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DEPARTMENT OF BIOMEDICAL ENGINEERING

VI Semester

24BM501 BIOMEDICAL DEVICE DESIGN

UNIT- III WEARABLE, IoT AND AI-ENABLED MEDICAL DEVICES

Smart Health Monitoring Devices:

Introduction and Definition

A **smart health monitoring device** is an intelligent, connected instrument that measures one or more physiological parameters, processes and interprets the data using embedded algorithms, communicates the result wirelessly and can trigger alarms or even therapy. "Smart" means the device has **sensing + processing + connectivity + decision/feedback** capability, unlike a conventional device that only displays a reading.

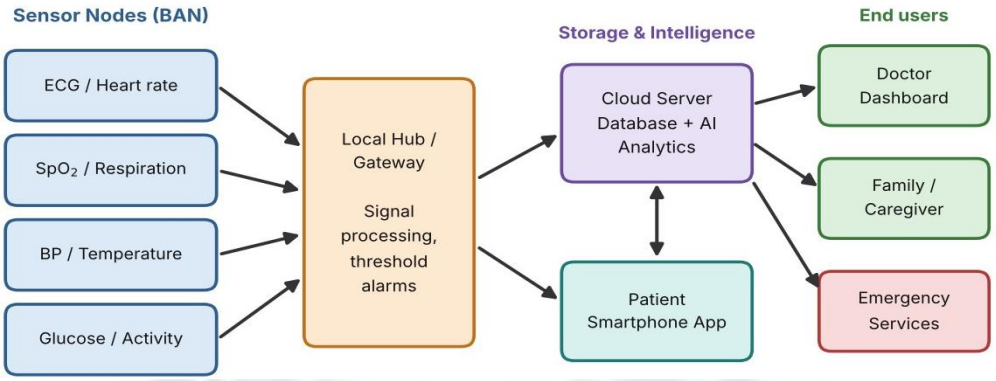
> **Definition: Smart health monitoring** is the continuous or periodic measurement of a person's vital signs and health indicators using connected sensor-based devices, with automatic data transmission, intelligent analysis and timely alerts to the patient, caregiver or clinician.

These devices are used in homes (self-care), hospitals (bedside and ward monitoring), ambulances and community clinics, and they form the **sensing end of the IoMT**. Wearables (Section 3.2) are a subset; this section also covers non-wearable and clinical-grade smart devices.

Architecture of a Smart Health Monitoring System

A complete smart monitoring system has five functional stages (Fig. 3.15): sensor nodes, local hub, communication network, cloud analytics and end-user interfaces.

Fig. 3.15 Architecture of a Smart Health Monitoring System



- **Sensor nodes:** measure ECG, heart rate, SpO_2, respiration, temperature, blood pressure, glucose and activity.
- **Local hub / gateway:** smartphone or bedside unit that collects data from the nodes, applies pre-processing and **threshold alarms** (e.g. $SpO_2 < 90$ %), and secures the data link.
- **Cloud server:** stores time-series data, runs trend analysis and AI models, and generates reports.
- **Patient app:** displays readings, medication reminders and education.
- **Doctor dashboard, caregiver app and emergency services:** receive summaries and critical alerts.

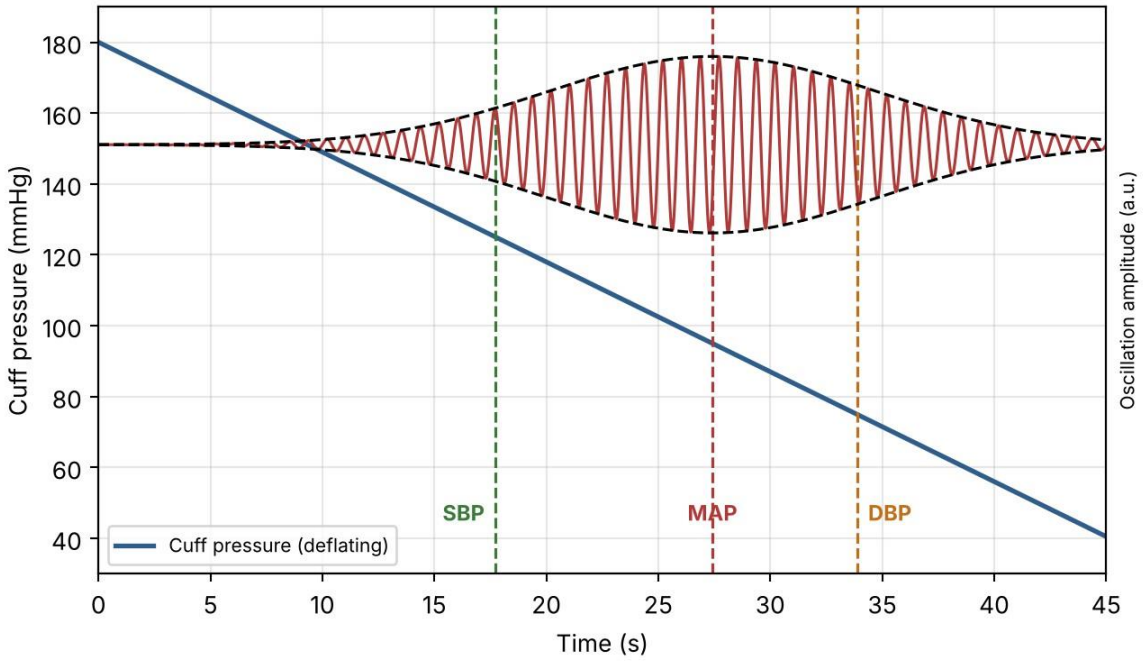
Vital Parameters Monitored

Parameter	Normal adult range	Typical sensing method
Heart rate	60-100 beats/min	ECG electrodes or PPG
Respiratory rate	12-20 breaths/min	Impedance, accelerometer, PPG-derived, thermistor
Blood pressure	< 120/80 mmHg (normal); ≥ 140/90 mmHg is hypertension range	Oscillometric cuff; cuff-less pulse-transit-time methods (research)
SpO_2	95-100 %	Reflective/transmissive pulse oximetry
Body temperature	36.5-37.5 °C (97.7-99.5 °F)	Thermistor, IR, digital contact thermometer
Blood glucose	Fasting 70-100 mg/dL (3.9-5.6 mmol/L)	Enzymatic strip glucometer, CGM
ECG	P-QRS-T morphology, PR 120-200 ms, QRS < 120 ms	Skin electrodes, patches
Physical activity / sleep	Steps, activity minutes, sleep stages	Accelerometer / gyroscope, PPG

Smart Blood Pressure Monitor

Most smart home BP monitors use the **oscillometric method**. A cuff is inflated above the systolic pressure to occlude the brachial artery and then deflated slowly (about 3 mmHg/s). As the cuff pressure falls, the artery wall begins to oscillate and these small pressure oscillations are superimposed on the cuff pressure signal (Fig. 3.17). The oscillation amplitude rises to a maximum and then falls.

Fig. 3.17 Oscillometric Blood-Pressure Measurement



- **Mean arterial pressure (MAP)** is the cuff pressure at which the oscillation amplitude is maximum.
- **Systolic pressure (SBP)** is estimated at the point on the rising side where amplitude is about 50-60 % of the maximum; **diastolic pressure (DBP)** at the falling side where amplitude is about 70-80 % of the maximum (characteristic ratios are device-specific).
- Relation: MAP ≈ DBP + (SBP − DBP)/3.
- Smart features: Bluetooth transfer to the app, irregular-heartbeat detection, user profiles, trend graphs and sharing with the doctor. Validation follows ISO 81060-2 / AAMI protocols.

Smart Pulse Oximeter

A smart pulse oximeter (finger-clip, wrist or patch type) uses the red/infrared principle explained in Section 3.2.6. In addition to SpO_2 and pulse rate it shows the **perfusion index (PI)**, stores overnight data to detect desaturation events and sends alerts through BLE. It was widely used for home monitoring of COVID-19 patients because silent hypoxia could be detected early.

Smart Thermometer

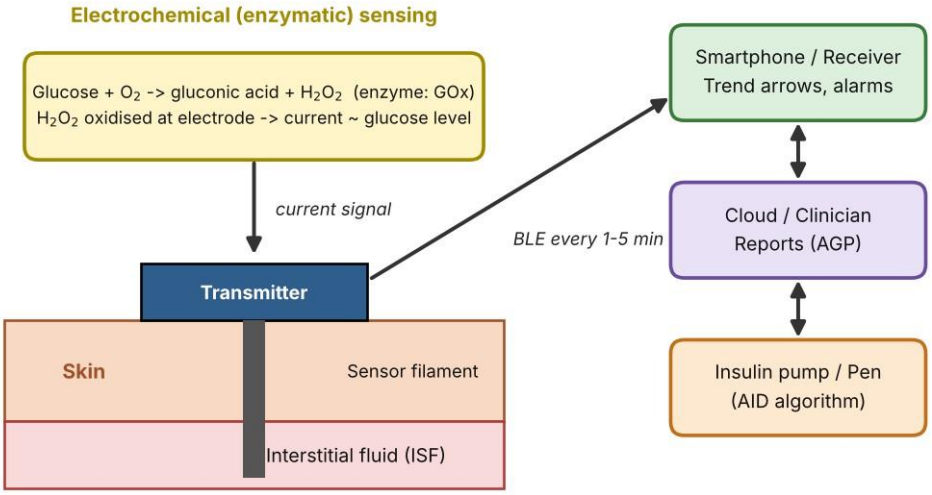
Smart thermometers use thermistors or infrared thermopile sensors with digital compensation and BLE. Wearable patch thermometers record continuous temperature (fever curve) for children and post-operative patients, and the app can log medication and symptoms. Non-contact IR thermometers

are used for mass screening but must be used with correct distance and ambient-temperature compensation.

Continuous Glucose Monitoring (CGM) and Smart Insulin Delivery

A traditional glucometer needs a finger-prick blood drop and gives a single reading. A **CGM system** measures glucose in the **interstitial fluid** every 1-5 minutes through a tiny sensor filament inserted just under the skin (Fig. 3.13). The sensor is coated with the enzyme **glucose oxidase (GOx)**; glucose reacts to form gluconic acid and hydrogen peroxide, and the current produced at the electrode is proportional to the glucose concentration. A transmitter sends the value by BLE to a phone/reader.

Fig. 3.13 Continuous Glucose Monitoring (CGM) System

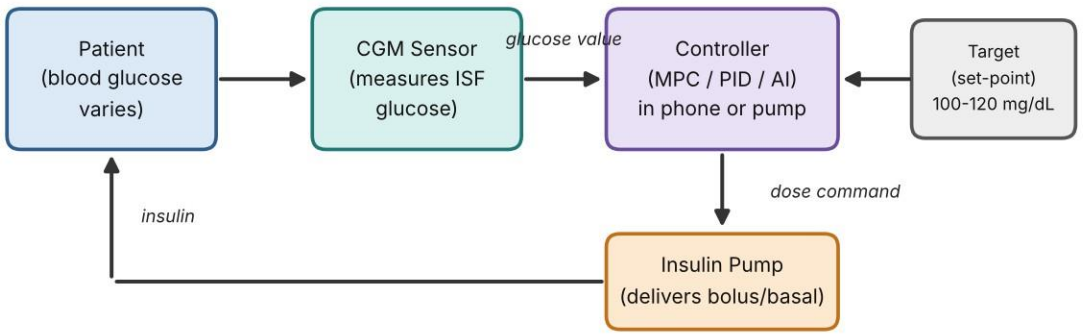


- **Trend arrows and alarms** warn of rapid rise or fall and of hypoglycaemia (< 70 mg/dL) before it becomes dangerous.
- **Time in Range (TIR):** percentage of time the glucose stays within 70-180 mg/dL; a target of more than 70 % is commonly recommended for most adults with diabetes.
- **Lag:** interstitial glucose lags blood glucose by about 5-15 minutes, so confirmatory finger-prick is advised in some situations.
- **Smart insulin pens** log the dose and time automatically and send reminders for missed doses.

➢ Closed-loop insulin delivery (Artificial pancreas / Automated Insulin Delivery)

In a closed-loop system the CGM, a control algorithm and an insulin pump work together (Fig. 3.14). The controller compares the sensed glucose with the target and automatically adjusts the basal insulin delivered by the pump, so that the patient's glucose remains near the set-point. Controllers use PID, **model predictive control (MPC)** or AI-based policies.

Fig. 3.14 Closed-Loop Insulin Delivery (Artificial Pancreas)



Smart Cardiac Monitoring Devices

- **Mobile cardiac telemetry and ECG patches:** continuous ECG for up to 14 days with automatic arrhythmia detection and transmission to a monitoring centre.
- **Implantable loop recorder (ILR):** a small subcutaneous device recording ECG for up to 3 years for unexplained fainting or cryptogenic stroke.
- **Smart pacemakers / ICDs:** remote monitoring home transmitters send battery status, lead impedance and arrhythmia episodes to the clinic.
- **Smart stethoscope:** digitises heart and lung sounds, filters noise and may use AI to detect murmurs; supports tele-auscultation.

Smart Devices for Medication Adherence

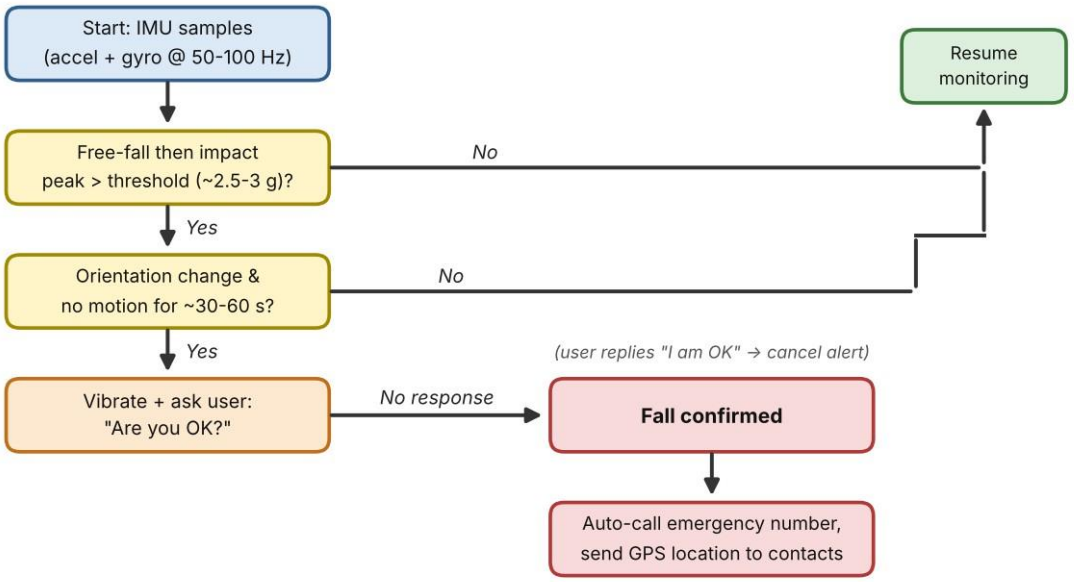
- **Smart pill dispenser / pill box:** opens at the scheduled time, sounds a reminder and informs the caregiver if the dose is missed.
- **Smart inhaler:** sensor attached to the inhaler records time and technique of each puff and links to the app; helps asthma and COPD control.
- **Ingestible event marker:** a tiny sensor in the tablet is activated by stomach fluid and sends a signal to a skin patch confirming ingestion.

Fall Detection and Ambient Assisted Living

Elderly people living alone are at high risk from falls. A fall-detection device (wrist watch, pendant or smart-home

sensor) uses an accelerometer and gyroscope. The algorithm (Fig. 3.18) checks for a free-fall phase followed by a high-impact peak and then a period of no motion with a change in body orientation. If the user does not respond to a prompt, an emergency call with GPS location is sent automatically. Ambient systems use radar, floor pressure mats, thermal arrays or camera-free depth sensors to avoid wearing a device.

Fig. 3.18 Flow Chart of Smartwatch Fall Detection and Alert



Smart Beds, Sleep Monitors and Smart Hospital Devices

- **Smart hospital bed:** load cells and pressure mats detect patient presence, movement, bed-exit and posture; they remind staff to turn the patient to prevent pressure ulcers.
- **Under-mattress sleep sensors:** ballistocardiography (BCG) senses heartbeat, breathing and movement without contact.
- **Multi-parameter bedside patient monitors:** ECG, SpO_2, NIBP, temperature, respiration and capnography on one screen, linked to the central nurse station and EHR.
- **Smart infusion pumps:** drug library with dose-limit software, wireless link to the EHR for automatic programming, reducing medication errors.
- **RFID / BLE real-time location system (RTLS):** tracks wheelchairs, ventilators, staff and patients.

Alarms and Early Warning Scores

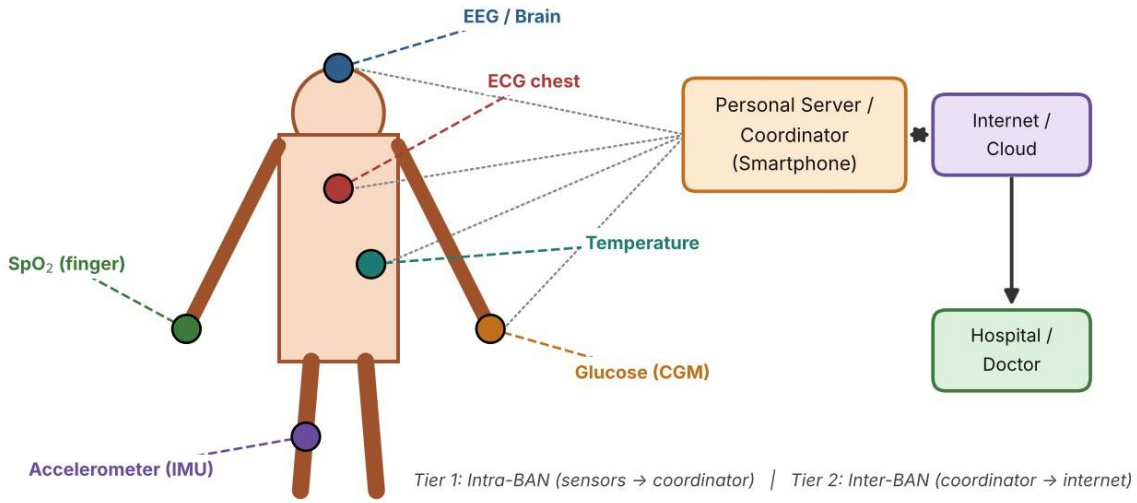
Smart monitors generate alarms when parameters cross preset thresholds. To reduce **alarm fatigue** caused by too many false alarms, modern systems use delayed alarms, adaptive thresholds, multi-parameter logic and AI. Hospitals also use aggregate scores such as the **National Early Warning Score 2 (NEWS2)**, which combines respiratory rate, SpO_2, use of supplemental oxygen, systolic BP,

pulse, level of consciousness and temperature into a single number that triggers escalation of care when it is high.

Wireless Body Area Network (WBAN)

A WBAN is a short-range wireless network of sensor nodes placed on, in or around the human body, all reporting to a central coordinator (personal server), usually a smartphone (Fig. 3.16). It is governed by **IEEE 802.15.6** and uses low-power technologies such as BLE and Zigbee.

Fig. 3.16 Wireless Body Area Network (WBAN)



- **Tier 1 (Intra-BAN):** communication between the body sensors and the coordinator.
- **Tier 2 (Inter-BAN):** communication from the coordinator to an access point / cellular network / internet.
- **Tier 3 (Beyond-BAN):** cloud servers, hospital databases and the doctor's application.
- Design issues: very low power, small size, tolerance to body shadowing of radio waves, low specific absorption rate (SAR), security and quality of service for emergency data.

Signal Processing in Smart Monitoring Devices

- **Pre-processing:** amplification, anti-aliasing filter, ADC, removal of baseline wander (high-pass ≈ 0.5 Hz), power-line noise (50 Hz notch) and high-frequency noise (low-pass).
- **Motion artefact reduction:** adaptive filters using accelerometer as reference, wavelet de-noising, independent component analysis.
- **Feature extraction:** R-peak detection, HRV measures, PPG pulse features, SpO_2 ratio-of-ratios, signal quality index.
- **Decision:** threshold rules, classifiers and machine-learning models, then alarm or report generation.

- **Data compression and secure packetisation** before transmission to save power and bandwidth.

Design Considerations, Standards and Calibration

Design factor	Requirement / standard
Accuracy and calibration	Periodic calibration against reference devices; validation protocols (ISO 81060 for BP, ISO 80601-2-61 for oximeters, ISO 15197 for glucometers)
Electrical safety and EMC	IEC 60601-1 (safety), IEC 60601-1-2 (electromagnetic compatibility), patient leakage current limits
Software	IEC 62304 software life cycle; cybersecurity guidance
Usability	IEC 62366-1; simple interface for elderly and non-technical users
Risk management and quality	ISO 14971 risk management; ISO 13485 quality management system
Power and size	Low-power design, battery safety (IEC 62133), biocompatibility (ISO 10993) for skin contact
Wireless coexistence and security	Reliable links in the crowded 2.4 GHz band; encryption and authentication

Advantages and Limitations of Smart Monitoring Devices

Advantages	Limitations
Early detection of deterioration and emergency alerts	Accuracy depends on correct use and calibration
Convenient self-monitoring at home; patient engagement	False alarms and alarm fatigue
Reduced hospital stay and healthcare cost	Data privacy and cyber-security risks
Objective, long-term data for the doctor	Cost, battery replacement and connectivity requirement
Supports telemedicine and rural healthcare	Over-reliance and anxiety for patients; digital literacy needed

Case Study: Remote Monitoring of a Heart-Failure / Hypertensive Patient

A patient discharged after heart failure is given a Bluetooth weighing scale, BP cuff, pulse oximeter and ECG patch. Readings are taken every morning and sent through the smartphone gateway to the cloud. If the **weight rises by more than 2 kg in 3 days**, BP falls, resting heart rate rises or SpO_2 drops, the system flags possible fluid retention. The care team receives an alert, calls the patient and adjusts diuretic medication, thereby preventing a hospital re-admission. This illustrates how a smart monitoring system converts raw data into timely clinical action.