SpoilSense

ECE 445
Senior Design Laboratory
Project Proposal
Team 25

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Introduction

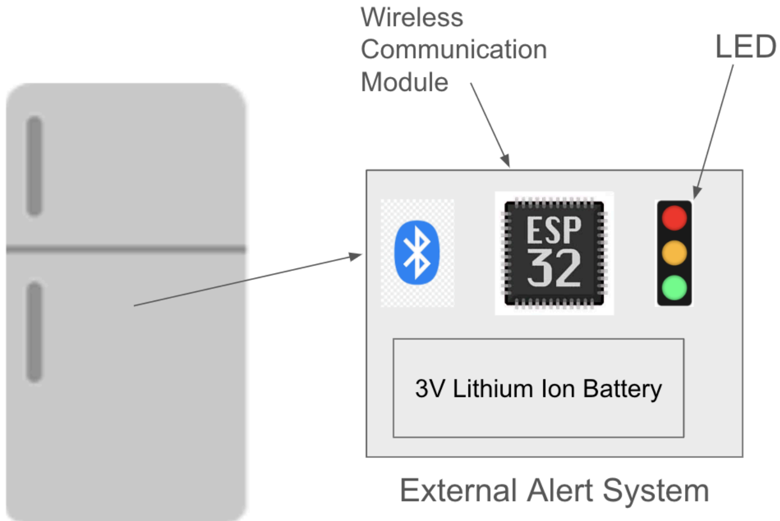
Problem

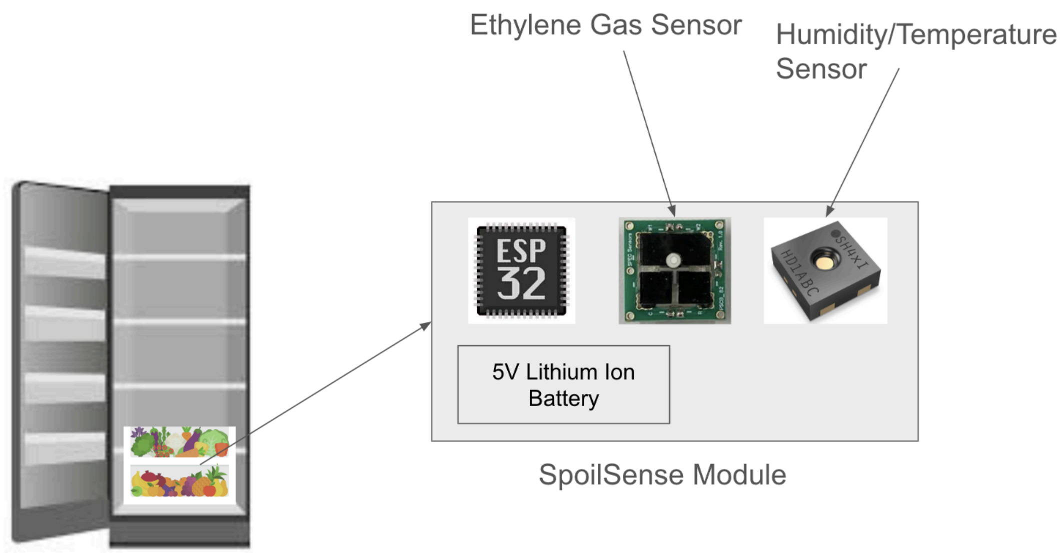
Maintaining the freshness of produce in household refrigerators is a common and persistent challenge faced by many individuals and families. Despite best efforts to consume food before it spoils, fruits and vegetables often go unnoticed at the back of the fridge until they become overripe or rotten. This not only leads to unnecessary food waste and financial loss but also creates unpleasant odors that can permeate the entire refrigerator. Moreover, spoiled produce can accelerate the decay of nearby fresh items by emitting ethylene gas and fostering the growth of mold and bacteria, thereby 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 (UNEP).

Solution

Our project aims to develop a monitoring device that can detect when produce inside a refrigerator is going bad. The system will utilize sensors to monitor humidity and detect ethylene gas, which is emitted by spoiling fruits and vegetables. Once spoilage is detected, the system will alert the user via wireless communication to an external LED indicator, which will be magnetically attached to the refrigerator's exterior. This solution will automate the process of monitoring produce freshness, allowing households to take timely action and reduce food waste, while also maintaining food quality and saving costs. More than 80 percent of Americans discard perfectly good, consumable food simply because they misunderstand expiration labels (UNEP).

Visual Aid



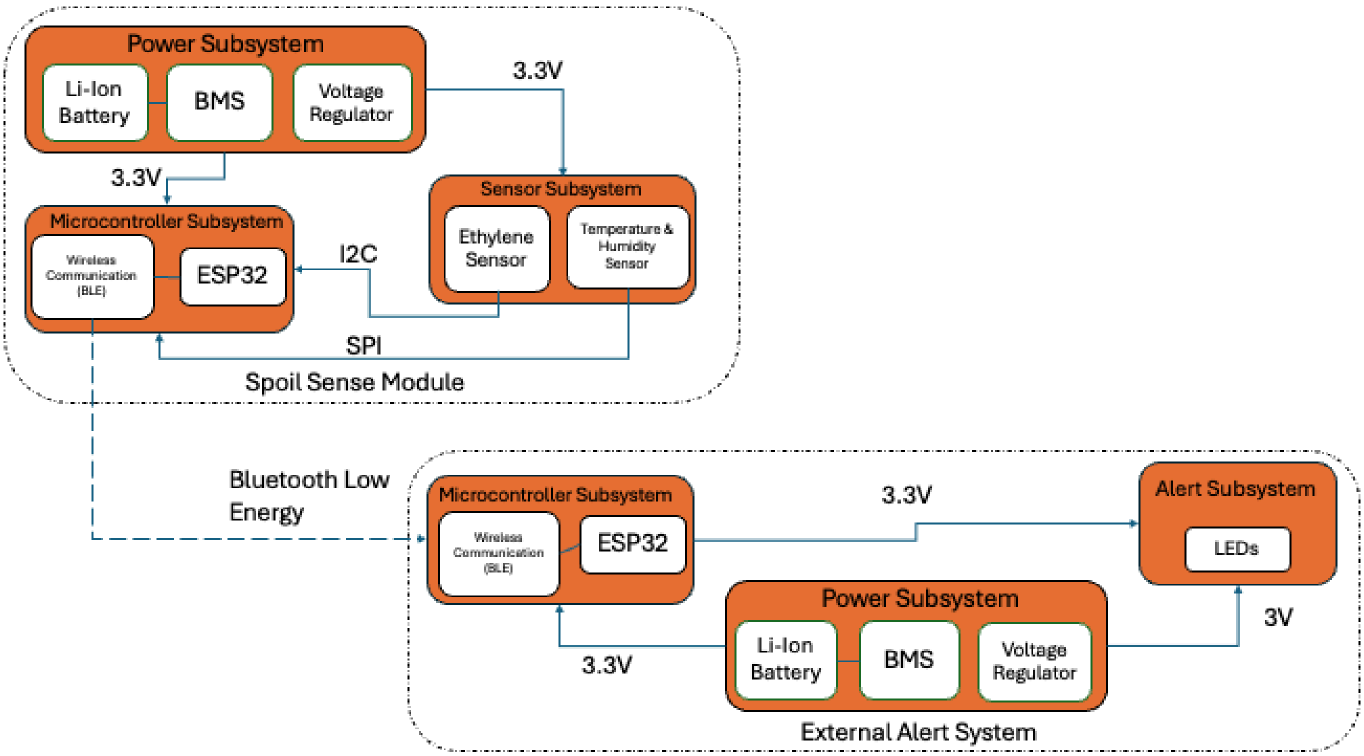


High-Level Requirements

1. The module should be accurate in detecting the presence of Ethylene gas up to a threshold of 100 ppm in order to trigger an alert.
2. Design should be durable and have a small form factor, less than 5in x 3in x 1in in order to withstand the fridge environment and not take up too much space in.
3. The system must respond to detected ethylene gas concentration changes and trigger an alert within 30 seconds of the threshold being met. The microcontroller should process sensor data in real time and communicate with the external alert system (LED).

Design

Block Diagram



Subsystem Overview

SpoilSense Module

Sensor:

The sensor subsystem is responsible for monitoring environmental conditions in the refrigerator's produce drawer to detect potential spoilage. It consists of a SHT40I-AD1B-R3 humidity sensor, which measures humidity levels, and a 110-65x ethylene gas sensor, which detects ethylene gas emitted by spoiling produce. Both sensors are connected to the microcontroller via digital lines and trigger hardware interrupts when their respective thresholds are exceeded. The humidity sensor monitors relative humidity levels, while the ethylene gas sensor detects gas concentrations. When these thresholds are met, the sensors send data to the microcontroller for processing. If spoilage conditions are detected, the microcontroller initiates wireless communication to the external LED alert system.

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.

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 humidity and ethylene gas sensors through digital communication protocols I2C and SPI, respectively. The microcontroller processes this data to determine whether spoilage conditions, such as high humidity or elevated ethylene 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.

External Alert System

Alert:

The alert component consists of an LED indicator which provides real-time visual alerts to the user, changing color severity of spoilage detected by the internal sensors. The LED is 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.

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, prevent overcharging, 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. The system's low power consumption ensures long battery life while supporting consistent performance.

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 about the status of the produce 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.

Subsystem Requirement

SpoilSense Module

Sensor:

1. Contribution:
    a. This subsystem enables real-time detection of spoilage, meeting the requirement for accurate detection of environmental conditions in the produce drawer.
2. Interfaces:
    a. Connects to the internal module **Microcontroller**: Sends data via SPI communication.
    b. Powered by the **Power Subsystem**: Receives 3.3V from the power system.
3. Requirements:

a. The humidity sensor must detect relative humidity in the range of **20%-90% RH** with an accuracy of **±5%**.
b. The ethylene gas sensor must detect gas concentrations within a range of **0 - 100 ppm**, with a detection accuracy of **±5%.**

Power:

1. Contribution:
    a. This subsystem ensures continuous operation, meeting the requirement for good battery life in a continuously monitoring system.
2. Interfaces:
    a. Connects to the internal module **Microcontroller**: Provides 3.3V power to the microcontroller.
    b. Connects to the **Sensors**: Supplies 3.3V to the humidity and ethylene gas sensors.
3. Requirements:
    a. Must supply **3.3V ± 0.1V** to the microcontroller and sensors continuously.

Microcontroller:

1. Contribution:
    a. 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.
2. Interfaces:
    a. Receives power from the **Power Subsystem** (3.3V).
    b. Receives sensor data from the **Sensor Subsystem** via SPI/I2C (depends on sensor).
    c. Communicates wirelessly with the **External Alert System** via BLE.
3. Requirements:
    a. Must process sensor data and trigger alerts within **30 seconds** of spoilage detection.
    b. Must maintain a wireless communication range of **2 meters** with the external alert system, using BLE

External Alert System

Alert:

1. Contribution:
    a. This subsystem ensures users are promptly and clearly alerted to spoilage conditions, satisfying the requirement for effective notifications.

2. Interfaces:
    a. Receives control signals from the external system **Microcontroller** .
    b. Receives power from the **Power Subsystem**.
3. Requirements:
    a. Must be able to accurately change colors based on the detected amount of gas in the subsystem
        i. Green light: 0 - 15 ppm
        ii. Yellow light: 15 - 50 ppm
        iii. Red light: 50 - 100 ppm

Power:

1. Contribution:
    a. This subsystem ensures continuous operation, meeting the requirement for good battery life in a continuously monitoring system.
2. Interfaces:
    a. Connects to the external module **Microcontroller**: Provides 3.3V power to the microcontroller.
    b. Connects to the **Alert**: Supplies 3.3V to the LED component
3. Requirements:
    a. Must supply **3.3V ± 0.1V** to the microcontroller and LED continuously.

Microcontroller:

1. Contribution:
    a. This microcontroller ensures timely visual alerts when spoilage is detected, fulfilling the high-level requirement for immediate user notification.
2. Interfaces:
    a. Receives power from the internal module **Power Subsystem**.
    b. Communicates wirelessly with the internal sensing module's microcontroller via BLE.
    c. Controls the **LED** by sending signals to change the LED colors.
3. Requirements:
    a. Must maintain a wireless communication range of **2 meters**.
    b. Must trigger alerts from the LED within **30 seconds** of receiving signal from the internal module microcontroller.

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. To understand the feasibility of the power supply, there were careful considerations in selecting the corresponding components in the system. Both the microcontroller and the sensor require an output of 3.3V, and considering the low power consumption approach in the system's design, the battery should sustain continuous operation. The low power consumption design plays a significant role in the selection of components with low power modes and sleep modes to conserve energy. 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. Similarly, the sensors also have low power modes. The design hopes to 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 & 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

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