Adherascent Wearable and Pillbox Scent Reminder System

ECE 445 Design Document - Fall 2025

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1 Introduction

1.1 Problem Statement

Over 66% of Americans take some form of prescription medication, ranging from daily life-saving treatments to lifestyle or quality-of-life improvements. However, the effectiveness of these medications depends heavily on regular, consistent intake. For many individuals, establishing and maintaining a new medication routine can be challenging. Remembering to take a pill at the same time every day is especially difficult for patients with busy, irregular schedules or multiple prescriptions.

Traditional reminder systems, such as smartphone notifications, sticky notes, or alarms, rely on visual or auditory cues that can be easily ignored or silenced. Even existing "smart" pill bottles with sound or light indicators often fail to maintain long-term adherence. This gap motivated the development of the **Adherascent System**, an olfactory-enhanced medication reminder that introduces a novel sensory cue to medication adherence.

1.2 Proposed Solution

Adherascent introduces a two-part hardware system integrated with a hybrid software platform to form a closed-loop medication adherence solution. The first hardware component, a **wearable scent emitter**, releases a short, non-intrusive fragrance when a scheduled dose is missed. The second component, a **smart pillbox**, detects when a medication lid is opened via capacitive touch sensing and communicates this event wirelessly to the desktop application.

The software application, developed using the **Electron framework** with a **Python backend**, manages dose scheduling, reminders, and BLE (Bluetooth Low Energy) communication. It tracks user confirmations through the pillbox and triggers the wearable if a scheduled dose is not taken within a set time window. This architecture ensures reliable communication, low latency, and a responsive user experience.

Together, these modules provide a self-contained adherence monitoring system that supports user independence by automating feedback and reducing reliance on manual interaction.

1.3 System Overview

The Adherascent system consists of three core components:

1. **Mobile/Desktop Application** – Built using Electron and Python. It stores medication schedules, issues notifications, receives pillbox confirmation events, and controls wearable activation via BLE.

2. **Smart Pillbox Module** – An ESP32-S3-based unit that detects lid openings through capacitive touch sensing and transmits a BLE notification to the app.

3. **Wearable Module** – A BLE-controlled scent emitter powered by a 3.7V Li-Po battery and controlled via a MOSFET-heater circuit. When triggered, the heater briefly warms scented wax to produce a short fragrance burst.

1.4 Block Diagram

The overall system architecture is summarized in Figure 1, which shows the interaction between the three main components: the software application, pillbox, and wearable module.

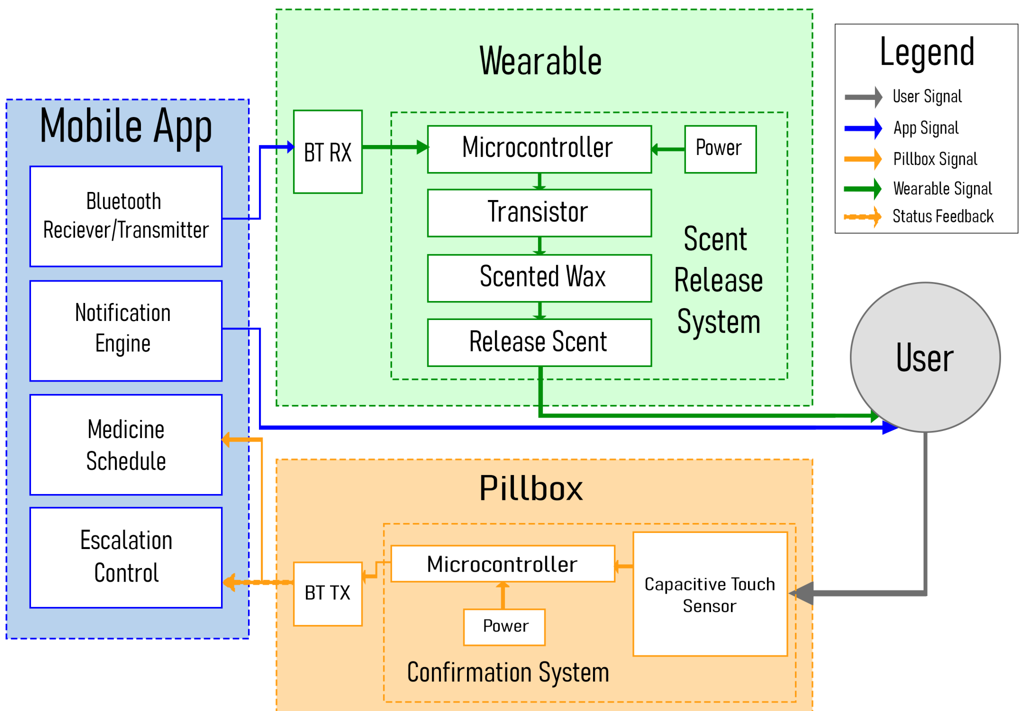

Figure 1: System Block Diagram of the Adherascent Medication Adherence Device

1.5 Visual Aid

Figure 2 illustrates how the user interacts with the system during a typical medication cycle. When the scheduled time arrives, the app issues a reminder. If the user opens the pillbox, the event is logged and the schedule updates. If the user does not take their dose within the time limit, the wearable releases a scent cue as a secondary reminder. The process then repeats until requirements are met.

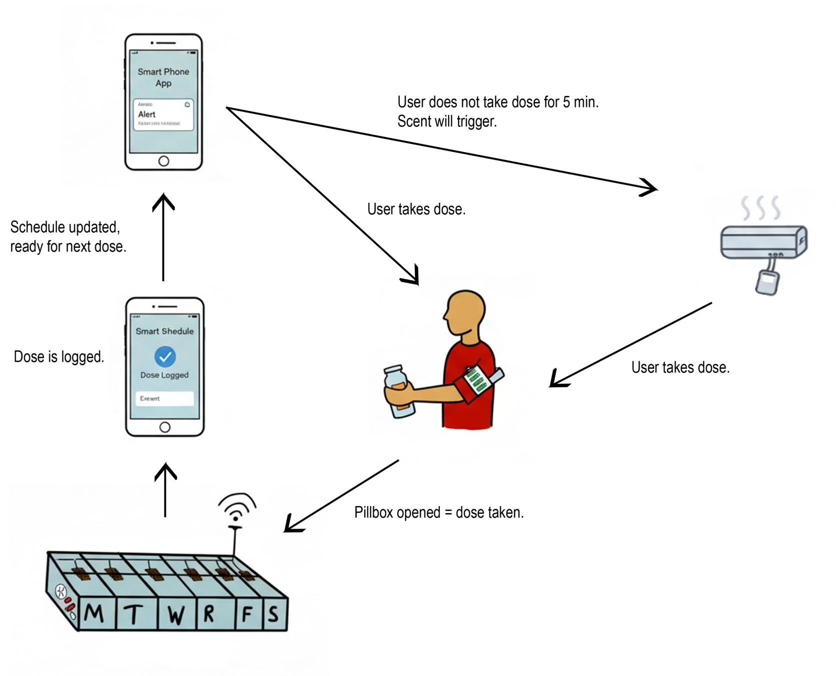

Figure 2: Visual Aid Showing User Interaction and Feedback Cycle

1.6 High-Level Requirements

The following requirements were defined in collaboration with the medical advisory team and refined for feasibility within the scope of this class project:

1. **App Functionality Among Subsystems:** The application must properly receive and send signals to both the pillbox and the wearable device. The signal sent to the wearable device will activate or deactivate the heating element causing the scent to be released. The signal received from the pillbox will be used to determine if the medication has been taken, and in turn, whether or not the scent should continue to be emitted.

2. **Reliable Detection:** The pillbox must detect lid openings through capacitive touch sensing with at least 95% accuracy over 100 test trials.

3. **Timed Scent Feedback:** The wearable device must receive the signal from the application. This signal must properly activate as well as deactivate the heating element, causing the scent to emit. In addition to this we must ensure that the timing of these signals is correct within 100 microseconds or so.

2 Design Overview

2.1 System-Level Description

The Adherascent system consists of three interacting layers: the desktop/mobile application, the wearable scent-emitting device, and the pillbox sensor module. The application manages scheduling, event handling, and user interaction, communicating with the two hardware peripherals over Bluetooth Low Energy (BLE).

The wearable converts electrical energy into heat to melt a small wax reservoir and release fragrance as a reminder signal, while the pillbox uses capacitive touch sensing to detect lid openings. Each module operates independently on an ESP32-S3 microcontroller and exchanges data using the Nordic UART Service (NUS) protocol, which standardizes BLE read/write and notification characteristics.

Both hardware modules are battery-powered with a 3.7 V Li-Po cell, and each includes an onboard AP2112K-3.3 V linear regulator to provide a stable logic rail for the ESP32-S3. A shared communication structure ensures the app can issue control commands to the wearable and receive confirmation events from the pillbox.

2.2 Functional Flow

At the start of operation, the desktop application establishes BLE connections with both ESP32-S3 modules. The pillbox remains in a low-power state, waking periodically to monitor its capacitive pad. When a lid-opening event is detected, the pillbox transmits a BLE notification to the app (`EVENT:PILLBOX_BUTTON_PRESSED`).

The app logs the confirmation, resets the reminder timer, and updates the user interface. If no confirmation occurs within the designated time window (five minutes per full operation, one minute in demo mode), the application sends a BLE command (`LED ON`) to the wearable's receiver characteristic, activating the MOSFET-driven heater for a short burst to release fragrance. After heating, the wearable enforces a firmware-level cooldown before accepting another trigger.

This event flow creates a closed feedback loop:

1. User scheduled medication time is reached.
2. Application issues reminder and starts timer.
3. Pillbox lid opens → BLE event sent to app.
4. App logs confirmation and cancels reminder.
5. If no event received → App sends scent trigger command to wearable.

6. Wearable activates heater for $\leq$10 s, then enters cooldown (30–40 s).

2.3 Design Constraints

System constraints are defined primarily by power, communication, and thermal considerations:

- **Power:** Both modules are powered by single-cell Li-Po batteries rated at 3.7 V nominal (range 3.4–4.2 V). The wearable's heater draws approximately 400 mA during activation, while the ESP32 and LDO maintain efficiency at 3.3 V logic operation.
- **Thermal:** The heating element (Vishay PR03, 9 Ω) must achieve 80–100°C surface temperature within 8–10 s and remain under 35°C externally to ensure user safety. A silicone barrier thermally isolates the battery from the heater.
- **Communication:** The BLE connection uses the Nordic UART Service. Data packets (RX for control, TX for notification) must maintain latency <1 s between the Python backend and ESP32-S3 peripherals.
- **Physical:** The wearable must weigh under 50 g, maintain battery isolation clearance $\geq$15 mm from the heater zone, and survive repeated thermal cycles without delamination.

These constraints ensure that the prototype remains safe, energy-efficient, and compliant with ECE 445 project standards.

3 Design Details

3.1 Software Design

The software follows a hybrid architecture that separates the user interface from hardware control for stability and responsiveness. The desktop application is developed using the **Electron framework**, which employs standard web technologies (HTML, CSS, JavaScript) for the graphical interface. All direct BLE communication occurs in a background **Python script** using the *bleak* library, ensuring that Bluetooth tasks do not interrupt user experience.

This structure allows asynchronous BLE transactions to occur in parallel with real-time user interactions, maintaining low latency and robust connectivity.

3.1.1 System Architecture

The application is organized as a three-tier model that clearly separates user interface logic, process management, and hardware control:

- **Renderer Process (renderer.js):** This is the user-facing interface responsible for displaying the medication schedule, receiving user input, and showing reminder states. It visually represents device feedback and sends user commands (e.g., color or alert changes) to the backend via Electron's Inter-Process Communication (IPC) system.
- **Main Process (main.js):** This acts as the application's central bridge and orchestrator. It launches the Python backend at startup, listens for commands from the renderer (e.g., "set-light-color, red"), and forwards them to Python. It also captures hardware notifications received from Python and forwards them to the UI for confirmation.
- **Hardware Controller (bluetooth_handler.py):** This background Python script handles all BLE communication using the `bleak` library. It connects to the ESP32-S3 peripherals via hardcoded MAC addresses (48:CA:43:AF:1E:D1 for the Pillbox and 48:CA:43:AF:1B:01 for the Wearable). The script writes commands to RX characteristics and subscribes to TX notifications, managing event-driven data flow between app and peripherals.

3.1.2 Bluetooth Parameters

The ESP32-S3 peripherals utilize the Nordic UART Service (NUS) for BLE communication, which provides standardized serial-like data channels for asynchronous read/write operations.

UUID Assignments:

- Service UUID: `6E400001-B5A3-F393-E0A9-E50E24DCCA9E`
- RX Characteristic (write): `6E400002-B5A3-F393-E0A9-E50E24DCCA9E`
- TX Characteristic (notify): `6E400003-B5A3-F393-E0A9-E50E24DCCA9E`

Data Flow:

1. **Hardware to App:** When the pillbox detects a lid-opening event, the ESP32-S3 transmits a BLE notification (`EVENT:PILLBOX_BUTTON_PRESSED`) to the Python controller. The message is printed to stdout, captured by `main.js`, and relayed via IPC to the UI for confirmation logging.
2. **App to Hardware:** When the app detects a missed dose, it sends an IPC command to activate the wearable (e.g., `LED ON`). This command passes through `main.js` to the Python controller, which writes the string to the wearable's RX characteristic. The wearable activates its MOSFET-driven heater for a controlled 10-second burst and returns to cooldown.

3.1.3 Signal Flow Summary

The application's logic layer continuously compares real-time data with the stored medication schedule to determine user adherence. This process is governed by the `adherenceMonitor.js` module, which operates as a finite state machine. Communication signals are exchanged as formatted strings between subsystems, ensuring event traceability and error detection.

Signal Map:

- App → Wearable: `LED ON`, `LED OFF`
- Wearable → App: `ACK:HEATER_ON`, `ACK:HEATER_OFF`
- Pillbox → App: `EVENT:PILLBOX_BUTTON_PRESSED`
- App → Pillbox: (none; operates event-only)

3.1.4 State Machine (adherenceMonitor.js)

The `adherenceMonitor.js` module manages all decision-making through a state-based structure that tracks reminders, confirmations, and escalation logic.

- **State 1 – Notification Sent:** When a medication is due, the system issues a reminder and starts a one-minute (demo) timer. A temporary "dose tracker" object is created for that medication.
- **State 2 – Acknowledged (Confirmation):** If the user acknowledges the dose—either by pressing the pillbox touch pad or confirming via the app—the `confirmDose()` function clears the timer, updates the log, and triggers `onLightChangeCallback()` to set the wearable's status LED to green.
- **State 3 – Escalation Active:** If the timer expires before confirmation, the system escalates by triggering `onLightChangeCallback()` to set the wearable's LED to red. If confirmation later occurs, it is still logged as valid, and the LED reverts to green.

3.1.5 Mobile Application Integration for iOS and Android

While the current desktop application provides a stable proof-of-concept for managing BLE communication and medication scheduling, the final implementation of the Adherascent system will transition to a cross-platform mobile application for both iOS and Android. This mobile app will serve as the primary control interface for end users, maintaining all adherence logic while improving portability and accessibility.

The mobile platform will replicate the existing Electron–Python functionality within a native environment that supports Bluetooth Low Energy (BLE) communication and push notifications. This will allow users to manage reminders, receive notifications, and confirm doses directly from their smartphones without a constant desktop connection.

Framework Selection: The mobile application will be developed using a modern cross-platform framework such as React Native or Flutter. These frameworks enable shared codebases between Android and iOS while providing access to native device features. Using a dedicated BLE library—such as `react-native-ble-plx` for React Native or an equivalent Flutter package—the application will manage connections to the wearable and pillbox peripherals as BLE central devices.

Bluetooth Low Energy (BLE) Management: Native BLE functionality will replace the current Python *bleak* library. The app will implement the same UART-based communication protocol defined in the desktop prototype, where:

- The mobile app acts as a **BLE Central** device.
- The ESP32-S3-based peripherals (wearable and pillbox) act as **BLE Peripherals**.

This ensures consistent pairing behavior and message exchange without modifications to the existing firmware.

User Interface and Notifications: The mobile interface will include built-in notification support using Android and iOS native APIs. Users will be able to:

- Add, edit, and delete medication schedules.
- Receive visual and audible notifications when a dose is due or missed.
- View device connection status and confirmation history.

By leveraging a cross-platform architecture, the Adherascent system can maintain the same BLE communication and adherence logic from the Electron prototype while reaching a broader user base. This approach also minimizes development overhead by reusing existing JavaScript-based scheduling and state logic from `adherenceMonitor.js`.

3.2 Global Power System

The Adherascent system employs a unified low-voltage power architecture shared across both hardware modules: the wearable scent emitter and the pillbox confirmation device. Each subsystem operates from a single-cell lithium-polymer (Li-Po) battery rated at 3.7 V nominal. Power distribution is designed for electrical safety, noise isolation, and consistent voltage regulation across all components.

The wearable module draws the highest instantaneous current—approximately 400 mA during scent heater activation—while the pillbox operates primarily in low-power standby mode, only waking periodically for Bluetooth communication. To maintain stable operation, both modules implement current limiting, overvoltage protection, and local regulation for digital logic.

3.2.1 Battery Specifications

Both modules are powered by a 3.7 V 850 mAh lithium-polymer cell, **SparkFun Electronics P/N 13854**, which includes a built-in protection circuit (PCM) for overcharge, over-discharge, and short-circuit protection. The battery connects to each PCB using a **JST-PH 2-pin** connector (**B2B-PH-K-S**), simplifying serviceability and replacement.

Table 1: Battery Specifications for Wearable and Pillbox Modules

Parameter	**Specification**
Type	Single-cell rechargeable Li-Po with PCM
Nominal Voltage	3.7 V (operating range 3.4–4.2 V)
Capacity	850 mAh
Connector	JST-PH 2-pin (Pin 1 = BAT+, Pin 2 = GND)
Continuous Discharge Current	$\leq$ 1 A
Protection Features	Integrated PCM for short, over/under-voltage protection
Typical Runtime	$\approx$ 12 hours (5 BLE events + 1 heat activation per hour)

In the wearable device, a **Littelfuse 1812L075/33** resettable polymer PTC fuse is placed in series with the battery's positive terminal to protect against overcurrent or short conditions. The fuse holds at 0.75 A and trips at 1.5 A, automatically resetting once power is removed. The pillbox relies on its battery's built-in PCM for protection due to its significantly lower current draw.

3.2.2 Voltage Regulation

Both modules use an **AP2112K-3.3 V LDO** linear regulator to provide a stable 3.3 V rail for the ESP32-S3 microcontroller and BLE interface. The regulator operates from 3.4–4.2 V input, supplying up to 600 mA continuous current with a dropout voltage under 250 mV at moderate load.

- **Input capacitor:** 1 µF X7R 0805 (`CL21B105KBFNNNG`) between VIN and GND.
- **Output capacitor:** 1 µF X7R 0805 (`CL21B105KBFNNNG`) between VOUT and GND.

- **Local decoupling:** 1 µF + 0.1 µF placed adjacent to ESP32 VDD pins.

The wearable's heater circuit is powered directly from the Li-Po battery through a **Vishay BC PR03000209108JAC00** 9.1 Ω (±5%) , 3 W axial resistor and an **AO3400A N-channel MOSFET**. The MOSFET switches battery current to the resistor under firmware control, converting electrical energy into heat to release the fragrance. Thermal isolation and copper pours are used on the PCB to prevent heat conduction to sensitive circuitry.

This power subsystem supports safe, reliable operation of both Adherascent hardware devices. The combination of Li-Po energy storage, integrated protection, low-dropout regulation, and resettable fuse protection ensures stable voltage rails and controlled current delivery across all functional modes.

4 Hardware Design

4.1 Global Power System

Both hardware modules are powered by single-cell 3.7 V Li-Po batteries (**SparkFun 13854, 66005201**) that include integrated protection circuitry. Each module regulates power for logic and sensing components to 3.3 V using an **AP2112K-3.3 V LDO** voltage regulator. Both input and output pins of the regulator are decoupled with 1 µF X7R capacitors for stability, and an additional 0.1 µF bypass capacitor is placed near the ESP32's VDD pins to suppress transient noise and maintain a clean logic rail.

The wearable circuit incorporates a resettable PTC fuse (**Littelfuse 1812L075/33**) rated for 0.75 A hold / 1.5 A trip, providing protection against short circuits or over-current events during heater activation. The pillbox omits this fuse since its steady-state current remains under 60 mA, and the battery's built-in PCM circuitry provides sufficient protection.

The LDO maintains a stable 3.3 V output across the Li-Po range of 3.4–4.2 V, given its 0.3 V dropout voltage. The theoretical regulation relationship is:

$$V_{\text{OUT}} = V_{\text{IN}} - V_{\text{dropout}}$$

At minimum battery voltage (3.4 V), the regulator still provides 3.1 V, ensuring reliable ESP32-S3 operation. Power distribution for both modules follows the same flow:

Li-Po Battery → AP2112K LDO (3.3 V) → ESP32-S3 MCU and Peripheral Subsystems

The wearable also includes over-temperature and current safeguards in firmware that disable the heating element if a BLE disconnect or timeout occurs.

4.2 Subsystem 1 – Wearable Scent Emitter

The wearable scent emitter converts electrical energy into heat to melt a small wax reservoir, releasing a controlled fragrance when a user fails to confirm a scheduled dose. The subsystem is built around an **ESP32-S3-WROOM-1** microcontroller, which receives BLE commands from the host Python or mobile application. When a valid activation command is received, the ESP32 drives **GPIO 4**, which controls an **AO3400A N-channel MOSFET**. The MOSFET switches current through a **Vishay PR03 power resistor** (9.1 Ω, 3 W), converting electrical energy into thermal energy.

4.2.1 Electrical Theory

The resistor dissipates power according to:

$$P = \frac{V^2}{R}$$

At the nominal 3.7 V supply, the theoretical heater power is:

$$P = \frac{(3.7)^2}{9.1} = 1.5 \text{ W}$$

This power level heats the resistor to approximately 80–100 °C within 8–10 seconds, enough to liquefy the wax sample. Firmware restricts heater activation to 10 seconds followed by a 30–40 second cool-down to prevent thermal runaway and extend component lifespan.

4.2.2 Physical Design

The Vishay PR03 resistor is bonded to a 25 × 25 × 1.5 mm 6061-T6 aluminum plate using high-temperature silicone thermal adhesive to enhance heat spreading. A wax cup (25–30 mm diameter) is permanently attached with silicone sealant. The PCB is mounted directly beneath the plate with M2.5 screws, and the Li-Po battery is isolated from the heating region by a thin plastic thermal barrier to prevent heat damage.

4.2.3 Circuit Implementation

Figure 3 shows the complete schematic for the wearable scent emitter subsystem.

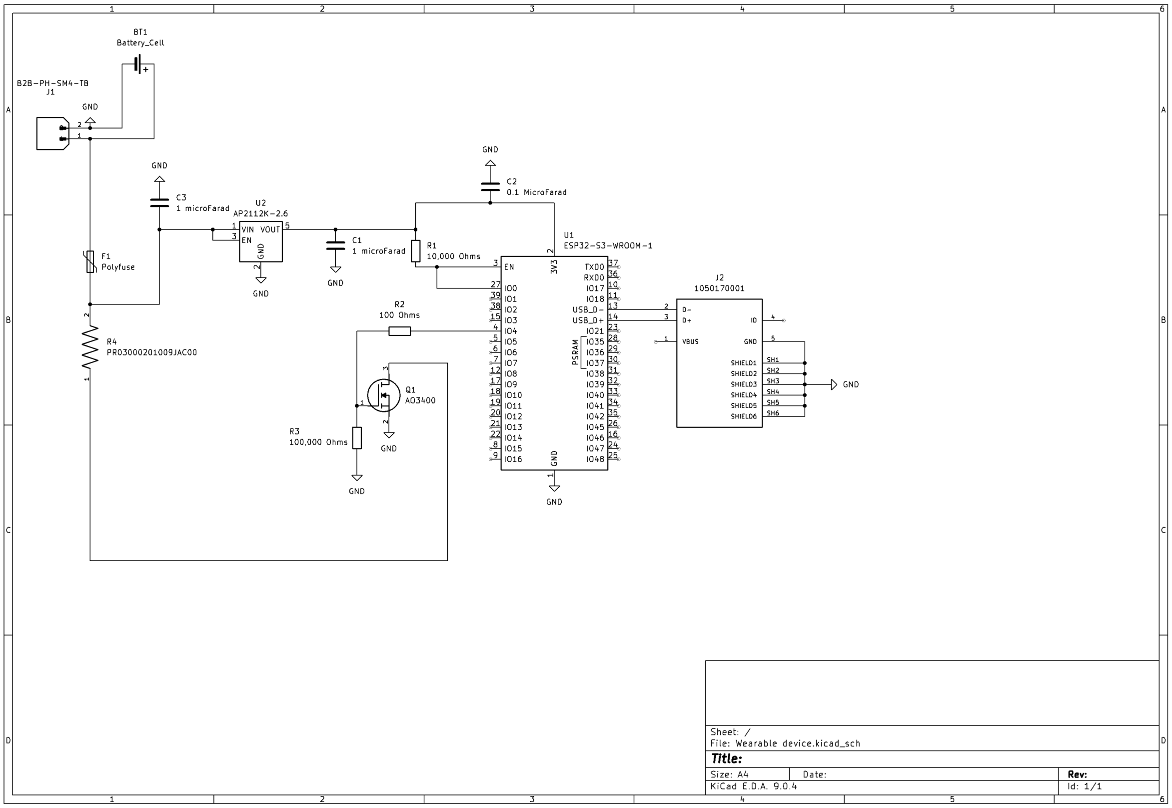

Figure 3: Electrical schematic for the wearable scent emitter subsystem.

Circuit interconnections:

- Li-Po Battery → PTC Fuse → AP2112K LDO → ESP32 VDD (3.3 V)
- ESP32 GPIO 4 → 100 Ω resistor → AO3400A MOSFET Gate
- MOSFET Drain → Heater Resistor (PR03) → Battery Positive
- MOSFET Source → Ground
- Decoupling capacitors (1 µF and 0.1 µF) placed near VDD pins

4.2.4 Requirements and Verification (Planned)

Table 2: Wearable Subsystem Requirements and Verification Plan

Requirement	Verification Method
Requirement	Verification Method
Heater must reach ≥ 80 °C within 10 s	Measure surface temperature with infrared thermometer after activation
MOSFET must fully saturate at 3.3 V gate voltage	Probe gate voltage and confirm < 0.1 V V_{DS} drop
Fuse must limit fault current $\leq$ 1.5 A	Simulate short across heater and observe current interruption
Battery voltage must remain within 3.4–4.2 V	Monitor voltage during operation
BLE command must trigger heater without delay < 1 s	Observe software log latency between BLE command and heater activation

4.3 Subsystem 2 – Smart Pillbox

The pillbox subsystem detects when the lid is opened to log medication adherence. An **ESP32-S3-WROOM-1** microcontroller is configured for capacitive touch sensing using **GPIO 1**. A copper foil pad (15–20 mm diameter) mounted inside the lid is connected through a 470 Ω series resistor. When the lid is touched, the pad's capacitance rises above a preset threshold, triggering an interrupt. The ESP32 then transmits a BLE notification to the Python or mobile application for dose confirmation.

4.3.1 Electrical Design

Power regulation mirrors the wearable subsystem. The 3.7 V battery feeds the **AP2112K-3.3 V LDO**, which supplies the logic rail. The pillbox omits a PTC fuse since its quiescent current is below 60 mA and protected by the battery's PCM. A **Molex 105017-0001 Micro-USB connector** is included for programming and UART-based debugging.

4.3.2 Physical Design

The PCB is mounted at the base of the pillbox and wired to the copper touch pad via 26–30 AWG wires through the hinge. A Kapton (polyimide) film insulates the copper pad from direct contact while preserving capacitive sensitivity. This configuration allows consistent detection of intentional touches while rejecting noise from incidental contact or environmental interference.

4.4 Circuit Implementation

Figure 4 shows the full schematic of the smart pillbox subsystem.

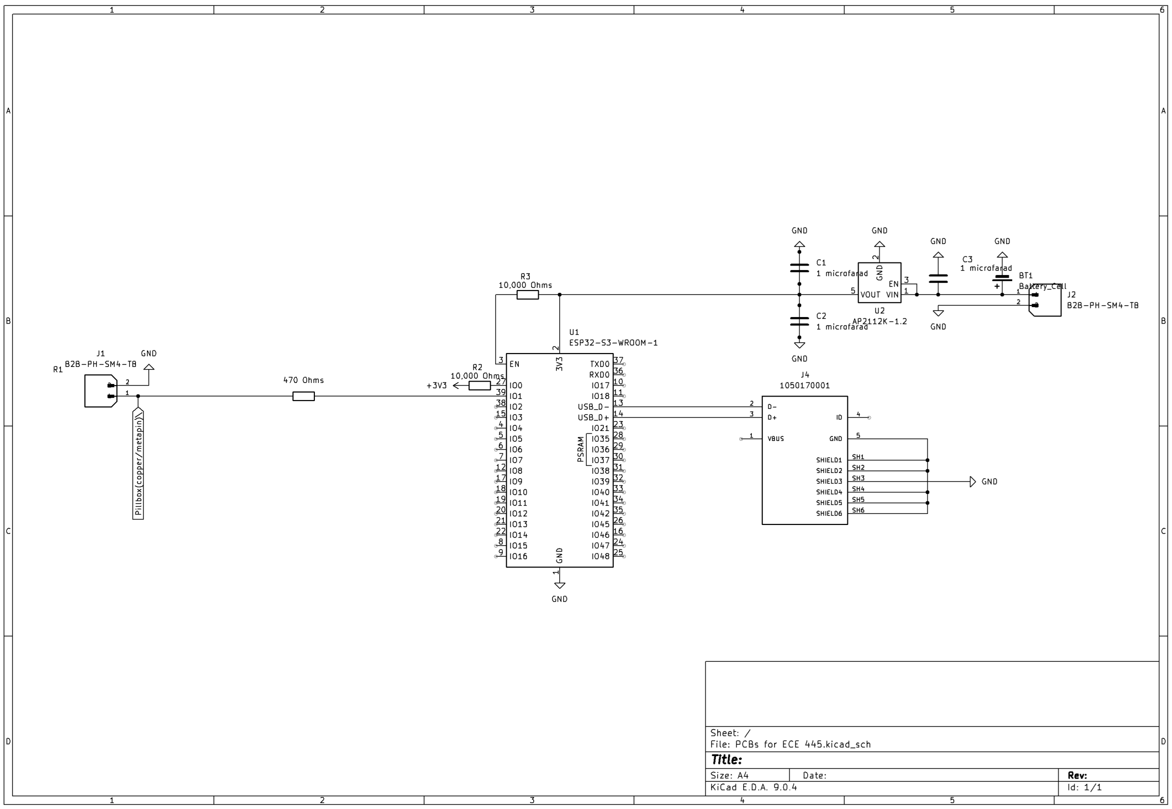

Figure 4: Electrical schematic for the smart pillbox subsystem.

Circuit interconnections:

- Li-Po Battery → AP2112K LDO → ESP32 3.3 V rail
- GPIO 1 (TOUCH1) → 470 Ω resistor → Copper foil pad (lid)
- Ground → Battery negative terminal
- Molex USB connector → ESP32 UART TX/RX pins

4.4.1 Requirements and Verification (Planned)

Table 3: Pillbox Subsystem Requirements and Verification Plan

Requirement	**Verification Method**
Touch sensor must detect lid open reliably	Simulate touch and record BLE event logs
Notification must reach app within 1 s	Measure delay between touch and event display
Deep sleep current must remain under 10 µA	Measure quiescent current with multimeter
USB interface must enable firmware flashing	Connect via UART and confirm upload success
Kapton layer must not reduce sensitivity beyond threshold	Compare raw sensor values before and after insulation

5 Tolerance Analysis

The critical tolerance consideration for the Adherascent system lies in the wearable heating assembly, where thermal performance directly affects both user safety and functional reliability. The heater's output power is calculated using:

$$P = \frac{V^2}{R}$$

For a battery voltage range of 3.4–4.2 V and resistor tolerance of ±5% (8.55–9.45 Ω), the theoretical heating power varies between 1.22 W and 2.06 W. This results in an estimated surface temperature variation of approximately ±15 °C. Even at the upper bound, the surface temperature remains below 100 °C, ensuring user safety through the silicone thermal barrier and enclosure insulation.

The **AP2112K** regulator maintains a stable 3.3 V output with voltage ripple under 50 mV, ensuring reliable ESP32 logic operation across the full discharge cycle of the Li-Po cell. The **AO3400A** MOSFET exhibits a low $R_{DS(on)}$ ($< 0.05\ \Omega$) even at 3.3 V gate drive, ensuring consistent switching efficiency despite battery voltage variation.

The combined component tolerances confirm that all electrical and thermal parameters remain within acceptable limits under realistic component variations.

Table 4: Key Tolerance Parameters and Expected Variations

Parameter	Nominal	Tolerance	Range	Effect on System
Battery Voltage	3.7 V	±0.5 V	3.2–4.2 V	Affects heater power output
Heater Resistance	9.1 Ω	±5%	8.55–9.45 Ω	Changes heating rate
Heater Power	1.5 W	±20%	1.2–1.8 W	Thermal variation within safe limit
Regulator Output	3.3 V	±2%	3.23–3.37 V	Stable logic voltage for ESP32
BLE Timing Delay	1 s max	±0.2 s	0.8–1.2 s	Negligible latency for user feedback

6 Risk Analysis

The Adherascent system complies with IEEE safety and ethical standards by prioritizing low-voltage operation, user comfort, and data security. All circuits are isolated from direct user contact, and heating is controlled within software-defined time limits. The system collects no personal or medical data, minimizing privacy concerns.

Table 5: System Risks and Mitigation Strategies

Risk	Likelihood	Mitigation Strategy
Excessive heat output or skin irritation	Unlikely	Limit heater activation to ≤10 s; include 30–40 s cooldown enforced by firmware; thermal insulation and vented enclosure
Li-Po overcurrent or short circuit	Rare	Littelfuse 1812L075/33 PTC fuse; PCM circuit disconnects at 3.2 V or >1.5 A
Faulty BLE communication or duplicate trigger	Moderate	App-level verification and event acknowledgment required before activation
Battery discharge below safe threshold	Rare	PCM module auto-disconnects below 3.2 V
Incorrect or missed user notification	Moderate	Multi-sensory alert (scent, app notification); redundant trigger logging in software

7 Cost Analysis

Total project cost includes both material expenses and team labor. Labor is estimated at $40/hour for each team member working 8 hours per week over 14 weeks:

$$40 \times 8 \times 14 = 4480 \text{ USD per member}$$

$$\text{Total Labor Cost} = 3 \times 4480 = 13440 \text{ USD}$$

Component costs were obtained from Digikey and Mouser (October 2025).

Table 6: Detailed Component Cost Breakdown

Component	Manufacturer	Part Number	Qty	Unit ($)	Total ($)
Li-Po Battery (850 mAh, 3.7 V)	EEMB	LP503450-PCM-JST	2	8.95	17.90
MOSFET (N-channel, logic level)	Alpha & Omega	AO3400A	5	0.34	1.70
PTC Fuse (0.75 A hold, 1.5 A trip)	Littelfuse	1812L075/33DR	5	0.81	4.05
Power Resistor (9.1 Ω, 3 W)	Vishay BC Components	PR03000209108JAC00	5	0.87	4.35
Voltage Regulator (3.3 V LDO)	Diodes Inc.	AP2112K-3.3	3	0.45	1.35
Microcontroller Module	Espressif Systems	ESP32-S3-WROOM-1	2	6.10	12.20
JST-PH Connectors (2-pin)	JST Sales America	B2B-PH-K-S	10	0.12	1.20
Header Pins (2.54 mm)	Amphenol	67997-206HLF	3	0.33	0.99
PCB Fabrication	JLCPCB	Custom	2	9.00	18.00
3D-Printed Enclosures	Custom	PLA Model	2	4.50	9.00
Thermal Insulation Sheet	McMaster-Carr	9323K13	1	7.00	7.00
Wiring & Misc. Materials	Adafruit	Various	-	5.50	5.50
Subtotal (Parts)					**82.24**
Labor (3 Members)					**13,440.00**
Grand Total					**13,522.24**

The total estimated cost to construct one complete Adherascent prototype is therefore approximately **$13,522.24**.

8 Schedule

The project schedule aligns with the ECE 445 Fall 2025 course calendar. Hardware, software, and documentation deliverables are distributed according to member responsibilities.

Team Roles:

- **Hardhik Tarigonda** – Lead Hardware Engineer: Circuit design, breadboard testing, schematic creation, PCB layout.

- **Jonathan Liu** – Systems & Verification Engineer: Testing, debugging, documentation, part procurement, KiCad PCB transfer and footprint verification.
- **Dhiraj Bijinepally** – Lead Software Engineer: Desktop and mobile application development, BLE communication, UI/UX, firmware integration.

Table 7: Adherascent Development Schedule (Fall 2025)

Date / Week Range	**Task / Deliverable**	**Responsible Member(s)**	**Category**
8/25–8/31	Project approval, topic selection, proposal draft	All Members	Planning
9/1–9/7	Circuit concept and MOSFET selection (AO3400A) BLE architecture setup with ESP32 devkit	Hardhik Dhiraj	Hardware Software
9/8–9/14	Component research (Vishay PR03, AP2112K, PTC fuse) BLE connection test and communication validation	Hardhik, Jonathan Dhiraj	Hardware Software
9/15–9/21	Breadboard heating test with Li-Po supply BLE trigger confirmation in app console	Hardhik Dhiraj	Hardware Software
9/22–9/28	Proposal review, fuse integration, power stability test Software timeout logic and response verification	Hardhik, Jonathan Dhiraj	Hardware Software
9/29–10/5	Breadboard Demo 1 preparation, verified thermal results Developed desktop GUI and BLE status indicator	Hardhik, Jonathan Dhiraj	Hardware Software
10/6–10/12	Design Document drafted, KiCad schematic created Desktop app fully communicating with ESP32	Hardhik, Jonathan Dhiraj	Hardware Software

10/13–10/16	Completed PCB footprint design in KiCad Mobile app framework setup for Android/iOS	Hardhik, Jonathan Dhiraj	Hardware Software
10/20–10/26	Breadboard Demo 2, thermal safety validation BLE reliability testing, event logging feature	Hardhik Dhiraj	Hardware Software
10/27–11/2	Hardware revision planning for PCB manufacturing Cross-platform BLE testing and integration	Hardhik, Jonathan Dhiraj	Hardware Software
11/3–11/9	PCB Audit Review 1, schematic verification Added BLE data visualization graph	Hardhik, Jonathan Dhiraj	Hardware Software
11/10–11/16	PCB Audit Review 2, PCB sent to JLCPCB Continued Android/iOS interface development	Hardhik, Jonathan Dhiraj	Hardware Software
11/17–11/23	Mock Demo, PCB assembly and BLE test	All Members	Integration
11/24–11/30	Fall Break (No active development)	–	–
12/1–12/7	Final system assembly and BLE verification Final UI polish and cross-platform testing	Hardhik, Jonathan Dhiraj	Hardware Software
12/8–12/13	Final Demo and Presentation; Final Report submission	All Members	Final Presentation

9 Ethics & Safety

This section discusses the ethical and safety foundations of the Adherascent project. Our approach follows the **IEEE Code of Ethics** [1] and the **ACM Code of Ethics and Professional Conduct** [2]. As engineers, we understand that wearable technologies directly affect user safety and trust, and therefore we prioritize fairness, collaboration, honesty, and responsibility in every design decision.

1. To treat all people fairly and respectfully, avoiding discrimination, harassment, or harm

Team members collaborate respectfully and equitably. Design decisions are guided by evidence and testing, not hierarchy or bias. Given that the wearable device involves resistive heating, user protection is central to our design. Thermal insulation, current limiting, and software-enforced safety thresholds ensure the device cannot reach unsafe surface temperatures. A physical enclosure and silicone thermal barrier prevent any direct heat conduction to the skin.

2. To seek, accept, and offer honest criticism while remaining true to the facts and available data

Constructive feedback is sought weekly from teaching assistants and instructors, and implemented through iterative testing. When earlier prototypes exhibited higher-than-expected heat rise, we documented the results, disclosed them in reviews, and redesigned the firmware to shorten activation time and enforce cooldowns. Each member maintains entries in a shared laboratory logbook that includes all measurements and test outcomes to ensure transparency and data integrity.

3. To continue developing technical competence and perform only work we are qualified for

All members completed soldering and KiCad certification modules provided by the *Grainger College of Engineering*. Before integrating any component, we review the official manufacturer datasheets to ensure proper handling, polarity, and current ratings. For instance, the team studied Espressif's BLE documentation to verify reliable communication between the ESP32 and the mobile app, and consulted Littelfuse and Vishay references to confirm safe operating temperatures for the heater resistor. This commitment to continuous learning safeguards the reliability of both hardware and firmware.

4. Safety Protocols and Implementation

The Adherascent system incorporates multiple electrical and thermal protections:

- Operates at 3.7 V nominal and under 0.5 A load current to minimize electrical risk.

- **Heater:** Vishay PR03, 9.1 Ω, 3 W resistor, isolated using silicone and aluminum spreaders.
- **Fuse:** Littelfuse 1812L075/33DR resettable PTC, 0.75 A hold, 1.5 A trip current, auto-reset after fault.
- **Battery:** SparkFun PRT-13854 (66005201), 3.7 V 850 mAh Li-Po cell with PCM for over-voltage, over-discharge, and short-circuit protection.
- **Regulator:** AP2112K-3.3 V LDO ensures stable logic supply within ±2 %.
- **Connector:** Molex 105017-0001 JST-PH compatible 2-pin battery connector.
- Firmware restricts heater activation to 10 s with enforced 30–40 s cooldown intervals.

No personal or medical data are stored or transmitted. BLE communication occurs solely between the user's mobile app and the wearable device, satisfying privacy and ethical data-handling principles. Overall, Adherascent upholds the IEEE and ACM standards of **safety, honesty, accountability, and respect for human welfare**.

References

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