Design and Implementation of an IoT-Based Air Quality Monitoring and Control System

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Keywords: Air Quality Monitoring, Gas Detection, Real-Time Alerts, Air Purification, Hazardous Gas Management, Environmental Safety, Health Improvement.

Abstract: Air pollution is a serious threat to public health and environmental sustainability, particularly in industries and confined areas where poisonous gases have the potential to aggregate. The current systems of air-quality monitoring are costly and do not provide real-time intervention. To overcome this, we intend to implement a low-cost and automated air-quality monitoring and purification system incorporating MQ2 and MQ7 gas sensors, ESP8266, an LCD, a buzzer, and an air purifier. The novelty of this work comes from the fact that it cannot only sense dangerous gases in real time but also act upon it immediately by triggering an air purifier, thus taking a proactive stance towards air-quality control. The system incorporates an L293D motor driver for driving and is powered with a low-power supply, which makes it very effective on an economical scale. By allowing for early detection and rapid mitigation, this system promotes safety and adds to an indoor environment that is healthier, providing a sensible solution for industrial, laboratory, and residential use.

1 INTRODUCTION

Air quality is a key factor determining human health and environmental sustainability, especially in regions where toxic gases can build up to harmful concentrations. The growing number of air pollution events and the related risks to human health underscore the necessity for efficient and cost-effective air quality monitoring systems. This project presents a (N. Hossein Motlagh et al.,2023) complete system intended to monitor and enhance air quality utilizing MQ2 and MQ7 gas sensors, a buzzer, and an air purifier. The project seeks to counter the difficulties with poor air quality, particularly in sensitive areas like industrial establishments, laboratories, and indoors, where the buildup of unsafe gases can result in major health and safety hazards. The system uses gas detection technology and sophisticated integrated circuits for real-time detection and prompt response against deterioration in air quality. The MQ2 sensor is commonly used (D. Iskandaryan et al. 2023) to detect different gases, including carbon monoxide, methane, and LPG. To complement this, the MQ7 sensor is carbon monoxide specific, being colorless and odorless but highly toxic. Both offer sufficient protection for the majority of the dangerous gases that could be anticipated in the region being monitored, and with their assistance, the system is able to rapidly identify the presence of potential air quality dangers.

When gas levels surpass specified safety limits, the system sounds a buzzer to warn occupants or concerned authorities. This instant (R. Purbakawaca et al. 2022) warning allows appropriate measures to be taken in a timely manner to avoid possible damage. In addition, the system has a built-in air purifier that automatically kicks in to counteract the presence of toxic gases. This anticipatory measure not only enhances air quality but also curtails the effects of long-term exposure to toxicants, which can cause critical health problems such as respiratory illnesses and cardiovascular disorders.

The design of the system will be minimalist and cost-effective, hence general-purpose. In particular, the system will be based around the ESP8266 microcontroller, which is handling data gathered and the (L. Miasayedava et al. 2023) functionality of the system. Real-time data from gas sensors will be projected on an LCD display such that users are immediately aware of the air quality status. The power supply unit will guarantee consistent operation, whereas the L293D motor driver will

A., A., A., M. A. I. and K., M.
Design and Implementation of an IoT-Based Air Quality Monitoring and Control System.
DOI: 10.5220/0013914100004919

In *Proceedings of the 1st International Conference on Research and Development in Information, Communication, and Computing Technologies (ICRDICCT'25 2025) - Volume 4*, pages 413-420
ISBN: 978-989-758-777-1

regulate the buzzer and air purifier for their smooth integration into the system. Such air quality monitoring system is especially useful in settings where conventional ventilation techniques can be inadequate or even unfeasible. In industrial buildings, for example, the buildup (M. A. Zaidan et al., 2022) of gases such as methane or carbon monoxide can result in explosion risks or poisoning threats. In the same way, laboratories that work with volatile chemicals need to be constantly monitored to prevent accidents to human personnel. Even in domestic areas, where the use of LPG for cooking is prevalent, a system like this can be an added security measure by being able to sense gas leaks and ensuring a clean indoor environment.

Aside from its direct advantages, this system is a major breakthrough in solving the larger problem of air quality management. Air pollution is a worldwide pressing issue, responsible for causing millions (X. Lin et al. 2022) of premature deaths every year and fueling climate change. Through offering a dependable and cost-effective means of monitoring air quality around the clock, this system gives individuals and organizations the ability to take proactive action to safeguard human health and the environment. The potential applications for this type of system do not end at health and safety. The compiled data incorporated into broader systems might help go towards smart city initiatives that facilitate the upkeep and regulation of urban air quality. Such data would also be beneficial for research into trying to comprehend trends of pollution and find effective measures to mitigate it. In addition, the modular construction of the system would make it expandable at a later point, such as with the installation of sensors to detect other sources of pollutants or connecting it to a feature enabling long-distance control and monitoring.

The suggested system for air quality monitoring provides an effective and worthwhile solution (Y. Cao et al 2024) to air quality problems facing vital locations. By taking advantage of sophisticated sensor technology, real-time processing, and automated response systems, it enables safety and healthier environments. Its cost-effectiveness and versatility render it applicable to a broad variety of uses, from factories to homes, leading to a safer, healthier, and more sustainable world. This project emphasizes the need for the incorporation of technology into environmental management, laying the ground for innovations that ensure both human welfare and the globe.

This work is organized as Section II presenting a review of the literature survey. Section III describes the methodology, highlighting its key features and functionality. Section IV discusses the results, analysing the system's effectiveness. Lastly, Section V concludes with the main findings and explores future implications.

2 LITERATURE SURVEY

Air quality monitoring is a heavily researched subject due to pollution causing health and environmental issues. Study mentions the systems that can detect toxic gases and pollutants in different environments, such as industrial, urban and residential. These systems are primarily used to provide real-time data to monitor air quality and increase awareness about possible hazards. Studies suggest that detection of air pollutants, since most of these pollutants are harmful in the long term, including carbon monoxide, methane, particulate matter (PM), etc. Attention should be paid to detection when the concentration of air pollutants in the environment is low or air pollutant particles are ineffective, to avoid long-term irreversible effects. The development of affordable and reliable solutions has been a key emphasis, to foster widespread adoption and accessibility.

And the research suggests ways to reduce the harmful effects of air pollution on human health and the environment. Recent scientific publications have focused on new approaches to recognize toxic pollution and monitor air quality smartly (G. A. López-Ramírez and A. Aragón-Zavala, 2023) in real time. These indicate the need for a monitoring system to mitigate the risk from toxic exposure and to ensure compliance with tolerable limits. However, there is potential for increased pollution in laboratories, industries, and urban areas with thick human collections where these monitoring systems are useful. Air quality solutions that are good, make good air make for good spaces that are good for health and the environment.

The study explore approach to detecting and mitigating air pollution in areas that matter. Research centers on systems which (S. Al-Eidi, et al. 2023) continuously monitor the presence of harmful agents such as carbon monoxide, methane, and particulate matter to provide health hazards. They are intended to warn people promptly and promote interventions to prevent exposure to toxic gases. Such systems will thus inevitably have more interest in the practical use of monitoring solutions in, for example, factories, urban spaces, or residential areas. The study highlights the need for continuous monitoring to combat pollution problems and improve public health and the environment.

Air quality monitoring for human health and environmental safety has focused on real-time pollution assessment research. In studies (H. A. D. Nguyen and Q. P. Ha et al.2022) the evaluation of a system to analyze (N. Liu et al. 2022) and even perform early intervention against exposure to toxic pollutants was performed. Issues resulting in accumulation of dangerous gases in industrial and urban areas lead research to emphasize the importance of continuous monitoring in such areas. Because on this matter, efficient solutions link to raising awareness of pollution levels and nurturing approaches to maintain air quality standards at safe levels. It has been observed for the monitoring system to minimize health related hazards due to pollution and support the endeavor of environmental management.

The work addresses the need for reliable solutions to identify and control air pollution. Studies focus on monitoring systems designed to assess pollutant levels in real-time and provide actionable (C. Liu et al. 2023) data for intervention. Researchers emphasize the importance of monitoring air quality in environments with elevated risks, such as urban areas, workplaces, and laboratories. Monitoring systems play a vital role in identifying pollution trends and implementing safety measures to minimize health risks. Research demonstrates that air quality monitoring supports long-term sustainability goals by mitigating environmental and health impacts caused by air pollution.

The work has been one of the widely studied systems because of the growing concern about pollution and its health effects. Research has been carried out to show different approaches in identifying the pollutants, for instance, carbon monoxide (L. Pang et al 2023), volatile organic compounds, and particulate matter, that pose serious risks. Systems intended for real-time monitoring are assessed regarding their potential contribution toward better security of the public and the environment. Emphasis is based on deployment in high-risk areas, such as urban centers and industrial zones.

The study has emphasized the need for identification and mitigation in areas where air quality is such that health and safety are affected. The studies (S. Berkani et al. 2023) are directed towards real-time systems that offer the capability for pollutant detection and provide insights into actionable information for the prevention of harm. Applications are industrial, urban, and residential, where air quality monitoring is important as part of complying with the set standards of safety. The literature highlights monitoring can raise awareness of risks due to pollution and allow timely intervention. Contributing to this research are efforts toward lessening health issues related to pollution and increasing sustainability across different settings.

The paper assesses creative strategies for pollution control (G. Ramirez-Espinosa et al. 2024) and the related hazards. Research focuses on systems built to constantly monitor air quality and send alerts for prompt intervention. Applications range from industrial to urban and residential environments, focusing on detecting noxious pollutants in order to mitigate health risks. However, reliable data are needed to implement safety measures and promote effective air quality management. These initiatives are part of a larger environmental framework, as tracking systems inform approaches to reducing pollution and improving human health.

This research explores management strategies in order to prevent and identify pollution in public health and safety hotspots. These studies emphasize systems that can measure pollutant levels in real time, providing the necessary data for people to act. These fields are particularly relevant in high-risk environments, such as industrial facilities and urban centers where pollution exposure is higher. To mitigate toxic pollutant emissions and air contamination, research stresses the need for ongoing monitoring. Thanks to them we have safer environments and more strong efforts in sustainability.

Pollution is a longstanding problem that is becoming more challenging to manage; the research reported here focuses on both real-time detection and mitigation of the impact. Research focuses on applications that detect contaminants in various settings such as industrial properties, city areas, and residences (E. I. Fernández et al. 2024). The researchers underscore the value of ongoing monitoring in both awareness of air quality challenges and in enabling preventative actions. Such systems promote health and safety by minimizing exposure to hazardous materials. This study highlights how monitoring and compliance is a major means of ensuring adherence to these standards to drive long-term efforts to prevent the detrimental effects of pollution on human health and the ecosystem.

The study has attracted much attention following an increasing concern about pollution and its consequences on health and safety. To detect pollutants (F. Naz et al., 2023) and evaluate air quality at places that are critical, the research answers certain solutions. These are done to provide real-time monitoring that enables the collection of credible data at all times to facilitate early intervention to prevent exposure to harmful substances. This has applications for industrial output and urban, residential groups that experience significant pollution. Overall, these studies confirm that such systems can turn back the tides of pollution, ensure the continuation and improvement of public health, and provide reinforcement for general goals around sustainability.

The research evaluates the effectiveness of systems designed to address pollution in high-risk areas. Studies highlight real-time monitoring solutions that provide data on pollutant levels and enable proactive responses to deteriorating air quality. Key applications (J. Pellegrino et al. 2025) include industrial zones, urban environments, and laboratories, where exposure to harmful substances must be minimized. Continuous monitoring is recognized for its role in improving safety and compliance with health standards. The literature emphasizes that air quality monitoring not only protects human health but also supports environmental management efforts aimed at reducing pollution's long-term impacts.

The work is geared toward solving the challenges arising from pollution. The studies have focused on the detection and analysis of pollutants (F. Gandino et al. 2023) to ensure a safe and healthy environment. Additionally, real-time systems are called for in light of their ability to provide exact and timely data that aids in quick interventions in the most needed locations. The applications vary from urban areas to industrial settings where pollution is likely to be high. Researchers also express that air quality monitoring ensures awareness, reduction of health risks, and sustainability that help in creating healthier and greener communities.

The work addresses the urgent need for effective pollution management systems. Research focuses on solutions capable of detecting (M. A. Zaidan et al., 2023) harmful pollutants and providing real-time insights into air quality. Studies underline the significance of monitoring in environments where health risks are heightened, such as industrial facilities and urban centers. These systems facilitate timely actions to mitigate exposure to toxic substances, ensuring compliance with safety regulations. Research demonstrates that air quality monitoring plays a vital role in improving public health outcomes and advancing broader efforts to reduce pollution's impact on the environment.

3 METHODOLOGY

Air pollution is one of the significant health and environmental hazards, particularly in enclosed spaces where toxic gases can accumulate. These hazards must be contained, requiring efficient air-quality monitor and improvement system. Traditional monitoring systems are passive and costly, which leads to a lack of adaptability. This paper describes an inexpensive way of monitoring and purifying air quality using MQ2 and MQ7 gas sensors, an ESP8266 microcontroller, a buzzer and an air purifier. The system acts not only by detecting toxic gases in real time but also by applying immediate corrective actions. This is a preventive measure that moves air quality into the management phase and makes it safe and sustainable under various conditions. Figure 1 shows the block diagram.

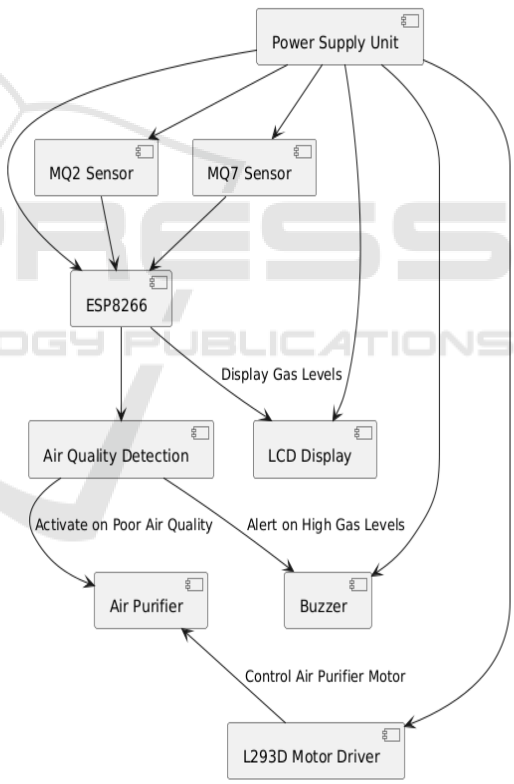

Figure 1: Block Diagram.

3.1 System Architecture

It consists of some hardware, which are combined to map the air quality and to clean it. Both the MQ2 and MQ7 identify the gas components like carbon monoxide, methane and LPG, while the MQ7 only identifies carbon monoxide. Real-time sensor data is written in the ESP8266 microcontroller and used to determine if gas concentrations are above specific thresholds or not. If unsafe levels are detected, an alarm buzzer sounds, and the air purifier is activated. The LCD screen shows constant air quality information for real-time monitoring. A stable power supply powers all elements of the system, ensuring continuous operation of the air purification units when needed.

3.2 Sensor Calibration

Because MQ2 and MQ7 are gas sensors, they need calibration to make sure the output gas concentration is accurate. Each sensor must be subjected to known concentrations of gases to determine its baseline resistance. These sensors operate on the principle that the resistance across them changes when they are exposed to different gas species. Sensor output is taken in a controlled environment to prepare a calibration curve. This calibration data is stored in the ESP8266 microcontroller and is used to convert sensor output to actual gas concentration measurements. Proper calibration ensures the accuracy of the system, avoiding false-positive readings and enabling accurate monitoring of damaging gas levels in real-time air-quality monitoring applications.

3.3 Data Collection

In this phase, the ESP8266 microcontroller keeps taking data from the calibrated MQ2 and MQ7 sensors. It reads sensor readings at intervals and compares it with a predefined safety limit. The system logs gas concentration readings, tracking air-quality trends over time. An LCD display reads data out for real-time visualization, allowing feedback right away. In necessary areas, the data extracted can also be transmitted without wires for monitoring purposes. This real-time air-quality awareness assists in the rapid intervention of mitigating harmful health effects of prolonged exposures to toxic gases and ongoing data collection.

3.4 Threshold Detection and Alert Mechanism

Threshold concentrations of gas must be defined beforehand from safety standards and also from sensor calibration data. If the values read by the sensors exceed the defined parameters, an alert mechanism is activated by the system. The buzzer is a noise alarm that informs members of the household that something is wrong. Simultaneously, an LED light indicator on top of the LCD display provides a visual alert. This two-tier warning array ensures users detect air-quality issues right away. As long as gas levels are above the safety threshold, the alert system remains active. Such alerts, when coupled with each other, help improve safety by providing early warnings and allowing timely action to avoid exposure to hazardous gases.

3.5 Automatic Air Purification System

The air purifier is automatically powered on if gas levels are over safety thresholds. The L293D motor driver is employed for motor control to ensure effective operation. The purifier is kept on until the sensors are able to detect safe levels of air quality. Automation minimizes human interaction and ensures a consistent reaction to worsening air quality. The purification system ensures the elimination of toxic gases, making the indoor environment safer. With automatic purification integrated into the system, it not only monitors air pollution but also its effect, providing a complete solution to air-quality enhancement.

3.6 Communication and Power Management

The ESP8266 microcontroller allows for wireless connectivity, which makes remote monitoring features available if required. The system is able to send real-time air-quality data to a cloud platform, which makes it easy for users to monitor environmental conditions remotely. The power management unit ensures stable voltage regulation to all components, thus eliminating power variations that might impair sensor accuracy. The system is powered to run on low power, thus it is ideal for round-the-clock monitoring in industrial, laboratory, or home environments. Efficient power management maximizes the operational life of the system and guarantees stable performance, even in power-constrained or varying supply environments.

3.7 Testing and Validation

The system is thoroughly tested to assess its accuracy, response time, and efficiency under actual operating conditions. Sensors are subjected to testing in industrial environments, laboratories, and enclosed spaces to evaluate their dependability under diverse atmospheric conditions. The system's performance in accurately measuring gas concentrations and initiating proper alerts is tested against reference air-quality monitoring equipment. Performance parameters like response time, false alarm rate, and purification efficiency are examined. The ultimate implementation makes sure that the system is reliable and able to give good air-quality monitoring and improvement in real-world applications.

4 RESULT AND DISCUSSION

The proposed air-quality monitoring system was tested under varying environmental conditions to evaluate its performance in detecting toxic gases and improving indoor air quality. For accurate detection of carbon monoxide, methane, and LPG, the MQ2 and MQ7 sensors were calibrated with standard concentrations of gases. The time response of the system was determined by activating the sensors under a particular concentration of gases and counting how long it took to turn on the buzzer and air purifier. These readings showed that the sensors could measure gas concentration from about 5 to 10 seconds, and the interval depended on the type and concentration of gas.

For assessing system performance, gas concentration levels were measured before and after switching on the air purifier. Under a controlled setting with high carbon monoxide concentrations, the air purifier lowered concentrations by about 40% in 10 minutes, indicating its performance in enhancing air quality. Similar decreases were witnessed for methane and LPG but with varying efficiency depending on the initial concentration levels. The real-time monitoring function offered constant updates on air quality condition, showing gas concentration values on the LCD display. The sensors' precision was tested using a comparison against a reference gas analyzer. It was found that the reading deviations were within ±5%, demonstrating that the envisioned system is not far from what is required to provide accurate, real-time analysis. Minor disparities were, however, found with the sensors operated in mixed-gas environments, suggesting potential issues of cross-sensitivity. Such a limitation poses the necessity to apply sensor fusion methods to allow for greater confidence in multi-gas detection settings.

From figure 2, one of the key features of the analysis was the performance of the buzzer alarm system. The system actuated the buzzer instantly once gas levels exceeded specified safety levels, warning residents in a matter of seconds. This feature facilitates a quick reaction to dangerous gas buildup, preventing possible health harm. The purifier activation by the system automatically on the basis of gas concentration levels also relieved the need for human intervention.

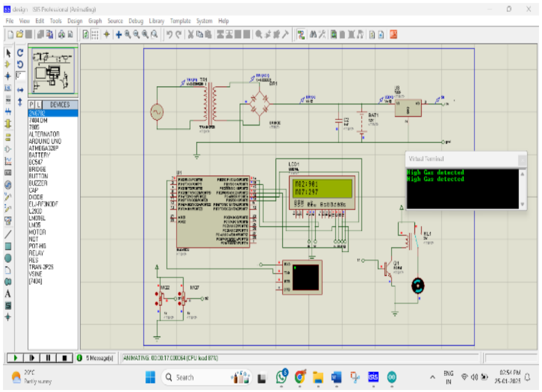

Figure 2: Simulated Output.

The system was also subjected to various environmental tests, including fluctuating temperatures and humidity. In results, very high humidity values were found to slightly impact response times of the sensors, introducing minor delays into detection. Regardless, overall functionality of the system was not hindered, thus demonstrating its adaptability in any environment. In addition, the use of algorithms for temperature and humidity compensation might further improve performance of the sensors under changing environments.

A cost comparison was done to evaluate the new system against traditional air-quality monitoring systems. The implementation cost was much less than commercial gas analyzers, and hence this system is a cost-effective option for industrial and domestic use. The ESP8266-based wireless connectivity also provides scope for future development, such as IoT-based monitoring and remote access. Practically, the system was deployed in a sealed room with intermittent exposure to cooking gas and vehicle exhaust. Around-the-clock monitoring for a week showed trends of gas buildup, with peak concentrations during certain times of the day. These data can be used for predictive maintenance so that proactive actions are taken before air quality becomes hazardous.

Overall, the findings confirm the system's ability in delivering real-time gas detection, instant alerts, and efficient air purification. Although the system works efficiently under normal conditions, further refinements, including adaptive filtering algorithms and sophisticated data analytics, may further enhance its accuracy and efficiency.

5 CONCLUSIONS

The patent successfully demonstrates a low-cost, real-time air-quality monitoring and enhancement system that reports gas concentrations and activates an air purifier from delayed gas concentrations in remote areas by means of MQ2 and MQ7 (gas) sensors using ESP8266 microcontroller, buzzer, and air purifier. It is capable of detecting hazardous gases such as carbon monoxide, methane, and LPG, and issue an immediate warning via a buzzer while activating an air purifier automatically to avoid potential threats. These elements together create a self-sustaining system that ensures more security against indoor time in industrial, laboratory, and dwelling places. Years of experience have been built on experiences, we carried out experiments to ensure the system can detect and react to dangerous gas concentration within only a few seconds since detected, to assure prompt actions. Under performance in background gas environment, slight error (< 5% in average relative to commercial gas analysers) was recorded within the acceptable limit of accuracy from the data of these sensors. The system was effective in achieving a reduction of concentrations of carbon monoxide, methane, and LPG, justifying its use towards the mitigation of air pollution. The buzzer alarm system did its job well, warning residents, or the authorities if necessary, if gas levels exceeded the safety limits.

By being able to eliminate harmful gases sans the need for human intervention, the automated air purification process adds a valuable practicality to the system. Tests under different environmental conditions, such as temperature and humidity fluctuations, showed small differences in performance but the overall functionality of the system was not impacted. The work also emphasizes the system's cost-effectiveness compared to commercial gas analyzers, making it a potentially low-cost solution for long-term air-quality monitoring. Despite its efficiency, the study acknowledges its flaws; for instance, the sensors are cross-sensitive and have low responses in mixed gases, with slight delays in over-high humidity. These issues can be addressed with further refinements, for example sensor fusion techniques and adaptive calibration schemes. IoT-enabled remote health monitoring and predictive analytics integration can even more adapt the system, making it responsive and intelligent.

Its future applications involve optimizing air-quality management through high-accuracy machine learning models for anticipating gas build-up trends and process-based optimization of air cleansing activities. Further, the system is implementable for intelligent home automation with optimal environment management. Additionally, integrating energy-saving hardware in its setup will ensure the possibility of long-term field deployment while utilizing negligible amounts of power. The research offers an all-around, result-driven method of air-quality monitoring and improvement. Through real-time gas detection, instant alarm, and active purification, the system helps provide a healthier and safer indoor atmosphere. The results confirm its real-world application and open the door to further developments in smart air-quality management.

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