ECE 445

SENIOR DESIGN LABORATORY

FINAL REPORT

Waste Bin Management System

Team #1

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1 Abstract

The following document details the design, construction, and performance of an electronic waste bin monitoring system intended to be used by restaurants or other establishments which need to regularly empty several distributed trash cans. The final system is based on a central hub which communicates with sensor tags, one placed inside each trash can, in order to display the state of the trash cans and determine when one must be emptied. The system was found to perform as desired when monitoring the trash level, air quality, temperature, and humidity inside a trash can, and the use of the ESPNOW communication protocol made the system suitably robust; the cans may be distributed over a large area comparable to the size of a typical restaurant and do not require a Wifi connection.

Contents

2 Introduction

Restaurants produce large volumes of waste every day which can lead to many problems like overflowing waste bins, foul smelling trash cans, and customers questioning the cleanliness of a restaurant if it is not dealt with properly. Managers of restaurants value cleanliness as one of their top priorities. Not only is the cleanliness of restaurants required by law, but it is also intrinsically linked to their reputation. Customers can easily judge the worth of a restaurant by how clean they keep their surroundings. A repulsive odor from a trash can, pests, or even just the sight of a can overflowing with refuse can easily reduce the customer base of an establishment. With this issue in mind, there are many restaurant owners and managers that will likely purchase a device that will help them monitor the cleanliness of aspects of their restaurants. With the hassle of getting an employee to leave their station, walk to a trash can out of sight or far away, possibly even through external weather conditions, and then return to their station after washing their hands, having a way to easily monitor the status of trash cans from the kitchen or another location would be convenient and save time for restaurant staff. Fullness of each trash can isn't the only motivating factor to change out the trash. Maybe the trash can is mostly empty, but is extremely smelly. People are usually unable to tell if a trash can is smelly just from sight alone, and would need to get close to it, open it up, and expose themselves to possible smells in order to determine if the trash needs to be changed.

The solution to this problem is a network of sensors placed on each trash can with a central hub that has a screen to display data from all the trash cans. The sensor tags will be mounted to the top of a waste bin to monitor fullness of the can with an ultrasonic sensor, the odor/toxins in the trash with an air quality/gas sensor, and also the temperature of the trash can as high temperatures can lead to more potent smells. The tags will specifically be mounted on the underside of the trash can lids so the ultrasonic sensor has a direct line of sight to the trash inside and the gas sensor is directly exposed to the fumes generated by the trash, which are expected to migrate upward past the sensor and out the lid of the can. The central hub will has an LCD display that will show all of the metrics described in the sensor tags and alert workers if one of the waste bins needs attention with a flashing LED. This system will give workers one less thing to worry about in their busy shifts and give managers peace of mind knowing that workers will be warned before a waste bin overflows. It will also improve the customer experience as they will be much less likely to encounter overflowing or smelly trash cans.

3 System Functionality

The network consists of one central hub and 2 sensor tags. The sensor tags are to be mounted on the top of each trash can with the sensors pointed at the bottom of the can. The sensor tags each have an ultrasonic sensor, MQ135 gas sensor, and a temperature/humidity sensor. All these sensors will be collecting data that will be analyzed and compiled into a packet of data that will be sent to the central hub. The central hub receives the data wirelessly and processes it to send it to the screen. The screen will then display the data so users can know when they should empty the trash.

3.1 High-Level Requirements List

1. The ultrasonic sensors on the sensor tags must be able to accurately determine the level of trash when the trash can is almost full. This minimum level of trash is discussed in the Tolerance Analysis section.
2. The gas sensors on the sensor tags must be able to detect an unhealthy indoor air quality index, displaying a level of 4-5 when the air quality reaches levels unsafe for humans.
3. The temperature and humidity sensors on the sensor tag must be able to accurately determine the conditions within each trash can.
4. The central hub must display up-to-date information. In other words, the data displayed on the central hub for each trash can must represent a state experienced by that trash can within the last minute. This would include the level of trash, temperature, humidity, and indoor air quality index.

4 Subsystem Overview

4.1 Microcontroller Subsystem

The microcontroller will function differently based on if it is in a sensor or the hub. The sensor microcontroller will collect all the data from the gas sensor, temperature sensor, and distance sensor and wirelessly send this data to the hub. The hub microcontroller will receive the data and display it on the LCD screen, if there is a reason for the trash to be changed, the microcontroller will light up an LED to alert workers.

4.2 Power Subsystem

The power subsystem is relatively simple as there will be a wall outlet that will output 5v to the pcb, it will also have a voltage regulator to step the voltage down to 3.3v for the microcontroller. This subsystem will be the same on both the sensor and central hub.

4.3 Sensor Subsystem

The sensors will be connected to 5v and collect data that will be sent to the microcontroller where it will be processed.

4.4 User Interface Subsystem

The user interface will consist of an LCD screen and a flashing indicator light, the user interface will show the user how full each trash can is as well as the temperature and if there are any dangerous fumes in the trash. It will also flash an indicator so users know when to give the screen attention.

5 Design

5.1 Block Diagram

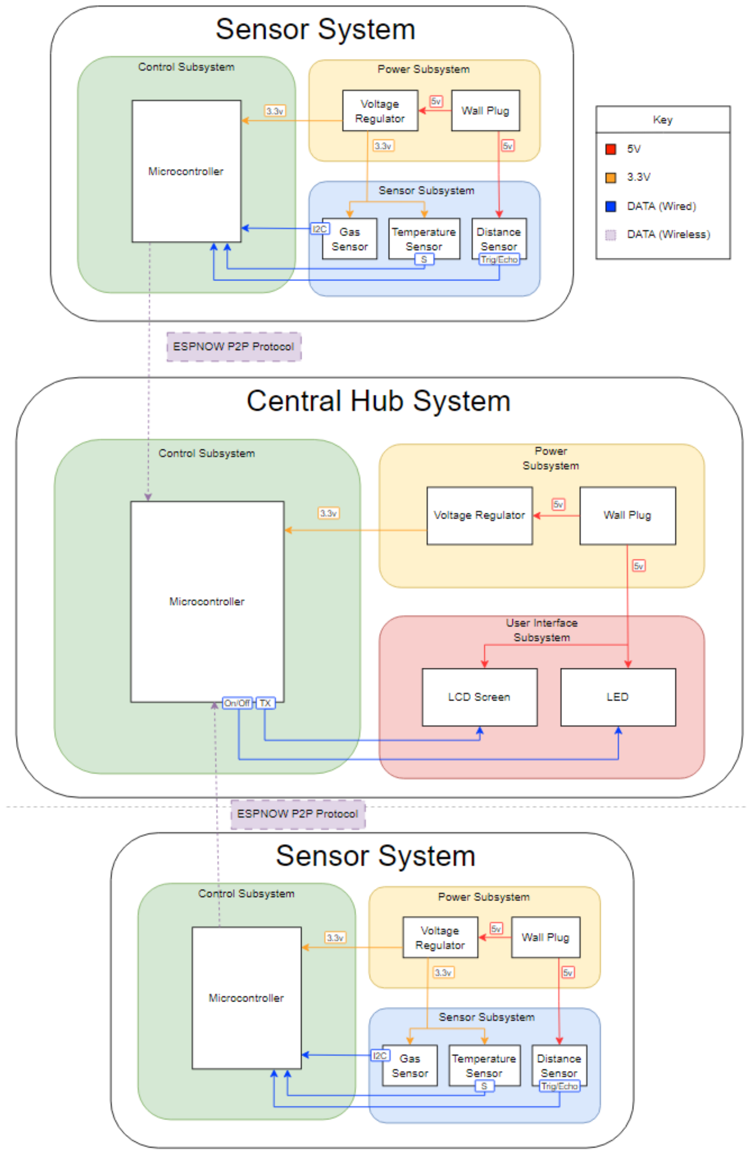

Figure 1: Block Diagram

5.2 Physical Design

We decided to 3d model and print cases to encapsulate our PCB. For the screen, we focused on making the screen the main focus and blocking out the possibility of touching any of the other electronics on the hub PCB, while for the sensor tag, we decided to minimize the number of openings in the case to protect against potential water damage from the trash.

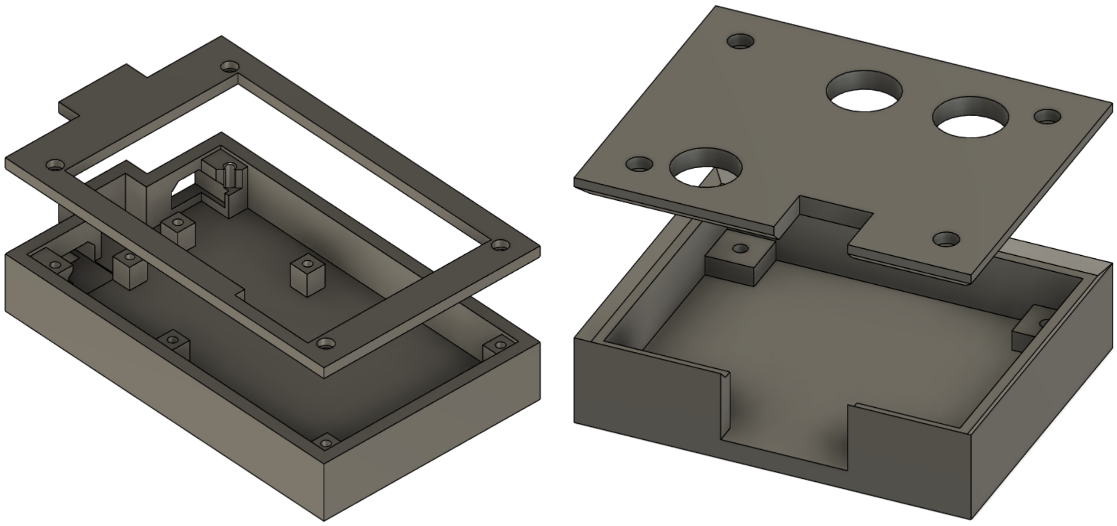

Figure 2: 3D Model of cases

Figure 3: Hub and Sensor installed in cases

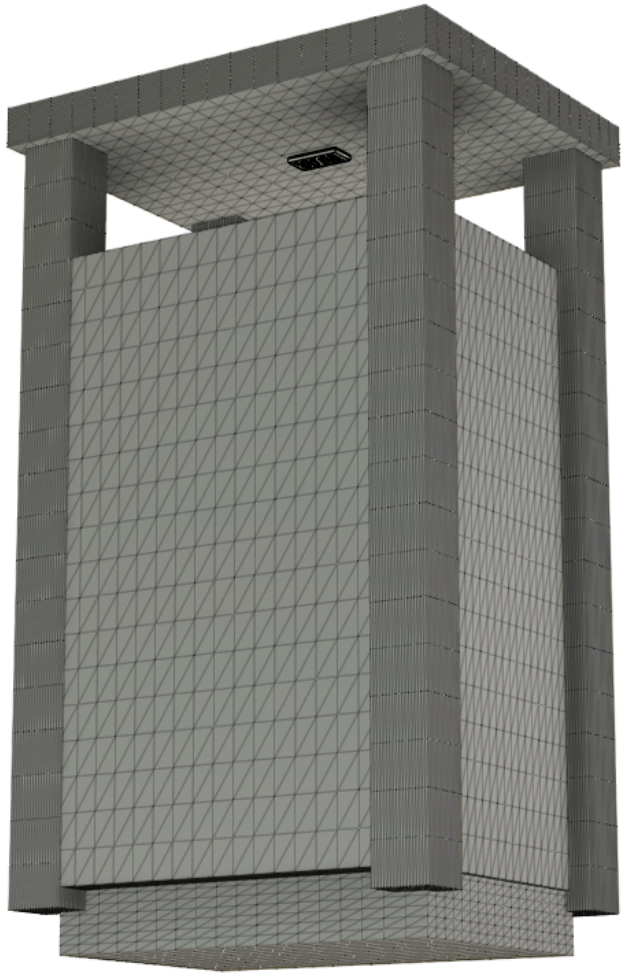

Figure 4: Sensor Component mounted on Trash can

5.3 PCB Layout

In our pcb layout, we focused on achieving several main objectives. We spaced apart sensors to prevent interference and shaped the hub board to fit underneath the Nextion LCD screen.

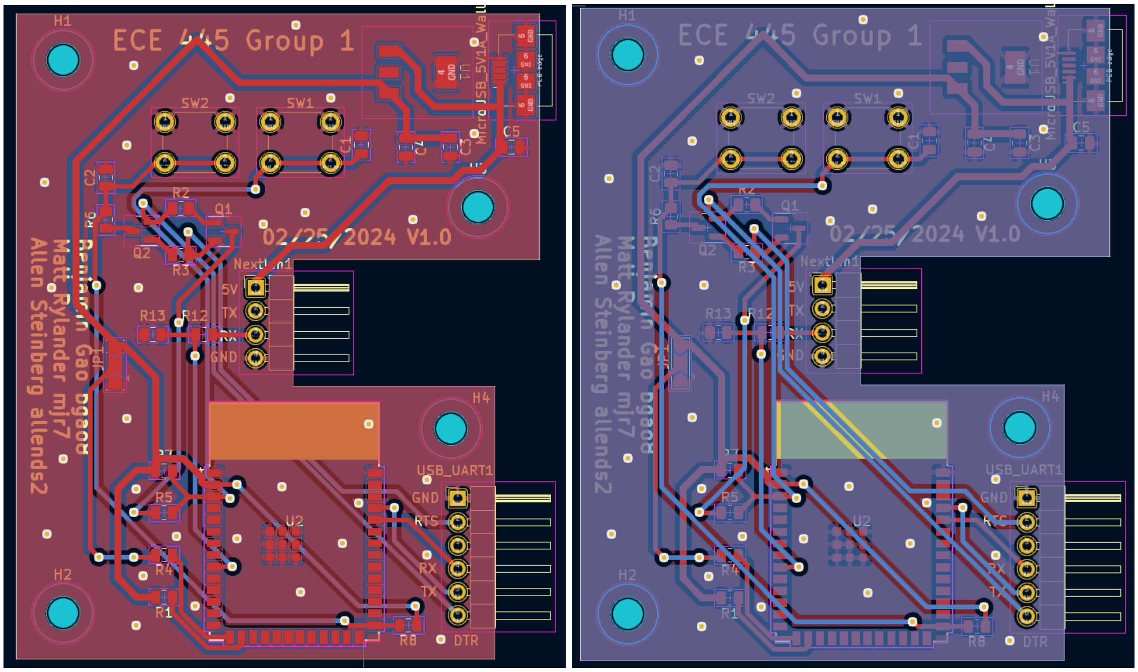

Figure 5: Both sides of the hub board

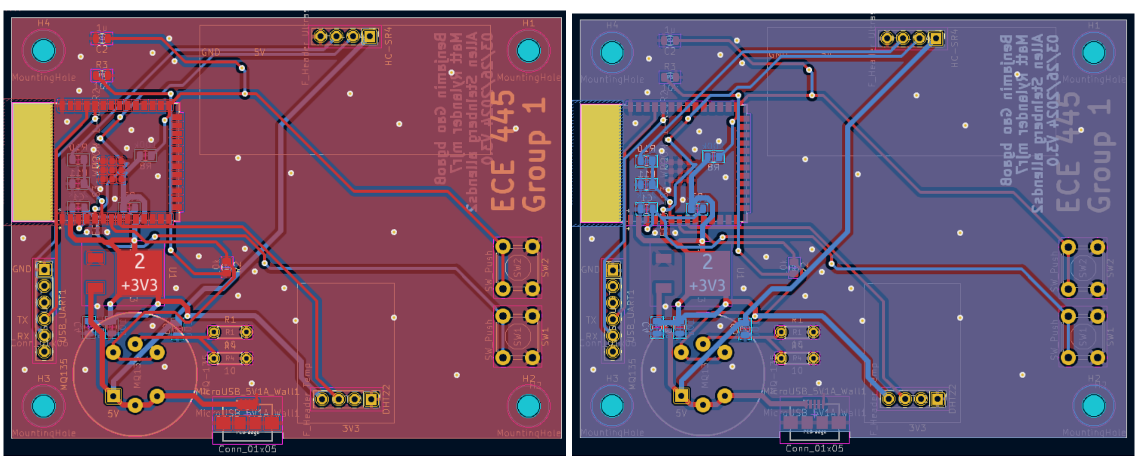

Figure 6: Both sides of the sensor board

5.4 Subsystem Designs

5.4.1 Microcontroller Subsystem

The Microcontroller subsystem consists of an ESP32-S3-WROOM powered by 3.3VDC which is connected to all other components in each board. In the sensor board it is the main processor for all the data collected by the sensors. It collects all the data, compiles the data into a packet, and sends it wirelessly through a

Peer-to-Peer(P2P) communication method called ESPNOW. This data is recieved by the hub unit's ESP32 where the data is processed and sent through signals to the LCD screen.

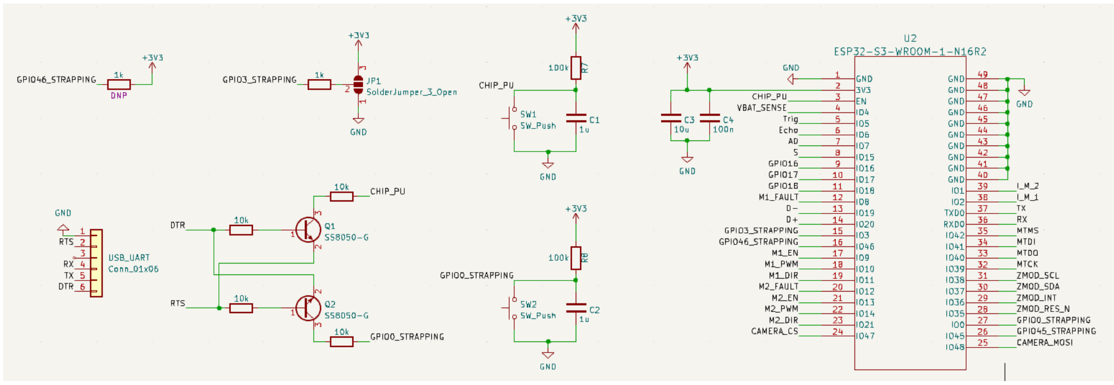

Figure 7: Microprocessor and programming Schematic

The programming circuit for the ESP32 is as bare bones as possible to negate any wasted components and make debugging as simple as possible. We only ended up using the buttons to manually put the ESP32 in programming mode and reset it with SW1.

5.4.2 Power Subsystem

The power subsystems in our project process the 5VDC USB input power and generate 3.3VDC for components such as the ESP32 and temperature sensor. Both boards contain the same power subsystem consisting of an AZ1117-3.3 3.3V voltage regulator, a micro-USB jack, and a bypass capacitor as shown below.

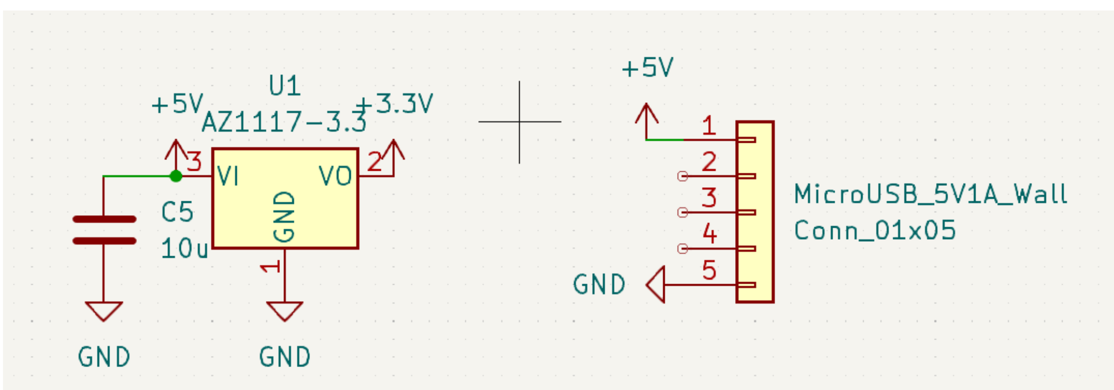

Figure 8: Power and Voltage Regulator Schematic

When designing the boards, it was considered that the 3.3V components on the boards may consume too much power, causing the voltage regulators to overheat and eventually fail. To address this issue, we calculated the typical current that would be drawn by all the components on the sensor board and performed a thermal circuit analysis of the voltage regulator. Since the hub board contains only one 3.3V component, the ESP32, and the sensor board contains this component and more, we would expect that if the sensor board regulator remains cool enough, the hub board regulator will as well. It was found that the total current draw expected from the 3.3V components on the sensor board is 217.9 mA. Using the following ratings for the AZ1117CD-3.3TRG1 regulator[1]:

Property	Rating	Comments
Maximum output current	1.35 A	Typical rating
Maximum junction operating temperature	150 °C	
Thermal resistance	100 °C/W	Without heatsink

We set up the thermal circuit equation to solve for the equilibrium temperature of the regulator junction:

$$T_J = T_A + P\Theta = 40°\text{C} + (0.2179A)(5V - 3.3V)(100°\text{C}/W) \approx 77°\text{C}$$

As this is below the maximum operating temperature of the junction, we expect both power subsystems to function without the risk of failure due to overheating.

5.4.3 Sensor Subsystem

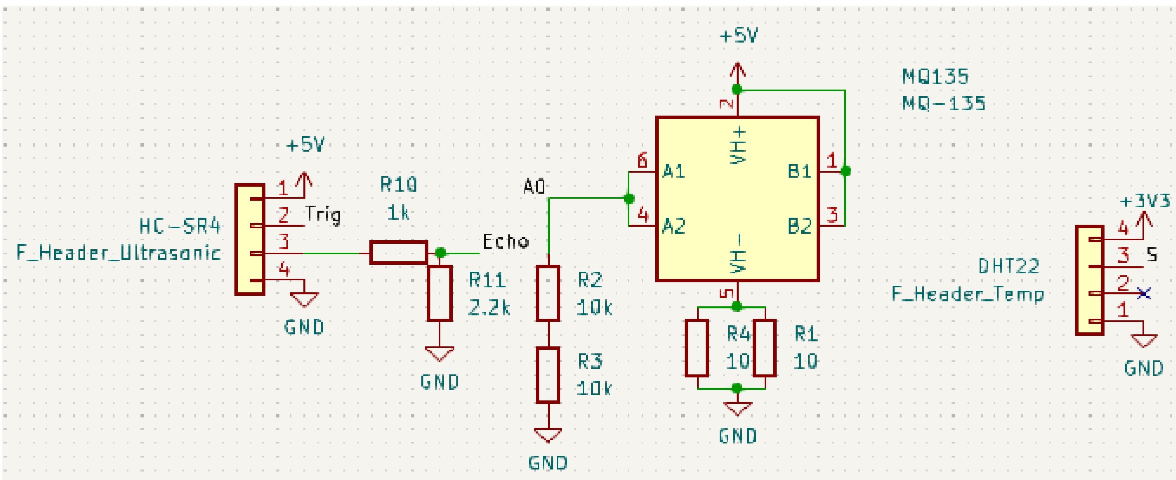

Figure 9: Sensor Subsystem Schematic

The sensor subsystem is composed of a standard HC-SR4 ultrasonic sensor module, a MQ135 Gas sensor, and a DHT-22 temperature/humidity sensor.

We chose the HC-SR4 as our distance/trash fullness sensor due to it being the most economical, easily available, and all-around best-performing choice (the alternatives being lidar or laser sensors, both of which are very expensive). The MQ-135 returns an analog voltage value based on the amount of various organic gasses in the air, primarily CO2 which is heavily associated with trash decomposition. The DHT22 was chosen as a general use sensor that has high precision and fits our budget.
All the sensors are connected directly to the inputs of our ESP-32 (Microcontroller subsystem).

5.4.4 User Interface Subsystem

The user interface subsystem in the hub, composed of the LCD screen, which is connected to the ESP32 through its TX and RX pins which allow it to communicate directly with the ESP32. The ESP32 sends signals to update certain values on the screen which happen almost instantaneously. The screen has touch screen capabilities that were not utilized in this project, but provide a great stepping stone to further work which is discussed in the conclusion section.

6 Design Verification

6.1 Ultrasonic Sensor

6.1.1 Requirement

The Sensor Subsystem must be able to provide distance values accurate to +- 5 cm when trash is within 80 cm of the sensor.

6.1.2 Verification

To verify the accuracy of the ultrasonic sensor[2], We filled a trash can with cardboard boxes at different heights to verify the accuracy. The value we took for each measurement is an average of 5 separate measurements done in quick succession as there are occasional outliers. Below is a table below with the results:

Actual Distance(cm)	**Measured Distance(cm)**
65	62.4
53.5	50.8
44.5	46.6
32	33.7
20.5	19.8
12	12.1
9	8.6
4.5	4.3

The distance sensor measurements all fall within 5cm of the actual value which passes our verification of sensor functioning as expected. It is also interesting to note that the distance sensor gets more and more accurate as the distance measured decreases.

6.2 Temperature Sensor

6.2.1 Requirement

The Sensor Subsystem must be able to provide temperature values accurate to +- 1 C at temperatures between 4-28 C (reasonable indoor temperatures)

6.2.2 Verification

To verify the accuracy of the temperature sensor, we measured the temperature reading of a handheld thermometer and the DHT22[3] output while both were side by side in the same location. we did this indoors as well as multiple days outside to get a range of temperature measurements. Given the Illinois climate, the temperatures available to test at were very limited. Below is a table below with the results:

Thermometer Temp(F)	Measured Temp(F)
72	72.0
70	69.9
59	59.6
45	44.4
41	41.1

All the temperature measurements fell within 1 degree Fahrenheit of the thermometer value. This passes our verification of the sensor functioning as expected.

6.3 Gas Sensor

6.3.1 Requirement

Our requirement for the gas sensor was:
The gas sensor must be able to provide indicators of when there is a smell. The gas sensor should show an increase in analog voltage level (relative to the healthy-air calibration level) of at least 100 on a 0-to-4095 scale when exposed to elevated CO2 levels from, for example, exhaled air.
Since the gas sensor is wired in a voltage divider configuration as the upper resistor, and its resistance decreases with increasing gas concentration, the output voltage of this divider will increase with increasing gas concentration. This is measured by the ESP32, which outputs a value on a 0-to-4096 scale representing voltages from 0V to 3.3V. A change of 100 therefore corresponds to about 0.08V, which represents an increase in gas concentration of about a few thousand parts per million according to the datasheet for the MQ135[4].
We chose to perform the test with CO2 for two reasons: first, considering the practicalities of performing the test, a low concentration of CO2 (about 40,000 ppm) could be produced by simply breathing on the gas sensor. If we were to try performing the test with another type of gas that the sensor detects, such as NH3, we would need to observe additional safety precautions and would also risk damaging the sensor with too high a concentration of a highly reactive substance. Second, landfill gas, the gas produced in an enclosed landfill, has been found to contain about 50% CO2[5]. This indicates that decomposing trash releases more CO2 than any other gas, so it is the logical choice to try to detect in this application.

6.3.2 Verification

The following procedure was followed to verify the above requirement.

1. Power on all systems, place the sensor tag within an enclosure(e.g. a small box).
2. Verify that the hub screen shows a low analog voltage reading from the gas sensor corresponding to the healthy-air calibration level.
3. Exhale into the cardboard box, raising the CO2 level near the sensor tag.
4. Verify that the hub screen has displayed a change in air quality, with an increase of at least 100 in the 0-to-4095 analog voltage reading relative to the calibration level.

When performing the test, it was found that the sensor tag did not even have to be enclosed in a cardboard box; simply exhaling near the gas sensor produced an increase in analog voltage reading of at least 450, well above our requirement.

6.4 Power subsystem

6.4.1 Requirement

The Power Subsystem for the hub board must be able to provide at least 1.0A at 5 +- 0.35V to the User Interface Subsystem and provide at least 80mA at 3.3 +- 0.3V to the Control Subsystem

The Power Subsystem for the sensor board must be able to provide at least 20mA at 5 +- 1V to the Sensor Subsystem and provide at least 20mA at 3.3 +- 0.3V to the Control Subsystem

6.4.2 Verification

To verify that the output voltage is consistent with the requirements of the Power Subsystem, we measured the voltage at test pins with a multimeter during operation.

Operation	**Hub Board 5V Pin**	**Hub Board 3V3 Pin**	**Sensor Board 5V Pin**	**Sensor Board 3V3 Pin**
Calibration/Warmup	4.99V	3.30V	4.98V	3.31V
Idle	4.98V	3.30V	4.98V	3.30V

6.5 Control subsystem

6.5.1 Requirement

The Control subsystem for both boards must be able to send/receive data from a distance of at least 20 meters and send/receive data with a delay time of within 10 seconds.

6.5.2 Verification

We separated the hub and sensor boards until they stopped transmitting new values, and finding a distance of around 30 meters with multiple walls in between was a practical estimate for the range. We tested delay time by putting our hand in front of the distance sensor to time the response. We found that the delay corresponded to roughly less than/around a second, too little to time precisely but more than meeting our criterion.

7 Cost & Schedule

7.1 Cost Analysis

7.1.1 Labor Costs

After looking at salaries for internships and jobs for our education and skill levels, we have determined that our hourly pay would be about $50 per hour. We have about 8 weeks that we will be working approximately 12 hours per week on the project. This equates to 96 hours per person, or 288 hours total. At a wage of $50/hour the total labor cost would be about $14,400.

7.1.2 Part Costs

Part	Quantity	Cost
ESP32-S3-WROOM-1- N16R2	3	3 x $2.50ea = $7.50
10u (106) Capacitor	6	6 x $0.35ea = $2.10
1u (105) Capacitor	12	12 x $0.50ea = $6.50
100n (104) Capacitor	6	6 x $0.40ea = $2.40
100k Resistor	12	12 x $0.10ea = $1.20
10k Resistor	24	24 x $0.10ea = $2.40
1k Resistor	12	12 x $0.10ea = $1.20
ss8050-g BJT NPN	6	6 x $0.29ea = $1.74
3.3V voltage regulator	3	3 x $1.10ea = $3.30
Barrel Jack or USB micro connector	3	3 x $0.30ea = $0.90
Wall Plug	3	3 x $8.00 = $24
LED	1	$0.25
Nextion 5.0 Intelligent HMI Display	1	$68.99
DHT22/AM2302 Digital Temperature and Humidity Sensor	2	2 x $5.90ea = $11.80
ZMOD4410 gas sensor	2	2 x $4.79 = $9.58
Ultrasonic Distance Sensor - HC-SR04	2	2 x $2.50 = $5.00

7.1.3 Total Cost

The total cost of the parts is $148.86. With the labor costs at $14,400, this brings the grand total to $14,548.86.

7.2 Schedule

Week of 2/26	• Design Review with Instructor and TAs • Finalize design for first PCB Order • PCB Review
Week of 3/4	• Order PCB • Order Wall plugs and jacks • Teamwork Evaluation • Finish UI design for screen and test functionality Independently
Week of 3/11	• Spring Break
Week of 3/18	• Solder PCB and test functionality • Identify any issues with the PCB to fix • Redesign and Reorder PCB if necessary
Week of 3/25	• Solder PCB and test functionality • Identify any issues with the PCB to fix • Redesign and Reorder PCB if necessary • Individual progress report
Week of 4/1	• Solder PCB and test functionality • Identify any issues with the PCB to fix • Redesign and Reorder PCB if necessary • Design and 3D print housings for both sensor and hub components
Week of 4/8	• Finalize any issues with the software • Clean up and comment code • Prepare for demo
Week of 4/15	• Mock Demo with TA • Team contract fulfillment • Begin final paper writing
Week of 4/22	• Final Demo With Instructor and TAs • Mock Presentation with Comm and ECE Tas
Week of 4/29	• Final Presentation • Submit Final Paper • Turn in all checked out materials • Turn in Lab Notebooks

8 Conclusion

8.1 Accomplishments

Our project successfully fulfilled all of its high-level requirements and would be capable of performing its intended function in a real-world restaurant setting. Both of our PCB designs worked as intended; all of the sensors on the sensor hubs could accurately detect the desired qualities of the trash can (level of trash, air quality, temperature, and humidity), while the ESP32s on both boards were consistently capable of collecting, processing, and displaying this data on the central hub's LCD screen almost in real time. Importantly, the sensor tags could send data to the central hub through walls and over large distances of around 50 meters or more, which indicates that this system could be deployed successfully even in large restaurants. We were also able to make professional packaging for all the components of the project which improves their appearance and protects them against the harsh environment they would be exposed to inside trash cans.

8.2 Ethics and Safety

In order to maintain proper ethics and safety standards while building this waste management system, we are pledging to adhere to the IEEE code of ethics; specifically section II which states: "To treat all persons fairly and with respect, to not engage in harassment or discrimination, and to avoid injuring others."[6]

8.3 Ethical Concerns

Privacy of users is paramount with any technological device, and ours is no different. With wireless connections and data streaming, the sensors could be modified to be a recording device. When designing the device we will follow the IEEE code of ethics section 1.1 which says: "to strive to comply with ethical design and sustainable development practices, to protect the privacy of others, and to disclose promptly factors that might endanger the public or the environment"[6]. We will make sure users of the device know what data will be tracked and not collect any sensitive data.

8.4 Safety

8.4.1 OSHA and Illinois Department of Health Safety Standards

Our project should help facilitate a more healthy restaurant environment by eliminating overflowing cans. It should be clear that our project is only a tool and means for notification when a trashcan should be emptied, it should not be used as a rule of when to change out the trash. Good human judgment should have the final say as letting waste fester for long periods of time can be dangerous to employees and customers. According to the Illinois Department of Health[7], garbage cans should be emptied at least once a day, preferably right after closing. Workers should always be considerate of their customers and produce a safe environment for visitors.

Additionally, OSHA's safety standards with regards to waste containers should be followed as well. "Receptacles constructed of smooth, corrosion resistant, easily cleanable, or disposable materials, shall be provided and used for the disposal of waste food. The number, size, and location of such receptacles shall encourage their use and not result in overfilling."[8]

8.4.2 Safety Concerns

Our primary safety concern that arose in our design process was the possibility of waste and liquid splashing up on our sensor when people throw trash in the can. This can be a safety hazard as water could damage our circuits and in a worst case scenario, hurt someone. To protect against this, we will be creating a housing for the sensor unit so the PCB and its components will be protected from splashing water.

Another safety concern we should consider is the weight of the trash bag. OSHA recommends that workers do not lift more than 51 pounds[9] at a time to avoid injury. It is hard to measure weight when our device will only be able to calculate volume, so a weight sensor may be a good addition to the sensors we are creating.

8.5 Future Work

We created a project that we feel is marketable to restaurant owners and staff, given the specific issue it targets and its focus on increasing efficiency and saving time for restaurant workers. Any more features that we add would have to be carefully balanced to avoid adding any setup difficulty or maintenance requirements to the end product, due to the possibility of making the product more trouble than it is worth.

In the end, we settled on a few things that could potentially be improved upon. For example, we could likely make the space usage on the layout even more efficient, reducing the form factor of the sensor tags so that they are even less likely to get in the way of trash. Another potential improvement we considered was adding a small battery system to act as a buffer in case of a power outage. Lastly, the major improvement we would want to focus on for future work would be to alter the UI so that it supports more than 2 trash cans (the current UI doesn't feature a scroll bar or menu that would allow you to monitor more than two).

9 R/V Tables

9.1 Microcontroller Subsystem (Central Hub)

Requirement	Verification
Must be able to receive data from the sensor tag microcontroller subsystem within 10 seconds.	1. Power on central hub and tag. 2. Update the value from the sensor tag by placing an object in front of the ultrasonic sensor. 3. Measure response time and verify it takes less than 10 seconds to update data.

9.2 Microcontroller Subsystem (Sensor Tag)

Requirement	Verification
Must be able to send accurate data to the hub microcontroller subsystem within 10 seconds.	1. Power on central hub and tag. 2. Update the value from the sensor tag by placing an object in front of the ultrasonic sensor. 3. Measure response time and verify it takes less than 10 seconds to update data.

9.3 Power Subsystem (Central Hub)

Requirement	Verification
The Power Subsystem must be able to provide at least 1.0A at 5 +- 0.35V to the User Interface Subsystem.	1. Connect the central hub system to power and ensure all subsystems are connected to the power subsystem. 2. Verify that the LCD Screen is powered and is updating properly. 3. Using a multimeter, measure the output voltage of the 5V pin, and verify it is within tolerances. 4. Disconnect other subsystems from the 5V power pin, connect resistors with a total rating of at least 5.35 Watts from the 5V output to GND. 5. Using a multimeter, measure voltage across the resistor to verify at least 1 A is being passed through the resistor. 6. Disconnect the circuit and verify the value of the resistor with the multimeter.
The Power Subsystem must be able to provide at least 80mA at 3.3 +- 0.3V to the Control Subsystem..	1. Connect the central hub system to power and ensure all subsystems are connected to the power subsystem. 2. Verify that the LCD Screen is powered and is updating properly. 3. Using a multimeter, measure the output voltage of the 3V3 pin, and verify it is within tolerances. 4. Disconnect other subsystems from the 3V3 power pin, connect resistors with a total rating of at least 0.29 Watts from the 3V3 output to GND. 5. Using a multimeter, measure voltage across the resistor to verify at least 80mA is being passed through the resistor. 6. Disconnect the circuit and verify the value of the resistor with the multimeter.

9.4 Power Subsystem (Sensor Tag)

Requirement	Verification
The Power Subsystem must be able to provide at least 25mA at 3.3 +- 0.3V to the Control Subsystem	1. Connect the central hub system to power and ensure all subsystems are connected to the power subsystem. 2. Verify that the LCD Screen is powered and is updating properly. 3. Using a multimeter, measure the output voltage of the 3V3 pin, and verify it is within tolerances 4. Disconnect other subsystems from the 3V3 power pin, connect resistors with a total rating of at least 90 mW from the 3V3 output to GND 5. Using a multimeter, measure voltage across the resistor to verify at least 25mA is being passed through the resistor. 6. Disconnect the circuit and verify the value of the resistor with the multimeter.
The Power Subsystem must be able to provide at least 20mA at 5V +- 1V to the Sensor Subsystem.	1. Connect the central hub system to power and ensure all subsystems are connected to the power subsystem. 2. Verify that the LCD Screen is powered and is updating properly. 3. Using a multimeter, measure the output voltage of the 5V pin, and verify it is within tolerances 4. Disconnect other subsystems from the 5V power pin, connect resistors with a total rating of at least 102 mW from the 5V output to GND 5. Using a multimeter, measure voltage across the resistor to verify at least 20mA is being passed through the resistor. 6. Disconnect the circuit and verify the value of the resistor with the multimeter.

9.5 Sensor Subsystem

Requirement	Verification
The Sensor Subsystem must be able to provide distance values accurate to +- 5 cm when trash is within 80 cm of the sensor	1. Power on all systems, measure a 50cm distance from ultrasonic sensor input 2. Place objects at distances in increments of 10cm from 0-80cm, and take 2-3 measurements of each distance from the hub output, verifying that they are within the error range. 3. Recalibrate sensor if necessary.
The Sensor Subsystem must be able to provide temperature values accurate to +- 1 C at temperatures between 4-28 C (reasonable indoor temperatures)	1. Power on all systems, place a thermometer next to the sensor tag. 2. Measure room temperature and compare value to a thermometer, verify within error. Recalibrate voltage difference from sensor if necessary. 3. Place tag and thermometer within enclosure/cardboard box, Raise temperature using either blow dryer or heat gun from soldering station (low setting). 4. Measure temperature and compare value to the thermometer, verify within error. Recalibrate Voltage difference in sensor if necessary.
The Sensor Subsystem must be able to provide humidity values accurate to +- 5% RH within the 0-100% RH range.	1. Power on all systems, place a hydrometer next to the sensor tag. 2. Measure humidity values and compare them with the hydrometer. Adjust voltage difference in sensor if necessary.
The Sensor Subsystem must be able to provide indicators of when there is a smell. The gas sensors should show an increase in analog voltage level (relative to the healthy-air calibration level) of at least 100 on a 0-to-4095 scale when exposed to elevated CO_2 levels from, for example, exhaled air.	1. Power on all systems, place the sensor tag within an enclosure(e.g. a small box). 2. Verify that the hub screen shows a low analog voltage reading from the gas sensor corresponding to the healthy-air calibration level. 3. Exhale into the cardboard box, raising the CO2 level near the sensor tag. 4. Verify that the hub screen has displayed a change in air quality, with an increase of at least 100 in the 0-to-4095 analog voltage reading relative to the calibration level.

References

[1] DIODES. “”LOW DROPOUT LINEAR REGULATOR”.” (), [Online]. Available: https://www.diodes.com/assets/Datasheets/AZ1117C.pdf (visited on 04/16/2024).

[2] Sparkfun. “”Ultrasonic Ranging Module HC - SR04”.” (), [Online]. Available: https://cdn.sparkfun.com/datasheets/Sensors/Proximity/HCSR04.pdf (visited on 02/03/2024).

[3] Sparkfun. “”Digital-output relative humidity temperature sensor/module”.” (), [Online]. Available: https://www.sparkfun.com/datasheets/Sensors/Temperature/DHT22.pdf (visited on 02/03/2024).

[4] Olimex. “”TECHNICAL DATA MQ-135 GAS SENSOR”.” (), [Online]. Available: https://www.olimex.com/Products/Components/Sensors/Gas/SNS-MQ135/resources/SNS-MQ135.pdf (visited on 04/16/2024).

[5] EPA. “”Frequent Questions about Landfill Gas”.” (), [Online]. Available: https://www.epa.gov/lmop/frequent-questions-about-landfill-gas#:~:text=Project%20Development%20Handbook.-,What%20components%20make%20up%20landfill%20gas?,trace%20amounts%20of%20inorganic%20compounds (visited on 04/30/2024).

[6] IEEE. “”IEEE Code of Ethics”.” (), [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html (visited on 02/16/2024).

[7] I. D. of Health. “”Food Safety”.” (2016), [Online]. Available: https://dph.illinois.gov/topics-services/food-safety.html (visited on 02/07/2024).

[8] OSHA. “”OSHA 1910.141 - Sanitation.”” (), [Online]. Available: https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.141#:~:text=They%20shall%20be%20emptied%20not,without%20use%20of%20a%20cover (visited on 02/16/2024).

[9] OSHA. “”OSH Act: Section 5(a)(1)”.” (), [Online]. Available: https://www.osha.gov/laws-regs/standardinterpretations/2013-06-04-0#:~:text=The%20lifting%20equation%20establishes%20a,easy%20it%20is%20to%20holdr (visited on 02/16/2024).