An Integrated Ammonia Gas Detection and Monitoring System for Industrial Safety and Environmental Health

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Abstract. Ammonia (NH_3) plays a vital role in various industries, serving as a key raw material for fertilizers, plastics, explosives, and industrial processes like metal treating and cleaning. In the food industry, it is used as a leavening agent, preservative, and pH regulator for baked goods, processed meats, beer, and soft drinks. Its versatile applications make ammonia essential for chemical, industrial, and food production sectors. However, ammonia is a major air pollutant with a pungent odor and poses significant health risks, including skin, eyes, and respiratory tract irritation, burns to moist tissues, and potential long-term effects like reduced lung function and rare neurological conditions. While short-term exposure often results in recoverable injuries, prolonged or high-level exposure can lead to permanent respiratory damage and, in extreme cases, brain-related diseases. This emphasizes the critical need for effective NH_3 monitoring and mitigation measures to safeguard human health and the environment.In response to this challenge, this paper presents a low-cost ammonia gas detection system developed using an MQ-137 sensor, NodeMCU microcontroller, and ThingSpeak IoT platform. The system provides real-time monitoring, alerts, and data visualization, promoting industrial safety and environmental compliance. An automated alert mechanism ensures timely intervention when gas levels surpass hazardous thresholds. Testing under controlled and real-world conditions demonstrated the system's high precision, fast response, and robust performance. Compared to existing commercial solutions, this system offers superior accessibility and practicality. Future improvements will focus on integrating remote monitoring capabilities and linking the system to broader industrial frameworks, further enhancing its utility in reducing NH_3-related risks.

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Keywords. Ammonia Detection, Industrial Safety, Real-Time, Gas Exposure, Human Health, IOT, Environmental Monitoring

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1. Introduction

Ammonia (NH_3) is a vital chemical widely used in industries such as agriculture, food production, and manufacturing. It serves as a key ingredient in fertilizers, cleaning agents, and refrigeration systems, making it indispensable to modern industrial processes. However, alongside its numerous applications, ammonia poses significant health risks, especially in environments where its release or mishandling can lead to unsafe levels of exposure.

Exposure to ammonia, even at low concentrations, can irritate the eyes, skin, and respiratory tract. Prolonged or high-concentration exposure is far more hazardous, causing severe burns, tissue damage, and chronic respiratory issues such as reduced lung function or asthma. In extreme cases, exposure has been linked to neurological damage and other long-term health effects. Ammonia emissions also contribute to the formation of fine particulate matter (PM2.5), which penetrates deep into the lungs, leading to serious conditions like COPD and lung cancer. These health risks are compounded by the lack of adequate monitoring systems in many industrial environments, where accidental leaks or continuous low-level emissions often go undetected until they pose serious health hazards.

To address this pressing need, our project aims to develop a real-time ammonia gas detection system designed with health and safety as primary considerations. By providing continuous monitoring, automated alerts, and data visualization, this system ensures early detection of ammonia concentrations exceeding safe thresholds, enabling timely interventions. This approach not only safeguards human health but also supports compliance with occupational and environmental safety standards.

2. Literature Survey

Numerous studies have investigated ammonia gas detection systems, highlighting the importance of reliable and accurate mo
nitoring in industrial settings. Recent advancements in sensor technologies and IoT-based systems have enabled the development of cost-effective and efficient ammonia detection solutions. The following literature review summarizes key findings from various research studies, including IoT-based ammonia detection systems [1], wireless ammonia detectors [2], and advanced sensor technologies [3-13]. J. Vijayalakshmi et al. (2019) implemented an IoT-based ammonia detection system using the MQ135 sensor, enabling low-cost, remote monitoring with safety alerts [1]. J. Gu et al. (2016) developed wireless ammonia detectors using ZigBee and Bluetooth, facilitating portable and efficient gas monitoring in industrial settings [2]. Calibration Technologies, Inc. (2022) emphasized minimizing false alarms in gas detection through optimal sensor placement and regular calibration [3]. C. Egenhofer et al. (2014) analyzed the impact of energy costs on ammonia-intensive industries, stressing the need for cost-efficient monitoring systems [4]. M. Diana et al. (2018) studied ammonia exposure impacts on human health, highlighting the importance of accurate and reliable detection systems [5]. D. Kwak et al. (2019) provided an overview of ammonia detection techniques like photoacoustic spectroscopy and

metal-oxide semiconductors, comparing their sensitivity and industrial applications [6]. A. Machín et al. (2023) demonstrated that single-walled carbon nanotube (SWCNT) sensors achieved high sensitivity and fast recovery at near-room temperatures for ammonia detection [7]. A. A. Amran et al. (2022) compared gas sensor technologies and found that optical sensors had higher accuracy but were hindered by cost concerns [8]. H. Liu et al. (2019) developed Ag-decorated TiO2 quantum dots that enabled ammonia detection with high sensitivity and low energy consumption [9]. H. Fujita et al. (2022) introduced paper-based wearable ammonia sensors that were lightweight, cost-effective, and suitable for real-time monitoring [10]. A. Sharma et al. (2021) highlighted that graphene oxide-based sensors enhanced ammonia detection accuracy due to their increased surface area and molecular interactions [11]. F. Li et al. (2022) evaluated tunable diode laser absorption spectroscopy (TDLAS) for its superior accuracy and rapid ammonia detection in interference-heavy environments [12]. R. Singh et al. (2023) integrated ammonia sensors with AI models to enable predictive safety management in smart industrial environments [13]

3. Proposed Methodology

A. Block Diagram

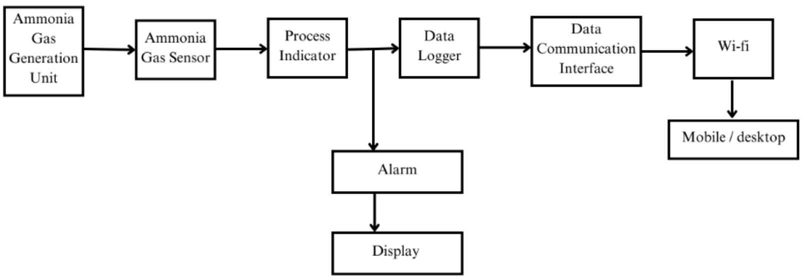

Fig 1. Block Diagram of system

Figure 1 illustrates the architecture of the proposed ammonia gas detection and monitoring system, designed for precise, real-time measurement of ammonia concentrations to enhance industrial safety and environmental monitoring. The system integrates multiple components to ensure efficient detection, alerting, and remote accessibility.

The system begins with an Ammonia Gas Generation Unit, used for testing and calibration purposes by simulating ammonia gas. The Ammonia Gas Sensor detects the concentration of ammonia in the environment and transmits the data to a Process Indicator, which processes the sensor output into analyzable information. This processed data is recorded by a Data Logger, enabling continuous tracking of ammonia levels for both real-time evaluation and historical trend analysis. For safety assurance, an Alarm system is included to provide immediate warnings when ammonia levels surpass predefined thresholds. Additionally, a Display is utilized to present the ammonia concentration in real-time for local monitoring. To facilitate remote access, the system employs a Data Communication Interface paired with a Wi-Fi module, allowing the data to be seamlessly transmitted to mobile or desktop devices. This functionality ensures that end-users can access ammonia concentration data remotely and act promptly when needed. By integrating reliable sensing, immediate alerts, and remote accessibility, this system offers a comprehensive and user-centric approach to ammonia gas monitoring, making it well-suited for industrial applications and environmental health management.

B. Experimentation

Sensor Selection:
Ammonia (NH_3) is an important chemical used in various industries, including the production of fertilizers, refrigeration, and petrochemicals. However, it can pose serious health and environmental risks because of its toxicity and reactivity. Regulatory guidelines set safe exposure limits at 25 ppm for 8 hours and 35 ppm for a short 10-minute exposure, which highlights the need for careful monitoring. Moreover, ammonia contributes to environmental pollution by creating aerosols that can affect air quality and climate. As a result, reliable detection of NH_3 is essential for ensuring safety in the workplace, protecting the environment, and in medical diagnostics, where ammonia can serve as a marker for certain health issues.

In the process of choosing an ammonia (NH_3) gas sensor, several technologies were reviewed, including conducting polymer sensors, optical absorption sensors, and electrochemical sensors. Designed with flexibility in mind, conducting polymer sensors are tunable for different applications but have limited long-term stability and slower responses because they depend on chemical reactions. Optical absorption sensors exhibit exceptional sensitivity and selectivity, however they are typically complicated and expensive to construct as they require detailed equipment which is too sophisticated for cheap portable devices. Electrochemical sensors are relatively accurate and can function properly in harsh environments, however they have a few disadvantages such as the need for maintenance and having a short lifespan of their components.

The MQ-137 semiconductor sensor appeared to be the optimal selection due to its simplicity of assembly, robustness, and affordability. The sensing material of the sensor is SnO_2, with a high sensitivity to NH_3 but also stability performance in long-term. The MQ-137 sensor, compared to polymer and electrochemical sensors allows for excellent functioning over a broad spectrum of conditions without the requirement of cumbersome calibration or additional parts. It has a simple conductivity-based mechanism which provides faster response on high change in ammonia concentration, thus suitable for real time online based monitoring of industrial environment [10]. The MQ-137 is a very stable sensor and will work with low-power microcontrollers (NodeMCU), so it was the obvious choice for main senor in this project.

Table 1. Sensor Specifications

Model	MQ137
Sensor Type	Semiconductor
Standard Encapsulation	Bakelite, Metal cap
Target Gas	Ammonia Gas (NH_3)
Detection range	5～500ppm NH_3
Standard test circuit	Vc:5.0V±0.1V；VH: 5.0V±0.1V

Design and Development:

An ammonia gas detector, based on an MQ-137 sensor, an OLED display, and a NodeMCU microcontroller. It measures changes similar to conductivity and can accurately measure ammonia concentrations, so for each of its (specifically air humid with ammonia gas) applications, the carbon sensor can detect wet gas composition but not excess ammonium or acid. Once the data from the sensors is processed, this information gets sent over to the OLED display through the NodeMCU for real-time graphical feedback. It is small, as well as energy efficient, so can be carried and operated well. The automated alert function alerts when ammonia is above predefined limits and the rescue team can be dispatched in case of an emergency.

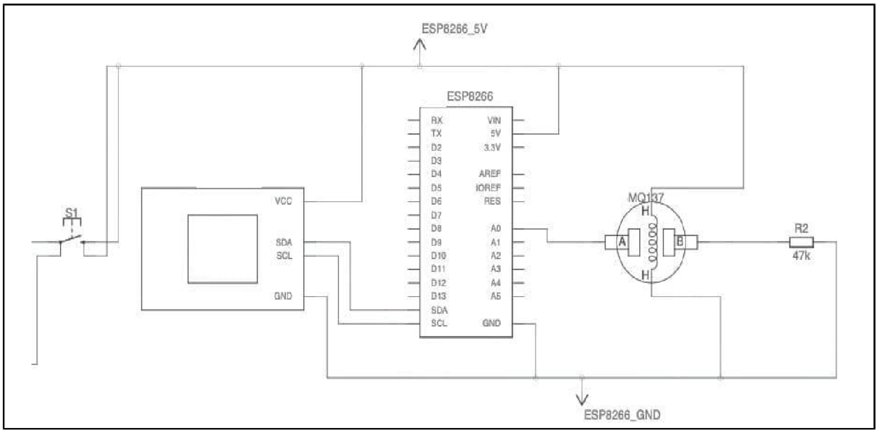

Fig 2. Design of circuit

The MQ-137 sensor measures the ammonia concentration around it in parts per million (ppm) through changes in resistance. The sensor is calibrated, that is, R0 which represents the resistance of a clean sensor in the fresh air, and is found based on analog averaging to make sure the measurements are precise. Ammonia concentration is then calculated using the formula:

$$ppm = pow\left(\frac{R_s}{R_o}\right), \frac{Midpoint_{Nh3}}{Slop_{Nh3}} \quad (1)$$

where Rs is the sensor resistance during exposure. The constants used are RL=47 Ω, VCC_BOARD_IN=3.3 V, AIR_CLEAR=3.6, SLOPE_NH3=0.23, and MIDPOINT_NH3=−0.7

The threshold of 30 ppm was chosen considering safety guidelines, as prolonged exposure above this level can irritate the eyes, nose, and throat. It aligns with OSHA's permissible exposure limits and ensures early detection, triggering a buzzer to alert users when the ammonia concentration exceeds the threshold. This proactive warning mechanism ensures timely interventions to prevent health hazards, making the system ideal for industrial and environmental applications

Data transmission and visualization

The system proficiently sends real-time data to ThingSpeak, an advanced IoT analytics platform, by utilising the NodeMCU's Wi-Fi capabilities. Smooth remote monitoring is made possible by the use of Wi-Fi for data transfer, which eliminates the need for complex wiring.

This is possible with the help of ThingSpeak- a process management platform that aids in easy visualisation of gas concentration patterns allowing the user to interpret the data quickly and take necessary actions. In addition to simplifying data storage and retrieval, this connection also greatly enhances the overall usability and efficiency of the system.

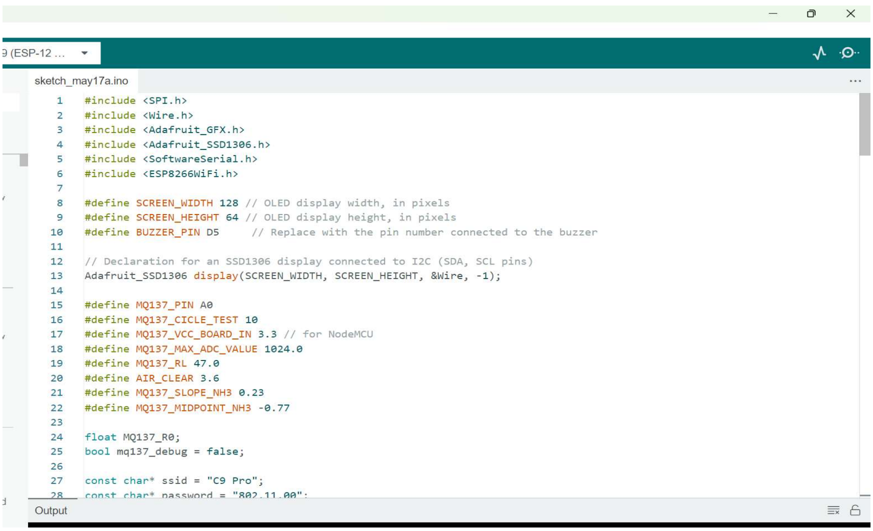

Fig 3. Connecting MQ-137 to NodeMCU

Fig 4. Connecting to ThingSpeak

Fig 5. Portable Ammonia Gas Detector

The final setup of the ammonia gas detection system is illustrated in the image. The compact and portable device features an IoT-based cloud platform for real-time ammonia detection and analysis. It is housed in a robust enclosure to ensure durability and is mounted on a stand for stability during operation. The design facilitates seamless data transmission to a cloud platform, enabling remote monitoring and data analysis via mobile or desktop devices.

This setup is an efficient and user-friendly solution for monitoring ammonia levels, ensuring enhanced industrial safety and environmental health.

4. Result and Discussion

The ammonia gas detection system performed very efficiently and reliably during the tests. The MQ-137 sensor was able to accurately detect ammonia concentrations from 5 to 500 ppm, while the OLED panel clearly displayed real- time data. We were most impressed with the automatic alert system, which was effectively a type of early warning system that would sound a buzzer when ammonia concentrations passed the defined safety limit (30 ppm).

By integrating with ThingSpeak, remote data transmission and visualization were made possible which further enhanced the utility of the system. Even though the gauge chart displayed current levels quickly and intuitively, the line graph was beneficial for visualizing ammonia concentration patterns in time. These aids were better able to identify trends, as well as any safety concerns that might have arisen in the previous week,. Additional visual aids encouraged more proactive decision-making.

Using Wi-Fi for transferring data also promoted mobility by aggrandizing the simplicity of deploying a wireless infrastructure, which provided seamless communication while minimizing wiring complexity. In short, these results indicate that the proposed ammonia gas detection system is a feasible, inexpensive, and efficient continuous- ammonium monitoring strategy for practical industrial applications. Besides being a safety standard that all companies have to follow, it is the essential tool required for ensuring environmental compliance and promoting worker safety.

Fig 6. Representation of measured NH3

The image illustrates two visualizations used for monitoring ammonia gas concentrations in real-time. The line graph on the left shows the variations in gas concentration (in ppm) over time, with the x-axis representing time and the y- axis displaying concentration levels. This graph effectively captures trends and fluctuations in the detected gas levels. On the right, the gauge chart provides a quick and intuitive snapshot of the current ammonia concentration, with a needle indicating the real-time value on a scale from 0 to 100 ppm. The combined visualizations deepen the system's message, moving from detailed trends to immediate safety conditions at a glance.

Through this approach, the system provides an ammonia gas detection solution along with timely information about gas concentration levels. This allows industries to make informed decisions and take quick actions to avoid safety risks, thereby improving workplace safety and environmental compliance.

5. Future Scope

Lastly, the ammonia gas detection system developed in this research has great potential for future enhancements: (1) it could be coupled with predictive analytics through machine learning (ML) models based on previously accumulated data and can guide industries in planning against hazardous conditions; ML algorithms can learn to predict anomalies and patterns based on thingspeak's historical gas concentration data, which have been shown to identify patterns leading to equipment failures or process inefficiencies. You could also apply data science techniques like clustering.

Future versions may also incorporate Internet of Things-based industrial automation frameworks for easier integration between gas detection and corresponding aeration or containment systems solutions. If the current sensor array could be expanded to an unaffordable scale so that other gases could also be detected along with ammonia (by at least one other gas, found in this study), the potential for wider industrial and environmental applications would be even greater.

6. Conclusion

This research contributes to the development of a comprehensive ammonia gas detection system, integrating IoT technologies, sensor systems, and data analytics. The proposed system offers a reliable, efficient, and cost-effective solution for monitoring ammonia concentrations and promoting workplace safety, environmental compliance, and public health. The ammonia gas detection system demonstrates a significant advancement in monitoring and detecting ammonia concentrations, ensuring a safer working environment and reducing the risk of accidents. The system's successful testing and validation demonstrate its potential for widespread adoption and positive impact on workplace safety and environmental compliance.

The MQ-137 gas sensor demonstrates the feasibility of an inexpensive and effective scheme to monitor ammonia concentrations as shown in this study. The system development was based on measuring ammonia concentration vapor using calibration factors such as R_0 and the ratio of sensor resistances. A proactive hazard detection method, compliant with occupational safety regulations, ensures the 30 ppm threshold is an actionable level. ThingSpeak integration enables real-time data visualization and analysis, allowing for meaningful trend monitoring and reporting on ammonia level fluctuations. Additionally, the NodeMCU microcontroller with Wi-Fi capabilities increases usability and data transmission efficiency.

With this system, industrial and environmental safety compliance can be greatly enhanced to promote air quality monitoring. Future iterations could expand its applications by integrating additional sensors and utilizing advanced analytics for broader adoption.

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