Department of Biomedical Engineering

VI Semester

CBM 370 - Wearable Devices

Unit- 2 Signal Processing and Energy Harvesting for Wearable Devices

2.1 Wearability Issues - physical shape and placement of sensor

Wearable devices and electronics present a unique interface of technology and humanity, thus producing unique challenges that need to account both for technological and human aspects of the problem. Human behavior may affect the operation of wearable as much as the technology advance.

2.1.1 Factors to be considered as some of the challenges facing the field of wearables:

1. **Break-through applications of wearable electronics:** Since ancient times, wearable technology has evolved based on practicality, usefulness, and convenience. Modern wearable electronics face the challenge of finding widespread use, as their future depends on new applications in health, wellness, and personal needs. To support these innovations, wearables may require ***advanced sensing and data analysis***, making them even more valuable.

2. **Minimization of user burden and integration with everyday wear items**: Illustrations of wearable devices often show people wearing them on different parts of the body, such as the arms, legs, and torso. Practically, such a scenario represents an unrealistically high user burden and is unfeasible. A related

challenge is integrating wearable electronics into everyday items. These include clothing, footwear, and accessories.

3. **Efficient and informative interpretation of data generated by wearable devices**: Wearable devices may generate an abundance of data, for e.g., health-related sensor signals. The challenge lies in the interpretation of such data streams and connection with health outcomes, using sensor data to guide behavioral interventions and health education. Emerging methods of artificial intelligence carry a promise of solution to the problem of data analysis and interpretation.
4. **Ultra-low power operation**: A wearable device should ideally sustain a lifetime operation without or minimal user interference. In terms of power, this implies operation on a ***battery, energy harvested from the body***, or a combination thereof. This requires low-power operation both for analog and digital electronics of a wearable. ***Wireless power delivery*** may be explored to ***seamlessly charge*** many devices without need to connect each individual device to a charging circuit (for e.g., charging all socks in a drawer), biofuel cells and supercapacitors may need to be utilized in the power subsystems.
5. **Flexible and stretchable electronics**: Epidermal and body compliant electronic devices may be considered a subset of wearables with additional requirements of allowing ***shape changes in response to body movement***, making such devices especially sensitive to motion artifacts, demanding high biocompatibility and adaptability to variation in human body shapes, sizes, and characteristics.
6. **Biocompatible communications:** Communications from the body (to the outside world) and on the body (between multiple wearables) demand new solutions, as traditional radio methods experience challenges due to absorption by body tissue. The related challenges include development of efficient methods for communicating through or on the body, including the organization of wearables in body sensor networks and their integration into the Internet of Things Biodegradable Electronics. If wearable electronics are to become the true mainstream, the challenge of sustainable, ecologically viable manufacturing, and disposal needs to be addressed.

7. **<u>Privacy and Security</u>**: By definition, a wearable is an electronic device that resides on or close to a person and is present in a variety of life situations. The challenges include protection of personal information, preventing the unauthorized use of wearables for biometric identification, and ownership of the data produced by wearables

2.1.2 <u>While these physiological monitoring devices provide valuable data, their wearability can pose several challenges. Here are some Challenges:</u>

1<u>. Comfort and Fit</u>

- **Headset (EEG sensors)**:
    - ❖ Can be tight or heavy, causing discomfort over long periods.
    - ❖ May not fit all head shapes properly.
    - ❖ Electrodes may require **good skin contact**, which can be uncomfortable.
- **Chest strap sensors**:
    - ❖ Can feel restrictive and uncomfortable, especially for extended wear.
    - ❖ May slip during movement, requiring frequent adjustments.
    - ❖ Sweating can cause irritation or slippage.
- **Wristbands and finger electrodes**:
    - ❖ Some users may feel discomfort due to tight straps or rigid materials.
    - ❖ **Finger electrodes** may limit hand mobility and be inconvenient for daily activities.

2. <u>Skin Irritation and Allergies</u>

- ❖ Long-term use of **chest straps, wristbands, and electrodes** can cause **skin irritation** or **allergic reactions**, especially if worn tightly.
- ❖ **Adhesive electrodes** (for EEG or GSR) can lead to redness, itching, or even rashes.

3. Mobility and Daily Activities

- **Chest straps** can restrict breathing or be annoying during movement.
- **Headsets** may not be practical for daily wear due to their bulkiness.
- **Finger electrodes** can interfere with tasks like typing, eating, or using a phone.
- **DataLOG device** on the arm adds extra bulk, which may limit movement.

4. Power and Battery Life

- Many wearable sensors require **frequent charging**, which can be inconvenient.
- Heavier batteries can make devices **bulky** and uncomfortable.
- Extended use may require **swapping or recharging batteries**, leading to interruptions in data collection.

5. Data Accuracy vs. Wearability Trade-Off

- Loose or improperly worn sensors can cause **data loss or poor signal quality**.
- **Sweat, hair, or movement artifacts** can distort signals (especially EEG and chest strap readings).
- Users may have to **adjust the sensors frequently**, reducing convenience.

6. Aesthetic and Social Acceptance

- **Head-worn EEG devices** can look unusual in public, making users self-conscious.
- Chest straps and finger electrodes are **not discreet**, which can make them impractical for daily use.
- People may feel uncomfortable wearing multiple visible sensors in social or professional settings.

Possible Solutions for Better Wearability:

1. **Flexible and breathable materials** to enhance comfort.
2. **Wireless, lightweight, and compact designs** to reduce bulkiness.
3. **Skin-friendly adhesives and adjustable straps** to minimize irritation.
4. **Longer battery life** to reduce charging interruptions.
5. **Smart textile integration** (e.g., biosensors embedded in clothing) for more +10-natural wearability.

Physical shape and placement of sensor:

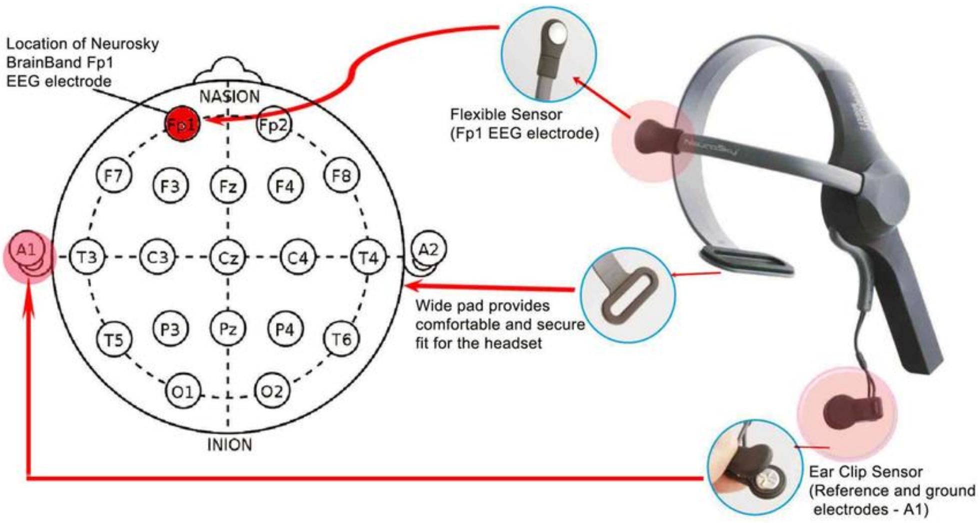
- Design for wearability requires unobtrusive sensor ***node placement*** on the human body based on application-specific criteria. Criteria for placement can vary with the needs of functionality and convenience.
- Functionality criteria constrains node placement to regions where relevant data can be sensed. The number of nodes required to capture all relevant data can vary based on the ***quality of information sensed*** at individual locations. Convenience criteria include:
    - (1) physical interference with movement,
    - (2) difficulty in removing and placing nodes,
    - (3) social and fashion concerns,
    - (4) frequency and difficulty of maintenance (charging and cleaning)
- For example, in continuous healthcare monitoring, patients will be expected to ***charge the sensors*** or ***replace the batteries*** on a regular basis, as they do with cell phones and other electronics. However, the frequent need to charge and the bulk of the battery can frustrate the users, causing them to no longer wear the sensors. Furthermore, batteries are the heaviest component in the system. ***By decreasing power usage***, the size and weight of each sensor node can decrease, thus increasing patient comfort and device wearability.
- This makes ***energy usage a primary constraint in designing BSNs*** (Body Sensor Networks), limiting everything from data sensing rates and link bandwidth, to node size and weight. Thus, one of the important goals in designing BSNs is to ***minimize energy consumption*** while preserving an acceptable quality of service. Energy consumption can be decreased by lower

sampling frequency, decreasing processing power, and simplifying signal processing.

The wearability of physiological sensors depends heavily on their **physical shape, size, and placement on the body**. Here's a breakdown of the different sensor types shown in the image:

1. MindWave Mobile EEG Headset

- **Physical Shape**:
  - A lightweight **headband** with dry electrodes that sit on the forehead and behind the ears.
- **Placement**:
  - Worn around the **head**, with the main electrode on the **forehead** and reference electrodes near the **earlobes**.
- **Challenges**:
  - Can be bulky and uncomfortable over long periods.
  - Electrodes may lose contact due to hair, sweat, or head movement.



2. Chest Strap Sensors

- **Examples**: AutoSense, SleepSense, Cardiosport TP3, Wahoo chest belt, BioHarness 3

- **Physical Shape**:
  - A **flexible elastic band** embedded with **ECG or respiration sensors**.
- **Placement**:
  - Wrapped tightly around the **chest**, just below the pectoral muscles.
- **Challenges**:
  - Can feel restrictive or uncomfortable, especially during physical activities.
  - Can slide down if not fitted properly.
  - May cause skin irritation due to sweating and prolonged wear.

Sleepsense sensor

Cardio port TP3

3. <u>Wristband-Like Sensors</u>

- **Examples**: Empatica E4, Q-Sensor, BN-PPGED, Shimmer Sensor

<u>Empatica E4</u>

accelerometers (ACC), as well as, sensors to measure skin temperature (ST), electrodermal activity (EDA), blood volume pulse (BVP), heart rate (HR), and heart rate variability (HRV)

<u>Q-Sensor</u>

Record physiological signs of stress and excitement by measuring slight electrical changes in the skin

Shimmer sensor

GSR Measurement/PPG Sensor/Heart Rate

- **Physical Shape**:
  - Compact, watch-like **bracelets** made of soft plastic or silicone.
- **Placement**:
  - Worn on the **wrist**, similar to a smartwatch or fitness band.
- **Challenges**:
  - May feel uncomfortable if worn too tightly.
  - Wrist movement can create signal artifacts.
  - Can interfere with wearing other accessories like a smartwatch.

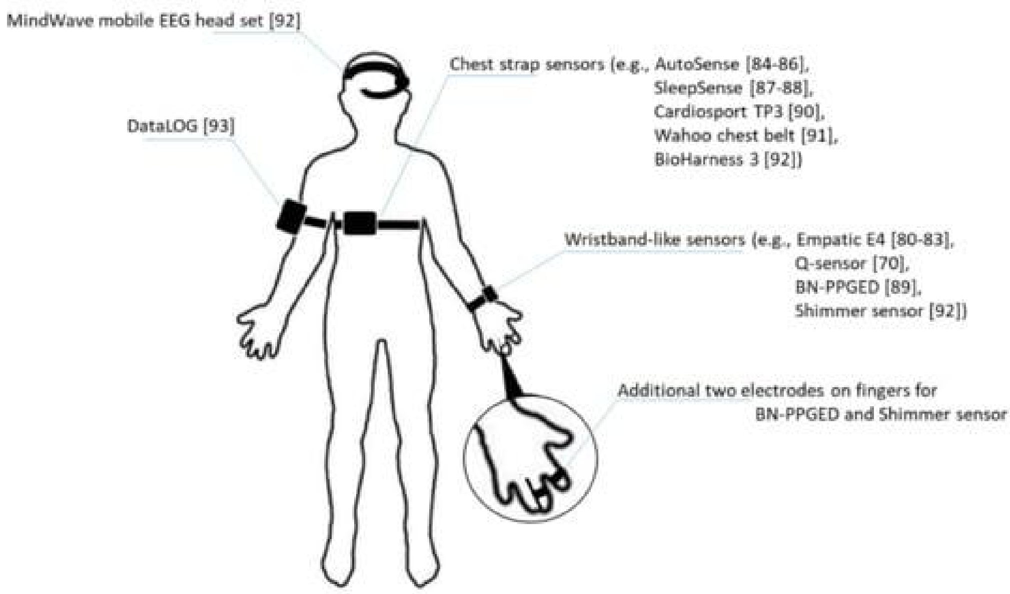
4. DataLOG Device:

- **Physical Shape**:
  - A small **box-like data recorder** with a display and connectors for external sensors.
- **Placement**:
  - Strapped to the **upper arm** using a band or clip.
- **Challenges**:
  - Adds extra weight and bulk, which may limit arm movement.
  - Needs secure fastening to prevent shifting during activity.

5. Additional Finger Electrodes:

- **Examples**: BN-PPGED, Shimmer Sensor
- **Physical Shape**:
  - Small **gel or dry electrodes** attached using adhesive or rings.
- **Placement**:
  - Positioned on **two fingers** (index and middle) for **electrodermal activity (EDA)** measurement.
- **Challenges**:

- Can restrict finger movement, making typing or handling objects difficult.
- Adhesive sensors may cause skin irritation or discomfort.



Sensor Type	Shape	Placement	Wearability Issues
EEG Headset	Headband with electrodes	Forehead & ears	Can be bulky, affected by hair/sweat
Chest Strap	Elastic band with embedded sensors	Chest	Can feel tight, may slip, discomfort during movement
Wristband Sensors	Watch-like, soft silicone	Wrist	Can interfere with other wearables, movement artifacts
DataLOG	Small box, strapped	Upper arm	Adds bulk, may limit arm movement
Finger Electrodes	Small adhesive/ring electrodes	Two fingers	Restricts hand movement, potential irritation

Wearable Issues on physical shape and placement of sensor:

Wearable sensors, while offering numerous benefits in healthcare and fitness monitoring, face challenges related to their physical shape and sensor placement.

Physical Shape:

- **Bulkiness:** Many wearable devices are bulky and uncomfortable, hindering their long-term wearability. This is particularly problematic for sensors that need to be worn continuously, such as those monitoring vital signs.
- **Rigidity:** Rigid devices can restrict movement and cause discomfort, especially during physical activities. This can lead to inconsistent data collection and user dissatisfaction.
- **Aesthetics:** Unattractive or conspicuous devices may deter users from wearing them, especially in social settings.

Sensor Placement:

- **Optimal Placement:** Finding the most accurate and reliable sensor placement can be challenging. Different activities and body types may require different placements.
- **Movement Artifacts:** Sensor movement due to body motion can introduce noise and artifacts into the data, reducing accuracy.
- **Skin Irritation:** Prolonged skin contact with certain materials can cause irritation or allergic reactions, especially for sensitive individuals.

Addressing these issues is crucial for the widespread adoption of wearable sensors. Ongoing research and development focus on:

- **Miniaturization:** Reducing the size and weight of devices to improve comfort and aesthetics.
- **Flexible Materials:** Using flexible and stretchable materials to enhance comfort and conform to body contours.
- **Smart Textiles:** Integrating sensors into clothing to improve comfort and minimize visibility.

- **Advanced Algorithms:** Developing algorithms to filter out noise and artifacts caused by sensor movement.
- **Personalized Placement:** Developing personalized placement recommendations based on individual body characteristics and activity patterns.

By overcoming these challenges, wearable sensors can become more ubiquitous and effective tools for health monitoring and personalized healthcare

****