SpoilSense

ECE 445
Senior Design Laboratory
Design Document
Team 25

Azim Shad (azimms2)
Sarthak Shah (spshah8)
Vikram Harish (vharish3)

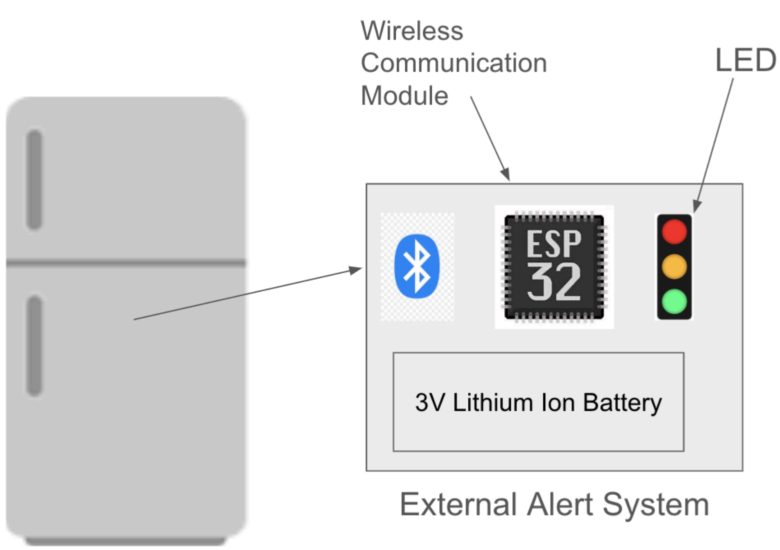
Introduction

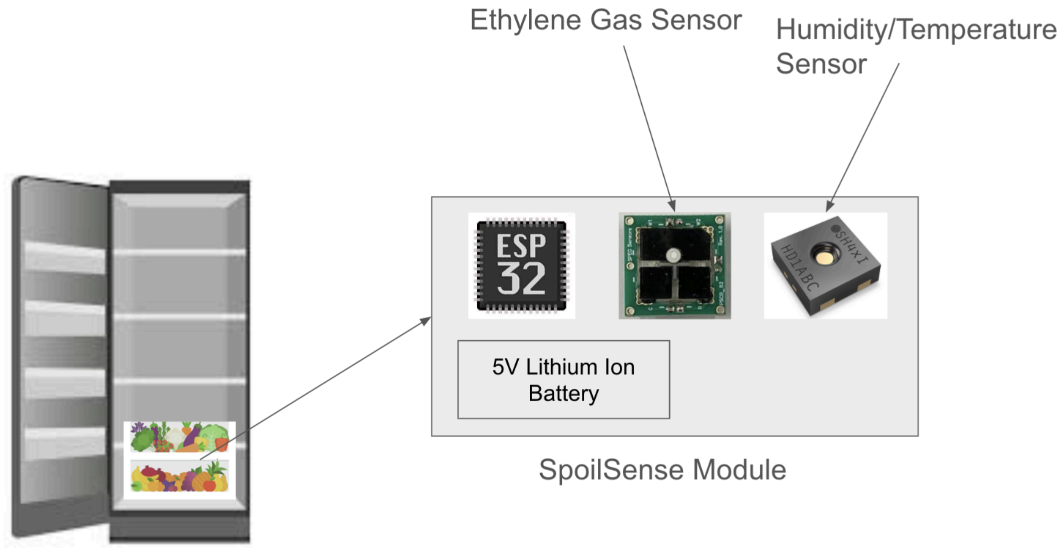
Problem and Solution

Maintaining the freshness of produce in household refrigerators is a persistent challenge faced by many individuals and families. Fruits and vegetables often go unnoticed at the back of the fridge until they become overripe or rotten, leading to unnecessary food waste, financial loss, and unpleasant odors that permeate the entire refrigerator. Spoiled produce emits various gasses that foster the growth of mold and bacteria, accelerating the decay of nearby fresh items and compromising the overall quality and safety of other stored foods. In the U.S. alone, an estimated 133 billion pounds of edible food—worth over $161 billion—goes to waste every year. Alarmingly, more than 80 percent of Americans discard perfectly good, consumable food simply because they misunderstand expiration labels (UNEP).

To address this pervasive issue, our project SpoilSense aims to develop a monitoring device that detects when produce inside a refrigerator is going bad. The system will utilize sensors to monitor humidity and detect ethylene gas emitted by spoiling fruits and vegetables. Once spoilage is detected, it will alert the user via wireless communication to an external LED indicator magnetically attached to the refrigerator's exterior. This solution automates the process of monitoring produce freshness, allowing households to take timely action to reduce food waste, maintain food quality, and save costs.

Visual Aid



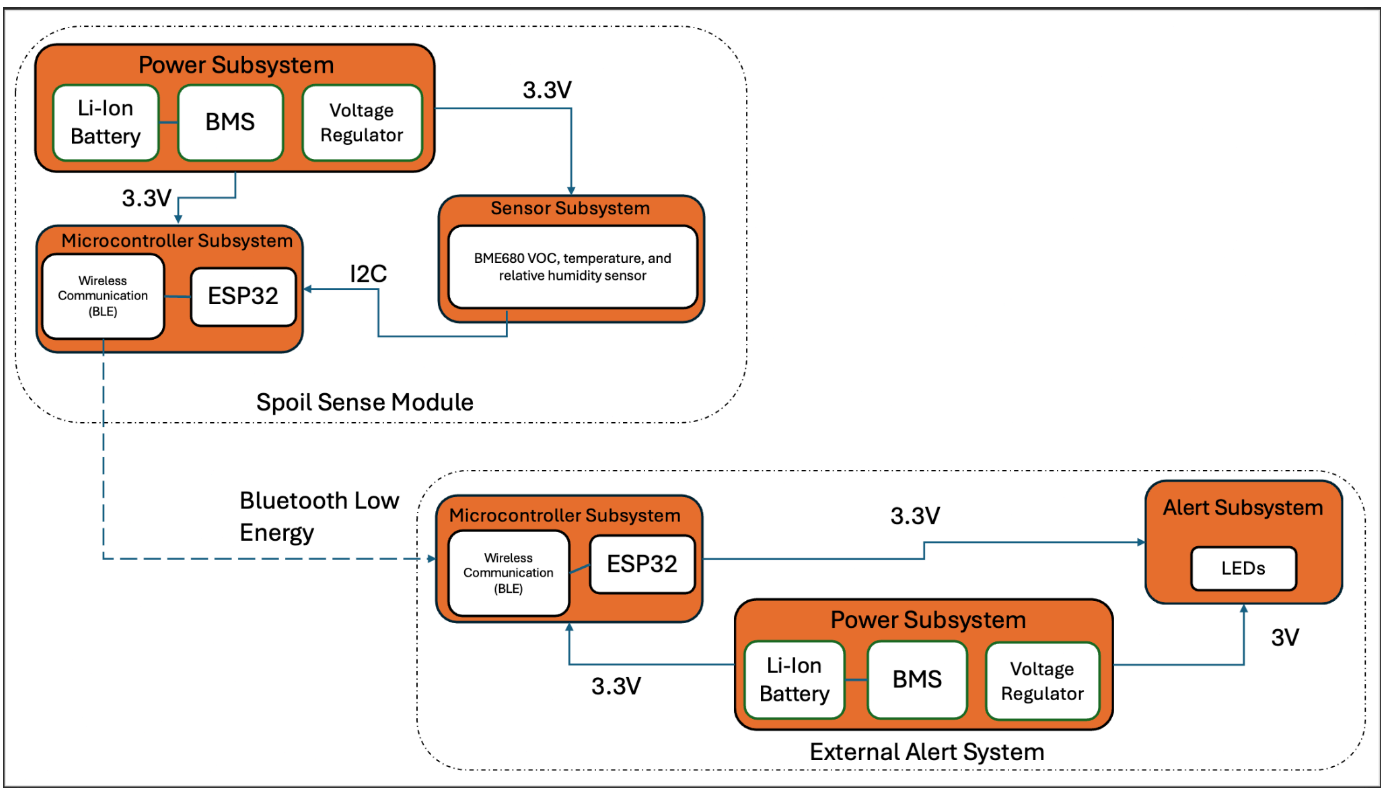


High-level Requirements

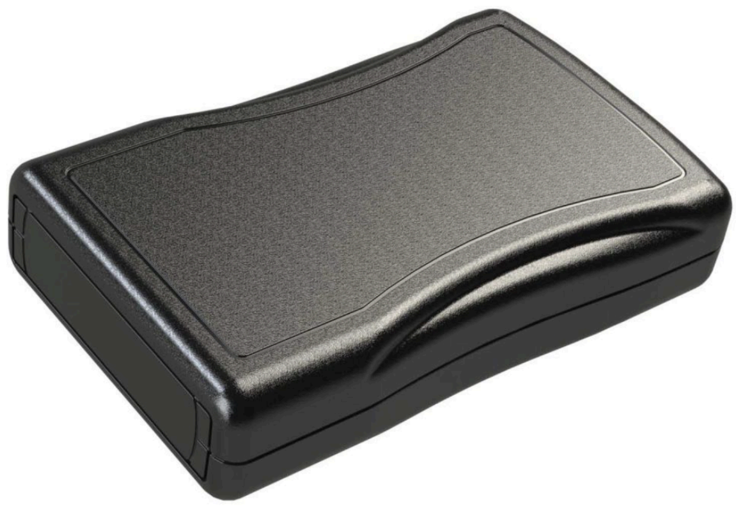
1. The module should be accurate in detecting the presence of VOCs (volatile organic compounds) up to a threshold of 3000 PPM for CH_4 and 50 PPM for NH_3 in order to trigger an alert.
2. The design should be capable of withstanding standard refrigerator temperatures and should maintain a form factor that is at most dimensions of 5 in x 4 in x 2 in.
3. The system must respond to detected ethylene gas concentration changes and trigger an alert within 30 seconds of the threshold being met.

Design

Block Diagram



Physical Design



SpoilSense Module

Sensor

The sensor subsystem is responsible for monitoring environmental conditions in the refrigerator's produce drawer. In particular, it is responsible for various volatile organic compounds and the relative humidity in order to mitigate potential spoilage. It consists of a BME680 VOC sensor, which measures relative humidity levels and the existence of various VOCs that are present in the air. The sensor is connected to the microcontroller via digital lines and triggers hardware interrupts when their respective thresholds are exceeded. The VOC sensor monitors relative humidity levels and detects VOC concentrations up to a threshold of 900 kOhms which gives a measure of the VOCs present. When these thresholds are met, the sensor sends data to the microcontroller for processing. If spoilage conditions are detected, the microcontroller initiates wireless communication to the external LED alert system. This subsystem enables real-time detection of spoilage, meeting the requirement for accurate detection of environmental conditions in the produce drawer. Furthermore, it interfaces with the microcontroller by sending sensor data via SPI and receives 3.3V from the power system.

Requirements	Verification
The BME680 VOC sensor should be able to accurately detect the presence of volatile compounds up to 900 kOhms with an accuracy of ±5%	To verify the VOC sensor's accuracy up to 900 kOhms with ±5% precision, set up a controlled test environment with some sort of spoiled food. We will conduct incremental tests at various concentrations, recording the sensor's readings to a serial console alongside the reference measurements, and calculate the percentage error for each level. Once we find a resistance value that indicates spoilage, that value will be our threshold for the microcontroller. Analyze the data to confirm that the sensor's readings consistently fall within the ±5% accuracy range across all tested concentrations.

Power

The power subsystem of the SpoilSense module is designed to supply energy to all components, ensuring long-term operation with minimal maintenance. It includes a battery that powers the sensors, microcontroller, and wireless communication system. A Battery Management System (BMS) is incorporated to regulate charging and discharging, protecting the battery from overcharging and ensuring safe operation. A voltage regulator ensures the correct voltage is supplied to the various components, providing 3.3V for the microcontroller and 3.3V for the sensors. This subsystem is critical to satisfying all of our high-level requirements as it powers the whole entire SpoilSense module and interfaces all the subsystems within it. This subsystem connects to the microcontroller and sensors as it provides 3.3V to the microcontroller and humidity and ethylene gas sensors.

Requirements	Verification
Must supply voltage to microcontroller within operating range of 3V - 3.3V	Measure voltage reading across terminals via oscilloscope, to verify it is within range. Save voltage readings for presentations.
Supply voltage to BME680 VOC sensor should range between 1.7 V - 3.6 V	Operating bias voltage range is 1.7 V - 3.6 V, so measure voltage readings across terminals via oscilloscope. Save voltage readings for presentation.

Microcontroller

The microcontroller subsystem of the SpoilSense module is the central processing unit that manages sensor data and coordinates wireless communication. It is responsible for collecting real-time data from the VOC sensor through digital communication protocols I2C and SPI, respectively. The microcontroller processes this data to determine whether spoilage conditions, such as high humidity or elevated VOC levels, have been met. Once spoilage is detected, the microcontroller triggers the external alert system by sending a wireless signal via Bluetooth Low Energy (BLE). The microcontroller is crucial for real-time monitoring and efficient wireless communication, ensuring timely notifications to the user through the external LED alert system. This subsystem manages the entire system, ensuring timely and efficient communication between the sensors and external alert system, fulfilling the high-level requirements for accuracy and timely response. In terms of interfaces, it receives 3.3V from the power subsystem and receives sensor data from the sensor subsystem via Inter Integrated Circuit (I2C). Finally, it communicates wirelessly with the External Alert System via BLE.

Requirements	Verification
Must process sensor data and trigger alerts	Create a controlled test environment where

within 30 seconds of spoilage detection.	spoilage conditions are simulated and detected by the sensors. Initiate the spoilage event and start timing simultaneously, then record the exact time when the alert is triggered by the system. Repeat this test multiple times to ensure reliability and account for any variations in processing time. Analyze the collected data to confirm that the system consistently processes the sensor input and issues alerts within the 30-second threshold, thus meeting the specified design requirement.
Must maintain a wireless communication through the door of the fridge with the external alert system, using BLE	Set up a controlled environment where the device and the alert system are placed at varying positions on either side of the metal barrier. At each position, conduct communication tests to assess successful pairing, data transmission reliability, signal strength, and latency, while recording any instances of dropped connections or errors. Ensure that external factors such as interference from other wireless devices, obstacles, and environmental conditions are minimized or kept consistent to accurately evaluate the BLE performance. Analyze the collected data to confirm that the device consistently maintains a stable and reliable BLE connection with the external alert system at a distance of 2 meters, thereby meeting the specified design requirement.

External Alert System

Alert

The alert component consists of 2 LED indicators which provide real-time visual alerts to the user, changing color based on spoilage or no spoilage, detected by the internal sensor. The LEDs are controlled by the microcontroller inside the external system which is wirelessly connected to the microcontroller of the SpoilSense module, receiving signals via Bluetooth Low Energy (BLE) when spoilage thresholds are met. The external alert system is designed to be power-efficient, requiring minimal energy to operate, and is visible enough to immediately catch the user's attention. Its magnetic housing allows for flexible placement on the refrigerator's exterior. The alert subsystem ensures users are promptly and clearly alerted to spoilage conditions, satisfying the requirement for effective notifications. This subsystem receives control signals from the microcontroller and power from the power subsystem in the external alert system.

Requirements	Verification
Must be able to accurately light the LEDs based on detecting a certain amount of VOCs (based on the threshold) or not in the subsystem. LED 1: no spoilage detected LED 2: spoilage detected	To verify that the system accurately changes LEDs based on the detected gas concentrations, conduct controlled tests by introducing known spoiled food. For each spoiled item, observe and record the LED that is lit by the system, ensuring it matches the expected LED for whether or not the food is spoiled. Pay special attention to the transition thresholds to confirm that the LED changes precisely at the specified points without delay. Document the testing procedures, observations, and results to confirm that the system reliably and consistently meets the design requirement of changing LEDs accurately based on the presence of spoiled food or not.

Power

The power subsystem of the external alert system provides energy to both the LED indicator and the microcontroller that manages wireless communication. It consists of a battery designed for long-term operation, ensuring that the alert system remains functional for extended periods without frequent changing. The subsystem includes a Battery Management System (BMS) to regulate power usage and optimize battery life. A voltage regulator is used to supply the necessary voltage to the LED and the microcontroller, typically providing 3.3V to the microcontroller and appropriate voltage to the LED for optimal brightness and functionality. This subsystem ensures continuous operation, meeting the requirement for good battery life in a continuously monitoring system. It connects to the external module microcontroller and alert subsystem LED supplying 3.3V to both.

Requirements	Verification

Must supply 3.3V ± 0.1V LED continuously.	Measure voltage via oscilloscope and record readings while performing tests.
Must supply voltage to microcontroller within operating range of 3V - 3.3V	Measure voltage via oscilloscope and record readings while performing tests.

Microcontroller

The microcontroller subsystem of the external alert system is responsible for receiving wireless signals from the microcontroller inside the SpoilSense module and triggering the LED alert accordingly. Using Bluetooth Low Energy (BLE), this microcontroller continuously waits for updates from the internal module for a signal containing the status of the in the fridge. Upon receiving a signal that spoilage conditions have been met, it processes the data and promptly activates the LED, instructing it to change color based on the severity of the detected spoilage. It plays a critical role in ensuring the timely and accurate display of alerts to the user, allowing for quick action to reduce food waste. Receives power from the internal module Power Subsystem and communicates wirelessly with the internal sensing module's microcontroller via BLE. It also controls the LED by sending signals to change the LED colors.

Requirements	**Verification**
Must maintain a wireless communication range across the door of the fridge.	To verify that the device maintains wireless communication through the fridge door, set up a controlled environment where the device and its corresponding receiver are placed at various positions on either side of the metal door. We will then conduct communication tests at each position, recording any instances of dropped connections or errors. We will ensure that external factors such as interference, obstacles, and environmental conditions mimic that of a standard refrigerator.
Must trigger alerts from the LED within 30 seconds of receiving signal from the internal module microcontroller.	To verify that the device triggers alerts from the LED within 30 seconds of receiving a signal from the internal module microcontroller, we will set up a controlled test environment where the microcontroller is programmed to send activation signals to the LED at predetermined times. We will use

	precise timing logs to measure the elapsed time between the microcontroller's signal transmission and the LED's alert activation. Multiple trials will be done to account for any variability, ensuring consistent refrigerator environmental conditions during testing. Analyze the recorded times to confirm that the LED consistently triggers alerts within the 30-second requirement, thereby validating compliance with the design specification.

Cost and Schedule

Cost

Part Name	Part Number	Manufacturer	Quantity	Cost
ESP32 Microcontroller	ESP32-S3	Esspressif Systems	2	$3.70

Plastic Casing	VM-24M19VMTT	PolyCase	2	$17.06
Magnetic Sticker	-	Homakover	1	$8.99
6V Lithium Ion Battery	DL-40	Dantona Industries	2	$15.09
LED	SSL-LX5097SISG SYC	Lumex Opto/Components Inc.	3	$13.21
Voltage Regulator	LM1117-5.0	Texas Instruments	2	$5.00
			Total Cost	$76.90

Category	**Estimated Hours**		
	Azim	**Sar**	**Vikram**
Circuit Design (SpoilSense Module)	8	8	6
Circuit Design (Alert System)	2	9	7
Soldering	12	12	8
Prototyping and Debugging	10	10	10

Documentation	5	5	5
Total Hours	**37**	**44**	**36**

All members of this group are Computer Engineering students. According to the Grainger College of Engineering's website on postgraduate success [6], the average starting salary for a Computer Engineering graduate is $118,752 per year , which equates to $57.09 per hour.

Based on the estimated total hours and the estimated hourly wage, the estimated total cost of labor for our project is $6,679.53. With the cost of our materials, the estimated total cost of the project is $6756.43.

Schedule

October 7th - October 14th:

- Finalize board schematic and design based on design document feedback
- Order sensors and parts for design prototype
- Research about microcontroller bluetooth communication

October 14th - October 21st:

- Continue ordering PCB parts
- Order PCB
- Finalize physical design with machine shop

October 21st - October 28th:

- Write software for microcontroller communication
- Write software for communication between microcontroller and sensors

October 28th - November 4th:

- Receive PCB parts and board
- Start assembly of 1st board
- Unit test software from previous week and develop as needed

November 4th - November 11th

- Get internal PCB working with detecting gas and turning on LED
- Debug hardware and software as needed
- Get 2nd PCB (external alert system) assembled and start debugging

November 11th - November 18th

- Get 2nd PCB working with wireless communication from internal module
- Finalize both modules
- Prepare for mock demo

November 18th - November 25th

- Wrap up loose ends and finalize components
- Mock demo

November 25th - December 2nd

- Fall Break

December 2nd - December 9th

- Final Demo
- Prepare final papers/presentation

December 9th - December 12th

- Final presentation
- Final paper

Tolerance Analysis

A potential risk to the project's success is in the power subsystem, regarding the reliability of the battery's long-term performance in maintaining a stable voltage supply for the microcontroller, sensors, and wireless communication components. Failures can arise if the battery is depleted faster than anticipated, which would lead to a system failure or dysfunctional components.Both the microcontroller and the sensor require an input of 3.3V, we want to maintain a low-power architecture so that we could achieve the goal of a robust and reliable design. The low power consumption architecture plays a significant role in the selection of components with low power modes and sleep modes to maintain low power. The microcontroller is chosen based on its ability to operate in low power modes, which will reduce the power draw when the device is not actively transmitting data or performing critical operations.

t The design must operate in refrigerator conditions and needs to monitor environmental conditions continuously. The approach is to implement a long-term operation where minimal maintenance is essential, hence the use of low power modes. Additionally, there will be measures to ensure tolerance levels remain (+/- 5%) under a typical load, which ensures the voltage regulator and battery management system can effectively maintain stable power delivery throughout operation. An additional risk is the effect of temperature on the battery. The power subsystem must be able to function in typical refrigerator temperatures, which can range from 2 C - 5 C. The components of our project are chosen such that they can withstand these conditions, as described below:

- Duracell Procell Battery:
  - -20 to 54 C
- ESP32:
  - -40 to 150 C
- Ethylene Sensor:
  - -30 to 55 C
- Humidity Sensor:
  - -40 to 125 C

Ethics and Safety

In regards to ethics and safety, our group is referring to the IEEE Code of Ethics to ensure we follow the standards adopted by the IEEE board of directors. We aim to hold ourselves to the following standards:

Transparency and Communication

All members of the development team aim to inform each other of any limitations or risks associated with the technology being developed. Members will disclose potential conflict of interest, technical limitations, and any other issues that may compromise the project’s integrity, which ensures everyone understands any implications involved. If there are any unforeseen safety or ethical concerns, all members must promptly inform the others to help ensure these concerns are promptly mitigated.

Continuous improvement and Accountability

Team members will regularly provide feedback on the technical aspects of each other's work to ensure continuous improvement. Members will be open to constructive criticism and address concerns as they arise. Each member will be responsible for completing any necessary training for technical components, and providing aid to other members if need be. Everyone will complete technical tasks within their capabilities, and transparently describe any limitations they face. Any necessary improvements in our design and technology will be addressed as a team.

Prioritizing Safety

The team will design and implement the technology with a focus on safety as a fundamental principle throughout the project's development. The team will conduct risk assessments to identify potential issues the product can have on users and the environment. Any potential risks that are deemed unsafe will be addressed as they arise, with an overall goal to prioritize the safety of the team, the product development, and for users of the product.

When addressing the safety of the various subsystems, we will implement the following safety procedures to ensure a safe and reliable working environment:

Power Subsystem Safety Procedure

Risk identification and protection: the team will implement general precautions to prevent possible short circuits. This will include but not limited to the following: overload protection, surge protection, proper grounding, insulation, component labeling, emergency shut down, regular monitoring.

Microcontroller Safety Procedure:

The team will ensure component protection by monitoring power and static electricity. There will be extra components in case of a system failure. Proper wiring and pin safety will be critical.

Sensor Safety Procedure:

Ensure regular calibration and proper mounting of the sensor. Follow the necessary documentation to account for all components, calibration and management of the sensor.

References

[1] United Nations Environment Programme. “Promoting Sustainable Lifestyles.” UNEP. https://www.unep.org/regions/north-america/regional-initiatives/promoting-sustainable-lifestyles (accessed September 19, 2024).

[2] IEEE. “”IEEE Code of Ethics”.” (2016), [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html (visited on 09/19/2024).

[3] LED OSTAR RGBY 625/525/453NM SMD, LE RTDCY S2WN, Ver. 1.11, OSRAM USA Inc., 2022. [Online] Available: https://www.digikey.com/en/products/detail/ams-osram-usa-inc/LE-RTDCY-S2WN-KBLA-1-MANA-P-AXAZ-3-LBMB-YS/9999359?s=N4IgjCBcoMwOxVAYygMwIYBsDOBTANCAPZQDaIMATAAwCsALAGwgC6hADgC5QgDKnAJwCWAOwDmIAL6EwATgAcsxCBSQMOAsTIhqrSdJCVtmXABM9QA

[4] INDUSTRIAL SENSOR HUMID/TEMP, SHT40I-AD1B-R3, Ver. 3.4, Sensirion AG, 2024. [Online] Available: https://www.digikey.com/en/products/detail/sensirion-ag/SHT40I-AD1B-R3/15792545

[5] Ethylene Gas Sensor, 110-65X Family, No Ver., No Year, [Online] Available: https://www.spec-sensors.com/product/c2h4-ethylene/

[6] Grainger Engineering “Illini Success: All-Campus Undergraduate Report.” Electrical & Computer Engineering | UIUC, 2022-2023,