

An IoT-Based Real-Time Quality Monitoring System for Cooking Dairy Products Via Ammonia Emission Detection

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Received 13 August 2025, Received in revised form 10 June 2026

Accepted 10 July 2026, Available online 30 September 2026

ABSTRACT

As the awareness on food safety and quality continuously growth, the significance of effective monitoring system becomes more evident, specifically in dairy industry, where spoilage becomes common within short period of consumption. Fresh milk storage at an elevated temperature with unhygienic practices of product preparation may results to inferior-quality of dairy production. An inferior dairy product emits gases such as ammonia(NH₃), carbon dioxide(CO₂) and methane(CH₄), which instigated of foodborne illnesses when consumes by consumers. This escalates public health risks and economic instability in the food industry. Hence, this study proposes and experimentally investigates an Internet of Things (IoT)-enabled real-time monitoring system for spoilage detection in dairy products via ammonia nitrogen trihydride (NH₃) emissions patterns analysis. The system integrates gas sensors of MQ 135 and MQ 137, a temperature sensor and a NodeMCU esp8266 microcontroller with cloud based monitoring via Adafruit IO and Telegram Bot alerts. The system is then, validated by conducting nine (9) dairy products in which includes of animal and plant-based in liquid and solid forms over 24 hours under controlled enclosed conditions. Results show that MQ 137 provides higher NH₃ selectivity and sensitivity compared to MQ 135 due to its narrower cross-sensitivity spectrum with a specific response only towards NH₃ within 5-500 ppm. The system indicates an early spoilage detection (32-35 ppm), remote monitoring and an alert automation that contributes an economical, a scalable alternative of experimental testing to support food safety monitoring with digital transfromation in the dairy industry.

Keywords: Food industry; Internet of Things (IoT); Ammonia (NH₃); real-time monitoring system; dairy products

INTRODUCTION

In the context of the Fourth Industrial Revolution, the quality of dairy products is a major problem in the food industry since it has a direct impact on customer health and satisfaction, resulting in several foodborne illnesses (Gupta-Smith 2024). Foodborne illness caused by pathogenic bacteria including Salmonella, Listeria, and E. coli can cause severe gastrointestinal distress, dehydration, and even death. Allergic responses initiated from a spoilage dairy products can cause moderate symptoms such as

rashes and itching to severe anaphylactic shock, requiring quick healthcare. Detrimental effects on the liver, kidneys, and immune system can also be stemming from mycotoxin exposure ensuing from bacterial contamination by fungi released during the decomposition of dairy products, potentially leading to long-term health issues (Sun et al. 2022). Traditional quality assessment methods for dairy products, including sensory evaluations, chemical analysis, and microbiological testing, are normally performed in laboratories, which requires long time to get results (Fernández González et al. 2024; Ahmadi et al. 2023).

Another methods like visual examinations is conducted via few meticulous steps that are necessary to ensure product quality. The color, texture, and number of contaminants in dairy products such as milk, cheese, and yogurt must be visually inspected before assuring the products are highly qualified for consumers. The taste test checks freshness and flavor profiles; the smell test is essential for identifying any smells that might point to spoiling or contamination. The firmness, creaminess, and smoothness of dairy products are determined by texture analysis. Dangerous bacteria can be found by microbiological testing, whereas chemical analysis quantifies factors including pH, lipid, and protein concentration (Saila et al. 2023). While keeping an eye on storage conditions preserves freshness and increases shelf life, packaging inspection ensures optimal sealing and protection. Even though these conventional techniques are comprehensive, they could take a long time, need specific knowledge and lacking real-time analysis for monitoring purposes. Such constraint impedes the real-time detection and mitigation of quality nomalies, thereby elevating the risk to consumer health and incurring financial losses from product spoilage and reduced consumer confidence. Thus, food industry is changing to smart food analysis systems to solve the issues associated with present approaches (Bhat et al. 2025).

Integrating IoT into dairy product monitoring not only enables real-time tracking but it also introduces concerns about data security (Manisha & Jagadeeshwar, 2023; Seliem et al. 2018; Azolla, 2015). To maintain the reliability of IoT systems, it is critical to handle any network breaches that may compromise the system and result in data manipulation or unauthorised access. Maintaining the reliability of IoT is critical, as failures or inaccurate readings can lead to poor-quality decisions, and the associated expenses may discourage small businesses from using it.

Many researchers have engineered smart quality assessment systems and automations, offering innovative alternatives developed specfically in food industry modernization to overcome the challenges posed by traditional food industry. In (Shaw 2022), the paper focuses on an application using Arduino UNO and MQ 135 gas sensor to detect milk expired, offering a cheaper alternative to methods in (Tian et al. 2025; Wu et al. 2024; Kalaiarasi et al. 2022; Saravanan et al. 2021). However, it does not have an IoT method to store data, unlike methods in (Saravanan et al. 2021; Subramanian et al. 2025, 2020; Mahesh et. al 2023), which use microcontrollers and IoT platforms for real-time data on food products. Although the inteference is user-friendly, it reliances on gas sensors leads to calibration issues, and it detects spoilage only after milk deformation. In comparison, gas sensors used in

studies like (Tian et al. 2025) provide good stability but are time consuming for spoilage detection, making them more suitable for lab-scale usage. The advanced gas sensor methods deliver more precise data like (Subramanian et al. 2025; Suthagar et al. 2019) but are less practical for home consumers and require extensive procedures. Despite numerous studies of the integrated platforms of gas sensors with IoT for dairy spoilage detection, few perennial limitations remain includes a limited experimental scale studies with short monitoring duration, insufficient comparative analysis over various types of dairy products and lack exploration on the potency of enviromental factors toward sensor performances (Fernández González et al. 2024, Bhat et al. 2025).

Hence, this paper proposes a quality evaluation system for various dairy products spoilage detection that capable in monitoring ammonia gas (NH_3) levels in ppm and environmental factors such as temperature levels ($^{\circ}\text{C}$) and humidity in (rh%) over a 24-hour period of controlled experimental conditions. The system is programmed using the Arduino IDE software and a NodeMCU module to systematically controls the gas and temperature sensors. It supports secure remote management via an authorized password protected smartphone-app, featuring integrated Telegram notifications. This feature not only improves user convenience but also protects sensitive data. The operations functionalities, and key features of the system are thoroughly described in the following sections of this paper,

EXPERIMENTAL DESIGN

The experiment was conducted in an enclosed laboratory environment with an ambient temperature of 28°C to 31°C and humidity of 70%rh to 80%rh. Each dairy sample was placed in 3500 ml airtight container for assuring the consistency of gas accumulation circumstances. There were nine (9) dairy products tested, which composed of six (6) liquid samples for 750 ml each and three (3) solid samples for 250 g each. All measurements were recorded for every 30 minutes for a period of 24 hours. Each samples were repeated three (3) times with the calculated mean values and standard deviations as displayed in Table 1.

Commonly, ammonia generation during spoilage is primarily caused by microbial proteolysis, where proteins are degraded into amino acids followed by deamination reactions that release NH_3 gas (Sun et al. 2022). Ammonia has therefore been recognized as a reliable volatile indicator for dairy spoilage detection (Fernández González et al. 2024).

METHODOLOGY

SYSTEM OPERATION

Figure 1 illustrates the operational flowchart of quality evaluation of cooking dairy products to monitor ammonia gas levels and temperature while interacting with an app and Adafruit.io. Data acquisition includes NH_3 levels (ppm), voltage drops (V), temperature ($^{\circ}\text{C}$), and humidity (rh%) for dairy products when experiencing spoilage conditions. The system starts by calibrating the sensors for an accurate reading to avoid any faulty readings. Thereafter, it attempts to connect to Wi-Fi that has been set. Once connected, it can operate and measure ammonia levels in ppm and temperature level. If the ammonia concentration exceeds 30 ppm, the system issues an alert by triggering a voice

alarm and turning on a red light, as well as displaying the value on an LCD and sending data to Adafruit.io for dashboard display. Noise filtering was performed using average smoothing over three (3) consecutive readings.

For continuous monitoring, the system observes temperature and gas levels in ppm and sends the results to Adafruit.io and a smartphone app for remote viewing. It also receives app commands that activate an alarm and a light. All data, including ammonia levels and temperature readings, is displayed on an LCD screen and accessed remotely via the Adafruit.io dashboard and app. IoT-based food monitoring systems are vulnerable to unauthorized access and data manipulation; therefore, secure authentication mechanisms are essential to maintain system reliability (Seliem et al. 2018). In this study, Telegram Bot token-based authentication was implemented to restrict user access.

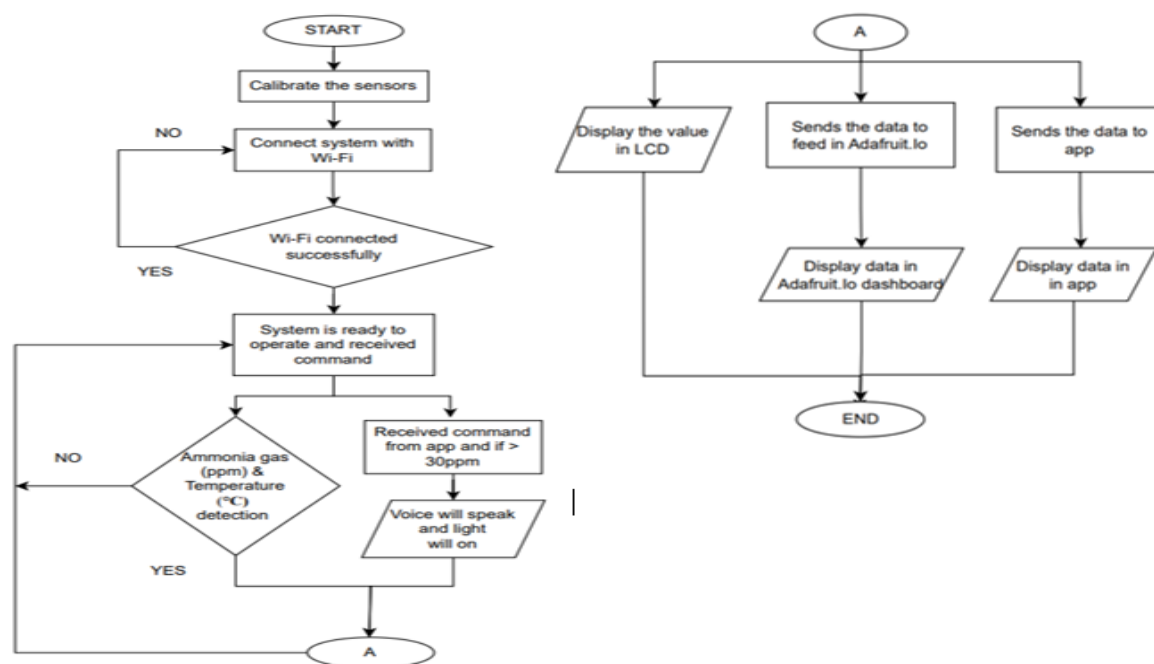


FIGURE 1. Flowchart of the quality evaluation of cooking dairy product operation

EXTERNAL HARDWARE

Figure 2 shows the system's external components, which include two types of gas sensors, a temperature sensor, three different light-emitting diode (LED) lights, a 20x4 liquid crystal display (LCD) panel, and a DF mini player with a speaker. A NodeMCU is attached on an expansion board inside a 3D-printed module and controls the gas sensors, temperature sensor, and DF mini player. The 3D-printed module is placed on a 3500 ml container that is used to store cooked dairy products, with the correct

quantity added to monitor the ammonia gas level in ppm and temperature level. The gas sensors are attached below the 3D-printed module through a hole that links to the container, enabling for the monitoring of ammonia gas levels in ppm. Additionally, the 3D-printed module contains the DF mini player. The temperature sensor, LCD display, and speaker are installed on top of the 3D-printed module for simple access, allowing for immediate warnings of ammonia gas levels and temperature. The speaker can be activated using a smartphone app, with the NodeMCU ESP8266 providing 5V in response to app commands.



FIGURE 2. Internal hardware : a) bottom view and b) top view of the hardware

CALIBRATION

The operation of MQ-series gas sensors are operated based on changes in semiconductor resistance when exposed to target gases. The ratio of R_s/R_o is used to estimate gas concentration according to manufacturer sensitivity curves (Kalaiarasi et al. 2022). Cross-sensitivity to other gases has been reported, highlighting the importance of calibration prior to measurement (Putra et al. 2018).

To calibrate MQ135 and MQ137 sensors for ammonia (NH_3), start by preheating the sensors to stabilize their readings this involves a 24–48 hours initial preheating period and 5–10 minutes before subsequent calibrations. First, the baseline resistance (R_o) is measured by exposing the sensors to clean air in a well-ventilated, ammonia-free environment. The resistance (R_s) is calculated using the formula

$$R_s = V_{cc} - V_{out} / V_{out} \cdot R_L \quad (1)$$

$$\log(R_s/R_o) \quad (2)$$

Where V_{cc} is the supply voltage, V_{out} is the voltage across the load resistor (R_L), and R_L is typically 10 k Ω . Next, the sensors are exposed to detect NH_3 sources, such as diluted household ammonia solutions, maintaining a consistent distance like 10–15 cm from the source. The sensor's resistance (R_s) is recorded for various ammonia concentrations after allowing the readings to stabilize for 1–2 minutes. Eq.(3.2) is calculated and plotted against NH_3 concentration. The calibration is conducted before each experiment trial in consideration of environmental factors, such as temperature and humidity.

RESULT AND DISCUSSION

TYPES OF DAIRY PRODUCTS

Figure 3 shows types of dairy products conducted into animal and plant-based categories. The animal-based products studied include solids such as butter, blue cheese, and soft cheese, along with liquids like fresh milk, whipping cream, and yogurt. The plant-based alternatives analyzed are coconut milk, soy milk, and almond milk.

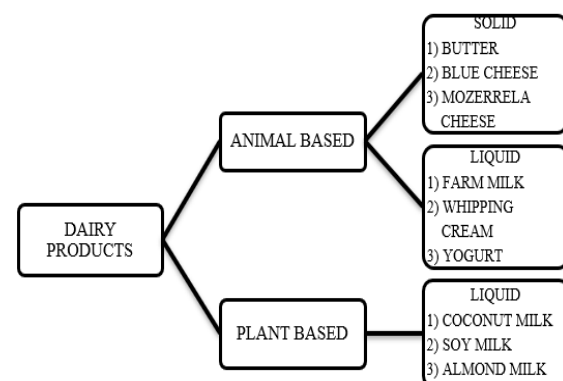


FIGURE 3. Type of Dairy Products

Table 1 indicates the NH_3 levels(ppm), voltage drops (V), temperature ($^{\circ}C$), and humidity (rh%) for dairy products when experiencing spoilage conditions. The comparison of animal-based and plant-based dairy products, as well as their liquid and solid forms, reveals significant differences in spoilage patterns, NH_3 concentration, and voltage levels over the 24-hour testing period. Animal-based products, particularly liquid forms such as farm milk, yogurt, and whipped cream, exhibited higher NH_3 concentrations and faster spoilage rates due to their high protein and fat content

with higher water activity which serve as an ideal substrate for microbial growth (Mullie et al. 2016; Fernández González et al. 2024). Higher protein yields higher NH_3 concentrations by the reason of microbial proteolysis phenomenon. Bacteria decompose proteins into amino acids and subsequently deaminate them, releasing NH_3 gases (Sun et al. 2022).

In contrast, plant-based products like almond milk, soy milk, and coconut milk showed slower increases in NH_3 concentration, particularly during the initial hours, due to their lower protein content and the presence of natural preservatives, such as lauric acid in coconut milk. Among plant-based options, soy milk experienced a more rapid NH_3 increase compared to almond and coconut milk, reflecting its higher protein content.

The differences between animal-based and plant-based products, as well as between liquid and solid forms, can be attributed to several factors. Animal-based products spoil faster due to their higher protein and fat content, providing nutrients that accelerate microbial metabolism. In contrast, plant-based products, particularly almond and coconut milk, are more resistant to spoilage due to their lower protein content and natural antimicrobial properties. Solid products, such as butter and blue cheese, spoil more slowly than liquids because of reduced water activity, which limits microbial metabolism, while the high moisture content in liquids promotes faster microbial and rapid reactions of enzymatic activity.

Environmental factors such as temperature and humidity also played a significant role in the spoilage process. Higher temperatures and humidity levels during the testing period accelerated microbial activity, particularly in liquid products, which are more sensitive to environmental changes. Additionally, the natural acidity of yogurt and certain plant-based products like coconut milk inhibited microbial growth during the initial hours, delaying spoilage progression.

Therefore, the spoilage behavior of dairy products is influenced by their composition, form, and environmental conditions. Animal-based products are more prone to spoilage due to their higher nutrient content, while plant-based products benefit from natural preservatives and lower protein levels. Liquid products spoil more quickly than solids because of their higher moisture content, which supports microbial growth. These findings highlight the importance of considering composition and environmental

factors in extending the shelf life and maintaining the quality of dairy products.

Similar trends are found in voltage- NH_3 relationship, where the voltage recorded an increment in liquid products, compared to solid products. The sensors' voltage proportionally increased with NH_3 concentration. In essence, metal oxide semiconductors (MOS) sensor becomes operatives via adsorption of oxygen molecules on the heated sensor surface. The oxygen released electrons back into the conduction band, when being exposed to reducing gases like NH_3 , thus reducing resistance and enhancing the output voltage (Liu et al. 2022).

As farm milk emitted the highest NH_3 emissions due to rapid spoilage if compared to others, figure 4 a), b) and c) detail its results consisting the plotted graph of NH_3 concentration (ppm), surrounding temperature ($^{\circ}\text{C}$), and humidity (rh%) over a 24-hour period. The data is observed every 30 minutes. As shown in Figure 4 a), the NH_3 concentration remained low and stable during the first 4 hours, indicating minimal microbial activity, but increased significantly between 6 and 12 hours as microbial growth and enzymatic processes broke down proteins, releasing ammonia. Concentration peaked after 12 hours, signaling advanced spoilage, and plateaued slightly after 18 hours as nutrient availability diminished.

Environmental factors such as temperature and humidity in figure 4 b) and c) influenced the spoilage process, with variations accelerating microbial activity during peak spoilage phases. From Table 1, MQ137 gives lower mean standard deviation (SD) compared to MQ135, whereby the mean SD MQ137 and MQ135 are 1.69 ppm and 2.68 ppm respectively. This signifies MQ137 has higher repeatability and variability towards NH_3 gases, as well as better measurement precision. Although laboratory ammonia spectroscopy is not conducted in this study, the ammonia range within 30 ppm to 50 ppm consistently aligned with the former studies of dairy milk spoilage using gas sensing system with similar time and temperature conditions (Putra et al. 2018; Tian et al. 2025).

Moreover, figure 5 a) shows farm milk before and b) after spoilage, highlighting changes like curdling and discoloration caused by microbial activity. These visual changes align with increased NH_3 levels and sensor readings, illustrating spoilage progression. Fresh farm milk has a light, pure, and creamy smell, but when it goes bad, it becomes sour, pungent, and foul.

TABLE 1. Measurements of NH_3 level, Voltage drop, temperature and humidity for all dairy type products during spoilage condition

Type of milk	Parameters (ml/gram)	NH_3 level (ppm)		Voltage Drop (V)		Temperature (°C)	Humidity (rh%)
		MQ-135	MQ-137	MQ-135	MQ-137		
Coconut milk	750 ml	38.6 ± 2.8	44.2 ± 2.0	1.39	1.56	30.6 ± 0.4	70.0 ± 1.1
Soy milk	750 ml	39.4 ± 3.1	42.3 ± 1.9	1.42	1.46	28.6 ± 0.3	81.80 ± 1.4
Almond milk	750 ml	39.1 ± 2.7	39.5 ± 1.8	1.36	1.42	28.2 ± 0.4	82.5 ± 1.2
Farm milk	750 ml	46.3 ± 3.2	49.1 ± 1.8	1.71	1.83	29.6 ± 0.4	80.1 ± 1.2
Yogurt	750 ml	43.2 ± 2.9	46.0 ± 1.7	1.51	1.61	29.3 ± 0.3	83.2 ± 1.0
Whip cream	750 ml	40.4 ± 2.5	43.2 ± 1.6	1.44	1.51	28.9 ± 0.5	81.8 ± 1.3
Blue cheese	250 g	32.8 ± 2.2	35.2 ± 1.4	1.22	1.31	29.3 ± 0.4	80.2 ± 1.1
Mozzarella cheese	250 g	32.1 ± 2.0	33.4 ± 1.3	1.21	1.30	28.9 ± 0.5	82.0 ± 1.2
Butter	250 g	32.4 ± 1.9	34.1 ± 1.2	1.27	1.33	30.6 ± 0.3	70.0 ± 0.9

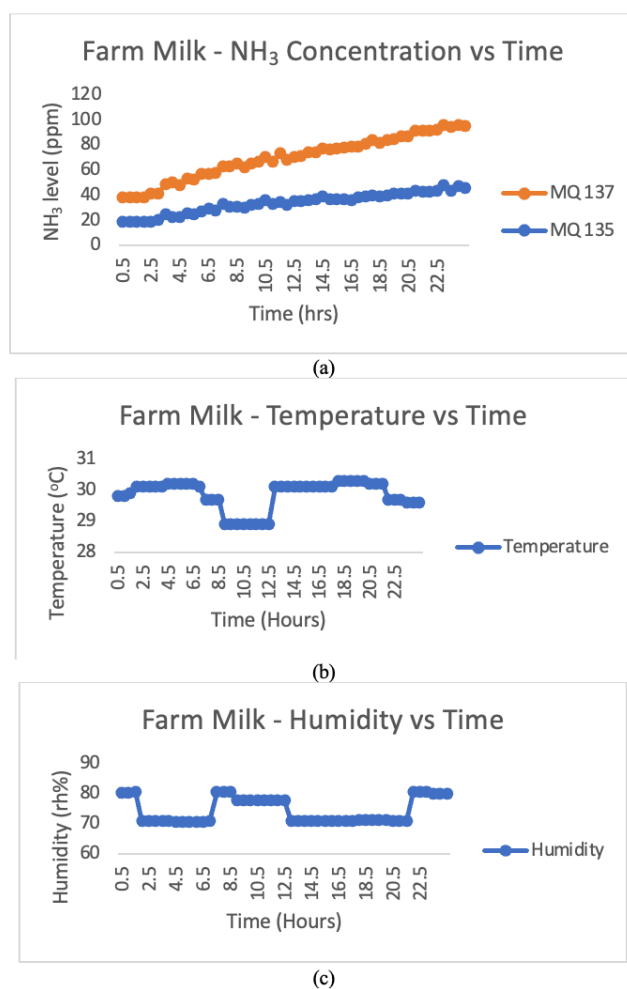
FIGURE 4. Graph of farm milk liquid type animal-based dairy product over a 24 hours period for a) NH_3 level b) Temperature c) Humidity



FIGURE 5. Condition of farm milk a) before spoilage b) after spoilage

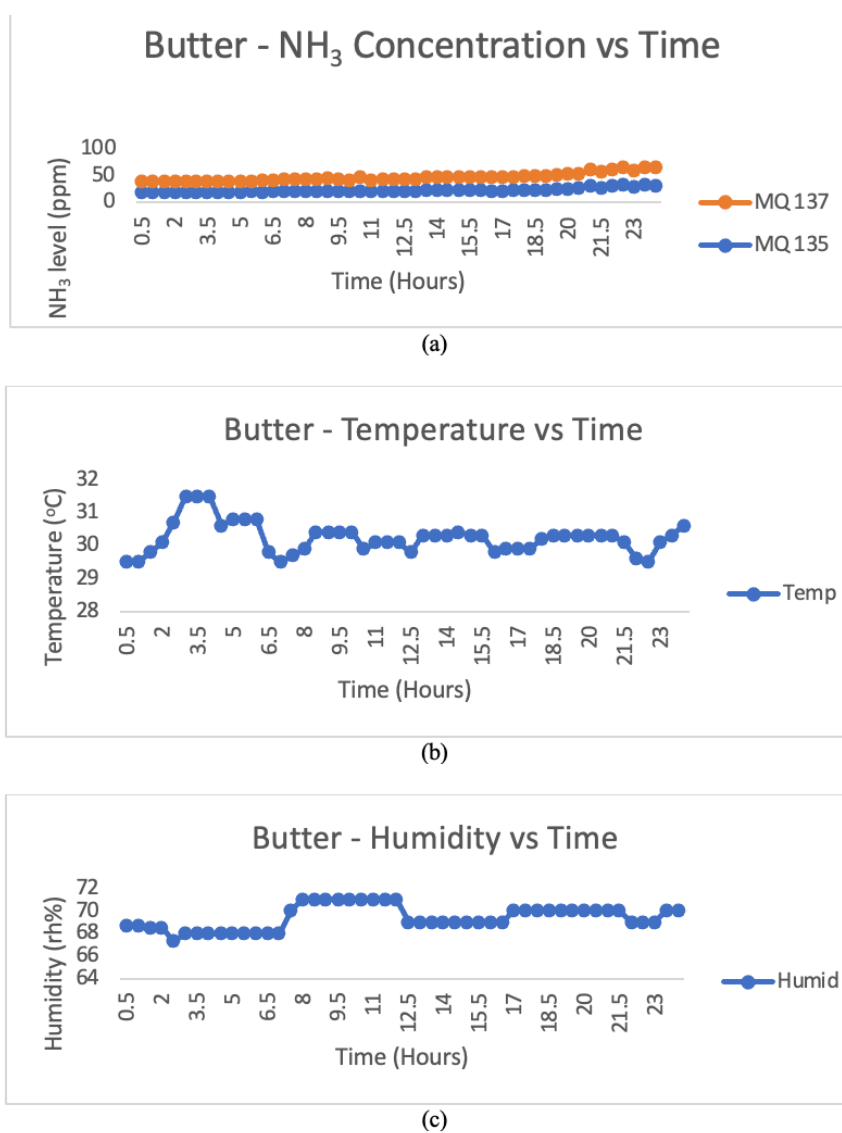


FIGURE 6. Graph of butter solid type animal-based dairy product over a 24 hours period for a) NH_3 level b) Temperature c) Humidity



(a)



(b)

FIGURE 7. Condition of butter a) before spoilage b) after spoilage

For solid based products like butter, which indicates gradual spoilage pattern, when compared to other types of dairy products, Figure 6 a). b) and c) illustrate the analysis of butter, examining NH_3 concentration (ppm), sensor voltage levels (V), ambient temperature ($^{\circ}\text{C}$), and humidity (rh%) over a 24-hour period, with measurements taken every 30 minutes. Figure 6 a) shows that the NH_3 levels remained low for the first 6 hours, owing to butter's high fat content and low water activity, which limit microbial growth and protein breakdown. From 8 to 14 hours, NH_3 levels showed a steady increase as microbial activity intensified, reaching a peak at 16 hours before stabilizing around 18 hours as nutrients became scarce. Environmental conditions, including fluctuations in temperature and humidity in figure 6 b) and c), influenced the spoilage process by accelerating microbial growth during later stages. Not only that, but minimum water availability also limits bacterial metabolism, which delay the development of spoilage in the solid products (Mullie et al. 2016; Bhat et al. 2025).

The MQ137 sensor detected higher, and more ammonia-specific readings compared to the MQ135 sensor during spoilage. These results highlight butter's inherent resistance to spoilage (Amran et al., 2026) due to its composition and underscore the

significance of environmental conditions and accurate sensors in quality monitoring. Figure 7 a) presents butter before and b) after spoilage, revealing changes such as texture shifts or discoloration due to microbial growth. These physical transformations correlate with elevated NH_3 levels and sensor readings, signaling spoilage progression. Fresh butter has a smooth, light, and slightly sweet aroma, but when it goes bad, it turns sour, stale, or rancid.

REAL-TIME MONITORING

Figure 7 a) and b) show a system that uses Adafruit IO for data monitoring and storage in the cloud. Once the system is connected to Wi-Fi, it establishes a connection with Adafruit IO using an IO key to access its feeds. This setup allows the system to monitor data in real-time and simultaneously save it to the cloud for storage and analysis. The integration ensures that the data can be accessed remotely, providing a reliable way to track and manage information over time. This solution not only enhances safety and quality control for dairy products but also increases convenience by enabling continuous access to monitoring data from any location at any time.

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New Feed

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Default				
Feed Name	Key	Last value	Recorded	
☐ HA	ha	82.50	12 days ago	
☐ HBC	hbc	82.30	6 days ago	
☐ HCM	hcm	70.00	15 days ago	
☐ HM	hm	80.10	14 days ago	
☐ HS	hs	81.80	13 days ago	
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(a)

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+ Add Data Download All Data Filter		
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Created at	Value	Location
2025/01/10 02:15:55AM	46.00	
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2025/01/10 12:45:37AM	45.00	

(b)

FIGURE 7. Adafruit IO: a) Data feeds of all dairy products and b) Data and graph of NH_3 level vs Time

The quality evaluation of cooking dairy products system uses Wi-Fi and Telegram bot app for real-time notifications and control. Upon powering on, it connects to Wi-Fi and Telegram bot app, with the status shown on the serial monitor. The system monitors gas levels (MQ-135 and MQ-137 sensors), temperature, and humidity to detect food spoilage. Users can issue three Telegram bot app commands as displayed in Figure 8 : “/warning” to alert when food is about to spoil (yellow LED), “/take” to warn about spoiled food removal (red LED), and “/reset” to turn off the LEDs. Automatic alerts are triggered when gas levels reach 29-30 ppm (yellow LED, voice alert) for impending spoilage and above 31 ppm (red LED, urgent voice alert) for spoiled food



FIGURE 8. Telegram Bot app command for control system

COMPARISON WITH PREVIOUS STUDIES

The comparison between the experimental results and previous studies highlights distinct advantages and differences. Previous studies, such as (Shaw, 2006; Gupta-Smith, 2024) used MQ-135 and MQ-137 sensors for smaller milk volumes (50 ml and 230 ml) and shorter durations, detecting ammonia levels of 40.9 ppm and 30.3 ppm, respectively. Study by (Tian et al. 2025) employed a metal oxide gas sensor to detect 500 ppm after 96 hours for 250 ml of milk, demonstrating an excellent stability but limited to room-temperature sensitivity and liquid-rich environments.. Study in (Putra et al. 2018) used MQ-137 for 250 ml of milk and detected 122 ppm of ammonia in 6 hours, likely due to a higher milk ammonia concentration, shorter testing time, or differing environmental factors. In contrast, this study tested a larger volume of farm milk (750 ml) over 24 hours, achieving ammonia levels of 46 ppm with MQ-135 and 49 ppm with MQ-137.

Despite of the ability in early detection of NH_3 at 10 ppm, the MIP (molecular imprinted polymer) sensor suggested by (Subramanian et al. 2025) necessitates rigorous synthesis to produce accurate and consistent results. While previous studies employed advanced systems like potentiometric sensors and neural networks, which improve accuracy but increase cost and complexity, this approach provides a cost-effective and functional alternative by utilizing inexpensive sensors and IoT integration for real-time monitoring. The extended duration allowed for a more comprehensive assessment of ammonia concentration changes, enhancing accessibility and feasibility for broader applications, making it scalable and practical compared to studies like (Tian et al. 2025; Singh et al. n.d; Putra et al. 2018).

TABLE 2. Comparison of results with previous studies

This Study	Sensor	NH ₃ (ppm)	Voltage (V)	Duration	Volume (ml)
Farm Milk	MQ-135	46	1.03	24 hours	750
	MQ-137	49	1.15		
Previous Researches					
Shaw, 2006	MQ 135	409.32	3.1	10 hours	50
Tian et al. 2025	Metal-oxide	500	NA	96 hours	250
Putra et al. 2018	MQ 137	30.3	1.15	6 hours	230
(Subramanian et al. 2025)	MIP	10	NA	NA	NA

CONCLUSION

This study aimed to experimentally investigate an Internet of Things (IoT)-enabled real-time monitoring system for spoilage detection in dairy products via ammonia nitrogen trihydride (NH_3) emissions patterns analysis. Technical contribution composed of the integration of calibrated MQ137 and MQ135 sensors with a temperature sensor and a NodeMCU esp8266 microcontroller with cloud-based monitoring via Adafruit IO and Telegram Bot alerts.

Experimental findings demonstrate that NH_3 concentration increases during dairy products spoilage, with farm milk gained 46 ppm to 49 ppm, while butter gave gradual accretion within the ranges of 32 ppm to 34 ppm. The higher moisture content in liquids facilitates microbial growth and ionic changes, leading to faster

spoilage progression. In solid products like butter and blue cheese, spoilage was slower due to lower water activity. Butter, in particular, exhibited the slowest spoilage rate among animal-based products because of its high fat content and minimal water activity, which inhibit microbial and enzymatic activity.

The system provides an economical, a scalable alternative of experimental testing to support food safety monitoring with digital transformation in the dairy industry. However, few constraint remain due to the absence of laboratory chemical validation and long term drift analysis.

ACKNOWLEDGEMENT

We would like to express our appreciation to the Universiti Teknikal Malaysia Melaka (UTeM) for their assistance in funding materials for this project as well as the publication expenses.

DECLARATION OF COMPETING INTEREST

None.

REFERENCES

- Ahmadi, A., Khezri, A., Nørstebø, H. & Ahmad, R. 2023. A culture-, amplification-independent, and rapid method for identification of pathogens and antibiotic resistance profile in bovine mastitis milk. *Frontiers in Microbiology* 13: 1104701. DOI: 10.3389/fmicb.2022.1104701.
- Azzola, F. 2015. Internet of Things project: Connect Arduino to Ubidots and Android – Part 1. *Java Code Geeks*.
- Amran, A. H., Shamsudin, N. H., Aziz, S. A. C., Chachuli, S. A. M., & Haris, N. F. (2026). Smart sensor integration for real-time quality monitoring in processed frozen foods. *Bulletin of Electrical Engineering and Informatics*, 15(4), 2900–2909. <https://doi.org/10.11591/eei.v15i4.10480>
- Bhat, M.A., Rather, M.Y., Singh, P., Hassan, S. & Hussain, N. 2025. Advances in smart food authentication for enhanced safety and quality. *Trends in Food Science & Technology* 155: 104800. DOI: 10.1016/j.tifs.2024.104800.
- Fernández González, A., Badía Laíño, R., Costa-Fernández, J.M. & Soldado, A. 2024. Progress and challenge of sensors for dairy food safety monitoring. *Sensors* 24(5): 1383. DOI: 10.3390/s24051383.
- Kalaiarasi, G., Dinakaran, K., Ashok, J., Kathirvelu, M. & Anandkumar, A. 2022. IoT based milk analyzer using Arduino with Wi-Fi module. In 2022 IEEE 2nd International Conference on Mobile Networks and Wireless Communications (ICMNWC), 1–5. DOI: 10.1109/ICMNWC56175.2022.10031666.
- Liu, L., Wang, Y., Liu, Y., Wang, S., Li, T., Feng, S., Qin, S. & Zhang, T. 2022. Heteronanostructural metal oxide-based gas microsensors. *Microsystems & Nanoengineering* 8: 85. DOI: 10.1038/s41378-022-00410-1.
- Mahesh, N., Sozhaventhana, A., Sreekanth, S. & Vishnupriya, M. 2023. Design and implementation of an IoT-based system for milk quality testing. In 2023 International Conference on Self Sustainable Artificial Intelligence Systems (ICSSAS), 1289–1293. IEEE. DOI: 10.1109/ICSSAS57918.2023.10331817.
- Manisha, N. & Jagadeeshwar, M. 2023. BC driven IoT-based food quality traceability system for dairy product using deep learning model. *High-Confidence Computing* 3(3): 100121. DOI: 10.1016/j.hcc.2023.100121.
- Mullie, P., Pizot, C. & Autier, P. 2016. Daily milk consumption and all-cause mortality, coronary heart disease and stroke: A systematic review and meta-analysis of observational cohort studies. *BMC Public Health* 16: 1236. DOI: 10.1186/s12889-016-3889-9.
- Putra, M.A., Rivai, M. & Arifin, A. 2018. Milk assessment using potentiometric and gas sensors in conjunction with neural network. In 2018 International Seminar on Intelligent Technology and Its Application (ISITIA), 409–412. IEEE. DOI: 10.1109/ISITIA.2018.8710944.
- Saila, S., Bork, O., Tucker, I.G., Cranefield, S. & Bryan, M.A. 2023. Evaluation of an on-farm culture system for the detection of subclinical mastitis pathogens in dairy cattle. *JDS Communications* 4(4): 298–302. DOI: 10.3168/jdsc.2022-0312.
- Saravanan, S., Kavinkumar, M., Kokul, N.S., Krishna, N.S. & Nitheeshkumar, V.I. 2021. Smart milk quality analysis and grading using IoT. In 2021 5th International Conference on Intelligent Computing and Control Systems (ICICCS), 378–383. IEEE. DOI: 10.1109/ICICCS51141.2021.9432298.
- Seliem, M., Elgazzar, K. & Khalil, K. 2018. Towards privacy preserving IoT environments: A survey. *Wireless Communications and Mobile Computing* 2018: 1032761. DOI: 10.1155/2018/1032761.
- Shaw, M.S. 2022. Development and Testing of Device to Detect Milk Adulteration & Spoilage. Thesis. Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur.
- Singh, A., Anamika, Tanwar, J., Bhagat, K. & Rajashekhar, B.S. 2018. Electronic based artificial intelligence system for milk quality analysis. *International Journal of Advance Research in Science and Engineering* 7(7): 1204–1208.

- Subramanian, R.R., Krishna, G.V., Yeswanth, G.S., Charan, G. & Sashavali, G. 2025. Smart packaging: IoT-integrated sensors for food freshness. In 2025 International Conference on Computational Robotics, Testing and Engineering Evaluation (ICCRTEE), 1–6. IEEE. DOI: 10.1109/ICCRTEE64519.2025.11052946.
- Sun, Y., Tang, H., Zou, X., Meng, G. & Wu, N. 2022. Raman spectroscopy for food quality assurance and safety monitoring: A review. *Current Opinion in Food Science* 47: 100910. DOI: 10.1016/j.cofs.2022.100910.
- Suthagar, S., Tamilselvan, K.S., Mageshkumar, G., Muthupandian, S. & Vinod, V.M. 2019. Automated milk quantity and quality checking and vending machine. *International Journal of Recent Technology and Engineering* 8(3): 4369–4372. DOI: 10.35940/ijrte.C5521.098319.
- Tian, N., Wang, M., Song, Q., Liu, L. & Wu, Z. 2026. Synergistic gas sensing and superhydrophobic composites enabled real-time detection of milk spoilage. *ACS Sensors* 11(1): 570–580. DOI: 10.1021/acssensors.5c03391.
- World Health Organization. n.d. Food safety. World Health Organization. Accessed 10 May 2024.
- Wu, Y., Song, W., Wang, Y., Ma, D., Xu, W., Hassan, M. & Hu, W. 2024. VibMilk: Nonintrusive milk spoilage detection via smartphone vibration. *IEEE Internet of Things Journal* 11(10): 17184–17197. DOI: 10.1109/JIOT.2024.3359049.