse rate, heart rate variability, and blood flow. They are commonly integrated into

smartwatches, fitness bands, and pulse oximeters. The advantages of PPG sensors include low cost, simple design, and suitability for wearable health monitoring. However, their performance can be affected by body movement, ambient light, poor sensor contact, and variations in skin color.

The PPG sensor operates on the principle of **optical absorption**. When light is emitted into biological tissue, it is absorbed, scattered, and reflected by different tissues and blood vessels. Oxygenated and deoxygenated blood absorb light differently, and the amount of light absorbed changes with the pulsatile flow of arterial blood during each heartbeat. A photodetector measures these variations in light intensity, and the resulting electrical signal represents the blood volume pulse.

Construction of PPG Sensor

A PPG sensor consists of the following components:

1. Light Emitting Diode (LED)

The LED is the light source that emits light into the skin. Depending on the application, different wavelengths are used.

- Green LED (≈ 530 nm) – Heart rate monitoring
- Red LED (≈ 660 nm) – SpO_2 measurement
- Infrared LED (≈ 940 nm) – Deep tissue penetration and oxygen saturation measurement

The emitted light penetrates the skin and reaches the blood vessels.

2. Photodetector (Photodiode)

The photodiode detects the light that is either reflected from or transmitted through the tissue. As blood volume changes during the cardiac cycle, the amount of detected light also changes. The photodiode converts the received light into an electrical current proportional to the light intensity.

3. Signal Conditioning Circuit

The electrical signal produced by the photodiode is very weak. Therefore, it passes through a signal conditioning circuit consisting of:

- Instrumentation amplifier
- High-pass filter
- Low-pass filter
- Ambient light cancellation circuit

These circuits amplify the signal and remove unwanted noise.

4. Analog-to-Digital Converter (ADC)

The conditioned analog signal is converted into digital form using an ADC so that it can be processed by a microcontroller.

5. Microcontroller (MCU)

The microcontroller processes the digital PPG signal, extracts physiological parameters such as heart rate and pulse rate, and sends the results to the display or communication module.

6. Display/Communication Module

The processed data are displayed on an LCD, smartphone, smartwatch, or transmitted wirelessly using Bluetooth or Wi-Fi for remote monitoring.

Block Diagram

LED
↓
Human Skin and Blood Vessels
↓
Photodiode
↓
Signal Conditioning Circuit
(Amplifier + Filters)
↓
Analog-to-Digital Converter
↓
Microcontroller
↓
Display / Smartphone / Cloud

Types of PPG Sensor

1. Transmission Mode

- LED and photodiode are placed on opposite sides of the tissue.
- Light passes completely through the tissue before reaching the detector.
- Used in pulse oximeters placed on the finger or earlobe.
- Provides high-quality signals.

2. Reflectance Mode

- LED and photodiode are placed on the same side of the skin.
- The detector measures the light reflected from the tissue.
- Used in smartwatches, fitness bands, and wearable devices.
- Suitable for wrist, forehead, and chest measurements.

Working of PPG Sensor

The working of a PPG sensor can be explained in the following steps:

Step 1: Light Emission

The LED emits light toward the skin. The light penetrates the skin and reaches the arteries and surrounding tissues.

Step 2: Light Interaction with Tissue

As the light travels through the tissue, some of it is absorbed by blood, while the remaining light is scattered or reflected. The amount of absorbed light depends on the volume of arterial blood present at that instant.

Step 3: Detection of Reflected or Transmitted Light

The photodiode detects the reflected or transmitted light. During **systole**, arterial blood volume increases, resulting in greater light absorption and less light reaching the photodiode. During **diastole**, blood volume decreases, allowing more light to reach the photodiode.

Step 4: Signal Conversion

The photodiode converts the changing light intensity into a small electrical signal proportional to the blood volume changes.

Step 5: Signal Amplification and Filtering

The electrical signal is amplified and filtered to remove noise caused by body movement, muscle activity, and ambient light interference.

Step 6: Digital Signal Processing

The analog signal is converted into digital form using an ADC. The microcontroller processes the signal to calculate:

- Heart rate
- Pulse rate
- Pulse waveform
- Heart rate variability
- Blood oxygen saturation (when used with red and infrared LEDs)

Step 7: Display of Results

The processed physiological parameters are displayed on a smartwatch, fitness tracker, pulse oximeter, or smartphone application.

Components of the PPG Waveform

The PPG waveform consists of two major components:

1. AC Component

- Represents pulsatile changes in arterial blood volume caused by each heartbeat.
- Used for calculating heart rate and pulse rate.
- Varies with every cardiac cycle.

2. DC Component

- Represents non-pulsatile blood flow and absorption by skin, tissues, bones, and venous blood.
- Changes slowly over time.
- Used as the baseline signal.

SpO_2 Sensor (Pulse Oximeter Sensor)

An SpO_2 sensor, commonly known as a pulse oximeter, measures the oxygen saturation level of arterial blood. It operates based on the Beer–Lambert law, which states that oxygenated and deoxygenated hemoglobin absorb light differently at specific wavelengths. The sensor uses two LEDs: a red LED emitting light at approximately **660 nm** and an infrared LED emitting light at approximately **940 nm**. A photodiode detects the transmitted or reflected light, and the ratio of light absorption is used to calculate oxygen saturation. A normal SpO_2 value ranges from **95% to 100%**, while values below **90%** may indicate hypoxemia. Pulse oximeters are extensively used in hospitals, emergency medicine, anesthesia, COVID-19 monitoring, sleep studies, and wearable health devices. The major advantages are that they are non-invasive, portable, and provide rapid measurements. Limitations include reduced accuracy due to poor blood circulation, nail polish, excessive movement, or bright ambient light.

The SpO_2 sensor operates on the **Beer–Lambert Law**, which states that the amount of light absorbed by a substance is proportional to its concentration and the distance the light travels through it. Oxygenated hemoglobin (HbO_2) and deoxygenated hemoglobin (Hb) absorb light differently at different wavelengths.

- **Oxygenated hemoglobin (HbO_2)** absorbs more **infrared light (940 nm)** and less **red light (660 nm)**.
- **Deoxygenated hemoglobin (Hb)** absorbs more **red light (660 nm)** and less **infrared light (940 nm)**.

By comparing the absorption of red and infrared light, the pulse oximeter calculates the percentage of oxygen saturation in arterial blood.

Construction of SpO_2 Sensor

A pulse oximeter sensor consists of the following components:

1. Red LED (660 nm)

The red LED emits red light with a wavelength of approximately **660 nm**. Deoxygenated hemoglobin absorbs a greater amount of this light.

2. Infrared LED (940 nm)

The infrared LED emits light at approximately **940 nm**. Oxygenated hemoglobin absorbs more infrared light than deoxygenated hemoglobin.

3. Photodiode (Light Detector)

The photodiode is placed opposite the LEDs (transmission type) or beside them (reflectance type). It detects the light transmitted through or reflected from the tissue and converts the light intensity into an electrical signal.

4. Signal Conditioning Circuit

The electrical signal from the photodiode is very small and contains noise. Therefore, it is processed using:

- Instrumentation amplifier
- High-pass filter
- Low-pass filter
- Ambient light rejection circuit

These circuits amplify the signal and remove unwanted noise.

5. Analog-to-Digital Converter (ADC)

The analog signal is converted into digital form using an ADC for further processing.

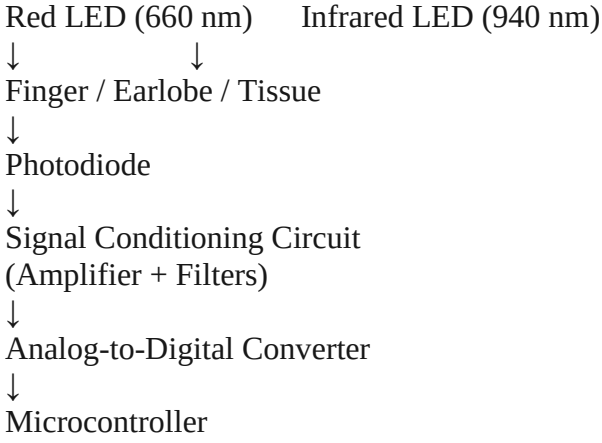
6. Microcontroller (MCU)

The microcontroller processes the digital signal, calculates the ratio of red and infrared light absorption, determines the oxygen saturation level and pulse rate, and controls the display.

7. Display Unit

The calculated SpO_2 percentage and pulse rate are displayed on an LCD, OLED, smartphone, or wearable device.

Block Diagram



↓
Display (SpO_2 & Pulse Rate)

Types of SpO_2 Sensors

1. Transmission Type

- LEDs and photodiode are placed on opposite sides of the finger or earlobe.
- Light passes completely through the tissue.
- Commonly used in fingertip pulse oximeters.
- Provides highly accurate measurements.

2. Reflectance Type

- LEDs and photodiode are placed on the same side of the tissue.
- Measures reflected light.
- Used in smartwatches, wearable devices, and forehead sensors.

Working of SpO_2 Sensor

The operation of a pulse oximeter consists of the following steps:

Step 1: Light Emission

The sensor alternately switches on the **red LED (660 nm)** and the **infrared LED (940 nm)**. These light beams pass through the finger, earlobe, or another measurement site.

Step 2: Light Absorption

As light travels through the tissue, part of it is absorbed by bones, muscles, skin, venous blood, and arterial blood. The amount of light absorbed depends mainly on the concentration of oxygenatedand deoxygenated hemoglobin in arterial blood.

Step 3: Detection by Photodiode

The photodiode measures the intensity of the transmitted or reflected light. Since arterial blood volume changes with every heartbeat, the detected light intensity also changes, producing a pulsatile signal.

Step 4: Signal Amplification and Filtering

The weak electrical signal generated by the photodiode is amplified and filtered to remove noise caused by body movement, ambient light, and electrical interference.

Step 5: Analog-to-Digital Conversion

The clean analog signal is converted into digital form using an ADC.

Step 6: Oxygen Saturation Calculation

The microcontroller calculates the **ratio of red and infrared light absorption** using the pulsatile (AC) and non-pulsatile (DC) components of the signal. This ratio is compared with calibration data stored in memory to determine the **SpO_2 percentage**. The pulse rate is also calculated from the pulsatile waveform.

Step 7: Display

Finally, the oxygen saturation percentage and pulse rate are displayed on the pulse oximeter screen or transmitted to a smartphone or monitoring system.

Components of Pulse Oximeter Signal

The pulse oximeter signal consists of:

1. AC Component

- Represents pulsatile arterial blood flow.
- Changes with every heartbeat.
- Used for SpO_2 and pulse rate calculation.

2. DC Component

- Represents absorption by skin, bones, muscles, and venous blood.
- Remains relatively constant.
- Serves as the baseline signal.

Normal Values

Parameter	**Normal Range**
SpO_2	**95–100%**
Pulse Rate	**60–100 beats/min**

Temperature Sensor

A temperature sensor is used to measure the body's core or skin temperature for assessing health conditions. Various types of temperature sensors include thermistors, thermocouples, resistance temperature detectors (RTDs), infrared sensors, and semiconductor temperature sensors. Most medical temperature sensors operate by converting temperature changes into corresponding electrical signals through changes in resistance or voltage. The normal human body temperature ranges from **36.5°C to 37.5°C**. Temperature sensors are widely used in digital thermometers, wearable health monitors, neonatal care, intensive care units, and fever screening systems. They provide rapid, accurate, and continuous temperature monitoring. However, environmental conditions, improper placement, and lack of calibration may affect measurement accuracy.

Principle of Temperature Sensor

A temperature sensor works on the principle that the **electrical properties of certain materials change with temperature**. In biomedical applications, the most commonly used sensor is the **thermistor**, whose electrical resistance changes with temperature.

- In an **NTC (Negative Temperature Coefficient) thermistor**, the resistance decreases as temperature increases.
- In a **PTC (Positive Temperature Coefficient) thermistor**, the resistance increases as temperature increases.

The change in resistance is converted into an electrical voltage, which is processed to determine the body temperature.

Construction of Temperature Sensor

A biomedical temperature sensor consists of the following components:

1. Temperature Sensing Element

The sensing element detects changes in temperature. Depending on the application, it may be:

- Thermistor
- RTD (Resistance Temperature Detector)
- Thermocouple
- Semiconductor sensor
- Infrared sensor

The thermistor is the most widely used sensing element in digital thermometers due to its high sensitivity.

2. Probe or Sensor Housing

The sensing element is enclosed inside a protective probe made of stainless steel or medical-grade plastic. The probe protects the sensor from damage and ensures safe contact with the patient's body.

3. Signal Conditioning Circuit

The small electrical signal generated by the sensing element is processed using a signal conditioning circuit consisting of:

- Wheatstone bridge (for resistance measurement)
- Amplifier
- Filter

This circuit improves the accuracy of the measurement.

4. Analog-to-Digital Converter (ADC)

The analog voltage corresponding to the temperature is converted into digital form using an ADC.

5. Microcontroller (MCU)

The microcontroller receives the digital signal, calculates the corresponding temperature using calibration data, and controls the display.

6. Display Unit

The measured temperature is displayed on an LCD, OLED, digital thermometer screen, or transmitted wirelessly to a smartphone or hospital monitoring system.

Block Diagram

Body Temperature
↓
Temperature Sensing Element
(Thermistor/RTD)
↓
Signal Conditioning Circuit
(Amplifier + Filter)
↓
Analog-to-Digital Converter
↓
Microcontroller
↓
LCD / Digital Display

Working of Temperature Sensor

The operation of a temperature sensor involves the following steps:

Step 1: Temperature Detection

The sensor is placed in contact with the patient's body (oral, axillary, rectal, forehead, ear, or skin). The sensing element absorbs heat from the body and reaches thermal equilibrium.

Step 2: Change in Electrical Property

As the temperature changes, the electrical resistance of the thermistor also changes.

- Higher temperature → Lower resistance (NTC thermistor)
- Lower temperature → Higher resistance

This resistance variation forms the basis for temperature measurement.

Step 3: Signal Generation

The resistance change produces a corresponding voltage variation in the signal conditioning circuit.

Step 4: Signal Conditioning

The voltage signal is amplified and filtered to remove electrical noise and improve measurement accuracy.

Step 5: Analog-to-Digital Conversion

The analog voltage is converted into a digital signal using an ADC.

Step 6: Temperature Calculation

The microcontroller converts the digital value into temperature using stored calibration equations or lookup tables.

Step 7: Display

The measured body temperature is displayed on the LCD screen or transmitted to a smartphone, wearable device, or hospital monitoring system.

Types of Temperature Sensors

1. Thermistor

- Most commonly used in biomedical devices.
- High sensitivity and accuracy.
- Suitable for body temperature measurement.

2. Thermocouple

- Produces voltage due to the Seebeck effect.
- Used for measuring a wide temperature range.

3. RTD (Resistance Temperature Detector)

- Uses platinum resistance.
- Highly accurate and stable.
- Used in laboratory and industrial applications.

4. Semiconductor Temperature Sensor

- Produces voltage proportional to temperature.
- Easy to interface with microcontrollers.

5. Infrared Temperature Sensor

- Measures temperature without touching the body.
- Used in forehead thermometers and thermal scanners.

Normal Body Temperature

Measurement Site	Normal Temperature
Oral	36.5°C–37.5°C
Axillary	36.0°C–37.0°C
Rectal	37.0°C–38.0°C
Ear	36.5°C–37.5°C

Respiration Sensor

A respiration sensor measures the breathing rate and respiratory pattern of an individual. It works by detecting changes associated with breathing, such as chest expansion, airflow, pressure variations, or changes in electrical impedance across the thorax. Different types of respiration sensors include piezoelectric sensors, airflow sensors, stretch sensors, MEMS pressure sensors, and impedance pneumography systems. The normal respiratory rate for a healthy adult ranges from **12 to 20 breaths per minute**. Respiration sensors are commonly used in ventilators, sleep apnea diagnosis, intensive care units, anesthesia monitoring, and wearable respiratory monitoring systems. These sensors help detect respiratory disorders at an early stage and provide continuous monitoring of breathing patterns. Their main limitations include sensitivity to body movement, improper sensor placement, and motion artifacts.

Principle of Respiration Sensor

A respiration sensor works on the principle that **breathing causes periodic changes in chest or abdominal movement, airflow, pressure, temperature, or electrical impedance**. These physiological changes are detected by the sensor and converted into electrical signals. The processed signals are used to calculate the respiratory rate and analyze the breathing pattern.

Construction of Respiration Sensor

A respiration monitoring system consists of the following components:

1. Sensing Element

The sensing element detects changes associated with breathing. Different sensing elements include:

- Piezoelectric sensor

- Stretch sensor
- Airflow sensor
- Thermistor
- MEMS pressure sensor
- Impedance pneumography electrodes

Among these, the **piezoelectric belt sensor** is commonly used because it measures chest expansion during breathing.

2. Chest Belt or Nasal Probe

Depending on the measurement technique:

- **Chest belt** measures chest expansion and contraction.
- **Nasal cannula or airflow probe** measures inhaled and exhaled air.
- **Thermistor probe** detects temperature differences between inhaled and exhaled air.

3. Signal Conditioning Circuit

The weak electrical signal generated by the sensor is amplified and filtered using:

- Instrumentation amplifier
- High-pass filter
- Low-pass filter

This removes unwanted noise and improves signal quality.

4. Analog-to-Digital Converter (ADC)

The analog respiratory signal is converted into digital form for processing.

5. Microcontroller (MCU)

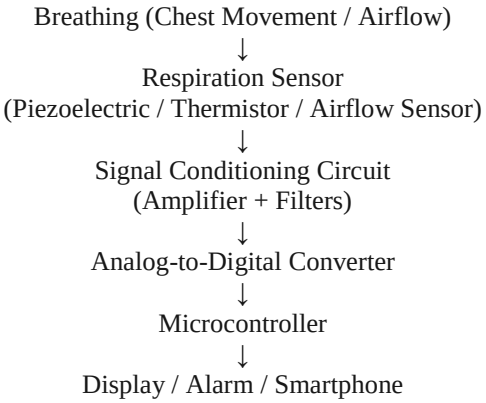
The microcontroller processes the digital signal to calculate:

- Respiratory rate
- Breathing pattern
- Inspiration and expiration time
- Apnea detection

6. Display/Communication Module

The processed respiratory information is displayed on an LCD screen or transmitted wirelessly to hospital monitoring systems, smartphones, or cloud platforms.

Block Diagram



Working of Respiration Sensor

The operation of a respiration sensor can be explained in the following steps:

Step 1: Breathing Activity

During **inhalation (inspiration)**, the lungs expand and the chest circumference increases. During **exhalation (expiration)**, the lungs contract and the chest circumference decreases.

Step 2: Detection by Sensor

The respiration sensor detects these physical changes.

- A **piezoelectric sensor** detects chest expansion.
- An **airflow sensor** detects air flowing through the nose or mouth.
- A **thermistor** senses the temperature difference between inhaled cool air and exhaled warm air.
- An **impedance sensor** detects changes in electrical impedance across the chest during breathing.

Step 3: Signal Generation

The detected breathing movement or airflow produces a small electrical signal proportional to the breathing cycle.

Step 4: Signal Conditioning

The electrical signal is amplified and filtered to remove noise caused by body movement, muscle activity, and electrical interference.

Step 5: Analog-to-Digital Conversion

The analog respiratory signal is converted into digital form using an ADC.

Step 6: Signal Processing

The microcontroller analyzes the respiratory waveform and calculates:

- Respiratory rate (breaths/min)
- Inspiration duration
- Expiration duration
- Breathing depth
- Detection of apnea or abnormal breathing

Step 7: Display

The respiratory rate and breathing waveform are displayed on the patient monitor or transmitted to a wearable device, smartphone, or hospital information system.

Normal Respiratory Rate

Age Group	Normal Respiratory Rate
Newborn	30–60 breaths/min
Children	20–30 breaths/min
Adults	**12–20 breaths/min**

Types of Respiration Sensors

1. Piezoelectric Respiration Sensor

Measures chest expansion using the piezoelectric effect. Widely used in wearable respiration belts.

2. Thermistor Respiration Sensor

Measures temperature differences between inhaled and exhaled air.

3. Airflow Sensor

Measures the volume and velocity of airflow through the nose or mouth.

4. Impedance Pneumography

Measures changes in electrical impedance across the chest due to lung expansion.

5. MEMS Pressure Sensor

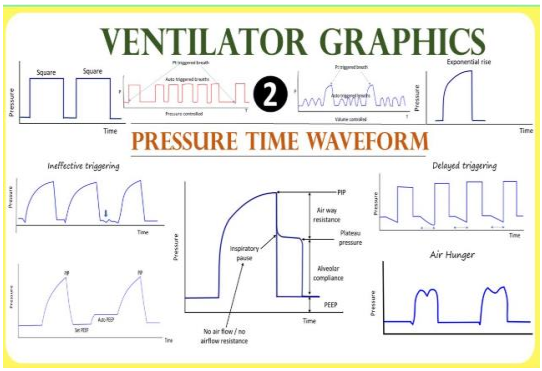
Detects pressure changes produced during inhalation and exhalation.

Respiratory Waveform

The respiration waveform consists of two phases:

- **Inspiration (Inhalation):** Air enters the lungs, causing chest expansion and an upward waveform.
- **Expiration (Exhalation):** Air leaves the lungs, causing chest contraction and a downward waveform.

The interval between successive breathing cycles is used to calculate the respiratory rate.



Sweat Sensor

Sweat sensors are wearable biochemical sensors that analyze the chemical composition of sweat to monitor a person's physiological condition. Human sweat contains several biomarkers such as sodium, potassium, chloride, glucose, lactate, cortisol, and pH, which provide valuable information about hydration status, metabolic activity, stress levels, and disease conditions. Sweat sensors typically use electrochemical or biosensing techniques to detect these biomarkers in real time. Modern sweat sensors are flexible, lightweight, and integrated into wearable patches or smart textiles for continuous health monitoring. They have applications in sports medicine, diabetes monitoring, personalized healthcare, stress assessment, military health monitoring, and fitness tracking. The major advantages of sweat sensors are that they are non-invasive, painless, and capable of providing continuous biochemical monitoring. However, variations in sweat production, limited sample volume, contamination, and sensor calibration remain significant challenges.

A sweat sensor works on the principle of **electrochemical sensing**. When sweat comes into contact with the sensing electrodes, the target biomarker undergoes a chemical or electrochemical reaction. This reaction produces changes in **voltage, current, or electrical resistance**, which are proportional to the concentration of the biomarker. The electrical signal is then processed to determine the concentration of substances such as glucose, sodium, lactate, or cortisol in sweat.

Construction of Sweat Sensor

A sweat sensor consists of the following components:

1. Sweat Collection Layer

The outer layer collects sweat directly from the skin surface. Modern sensors use **microfluidic channels** that guide sweat toward the sensing region without contamination.

2. Sensing Electrode

The sensing electrode is coated with enzymes or chemical receptors that react specifically with the target biomarker.

Common electrode materials include:

- Gold (Au)
- Platinum (Pt)
- Carbon
- Graphene
- Silver/Silver Chloride (Ag/AgCl)

These materials provide high sensitivity and excellent electrical conductivity.

3. Reference Electrode

The reference electrode provides a stable reference potential for accurate electrochemical measurements. An **Ag/AgCl electrode** is commonly used.

4. Signal Conditioning Circuit

The electrical signal generated by the sensor is very small and requires processing using:

- Amplifier
- Filter
- Analog front-end circuit

These circuits improve signal quality by reducing electrical noise.

5. Analog-to-Digital Converter (ADC)

The analog electrical signal is converted into digital form using an ADC.

6. Microcontroller (MCU)

The microcontroller processes the digital signal, calculates the concentration of the biomarker, stores the data, and controls wireless communication.

7. Display/Wireless Communication Module

The measured values are displayed on a wearable device or transmitted to a smartphone or cloud server through **Bluetooth**, **Wi-Fi**, or **NFC** for remote monitoring.

Block Diagram

Sweat from Skin
↓
Microfluidic Sweat Collection Layer
↓
Electrochemical Sensor
(Working Electrode + Reference Electrode)
↓
Signal Conditioning Circuit
(Amplifier + Filter)
↓
Analog-to-Digital Converter
↓
Microcontroller
↓
Display / Smartphone / Cloud

Working of Sweat Sensor

The operation of a sweat sensor can be explained in the following steps:

Step 1: Sweat Production

During exercise, stress, or normal body functions, sweat glands produce sweat containing water, electrolytes, glucose, lactate, cortisol, urea, and other biomarkers.

Step 2: Sweat Collection

Sweat released from the skin enters the microfluidic channels or absorbent layer of the sensor and reaches the sensing electrodes.

Step 3: Biomarker Detection

The target biomarker reacts with the sensing electrode.

For example:

- **Glucose oxidase** reacts with glucose.
- **Lactate oxidase** reacts with lactate.
- Ion-selective membranes detect sodium or potassium ions.

These reactions produce electrical signals proportional to the biomarker concentration.

Step 4: Signal Generation

The electrochemical reaction produces a measurable electrical signal in the form of:

- Voltage
- Current
- Change in resistance

Step 5: Signal Conditioning

The weak electrical signal is amplified and filtered to remove unwanted electrical noise and improve accuracy.

Step 6: Analog-to-Digital Conversion

The analog signal is converted into digital form using an ADC.

Step 7: Signal Processing

The microcontroller processes the digital signal and calculates the concentration of biomarkers such as:

- Glucose
- Sodium
- Potassium
- Lactate
- Cortisol
- pH
- Step 8: Display and Wireless Transmission

The processed data are displayed on the wearable device or transmitted wirelessly to smartphones, smartwatches, or hospital monitoring systems for continuous health monitoring.

Biomarkers Measured by Sweat Sensors

Biomarker	**Clinical Importance**
Sodium (Na^+)	Hydration status, electrolyte balance
Potassium (K^+)	Muscle and nerve function
Chloride (Cl^-)	Cystic fibrosis diagnosis
Glucose	Diabetes monitoring
Lactate	Exercise intensity and muscle fatigue
Cortisol	Stress monitoring

Biomarker	Clinical Importance
pH	Skin health and wound monitoring
Urea	Kidney function assessment

Types of Sweat Sensors

1. Electrochemical Sweat Sensor

Measures electrical current or voltage generated by chemical reactions.

2. Colorimetric Sweat Sensor

Changes color depending on biomarker concentration.

3. Flexible Wearable Sweat Sensor

Built on flexible materials for comfortable long-term use.

4. Microfluidic Sweat Sensor

Uses tiny channels to collect and analyze sweat efficiently.

5. Biosensor-Based Sweat Sensor

Uses enzymes, antibodies, or biomolecules for highly specific detection of biomarkers.