AdheraScent Pill Container

ECE 445 Final Report - Spring 2026

Project # 26

Albert Liu, Anshul Rao, Chia-Ti Liu

Professor: Arne Fliflet

TA: Zhuchen Shao

Abstract

AdheraScent is a battery-powered, smartphone-independent medication adherence device that combines real-time scheduling, contactless compartment sensing, and olfactory notification to remind users of missed doses. The system uses an ESP32-S3 microcontroller paired with a DS3231 real-time clock to monitor a user-configured daily medication window. Seven reed switches, each paired with an N52 neodymium magnet, provide contactless open/close detection across the pill container's compartments. If a compartment remains closed past the scheduled window, the ESP32 activates a 5V DC fan to push air across a replaceable scent pad, producing an escalating olfactory alert. An OLED display provides real-time clock and alarm status feedback. Verification testing confirmed a 100% detection rate over 100 mechanical cycles per compartment, with fan deactivation occurring within 5 seconds of pill removal against a 15-second requirement. The power subsystem supplies a regulated 3.3V logic rail via a TP4056 charger and AP2112K LDO, and a 5V fan rail via an MT3608 boost converter. Total component cost before labor was $302.

Contents

1 Introduction

1.1 Problem

Modern healthcare faces a “silent epidemic” that occurs after the patient leaves the hospitals or clinics: the failure to execute prescribed care. Even though medical diagnostics have advanced rapidly, the actual execution of care remains a significant failure point. As of 2026, approximately 50% of patients with chronic conditions fail to follow their prescribed treatment plan [1]. For most people, this is not a deliberate choice but a result of cognitive overload. Forgetfulness is the most frequent barrier, cited by 62 % of non-adherence patients [2], a struggle caused by the rise of “polypharmacy” where individuals must manage complex schedules involving five or more daily medications [3]. This gap in care is extremely acute for the one in four adults who report experiencing memory loss or cognitive interference with daily tasks [4], making the development of automated adherence tools a critical necessity for maintaining public health and safety.

This widespread non-adherence presents a severe threat to public welfare and safety. Medication errors and missed doses lead to approximately 125,000 preventable deaths annually in the United States [5]. Beyond mortality, non-adherence is a primary driver of system-wide safety risks, currently linked to up to 25% of all hospital admissions [6]. Since consistent dosing is fundamental to controlling conditions like hypertension and diabetes, improving adherence is now recognized as a top public health priority, essential for reducing morbidity and ensuring that medical interventions achieve their intended life-saving outcomes.

The implications of this problem extend to global economic and environmental factors. Economically, non-adherence drains the U.S. healthcare system of $100 billion to $300 billion every year in avoidable emergency visits and complications [7]. Environmentally, suboptimal adherence is a major driver of pharmaceutical waste, contributing to a healthcare carbon footprint that accounts for nearly 5% of global greenhouse gas emissions [1]. Socially, the burden often falls on family caregivers who experience significant emotional and physical strain while managing the repercussions of a patient’s missed doses [6]. By addressing the technical barriers to medication timing, this project aims to mitigate these broad societal costs while promoting a more sustainable and effective model of care. From an engineering perspective, the challenge lies in developing a reminder mechanism that is independent of smartphones or external connectivity, physically present in the user’s environment, difficult to ignore yet non-disruptive, energy-efficient for long-term battery operation, and safe for use around medication storage.

1.2 Solution

The proposed solution, AdheraScent, is a battery powered pillbox that integrates time-based monitoring, compartment open and close detection, and a controlled scent emission mechanism to provide adaptive medication reminders. The system would continuously monitor scheduled medication windows with a real-time clock integrated with an ESP32 microcontroller. Each daily compartment of the 7-day pill container is equipped with an open/close sensor to determine whether medication has been accessed during its assigned time window. If the container remains closed after the scheduled window expires, the control unit activates the scent emitter.

The scent emission subsystem consists of a replaceable scent pad, a mechanically controlled airflow path, and a variable-speed DC fan. When triggered, airflow is enabled across the scent pad to release scent into the environment. The emission intensity is modulated using pulse width modulation (PWM), allowing gradual increases in scent if the medication is still missed. Once the container is opened, the emission will stop immediately.

To ensure long-term reliability, the system assumes a predetermined scent pad lifetime (e.g. 20 days). The microcontroller tracks elapsed time since installation of the scent pad and activates a blinking LED when the pad approaches the end of its effective service life. The system operates without smartphone integration and employs power management to extend battery life.

1.3 Visual Aid

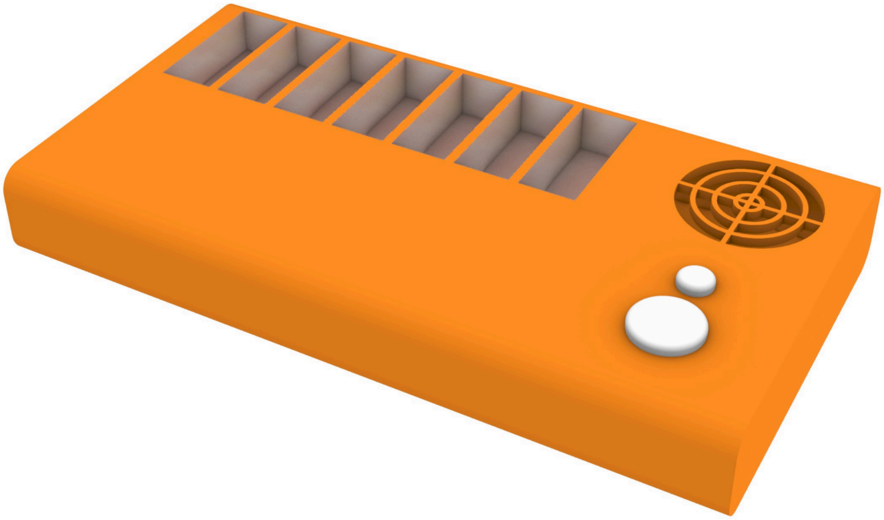


Figure 1: AdheraScent System 3D view. This view is to showcase the overall form factor for the user.

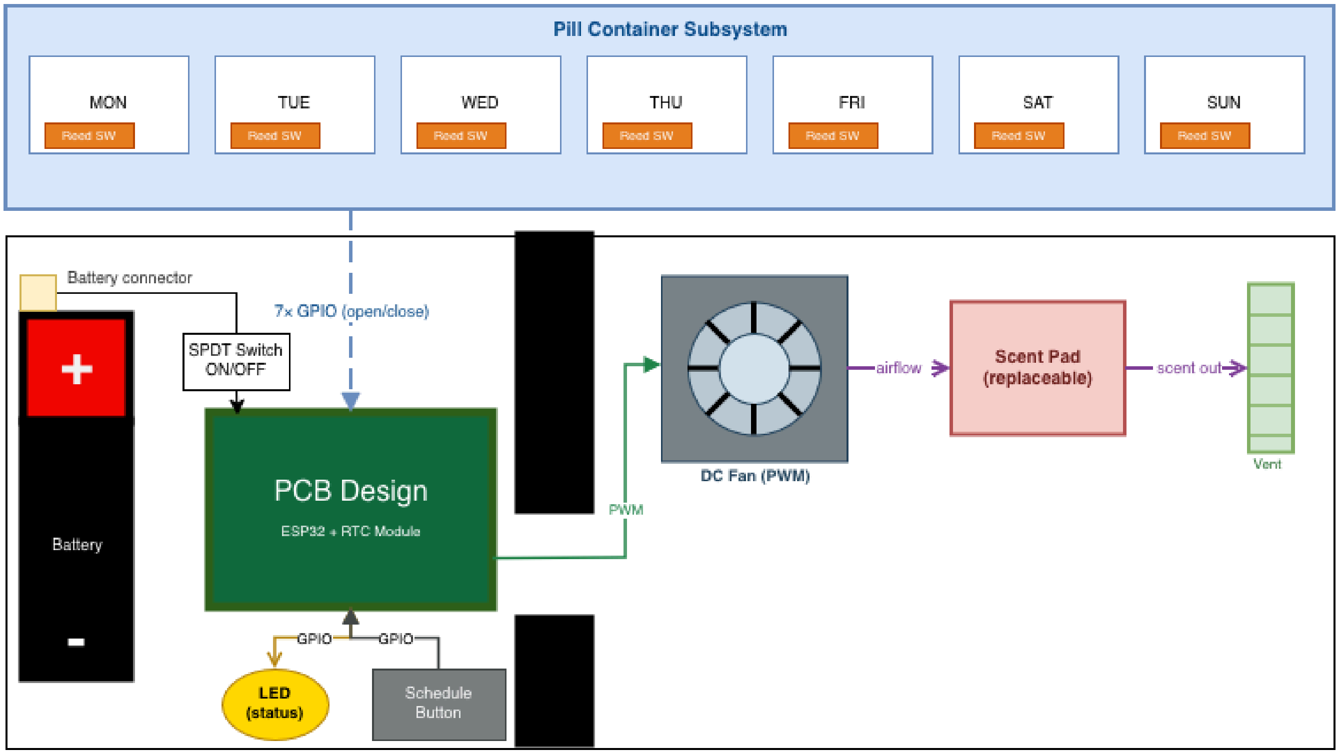


Figure 2: AdheraScent System Internal view. This view reveals the spatial allocation of the ESP32, the Timing Control Unit, and the mechanical components of the Scent Emitter Subsystem

1.4 High Level Requirements

To consider our project successful, our safety suite must fulfill the following:

1. **Missed medication detection and fan activation:** The system shall activate the scent-emitter fan within 10 seconds after the scheduled medication window has elapsed if and only if the corresponding pill compartment was not opened during that window.

2. **Scent notification effectiveness:** Once the fan is activated, the scent emitter shall produce an odor detectable by a user at a distance of 0.5 m in a standard indoor environment within 1 minute of fan activation.

3. **Compartment-open fan deactivation:** Once the corresponding compartment is opened, the system shall deactivate the fan within 10 seconds of detecting the open event, and the odor at 0.5 m from the device shall no longer be detectable by a tester after 10 minutes under standard indoor conditions.

2 Design

2.1 Block Diagram

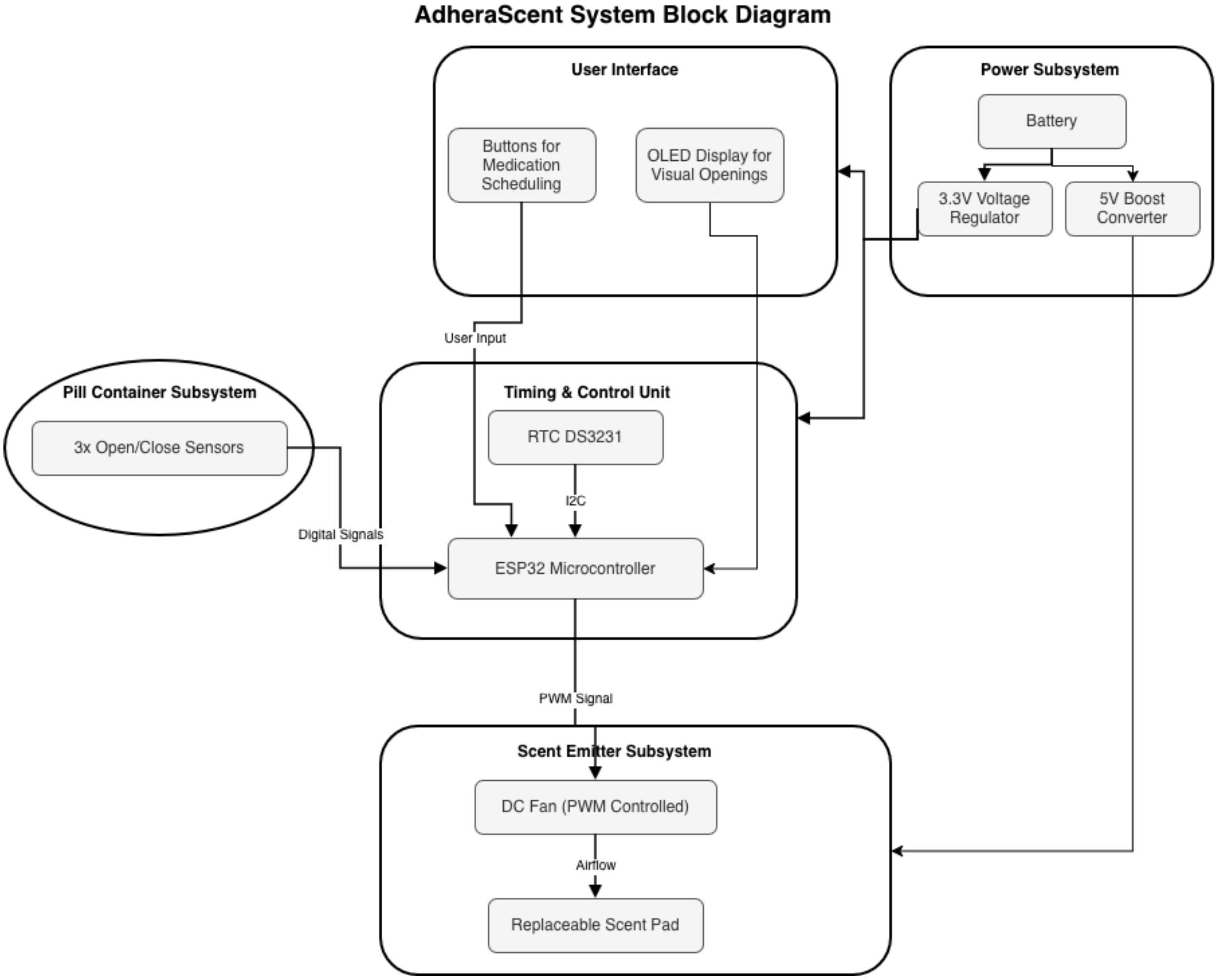


Figure 3: AdheraScent System Block Diagram. This diagram illustrates the high-level architecture of the pillbox, detailing the interconnections between the Power Subsystem, Timing & Control Unit (featuring the ESP32 and RTC DS3231), and the Scent Emitter output stage.

2.2 Functional Overview

2.2.1 Power & Control Subsystem

2.2.1.1 Design procedure

The power subsystem needed to supply two regulated rails — 3.3V for logic and 5V for the fan — from a single Li-Po battery while supporting USB-C charging. The TP4056 was selected as the charging IC due to its integrated overcharge and overdischarge protection for single-cell Li-ion batteries. An AP2112K LDO was chosen for the 3.3V logic rail for its low dropout voltage and sufficient current capacity for the ESP32, RTC, and peripherals. Rather than designing a discrete boost converter, an off-board MT3608 module was used for the 5V fan rail to simplify PCB layout and reduce switching noise risk near the logic circuitry.

2.2.1.2 Design details

The battery connects to the TP4056 module via J6. The TP4056 output feeds an SPDT switch (SW11) which, when closed, drives the VSYS node. VSYS supplies the AP2112K-3.3 LDO (U2), with 1µF bypass capacitors on both input and output. The EN pin is tied to VIN to keep the LDO always enabled when VSYS is present. VSYS also routes to J8, a header connecting to the external MT3608 boost module which produces the +5V fan rail.

2.2.2 Dispensing & Sensing Subsystem

2.2.2.1 Design procedure

The selection of a sensing mechanism for the pill container was driven by the need for long-term reliability and immunity to environmental interference. During the initial design phase, mechanical limit switches were evaluated but ultimately dismissed due to concerns regarding mechanical fatigue and the high precision required for alignment with 3D-printed components. Similarly, optical infrared break-beam sensors were considered; however, their susceptibility to varying ambient light conditions in a home setting made them less desirable for a medical safety device.

To resolve these challenges, a contactless magnetic sensing approach was chosen. Magnetic reed switches were selected because they are hermetically sealed, protecting the contacts from dust and oxidation, and they require no power in standby state. High strength N52 neodymium magnets were paired with these switches to ensure a robust magnetic field, providing a sufficient activation range to account for the tolerances of the 3D-printed housing.

2.2.2.2 Design details

The sensing circuit is implemented using a simple pull-up configuration, where each reed switch connects a microcontroller GPIO pin to ground when activated. A 10 kΩ resistor is used to pull the logic level high when the compartment is closed. The switches are physically integrated into the base of the device via precision-drilled ports and secured with thermal-bonded adhesive. To ensure consistent triggering, the magnets are mounted directly to the underside of the lids, maintaining a maximum operating gap of 12 mm.

A significant technical constraint involved the mechanical vibrations generated by the scent emitter's fan motor, which could potentially cause "contact chatter" in the reed switches. To mitigate this, a software-based noise guard was developed within the firmware. This filter requires a state change to persist for at least 200 ms before it is registered as a valid pill-dispensing event. This duration was mathematically determined to be longer than the maximum period of motor-induced vibration but short enough to remain responsive to human interaction.

2.2.3 Scent-Release Subsystem

2.2.3.1 Design procedure

Our design of the scent release subsystem was driven by the need to create a reminder mechanism that is noticeable to the user while remaining safe for use near medication storage. During the initial design phase, several methods of scent delivery were considered, including heating-based scent release, spraying, and air blowing scent dispersion. Heating-based scent release was avoided because heat would introduce unnecessary safety concerns near medication and battery-powered electronics. Spraying was also dismissed because storing liquid would also bring safety concerns which we wouldn’t want to contaminate our medicine.

To address these issues, an air blowing scent release approach was selected. The final design uses a 5 V DC fan to push air across a replaceable scent pad only when the system detects that a scheduled medication window has been missed. This approach allows the scent reminder to be controlled electronically by the microcontroller, and to avoid continuous passive odor release, a funnel-shaped 3D printed airflow guide was designed to concentrate the airflow and direct the scent outward from the device. This helped improve scent delivery while keeping the scent pathway physically separated from the pill storage area.

A key design revision involved reducing passive scent leakage when the fan was inactive. In earlier versions, the scent pad was more exposed to the environment, which created the possibility of odor leaking even when the reminder was not active. The final funnel implementation was designed to partially enclose the scent pad area and direct the airflow only through the intended outlet path. Although this would not completely eliminate passive leakage, it improved the practical performance of the subsystem and made the reminder more distinct when the fan was activated.

2.2.3.2 Design details

The scent release subsystem consists of a 5 V DC fan, a replaceable scent pad, a 3D-printed funnel structure, and a MOSFET-based fan driver controlled by the ESP32. The fan is positioned below the funnel inlet so that, when activated, it pushes air upward through the scent pad region. The funnel geometry was designed in Fusion 360 and then 3D printed. Four scent-pad slots were included in the funnel to increase the contact area between the airflow and the scent source, allowing more scent to be carried out of the device. The scent-pad slots was also designed so that scent pads are replaceable without tools.

The electrical control of the fan is implemented using a low-side N-channel MOSFET switch. The ESP32 outputs a control signal to the MOSFET gate, allowing the microcontroller to turn the fan on or off based on the medication reminder state. When the real-time clock reaches the scheduled medication time and the corresponding pill compartment remains closed after the programmed grace period, the ESP32 activates the fan. Once the pill compartment is opened and the reed-switch sensing subsystem detects pill removal, the ESP32 disables the fan so that scent emission stops. A software auto-cutoff was also included to prevent the fan from running indefinitely, reducing the risk of motor overheating and unnecessary battery drain.

3 Verification

3.1 Power & Control Tests

Voltage regulation was verified by taking 10 repeated measurements on each power rail using a multimeter. The 3.3V rail produced readings ranging from 3.324V to 3.386V with a mean of 3.345V, and the 5V fan rail ranged from 5.004V to 5.099V with a mean of 5.055V. Both rails remained within the required ±5% tolerance bands of 3.135V–3.465V and 4.75V–5.25V respectively. RTC backup was confirmed by disconnecting main power for one hour; upon reconnection, the displayed time matched the reference clock with no observable drift. Medication window persistence was verified by programming an alarm, power-cycling the device, and confirming the stored window remained intact on reboot. Full details are provided in Appendix A, Table A.1.

3.2 Dispensing and Interface Tests

Verification of the Dispensing and Interface subsystem confirmed that all high-level requirements regarding user feedback and pill detection were met. Electrical testing of the reed switches showed stable logic levels (0.1V for LOW, 3.3V for HIGH), providing clear signal differentiation for the microcontroller.

Reliability was validated via a 100-cycle stress test per compartment, resulting in zero missed triggers. Furthermore, the integration between the sensors and the OLED display was confirmed by measuring the "TAKE PILL!" state termination. Upon pill removal, the system consistently updated the display and deactivated the scent fan in under 5 seconds, significantly exceeding the 15-second requirement. For a detailed log of all low-level requirements and specific test procedures, refer to the Requirement and Verification Table in Appendix A.

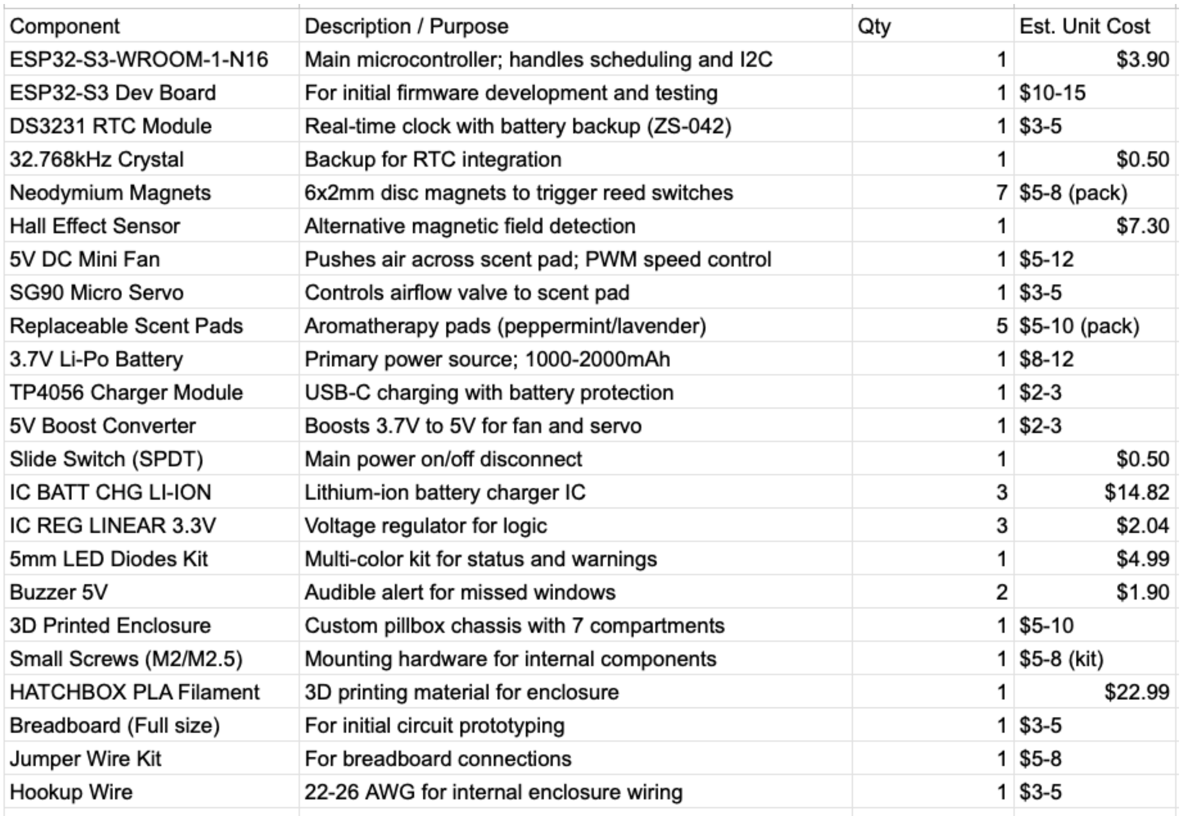
3.3 Scent-Release Tests

Verification of the Scent-Release subsystem focused on confirming that our fan-driven scent emitter could provide a noticeable reminder when needed. The airflow path was first verified by activating the 5V fan and confirming that air was directed through the 3D-printed funnel and across the replaceable scent pad. The fan operated did operated continuously. Scent effectiveness was tested by replacing multiple testers at a distance of 0.5m from the outlet with fan activating under normal indoor conditions. The scent was consistently detectable within the required window. The fan also operated continuously during the test without visible instability, mechanical interference, or system reset.

Scent pad replacement was also verified by manually removing and reinstalling the scent pad without tools, and this process was also tested by multiple testers. Airflow path also verified that our scent emission path would be completely separated from our medicine storage, which also satisfied our requirement for safety. For a detailed log of all low-level requirements and specific test procedures, refer to the Requirement and Verification Table in Appendix A.

4 Costs

The total cost for parts as seen below in Figure 18 before shipping is $302.00. 5% shipping cost adds another $15.1 and 10% sales tax adds another $30.20. We can expect a salary of $40/hr×2.5 hr×60 = $6000 per team member. We need to multiply this amount with the number of team members, $6000× 3 = $18,000 in labor cost. This comes out to be a total cost of $18,347.3.



Component	Description / Purpose	Qty	Est. Unit Cost
ESP32-S3-WROOM-1-N16	Main microcontroller; handles scheduling and I2C	1	$3.90
ESP32-S3 Dev Board	For initial firmware development and testing	1	$10-15
DS3231 RTC Module	Real-time clock with battery backup (ZS-042)	1	$3-5
32.768kHz Crystal	Backup for RTC integration	1	$0.50
Neodymium Magnets	6x2mm disc magnets to trigger reed switches	7	$5-8 (pack)
Hall Effect Sensor	Alternative magnetic field detection	1	$7.30
5V DC Mini Fan	Pushes air across scent pad; PWM speed control	1	$5-12
SG90 Micro Servo	Controls airflow valve to scent pad	1	$3-5
Replaceable Scent Pads	Aromatherapy pads (peppermint/lavender)	5	$5-10 (pack)
3.7V Li-Po Battery	Primary power source; 1000-2000mAh	1	$8-12
TP4056 Charger Module	USB-C charging with battery protection	1	$2-3
5V Boost Converter	Boosts 3.7V to 5V for fan and servo	1	$2-3
Slide Switch (SPDT)	Main power on/off disconnect	1	$0.50
IC BATT CHG LI-ION	Lithium-ion battery charger IC	3	$14.82
IC REG LINEAR 3.3V	Voltage regulator for logic	3	$2.04
5mm LED Diodes Kit	Multi-color kit for status and warnings	1	$4.99
Buzzer 5V	Audible alert for missed windows	2	$1.90
3D Printed Enclosure	Custom pillbox chassis with 7 compartments	1	$5-10
Small Screws (M2/M2.5)	Mounting hardware for internal components	1	$5-8 (kit)
HATCHBOX PLA Filament	3D printing material for enclosure	1	$22.99
Breadboard (Full size)	For initial circuit prototyping	1	$3-5
Jumper Wire Kit	For breadboard connections	1	$5-8
Hookup Wire	22-26 AWG for internal enclosure wiring	1	$3-5

Figure 4: Itemized list of Components and Cost

5 Conclusion

AdheraScent successfully met its primary objective of creating a multimodal medication reminder system that accurately detects user interaction. By integrating magnetic sensing with thermal scent dispersal and a digital interface, the project demonstrated that sensory-based notifications can be effectively synchronized with physical dispensing hardware. The high success rate in compartment detection and the stability of the power and control systems confirm that the design is a viable solution for improving patient medication adherence.

5.1 Accomplishments

The project achieved a robust 100% detection rate during mechanical stress testing, validating the decision to utilize contactless magnetic reed switches over mechanical alternatives. Furthermore, the firmware's noise guard successfully filtered out motor-induced vibrations, ensuring system stability even during maximum scent emission. The integration of the real-time clock with the OLED interface provided a seamless user experience, allowing for independent alarm scheduling that persisted through power cycles.

5.2 Uncertainties

While the system performed reliably in controlled environments, some uncertainties remain regarding the long-term depletion rate of the scent pads and the dispersal efficacy in very large or highly ventilated rooms. Additionally, the current 12 mm magnetic trigger gap is optimized for the current 3D-printed tolerances; however, variations in filament type or print quality could necessitate recalibrating the pull-up resistor values or magnet strength in a mass-production scenario.

5.3 Ethical Considerations

In alignment with the **IEEE Code of Ethics**, specifically the commitment to hold paramount the safety, health, and welfare of the public, AdheraScent was designed with multiple safety safeguards. To avoid the risk of accidental double-dosing, the system utilizes monitoring rather than forced dispensing, ensuring the user remains the final decision-maker in their care.

Furthermore, we addressed potential health risks by incorporating a scent pad usage counter, preventing the degradation of materials that could lead to respiratory irritation. All electrical components were housed in secure, precision-drilled enclosures to prevent accidental exposure to battery terminals or thermal elements, adhering to the ethical obligation to disclose and minimize potential risks to users.

References

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Appendix A Requirements and Verification Tables

Table A.1: Power and Control Subsystem – Requirements & Verification

Requirements	Verification
The subsystem shall provide a regulated 3.3V±5% supply to the ESP32, RTC, sensors, and OLED.	Measure the 3.3V rail under maximum load with a multimeter to confirm voltage remains within 3.135V−3.465V.
The subsystem shall provide a regulated 5V±5% supply to the scent fan.	Measure the 5V fan rail while active to confirm voltage remains within 4.75V−5.25V.
The subsystem shall maintain accurate time using the DS3231 RTC, even during main battery disconnect.	Disconnect main power for 1 hour; upon reconnection, verify RTC time remains within 1 minute of a reference clock.
The subsystem shall allow medication windows to be stored in non-volatile memory (EEPROM/Flash).	Program an alarm window, power-cycle the device, and verify the stored window persists upon reboot.

Table A.2: Dispensing & Interface Subsystem – Requirements & Verification

Requirements	Verification
Each compartment sensor shall provide a stable digital signal (Low < 0.8V, High > 2.4V).	Measure GPIO pin voltage during open/closed states using a multimeter to confirm logic thresholds.
The system shall detect a compartment open event and update the OLED status within 1 second.	Monitor serial debug timestamps during an open event to confirm detection latency is under 1 second.
The system shall terminate the "TAKE PILL!" alarm (fan and OLED alert) within 15 seconds of pill removal.	Trigger the alarm, remove the magnet from the active slot, and measure time until the fan stops and OLED displays "DONE!".
The sensors and housing shall operate reliably over 100 repeated mechanical cycles.	Perform 100 open/close cycles per compartment and verify 100% detection rate with no false triggers.
The OLED shall display real-time clock, alarm status, and "REPLACE PAD" notifications clearly.	Observe the display under typical indoor lighting to confirm all text is legible and notifications trigger correctly.

Table A.3:Scent Release Subsystem – Requirements & Verification

Requirements	Verification
The subsystem shall support continuous scent emission without thermal shutdown for 10 minutes.	Activate the fan at 100% PWM for 10 minutes and verify stable airflow and driver temperature remains below manufacturer rating.
The fan shall produce measurable airflow that carries scent at least 1 meters from the device.	Trigger scent emission and verify noticeable scent dispersal at a 1-meter radius in a standard room.
The subsystem shall not cause voltage droop or system resets during fan startup.	Monitor the 3.3V rail with an oscilloscope during fan activation to confirm voltage remains within ±5%.
The scent pad shall be replaceable by the user without tools in under 30 seconds.	Perform a timed replacement test to confirm the mechanical housing allows for tool-less pad swapping.