Final Report

Automatic Cat Litter Box
ECE445 Fall 2023

Team #12
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Abstract

This project successfully addresses the limitations of conventional automatic cat litter boxes by focusing on enhanced odor control and meticulous tracking of cats' litter box usage. The innovative solution features a cat litter box integrated with a motorized raking mechanism, weight sensors, and odor sensors. The motorized rake is triggered by weight sensors to scoop waste efficiently. These sensors are crucial for monitoring the cat's weight, as well as the frequency and duration of litter box use, providing valuable insights into the cat's health. Odor sensors effectively detect and manage ammonia levels, ensuring a more pleasant living environment. The data collected is relayed to the user's smartphone via Wi-Fi, allowing for remote monitoring and control. Collaborating with the ECE Machine Shop, the team achieved all high-level requirements, including 70% accuracy in detecting cat weight, usage frequency, duration, and efficient waste raking. This advanced system enhances cleanliness, offers health monitoring benefits, and ensures a stress-free atmosphere for both cats and their owners.

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1 Introduction

1.1 Problem

Modern automatic cat litter boxes neglect the crucial issue of odor control and often lack the capability to track the duration and frequency of a cat's litter box usage. Over time, as these systems accumulate waste, odors can intensify, causing discomfort for both cats and owners. Given cats' highly sensitive sense of smell, they detect these odors well before humans do. Without monitoring their habits, changes in litter box behavior such as prolonged visits or increased frequency may be missed, which can indicate potential health concerns such as urinary tract infections or digestive issues. These oversights can create an unpleasant living environment, pose health concerns, reduce usability and contribute to stress and anxiety.

1.2 Solution

The proposed solution centers around a cat litter box with a motorized raking mechanism for scooping. The motor will control a pulley system that directs the rake through the entire length of the litter box. Weight sensors will be positioned beneath the litter box. These sensors are responsible for initiating the motorized raking process upon detecting the entry and exit of the cat. Beyond triggering the raking process, these sensors will also act as the means to monitor the cat. By continuously capturing data, they quantify the duration of each cat visit, the frequency of visits and the weight of the cat itself. Odor sensors will be placed within the hood of the litter box, designed to detect and monitor the buildup of ammonia in real-time. This information will be communicated to the user through their phone. The connection between the litter box and the user's phone will be via Wi-Fi. The user will also be able to control the raking through the phone.

1.3 Subsystem Overview

Figure 1 shows an overview of the subsystems of our project. There will be a motor subsystem for raking, a communication subsystem for remote user interactions, and a sensor subsystem to monitor cat health. Additionally, there will be a power subsystem to provide enough power to all the other subsystems. Figure 2 is a more detailed subsystem block diagram.

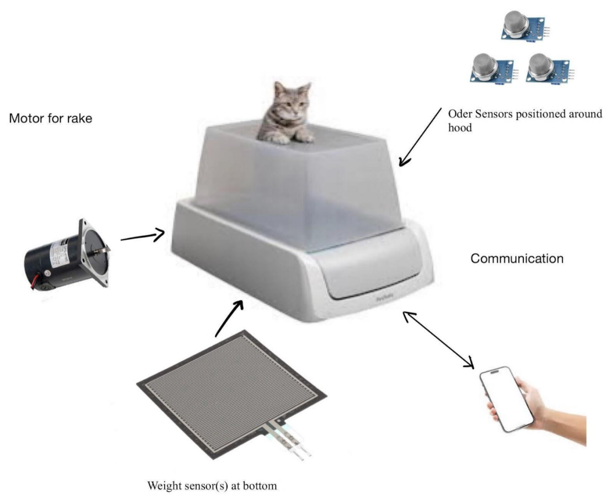

Figure 1: Visual Aid

1.4 High Level Requirements

- The litter box should accurately detect the cat's frequency of use, and the duration with an accuracy of 70% or higher.
- The rake should be able to rake the majority of waste into the disposal area (>70%).
- The user should be notified in a timely manner, within 5 minutes from the detection of the sensors.

2 Design

2.1 Block Diagram

Figure 2 shows the hardware block diagram of our design.

Software is also needed for the ESP32C3 microcontroller to interact with the hardware and achieve the desired functionalities. Figure 3 shows the software architecture of our design.

2.2 Board Subsystem

This subsystem has an ESP32C3-Mini microcontroller SoC as the core, and has any needed components attached (antenna, H-bridge, voltage regulators,

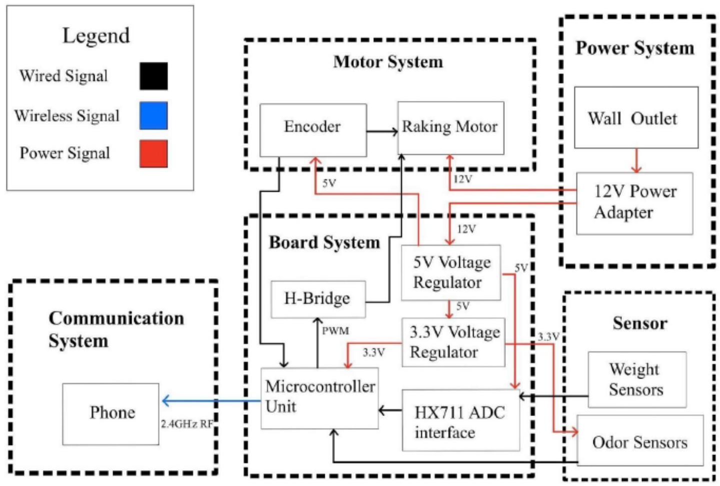

Figure 2: Hardware Block Diagram

etc). It is used for connecting and interfacing with the motors, sensors and the user. The board subsystem worked as expected, with the MCU being able to be programmed and run programs and all components running stable under full load. Figure 4 shows the draft of the schematic for the PCB.

2.3 Power Subsystem

This subsystem takes incoming 110V AC voltage and transform it to DC voltage at 12V, ensuring safe and stable power throughout the litter box for every component that needs it. Voltage regulators (12V-3.3V and 12V-5V) are used to supply different voltage levels for corresponding components. The power subsystem successfully delivered sufficient current and stable voltage for the motors, board components, and sensors to be used together. Figure 5 shows the schematic of the power subsystem.

2.4 Communication Subsystem

This subsystem allows for the notification to the user. It communicates and transmits data from the MCU to the phone, giving insight to anything the user may need to know through Wi-Fi. In order to support remote controllability, the communication between the litter box and the phone will be over the Internet through MQTT protocol. A web application that can be accessed through phone or computer was also made. There is an odor level

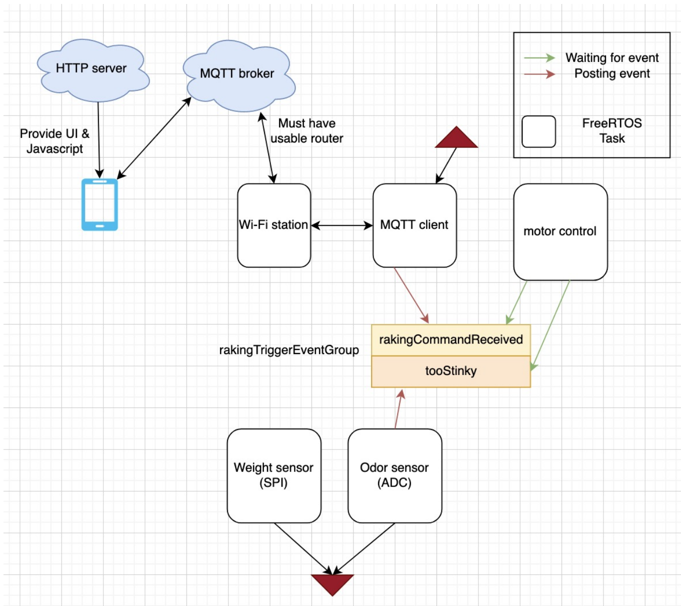

Figure 3: Software Architecture

indicator, a rake button that can trigger an instant raking, and a usage chart that visualizes litter box usage duration and frequency. The communication subsystem successfully transmitted desired data between the user's phone and the litter box. Figure 6 shows the user interface of the web application.

2.5 Motor Subsystem

This subsystem bridges the functionality of the code and data to the physical litter box. It is directly controlled by the MCU. It is attached to the rake through a pulley system for cleaning the litter box. The rake and the pulley system are attached on a stand around the litter box. The motor subsystem was successful in performing raking and provided enough torque to rake through sand. Figure 7 shows the schematics of the motor subsystem.

2.6 Sensor Subsystem

This subsystem gives the MCU the signal to start the cleaning process to ensure a tidy litter box. It is also the sole provider of any information collected concerning the health of the cat and the state of the litter box. The weight sensors are recalibrated after every visit from the cat to ensure the loss of litter will not affect the accuracy. The weight sensors are placed at the bottom of

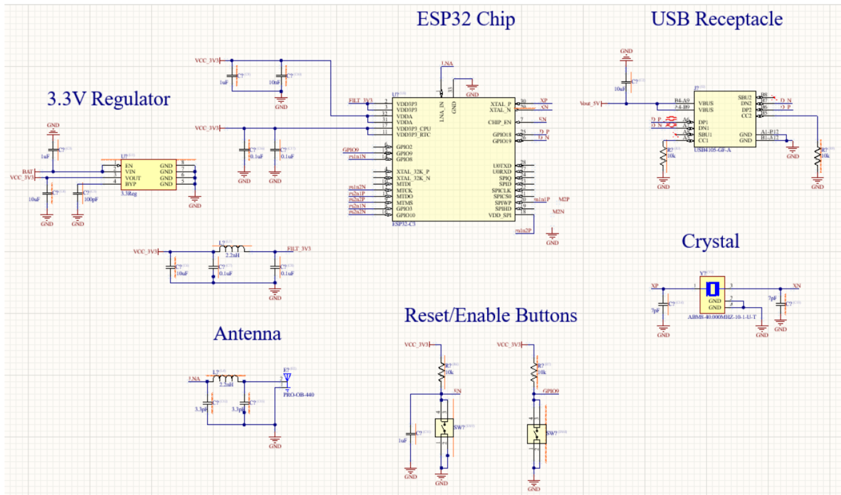

Figure 4: Board Schematic

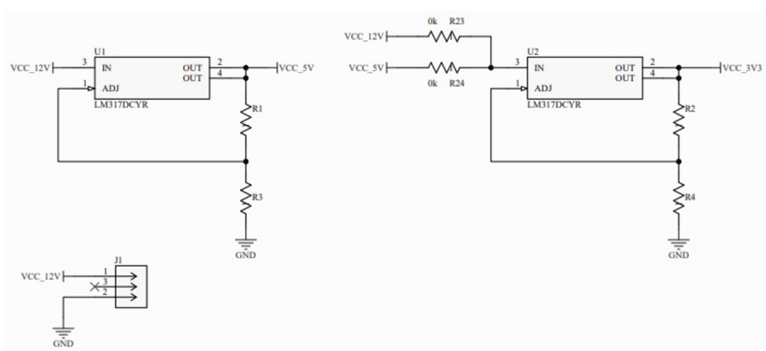

Figure 5: Power Supply Schematic

our entire system, so the entire weight of the system are measured at all times. The odor sensor simply produces an analog output, while the weight sensors operate through the HX711 serial interface, as shown in Figure 8. The odor sensor broke due to direct contact with ammonia solution, while the weight sensors were able to produce accurate readings.

3 Requirements & Verification

The complete R-V table can be found in Appendix A.

Figure 6: User Interface

3.1 Board Subsystem

1. **Test: Voltage Regulator Stability Under Load**

   - **Description:** Measure the output voltage of the voltage regulator with a multimeter under load conditions to ensure stability within the 3.0-3.6V range.
   - **Results:** The voltage regulator maintained a stable output within the required range of 3.0V to 3.6V under varying load conditions.

3.2 Power Subsystem

1. **Test: 12V Power Adapter Output Stability**

   - **Description:** Measure the output voltage of the 12V power adapter under load, ensuring stability within 12V ±5%.
   - **Results:** The adapter provided a stable 12V output with deviation within 0.35V (3%).

2. **Test: Power Supply to PCB and Motors**

   - **Description:** Connect the power adapter to the PCB and verify the operation of the motor and sensors.
   - **Results:** The adapter successfully supplied power to the PCB and motors, with all components functioning correctly.

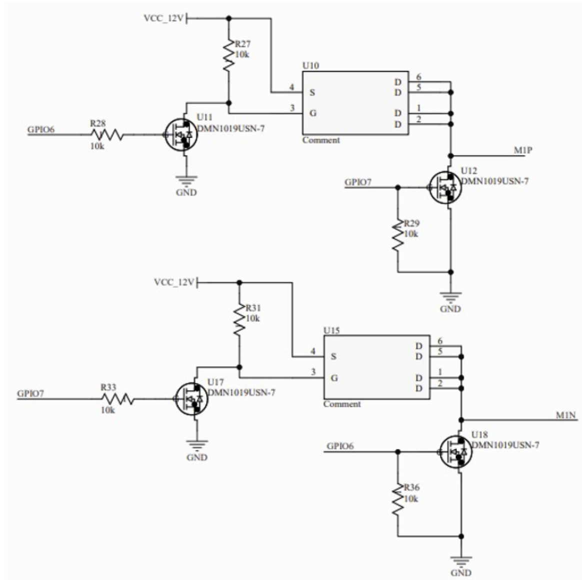

Figure 7: Motor Subsystem

3.3 Communication Subsystem

1. **Test: Communication Range and Stability**

   - **Description:** Perform range tests with the ESP32-C3 and a phone with hotspot to simulate a Wi-Fi router at distances up to 15 meters to confirm stable communication at 10 meters.
   - **Results:** Stable connection between the MCU and the phone was maintained up to 10 meters.

2. **Test: Timely Notification Delivery**

   - **Description:** Simulate excessive odor or litter box use and verify that notifications are sent to the app within 5 minutes.
   - **Results:** Notifications were consistently delivered within 10 seconds, which is much shorter than 5 minutes.

3.4 Motor Subsystem

1. **Test: Raking Motor Positional Accuracy**

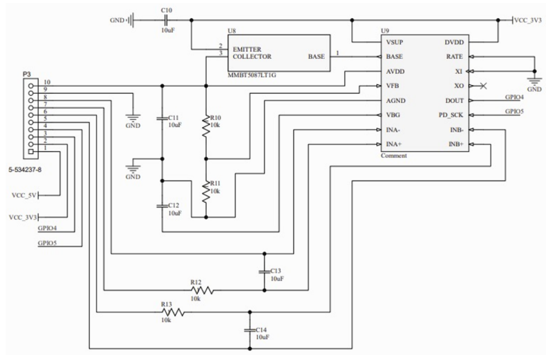

Figure 8: HX711 schematic

- **Description:** Put sand and golf balls in the litter box and start raking, ensuring the motor's position does not deviate by more than 10%.
- **Results:** The motor showed minimal positional deviation under simulated conditions, within 1%.

2. **Test: Raking Motor Torque and Smooth Operation**
   - **Description:** Drive the comb through sand using the motor and observe movement, ensuring no stalling.
   - **Results:** The motor provided sufficient torque, and the comb moved smoothly through sand without stalling.

3.5 Sensor Subsystem

1. **Test: Weight Sensor Capacity and Calibration**
   - **Description:** Apply known weights around 25kg on the sensor and confirm operation. Calibrate and test the sensor with various known weights for accuracy.
   - **Results:** The sensor supported the maximum weight and showed accurate readings post-calibration.

4 Cost & Schedule

4.1 Cost

Labor Cost

The average starting salary of a UIUC electrical engineer grad was $87,769 which is around $42/hour. We have three members dedicating around 10 hours per week, for 12 weeks. The labor cost for our group is then $37,800:

$$\frac{\$42}{\text{hr}} \times \frac{10\text{ hr}}{\text{week}} \times 12\text{ week} \times 3\text{ persons} \times 2.5(\text{miscellaneous multiplier}) = \$37,800$$

We also asked the machine shop for help with our mechanical design. We will assume it takes one work week for two people to finish our design at $30/hr. The cost of the parts required by the machine shop will be simplified with a 2.5 multiplier. The labor cost for the machine shop is then $6,000:

$$\frac{\$30}{\text{hr}} \times \frac{8\text{ hr}}{\text{day}} \times 5\text{ day} \times 2\text{ persons} \times 2.5(\text{miscellaneous multiplier}) = \$6,000$$

Parts Cost

Table 1: Parts Costs

Description	**Manufacturer**	**Part #**	**Quantity**	**Total Cost ($)**
Stainless Steel Cat Litter Box	Kichwit	N/A	1	39.99
DC Gear Motor 12V Low Speed 10RPM	Bemonoc	N/A	2	29.79
12V 5A Power Adapter	Velain	N/A	1	10.98
USB 2.0 Type C Connector	GCT	USB4105-GF-A	1	0.81
Wi-Fi Module	Espressif	ESP32-C3-MINI-1-H4	1	1.9
Motor Driver	Texas Instruments	DRV8874PWPR	1	3.39

Description	Manufacturer	Part #	Quantity	Total Cost ($)
Load Cell Set	DIYMalls	N/A	1	7.99
Linear Regulator	Texas Instruments	LM317DCYR	2	1.6
Crystal Oscillator	Abracon	ABM8-40.000MHZ-10-1-U-T	1	1.03
Resistors, Various	N/A	N/A	~20	~5
Capacitors, Various	N/A	N/A	~30	~10
Misc. Board Components	N/A	N/A	N/A	~10
Taxes + Delivery	N/A	N/A	~12%	134.48

Total Cost

The total cost of this project is the sum of the labor cost and part cost:

$$\$37,800 + \$6,000 + \$135 = \$43,935$$

The total cost is **$43,935**.

4.2 Schedule

Table 2: Schedule

Week	Task	Person
9/25 - 10/1	Design review sign-up	All
	Make a sketch for litter box dimensions for machine shop	All
	Purchase hardware parts	All
10/2 - 10/8	Design review	All
	Purchase electronic parts	All
	Work on PCB design	Jonathan
	Research on ESP32 programming	Shihua & Michael
10/9 - 10/15	Teamwork Evaluation I	All
	Finalize PCB design	Jonathan

Week	Task	Person
	Work on driver for SPI interface to read weight sensor readings	Michael
	Work on GPIO driver to control motors	Shihua
10/16 - 10/22	Complete PCB order	All
	Test SPI driver with dev kit and weight sensor on breadboard	Michael
	Test PCB functionality	Jonathan
	Test GPIO driver for motor control on PCB	Shihua
10/23 - 10/29	Individual Progress Report	All
	Make changes to PCB should there be any issue, and order new PCB if necessary	Jonathan
	Work on driver for ADC on ESP32-C3 for odor sensor readings	Michael
	Work on driver for Wi-Fi on ESP32-C3 for communication subsystem	Shihua
10/30 - 11/5	Test ADC driver by connecting odor sensors and read sensor value in different environments	Michael
	Test Wi-Fi driver by trying to connect to phone and sending packets, and make a web application	Shihua
11/6 - 11/12	Finish subsystem drivers and integrate the drivers to the main program	Shihua & Michael
	Test system hardware functionality on litter box	Jonathan
	Finalize and prepare for mock demo	All
11/13 - 11/19	Mock demo	All
	Do final amendments to the project if necessary	All
	Team contract fulfillment	All
11/27 - 12/3	Final Demo	All
	Mock Presentation	All
	Prepare for final presentation	All

5 Conclusion

5.1 Accomplishments

The project's primary objective, to revolutionize the traditional cat litter box experience through automation and smart technology integration, has been met with resounding success. Our team's dedication to quality and innovation has culminated in a series of notable accomplishments that have not only fulfilled but also exceeded the project's high-level requirements.

Central to our achievements is the development and execution of a robust and reliable printed circuit board (PCB). The PCB has emerged as the cornerstone of our design, adeptly handling programs loaded onto the microcontroller unit and showcasing exemplary performance under full operational load.

Figure 9: The Completed Cat Litter Box

A crowning feature of our project is the web application, characterized by its user-friendly interface and efficient communication protocols. This application has successfully established seamless communication with the litter box via the Internet, facilitating a long-distance, real-time interaction that has proven to be both reliable and convenient for the end-user. Remarkably, the communication latency has been observed to be less than a few seconds, which is substantially lower than the five-minute response time outlined in the initial high-level requirements.

In terms of durability and design aesthetics, the cat litter box has been constructed using metal that promise longevity and ease of maintenance.

As we move towards the completion of this project, these achievements are not merely milestones but also a reflection of our team's unwavering commitment to excellence and the transformative potential of our innovative approach to automated pet care solutions.

5.2 Uncertainties

Despite the aforementioned successes, we encountered certain unpredicted challenges that introduced a degree of uncertainty to the project. The odor sensor, a critical component of our design, sustained damage due to direct contact with an ammonia solution, leading to its inability to read values post-exposure. Consequently, it consistently registered a reading of zero, which prevented us from displaying accurate odor levels on the web application as we had originally planned.

Moreover, the web application's current architecture does not support data persistence. This limitation necessitates that users keep their browsers active to receive notifications. This design shortfall poses a significant drawback for practical, everyday use where uninterrupted long-term monitoring is essential.

Our team is assessing these issues with a view to devising effective solutions that will enhance the system's reliability and user-friendliness, thereby ensuring that the final product not only meets but exceeds user expectations and requirements.

5.3 Ethical Considerations

Our project, guided by the IEEE Code of Ethics, emphasizes safety, integrity, and respect at every step.

Our top priority is the safety of both humans and cats. Every design choice will prioritize eliminating hazards, and we're committed to sustainable development practices. For example, all sensitive data are transmitted in encrypted protocols, ensuring privacy and data safety for our users. Also, the raking mechanism will never start if the weight sensor detects the presence of a cat, ensuring the safety of cats.

We welcome honest feedback and will promptly correct any errors. Every team member's contribution is valued, ensuring a collaborative effort. Everyone involved is treated with respect, and we have zero tolerance for any form of discrimination or harassment.

We aim to maintain these ethical standards throughout the project and expect our teammates to do the same, ensuring a supportive and ethical working environment.

5.4 Future Work

Although we have successfully achieved all of our high level requirements, some improvements can be made to make the project more well-rounded and useful in a practical sense.

First, we plan to integrate a high-quality ammonia sensor to the litter box which can read accurate ammonia levels through the ADC interface. With the integration of odor sensors, our users will be able to see accurate real-time odor level on the web application to determine whether raking is necessary.

Second, we plan to add a back-end process to our application that saves past data to a database and loads recent data when the website is accessed, making it possible for the user to keep track of their cat's health data without having to always keep the application open.

With these functionalities implemented, our cat litter box will make up for the features that most expensive automatic cat litter boxes on the market lack.

References

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[2] MQTT Protocol Specifications. *MQTT.org*. `https://mqtt.org`.

[3] Getting Started with ESP32. *Espressif Systems*. `https://docs.espressif.com/projects/esp-idf/en/latest/esp32/get-started/`.

[4] LM317 3-Terminal Adjustable Regulator. *Texas Instruments*. `https://www.ti.com/lit/ds/symlink/lm317.pdf`.

[5] Salary Averages. *ECE ILLINOIS*. `https://ece.illinois.edu/admissions/why-ece/salary-averages`.

Appendix A: R-V Table

Voltage Regulator

Requirement	**Verification**
R1. The voltage regulators must output a stable voltage within the operating voltage of the microcontroller, weight sensors, odor sensors (3.0-3.6V).	V1. Measure the output voltage of the regulator through a multimeter under load conditions and ensure it remains stable, within range.
R2. The voltage regulator must output a stable current that can supply all components of the PCB.	V2. Run the ESP32-C3 and weight sensor at the same time and measure the output current to make sure it is stable.

Raking Motor

Requirement	Verification
R1. The motor will not produce positional deviation due to resistance.	V1. Place sand and balls to simulate cat feces in the litter box, start raking and ensure that the position does not change by more than 10%.
R2. The motor must provide sufficient torque to ensure the comb moves smoothly through sand, overcoming resistance without stalling.	V2. Place the comb in a tray of sand. Drive the comb through the sand using the motor and observe the movement of the comb, ensuring there are no instances of stalling or getting stuck. Measure the torque or current of the motor during this process, ensuring they are within normal ranges.

Weight Sensor

Requirement	Verification
R1. The weight sensor must support the maximum weight for its usage (Combined weight of litter box and cat).	V1. Apply known weights around 25kg on the sensor and confirm the system works.
R2. The weight sensor must have calibration functionality.	V2. Calibrate and test the sensor with known weights to ensure its readings are accurate. Choose several different weight points for testing to verify accuracy post-calibration, including the minimum and maximum values within the calibration range.

Odor Sensor

Requirement	Verification
R1. The odor sensor must provide accurate and reliable odor detection.	V1. Test the sensor in environments with varying ammonia concentrations. Ensure the sensor's output accurately reflects the changes and can distinguish high (above 25 ppm) from low levels.
R2. The odor sensor must operate effectively in a humid environment with 80% RH.	V2. Add water to the sand in the litter box. Verify that the sensor continues to provide consistent and accurate odor readings.
R3. The sensor must be positioned optimally within the litter box for maximum odor exposure.	V3. Position the sensor at different locations within the litter box and measure its ability to detect odors accurately. Determine the optimal sensor placement for maximum exposure to litter box odors.

Communication Subsystem

Requirement	Verification
R1. The communication system must reliably maintain a range of approximately 10 meters at 9dBm transmit power.	V1. Perform range tests by placing the ESP32-C3 with the communication system and a paired phone app at varying distances from 1 to 15 meters. Confirm stable communication at 10 meters.
R2. The system must provide timely notifications within 5 minutes to the web app upon detecting excessive odor or litter box use.	V2. Simulate odor or litter box use events using odor sources/weights, and verify that the system sends notifications to the app within 5 minutes.

12V Power Adapter

Requirement	**Verification**
R1. The voltage adapter must provide a stable 12V output with an error of less than 5%.	V1. Measure the output voltage of the adapter under load conditions and ensure it remains stable at 12V $\pm5\%$.
R2. The adapter must consistently provide a minimum current output enough to support the PCB and motors ($\geq$2A)	V2. Plug the power adapter into the PCB and make sure the motor and sensors are working.

H-bridge

Requirement	**Verification**
R1. The H-bridge must provide bidirectional control of the 12-V DC motor.	V1.Connect the H-bridge to the ESP32 and the 12-V DC motor. Use GPIO pins on the ESP32 to send control signals to the H-bridge, verifying both forward and reverse motor rotations.