ECE 445: Senior Design Laboratory

Project Proposal: Neuroband

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1 Introduction:

1.a Problem

As augmented reality (AR) glasses become more powerful and mainstream, driven by advancements in LLM-based voice assistants, a significant interaction gap has emerged. Interacting with these devices via voice is often impractical or socially unacceptable in public environments due to ambient noise, privacy concerns, and social norms. Current alternative input methods are also insufficient; gaze and head-pose tracking can be imprecise for fine pointer-based tasks and lead to user fatigue. While camera-based hand tracking is a viable option, it is often dependent on specific hardware ecosystems, requires clear lines of sight, and can be unreliable in poor lighting conditions. Therefore, there is a pressing need for an interaction method that is discreet, device-agnostic, and responsive enough to support everyday AR tasks like pointing, selecting, dragging, and scrolling.

1.b Solution

We propose the development of a two-band wrist/forearm controller that functions as a standard Bluetooth HID mouse, offering an intuitive "virtual trackpad" experience. The system is composed of two distinct units: a wrist band for pointing and a forearm band for gestures.

The wrist band (Pointing Unit) will contain an Inertial Measurement Unit (IMU) to estimate the pitch and roll of the user's wrist relative to a calibrated neutral pose. This orientation data is then mapped to a bounded 2D plane to provide absolute cursor control, similar to a trackpad. A key feature is a "clutch" gesture, which allows the user to freeze the cursor's position, re-center their wrist comfortably, and then re-engage control.

The forearm band (Gesture Unit) will use non-invasive surface Electromyography (EMG) electrodes placed over the forearm muscles to detect distinct gestures like pinching and squeezing. These muscle activations will be processed to trigger discrete actions such as left/right clicks, click-and-drag, and scrolling. The forearm band will transmit gesture data to the wrist band. The wrist band acts as the primary device, fusing the pointing and gesture data and sending standard Bluetooth HID mouse reports to the host device (e.g., AR glasses, laptop). This approach creates a seamless, responsive, and private method for high-fidelity device interaction.

NOTE: We plan that the core interaction method will rely on surface EMG sensing for pinch and squeeze gestures. If EMG sensing proves unreliable in practice, we will fall back to a mechanical button input method to ensure a robust and demonstrable final system.

1.c Visual Aid

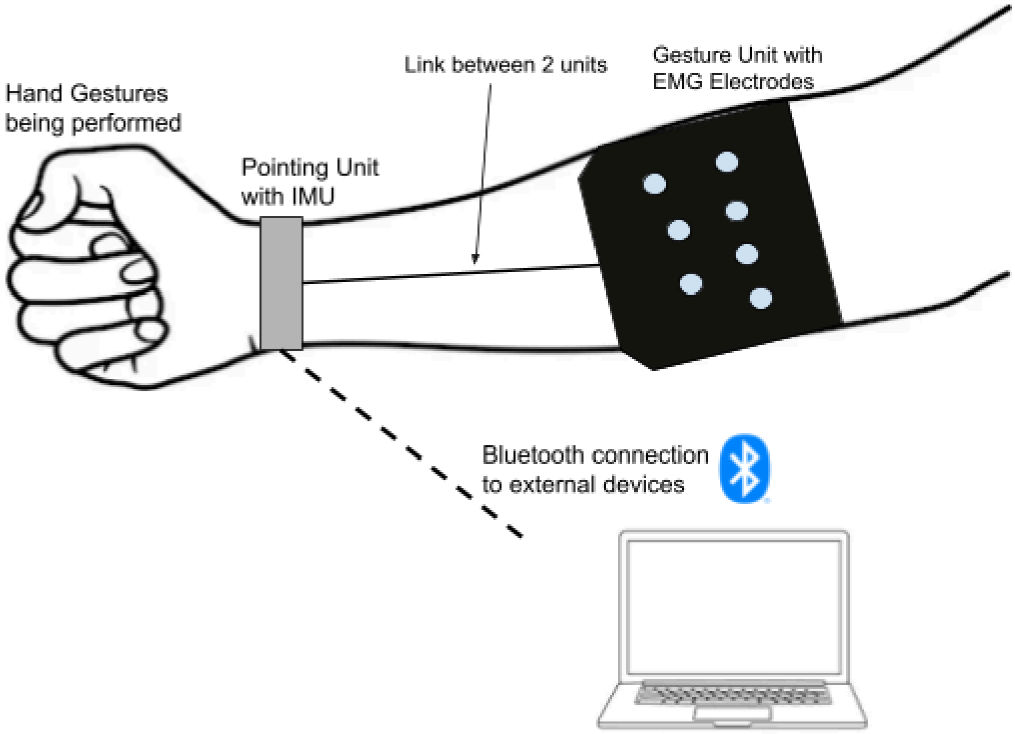

Figure 1: Pictorial representation of NeuroBand

1.d High Level Requirements

To be considered successful, the project must satisfy the following three high-level requirements:

- System Responsiveness: The end-to-end latency, from user motion to the cursor moving on the host screen, must be less than 60 milliseconds to ensure the interaction feels immediate and responsive.
- Gesture Accuracy: The system must achieve a true-positive rate of at least 90% for click gestures during normal use, with a low false-positive rate, ensuring reliable command input without accidental triggers. The system also correctly captures user intent for cursor motion.
- System Operational Time: The device must operate continuously for at least 4 hours on a single charge to be practical for a typical work or usage session.

2 Design:

2.a Block Diagram

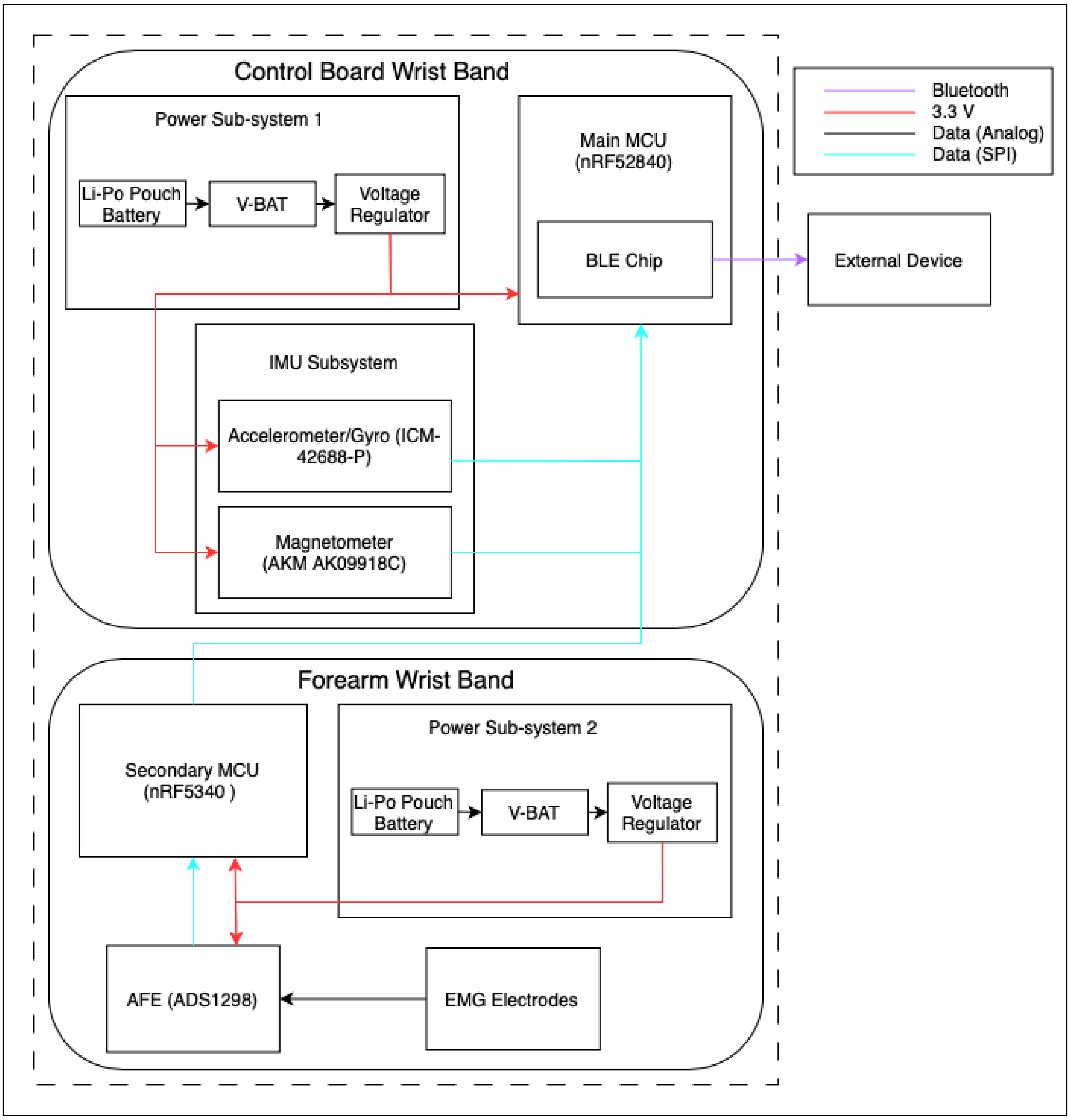

Figure 2: High-level Block Diagram

2.b Subsystem Overview

Our device is composed of two primary systems: the Control Board Wrist Band and the Forearm Wrist Band, each containing dedicated subsystems that work together to provide seamless AR interaction. The wrist band hosts the main MCU (nRF52840), BLE HID link to an external device and the IMU subsystem (ICM-42688-P accelerometer/gyroscope + AKM AK09918C magnetometer). This wrist band is responsible for capturing wrist orientation, fusing sensor data to get the absolute 2-D cursor motion and transmitting it wirelessly to external devices. The forearm band holds a secondary MCU (nRF5340) and the EMG subsystem (ADS1298 + electrodes). This part amplifies/digitizes muscle activity, extracts features, decides on gestures (pinch/squeeze), and forwards compact events to the wrist band over a short wired link. Furthermore, each of these bands have their own power system. Together, these systems share sensor, processing, and communication responsibilities, creating a robust wearable that functions as a Bluetooth HID mouse.

2.b.i Wrist Band

We plan that the wrist band will be made of a Nylon-spandex blend in order to give the user comfort while ensuring a tight fit for the electronics attached to ensure the sleeve doesn't keep moving from place to place and mess up readings.

2.b.i.1 Main MCU Subsystem + Bluetooth System

This subsystem fuses IMU pointing data from the wrist band along with EMG gesture data received from the forearm band to decide the mouse action (e.g., clutch to freeze, pinch to click/drag) and then outputs the result as standard Bluetooth HID mouse reports to the host device. To communicate the result from the MCU to the host device we plan to use BLE (Bluetooth Low Energy).

2.b.i.2 IMU Subsystem

The Inertial Measurement Unit (IMU) sensors will be integrated into the wrist band to capture wrist orientation and motion data. The subsystem consists of the ICM-42688-P accelerometer/gyroscope and the AKM AK09918C magnetometer, which together provide full 9-DOF sensing. These signals will be converted to a 2D plane reading and communicated to the Main MCU. This will be functioning as the primary pointing mechanism of the device.

2.b.ii Forearm Band

The forearm band will also be made of a nylon-spandex blend to provide both comfort and a snug, stretchable fit that ensures consistent contact between the EMG electrodes and the user’s skin, while also making sure that all electronics remain snuggly in place to prevent any error in readings.The Secondary MCU and EMG subsystem will be mounted to this band in fixed positions to simplify development and ensure robust data collection.

2.b.ii.1 Secondary MCU

The Secondary MCU Subsystem manages the acquisition and transmission of EMG signals from the forearm band. A low-power microcontroller, such as the nRF5340, will receive digitized signals from the EMG subsystem, run a small TinyML classifier (clutch, pinch, pinch-hold, none), and send gesture data via a short wired link. Doing ML at the source cuts bandwidth and adding this secondary MCU prevents noise and error in the data by ensuring that it doesn't get distorted over longer distances.

2.b.ii.2 EMG Subsystem

The EMG Subsystem is responsible for detecting muscle activation signals in the user's forearm to enable gesture recognition. Surface electrodes embedded in the forearm band will capture electrical activity from muscle contractions, such as pinching or squeezing. These signals will be conditioned through an analog front-end (AFE) for amplification and filtering before being digitized and sent to the Secondary MCU. The processed EMG data will then be transmitted using a wire to the Main MCU in the wrist band for integration with IMU-based pointing control.

2.b.iii Power Subsystem

The Power Subsystem provides stable and continuous energy to all electronic components across both the wrist and forearm bands. Power is split by band: the wrist and forearm each have their own single-cell Li-Po pouch (which comes with its own BMS), local charger, and regulation. The regulators ensure a consistent 3.3 V supply for the MCUs, IMU, and EMG front-end, while the battery management system (BMS) protects against overcharging and undervoltage. By isolating the power systems per band, each unit remains independently functional and easier to charge, while also reducing noise coupling between high-sensitivity EMG sensing and IMU processing.

2.c Subsystem Requirements

2.c.i Main MCU subsystem

The Main MCU + Bluetooth Subsystem is responsible for fusing IMU pointing data with EMG gesture data and outputting mouse actions as Bluetooth HID reports. Reliable processing and low-latency communication are critical for responsiveness.

1. BLE throughput: The subsystem must support at least 1 Mbps BLE data rate to ensure timely delivery of cursor and gesture data. Failure to meet this would increase end-to-end latency and violate High-Level Requirement #1 (Responsiveness).
2. Processing capacity: The MCU must be capable of running the fusion logic at 75 Hz update rate. If slower, cursor motion would appear laggy and violate High-Level Requirement #1.

2.c.ii IMU subsystem

The IMU Subsystem provides orientation and motion data from the wrist, which is mapped into 2-D cursor movement. It consists of the ICM-42688-P accelerometer/gyroscope and the AKM AK09918C magnetometer. Accurate, stable

IMU data is critical to meeting High-Level Requirement #1 (Responsiveness) and High-Level Requirement #2 (Gesture Accuracy).

1. Interface speed: The IMU must communicate with the Main MCU over SPI at a minimum clock rate of 1 MHz. Without this, sensor data cannot be transferred quickly enough to maintain responsiveness (HLR-1).
2. High DoF: The IMU must be able to measure roll, pitch, and yaw accurately to correctly map user intent for cursor motion, as well as scroll movements. The combination of the accelerometer, gyroscope, and magnetometer, giving us 9 DoF (HLR-2)
3. Measurement range: The accelerometer must tolerate at least ±4 g, and the gyroscope at least ±500 dps, to capture typical wrist motions without saturation. If the ranges are smaller, gestures and pointing would clip and accuracy would be lost (HLR-2).

2.c.iii Secondary MCU subsystem

The Secondary MCU Subsystem manages EMG signal acquisition and classification on the forearm band. It receives digitized signals from the EMG Subsystem, performs lightweight feature extraction/classification using machine learning, and forwards compact gesture events to the Main MCU over a short wired link. This reduces noise susceptibility and bandwidth requirements, directly supporting High-Level Requirement #1 (Responsiveness) and High-Level Requirement #2 (Gesture Accuracy).

Requirements:

1) Update rate: The Secondary MCU must classify EMG signals and produce gesture outputs at ≥ 50 Hz. If slower, gesture recognition would feel delayed and violate HLR-1.
2) Wired link interface: The Secondary MCU must support a UART or SPI link at ≥ 500 kbps to the Main MCU. If this bandwidth is not available, gesture data could be dropped or delayed, violating HLR-1.
3) Processing capacity: The Secondary MCU must be able to run a lightweight TinyML classifier (e.g., pinch, pinch-hold, squeeze, none) within ≤ 10 ms per cycle. If this timing requirement is not met, gesture events will lag and reduce accuracy (HLR-2).

2.c.iv EMG subsystem

The EMG Subsystem detects muscle activation signals in the user’s forearm and provides the raw data for gesture recognition. Surface electrodes embedded in the forearm band capture microvolt-level signals, which are amplified, filtered, and digitized through the ADS1298 analog front end before being sent to the Secondary MCU. Reliable detection and conditioning of these signals is essential for achieving High-Level Requirement #2 (Gesture Accuracy).

Requirements:

1) Signal resolution: The EMG subsystem must digitize signals at ≥ 12-bit resolution. If resolution is lower, subtle contractions may be lost, reducing classification accuracy (HLR-2).
2) Sampling rate: The EMG front end must sample at ≥ 500 samples/second per channel. If slower, temporal features needed for gesture recognition will be missed, violating HLR-2.
3) Gain range: The analog front end must support adjustable gain up to ~1000×, allowing amplification of microvolt-level EMG signals into the usable ADC range. If this gain is unavailable, the subsystem cannot detect signals reliably (HLR-2).

2.c.v Power subsystem

The Power Subsystem provides stable and continuous energy to all electronic components across both the wrist and forearm bands. Each band has its own single-cell Li-Po pouch battery with integrated battery management system (BMS), a local charger, and 3.3 V regulation. By isolating power per band, noise coupling between the wrist MCU/radio and the sensitive forearm EMG subsystem is minimized. Reliable power delivery is essential for achieving High-Level Requirement #3 (System Operational Time).

Requirements:

1) Voltage regulation: Each regulator must supply a stable 3.3 V ± 0.1 V rail to all subsystems. If voltage drifts outside this range, the MCUs, IMU, or EMG front end may fail to operate.
2) Current capacity: Each regulator must support at least 100 mA continuous current to provide sufficient headroom for the MCU, IMU, EMG front end, and peripherals. Without this, components could brown out under load, violating HLR-3.
3) Battery capacity: Each Li-Po cell must provide at least 150 mAh usable capacity, supporting a minimum of 4 hours of continuous operation under expected 30–40 mA draw. If capacity is lower, the runtime goal cannot be met (HLR-3).
4) Safety protections: Each BMS must enforce overcharge, over-discharge, and overcurrent protection to prevent unsafe battery operation. Without this, the device poses safety hazards to the user.

2.d Tolerance Analysis

To ensure the Power Subsystem can meet High-Level Requirement #3 (System Operational Time), we performed a runtime feasibility check based on estimated current draw from each major component.

Estimated current consumption (per band):
Main MCU (nRF52840, active with BLE): ~10 mA
Secondary MCU (nRF5340, active): ~10 mA

IMU (ICM-42688-P + AK09918C): ~2 mA
EMG Front End (ADS1298 + AFE): ~10 mA
Miscellaneous overhead (regulators etc.): ~5 mA

This results in an expected maximum current draw of ~35 mA per band during continuous operation.

Battery sizing:
With each band powered by a single-cell 150 mAh Li-Po. Since the estimated maximum current draw is 35 mA, using this figure the expected runtime is:

$$Runtime = \frac{150\,mAh}{35\,mA} = 4.3\ hours$$

This satisfies the target of ≥ 4 hours helping ensure we reach high level requirement 3.

Safety and Ethical Considerations

We anchor our project in the IEEE and ACM Codes of Ethics: prioritizing user safety and the public good, being honest and realistic in claims, respecting privacy and autonomy, and correcting errors promptly. Practically, we will present the wrist/forearm bands strictly as a human–computer interface (not a medical or diagnostic device), disclose limitations and risks in plain language, and only make claims supported by measured data such as latency, accuracy, and battery life. Team reviews and test logs will ensure issues are caught and corrected.

Because the device sits directly on the skin, user wellbeing is our first constraint. All electrical subsystems will be powered from low-voltage (3.7 V nominal) Li-Po cells with integrated protection circuits, and regulated to 3.3 V. Current draw is well below thresholds that could pose a shock hazard, and exposed conductive elements will be insulated except for the EMG electrodes, which are designed for surface bio-potential sensing. To minimize risks from batteries, each pack is paired with a charger and BMS that protects against overcurrent, overvoltage, and undervoltage.

Ethically, we recognize that motion and EMG data can be sensitive. During normal operation, we never store these data—all feature extraction and inference run entirely on-device with no external logging. For training our ML model, we will only collect motion/EMG data with informed consent, clearly stating purpose, scope, and duration. Collection will be the minimum necessary, stored securely for the shortest feasible time, and deleted once the model is trained.

By designing within these ethical and regulatory frameworks, and by foregrounding user safety and privacy, we ensure the project adheres to both professional codes of ethics and relevant safety standards.