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Department of Biomedical Engineering

VI Semester

CBM 370 - Wearable Devices

Unit- 2 Signal Processing and Energy Harvesting for Wearable Devices

2.4 Sampling frequency for reduced energy consumption

Reducing energy consumption in wearable devices while maintaining functionality often involves optimizing the **sampling frequency** of sensors.

2.4.1 Some key considerations for optimal sampling frequency:

1. Adaptive Sampling:

Instead of using a constant high-frequency sampling rate, adapt it based on user activity:

- **Event-driven sampling:** Increase sampling only when significant movement or changes are detected.
- **Context-aware sampling:** Lower frequency during low-activity periods (e.g., sleep mode).
- **Hierarchical sampling:** Use a low-power sensor (e.g., accelerometer) to trigger high-power sensors (e.g., ECG, gyroscope) when needed.

2. Optimal Sampling Rates for Different Sensors

Typical sampling rates (which can be reduced for power savings):

- **Accelerometer:** 10–50 Hz (high-motion activities) → Can drop to <10 Hz for idle states.

- **Gyroscope:** 20–100 Hz → Reduce in low-motion scenarios.
- **Heart Rate (PPG/ECG):** 10–500 Hz → Reduce during rest, increase during exercise.
- **Temperature:** 0.1–1 Hz → Can be sampled even less frequently.
- **Environmental sensors:** ~1 Hz or lower, depending on need.

3. Duty Cycling & Data Fusion

- **Duty cycling:** Turn sensors on/off periodically rather than continuous operation.
- **Data fusion:** Combine low-power sensors to estimate states and reduce reliance on power-hungry sensors.

4. Edge Processing & Compression

- Perform basic data processing locally to reduce transmission energy costs.
- Use efficient compression algorithms to reduce data size before transmission.

2.4.2 Optimal Sampling Frequencies:

Wearable devices, particularly those used for health monitoring, require careful consideration of sampling frequency to optimize both performance and energy consumption. The sampling frequency determines how often data is collected from sensors, directly impacting battery life and data management needs.

Heart Rate Monitoring:

Research indicates that the optimal sampling rate for wrist-worn optical sensors, which are commonly used for heart rate (HR) and heart rate variability (HRV) monitoring, ranges from 21 Hz to 64 Hz. Specifically, a rate of 64 Hz is recommended for comprehensive HR and HRV metrics, while rates as low as 32 Hz can maintain sufficient accuracy for many applications, reducing data storage needs by half[1]. For less precision-sensitive applications, a sampling rate of 21 Hz may be acceptable[1].

Energy-Efficient Human Activity Recognition:

In the context of human activity recognition, a lower sampling frequency can significantly reduce energy consumption. However, this reduction must be balanced against the potential loss of accuracy in recognizing activities. A careful analysis is needed to determine the lowest effective sampling rate that still meets accuracy requirements.

General Recommendations:

A common guideline across various studies emphasizes that while high sampling rates may enhance signal quality, they also lead to increased power consumption. Therefore, it is advisable to adopt the lowest possible sampling frequency that still fulfills the application's requirements. This approach not only conserves battery life but also minimizes data management challenges.

Trade-offs in Sampling Frequency

Battery Life vs. Data Quality: Higher sampling frequencies can lead to quicker battery depletion, necessitating more frequent charging or larger batteries that may compromise device portability.

Data Storage Requirements: Lowering the sampling rate can significantly decrease the volume of data generated, which is crucial for devices that continuously monitor health metrics.

2.4.3. General guide for various sensors commonly used in wearables:

1. Motion Sensors (Accelerometer, Gyroscope, Magnetometer)

Sensor Type	Activity Level	Recommended Sampling Frequency
Accelerometer	Low-motion (sleep, rest)	1–10 Hz
	Walking, daily activity	10–50 Hz
	High-motion (sports, falls)	50–200 Hz
Gyroscope	Low-motion	10–20 Hz
	High-motion (sports, VR)	50–200 Hz
Magnetometer	Orientation tracking	10–50 Hz

💡 **Power-saving tip:** Use an accelerometer to detect motion and activate the gyroscope only when needed.

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2. Physiological Sensors (Heart Rate, ECG, PPG, SpO_2, EEG, EMG)

Sensor Type	Use Case	Recommended Sampling Frequency
Heart Rate (PPG/ECG)	Resting HR	10–25 Hz
	Exercise monitoring	100–500 Hz
SpO_2 (Oxygen Saturation)	Continuous monitoring	1–10 Hz
EEG (Brain Activity)	Sleep monitoring	100–250 Hz
EMG (Muscle Activity)	Gesture detection	500–2,000 Hz

💡 **Power-saving tip:** Use lower sampling rates during rest and increase during activity.

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3. Environmental Sensors (Temperature, Humidity, Gas, Pressure)

Sensor Type	Use Case	Recommended Sampling Frequency
Temperature	Skin/body monitoring	0.1–1 Hz
Humidity	Comfort monitoring	0.1–1 Hz
Barometer (Pressure)	Altitude tracking	1–10 Hz

💡 **Power-saving tip:** These sensors can sample at low frequencies since changes occur slowly.

4. Audio & Communication Sensors (Microphone, Bluetooth, GPS)

Sensor Type	Use Case	Recommended Sampling Frequency
Microphone	Voice detection	8–16 kHz
	Speech processing	16–44.1 kHz
Bluetooth	Data transmission	Event-driven
GPS	Location tracking	0.1–1 Hz (1 reading every few sec/min)

💡 **Power-saving tip:** Use **event-driven** GPS updates instead of continuous tracking.

2.4.4. Strategies to Optimize Power Consumption

1. **Adaptive Sampling:** Lower frequency when motion is low.

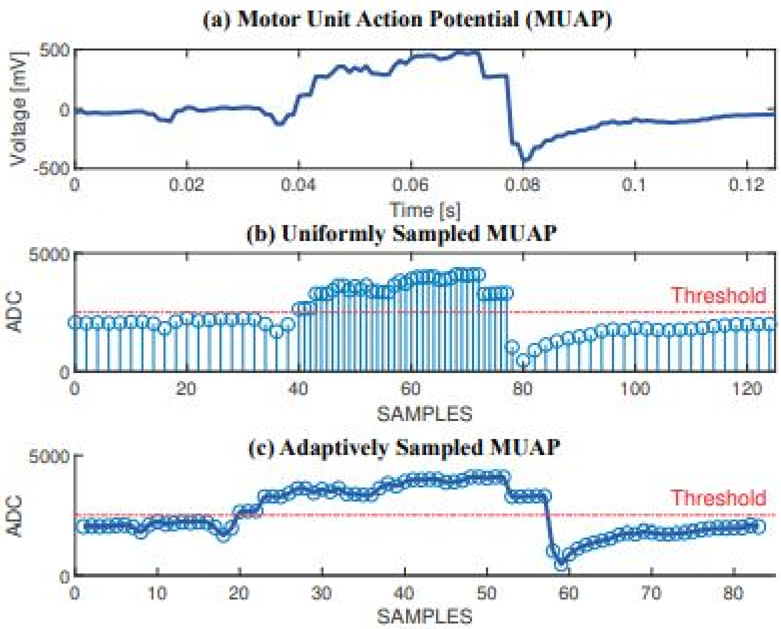

Fig (a) Motor Unit Action Potential (MUAP)

- **Description**: This plot shows the MUAP signal in terms of **voltage (mV) vs. time (s)**.
- **Key Observations**:
    - The signal starts at a relatively low voltage.
    - It then exhibits a significant peak followed by a sharp drop.
    - This pattern is typical of **MUAP**, which represents the electrical activity of motor units in response to neural stimulation.
    - The fluctuations suggest muscle activation and relaxation phases.

Fig. (b) Uniformly Sampled MUAP

- **Description**: This plot represents **ADC (Analog-to-Digital Converter) values vs. samples**, where the signal is sampled at a **fixed rate**.
- **Key Observations**:
    - The sampling rate remains constant throughout the signal.
    - During low-amplitude regions (flat parts), many redundant samples are collected.
    - During high-amplitude or rapid transition regions, the sampling may not be efficient enough to capture the full details.
    - A **red threshold line** is present, indicating a criterion for important signal variations.

Analysis:

- **Disadvantages**:
    - Inefficient use of sampling points, as too many samples are taken in less informative regions.
    - High data redundancy in flat regions.
    - Possible risk of missing finer details in regions of rapid change.
- **Advantages**:
    - Simple and predictable sampling strategy.

Fig. (c) Adaptively Sampled MUAP

- **Description**: This plot represents **ADC values vs. samples**, but with **adaptive sampling**, meaning the sampling rate **varies based on signal activity**.
- **Key Observations**:
    - More samples are taken during rapid signal transitions.
    - Fewer samples are used in relatively flat regions, reducing redundancy.
    - The **red threshold line** again indicates a trigger for denser sampling in critical regions.

Analysis:

- **Advantages**:
    - **Efficient use of data points**—it captures important details while reducing unnecessary samples.

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    - **Lower data storage and transmission needs** compared to uniform sampling.
    - **Better representation of signal variations**, as it prioritizes regions of significant change.
- **Disadvantages**:
    - More complex implementation compared to uniform sampling.
    - Requires adaptive algorithms for real-time processing.

2. **Event-Triggered Sampling:** Only activate high-power sensors when needed.
3. **Duty Cycling:** Periodically turn off sensors when data isn't critical.
4. **Edge Processing:** Process data locally to minimize wireless transmission.

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