Refrigerator Food Contamination Detection using Electronic Nose

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Introduction

1.1 Objective:

Food poisoning is a serious problem that affects thousands of people every year.Out of approximately 5000 total deaths reported in the United States every year, 1500 are caused by pathogens like Salmonella, Listeria and Toxoplasma. The World Health Organization (WHO) reports that salmonellosis caused by Salmonella spp. is the most frequently reported food borne disease worldwide [2]. Poisoning food must be detected early in order to prevent diseases. A lot of food gets wasted in developing countries or in tropical regions while getting transported from the farmlands to the markets, mainly because of improper intermediary storage techniques. This results in colossal amounts of post harvest losses that are incurred by the poor farmers or result in raised food prices to make up for the lost food. An early detection system can help prevent the rotting item from affecting the remaining produce. This will imply that food wastage is reduced and the prices associated with these goods don't skyrocket. Even in our households, we often forget about some food item stowed away in our refrigerator drawer hidden under other items, until it turns smelly and moldy, and needs to be disposed off. Having a device that detects this would be of great help in reducing such wastage. Not just in a household setting, an early food contamination detection system can find application in industrial refrigerators and storage units that cater to concentration of a single food item in refrigerators and incur losses due to spoilage of one element resulting in contamination of the entire unit.

Contaminated food is usually detected by odor which is composed of molecules of specific sizes and shapes with a corresponding receptor in the human nose. The brain identifies the smell associated with that particular molecule when signaled by the receptor. Electronic nose is an array of sensors that imitates this biological functionality.

Our goal is to build a modular electronic nose that can be fitted inside a refrigerator or any other closed food storage equipment and detect the onset of food spoilage. This early detection can then be notified to the user through an LCD screen, thereby allowing him to consume or dispose off the item, depending on its state. Concentration of certain gases and chemicals like CO_2, acetone, ethanol etc. increases because of rotten food and thus can be detected by the array sensors which are the heart of the design. Bluetooth modules situated on the electronic nodes and the central UI node will enable wireless communication and scalability of the setup.

1.2 Background:

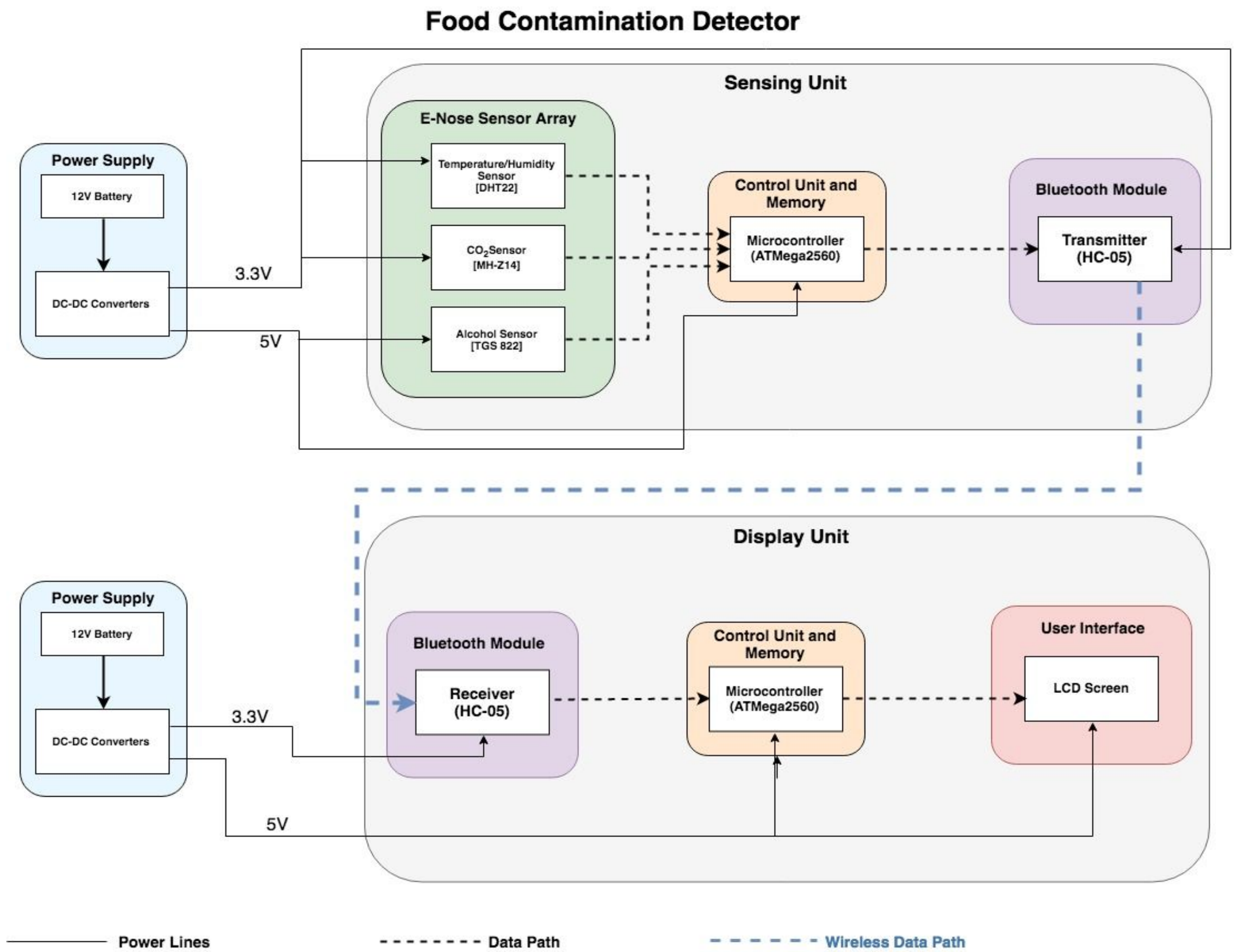
There is a niche market for electronic noses and the current market leader is the French company Alpha Mos which targets the very expensive, very high-performance laboratory equipment market. The relatively cheaper and more portable devices of Scensive Ltd (Bloodhound) and Smiths Detection (Cyranose models) frequently reported in academic literature are both based on conducting polymer arrays. All of the current devices are intended to strictly be used as laboratory instruments analogous to HPLC/GC's and spectrometers. All of these devices need to be individually calibrated for a particular application [6]. The company 'eNose' is working on a technology to build cheaper electronic noses but it is specific to medical industry and disease detection. There has been a lot of research in the industry to build electronic noses for food contamination detection but the white papers have targeted specific food items and the end products are expensive because of the price of the sensors being used in these experiments [5]. We are working on devising a modular, attachable and economical electronic nose system with a smoother user interface that can target the usual consumer markets and not just industries or laboratories.

1.3 High-Level Requirements:

- The e-nose detects the onset of food spoilage beyond a certain concentration of gases. We devise a threshold for this gas concentration based on experiments that we will conduct in the course of the build.
- The system should work under refrigerator temperature conditions (0°C - 10°C) as well as room temperature conditions (20°C - 25°C).
- The micro-controller performs the data-analysis and successfully displays a user-friendly infographic on an LCD screen and warns the user about the rotting food.

Design

2.1 Block Diagram:



Our design consists of 2 separate units. There is a power supply that is composed of a 12V battery to power all the circuitry and a DC-DC converter to provide each of the units with the required voltages. The sensor array unit consists of a CO2 sensor, Alcohol/Organic Solvent sensor and Temperature Humidity sensor - all working together to provide the values on detection of the chemicals at the particular temperature and humidity setting to contribute to accurate readings. The inputs from this unit are fed to the microcontroller which interprets the readings and passes a signal to the bluetooth module to be transmitted to the receiver. The other unit is composed of the bluetooth receiver module and another MCU that handles the received values, interprets the data and displays appropriate values on the LCD screen to notify the user of potential food contamination. There is a push button on the UI unit that acts as an acknowledgement for the LCD screen to be cleared after the user has seen the warning. The LCD screen will also warn the user if the battery in the refrigerator needs to be changed based on a message from the internal unit after studying any drop in voltage across the battery.

2.2 Functional Overview:

Power:

The main components of the power supply will include a 10.8V 1600mAh battery that will be used to power the sensor unit. The voltage requirements of each of the individual units are different and lesser than 10.8V. Linear regulators will be used to make sure that each of the units get the required voltage. The linear regulators will be chosen to have an enable mechanism to to switch off power supply when not required. We plan to run through monitoring cycles every 6 hours. This implies that the sensors will be powered for approximately 15 minutes every 6 hours for heating followed by taking the readings. Depending on the frequencies of selected sensors, readings can be obtained in time spans less than a minute. The net current needed by all the sensors, the MCU and the bluetooth transmitter is approximately 260 mA maximum. We will have 4 reading cycles each for 15 mins, which implies 1hr/day of activity. This accounts for .26Ah per day. As the capacity of the battery reduces over time, we need the battery to be approximately 1.2Ah so that it can support the sensor unit system for at least 5 days before it needs to be charged. This is a calculation on the higher end so we can in theory, manage to use the battery for around a week before the user is notified to change it.

The 10.8V supply will be converted to 10V, 5V and 3.3V using an Low Dropout voltage regulators to provide a higher efficiency in conversion.

Requirements	**Verification**
A. The battery should be able to provide 10.8V B. The battery stores at least 1.2 Ah of power to enable working of the system for approximately a week on average. C. The battery is rechargeable.	A. Connect the probes of battery to a voltmeter and verify it is 10.8V when fully charged B. Discharge the battery while powering the circuit in required 4 monitoring cycles/day. Connect a DMM to verify the discharge rate and capacity of the battery over time. C. Once battery is completely discharged, the battery is recharged and the charging curve is observed to find out if the battery restores back to its maximum level of 10.8V

To meet the above requirements, we will be choosing Tenergy NiMH 10.8V 1600mAh Rechargeable Battery Pack. The battery pack has a maximum voltage level of 10.8V, has more capacity than the required 1.2Ah and is rechargeable and thus would be a good choice for the project.

LDO Voltage Regulator:

The CO2 and temperature-humidity sensors, along with the Bluetooth module require 3.3V. The LCD screen, MCU and alcohol sensor requires 5V each. Thus we have the following requirements:

Requirements	Verification
A. Provides 3.3V from a 10.8V source with low dropout of about 200 mV as mentioned in the datasheet B. Provides 5V from a 10.8V source with low dropout of about 200 mV as mentioned in the datasheet C. Provides 10V from a 10.8V source with low dropout of about 200 mV as mentioned in the datasheet	A. Measure the output voltage using an oscilloscope, ensuring that the output voltage stays within 5% of 3.3V for a simple load circuit. B. Measure the output voltage using an oscilloscope, ensuring that the output voltage stays within 5% of 5V for a simple load circuit. C. Measure the output voltage using an oscilloscope, ensuring that the output voltage stays within 5% of 10V for a simple load circuit.

Based on the requirements we have selected the LP2985, STLQ50C33R and LDK320M50R voltage regulators.

E-Nose Sensor Array:

After studying certain white papers and analysing trends in food spoilage, we have realized that the gases that are released most often are CO_2 and certain types of alcohols and organic solvents like ethanol. This is because the bacteria numbers increase on food spoilage. Most papers mention studies that state that when certain foods like apples are about to get spoiled, the concentration of CO_2 is 0-5%VOL. The ranges for alcohol are around 20-100 ppm for rotten meat. We are including a temperature sensor to make sure that we calibrate the readings based on the temperature of the surrounding air because the sensitivity of the gas sensors as well as the rate at which food gets spoiled varies in different temperature and humidity conditions. Based on studies conducted, the optimal average relative humidity for refrigerators is within a range of 70-80% at 4°C.

Requirements	**Verification**
A. Alcohol sensor should be able to detect in the range 20-100 ppm B. CO2 sensor should be able to detect in the range 0-5%VOL C. The sensors should be able to operate between 0°C - 10°C D. The sensors should be able to detect and function in humid conditions with average relative humidity of 70-80% at 4°C	● Verify working of the sensor using substances that are proven to produce the target gas ● We set up a closed chamber with a food specimen and the sensor powered to record readings over a span of a few days at a temperature of around 4°C - and at an average relative humidity of 70-80%. ● We create a signature correlating the concentration of the gas in air due to spoilage to the voltage change. ● Using the data sheet of the sensors and doing necessary calculations, we verify that the concentration falls in the required range. *The above steps will be used to verify all the requirements.

Based on these requirements, we have decided to use the following sensors:

Sensor	Chemical Detected	Specifications	Protocol
TGS822	Organic Solvents, Alcohol	Heater Voltage : 5.0±0.2V (AC or DC) I = 132 mA (typ) Ps ≤ 15 mW; Ph = 660 mW (typ)	Voltage readings to be inferred
MH-Z14	CO_2	Working voltage: 4.5 V ~ 5.5V DC Average current: < 85 mA Interface level: 3.3 V	Output signal- PWM UART
DHT22	Temperature and Humidity	Source Voltage 3.3V - 6V Typical: 3.3V Power Consumption: 7.5 mW Current: 1.5 mA (typ)	Single bus serial interface

Micro-Controller:

The microcontroller will be the main control unit of the entire system. The MCU will communicate with the different blocks of the product to execute the seamless functional design of the contamination detector. We'll be using ATMega2561 MCU for the project as it satisfies the below requirements and the choice will be helpful in prototyping as well since Arduino Mega uses the same AVR Microcontroller.

Requirements	Verification
A. The MCU should have at least two UART to communicate with the CO_2 sensor and Bluetooth module at at least 9600 baud B. The MCU should be able to work with I2C protocol to communicate with the LCD screen of the UI C. The MCU should be able to communicate via a serial interface with the DHT22 sensor D. The MCU should have at least 2 pins to connect to the push-button circuit for the acknowledgement button	A. Connect microcontroller to USB UART bridge and to a terminal. Set up terminal at 9600 baud. Send and echo back 100 characters. Ensure that all characters match those sent B. I2C protocol can be verified by requesting the device ID from the display. Ensure that the data received matches the specification in the data sheet C. The MCUs digital pins will be used to design the protocol that is followed by the sensor. Perform tests on the design to retrieve the correct device ID to validate the serial interface D. Probe two pins with a multimeter to check if it has the voltage required by the push button switch at the two pins where it will be placed. Attach the button and notice a change in voltage value in software to see if the button gives the desired signal.

Since we have two separate units that will communicate using Bluetooth, we need two MCUs to handle the data to be sent and process the data received on the other end to be displayed on the UI.

User Interface:

For the prototyping phase, we plan to get started with using LEDs that would be an indication of whether the sensors provide adequate data for the ranges programmably fed into the microcontroller to abstract a message to the user. For the final product, we aim to integrate the circuitry with an LCD display that can warn the user of potential food contamination detection or of product expiry. In addition to that, the UI will have an acknowledge button that is simply a hardware interrupt to clear the message displayed on the screen indicating that the user has acknowledged the current notification from the system.

Requirements	Verification
A. A 16x2 LCD screen capable of displaying two lines of text in english with RGB backlight for clearer visibility. B. The working voltage of the display should be 5 V as that meets the power supply limits and operating current should be <100mA. C. The LCD screen should use I2C communication to interface with the microcontroller.	A. We connect the LCD to an arduino and print out two lines of text. If it displays them as desired, we know that the component is acceptable. B. We connect the LCD to a 5V supply and monitor its functioning. Additionally, we use an ammeter to measure the current passing through the circuit with the LCD being the only component. C. I2C protocol can be verified by requesting the device ID from the display. Ensure that the data received matches the specification in the data sheet

Bluetooth Module:

To aid with the user experience and to enable modularity in the design, we plan to include a bluetooth module that will have the transmitter along with the sensor array unit and the receiver on the User Interface unit so that both these blocks can be placed separately as per the user's convenience. This helps in situations where the notification screen would be placed on the door of the refrigerator and the electronic noses can be placed at multiple locations inside the refrigerator and can wirelessly communicate with this central node. This will enable scalability in the design. Additionally because of the range of signal needed for communicating in our proposed use-case environments, bluetooth is a feasible solution for enabling wireless communication. The sensors will not send data very frequently and thus the bitrate will be handled well by bluetooth as well. The operational bitrate will be a few bits per second.

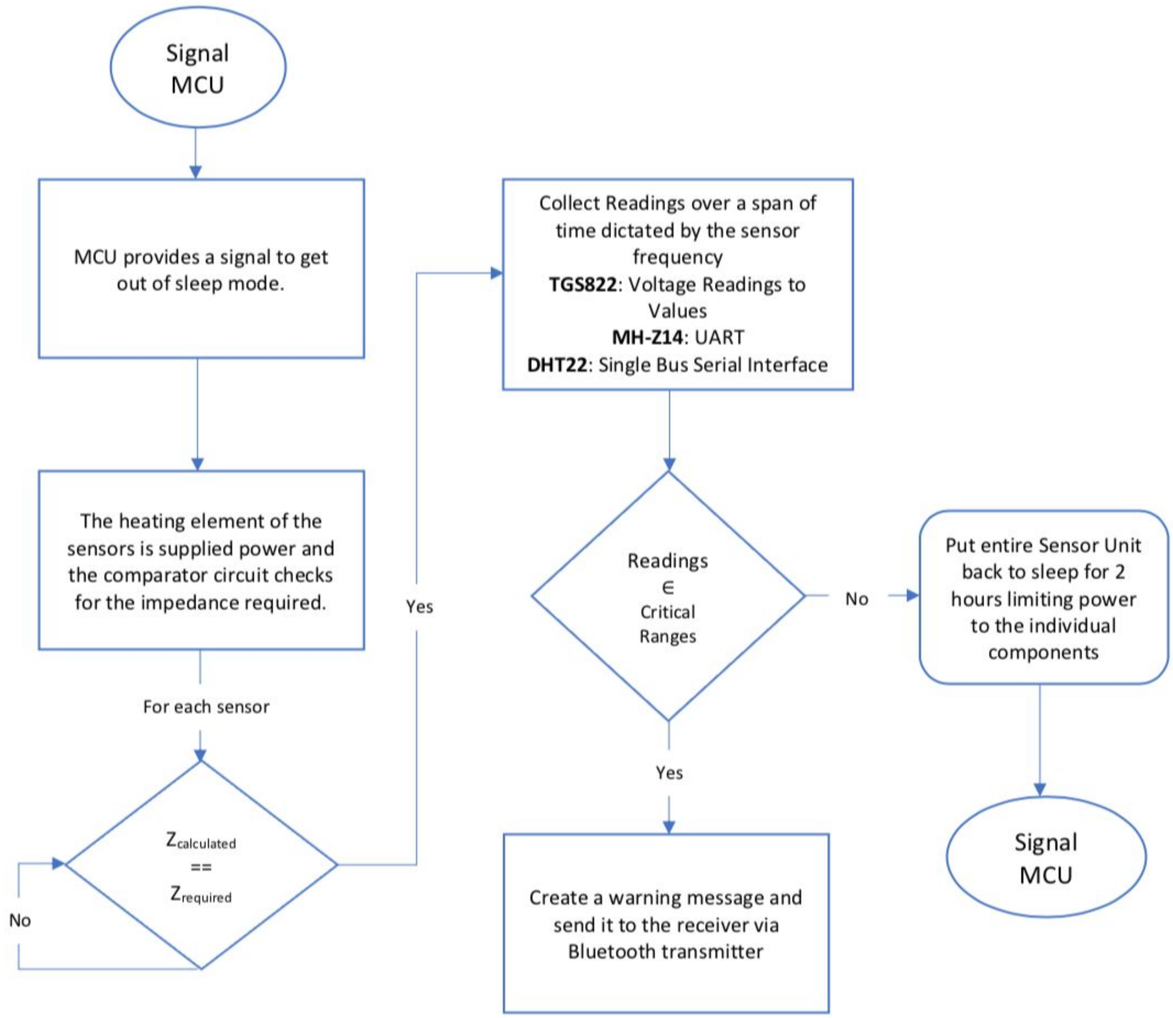
Requirements	Verification
A. The signal from the bluetooth modules can pass through the refrigerator door and cover the range of a refrigerator. B. The bluetooth module should be able to work with a serial communication interface to make sure that the MCU can communicate with it C. Operating voltage of the bluetooth module should be around under 7V. The current rating should be within 150mA so that it can work with the power specifications of the battery.	A. Place a bluetooth receiver attached to the CoolTerm Serial interface outside the refrigerator. Place the bluetooth sender inside the refrigerator. If the MCU can generate values on CoolTerm, it implies that the serial interface of the module was functional. B. Upload a executable to the bluetooth transmitter module to send packets with incrementing serial numbers and RSSI values as payload.Capture the packets on the receiver's end and print out the readings using the CoolTerm serial interface. If the packets are received, we know that the communication channel is functioning well. C. We use a voltmeter to measure the voltage across the bluetooth module and the ammeter to measure the current through it to make sure that those requirements are met. *CoolTerm is a simple serial port terminal application (no terminal emulation) that is geared towards hobbyists and professionals with a need to exchange data with hardware connected to serial ports such as servo controllers, robotic kits, GPS receivers, microcontrollers, etc.

Based on these requirements, we have decided to use HC-05 Bluetooth Module.
The specifications are as follows:
Communication Interface: UART
Supply Voltage: 3.3V
Supply Current: maximum 40mA
Power: 132 mW

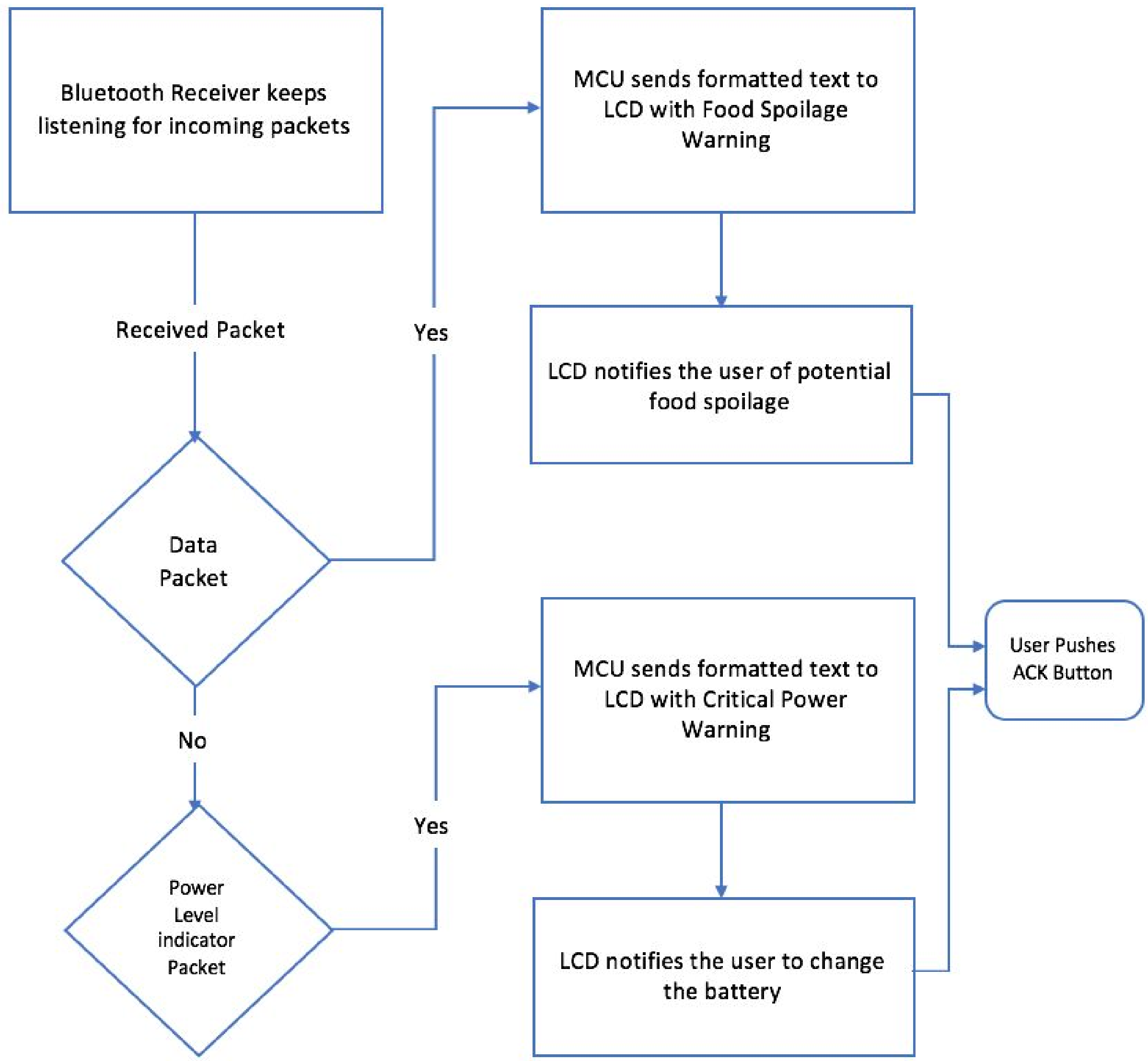
2.3 Software:

Our software handles communication between the different sensors and the microcontroller on one module. The data received from the sensors is processed by the MCU and appropriate data is sent through the bluetooth transmitter to the receiver on the display unit module. The data received is processed by the microcontroller on this module, and based on the type of data, relevant information is displayed on the LCD screen for the user to take necessary action. We will be implementing the UART, I2C communication protocols to be able to transmit and understand data between the MCU and other components. Also other than the data from the sensors, another type of data that is collected and processed is for power management. We have probes across the battery that measure the battery voltage from time to time. When the battery voltage falls below a certain threshold, we create a "Critical Battery Power" message packet and send it to the receiver to notify the user of the need to change the battery. This will function because the voltage required by the bluetooth module to function is under 7V as indicated by our requirements.

Sensor Unit:

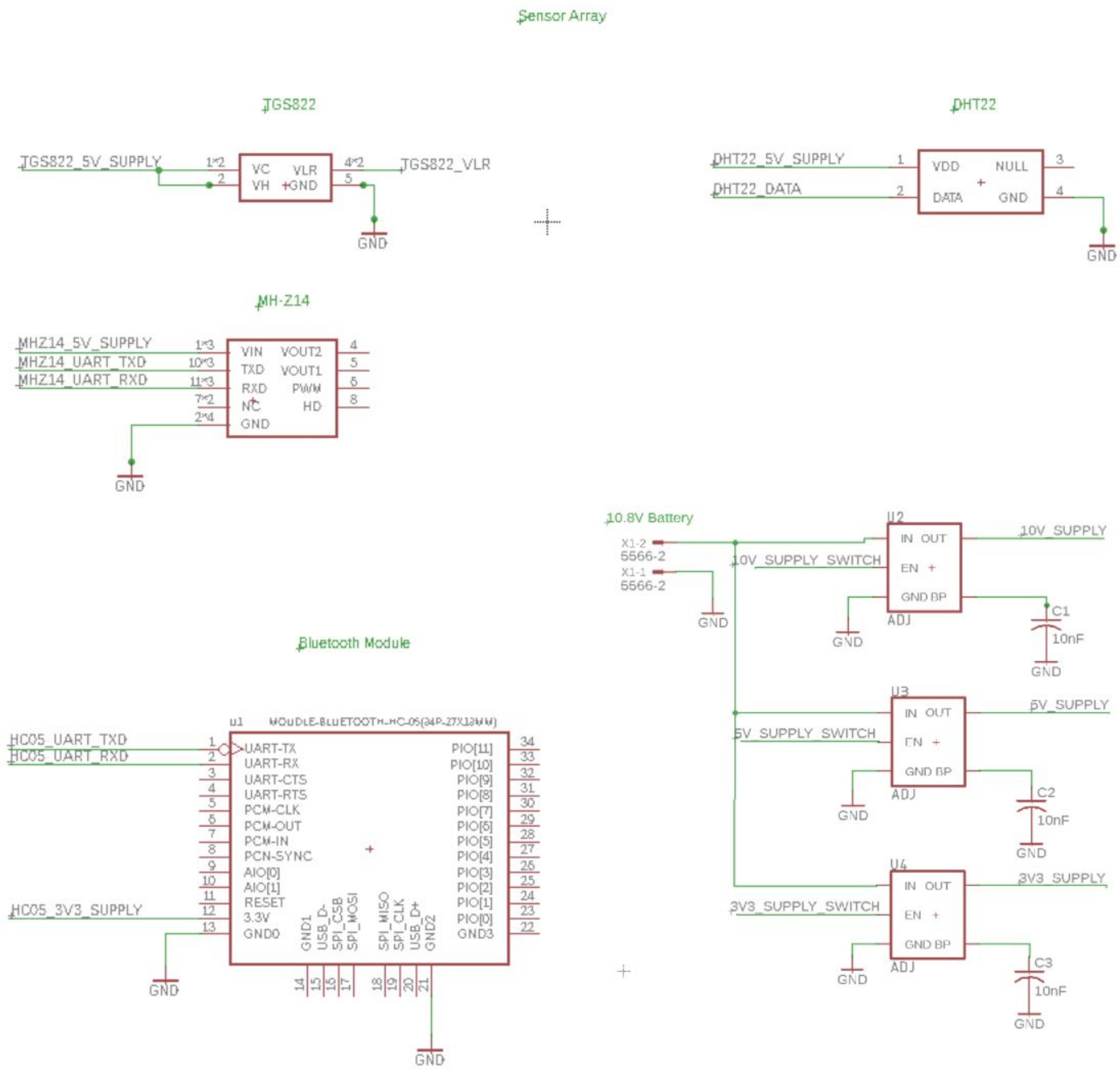

Signal
MCU
MCU provides a signal to get out of sleep mode.
The heating element of the sensors is supplied power and the comparator circuit checks for the impedance required.
For each sensor
Zcalculated
==
Zrequired
No
Yes
Collect Readings over a span of time dictated by the sensor frequency
TGS822: Voltage Readings to Values
MH-Z14: UART
DHT22: Single Bus Serial Interface
Readings
∈
Critical
Ranges
No
Put entire Sensor Unit back to sleep for 2 hours limiting power to the individual components
Yes
Create a warning message and send it to the receiver via Bluetooth transmitter
Signal
MCU

User Interface Unit:

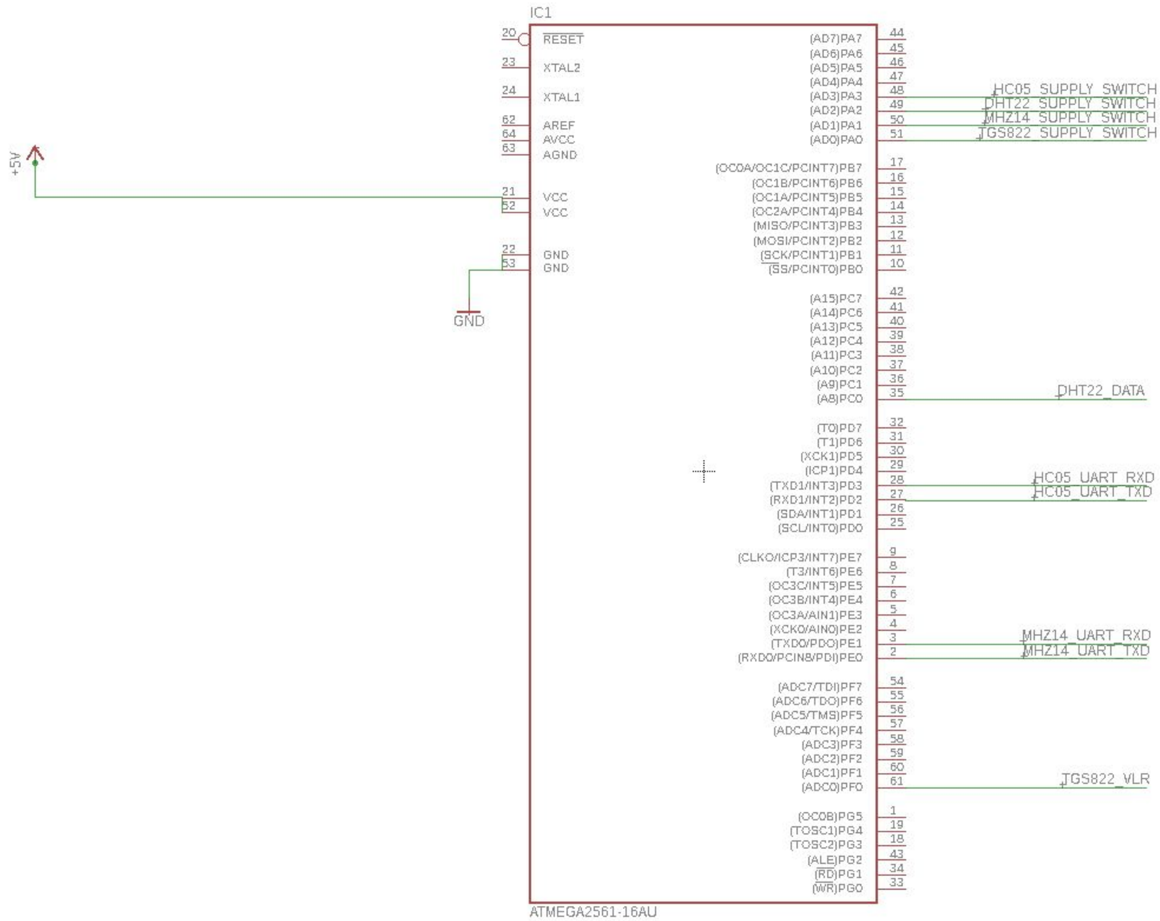


Schematics:

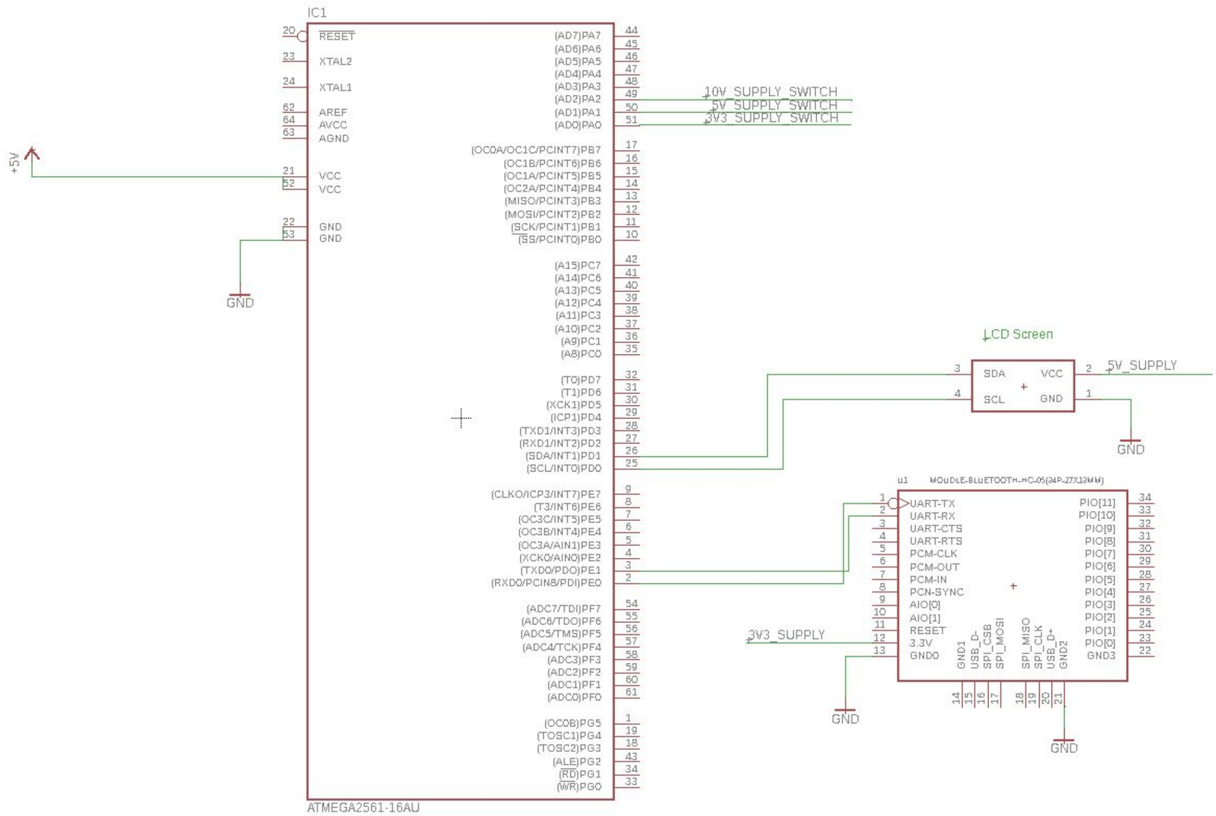
<u>Sensor Array, Power Unit, Bluetooth Module</u>



MCU - Sensing Unit



Display Unit



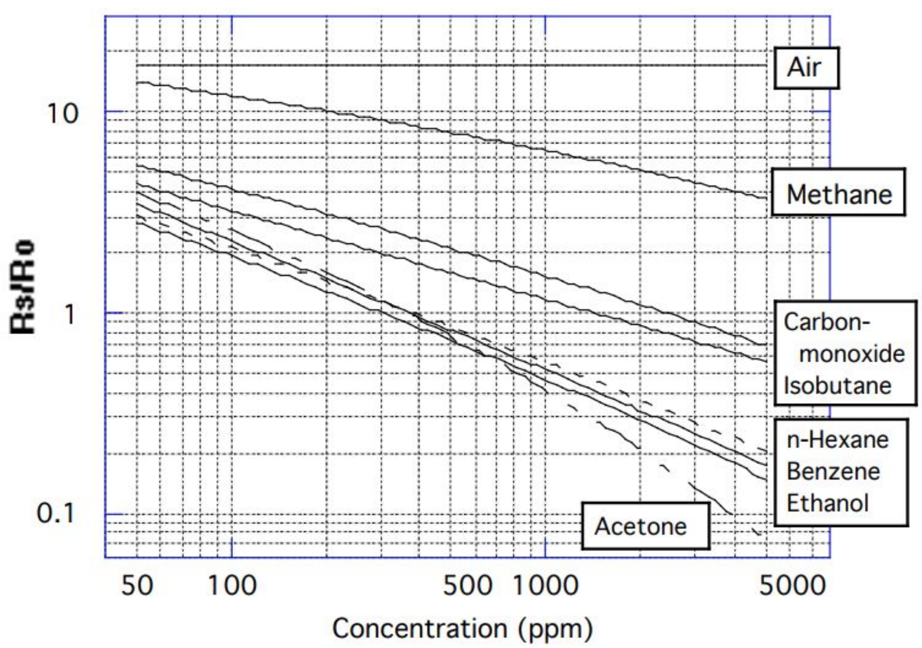
Calculations:

TGS822 sensor:

When it is connected as shown in fig.1, depending on the concentration of the gases, output across the Load Resistor (V_{RL}) increases as the sensor's resistance (Rs) decreases. Sensor Resistance (Rs) is calculated by the following formula:

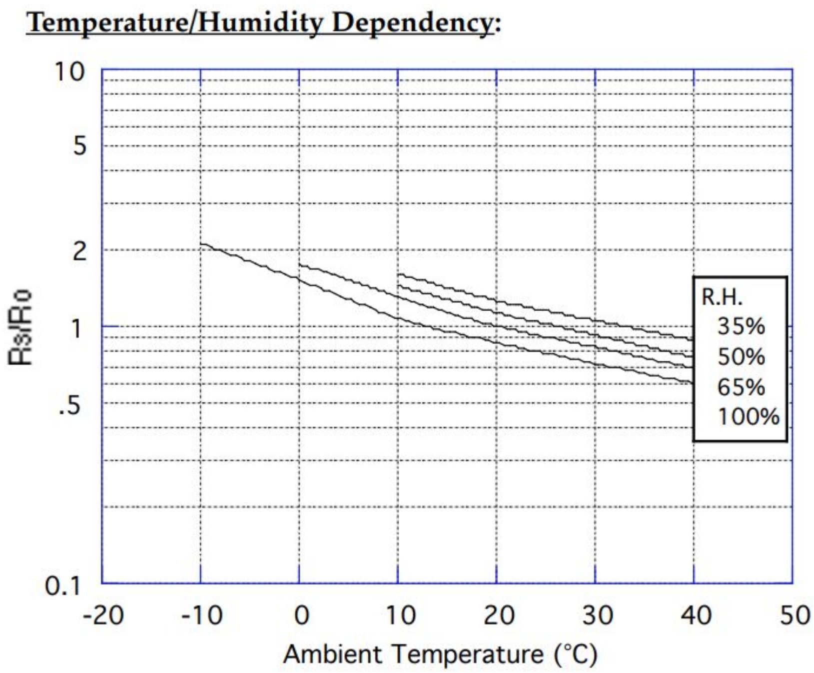
$$Rs = (\frac{V_C}{V_{RL}} - 1) \times R_L$$

Sensitivity Characteristics:



Rs = Sensor resistance of displayed gases at various concentrations

Ro = Sensor resistance in 300 ppm ethanol



Rs = Sensor resistance at 300 ppm of ethanol at various temperatures/humidities
Ro = Sensor resistance at 300 ppm of ethanol at 20°C and 65% R.H.

MH-Z14 sensor module:

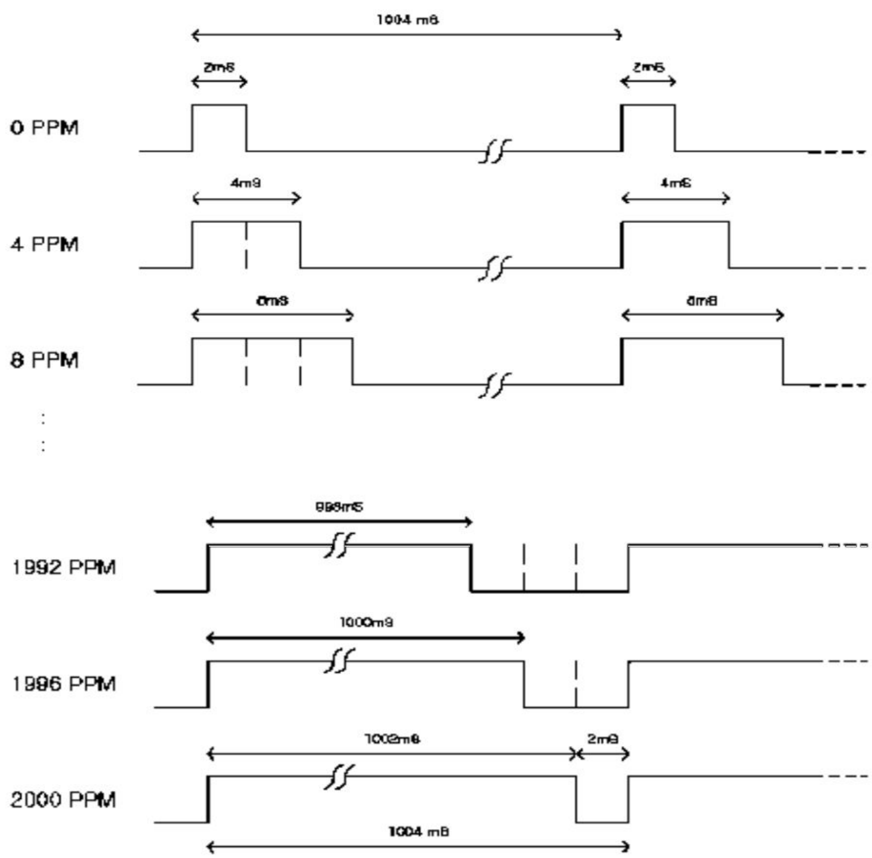
This particular sensor module has multiple output formats:

- PWM output - Formula for concentration of CO_2 from PWM output is as follows:

$$C_{ppm} = 2000 \times (T_H - 2ms) / (T_H + T_L - 4ms)$$

Where,

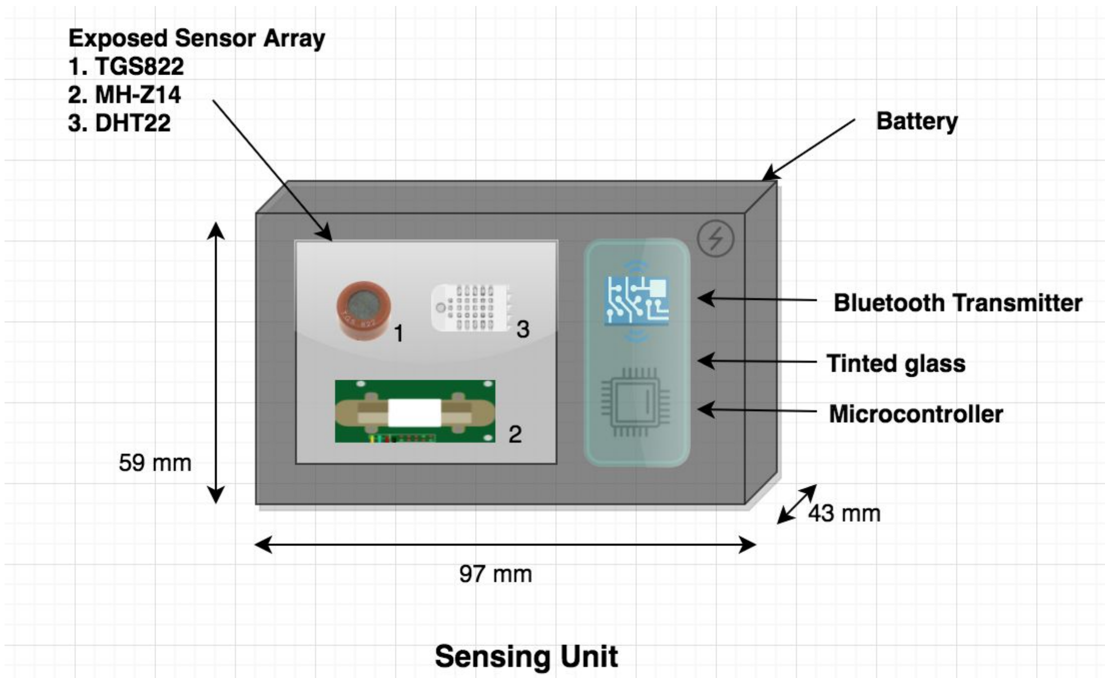
C_{ppm} ≡ calculated CO2 concentration, unit is ppm
T_H ≡ time for high level during an output cycle
T_L ≡ time for low level during an output cycle

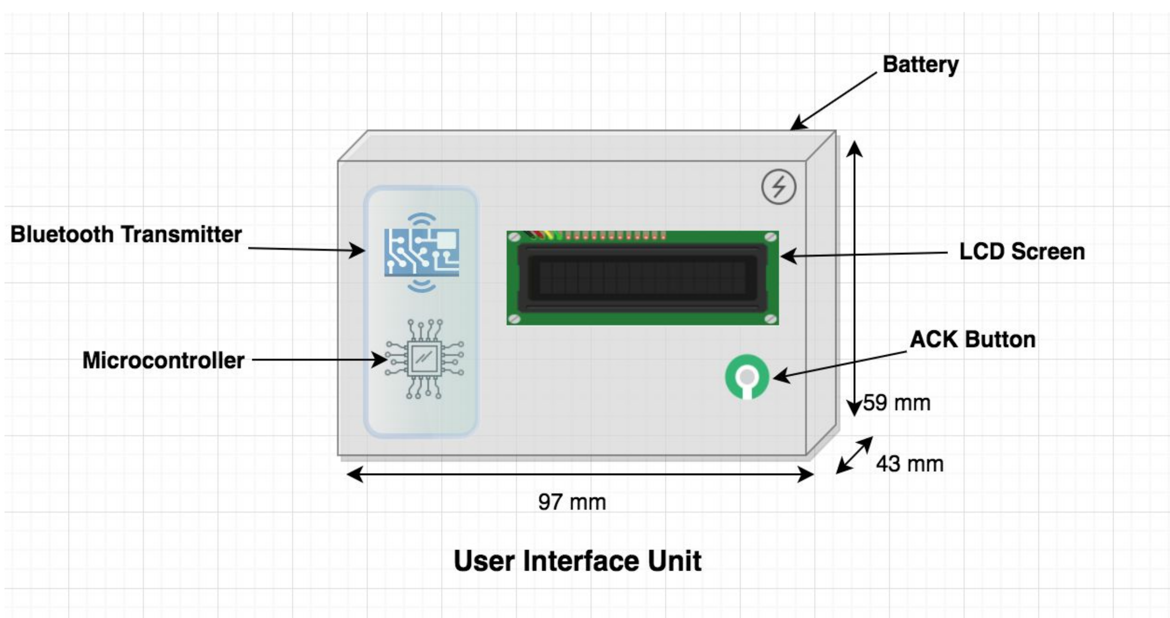


- UART output - Concentration can be read without any calculations

Physical Design:

The system will consist of the sensor unit + microcontroller placed inside the fridge as an attachable entity. Wires will be used to connect this system to the LCD screen that will be attached outside the enclosure or the fridge. The entire system which includes the screen and the electronic nose will be portable. The units can be placed securely with two-sided easy to remove tape.





Risk Analysis:

The e-nose sensor array is at the heart of this project and poses the greatest risk to successful completion. Since we are dealing with gases which have complex fluid dynamics, the ability of the sensors to accurately and consistently detect the concentration of gases would determine the correctness of the outcome. Moreover the biochemistry of food is quite intricate and dynamic. The concentration of gases released by spoiling food is a function of many different variables. Not only does it vary depending on the type of food but also changes based on the environmental conditions - temperature, humidity, presence of other gases. Hence devising a threshold for the concentration of a particular gas after which an item can safely be declared as spoilt, is a fairly challenging task.

Tolerance Analysis:

The biochemistry of food is itself a very complex subject. Since this project primarily depends on a somewhat consistent spoilage pattern of food, deviations in the amount of gases released by a specific food item will itself hamper the accuracy and reliability of our detection model. Having realized this, the next most critical component in our design that is under our control is the e-nose sensor array. These sensors form the heart of the device and are directly involved in the detection of the concentration of gases around stored food items. Based on the multiple papers that we have researched, it has been established that the emission of CO_2 is most common across different food types. Not only do fruits and vegetables themselves respire, but growing microbes also release CO_2, thereby making the MH-Z14 sensor a critical component of our project whose tolerance is analyzed in this section.

For our prototype purposes, we are targeting a set of food items namely - apples, bananas. Based on the relative tolerance to CO_2 scale in [9], The amount of CO2 in the air when apples and bananas begin getting spoilt is in the range of 0-2%VOL.

$$\text{Amount of CO2 for apple/banana spoilage start} = 0 \textit{ to } 2\% \text{ VOL}$$
$$= 0 \textit{ to } 2 \times 10000 \textit{ ppm}$$
$$= 0 \textit{ to } 20,000 \textit{ppm}$$

The accuracy of the MH-Z14 CO2 sensor is $\pm(50ppm + 5\% \textit{ reading value})$

So assuming the scenario when the actual reading value should be 20,000 ppm of CO2, the range of possible sensor readings would be: $18,950ppm \textit{ to } 21,050ppm$

The results in a error range of 5.25%. Food is dynamic and this tolerance level is acceptable for the following reasons:

- If it is sensing below the actual level at 18,950ppm, the amount of CO2 is changing with time. So within some time, it would exceed the threshold (let’s say 20,000 in this case) and notify the user.
- If it is sensing at 21,050ppm, this is still the threshold for early detection which denotes the food beginning to spoil. The line between a food item rotting but consumable and completely inedible is vague. So a 5% error will barely affect the reliability of the e-nose conclusion. Moreover after notifying a user, it is still upon the user’s discretion of whether he wants to consume the food or not. A 5% error will not affect the evaluation of the quality of the food being monitored.

Costs:

Labor: (For each member of group)

Salary: $40 /hr

Time per week: 8 hrs/week

Work Completion : 75%

Total = $40\ \frac{\$}{hr}\ \times 8\frac{hrs}{week}\ \times 16\ \frac{weeks}{.75}\ \times 2.5 = \$17{,}066$

Total labor costs = $3\ \times 17066\ =\ \$51,200$

Parts:

Description	Manufacturer	Part#	Quantity	Cost
CO_2 sensor	Winsen Electronics	MH-Z14	1	$41.52
Alcohol sensor	Figaro	TGS822	2	$14.53
Temperature and Humidity sensor	Aosong Electronics Co.	DHT22	1	$9.50
Microcontroller	Microchip	ATMega2561	2	$23.70
Bluetooth Module	NewZoll	HC-05	2	$21.14
LCD screen	Seeed	Grove - LCD RGB Backlight	1	$11.90
Battery	Tenergy	Ni-MH 10.8V 1600mAh	2	$44.70
Charger	Tenergy	UL 60950-1	1	$19.99
LDO Voltage regulator	Texas Instruments	LP2985	1	$0.58
LDO Voltage regulator	ST Microelectronics	STLQ50C33R	1	$0.87
LDO Voltage regulator	ST Microelectronics	LDK320M50R	1	$0.83
			Total:	$189.26

Schedule:

Week	Siddharth	Simran	Agnivah
2/26	Build prototype circuit	Write testing code for communicating with sensors	Write testing code for communicating with sensors
3/5	Schematics, PCB layout	Data Collection	Data Collection
3/12	PCB v1 ordered	Testing of sensor readings	Creating signatures of different concentrations
3/26	PCB testing. PCB v2 redesign and order	PCB testing. Final UI design start	PCB testing. Final UI design start
4/2	Check power monitoring circuitry	Sensing unit processing and bluetooth transmission	Bluetooth reception and processing for LCD display
4/9	1 week buffer for unexpected complications	1 week buffer for unexpected complications	1 week buffer for unexpected complications
4/16	Testing and debugging	Testing and debugging	Testing and debugging
4/23	Presentation and final paper	Presentation and final paper	Presentation and final paper

Ethics and Safety:

Potential applications of this device could be by businesses using it to monitor the quality of their produce or food items they are selling. This device could be tampered to show wrong results and deceive the consumers. Since the device is not connected to the network, hacking into it remotely would not be possible. However someone could reverse engineer and change the threshold of contamination detected by the sensors thereby declaring something as fresh to consume, despite being of inferior quality. This is in direct violation to #3 of the IEEE Code of Ethics which is "to be honest and realistic in stating claims or estimates based on available data".

Our project doesn't have serious potential hazards as such. One particular potential hazard could be the short circuit of the sensors. Since the sensor array is placed inside the refrigerator, a potential liquid spill could damage the e-nose sensors and cause a short-circuit. Since it is composed of gas sensors, complete waterproofing of the sensor array is not possible. The casing would adhere only IP61 guidelines, which protects it from condensation.

Battery needs to be handled safely. Although the risk of a fire in a Ni-MH battery is low compared to Li-poly, it is to be kept in mind that the high voltage and capacity of the battery need to be handled safely and avoid any shorting of terminals.

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