ECE 445

SENIOR DESIGN LABORATORY

DESIGN DOCUMENT

Waste Bin Management System

Team #1

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1 Introduction

1.1 Problem

Restaurants produce large volumes of waste every day which can lead to many problems like overflowing waste bins, smelly 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 such as flies, roaches, or rodents building up from a forgotten trash can, 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.

1.2 Solution

Our project will have two components: 1. distributed sensor tags on the trash can, and 2. A central hub for collecting data and displaying the state of each trash can. 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 have 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. The hub will also need to be connected to the restaurant's WiFi. 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.

1.3 Visual Aid
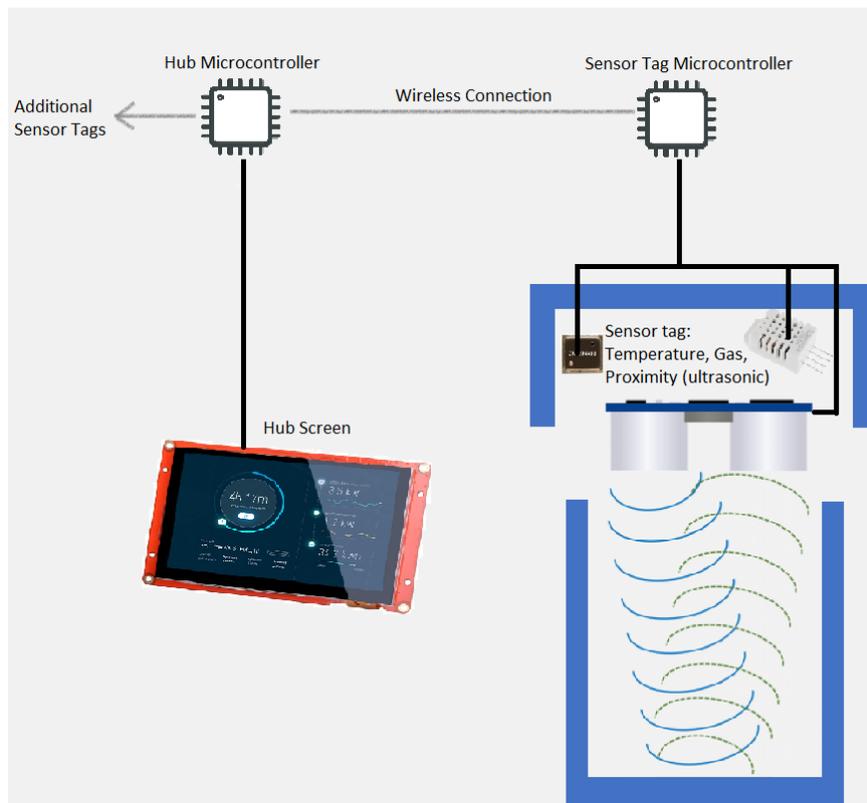
Figure 1: Visual Aid

1.4 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.

2 Design

2.1 Block Diagram
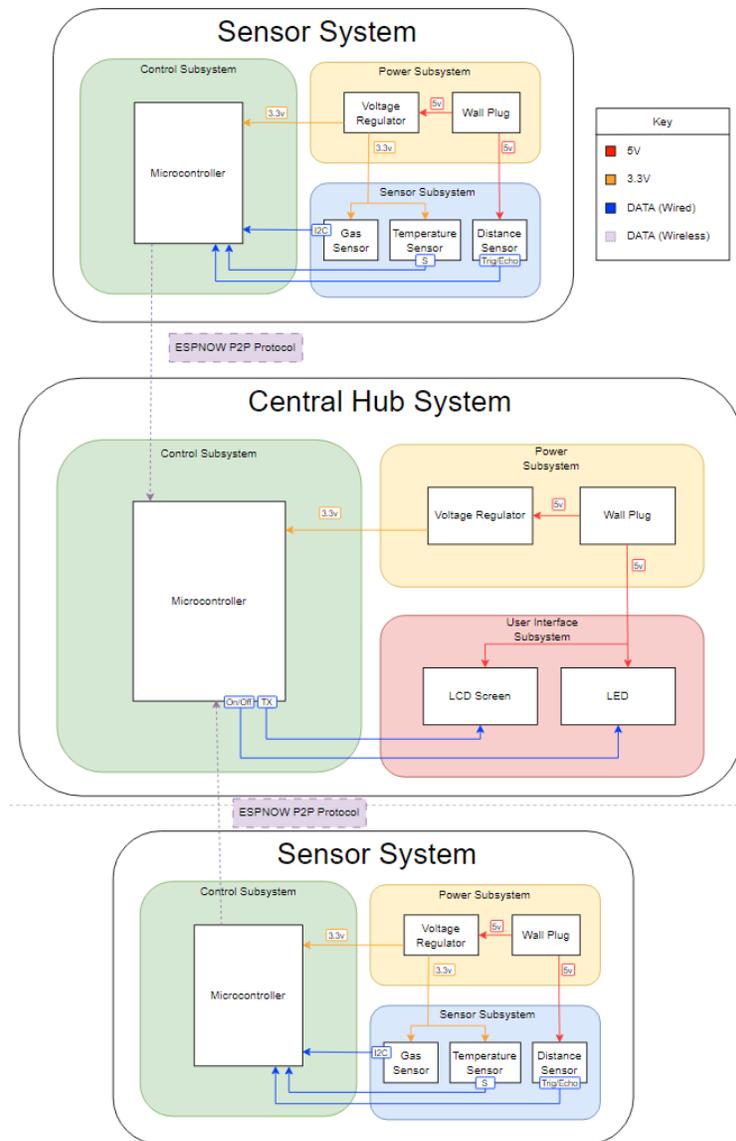
Figure 2: Block Diagram

2.2 Physical Design
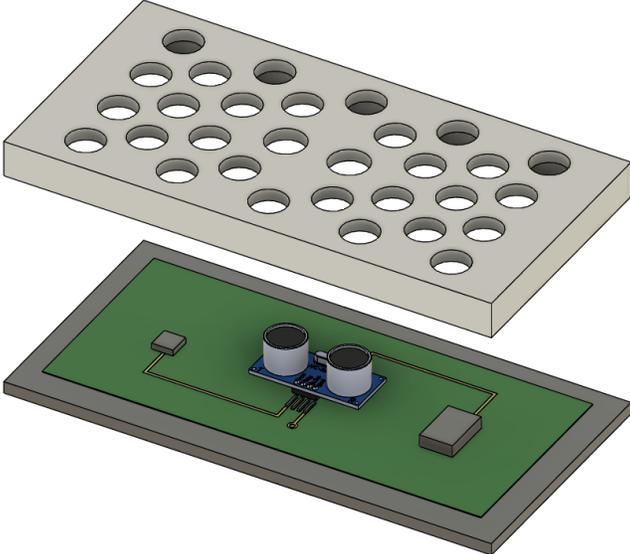
Figure 3: Sensors in tag
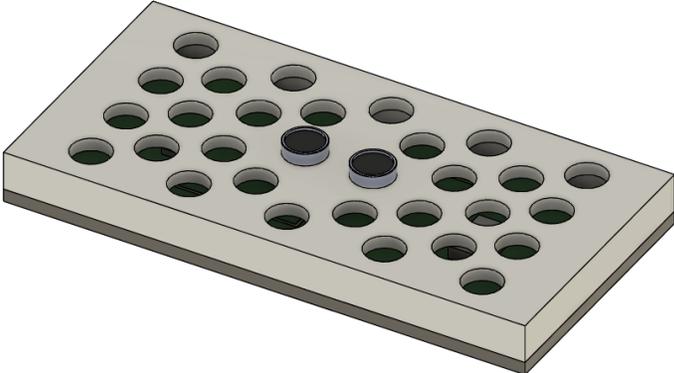
Figure 4: Sensors with Cover
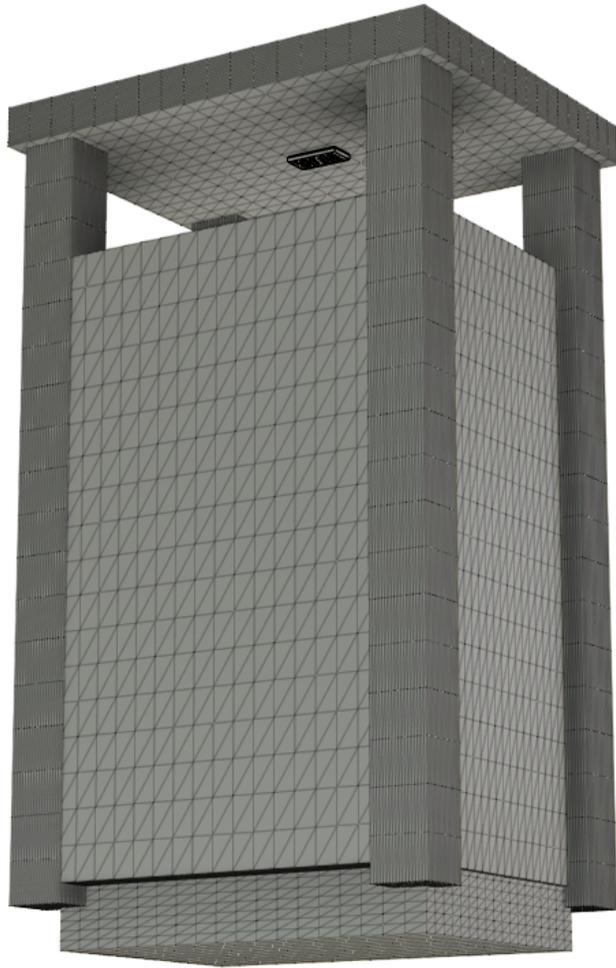
Figure 5: Sensor Component mounted on Trash can

2.3 Subsystem Overview

2.3.1 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.

2.3.2 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.

2.3.3 Sensor Subsystem

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

2.3.4 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.

2.4 Subsystem Requirements

2.4.1 Microcontroller Subsystem (Central Hub)

The Microcontroller Subsystem for the Central Hub must be able to receive data from the sensor tag through ESP-now at least once per minute and update the information on the LCD screen (user interface system) in a timely manner. If the microcontroller subsystem is unable to meet this requirement, then information will not be displayed to the user and the subsystem would fail to function.
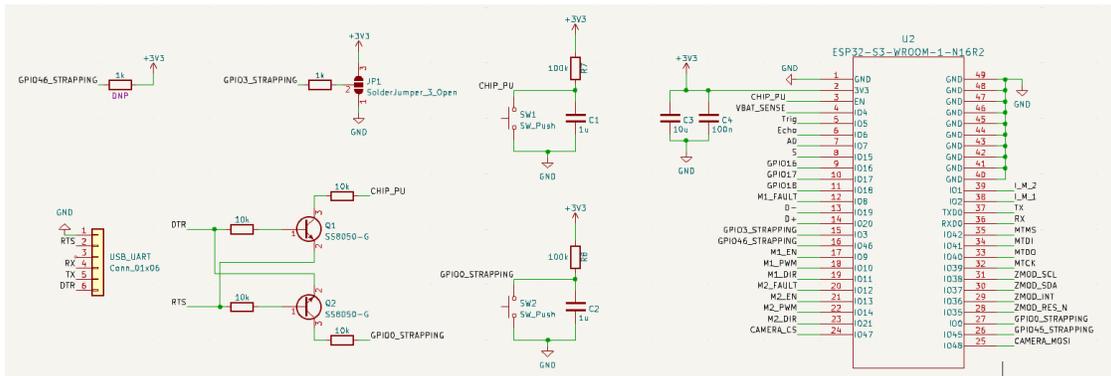
Figure 6: Microprocessor and programming Schematic

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.

2.4.2 Microcontroller Subsystem (Sensor Tag)

The Microcontroller Subsystem for the tags must be able to receive data from the sensor subsystem and transmit it to the Central Hub's microcontroller subsystem in a timely manner. If the microcontroller subsystem is unable to meet this requirement, then information will not be displayed to the user and the subsystem would fail to function. See Figure 6 above for the schematic.

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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.

2.4.3 Power Subsystem (Central Hub)

The Power Subsystem for the Central Hub must be able to supply adequate power to the screen directly from the 5V wall plug and adequate 3V3 power to the ESP-32. This subsystem provides power to the microcontroller (control subsystem) and LCD screen/Flashing Indicator (user interface subsystem). Failing to provide power to either would make the entire system fail.
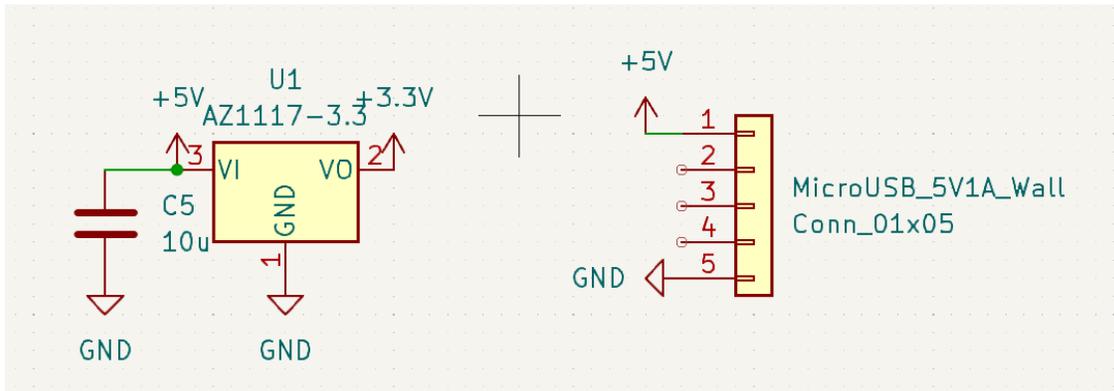

Figure 7: Power and Voltage Regulator Schematic

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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.

2.4.4 Power Subsystem (Sensor Tag)

For the tag, the Power Subsystem would need to supply 3V3 power to the ESP-32, and 5V power to the sensor subsystem through the wall plug. This subsystem provides power to the microcontroller (control subsystem) and the three sensors (sensor subsystem). A failure to power the sensors would result in erroneous or no data from the sensor tag, and a failure to power the sensor subsystem would cause the entire sensor tag to stop sending data to the central hub system. See Figure 7 above for the schematic.

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.

2.4.5 Sensor Subsystem

The DHT22[1] must provide temperature values from -40~80 +- 0.5C when queried at least once every minute, and the ZMOD4410[2] must be able to indicate high concentrations of TCOV contamination/air quality with an observable difference in different settings. The ultrasonic sensor[3] must be able to detect the level of trash to an accuracy of +- 5cm when the trash is within 80 cm from the top of the trash can, with this limit subject to the dimensions of the can.
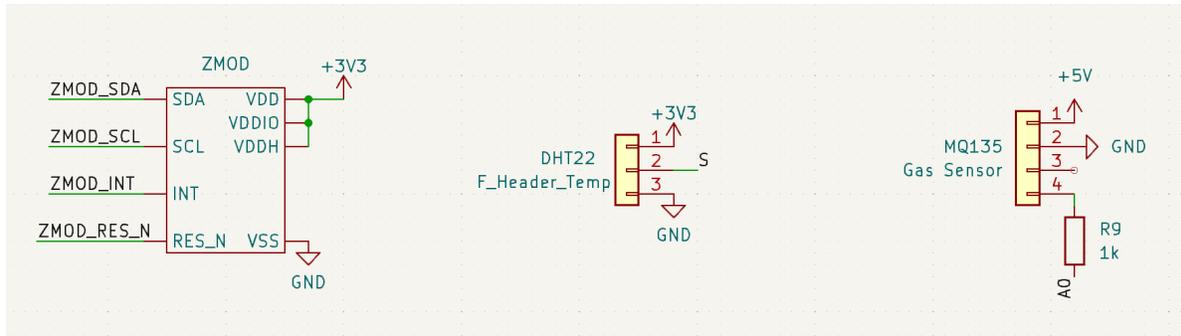
Figure 8: Power and Voltage Regulator Schematic

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, displaying a low gas quality warning($>=4$ air quality index)[2] on the hub screen when there is an odor or high concentrations of CO2 nearby.	1. Power on all systems, place the sensor tag within an enclosure(e.g. a small box). 2. Verify that the hub screen displays a normal air quality ($<=3$ air quality index)[2]. 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 one level of air quality index.

2.4.6   User Interface Subsystem

The user interface subsystem in the hub, composed of the LCD screen, must be able to display and update values sent to it by the control system. It must be capable of simultaneously displaying values of multiple sensor tags and all their output values (including distance/fullness, temperature, humidity, and air quality).

2.5   Tolerance Analysis

Our design presents several tolerance issues. We chose to focus on those listed below:

1. The ultrasonic sensor system used to detect the trash level may detect the sides of the trash can, which would be interpreted as an erroneously high level of trash.

2. The ultrasonic sensor may experience a large error in successive distance measurements.

3. The components on the sensor tag using 3.3V may draw too much current from the voltage regulator, causing it to overheat and eventually fail.

To address the first issue, we must consider the beam angle of the ultrasonic sensors in relation to the dimensions of the trash can. The combination of these factors set an upper limit on the detectable level of trash, defined as the spherical surface, centered at the sensor tag, of the smallest possible radius to intersect a piece of trash of detectable size (dimensions on the order of centimeters):

$$L \lessapprox \frac{W}{2\sin{(\theta/2)}}$$

where L is the level of trash, W is the smallest width dimension of the trash can, and theta is the total beam angle of the sensor. This equation neglects less significant factors like the dimensions of the sensor tag and the spacing between the ultrasonic transmitter and receiver. Since these factors will produce errors on the order of one centimeter, and our allowable error for L is ±5 cm, the approximate formula above is sufficient. The lesser width of the trash can we considered in our design (a 13.2 gallon can) is 10 in (25 cm). Using this value and a beam angle of 75 degrees (from the datasheet of the ultrasonic sensors we are using), the upper limit on L would be 21 cm. The height of the trash can is 23.5 in (60 cm), so the sensor tag would be able to detect when the trash can is above about 65% full. If we find that a larger upper limit is necessary, we can find ultrasonic sensors with a narrower beam angle.

In practice, we found that the effective beam angle is much more narrow and distances could be measured all the way to the bottom of the can. This means the effective beam angle is less than 46 degrees. The most likely reason for this is that the ultrasonic sensor does not respond to the first received wavefront, but to a wavefront of a certain amplitude. Fortunately, this aspect of the sensor's design will allow us to detect a level of trash all the way to the bottom of the can.

Regarding the second issue, a Sparkfun ultrasonic sensor module similar in design to the subsystem we will be building claims a minimum distance error of 0.3 cm.[1] However, past experiences with ultrasonic sensor modules have demonstrated single-measurement distance fluctuations of several centimeters. This error can be reduced by making multiple measurements in succession and calculating the mean or median value. We will also need to be careful to consider delays present in the circuitry, the microcontroller, and possible variations in the speed of sound with temperature to produce a reading with the desired accuracy (±5 cm).

The third issue requires the calculation of the maximum amount of current which would theoretically be drawn by the 3.3V components on the sensor tag. This value must then be compared to the current rating of our chosen voltage regulator. The expected temperature of the regulator can also be calculated at this current. The table below collects the typical current drawn by every 3.3V component in the circuit. Passive components were excluded as they will draw a negligible amount of current compared to the active components.

Component	Typical Current Draw [mA]	Comments
ESP32	~200[5]	Rough average of work modes used in our setup.
ZMOD4410	16.4[3]	
DHT22	1.5[2]	
Total	217.9	

The voltage regulator we will be using (TO-252-3 AZ1117CD-3.3TRG1) has the following ratings[6]:

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

From the maximum output current rating, it is clear that the maximum current draw is far below the maximum rating (about 16%). Assuming a maximum operating ambient temperature of 40 °C, an input voltage of 5V, and an output of voltage of 3.3V, the maximum junction temperature of the voltage regulator would be:

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

This is well under the maximum junction temperature rating (150°C from the above table) of the voltage regulator. Furthermore, since the voltage regulator will be dissipating heat through the PCB's ground plane, and the ESP32 doesn't consistently draw 200 mA, the actual temperature of the junction will likely be somewhat lower.

3 Cost Schedule

3.1 Cost Analysis

3.1.1 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.

3.1.2 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

3.1.3 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.

3.2   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

4   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."[4]

4.1 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"[4]. We will make sure users of the device know what data will be tracked and not collect any sensitive data.

4.2 Safety

4.2.1 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[5], 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."[6]

4.2.2 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[7] 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.

References

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

[2]   Renesas. “”ZMOD4410 Gas Sensor Module for TVOC and Indoor Air Quality”.” (), [Online]. Available: https://www.renesas.com/us/en/document/dst/zmod4410-datasheet (visited on 02/03/2024).

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

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

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

[6]   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).

[7]   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).