Budget Odor Detector: Design Document

Team #8

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ECE 445

Introduction

Objectives & Background

Roughly 20% of the general population has a bad sense of smell [2]. This, unfortunately, makes it hard to pick up odors, whether they are in the fridge, kitchen, bathroom, utility room, etc. These odors that go undetected may indicate a larger issue like a gas leak or chemical spill. The result of this, can cause damage to a home or warehouse, or even potentially put people in the vicinity of the gas/chemical in danger.

According to a study published by the American Chemical Society in 2020, there are approximately “630,000 natural gas leaks every year, just in the local distribution systems” [4]. Utility companies combat these leaks by spending billions of dollars every year [3] on technology like cars, drones and satellite data. Unfortunately, not all of these leaks can be fixed in time, and in 2023, there were a record-high 23 fatalities resulting from gas-fed explosions [5].

Our device is meant to combat this problem by giving homeowners and business owners direct access to gas sensing technology that gas companies have access to, at a more affordable price. Our device, the budget odor detector, will contain sensors that detect CH_4 (Methane), H_2S (Hydrogen Sulfide), NH_3 (Ammonia), and CO (Carbon Monoxide). In order to make our device more tailored to our target audience, we will have an LCD screen to show each gas’s ppm level in the room it is in, acting as a visual for the user. This will aid in the user’s interpretation of the room’s state, and allow our device to alert the user in a potentially dangerous situation.

If the device has a gas reading that crosses a dangerous threshold, it will sound a warning alarm to alert the user, a warning LED will illuminate, and the screen will display a warning notification. This is done to alert the user of a potential danger in more than one way, in case the user has a hearing or visual deficiency.

Most odor detectors will compensate for the issue this device covers, but they are expensive on the market, going upwards of $200. Additionally it is common to have to buy more than 1 device to sense more than 1 gas at a time as well, further increasing the total cost.

Because our device is designed for homeowners and business owners, not gas companies, the more affordable, multi-gas sensing device with a helpful display is what separates our Budget Odor Detector from other options on the market.

Visual Aid

Figure 1: A common gas/odor detector on the market

There is a common theme between gas detectors found on the market. They are handheld, and expensive. The one shown in figure 1 goes for $545. Our model, shown in figure 2, will be designed to be set down on a counter, or placed in an enclosure, clearly displaying gas levels to the user, without someone having to stick their arm in a potentially dangerous area in order to get readings. Our model will also be under $150, sticking to our team's goal of being budget and household friendly.

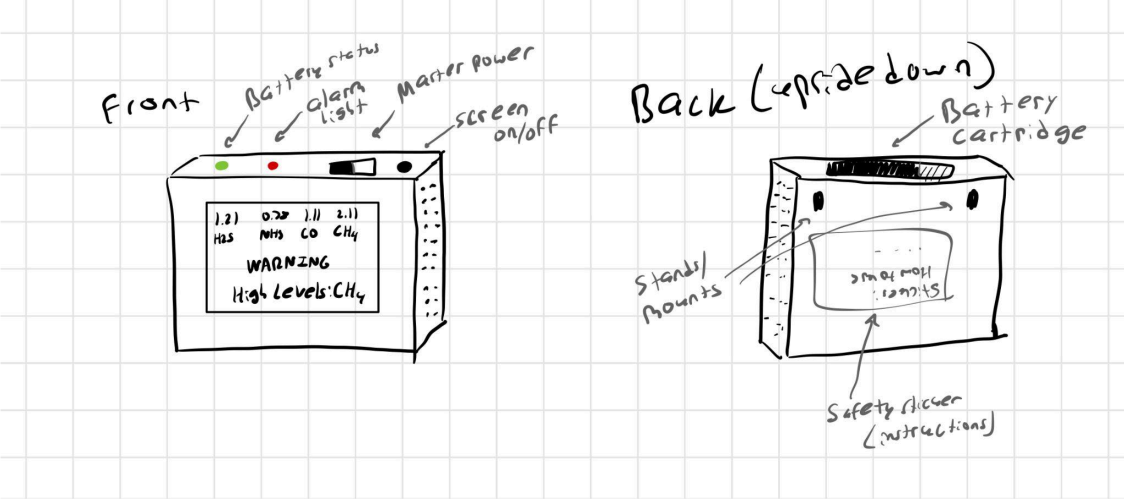


Figure 2: Rough sketch of our compact detector

Since we detect 4 different gasses, which all have different whereabouts, our device will have a few different applications. In figures 3, 4 & 5, you can see 3 examples of where our device may be used.

Figures 3, 4, 5: Budget Odor Detector in the real world– kitchen counter, bathroom, furnace room.

High Level Requirements

1) The device must be able to display input gas ppm levels every 0.5s ± 0.1s from the following ranges:
   - NH3 (Ammonia) from 0-50 ppm [21]
   - H2S (Hydrogen Sulfide) from 0-50 ppm [22]
   - CH4 (Methane) from 500-10000 ppm [23]
   - CO (Carbon Monoxide) from 10-200 ppm [24]
2) The device must audibly and visually alert the user within 0.5 ± 0.1s upon detecting the following thresholds for more than 5s straight (see Design - Control Unit for references):
   - NH3 when it exceeds 25 ppm
   - H2S when it exceeds 20 ppm
   - CH4 when it exceeds 1000 ppm
   - CO when it exceeds 150 ppm
3) The device must detect and display a warning light to indicate each of its following states:
   - Low battery within 0.5 ± 0.1s of the battery reaching 7v
   - Triggered alarm within 0.5 ± 0.1s (See #2 for trigger conditions)

Design

Block Diagram

The block diagram in Figure 2 outlines the design of our project. It is powered by a 9V battery with a voltage regulator, ensuring the proper voltage level for various components. The device includes four gas sensors to detect the concentration of CH4, H2S, CO, and NH3 in the environment. The detected data is then processed by the microcontroller STM32G030K8T6, and the gas concentrations will be displayed on the LCD. An alarm will be triggered if the concentrations of the gasses exceed the threshold. Additionally, we also have a LED which indicates the power status of the device.

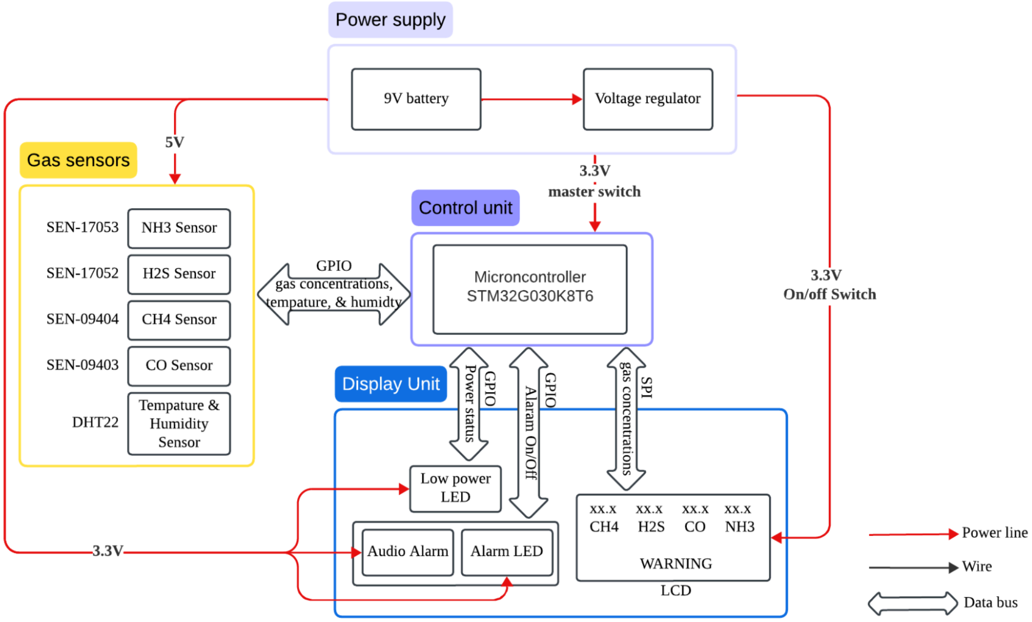
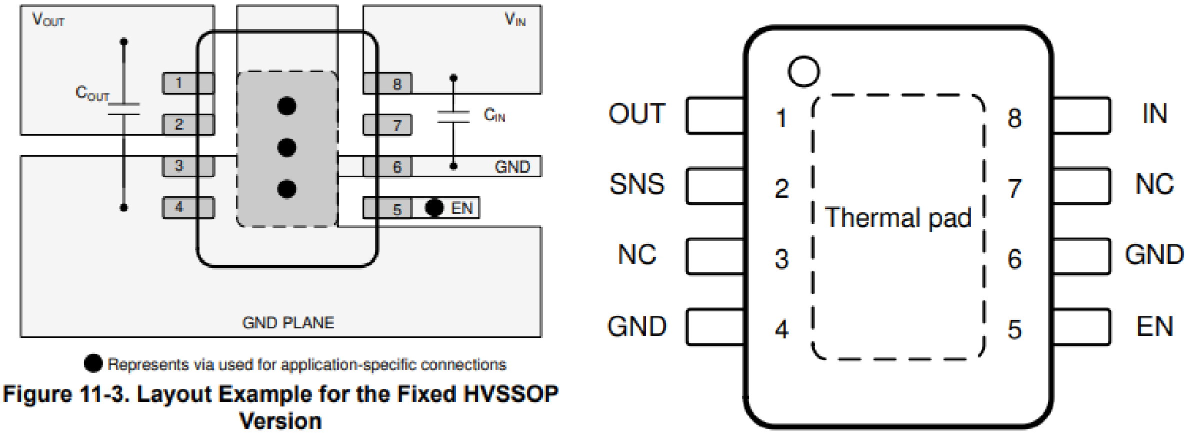


Figure 6: Budget Odor Detector Block Diagram

Power Supply

The power supply unit delivers the required power to the device. Using a linear positive-voltage low-dropout regulator (LDO regulator), this unit is able to convert the 9V battery input to the various voltage levels required by other components. It ensures the device operates continuously and plays a vital role in maintaining consistent functionality. The 9V battery MN1604-9V will be placed in a battery cartridge for any future replacement [7]. Additionally, this unit includes a master switch that allows the user to control the power state of the device. By turning the entire device on/off, it allows the user to conserve battery power when the device is not in use. There is also an additional button to turn the LCD on/off.

For the LDO, we chose to use TLV76733DGNR and TLV76750DGNR which step down 9V input from the battery to a stable 5V and 3.3V output correspondingly [6]. They also help smooth out any voltage fluctuations from the battery, protecting the device from any potential damage due to an unstable voltage level. Besides, these two LDOs are fixed output versions, so we do not need to connect extra feedback resistors to control the output voltage. Instead, we connect the LDOs into our power supply subsystem to step down the voltage in the way suggested in Figure 3. The V_IN is connected to the battery through the master switch, and the V_OUT is the required output for the other components in our device.



VOUT
COUT
1
2
3
4
8
7
6
5
VIN
CIN
GND
EN
GND PLANE
● Represents via used for application-specific connections
Figure 11-3. Layout Example for the Fixed HVSSOP Version
OUT
SNS
NC
GND
Thermal pad
IN
NC
GND
EN

Figure 7: Layout example for TLV767XXDGNR fixed HVSSOP version.

- The power subsystem must be able to supply at least 600mA to the four gas sensors, each drawing 150mA at 5V ± 5%.
- Additionally, the power subsystem must be able to supply at least 300mA continuously at 3.3V ± 5% to the rest of the system. This current is distributed as 100mA to the microcontroller, 135mA to the LCD screen, and 95mA to the remaining components.
- A master on/off slider is included to control the power state of the entire device.

Table 1: Power Supply Subsystem – Requirements & Verification

Requirements	**Verification**
The Power Supply Subsystem must be able to supply 600mA ±5% to the Sensor Subsystem at 5V ±5% and to the reset of the subsystem at a rate of 300mA ±5% and 3.3V ±5%.	● Connect inputs of the voltage regulators to the power supply. Connect outputs of the voltage regulators to the oscilloscope. ● Check voltage reading with the oscilloscope to make sure the output voltages do not fall outside of 3.3V±5% and 5V±5% for each regulator. ● Check current reading with a multimeter to make sure the output currents are at least 600mA to the gas sensors and 300mA to the reset of the device.
The master switch in the Power Supply Subsystem needs to turn the entire device on/off .	● Connect the outputs of the Power Supply Subsystem to the oscilloscope. ● Turn the master switch off. Check the current readings with the oscilloscope to make sure there is no current flow. ● Turn the master switch on. Check the current readings with the oscilloscope to make sure that the output current does not fall outside of 600mA ±5% and 300mA ±5%.

Any instability in the power subsystem will result in insufficient power or potential damage for the sensitive components in the device.

Control Unit

The control unit is the central system of the odor detection device. It processes data received from the gas sensors and handles the interface between sensors and the output devices (LCD, LEDs, and buzzer). It continuously reads the gas concentration levels from the gas sensors, compares them to the preset thresholds, and triggers alarms when necessary. It interfaces with the power subsystem for its own power, the sensors for data acquisition, and the display unit through Serial Peripheral Interface (SPI) protocol for visual/audio output.

The control unit will be run by a STM32G030K8T6 [8] microcontroller. It will need a stable 2-3.6V from the power supply to function. In order to flash and debug code to the STM32 microcontroller, it must be programmed via a ST-Link programmer that is integrated with a respective controller. When reading values from the sensor unit, it must be able to interpret these values through Analog to Digital Conversion (ADC) pins, and consistently be able to read and display them in real time. The controller will be interfacing with a voltage divider circuit in order to monitor the capacity of the 9V battery that supplies power to our power supply, and will alert the user with an LED when the capacity of the battery dips below its ideal operating voltage, which is anything below 7V.

In order to flash to our STM32 microcontroller, we will need to integrate a simple programming circuit into the system. In order to program the STM, we will use a SWDIO & SWCLK pin interface between the connector and the microcontroller, and on the connector, we will have a NRST, GND and Vd signal. This will allow us to flash code to our STM32, and debug our code in real time.

Finally, the control unit will output control signals through General Purpose Input Output pins (GPIO) to trigger an alarm and illuminate an LED when gas concentrations exceed the following thresholds. These thresholds are defined in accordance to OSHA or state/industry standards:

- NH3 (Ammonia) when it exceeds 25 ppm [9] [10].
- H2S (Hydrogen Sulfide) when it exceeds 20 ppm [11].
- CH4 (Methane) when it exceeds 1000 ppm [12].
- CO (Carbon Monoxide) when it exceeds 50 ppm for over 8 hrs, immediate if it exceeds 150 ppm [13] [14] [24]. The unique threshold is to prevent excessive false positives.

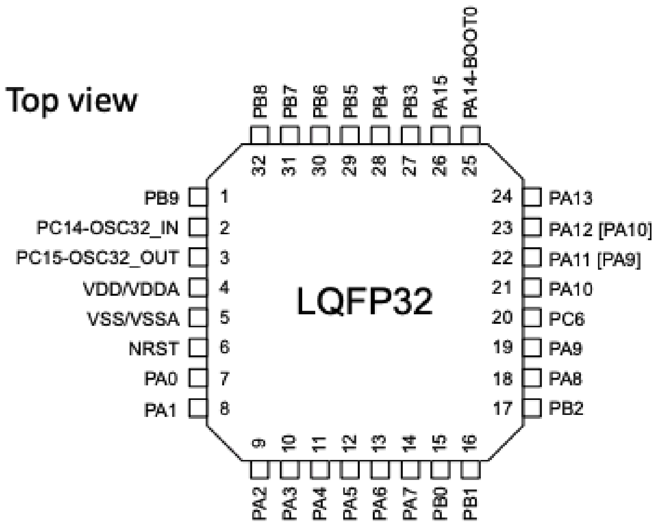


Figure 8: STM32G030K8T6 pin-out from the datasheet [8].

If the control unit fails to process data correctly or fails to communicate with sensors, the entire system will become ineffective in detecting gasses and unable to trigger the alarm when the threshold is exceeded.

Table 2: Control Unit Subsystem – Requirements & Verification

Requirements	**Verification**
● The STM32 microcontroller must receive a voltage of 2-3.6 V from the power supply.	● Before & after soldering the STM32, probe the ground and V_{dd} pads/pins to ensure that the voltage across them is 3.3V, supplied from an LDO.
● The STM32 microcontroller should be able to interpret data that is received from the sensors, and display it every 0.5 +/1 0.1 seconds.	● Using the ADC (Analog to Digital) peripheral, for all 4 sensors, read the inputs while in an inside controlled environment. Confirm that the data received is valid, and within the ranges specified in the gas sensor section. ● Then move the device/sensors to a different environment, maybe bathroom, outside, or to a room with a different gas disposition. Confirm that the readings change when the sensors are exposed to a different environment, and stay within the valid data ranges specified in the gas sensor section.

● The STM32 microcontroller must be able to be programmed and debugged using a USB interface.	● Using an ST-Link, plug into the connector interface on the PCB. Connections must align and be aligned to SWDIO, SWCLK, 3.3V, GND and NRST. Confirm that 3.3V is supplied to the connector with a multimeter probe. ● Using STM32IDE and STM32Programmer, flash base code generated with PIN outputs in STM32CubeMX, and confirm that the base code runs.
● The STM32 microcontroller must be able to probe the current voltage of the 9V battery in the system.	● Using the voltage divider probe built into an ADC (Analog to Digital) line of the STM32 microcontroller, read the input of the battery. ● Probe the battery's terminals with a multimeter to confirm that the readings obtained using the ADC communication line on the STM32 microcontroller is accurate to ± 0.1 V
● The STM32 microcontroller must be able to illuminate both the low battery and alarm LED, as well as sound the alarm buzzer, according to thresholds defined in the subsystem overview.	● To test the alarm LED, raise a flag in the code flashed to the STM32 that would virtualize a dangerous gas input, or virtualize a gas input to a dangerous reading. ● When the reading is virtualized, the alarm should sound, and the alarm LED should be illuminating red. ● To test the low battery LED, plug in a battery that has a capacity of <7V, or virtualize the battery GPIO reading to be less than the low battery threshold. ● After doing this, the low battery LED should be illuminated yellow.

Gas Sensors

The gas sensors continuously read the ppm levels in the room they are in and send data to the control unit. Sensor pin layouts will be used to hold these sensors in place [15].
Additionally, a sensor will read temperature and humidity to account for the gas sensor sensitivities varying from these factors (see Tolerance Analysis).
This subsystem is connected to the power supply unit for power, and it sends collected data to the control unit via ADC (Analog to Digital) protocol.
MQ Sensors (Gas):

- NH4 (Ammonia): MQ-137 [16]
- H2S (Hydrogen Sulfide): MQ-136 [17]
- CH4 (Methane): MQ-4 [18]
- CO (Carbon Monoxide): MQ-7 [19]

Calibration Sensor:

- Temperature and Humidity: DHT22/Aideepen 2302 [27]

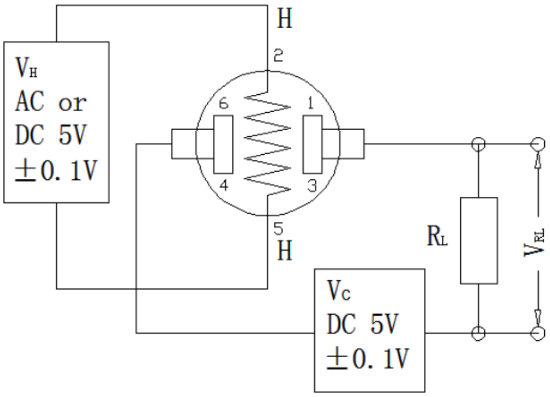


Figure 9: Circuit diagram of reading MQ sensor output in the datasheet [19]

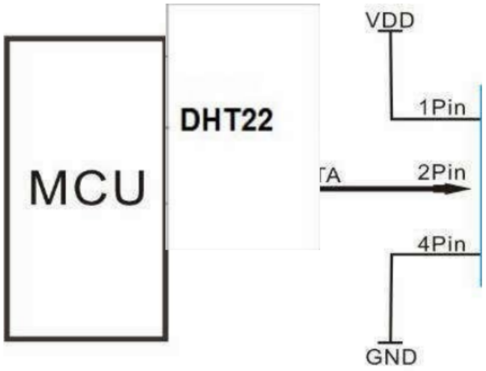


Figure 10: Pin layout of DHT22 sensor [27]

Table 3: Gas Sensor Subsystem – Requirements & Verification

Requirements	**Verification**
● The MQ sensors need to be supplied 5V to two components in each sensor in order to operate: Vc for power and Vh for heating.	● Before & after soldering the sensors, probe the ground and V_c/V_H pads/pins to ensure that the voltage across them is 5V±0.1V, supplied from an LDO.
● The sensors must be able to detect their respective gas ppm levels by giving an analog output (voltage). It must detect gas ppm levels below and above the threshold limits (see High Level Requirements).	● Before & after soldering the sensors, connect the sensors to power. Probe the ground and V_{RL} (see figure 5). Make sure when connected to power, the default analog output has a voltage reading within the ranges specified in the sensor datasheets [16] [17] [18] [19]. ● For example, the NH3 sensor must output <0.5V as its analog output, given CH4 contents are normally <50ppm. ● To test the sensor readings, first let the sensor heat up for >=4 hours for better accuracy. Provide concentrated gas samples surpassing the defined threshold limit to each sensor. Probe ground and V_{RL}, and make sure the analog output has a voltage reading within the ranges specified in the sensor datasheets. ● For example, the NH3 sensor must output ≥0.5V when exposed to ≥50 ppm of NH3. The supplied gas sample must contain sufficient NH3, e.g. from a cleaning product.
● The DH22 sensor needs to be supplied 3.3V in order to operate.	● Before & after soldering the sensor, probe the ground and V_c pad/pin to ensure that the voltage across them is 3.3V±0.1V, supplied from an LDO
● The DH22 sensor needs to read humidity and temperatures within its specified ranges in its datasheet: ○ Humidity 0-100% RH ○ Temperature: -40-80 Celsius	● To test the sensor readings, using an arduino, read the input of the DH22 sensors at standard room temperature/humidity. ● To test the sensor's detection of humidity, prepare a sample of humid air (via steam in a container). The sensor must output

	>50% RH from the arduino, which is the threshold of relative humidity [28]. ● To test the sensor’s detection of temperature, prepare samples of heat and cold (e.g. a hair blow dryer / container of air stuck in the freezer). Upon presenting the samples to the sensor, the sensor must output an increase/decrease in temperature from the arduino.

Display Unit

The display unit will display dangerous levels of gas with an audio alarm, a red LED and an LCD screen. Additionally, it will display low battery (when the battery drops below 7V) with a yellow LED and on the LCD screen. Lastly, the display unit will show the ppm readings of NH3, H2S, CH4, and CO on the LCD screen while it is on. This unit receives a 3.3V input from the power supply subsystem. The information that will be displayed on the LCD screen is transmitted from the control unit through SPI protocol.

In order for the LEDS to operate, they must be supplied with 1.3V. Since the STM32 GPIO pins operate with 5 mA current, we used the calculation in figure 7 to find the resistor needed to safely operate the LEDs.

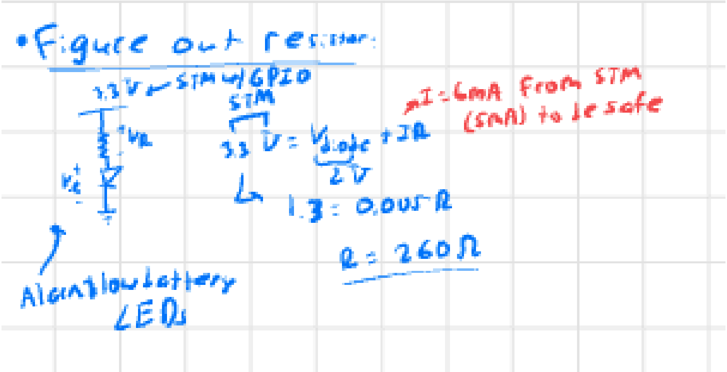


Figure 11: Calculations used for safe LED operation.

The alarm buzzer requires 30 mA of current in order to operate. Since the STM32 GPIO pins operate with 5 mA current, the GPIO will not supply enough current to sound the buzzer. To solve this issue, we decided on using a NMOS to toggle the buzzer. We used the calculation in figure 8 to design the circuit to safely and effectively operate the alarm buzzer.

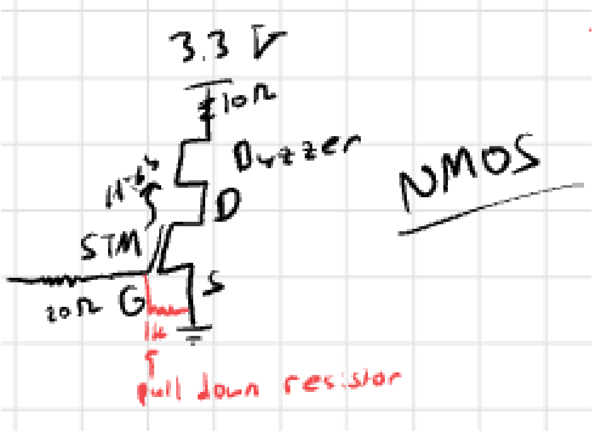


Figure 12: Calculations used for NMOS to operate the alarm buzzer.

- Alarm: AI-1223-TWT-3V-2-R
- LCD Screen: NHD-0420CW-AW3 (OLED Module 80 digits -> 4 rows of 20 characters)
- Alarm LED: LED Red Clear 0603 SMD
- Low Battery LED: Yellow Clear 0603 SMD

Table 4: Display Subsystem – Requirements & Verification

Requirements	**Verification**
● The red & yellow LEDs require 1.3V to operate.	● Before & after soldering the yellow & red LEDs, probe the connection between the pads with a multimeter to confirm that the voltage across is 1.3 ± 0.1V.
● When the battery voltage drops below 7V, the yellow LED must illuminate.	● To test the low battery LED, plug in a battery that has a capacity of <7V, or virtualize the battery GPIO reading to be less than the low battery threshold. ● After doing this, the low battery LED should be illuminated yellow.
● If there is a dangerous gas reading, the red LED must illuminate.	● To test the alarm LED, raise a flag in the code flashed to the STM32 that would virtualize a dangerous gas input, or virtualize a gas input to a dangerous reading. ● When the reading is virtualized, the alarm LED should be illuminating red.
● Alarm requires 30 mA of current to operate.	● Before & after soldering the alarm, probe the NMOS circuit used to toggle the alarm from the GPIO pin of the STM32 with a multimeter to confirm that there is 30 mA of current across it.
● When a gas exceeds a safe threshold, the alarm must sound within 0.5 ± 0.1s of receiving a dangerous threshold reading. It must sound until there is no longer a dangerous threshold reading present.	● To test the alarm, raise a flag in the code flashed to the STM32 that would virtualize a dangerous gas input, or virtualize a gas input to a dangerous reading. ● When the reading is virtualized, the alarm should sound without an audible delay, signifying a fast response. To test the 0.5 ± 0.1s threshold, time the GPIO clock cycle required to drive the alarm, and

	confirm that it is within 0.5 ± 0.1s of receiving a dangerous threshold reading.
● The LCD screen must receive 3.3V from the power supply	● With the device on, before & after connecting the LCD screen to its mount, probe the ground and supply voltage pins with a multimeter, and confirm that there is a 3.3V drop across them.
● The LCD screen must be able to be put to sleep by the user with a switch.	● Turn the device on. ● Once it is on, slide the switch to toggle the device on/off, and confirm that the device responds accordingly.
● When on, the LCD must be able to be visible in bright, regular and dim light.	● Turn on the device, and if the screen is off, hit the switch that toggles the display. ● Once the display is on, move the device between 3 levels of light, and confirm that the ppm levels and messages displayed on the LCD screen are still visible.
● When on, the LCD screen must be able to display the ppm of all 4 gasses detected every 0.5 ± 0.1 seconds (will be obvious if not– will be frame by frame otherwise).	● Turn on the device and LCD screen, and start reading values from the sensor unit. ● Confirm that the display shows the ppm readings of all 4 gasses detected. ● Confirm that the display is not like a "slideshow" or "framey"-- this would indicate that the display is not updating fast enough, and is not up to standard. If the display is smooth, and not choppy, this will pass based on the frame rate of the LCD system. For accuracy purposes, measure the SPI clock cycles and confirm that it takes less than 0.5 ± 0.1s to display gasses on the LCD screen after receiving the readings.
● When there is a dangerous gas reading, a warning message must be displayed on the LCD screen until the gas reading is back to a safe threshold.	● Raise a flag in the code flashed to the STM32 that would virtualize a dangerous gas input, or virtualize a gas input to a dangerous reading. ● Confirm that there is a warning message on the LCD screen regarding the dangerous gas input.

Software Design

Data Protocol

SPI: LCD Screen (Control Unit output, LCD input)
GPIO: Alarm, Alarm LED, Low_Battery LED (Control Unit output)
ADC: $V_{Battery}$ (Power output) and NH2, H2S, CH4, CO sensors (Sensor Board outputs)

State Diagram

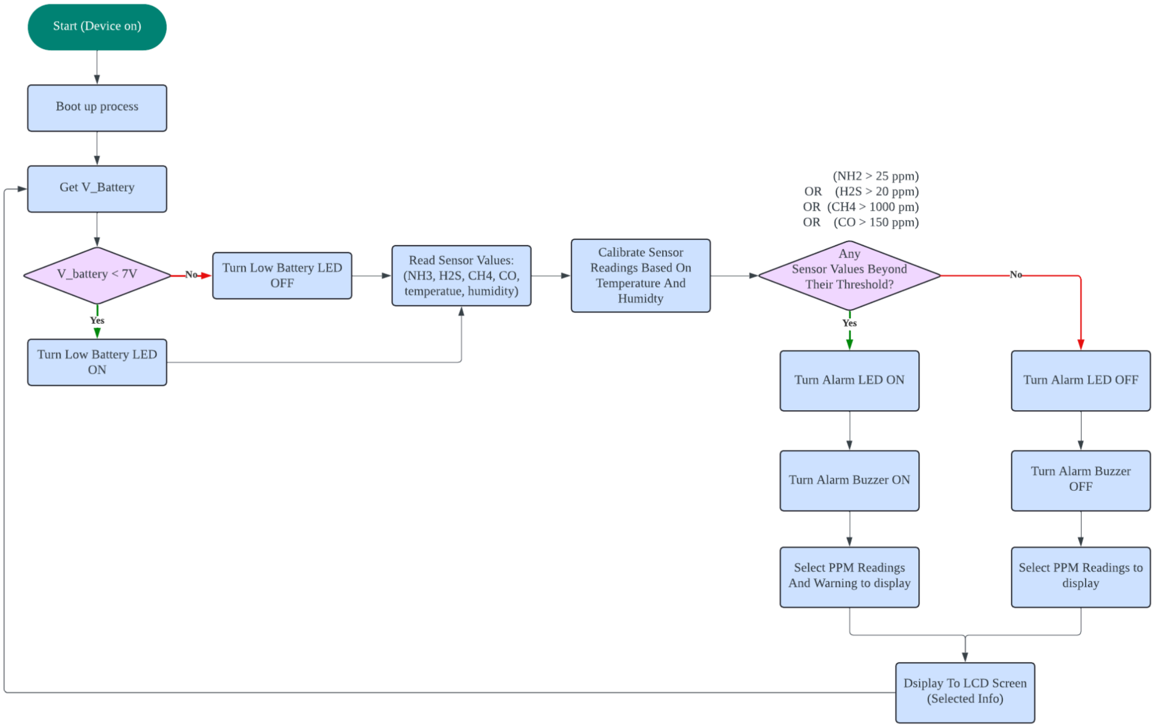

Start (Device on)
Boot up process
Get V_Battery
V_battery < 7V
No
Yes
Turn Low Battery LED OFF
Turn Low Battery LED ON
Read Sensor Values: (NH3, H2S, CH4, CO, temperatue, humidity)
Calibrate Sensor Readings Based On Temperature And Humidty
(NH2 > 25 ppm)
OR (H2S > 20 ppm)
OR (CH4 > 1000 pm)
OR (CO > 150 ppm)
Any Sensor Values Beyond Their Threshold?
Yes
No
Turn Alarm LED ON
Turn Alarm Buzzer ON
Select PPM Readings And Warning to display
Turn Alarm LED OFF
Turn Alarm Buzzer OFF
Select PPM Readings to display
Dsiplay To LCD Screen (Selected Info)

Figure 13: State diagram of the software design.

PPM Reading Conversion

We know that the sensors give an analog output. However, the device needs to read the following ranges of gas ppm levels:

1. NH3 (Ammonia) from 0-50 ppm [21]
2. H2S (Hydrogen Sulfide) from 0-50 ppm [22]
3. CH4 (Methane) from 500-10000 ppm [23]
4. CO (Carbon Monoxide) from 10-200 ppm [24]

Given that the sensors will give an analog output, the data still needs to be converted to ppm levels for the control unit to interpret. We will test out the conversions using an arduino before trying it on our STM32 as we are given open-source reference code that reads sensor values on an arduino. The below equations reference a website that reads data from a MQ-137 ammonia sensor [25]. The process could be broken into three parts:

1) Convert the data from an analog to voltage reading

   For the first step, The microprocessor will do an ADC read from the sensor output. It will receive a 10-bit value that represents voltage read from a resistor RL. Let's denote the voltage read as V_RL, where it ranges from 0-5V.

$$Vrl = analogRead(MQ\_sensor) * (5.0/1023.0)$$

2) Take the voltage reading to find the change in resistance in the sensor

   The second step is needed as the sensors have a variable resistance depending on the gas ppm contents. We are given the supply voltage Vc and the resistance RL used to read the sensor's output V_RL, which allows us to solve for Rs. Given the sensor datasheets have the same circuit layout, we can find the sensor's variable resistance using KVL [16] [17] [18] [19].

$$Vc = (Vrl * Rs/Rl) + Vrl$$

$$Rs = (Vc - Vrl) * Rl/Vrl$$

3) Use the change of resistance in the sensor to find ppm levels

   For the third step, the datasheets show graphs comparing this change Rs/Ro (y-axis) to the gas ppm levels (x-axis). Ro represents sensor resistance without the presence of the gas it detects, and Rs represents sensor resistance at various concentrations of the gas. We can find out these values via step 2. We will select points on the graph and create an equation between Rs/Ro and gas PPM levels to find PPM:

$$log(Rs/Ro) \ = \ m * log(PPM) \ + \ b$$

$$PPM = ((log10(Rs/Ro) - b)/m))$$

To circumvent inaccuracies relating to these two factors, we will adjust our sensitivity values Rs/Ro before converting it into gas PPM values (see Tolerance Analysis - Stable Sensor Unit Readings). For more consistent results, the sensor readings taken from the past ~5 seconds could be averaged to smoothen its output. This mitigates spikes that may happen from the sensor's analog output due to its readings being continuous.

Device Enclosure

As seen in the Visual Aid section, our device will have an enclosure that protects the internal PCB with sensors from the outside environment. The only parts of the enclosure that will show to the user are the 2 LEDs, the 2 power switches (1 for LCD, 1 for master on/off), and the LCD screen. These will be manually cut out, since our device will be made of plastic. In figure 14, you can see the approximate dimensions of our enclosure.

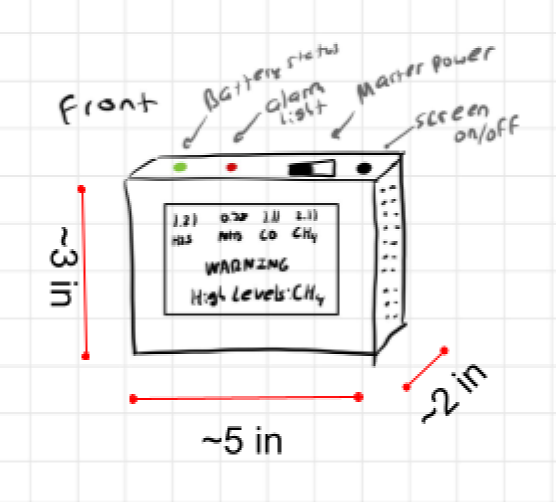


Figure 14: Dimensions of device enclosure

When choosing these dimensions, it is important to note the approximations. We felt that it would be better to leave a little more breathing room by over approximating than by giving exact specifications for how big things are going to be. The dimensions are heavily influenced by the size of the LCD screen, which is 3.6 inches x 1.25 inches. We chose to give some breathing room on all sides of the screen, since it will sit above our PCB. We also need to leave room for the LEDs, switches, and battery to be accessible to the user without moving the LCD screen around.

For the depth of the enclosure, we had to keep the sensors in mind. We are planning on designing a primary board with our control, display, and power units, and then a separate sensor board that we will put individual sensors on. The point of a separate sensor board is to be able to move the sensors around on the inside of our enclosure, having the boards be parallel to the depth of our enclosure. This will allow the sensor to point in the direction “outside” of the box, and be less influenced by the internal heat produced by the rest of our subsystems.

In order for the sensors to get readings through the enclosure, we are planning on poking small “breathing” holes on the side of the box, allowing small particles of air to get in and be read by the sensors.

Cost and Schedule

Labor

The average starting salary for an Electrical Engineering graduate from the University of Illinois Urbana-Champaign is $88,321, with an additional average signing bonus of $5,000 [26].

Given the average starting salary is about $88,321, the equivalent hourly rate is approximately $42.46. Using this rate, the labor cost for a project can be calculated by multiplying the hourly rate by 2.5 and then by the total number of hours required to complete the project. For our project, we estimate it will take us 100 hours of work, then the total labor cost for one partner would be $10,615. Therefore, with three partners working on the project, the total labor cost amounts to $31,845.

Power

PARTS

- 9V Battery: MN1604
- Battery Holder: 36-245-ND or HH-3634
- On/Off Slider: slider
- Connector: Connector and Connector Housings
- 3.3V LDO: TLV76733DGNR
- 5V LDO: TLV76750DGNR
- 1uF Capacitors: CL10B105KO8NNNC
- 10uF Capacitors: 1276-1096-2-ND
- 10kOhms Resistors: 311-10KJRTR-ND
- 20kOhms Resistors: P20.0KLTR-ND

COST

9V Battery:	$4.45
Battery Holder:	$2.53
On/Off Slider:	$0.63
Connector:	$0.35
3.3V LDO:	$0.92
5V LDO:	$0.92
1uF Capacitors (x2):	$0.10
10uF Capacitors (x2):	$0.10
10k Ohms Resistors:	$0.10
20k Ohms Resistor:	$0.10

Total Cost: $10.40 = (4.45 + 2.53 + 0.63 + 0.35 + 2*(0.92) + 2*(0.10) + 2*(0.10) + 0.10 + 0.10)

Gas Sensors

PARTS (From Manufacturer)

- Ammonia: MQ-137
- Hydrogen Sulfide: MQ-136
- Methane: MQ-4
- Carbon Monoxide: MQ-7
- Temperature & Humidity sensor: DHT22 / Aideepen 2302
- 4.7k Ohm Resistors (x4): RC0603FR-074K7L

COST

- Ammonia: $37.50
- Hydrogen Sulfide: $24.50
- Methane: $5.50
- Carbon Monoxide: $5.50
- Temperature & Humidity sensor: $10
- 4.7k Ohm Resistors (x4): $0.10

Total: $83.40 = (37.50 + 24.50 + 5.50 + 5.50 + 4*(0.10) + 10)

Control Unit

PARTS

- Microcontroller: STM32G030K8T6
- 5 pin debugging connector (through hole): SMC-1-05-1-GT
- 10 uF Capacitor (x2): 1276-1096-2-ND
- 4.7k Ohm Resistor (x6): RC0603FR-074K7L
- 100k Ohm Resistor (x3): ERJ-3EKF1003V

COST

- Microcontroller: $2.29
- Connector: $0.45
- Resistors: $0.20
- Capacitors: $0.20
- Resistors: $0.90

Total: $4.04 = (2.29 + 0.45 + 0.20 + 0.20 + 0.90)

Display Unit

PARTS

- Alarm: AI-1223-TWT-3V-2-R
- LCD screen: NHD-0420CW-AB3-ND
- LEDs:
  - Alarm LED: Red Clear 0603 SMD
  - Low battery LED: Yellow Clear 0603 SMD
- NMOS: 2N7002K-7
- Resistors:
  - 10 Ohms Resistor (x4): RC0805FR-0710RL
  - 20 Ohms Resistor: RC0603JR-0720RL
  - 1k Ohms Resistor(x2): RC0603FR-071KL
  - 270 Ohms Resistor (x2): RMCF0603JT270R
  - 10k Ohms Resistor: RMCF0603JT10K0
- 10uF Capacitor: 1276-1096-2-ND
- 20 pin connector: D01-9922046
- On/Off Slider: SLW-913535-2A-SMT

COST

- Alarm: $1.25
- LCD screen: $36.27
- LEDs:
  - Alarm LED: $0.15
  - Low battery LED: $0.15
- NMOS: $0.30
- Resistors:
  - 10 Ohms Resistor: $0.10
  - 20 Ohms Resistor: $0.10
  - 1k Ohms Resistor: $0.10
  - 270 Ohms Resistor (x2): $0.10
- 10uF Capacitor (x2): $0.10
- 20 pin connector: $1.22
- Slider: $0.63

Total Cost: $40.57 = (1.25 + 36.27 + 2*(0.15) + 0.30 + 3*(0.10) + 0.10 + 2*(0.10) + 1.22 + 0.63)

Total Component Cost: $127.41

Table 5: Itemized list of Components and Costs

Component	Manufacturer	Amount	Unit Price ($)	Link
9V Battery	Duracell Industrial Operations, Inc.	1	4.45	3046-9V-ND
Battery Holder	Keystone Electronics	1	2.53	36-245-ND
On/Off Slider	Same sky	2	0.63	SLW-913535-2A-SMT
Connector	Molex	1	0.21	900-0022232021-ND
Connector Housings	Molex	1	0.14	900-0022013027-ND
3.3V LDO	Texas Instruments	1	0.92	TLV76733DGNR
5V LDO	Texas Instruments	1	0.92	TLV76750DGNR
1uF Capacitors	Samsung Electro-Mechanics	2	0.10	CL10B105KO8NNNC
10uF Capacitors	Samsung Electro-Mechanics	5	0.10	1276-1096-2-ND
10kOhms Resistors	Stackpole Electronics Inc	2	0.10	RMCF0603JT10K0
20kOhms Resistors	YAGEO	1	0.10	RC0402FR-0720KL
Ammonia Sensor	SparkFun Electronics	1	37.50	MQ-137
Methane Sensor	SparkFun Electronics	1	5.50	MQ-4
Carbon Monoxide Sensor	SparkFun Electronics	1	5.50	MQ-7
Hydrogen Sulfide Sensor	SparkFun Electronics	1	24.5	MQ-136
Temperature & humidity sensor	Aideepen	1	10	Aideepen 2302
4.7 k Ohms Resistor	Stackpole Electronics Inc	10	0.10	RMCF0603JT10K0
Microcontroller	STMicroelectronics	1	2.29	STM32G030K8T6

5 pin debugging connector (through hole)	Adam Tech	1	0.45	SMC-1-05-1-GT
100k Ohms Resistor	Panasonic Electronic Components	3	0.10	ERJ-3EKF1003V
Buzzer	PUI Audio, Inc.	1	1.25	AI-1223-TWT-3V-2-R
LCD Screen	Newhaven Display Intl	1	36.27	NHD-0420CW-AB3-ND
Red LED	Würth Elektronik	1	0.15	150060RS75000
Yellow LED	Würth Elektronik	1	0.15	150060YS75000
NMOS	Diodes Incorporated	1	0.17	2N7002K-7
10 Ohms Resistor	YAGEO	4	0.10	RC0805FR-0710RL
20 Ohms Resistor	YAGEO	1	0.10	RC0603JR-0720RL
1k Ohms Resistor	YAGEO	2	0.20	RC0603FR-071KL
270 Ohms Resistor	Stackpole Electronics Inc	2	0.10	RMCF0603JT270R
20 pin connector	Harwin Inc.	1	5.73	D01-9922046
Labor: $31,845				
Total: $31,972.41 = 127.41 + 31,845				

Schedule

Week	Deadlines	Task	Person
September. 30th - October. 6th	10/3: Design Document Due	Work on Design Document	Everyone
		Order sensors for prototyping	Jeff
		Order LCD Screen for prototyping	David
		Order LDOs and 9V battery for prototyping	John
		Primary & sensor board PCB	Everyone
October. 7th - October. 13th	10/x: Design Review 10/11: PCB Review	Design & PCB Review	Everyone
		Select a device enclosure	Everyone
		Start prototyping LCD screen on STM32 Nucleo	David
		Build the prototype voltage regulator circuit on a breadboard	John
		Breadboarding sensor prototype for readings	Jeff
October. 14th - October. 20th	10/15: PCB Order #1 10/16: Team Evaluation #1	Team Evaluation	Everyone
		Manufacture/order device enclosure	Everyone
		Power switch, LEDs, voltage divider for battery, and alarm implementation on breadboard	John
		LCD Screen interface completed with Nucleo	David
		Algorithm to convert sensor outputs from Analog to ppm	Jeff
October. 21th - October. 27th	10/22: PCB Order #2	Manufacture PCB	Everyone
		Test PCB Voltage & Current connections across all pads	Everyone

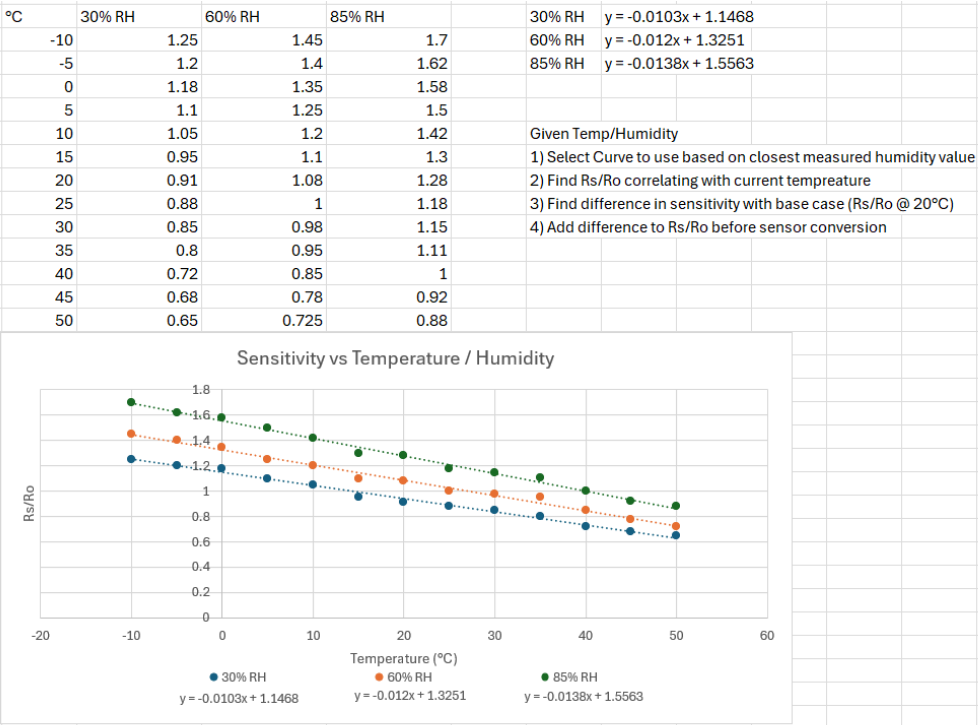
		Design Changes	Everyone
		Software for reading battery voltage, illuminating LEDs and triggering alarm	John
		Control unit logic completed	David
		Test converted ppm readings from sensors via Arduino	Jeff
October. 28th - November. 3rd	10/29: PCB Order #3	Manufacture PCB	Everyone
		Design Changes	Everyone
		Alarm, LEDs, battery logic and LCD on/off switch	John
		LCD UI logic & interface	David
		Integrating primary & sensor boards for distribution across all subsystems.	Jeff
November. 4th - November. 10th	11/5: PCB Order #4 11/6: Progress Report	Manufacture PCB	Everyone
		Design Changes	Everyone
		Integrating all Subsystems	Everyone
November. 11th - November. 17th	11/12: PCB Order #5	Manufacture PCB	Everyone
		Assemble device enclosure	Everyone
		Test final product, bug fixes	Everyone
November. 18th - November. 24th	11/x: Mock Demo 11/22: Team Contract Fulfillment	Mock Demo	Everyone
		Evaluate Team Contract	Everyone
November. 25th - December. 1st	Break	Presentation Slides, Paper & Final Demo	Everyone
December. 2nd - December. 8th	12/x: Final Demo 12/x: Mock Presentation	Work on Presentation Slides & Final Paper	Everyone
December.9th - December. 15th	12/x: Final Presentation 12/11: Final Paper 12/12: Lab Notebook	Turn in lab Notebook Finish Final Paper	Everyone

Tolerance Analysis

Stable Sensor Unit Readings

The sensor unit component is a critical component for the device's fundamental functionality. However, the MQ-Sensors may produce skewed data due to temperature and humidity. The MQ sensor's are altered to react differently to different gasses, but their identical design makes their change of their sensitivity Rs/Ro identical to temperature/humidity when looking at their datasheets.

The sensor data sheets contain a relation between sensor sensitivity Rs/Ro and temperature/humidity [16] [17] [18] [19]. Using the data, we will use a scatter plot to derive approximate curves relating temperature to sensitivity for different humidities. For simplicity, the curve is a linear trend line.



°C	30% RH	60% RH	85% RH
-10	1.25	1.45	1.7
-5	1.2	1.4	1.62
0	1.18	1.35	1.58
5	1.1	1.25	1.5
10	1.05	1.2	1.42
15	0.95	1.1	1.3
20	0.91	1.08	1.28
25	0.88	1	1.18
30	0.85	0.98	1.15
35	0.8	0.95	1.11
40	0.72	0.85	1
45	0.68	0.78	0.92
50	0.65	0.725	0.88

30% RH	y = -0.0103x + 1.1468
60% RH	y = -0.012x + 1.3251
85% RH	y = -0.0138x + 1.5563

Given Temp/Humidity

1) Select Curve to use based on closest measured humidity value

2) Find Rs/Ro correlating with current tempreature

3) Find difference in sensitivity with base case (Rs/Ro @ 20°C)

4) Add difference to Rs/Ro before sensor conversion

Figure 15: Graphs containing curves relating sensor sensitivity to temperature/humidity. Measured Points are prone to Rs/Ro ± 0.05 error due to human error.

The figure indicates that temperature and humidity are non-trivial factors that may significantly affect the sensor readings. Normally, the MQ sensors use a constant humidity at 60% RH and temperature at 20°C to measure gas ppm levels (see Software Design - PPM Reading Conversion). Its base sensitivity in this range is Rs/Ro=1.08 for all MQ sensors, using different gas ppm levels depending on the sensor to set this constant.

The following shows how much these variables may skew this sensitivity reading:

- Humidity: At 20°C, a humidity at 85% RH will skew the sensitivity Rs/Ro≈1.28, so the sensor may be off by error≈abs(1.28-1.08/1.08)≈18.5% from its original value.
- Temperature: At 60% RH, a temperature at 50°C will skew the sensitivity Rs/Ro≈0.725 (at 50°C),so the sensor may be off by error=abs(0.725-1.08/1.08)≈27.5% from its original value.

To mitigate inaccuracies relating to these two factors, we will adjust our read sensitivity values before converting it into gas PPM values. Given that our DHT22 sensor reads temperature and humidity, we could do the following steps:

1. Select the curve (see Figure 14) to use based on closest measured humidity value
    a. 30% RH: $y = -0.0103x + 1.1468$
    b. 60% RH: $y = -0.012x + 1.3251$
    c. 85% RH: $y = -0.0138x + 1.5563$
2. Using the measured temperature (=x), find Rs/Ro (=y)
3. Find the difference between Rs/Ro and base case sensitivity (Rs/Ro @ 20°C, 60% RH)
4. Add this difference in to the read Rs/Ro before converting it to gas ppm levels

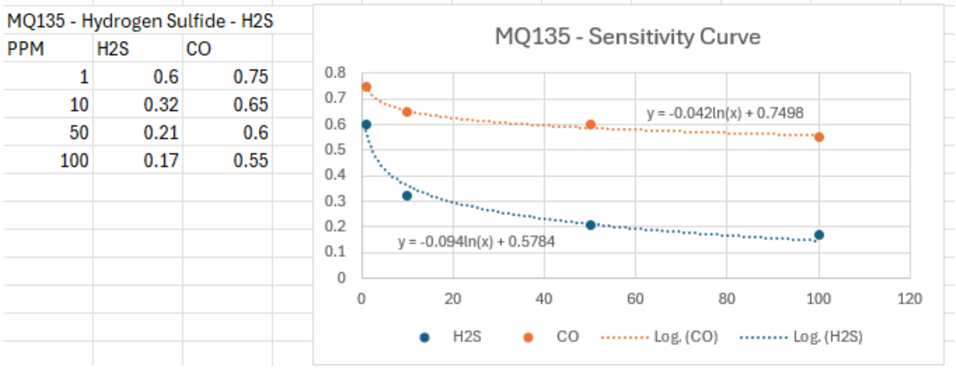
One other issue that we did not account for is that some of our MQ gas sensors are responsive to several gasses, which may lead to false readings. This is a repercussion of using cheaper sensors for a budget odor detector. The intended gasses the sensors are supposed to read are the following: MQ-137 reads NH_4, MQ-136 reads H_2S, MQ-4 reads CH_4, and MQ-7 reads CO.

Here are the all the gasses each MQ gas sensor reads (for reference, See below figures):

1. The MQ-137 only reacts to NH_4.
2. The MQ-136 reacts to CO on top of H_2S. H_2S sensitivity is much higher than CO's.
3. The MQ4 reacts to C_3H_8 and Alcohol on top of CH_4.
4. The MQ-7 reacts to CH_4 and H_2 on top of CO.

The problem arises whenever the curves for different gasses have the same Rs/Ro anywhere on the graph, leading to false readings of the intended gas from the sensor. The sensors that have this issue are the MQ4 and the MQ7. All of these gasses that the MQ4 reads are flammables, which means that false positives influenced from the other gasses are likely fine.

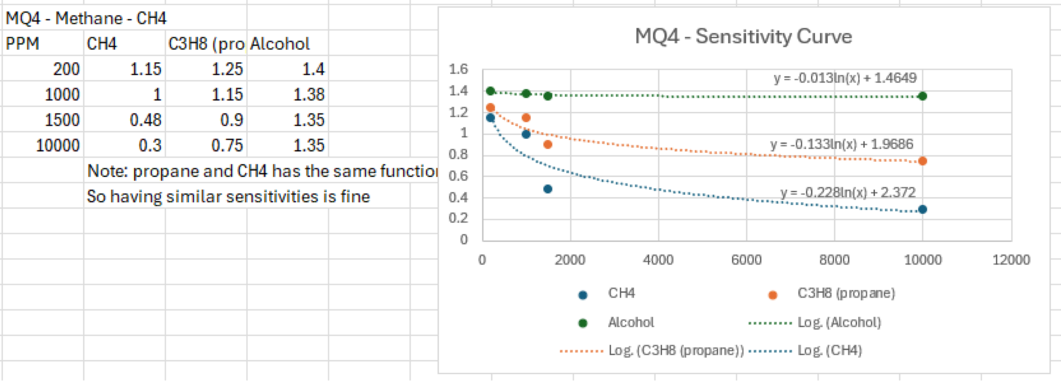
This leaves only the MQ7 sensor where conflicting gasses may pose a threat to its accuracy. The CH_4 sensitivity curve intersects CO's starting at ppm ~=100 (see figure 17). Given our device triggers at 150 ppm CO (see High Level Requirements) and the figure 17's approximate CO ppm curve $y=-0.05\ln(x) + 0.3379$, we could get the sensitivity Rs/Ro to be about 0.0873682 at 150 ppm CO. Given the sensitivity and the approximate CH_4 ppm curve $y = -0.072\ln(x) + 0.5983$, there must be approximately 1207.46 ppm of CH_4 to reach 150 ppm to trigger a false positive for the alarm. Keep in mind our alarm will trigger at 1000 ppm of CH_4, meaning a triggered alarm is still warranted given that only CH_4 is present. However, this means that due to the presence of CH_4, the readings for CO may be higher than intended and the alarm for CO may be preemptively triggered at levels below 150 ppm CO.



MQ135 - Hydrogen Sulfide - H2S

PPM	H2S	CO
1	0.6	0.75
10	0.32	0.65
50	0.21	0.6
100	0.17	0.55

Figure 16: Sensitivity Curve for MQ135 for different gasses [17]



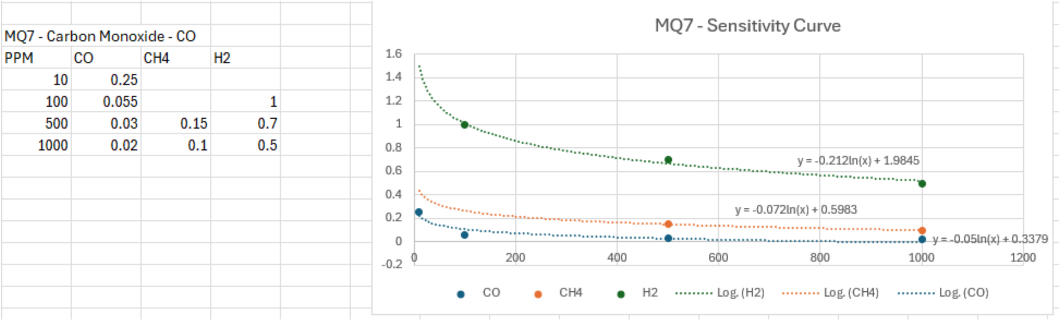
MQ4 - Methane - CH4

PPM	CH4	C3H8 (pro	Alcohol
200	1.15	1.25	1.4
1000	1	1.15	1.38
1500	0.48	0.9	1.35
10000	0.3	0.75	1.35

Note: propane and CH4 has the same functio

So having similar sensitivities is fine

Figure 17: Sensitivity Curve for MQ4 for different gasses [18]



MQ7 - Carbon Monoxide - CO

PPM	CO	CH4	H2
10	0.25		
100	0.055		1
500	0.03	0.15	0.7
1000	0.02	0.1	0.5

Figure 18: Sensitivity Curve for MQ7 for different gasses [19]

Stable Power Supply Unit

The power supply subsystem is a critical component in ensuring the reliable operation of our device. Specifically, the voltage regulator's ability to maintain a stable 3.3V and 5V outputs is crucial, as deviations beyond the specified tolerance of ±5% could lead to insufficient power delivery to the components. The chosen voltage regulator for this subsystem is the TLV76733DGNR, which must step down a 9V input from a battery to 3.3V while maintaining stability under varying load conditions. The same analysis applies to the TLV76750DGNR, which steps down the input voltage to 5V.

The TLV76733DGNR voltage regulator is designed to output a fixed 3.3V. According to the datasheet [6], the regulator has a dropout voltage V_DO ranging from 0.9V typical to 1.5V maximum at 1A load current for the DGN package. Under extreme conditions where the battery supplies 1A of current, the minimum voltage inputs are as follows:

$$V_{IN} >= V_{OUT} + V_{DO} = 3.3V + 1.5V = 4.8V$$

$$V_{IN} >= V_{OUT} + V_{DO} = 5V + 1.5V = 6.5V$$

Given that our input is a 9V battery, the input voltage is well above this threshold, even as the battery is under a low power status (7V).

In addition to the regulator itself, decoupling capacitors are placed on both the input and output to stabilize the voltage. By referring to the recommended operating conditions in the datasheet, we choose a 1µF capacitor on the input that helps smooth out voltage fluctuations, while a 10µF capacitor on the output ensures the stability of the 3.3V or 5V, filtering out any potential noise.

Besides, power dissipation is a crucial factor to consider, especially since the TLV767XXDGNR is a linear regulator, which dissipates excess energy as heat. An excessive amount of heat, 180 celsius temperature, will cause a thermal shutdown. The power dissipated by the regulator as heat can be expressed by:

$$P_{DISS} = (V_{IN} - V_{OUT}) * I_{OUT}$$

Given a 9V input and a 3.3V output with a maximum 1A load, the power dissipated would be:

$$P_{DISS} = (9V - 3.3V) * 1A = 5.7W$$

$$P_{DISS} = (9V - 5V) * 1A = 4W$$

This amount of power will be converted into heat, which must be managed to avoid thermal shutdown. The regulator's junction-to-ambient thermal resistance for the DGN is R_θJA=60.1°C/W. The junction temperature (T_J) can be estimated as:

$$T_J = T_A + (R_{\theta JA} * P_{DISS})$$

Assuming an ambient temperature T_A of 25°C:

$$T_J = 25 + (60.1 * 5.7) = 367.57°C$$

$$T_J = 25 + (60.1 * 4) = 265.4°C$$

These calculations show that, under extreme conditions, the junction temperature exceeds the maximum operating limit of 180°C, increasing the importance of effective thermal management. This will be achieved by connecting the thermal pad to a copper pad area to enhance heat dissipation.

It is important to note that these calculations represent extreme conditions with maximum current draw and without thermal protection. In practice, the actual current used by the components is much lower: for 3.3V output the required current is 300mA and 600mA for the 5V output. The thermal pad will further decrease the temperature of these regulators which ultimately leads to a significantly less power dissipation and thermal stress.

Noise Attenuated Analog to Digital Conversion (ADC) Readings

The control unit plays a critical role in being a central system of our odor detector. The control unit, manned by an STM32G0, connects all other subsystems together in a centralized hub. It monitors the current voltage capacity of the battery from the power subsystem. It takes in readings from all of the sensors in the sensor subsystem. And lastly, it controls our display, alarm, and LEDs in our display unit.

In order to communicate with other subsystems, we will be using GPIOs on our STM32 microcontroller. We are planning on using SPI protocol over an SPI interface in order to communicate with the LCD screen in the display unit, and simple GPIO read and write instructions will suffice for illuminating the LEDs, and toggling our alarm in the display unit. However, for monitoring the voltage of the 9V battery powering our device, and getting data readings from our sensors, we are planning on using ADC through GPIO pins on our microcontroller. This must be done in order to get analog readings into digital data that we can work with, and use in our state machine that will control the logic for toggling our display unit.

However, the main risk and issue with using ADC is high frequency noise that will occur due to impedance on the ADC inputs, and interference across the PCB from other devices that use other forms of communication protocol.

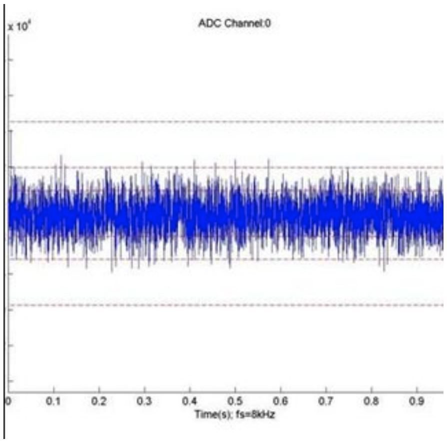


Figure 19: High Frequency Noise associated with ADC channel [29]

One of the best solutions to reducing noise, especially high frequency noise caused by other frequencies on the ADC channel, is by adding a capacitor. By adding a capacitor to the circuit, the capacitor must charge and discharge, allowing the voltage dip between the input and output to be staggered. As a result, the capacitor will absorb this higher energy in the form of high frequency noise, and will stabilize the voltage reading. In theory, this stabilization should result in the noise being attenuated enough to get a smoother, less noisy reading from our ADC channels.

Another solution on a software side, has already been mentioned– taking the average of a few seconds (likely 5 seconds) of sensor readings in order to manage outliers that may come through. In theory, this is called “oversampling”. Though we are still technically sampling at the same rate, by taking the average of many samples, we attenuate any values that would be considered “noise”.

Ethics & Safety

IEEE Guidelines [1]

Guidelines for the Project

- I.1:
    a) The Device needs to accurately read gas levels and detect dangerous thresholds. These dangerous thresholds must reach OSHA standards or state/industry standards if not regulated by OSHA.
    b) The Device needs to properly alert the user upon detecting a dangerous threshold(s) of gas
- I.2: We will disclose the technical aspects of our device and its capabilities/implications it will or may bring from it.
- I.3: We will avoid real or perceived conflicts of interest whenever possible, and to disclose them to affected parties when they do exist.
- I.4: We will not have unlawful conduct in professional activities, and will reject any form of bribery.
- I.5:
    c) If there are any deficiencies in the Device, we will report it.
    d) We will not have false or skewed data that may mislead the customer.
- I.6: We will improve the product whenever possible according to our technical abilities.

Guidelines for Team Dynamic

- II.7: We will treat each other uniformly regardless of our backgrounds/identities/predispositions.
- II.8: We will not harass each other in any form.
- II.9: We will avoid injuring others and/or conduct malicious actions, physically or verbally.
- III.10: We will support upholding this code of ethics with colleagues/co-workers, and will not retaliate against those who file violations against us.

IRB / IACUC Approvals

- The product's testing does not involve human/animal subjects, so IRB and IACUC approvals are not required.

Citations & References

[1] IEEE, “IEEE Code of Ethics,” *ieee.org*, Jun. 2020. https://www.ieee.org/about/corporate/governance/p7-8.html

[2] M. Kronenbuerger and M. Pilgramm, “Olfactory Training,” *PubMed*, 2022. https://www.ncbi.nlm.nih.gov/books/NBK567741/

[3] Joce Sterman and Bailey Williams, InvestigateTV. “Silent Threat: Gas Explosions Injured Hundreds, Killed Dozens Nationwide since 2010.” *Https://Www.Wbtv.Com*, 18 July 2022, www.wbtv.com/2022/07/18/silent-threat-gas-explosions-injured-hundreds-killed-dozens-nationwide-since-2010/.

[4] Weller, Zachary D, et al. “A National Estimate of Methane Leakage from Pipeline Mains in Natural Gas Local Distribution Systems | Environmental Science & Technology.” *ACS Publications*, 10 June 2020, pubs.acs.org/doi/10.1021/acs.est.0c00437.

[5] AARON, ANGIE MORESCHI and NATHAN. “2023 Was the Deadliest Year for Gas-Related Home Explosions in Decades.” *WPMI*, 15 Apr. 2024, mynbc15.com/sponsored/spotlight/2023-deadliest-year-for-gas-related-home-explosions-in-20-years.

[6] Texas Instruments, “TLV767 1-A, 16-V Precision Linear Voltage Regulator,” Dec. 2017. Accessed: Sep. 17, 2024. [Online]. Available: https://www.ti.com/lit/ds/symlink/tlv767.pdf?ts=1726554338155&ref_url=https%253A%252F%252Fwww.mouser.fr%252F

[7] Duracell Industrial Operations, “MN1604 Size: 9V (6LR61) Alkaline-Manganese Dioxide Battery.” Available: https://www.duracell.com/wp-content/uploads/2016/03/MN1604_US_CT1.pdf

[8] ST Electronics, “STM32G030K8T6 Microcontroller” Jan. 2012. Accessed: Sep. 17, 2024. [Online]. Available: https://www.st.com/resource/en/datasheet/stm32g030c6.pdf

[9]“Ammonia Detectors.” *Calibration Technologies*, 9 Oct. 2023, ctigas.com/ammonia-gas-detection/#:~:text=Ammonia%20detectors%20located%20in%20refrigerated,levels%20is%200%2D100%20ppm.

[10] “Https://Nj.Gov/Health/Eoh/Rtkweb/Documents/Fs/0084.Pdf.” New Jersey Department of Health, Feb. 2016.

[11] “Hydrogen Sulfide - Hazards.” *Occupational Safety and Health Administration*, 2024, www.osha.gov/hydrogen-sulfide/hazards.

[12] Atia , Atta. “Methane Safety .” Alberta Agriculture, Food and Rural Development, Aug. 2004.

[13] “Carbon Monoxide Poisoning .” OSHA , Apr. 2012. https://www.osha.gov/sites/default/files/publications/carbonmonoxide-factsheet.pdf

[14] Peavey, Jason. “Does Your Carbon Monoxide Detector Work?: PV Heating, Cooling.” *PV Heating, Cooling & Plumbing*, 26 Dec. 2023, www.pvhvac.com/blog/does-your-carbon-monoxide-detector-really-protect-you/.

[15] SparkFun, *SparkFun Gas Sensor Breakout*. https://www.sparkfun.com/products/8891

[16] Winsen Electronics, “Ammonia Gas Sensor (Model：MQ137) Manual,” 2015. Accessed: Sep. 17, 2024. [Online]. Available: https://cdn.sparkfun.com/assets/7/0/2/f/8/MQ137__Ver1.4__-_Manual.pdf

[17] Winsen Electronics, “Hydrogen Sulfide Gas Sensor (Model：MQ136) Manual,” 2015. Accessed: Sep. 17, 2024. [Online]. Available: https://cdn.sparkfun.com/assets/d/e/3/8/6/MQ136__Ver1.4__-_Manual.pdf

[18] Winsen Electronics, “Flammable Gas Sensor (Model：MQ-4) Manual,” 2014. Accessed: Sep. 17, 2024. [Online]. Available: https://cdn.sparkfun.com/datasheets/Sensors/Biometric/MQ-4%20Ver1.3%20-%20Manual.pdf

[19] Winsen Electronics, “Toxic Gas Sensor (Model：MQ-7) Manual,” 2014. Accessed: Sep. 17, 2024. [Online]. Available: https://cdn.sparkfun.com/datasheets/Sensors/Biometric/MQ-7%20Ver1.3%20-%20Manual.pdf

[20] Kim. *Sandbox Electronics*, 3 Feb. 2014, sandboxelectronics.com/?p=165.

[21] Renke, “Ammonia Sensor, NH3 Transmitter - Renke,” *Environment Monitoring Sensors Manufacturer*, Aug. 12, 2024. Accessed: Sep. 17, 2024. [Online]. Available: https://www.renkeer.com/product/ammonia-sensor/#:~:text=Ammonia%20sensor%20has%20three%20measuring.

[22] GDS Corp, “What Is a Hydrogen Sulfide/H2S Sensor?,” *Global Detection Systems Corp*, 2019. Accessed: Sep. 17, 2024. [Online]. Available: https://www.gdscorp.com/h2s-sensor/#:~:text=An%20H2S%20gas%20Sensor%20can.

[23] Gas Sensing, “Gas Sensor Aeroqual Methane (CH4) Sensor”, *Gas Sensing,* Accessed: Sep. 17, 2024. [Online]. Available: https://www.gas-sensing.com/aeroqual-methane-sensor-0-10000-ppm-mt.html#:~:text=10000%20ppm%20(MT)-,Methane%20Sensor%20Head%20uses%20Gas%20Sensitive%20Semiconductor%20(GSS)%20technology%20to,accuracy%20and%201%20ppm%20resolution.

[24] “Carbon Monoxide Levels,” Kidde, https://www.kidde.com/home-safety/en/us/support/help-center/browse-articles/articles/what-are-the-carbon-monoxide-levels-that-will-sound-the-alarm.html (accessed Sep. 17, 2024).

[25] E. Electronics et al., “Measuring PPM from MQ Gas Sensors using Arduino (MQ-137 Ammonia),” Circuit Digest, Feb. 09, 2018. https://circuitdigest.com/microcontroller-projects/arduino-mq137-ammonia-sensor

[26] G. E. O. of M. and Communications, “Electrical Engineering,” grainger.illinois.edu. https://grainger.illinois.edu/academics/undergraduate/majors-and-minors/electrical-engineering

[27] Aosong Electronics Co., “Digital-output relative humidity & temperature sensor/module”, Accessed: Oct. 1, 2024. [Online]. Available: https://www.sparkfun.com/datasheets/Sensors/Temperature/DHT22.pdf

[28] Molekule, “What Is Relative Humidity, and What’s an Ideal Level for Your Home?,” Accessed: Oct. 1, 2024 [Online]. Available: https://molekule.com/blogs/all/what-is-relative-humidity

[29] *Fig. 4. Power Spectral Density of ADC LTC2145 Input Stage Noise. The...*, www.researchgate.net/figure/Power-spectral-density-of-ADC-LTC2145-input-stage-noise-The-measurement-was-performed_fig3_317486761. Accessed 3 Oct. 2024.