

Compact Electronic Nose for Food Identification and Freshness Monitoring Design Document

ECE 445 Senior Design Laboratory

Team 29

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1 Introduction

1.1 Problem

Fresh fruit is a common part of everyday food storage, especially for people who buy several pieces at once for convenient breakfasts, snacks, or meal preparation. For example, someone may purchase a bunch of bananas at the beginning of the week with the intention of eating them over the next several days. However, after eating only a few of them, the remaining fruit can easily be forgotten in the refrigerator as other food is purchased and daily routines change. This is a particularly common problem with refrigerated fruit because, unlike food left in an open or frequently used area, it may remain out of sight for long periods of time.

To begin, fruit stored inside a refrigerator can continue to ripen and eventually spoil without being noticed by the user. Bananas, in particular, are climacteric fruits that continue to undergo ripening and quality deterioration after harvest and during storage [1]. When a person no longer plans to eat the fruit immediately, there is little reason to repeatedly look at or inspect it. In addition, the refrigerator itself creates a physical and visual separation between the user and the stored food. As a result, early signs of spoilage, such as changes in appearance or smell, may not be noticed during normal daily activity. In many cases, the fruit is only discovered again after a noticeable odor develops, at which point it may already be significantly overripe or spoiled.

Next, unnoticed fruit spoilage can lead to several practical problems beyond simply losing the fruit itself. The most direct consequence is unnecessary food waste, since fruit that could have been consumed earlier must instead be discarded. Spoiled food also contributes to household waste and the environmental impact associated with producing, transporting, refrigerating, and eventually disposing of food that is never consumed [2]. Furthermore, severely spoiled fruit stored near other foods may create unpleasant odors, leaking liquids, or conditions that can affect the cleanliness and safety of the surrounding storage area. Therefore, the difficulty of recognizing fruit spoilage early, particularly when the fruit is stored inside an enclosed and infrequently inspected space, represents a common problem in everyday food storage.

1.2 Solution and Project Objective

To address this problem, we will place both the fruit and the entire sensing board inside the same enclosed container to simulate a refrigerator-like environment. First, gases released by the fruit will be detected by four chemical gas sensors. The analog outputs from these sensors will then be sent to an ADC, which will convert the analog signals into digital data and pass them to an STM32 microcontroller. At the same time, a temperature and humidity sensor will collect environmental data and send it directly to the STM32.

We will then process all of the collected sensor data using predefined thresholds and response patterns stored within the microcontroller. These patterns will be determined through prior testing and will represent the sensor responses associated with different fruits and different stages of spoilage. The STM32 will compare the newly collected data against these predefined conditions to determine whether the fruit is still fresh or has begun to spoil. Finally, we will connect the STM32 to a computer through UART so that the processed result can be displayed and monitored by the user.

1.3 Visual Aid

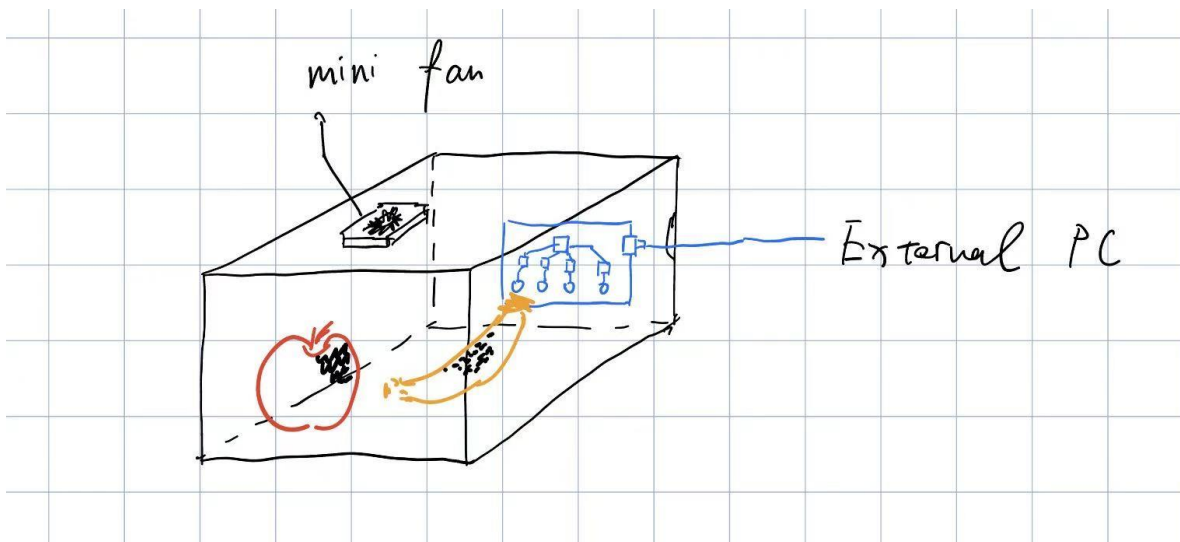


Figure 1. Intended use of the electronic nose. A fruit sample is measured in a closed chamber, and the computer records the response and displays the estimated fruit and stage.

1.4 High Level Requirements

To consider our project successful, our electronic nose must fulfill the following:

1. Our system is able to distinguish between different stages of spoilage for a single type of fruit, such as identifying the change from a fresh condition to a spoiled condition based on the characteristic response pattern of the gas sensors.
2. Our system is able to identify distinct spoilage-response patterns for at least two different types of fruit, such as bananas and apples, using the combined measurements from the four gas sensors.
3. Our system is able to correctly classify at least 70% of independently tested fruit samples whose freshness or spoilage conditions are known beforehand, under the same controlled testing procedure.

2 Design

2.1 Physical Design

For the physical design, we will use a simple transparent rectangular container. The system consists of four main parts: the container, the removable lid, the sensor board, and the fan. The fruit will be placed at the bottom of the container. The lid will rest on top and can be lifted off when we need to replace the fruit. Small magnets may be added at the four corners to help hold the lid in place.

The sensor board will be secured to the underside of the lid, with the four gas sensors facing down into the container. This keeps the sensors above the fruit and allows them to measure the gases released into the surrounding air without touching the sample. The temperature and humidity sensor on the board will also measure the conditions inside the container. Since the board is attached to the lid, it can be lifted out together with the lid when we need to access the inside.

The fan will also be mounted on the underside of the lid, next to the sensor board and fully inside the container. We will use the fan to help clear the remaining gases when changing fruit samples. During ventilation, the lid will be held slightly open so that air can move between the container and the room. This helps reduce the effect of the previous fruit sample on the next measurement.

Before taking measurements, we will also use the fan to bring fresh air into the empty container for a baseline reading. Once the sensors have warmed up and their readings are stable, we will record this baseline. We will then place the fruit inside, close the lid, and turn off the fan. Measurements will begin after a consistent waiting period so that each sample is tested under similar conditions.

The fan will have a separate manual on/off switch and will not be controlled by the sensor board. Turning the switch on will start the fan for ventilation, and turning it off will stop the fan for measurement. The STM32 on the sensor board will process the sensor readings and send the selected data or results to the computer through the UART connection. A thin cable will pass through a small opening in the side of the container and run close to the wall. A short length of slack inside will allow the lid to be lifted without pulling on the connection.

2.2 Block Diagram and System Operation

Figure 2 shows the block diagram of this project. The container presents a repeatable space to the gas-sensing subsystem. The sensing subsystem converts the changing odor mixture into four electrical signals(analog at first). The microcontroller will receive the digital signal after ADCs sample those signals together with temperature and humidity. Then it will process the data, and send the final decision to the computer. The computer will act as a monitor and a debugger as well(through UART).

Power and heater control support the sensor board, while the fan prepares the chamber for a new test. These two paths do not determine the fruit label directly, but they affect whether a measurement is valid. This separation lets the team verify the container, electronics, data transfer, and classifier independently before evaluating the complete system.

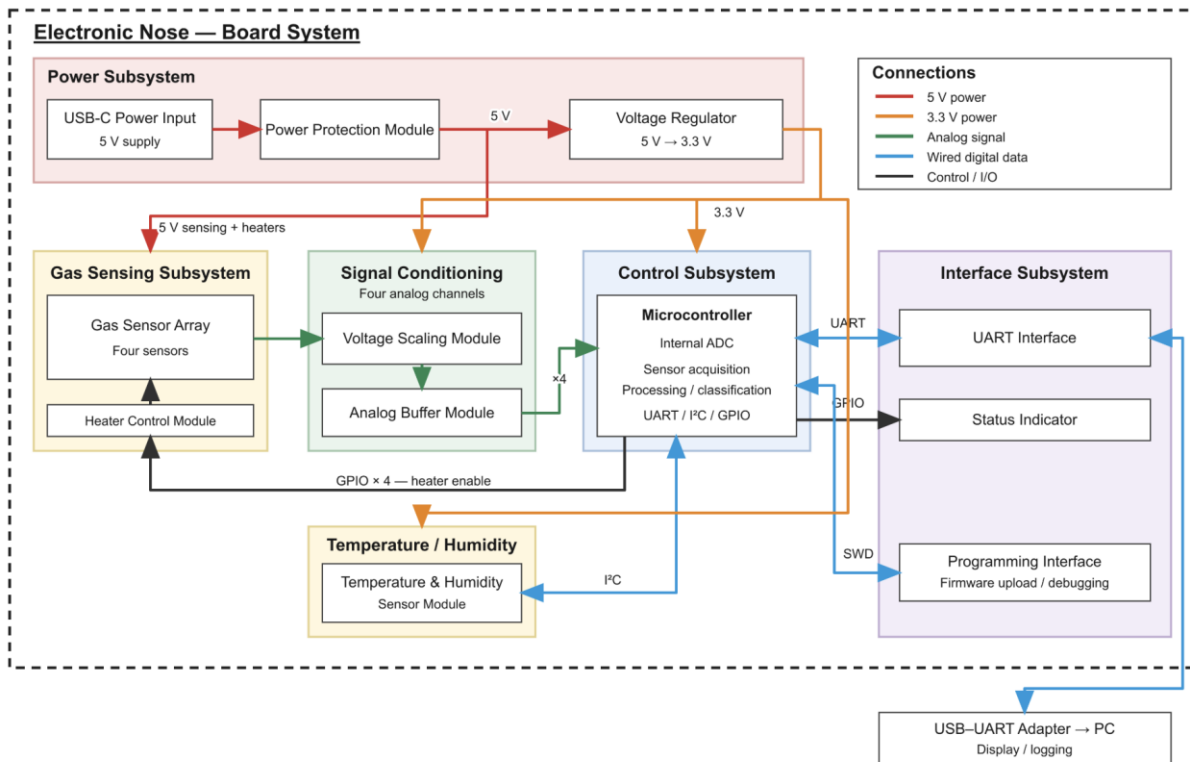


Figure 2. System block diagram and the flow from a labeled specimen to a stored gas signature and classification result.

2.3 Functional Overview and Subsystem Requirements

2.3.1 Power Subsystem

The Power Subsystem is responsible for supplying power to all electronic components on the board. The subsystem receives a 5 V supply through the USB-C power input and passes it through the power protection module before supplying the gas sensors and their heaters. The voltage regulator then converts the 5 V supply to 3.3 V for the signal conditioning circuitry, microcontroller, and temperature and humidity sensor. These supplies allow the sensing and control components to operate together throughout the measurement cycle.

Requirement	Verification
The assembled board must draw less than 1.0 A from the 5 V input with all four sensor heaters operating. The 3.3 V supply must remain within $\pm 5\%$ of its nominal voltage.	Operate the complete board for 10 minutes with all four heaters enabled and with sensor acquisition and UART communication active. Record the input current and 3.3 V supply voltage, and confirm that both remain within the specified limits.

2.3.2 Gas Sensing Subsystem

The Gas Sensing Subsystem is responsible for detecting changes in the gases released by the fruit specimen. The subsystem uses four gas sensors that respond differently to the gases present in the sampling chamber. Because a single sensor response is not sufficient to distinguish fruit type and ripeness, the system uses the combined responses of all four sensors.

The heater control module enables the sensor heaters at the command of the Control Subsystem. After the sensors have warmed up, their outputs are recorded before and during fruit exposure. The four analog signals are then passed to the Signal Conditioning module so that they can be sampled by the microcontroller. By comparing these readings with the readings taken before exposure, the system can determine how each channel responds to the fruit.

Requirement	Verification
After all four different sensors are installed on the circuit board, each sensor must show a discernible response trend when exposed to the gas to which it is sensitive. The specific numerical trend values are not required at this stage, as the response pattern will be established through later training.	Expose the fully assembled circuit board to the target gas for each sensor and record the responses over time. Confirm that each sensor exhibits a discernible change or trend in the expected direction relative to the baseline.
Touchable surfaces must remain at or below 45 °C, and fruit or loose material must not be able to contact the heated sensor cans.	Operate the closed, empty fixture for 30 minutes and measure the hottest accessible surface. Inspect the sensor guard with a test probe and confirm that it prevents contact with the heated sensor cans.

2.3.3 Signal Conditioning

The Signal Conditioning module is responsible for preparing the four gas-sensor outputs for measurement by the Control Subsystem. The voltage scaling module reduces each sensor output to a voltage within the microcontroller's input range. The analog buffer module then passes these signals to the microcontroller's analog-to-digital converter.

Each gas sensor has a separate signal path through this module. This allows the Control Subsystem to record the four responses individually and compare their changes during the measurement cycle.

Requirement	Verification
Each of the four conditioned outputs must remain within the microcontroller's 0–3.3 V ADC input range over the specified gas-sensor output range.	Apply test voltages covering the specified input range to each channel. Measure the corresponding conditioned output and confirm that it remains within 0–3.3 V and follows the intended scaling ratio.
The module must preserve four separate measurement channels without changing their channel assignments.	Apply a distinct test voltage to each channel and record the microcontroller readings. Then change one input at a time and confirm that the corresponding channel changes while the other channels remain within their established measurement tolerance.

2.3.4 Control Subsystem

The control unit and timing coordinator of the instrument is an STM32F072CBT6 32-bit ARM Cortex-M0 microcontroller [4]. The microcontroller conducts the sequential execution of the measurement cycle: it controls the power gates to safely preheat the gas sensor heaters, periodically polls the SHT31 environmental sensor via I2C, and samples the four analog gas-sensor channels using its internal 12-bit Analog-to-Digital Converter (ADC) [3].

In addition to timing the 60 s baseline and 300 s exposure intervals, the firmware monitors real-time limits to flag saturated channels or disconnected sensors. Synchronized measurement records (containing four gas voltages, temperature, relative humidity, timestamp, and cycle state) are packetized and transmitted via a 3.3 V UART serial interface to an external computer through a dedicated USB-to-UART bridge. A computer-side logging script archives the raw time-series data, links each file with its physical specimen metadata, and renders live response curves for visual inspection.

Requirement	Verification
Every saved trial shall contain timestamps, cycle state, four raw gas readings, temperature, humidity, specimen ID, assigned label, and validity status.	Process a prepared input file and compare every saved field with the source. Recalculate selected values and confirm that no required information is lost.
A failed channel, incomplete baseline, environmental violation, missing record, or purge timeout shall prevent a normal fruit result.	Inject one example of each failure. Every case must produce INVALID with a reason code and must not be counted as a valid classification trial.

2.3.5 Interface Subsystem

The Interface Subsystem is responsible for transferring measurement data to an external computer and indicating the operating status of the board. The UART interface connects the Control Subsystem to the computer through a USB-to-UART adapter. The computer then displays the sensor responses and saves the measurement records with the specimen information.

The status indicator receives commands from the Control Subsystem to show the current operating state or a detected fault. In addition, the programming interface provides an SWD connection for uploading firmware and debugging the microcontroller.

Requirement	Verification
Every saved trial must contain timestamps, cycle state, four raw gas readings, temperature, relative humidity, specimen ID, assigned label, and validity status.	Program the STM32 to generate known simulated sensor readings and trial information, package them into a data packet, and send it to the computer through UART. Compare every field received and saved by the computer with the simulated values sent by the STM32. Confirm that all required fields are present and that their values match.
The programming interface must support firmware upload and debugging through SWD.	Upload a test firmware image through the programming interface, confirm that it runs, and establish a debugging connection to the microcontroller.

2.4 Hardware Design

The custom PCB is the core for our project. It integrates the sensors, signal process circuit, microcontroller, temperature and humidity sensors. It also needs the USB power input and UART interface output. We integrate all these functions and subsystems on one single PCB to reduce wiring between experiments and provide control by the software in convenient ways.

Hardware group	Main implementation	Role in the system
Gas sensing	MQ-3B, MQ135, MQ136, and MQ138	Provide four overlapping responses that form the odor signature.
Signal conditioning	Four-channel analog front end	Scale and buffer the sensor voltages for reliable microcontroller sampling.
Control	STM32F072CBT6	Run the measurement, acquire data, detect invalid conditions and transmit records.
Environment	SHT31	Record chamber temperature and relative humidity for acceptance and analysis.
Power	Protected 5 V input, 3.3 V regulation, and heater switches	Supply the heated sensors and logic while keeping heaters off during reset or faults.
Communication	3.3 V UART	Support programming, debugging, and connection to the computer.

The USB-C connector is used for 5 V power only. Data will be sent through the UART header with an external USB-to-UART adapter. The external fan on the top is not controlled by the present PCB. We will put additional devices there to keep air exchange.

2.5 Software and Data Processing

2.5.1 Measurement Cycle

The final prototype will perform signal processing, feature extraction and classification directly on the STM32 microcontroller. A computer will still be used during development to collect labeled sensor data and train the classification model. After the model parameters have been determined, they will be stored in the

microcontroller's flash memory. During normal operation, the computer will only receive and display the classification result, although raw sensor data can still be transmitted in a separate debugging mode.

The firmware controls the measurement process as a sequence of defined states. After power-up, the system first checks the sensors and waits for the gas-sensor heaters to stabilize. The STM32 then records a baseline from the empty chamber. After the labeled fruit sample is inserted, the system enters the exposure state and samples the four gas-sensor channels together with temperature and humidity.

At the end of the exposure period, the STM32 completes feature extraction, applies the stored classification model, and sends the result through UART. The fruit is then removed, and the chamber enters the purge state. A new trial is allowed only after the sensor readings have returned sufficiently close to their baseline values.

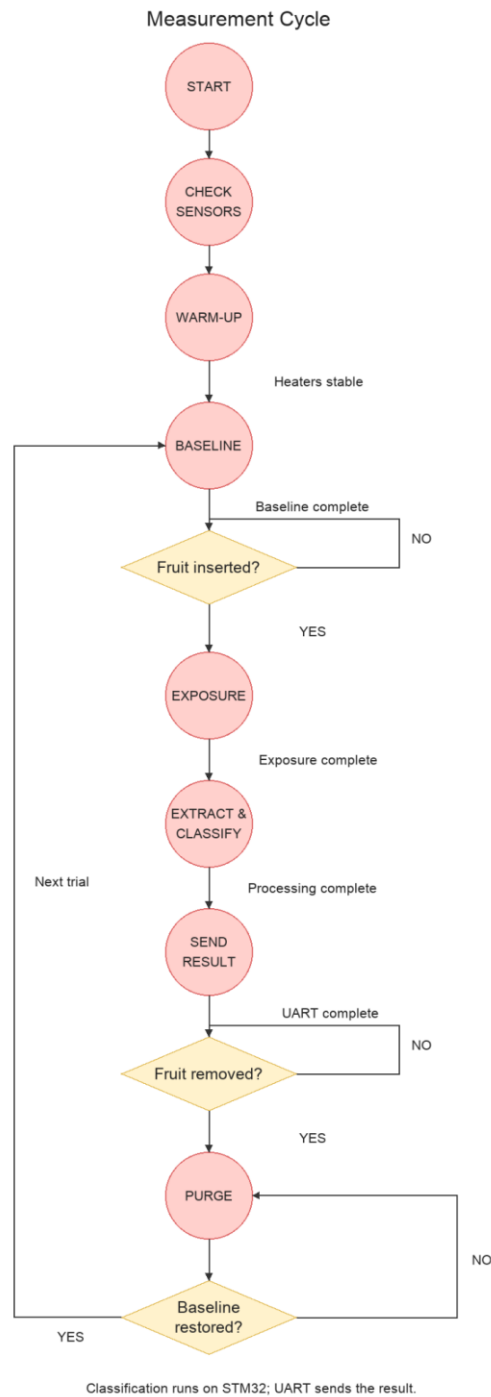


Figure 3. Measurement state machine to keep collection and recovery steps.

2.5.2 Fruit Stage Labels

Before validating the results, we assign labels in advance. The developmental stage of the fruit is determined based on standardized photographs and visual inspection. The classification criteria used in this project are presented in the table below. These criteria facilitate data classification and ensure the reproducibility of the

dataset. To maintain adherence to the experimental design protocol, we do not reclassify the samples after obtaining the sensor results.

Category	Project label
Apple A1 fresh or acceptable	Firm, with no mold or leakage and no soft-rot region larger than 5 mm.
Apple A2 spoiled	Noticeable color change or a soft-rot region larger than 5 mm.
Banana B1 unripe	More than half of the peel is green; the fruit is firm and has no mold or leakage.
Banana B2 ripe	At least 70% of the peel is yellow, with less than 20% dark coverage and no mold or leakage.
Banana B3 overripe or spoiled	At least half of the peel is brown or black, or visible mold or leakage is present.

2.5.3 Embedded Signal Processing and Feature Extraction

The STM32 will process the sensor signals as they are collected rather than storing the entire raw measurement in memory. Each gas channel will first pass through a simple digital smoothing filter to reduce short-term ADC noise. The filtered readings will then be compared with the baseline recorded at the beginning of the trial.

For each gas sensor, the firmware will calculate a small set of features, including the normalized response, maximum response, end-of-exposure response, response slope, and approximate area under the response curve. Temperature and humidity will also be recorded and used to determine whether the measurement conditions are valid. These features form a compact gas-signature vector that can be processed efficiently by the STM32.

2.5.4 Onboard Classification

The classification model will first be developed on a computer using labeled apple and banana measurements. Model training and parameter selection will not be performed on the STM32. Instead, the final thresholds, class

centroids, or model coefficients will be converted into fixed constants and stored in the microcontroller's flash memory.

During operation, the STM32 will compare the extracted feature vector with the stored model. The first classification stage will determine whether the sample is an apple or a banana. A second fruit-specific classifier will then estimate the stage of the sample. Apples will be classified as fresh or spoiled, while bananas will be classified as unripe, ripe, or overripe/spoiled. A result will not be produced if the sensor signals or environmental conditions are outside the accepted limits.

2.5.5 UART Output and Development Logging

In normal operating mode, the UART connection will transmit a compact result containing the specimen ID, fruit type, estimated stage, validity status, and model score. The computer will display and save this result but will not be required to perform the classification.

2.6 Tolerance Analysis

2.6.1 Sampling and Environmental Variation

The strongest non-fruit sources of variation are geometry, temperature, humidity, and incomplete chamber recovery. The fixture therefore limits sensor-to-sample distance and uses the same 60 s baseline and 300 s exposure for each trial. Temperature and humidity limits define when a trial may be used, while the recovery rule prevents residual odor from being carried into the next measurement. Repeatability is verified directly with three trials on each of at least 10 specimens, rather than assuming that fixed geometry alone is sufficient.

2.6.2 Analog Input Margin and Voltage Scaling

The gas sensors can produce output voltages that are higher than the microcontroller can measure. Therefore, each sensor signal must be reduced before it reaches the microcontroller. The following analysis checks whether the selected voltage divider keeps the signal within the permitted input range, even when the supply voltage and resistor values vary from their nominal values. This helps us determine whether the design leaves enough voltage margin to avoid exceeding the measurement range or damaging the input.

The four MQ gas sensors are powered from a regulated 5.0 V analog supply rail. Under high concentrations of target volatile compounds, the sensor output voltage across its load resistor can swing from near 0.0 V up toward the 5.0 V rail. However, the STM32F072 microcontroller operates on a 3.3 V logic supply ($V_{DD} = 3.30V$), and its internal analog-to-digital converter (ADC) pins cannot safely exceed V_{DD} without forward-biasing the internal electrostatic discharge (ESD) protection diodes and causing reading saturation.

To bridge this voltage domain difference safely without complex active circuitry, each sensor channel incorporates a passive, two-resistor voltage divider followed by an op-amp buffer. Specifically, a series resistor (designated as $R_{7,8,9,10} = 100.0k\Omega$) connects directly between the sensor output terminal and the intermediate sampling node, while a shunt resistor (designated as $R_{11,12,13,14} = 150.0k\Omega$) ties that intermediate sampling node to analog ground (GND). A 100 nF capacitor is placed in parallel across $R_{11,12,13,14}$ to suppress high-frequency heater switching noise.

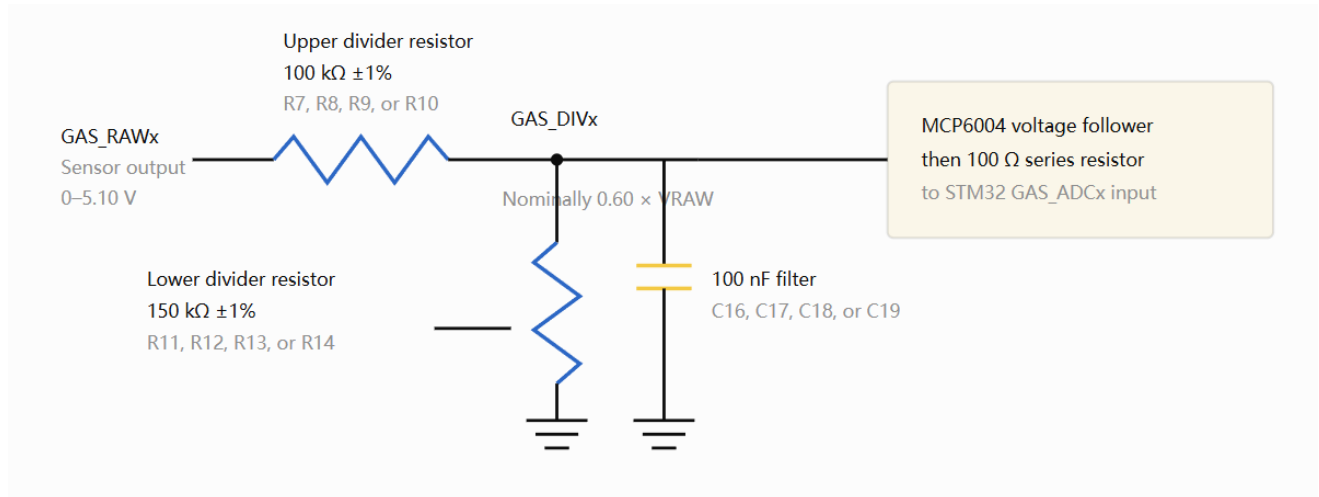


Figure 4. voltage-scaling and buffering circuit used for each gas-sensor channel.

The nominal attenuation scale factor (K_{nom}) of this resistive divider is given by:

$$K_{nom} = \frac{R_{11,12,13,14}}{R_{7,8,9,10} + R_{11,12,13,14}} = \frac{150.0k\Omega}{100.0k\Omega + 150.0k\Omega} = 0.600$$

Both R_1 and R_2 are specified as resistors with a 1% manufacturing tolerance. The worst-case (maximum) attenuation factor occurs when R_2 drifts to its upper bound (+1%, or 151.5kΩ) while R_1 drifts to its lower bound (-1%, or 99.0kΩ):

$$K_{max} = \frac{1.01 \cdot R_{11,12,13,14}}{0.99 \cdot R_{7,8,9,10} + 1.01 \cdot R_{11,12,13,14}} = \frac{151.5k\Omega}{99.0k\Omega + 151.5k\Omega} \approx 0.6048$$

Assuming a conservative worst-case scenario where the 5.0 V supply rail drifts upward by 2% to 5.10V and the sensor output reaches full saturation, the peak voltage delivered to the intermediate node is:

$$V_{ADC,max} = K_{max} \cdot V_{sensor,max} = 0.6048 \times 5.10V = 3.084V$$

This peak level is buffered by a unity-gain voltage follower operating on the 3.3 V rail before entering the microcontroller's ADC pin (PA0 through PA3). Comparing this maximum input against the 3.30 V supply rail demonstrates an overvoltage margin of:

$$V_{margin} = V_{DD} - V_{ADC,max} = 3.30V - 3.084V = 0.216V$$

This 216 mV margin guarantees that the ADC will operate strictly within its linear conversion range without full-scale clipping, prevents stress to the microcontroller's input protection circuitry, and ensures robust tolerance against supply fluctuations and component thermal drift.

Case	Resistor Condition	Scale factor (K)	Sensor Input (V_{sensor})	MCU ADC Voltage (V_{ADC})	Margin to 3.30 V
Minimum ratio	R_{7-10} (+1%) R_{11-14} (-1%)	0.5952	5.00 V	2.976 V	+0.324 V
Nominal	$R_{7-10}=100k\Omega$, $R_{11-14}=150k\Omega$	0.6000	5.00 V	3.000 V	+0.300 V
Maximum ratio	R_{7-10} (-1%) R_{11-14} (+1%)	0.6048	5.00 V	3.024 V	+0.276 V
Worst Case	R_{7-10} (-1%) R_{11-14} (+1%)	0.6048	5.10 V (+2% Drift of supply)	3.084 V	+0.216 V

2.7 Cost Analysis

The cost estimate covers one working prototype and assigns cost to parts already available in the laboratory. Reusable laboratory instruments are not included.

Category	Included items	Estimated cost
Gas sensors	Four MQ sensors	\$45.00

Category	Included items	Estimated cost
Control and analog electronics	Microcontroller, SHT31, amplifier, regulator, MOSFETs, and USB-C receptacle	\$22.30
Protection and passive parts	Fuse, transient protection, filters, resistors, and capacitors	\$15.00
Connectors and controls	Programming and UART headers, reset switch, boot header, and indicator	\$6.00
PCB fabrication	Five-board two-layer order	\$35.00
Power source	Regulated USB-C supply and cable	\$12.00
Development interfaces	USB-to-UART adapter and ST-Link compatible programmer	\$33.00
Mechanical system	Container, purge fan, lid fixture, guard, seals, and mounting hardware	\$47.00

Estimated parts subtotal: \$215.30.

We also estimate the salary for each person at \$50 per hour and 80 hours which leads to total labor of three teammates $Labor = \$45 \times 2.5 \times 70 \times 3 = \23625 . The resulting project estimate is \$23840.3 including parts and labor [5].

2.8 Schedule and Responsibilities

The team will work across different subsystems rather than permanently assigning ownership of isolated modules to specific individuals, thereby preventing single person error from paralyzing the entire system. During weekly meetings, members will share design decisions, test results, code changes and outstanding issues to ensure that everyone is capable of explaining and testing the complete system.

Week	Main work	Completion milestone
Sep 7 to Sep 21	Architecture, schematic and PCB layout	Problem statement, subsystem plan, and PCB design preliminarily completed.

Week	Main work	Completion milestone
Sep 28	First PCB submission	Design document submitted and refine the overall design.
Oct 5	Design review and buy parts	Received the first circuit board, verified the sensor and prepared a checklist for power-up debugging.
Oct 12	Breadboard demo and power bring-up	Test for sensors on the breadboard and make sure power rails, reset and UART are verified.
Oct 19	Soldering bring-up	Four channels acquired reliably and reference-response testing started.
Oct 26	Chamber and logger integration	Complete measurement cycle saved to a computer file.
Nov 2	Progress demonstration	Live four-channel response and a repeatable reference test demonstrated.
Nov 9	Fruit data collection	At least 50 independent specimens collected across five categories.
Nov 16	Mock demo on full process	Preprocessing and models setup before final evaluation.
Nov 23 to Dec 7	Verification, final demo, and report	Failed tests repeated, final evidence archived, and final presentation completed.

2.9 Risk Analysis

Risk	Effect on project	Response
Fruit stages do not separate clearly	The classifier may meet fruit-type accuracy but fail the ripeness-stage goal.	Keep labels and geometry consistent, collect more independent specimens, and revise features only with development data.

Risk	Effect on project	Response
Humidity dominates the gas response	The model may respond to the room rather than the fruit.	Record every trace, reject invalid conditions, compare matched conditions, and report the remaining limitation.
Sensors recover too slowly	Residual odor may affect the next sample and reduce daily test capacity.	Increase time for cleaning and dry the chamber, extend the interval between trials, and block classification until recovery.
PCB assembly or footprint problem	A sensor or control channel may not operate on the fabricated board.	Inspect packages before soldering, assemble in stages, use test points, and keep an adapter-board contingency.
Power or heater fault	The board may reset, overheat, or produce unstable sensor readings.	Use a current-limited source, verify the power budget, guard the heated sensors, and keep heaters off during reset.

3 Ethics and Safety

3.1 Intended Use and Social Impact

This low-cost electronic nose could help users record fruit quality changes and may support reduced food waste in homes and small shops. This prototype is now limited to apples and bananas measured under the documented chamber procedure but we may add more types of fruit if it is possible. A model trained on these conditions should not be assumed to apply to other foods, climates or storage conditions without new data and verification.

The system estimates the maturity or spoilage level of the item. It cannot detect toxins, pesticide residues, or all detailed mechanisms of food spoilage. Consequently, the interface presents the output as an estimate and indicates an invalid result when measurement conditions do not support reasonable readings. The system retains raw measurement data, as well as records of excluded tests and sample counts to enable the objective assessment of the report's performance. This aligns with IEEE requirements that technical claims be realistic and grounded in existing data [6].

This design also concerns environmental costs. The heating sensor consumes additional power and failed PCB iterations generate electronic waste. The project reduces the use of disposable circuits by employing a PCB-based design. Furthermore, the heater is deactivated when not in use, and components such as the chamber, programmer and communication adapter are reused. Electronic components will either be reused or sent to certified electronics recycling facilities [7].

3.2 Safety Considerations

Hazard	Safety response
Heated gas sensors	Use a nonflammable guard and standoffs, prevent sample contact, keep accessible surfaces below 45 °C.
USB power fault	Use a regulated 5 V source, input protection, current-limited power-up, and measured current before extended operation.
Liquid or condensation	Keep electronics above the chamber, place fruit on a removable tray, dry the chamber before power-up, and shut down immediately after a trial.
Ethanol reference	Use only TA-approved dilute solution and microliter volumes in an isolated cup for testing the sensors..
Spoiled fruit and mold	Wear gloves, minimize handling time, and keep the chamber closed during measurement. We will keep clean surfaces, and dispose of samples in sealed waste.
Toxic reference gases	We will not generate hydrogen sulfide or use concentrated ammonia. The related sensors are evaluated with ambient and fruit headspace only.

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