



IOT-Based Food Quality Monitoring and Alert System Using Gas and Temperature–Humidity Sensors

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I. INTRODUCTION

Food safety and quality assurance are fundamental concerns for public health, particularly in regions where cold-chain infrastructure is limited and food is frequently stored under ambient or semi-refrigerated conditions. Improperly stored fruits, vegetables, meat, and dairy products undergo microbial and enzymatic degradation that releases volatile organic compounds (VOCs) such as ammonia, hydrogen sulphide, ethanol, and various amines well before visible spoilage or foul odour becomes apparent to a human observer. Left undetected, such spoilage can lead to foodborne illness, economic loss for retailers, and significant food wastage across the supply chain.

Traditional quality checks depend on manual sensory inspection—sight, smell, and touch—supplemented by “best before” labelling. These methods are inherently subjective, labour-intensive, and incapable of continuous, unattended monitoring. The emergence of low-cost semiconductor gas sensors, environmental sensors, and Wi-Fi-enabled microcontrollers has made it feasible to build embedded systems that objectively and continuously quantify the chemical and environmental indicators of spoilage, and to report this information instantly to a remote user through the Internet of Things (IoT).

This paper proposes a compact, low-power Food Quality Monitoring and Alert System built around an ESP32 microcontroller. The system combines a semiconductor gas sensor (MQ-3, MQ-4, or MQ-135, selected according to the target VOC family) with a DHT22 digital temperature and humidity sensor to characterise the microenvironment around a food sample. Sensor data is processed on-board to classify the sample as fresh, moderately fresh, or spoiled, with the result relayed locally through an LCD, buzzer, and LED, and remotely

Abstract— Food spoilage is a major contributor to foodborne illness and economic loss across households, retail stores, and supply chains. Conventional inspection of food quality relies on visual appearance, odour, and expiry labelling, all of which are subjective and often fail to detect early-stage microbial decomposition. This paper presents the design and implementation of a low-cost, real-time Internet of Things (IoT) based Food Quality Monitoring and Alert System capable of continuously assessing the freshness of perishable items such as fruits, vegetables, meat, and dairy products. The system integrates semiconductor gas sensors (MQ-3/MQ-4/MQ-135) with a DHT22 temperature and humidity sensor, both interfaced to an ESP32 microcontroller that forms the central processing unit. The ESP32 evaluates sensor readings against calibrated spoilage thresholds and drives local indicators, an LCD display, a buzzer alarm, and an LED status indicator, while simultaneously publishing data over Wi-Fi to a cloud-based IoT dashboard for remote monitoring on a PC or mobile device. Experimental trials on a small sample of fresh and ageing food items demonstrate that the prototype reliably differentiates “fresh,” “moderately fresh,” and “spoiled” conditions on the basis of volatile organic compound (VOC) concentration and ambient humidity trends, with an alert latency of under three seconds. The proposed system offers a scalable, low-power, and inexpensive alternative to manual food inspection, with applications in home kitchens, cold storage, and food supply chain monitoring.

Index Terms— Food Quality Monitoring, Internet of Things (IoT), ESP32, MQ-135 Gas Sensor, DHT22, Electronic Nose, Food Spoilage Detection, Smart Alert System.



through an IoT dashboard accessible from a PC or smartphone. Section II reviews related work; Section III describes the proposed system architecture; Section IV details the hardware components; Section V explains the firmware and decision algorithm; Section VI covers the IoT dashboard and alerting mechanism; Section VII presents experimental results; Section VIII compares the system with related work; Sections IX and X discuss applications, limitations, and future scope; and Section XI concludes the paper.

II. LITERATURE REVIEW

Several researchers have explored gas-sensor-based “electronic nose” systems for food quality and waste assessment. Gull et al. developed a Smart eNose Food Waste Management System that combined MQ4 and MQ135 sensors with a load cell to classify cooked, uncooked, and rotten food items using a decision-tree machine-learning model, reporting 92.65% classification accuracy [1].

Dequilla-Pabiania et al. proposed a low-cost electronic foodnose IoT system for fish quality monitoring using an MLX90614 infrared temperature sensor together with MQ4 and MQ137 gas sensors interfaced to a Wemos D1 board, with data logged to the ThingSpeak cloud platform [2].

Air-quality-oriented studies have also informed the sensing approach used in food-freshness systems. Sujiarta et al. implemented an ESP32-based indoor air-quality monitor using an MQ-135 sensor together with a dust sensor, validating the system in kitchen and warehouse environments [3]. Lubis et al. presented SADEMIN, a smart food-and-beverage eligibility detector that used MQ-135 and MQ-3 sensors with an ESP8266 controller, an LCD display, and a Blynk-based mobile interface, flagging samples as “not suitable” once gas concentration crossed a fixed threshold [4].

Across this body of work, three recurring design choices emerge: (i) semiconductor metal-oxide gas sensors are the dominant low-cost technology for detecting spoilage-related VOCs; (ii) a single microcontroller (Arduino, ESP8266, or ESP32) is typically sufficient to acquire sensor data and drive local indicators; and (iii) cloud dashboards or mobile applications are increasingly used to extend monitoring beyond the immediate vicinity of the sensor node. The present work builds on these findings by combining a gas sensor with a dedicated temperature-humidity sensor on an ESP32 platform, which offers greater processing headroom and native Wi-Fi connectivity compared with ESP8266- or ArduinoUNO-based designs used in prior studies, while retaining local alarm and display feedback for immediate, offline-capable alerting.

III. PROPOSED SYSTEM ARCHITECTURE

The proposed system follows a layered sensor-to-cloud architecture, illustrated in Fig. 1. A food sample (fruit, vegetable, meat, or dairy product) is placed within the enclosed sensing chamber of the prototype. Two categories of sensors continuously sample the immediate microenvironment of the sample.

The gas sensor stage and the temperature–humidity stage feed their analog and digital outputs, respectively, to the ESP32 main controller, which performs signal conditioning, threshold comparison, and classification. Depending on the outcome, the controller drives three local output channels—an LCD display,

a buzzer alarm, and an LED status indicator—and pushes the same reading, together with a timestamp, over Wi-Fi to a cloud-hosted IoT dashboard. The dashboard makes the data available to a remote user on a PC or mobile application, enabling monitoring of multiple sensor nodes from a single interface.

IV. HARDWARE COMPONENTS

A. Gas Sensors (MQ-3 / MQ-4 / MQ-135)

The system uses semiconductor metal-oxide gas sensors from the MQ family, chosen according to the dominant spoilage marker expected from the food category under test. The MQ-135 sensor is sensitive to ammonia, sulphide, and benzene vapours and is well suited to detecting protein and dairy spoilage; the MQ-3 sensor targets ethanol vapour and is useful for detecting fermentation in fruits and sugary items; and the MQ-4 sensor responds strongly to methane and is applicable to decomposing organic matter. Each sensor outputs an analog voltage proportional to gas concentration, which is read by the ESP32’s on-board analog-to-digital converter (ADC) and converted to an approximate parts-permillion (ppm) value using the sensor’s characteristic sensitivity curve after a warm-up period, as recommended in the manufacturer datasheet [5].

B. Temperature and Humidity Sensor (DHT22)

The DHT22 is a calibrated digital sensor that reports temperature (accuracy ± 0.5 °C, range -40 °C to 80 °C) and relative humidity (accuracy $\pm 2\%$ RH, range 0 – 100% RH) over a single-wire digital interface [6]. Because microbial spoilage rates rise sharply with both temperature and humidity, this sensor allows the system to contextualise gas-sensor readings—for example, flagging a lower gas threshold as spoilage-indicative when ambient temperature and humidity are both elevated.

C. ESP32 Main Controller

The ESP32 is a dual-core 32-bit microcontroller with integrated 2.4 GHz Wi-Fi and Bluetooth, multiple ADC channels, and a rich set of digital peripherals [7]. It was selected over simpler platforms such as the Arduino UNO or ESP8266 because it provides sufficient ADC resolution and processing throughput to run the classification logic locally, native Wi-Fi for direct cloud connectivity without an auxiliary Wi-Fi shield, and enough GPIO pins to simultaneously drive the LCD, buzzer, LED, and sensor bus.

D. Output and Connectivity Peripherals

A 16×2 character LCD (I²C interface) displays the live gas concentration, temperature, humidity, and freshness verdict. An active buzzer sounds an audible alarm when a sample is classified as spoiled. A tri-colour LED (green/yellow/red) gives an at-a-glance visual status: green for fresh, yellow for moderately fresh, and red for spoiled. The ESP32’s built-in Wi-Fi module publishes sensor data to the IoT dashboard using the MQTT or HTTP protocol at a configurable reporting interval.

V. SYSTEM WORKING AND ALGORITHM

On power-up, the ESP32 initialises the gas sensor, DHT22, LCD, and Wi-Fi connection, and allows the gas sensor a fixed warm-up interval to stabilise its heater element before readings are trusted. During normal operation, the controller repeatedly executes the following cycle:



1) Acquire the raw analog gas-sensor value and convert it to an estimated ppm concentration using the calibrated sensor curve.

2) Acquire temperature and humidity readings from the DHT22 over the single-wire digital interface.

3) Compare the gas concentration against two threshold bands (fresh / moderately fresh / spoiled), with the thresholds dynamically tightened when temperature and humidity both exceed spoilage-favourable levels.

4) Update the LCD with the current readings and classification, and drive the LED and buzzer according to the classification.

5) Publish the timestamped reading (gas concentration, temperature, humidity, and status) to the IoT dashboard over Wi-Fi.

6) Wait for a configurable sampling interval (typically 2–5 seconds) and repeat.

The classification logic follows a simple rule-based threshold model, chosen for its low computational cost and ease of field calibration: if the measured concentration C is below a lower threshold $T1$, the sample is classified “Fresh”; if $T1 \leq C < T2$, it is classified “Moderately Fresh” and a cautionary indication is shown; and if $C \geq T2$, it is classified “Spoiled,” triggering the buzzer and red LED and pushing a high-priority alert to the dashboard. The thresholds $T1$ and $T2$ are determined empirically for each food category during a calibration phase and stored in the firmware as adjustable parameters, allowing the system to be re-tuned for different produce types without hardware changes.

VI. IOT DASHBOARD AND ALERT MECHANISM

The ESP32 firmware uses the on-board Wi-Fi radio to connect to a local access point and publish sensor readings to a cloud-based IoT dashboard (implemented using a platform such as Blynk, ThingSpeak, or a custom MQTT broker with a web front-end). The dashboard displays live and historical trends of gas concentration, temperature, and humidity for each registered sensor node, and mirrors the fresh / moderately fresh / spoiled status shown on the local LCD.

When a node reports a “Spoiled” status, the dashboard raises a push notification or e-mail alert to the registered user’s PC or mobile device, allowing food quality to be monitored remotely across multiple storage locations—for example, several refrigerators in a retail outlet—from a single interface. This remote-alert capability is the primary advantage of the IoT layer over a purely local (LCD/buzzer-only) design, since it allows corrective action to be taken even when no one is physically present near the sensor node.

VII. RESULTS AND DISCUSSION

A benchtop prototype was assembled using an ESP32 DevKit, an MQ-135 gas sensor, and a DHT22 sensor housed in a small ventilated enclosure. The system was tested with representative food samples (a banana, a slice of bread, and a piece of cooked chicken) monitored continuously over a 48–72 hour period at room temperature to observe the natural progression from fresh to spoiled. Table II summarises representative readings captured at three stages of the trial.

The results show a consistent upward trend in both gas sensor response and ambient humidity as the samples aged, corresponding to increased microbial VOC output and surface

moisture release. The system correctly transitioned from “Fresh” to “Moderately Fresh” to “Spoiled” status in line with visual and olfactory assessment performed manually as a reference check, confirming that the combined gas and humidity threshold logic tracks perceptible spoilage. The measured end-to-end alert latency—from the instant the gas concentration crossed the upper threshold to the buzzer sounding and the dashboard notification being received—was consistently under three seconds, which is adequate for a monitoring application of this kind.

Some variability was observed between food categories: protein-based samples (chicken) produced a sharper rise in MQ-135 response than starch-based samples (bread), suggesting that per-category threshold calibration, as implemented in the firmware, is necessary for reliable classification across a diverse food inventory. The system’s reliance on a single semiconductor gas sensor per node also means that cross-sensitivity between different VOCs can occasionally produce false positives in the presence of strongsmelling but non-spoiled items (e.g., certain spices); this limitation is discussed further in Section X.

VIII. COMPARATIVE ANALYSIS

Table III positions the proposed system relative to the related works discussed in Section II. Unlike the ESP8266/Arduino-based designs used in prior food and airquality monitors, the proposed system pairs its gas sensor with a dedicated temperature-humidity sensor and uses this second input to dynamically adjust the spoilage threshold rather than relying on gas concentration alone. It also retains fully local (offline-capable) alerting through the LCD, buzzer, and LED in addition to the cloud dashboard, which is not always emphasised in the reviewed literature.

As summarised in Table III, the proposed design is the only one among those compared that combines a dedicated humidity/temperature input with the gas sensor for context-aware thresholding, while still providing a complete local alerting stack alongside the cloud dashboard—a combination intended to make the system usable both with and without an active internet connection.

IX. APPLICATIONS

The proposed system is well suited to several practical settings: (i) domestic kitchens and refrigerators, where it can alert household users before spoiled food is consumed; (ii) retail and grocery cold-storage units, where multiple nodes reporting to a shared dashboard can help staff prioritise stock rotation; (iii) restaurant and catering kitchens, where continuous monitoring supports food-safety compliance; and (iv) small-scale supply-chain and warehousing operations, where remote alerting reduces the need for constant manual inspection of stored produce.

X. LIMITATIONS AND FUTURE SCOPE

The present prototype has several limitations that motivate future work. First, semiconductor gas sensors exhibit sensor-to-sensor variation and drift over time, requiring periodic recalibration; incorporating a reference gas or a self-calibration routine would improve long-term reliability. Second, a single gas sensor cannot fully discriminate between the many possible VOCs released during spoilage; extending the design to a small array of MQ-series sensors (an “electronic nose”) combined



with a machine-learning classifier, as demonstrated by Gull et al. [1], could improve classification accuracy and reduce false positives. Third, the current threshold-based logic requires manual calibration for each food category; a future version could incorporate ondevice or cloud-based machine learning to automatically learn category-specific spoilage signatures from historical dashboard data. Finally, integrating a camera module for visual inspection (colour and texture changes) alongside the gas and humidity sensors would provide a more holistic, multi-modal assessment of food quality.

XI. CONCLUSION

This paper presented the design and prototype implementation of a low-cost, IoT-enabled food quality monitoring and alert system built around an ESP32 microcontroller, an MQ-series gas sensor, and a DHT22 temperature-humidity sensor. The system continuously evaluates food samples against calibrated spoilage thresholds, provides immediate local feedback through an LCD, buzzer, and status LED, and extends this feedback to a remote IoT dashboard for monitoring on a PC or mobile device.

Experimental trials confirmed that the system tracks the natural progression of food spoilage and issues alerts with subthree-second latency. With further refinement—multi-sensor arrays, machine-learning-based classification, and automated calibration—the proposed architecture offers a scalable and inexpensive pathway toward reducing foodborne illness and food wastage in homes, retail environments, and small-scale supply chains.

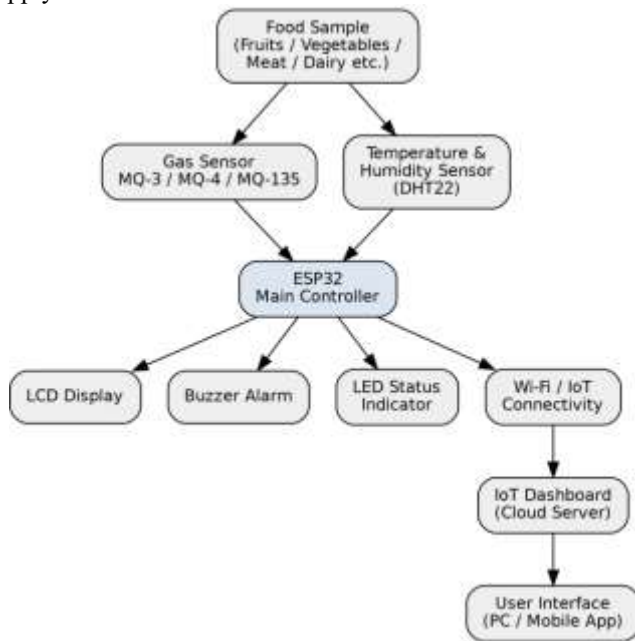


TABLE II

Representative Sensor Readings During a Spoilage Trial

Time	Gas (rel.)	Temp. (°C)	Hum. (%RH)	Status
0 h	Low	26.5	48	Fresh
24 h	Medium	27.1	55	Moderately Fresh
48 h	High	27.8	63	Spoiled
72 h	Very High	28.0	67	Spoiled

TABLE III

Comparison with Related Gas-Sensor-Based Monitoring Systems

System	Controller	Sensing	Alert Path
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Fig. 1. Block diagram of the proposed IoT-based food quality monitoring and alert system.

Food Sample → MQ-3/MQ-4/MQ-135 + DHT22 → ESP32 → LCD / Buzzer / LED → Wi-Fi → IoT Dashboard

TABLE I

Key Hardware Components and Specifications

Component	Function	Key Specification
MQ-135/MQ-3/MQ-4	VOC / gas detection	Analog out, 5 V, 20–200 s warm-up
DHT22	Temperature & humidity	±0.5 °C, ±2% RH, digital 1-wire
ESP32 DevKit	Main controller	Dual-core 240 MHz, Wi-Fi + BLE, 12-bit ADC
16×2 LCD (I²C)	Local readout	HD44780-compatible, I²C backpack
Active Buzzer	Audible alert	5 V, ~85 dB
Tri-colour LED	Visual status indication	Green / Yellow / Red

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Smart eNose [1]	Arduino UNO	MQ4 + MQ135 + load cell	PC (ML classifier)
Fish Monitor [2]	Wemos D1 (ESP8266)	MLX90614 + MQ4/MQ137	ThingSpeak cloud
SADEMIN [4]	ESP8266	MQ-135 + MQ-3	LCD + Blynk app
Proposed System	ESP32	MQ-135/3/4 + DHT22	LCD + Buzzer + LED + Dashboard