Unit 4-Smart Wearable Devices & Body Area Networks

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Module Overview

- **Body Area Networks (BAN)** – Definition & Architecture
- **Sensors for Wearables** – Types, Specifications, Examples
- **Communication Protocols** – Bluetooth, Zigbee, LPWAN, etc.
- **Applications in Healthcare & Activity Monitoring**
- **Standards, Security, and Future Trends**

What are Smart Wearable Devices?

- **Definition:**
  Electronic devices worn on the body, often equipped with sensors, microprocessors, and wireless connectivity to collect, process, and transmit data.
- **Examples:**
- Smartwatches (Apple Watch, Fitbit)
- ECG Monitors
- Smart Glasses
- Wearable Patches

Introduction to Body Area Network (BAN)

- **Definition (IEEE 802.15.6):**
  A short-range wireless communication standard optimized for low-power wearable and implantable devices operating in/around the human body.
- **Key Features:**
- Short range (< 2 m)
- Low power consumption
- Reliable data transmission in/around body

BAN Architecture

- **Three-tier structure:**
- **Tier 1:** Wearable/Implantable Sensor Nodes
- **Tier 2:** Personal Device (Smartphone/Gateway)
- **Tier 3:** Cloud/Medical Server
- [Sensor] → [Smartphone] → [Cloud/Server]
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Quiz 1 – BAN Basics

- What is the typical range of a BAN?
  a) < 2 m
  b) 10 m
  c) 100 m
  d) 1 km
- Which standard specifically addresses BAN communication?
  a) IEEE 802.11
  b) IEEE 802.15.6
  c) IEEE 802.3
  d) IEEE 802.16

- **Answers:** 1-a, 2-b

Sensors in Wearable Devices – Overview

- **Role:** Convert physiological/kinetic parameters into electrical signals.
- **Classification:**
- **Physiological:** ECG, EEG, EMG, PPG, Temperature
- **Kinematic/Motion:** Accelerometer, Gyroscope, Magnetometer
- **Environmental:** SpO_2, Humidity, GPS

Physiological Sensors – ECG & PPG

- **ECG Sensor:** Measures electrical activity of the heart.
  Example: AD8232 Single-Lead ECG Sensor.
- **PPG Sensor:** Measures blood volume changes using optical method.
  Example: MAX30102 for heart rate and SpO_2.

Motion Sensors

- **Accelerometer:** Measures acceleration (static & dynamic).
  Example: ADXL345 (3-axis digital accelerometer).
- **Gyroscope:** Measures angular velocity.
  Example: MPU6050 (6-DoF IMU).
- **Magnetometer:** Measures magnetic field for orientation.
  Example: HMC5883L.

Environmental & Other Sensors

- **SpO_2 Sensor:** Measures blood oxygen saturation.
- **Temperature Sensor:**
  Example: MAX30205 (human body temperature).
- **Galvanic Skin Response (GSR):** Measures skin conductance for stress detection.

Quiz 2 – Sensors

- Which sensor is used for blood oxygen measurement?
  a) ECG
  b) PPG
  c) Accelerometer
  d) GSR
- MPU6050 combines which sensors?
  a) ECG & Temperature
  b) Accelerometer & Gyroscope
  c) PPG & SpO_2
  d) Magnetometer & GPS

- **Answers:** 1-b, 2-b

Communication Protocols for Wearables

- **equirements:**
- Low power
- Short to medium range
- Reliable
- Secure
- **Common Protocols:**
- Bluetooth Low Energy (BLE)
- Zigbee
- ANT+
- LoRaWAN (for long-range health monitoring)

Bluetooth Low Energy (BLE)

- Part of Bluetooth 4.0+
- Low power consumption
- Ideal for frequent, small data transmission
- Used in: Fitness bands, smartwatches, medical patches
- **Profile Example:**
- GATT (Generic Attribute Profile) for data exchange

Zigbee & ANT+

- **Zigbee (IEEE 802.15.4):**
- Mesh networking
- Low data rate, low power
- Used in remote patient monitoring systems
- **ANT+:**
- Ultra-low power
- Interoperability between devices
- Common in fitness sensors (heart rate monitors)

LPWAN for Wearable Health Monitoring

- **LoRaWAN:**
- Long range (km), low power
- Suitable for rural/remote health monitoring
- Example: Elderly fall detection with GPS + LoRa

Quiz 3 – Communication Protocols

- Which protocol is most common in smartwatches for smartphone pairing?
  a) Zigbee
  b) LoRa
  c) BLE
  d) NFC
- Which supports mesh topology?
  a) ANT+
  b) BLE
  c) Zigbee
  d) LoRaWAN

- **Answers:** 1-c, 2-c

Applications in Healthcare

- **Remote Patient Monitoring:** ECG, blood pressure, glucose monitoring
- **Chronic Disease Management:** Diabetes, hypertension
- **Elderly Care:** Fall detection, medication reminders
- **Post-operative Monitoring:** Wound healing, vitals tracking
- **Case Study:**
- **Apple Watch** with ECG and atrial fibrillation detection (FDA approved)

Activity Monitoring Applications

- **Fitness Tracking:** Steps, calories, heart rate
- **Sports Analytics:** Motion capture, performance metrics
- **Sleep Monitoring:** Sleep stages, disturbances
- **Posture Correction:** Wearable feedback devices
- **Example:**
- **Fitbit Charge 6** – Multi-sensor activity tracking with GPS

Real-Time Health Monitoring System Example

- [ECG Sensor] → [Microcontroller] → [BLE] → [Smartphone App] → [Cloud DB] → [Doctor’s Dashboard]

- **Components:**
- Sensor: AD8232
- MCU: ESP32 (Wi-Fi/BLE)
- Cloud: AWS IoT/ThingSpeak

Standards for Wearable Devices

- **IEEE 802.15.6** – BAN communication standard
- **ISO/IEEE 11073** – Medical device communication
- **FDA Guidelines** – For medical-grade wearables
- **GDPR & HIPAA** – Data privacy and security regulations

Security & Privacy in BANs

- **Challenges:**
- Data encryption
- User authentication
- Eavesdropping protection
- Secure over-the-air updates
- **Solutions:**
- AES-128 encryption in BLE
- Secure boot in microcontrollers
- Blockchain for health data integrity (emerging)

Case Study – Continuous Glucose Monitor

- **Device:** Dexcom G7
- Sensor measures glucose subcutaneously
- BLE sends data to smartphone
- Alerts for hypo/hyperglycemia
- FDA approved, used by diabetics

Future Trends

- **Energy Harvesting:** From body heat, motion, RF
- **Flexible & Stretchable Electronics:** Skin-like sensors
- **AI Integration:** Predictive health analytics
- **Implantable BANs:** For deep health monitoring

Quiz 4 – Applications & Standards

- Which standard focuses on medical device communication?
  a) IEEE 802.11
  b) IEEE 11073
  c) IEEE 802.3
  d) Bluetooth 5.0
- CGM devices commonly use which wireless protocol?
  a) Zigbee
  b) LoRa
  c) BLE
  d) NFC

- **Answers:** 1-b, 2-c

Project Ideas

- ECG monitor with ESP32 and cloud dashboard
- Fall detection using MPU6050 and GSM alert
- Smart wearable for stress detection using GSR & PPG
- BAN-based multi-sensor health patch with LoRa

Industry Players

- **Apple** (Apple Watch, HealthKit)
- **Fitbit/Garmin** (Fitness wearables)
- **Philips** (Healthcare wearables)
- **Bio IntelliSense** (Medical-grade patches)

Key Takeaways

- BAN enables low-power, short-range communication for wearables
- Sensor choice depends on target physiological parameter
- BLE is dominant for consumer wearables
- Healthcare wearables require regulatory compliance
- Security and privacy are critical in design
- *“Innovation in wearables is not just about technology—it’s about improving human life.”*

References

- IEEE 802.15.6-2012 Standard
- “Body Area Networks: Safety, Security, and Sustainability” by Mehmet Yuce
- Sensors Journal, IEEE
- “Wearable Technology in Healthcare” – Springer
- FDA Guidelines on Wearable Medical Devices