Design and Development of an IoT-Enabled Smart Air-Purifying and Monitoring Mask for Hazardous Industrial Environments

Abstract

Air pollution continues to pose severe health risks, particularly for workers in hazardous industrial environments such as recycled plastic manufacturing units and coal mines. Prolonged exposure to harmful gases and particulate matter (PM) in such settings can lead to chronic respiratory issues, cardiovascular diseases, and other health complications. To address this challenge, this paper presents the design and development of a compact, wearable, smart air-purifying and monitoring mask tailored for industrial workers operating in extreme air quality conditions. The proposed device integrates multiple gas and environmental sensors, a HEPA filtration system, and real-time data communication using an IoT-based framework. The system incorporates MQ135 and MQ9 gas sensors to detect harmful gases such as carbon monoxide (CO), ammonia (NH_3), and benzene derivatives, along with a DHT11 sensor to monitor temperature and humidity. A HEPA filter combined with an active carbon layer is paired with a CPU fan to ensure continuous and adaptive air purification. Airflow is dynamically regulated based on sensor data, enhancing user comfort and maximizing energy efficiency. NeoPixel LEDs serve as a visual indicator for real-time air quality feedback. At the core of the system lies the ESP8266 microcontroller, which not only controls sensor operations and actuators but also transmits data wirelessly to a mobile device using the Blynk IoT platform. Users receive real-time air quality updates, historical logs, and alert notifications through the mobile app interface. Additional features include a buzzer for immediate hazardous gas warnings, a rechargeable 3.7V Li-ion battery with a boost converter for consistent power delivery, and an adjustable Velcro strap for ergonomic comfort. The proposed system was tested in simulated industrial conditions, demonstrating reliable sensor readings, responsive filtration adaptation, and robust wireless communication. The wearable prototype is designed with cost-efficiency and manufacturability in mind, making it suitable for mass adoption in developing regions where industrial health risks are prominent. The smart air mask aims to enhance worker safety and promote preventive health measures in industries often neglected by conventional air purifying solutions. Future enhancements may include AI-based predictive analytics, automated fan speed control via environmental classification, and cloud-based occupational health monitoring.

Keywords: Smart Air Mask, IoT-based Air Quality Monitoring, Industrial Safety, ESP8266, HEPA Filter, Blynk App, Gas Detection, Wearable Health Device, Pollution Control, Environmental Sensing

1. Introduction

Air pollution remains one of the most critical environmental health challenges faced globally, with a disproportionately high impact in developing countries like India. According to the Global Burden of Disease study, air pollution contributes to approximately 6.7 million premature deaths worldwide each year, with India bearing a significant share due to persistent exposure to fine particulate matter (PM2.5), carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and other hazardous airborne substances (HEI, 2020). The concentration of these pollutants is particularly severe in industrial zones such as recycled plastic factories, coal mines, and open waste dumps, where laborers often work long hours without adequate protective equipment. Existing air purification systems and face masks, although effective in certain urban scenarios, are often not designed to cater to the dynamic, high-pollution, and physically demanding environments of industrial workers. Most commercial masks lack real-time sensing, do not offer feedback on air quality, and do not adjust purification based on environmental conditions. As a result, workers are forced to rely on static protection, which provides only partial safety from exposure to noxious gases and particles (Cohen et al., 2017). Moreover, industrial workers such as rag pickers, miners, and construction laborers face additional challenges including limited access to healthcare, lack of awareness, and poor enforcement of occupational safety regulations (ILO, 2019). It is thus essential to develop an affordable, portable, and intelligent device that not only filters contaminated air but also monitors air quality continuously and provides actionable feedback to the user. To address this gap, the present study proposes the development of a wearable, sensor-integrated smart air-purifying mask. The system utilizes gas sensors (MQ135, MQ9), a temperature and humidity sensor (DHT11), and an adaptive CPU fan paired with a HEPA and activated carbon filter to purify incoming air based on real-time pollution levels. An ESP8266 microcontroller controls the hardware and transmits sensor data wirelessly to a mobile application using the Blynk IoT platform, allowing users to monitor air quality in real-time. Visual alerts using NeoPixel LEDs and an audio buzzer further enhance situational awareness for the user. This study aims to evaluate the feasibility, performance, and practical implications of deploying such a system in high-risk environments (Chandak et al., 2025; Gadhavi et al., 2025; Gohil et al., 2023; Joshi et al., 2025; P. Parikh et al., 2016, 2017, 2018, 2024, 2025; P. A. Parikh et al., 2020, 2023; Sanadhya et al., 2025). Through real-world testing, we analyse the effectiveness of the prototype in detecting harmful gases, adjusting airflow, and improving the safety and comfort of users. Ultimately, this research contributes toward low-cost, scalable solutions for occupational health in industrial settings where traditional air quality systems are either absent or inadequate.

2. Literature Survey

The use of wearable air-purifying devices and smart environmental monitoring systems has garnered increasing attention due to the growing risks associated with industrial pollution. Several studies have explored the design and implementation of air quality monitoring systems using gas sensors and wireless communication modules. For example, Manikandan et al. (2019) developed an IoT-based air pollution monitoring system using MQ-series gas sensors and Arduino, which enabled real-time data transmission and analysis. However, such systems were stationary and lacked portability for use in wearable applications. Wearable devices specifically designed for health and safety applications have been investigated in recent years. Lin et al. (2020) proposed a wearable mask embedded with sensing elements to detect particulate matter and CO_2, offering feedback through an app interface. However, the design was limited in terms of actuation or adaptive purification. Similarly, Ghosh et al. (2018) explored smart masks for urban pollution control, but the study emphasized urban commuters rather than industrial workers who face harsher environmental conditions. Air purification technologies such as HEPA and activated carbon filters have been well-studied for their efficacy in removing airborne particles and volatile organic compounds (Gogate & Pandit, 2015). Yet, their integration into compact, battery-powered wearables remains a design challenge. Moreover, studies like Zhang et al. (2020) have stressed the need for fan-assisted airflow in purification masks to reduce breathing resistance, especially during prolonged usage in high-exertion tasks. The integration of gas sensors such as MQ135 and MQ9 for detecting ammonia, benzene, and carbon monoxide is widespread in environmental sensing systems (Rahman et al., 2018). These sensors have been used in combination with Wi-Fi-enabled microcontrollers like ESP8266 to build low-cost, scalable solutions for pollution detection (Kumar & Rajasekaran, 2019). However, few studies have implemented them in a wearable form factor with feedback mechanisms such as LEDs or buzzers for immediate user awareness. The DHT11 sensor, commonly used for ambient temperature and humidity monitoring, plays a crucial role in adjusting the mask's airflow and improving comfort levels (Zhou et al., 2021). While this sensor is frequently used in weather monitoring projects, its inclusion in wearable respiratory protective gear remains underutilized. Recent advancements have explored the role of Internet of Things (IoT) platforms such as Blynk for remote monitoring and data visualization (Sharma et al., 2020). These platforms help bridge the gap between sensor data and user interaction. Additionally, the use of artificial intelligence (AI) for environmental prediction and anomaly detection in smart air monitoring systems is gaining traction (Nair et al., 2022), though not yet fully explored in wearables. Despite these developments, there is limited literature focusing on the convergence of air purification, adaptive fan control, real-time gas detection, and IoT-based feedback in a wearable form for industrial applications. The current work aims to address this gap by proposing an integrated, cost-effective, and user-friendly smart air-purifying mask tailored for hazardous industrial environments.

3. Problem Statement

Industrial workers in environments such as recycled plastic factories, coal mines, and open waste dumps are routinely exposed to hazardous gases, fine particulate matter (PM), and volatile organic compounds. Prolonged exposure to these pollutants significantly increases the risk of respiratory diseases, cardiovascular issues, and long-term health deterioration. Despite the seriousness of these health hazards, the majority of laborers lack access to intelligent, adaptive, and wearable protective equipment capable of real-time air quality monitoring and dynamic purification. Existing commercial air-purifying masks are largely designed for urban and lifestyle use, offering static protection without accounting for the varying intensity of environmental pollutants or the physical demands of industrial labour. These masks typically lack real-time feedback, sensor-based responsiveness, data connectivity, and ergonomic considerations suitable for continuous wear in high-pollution and high-exertion conditions. There is a critical need for a smart, sensor-integrated, IoT-enabled, and ergonomically designed air-purifying mask that can continuously monitor environmental parameters, filter harmful particles dynamically, and communicate real-time data to users and health monitoring systems. The absence of such an integrated solution leaves a major technological and health protection gap for vulnerable industrial workers. This research aims to address this gap by designing and developing a compact, cost-effective, and intelligent wearable mask that combines air purification, environmental sensing, wireless data transmission, and user alerts to safeguard industrial laborers' health in hazardous settings.

4. Objective and Methodology

4.1 Objectives

The primary objective of this research is to design and develop a **smart, wearable air-purifying and monitoring mask** tailored for industrial workers exposed to hazardous environments such as recycled plastic processing units and coal mines. The specific objectives include:

- To develop a **compact, lightweight, and ergonomic mask** that is comfortable for long-duration industrial use.
- To **integrate multiple environmental sensors** (e.g., gas, temperature, humidity) for real-time air quality monitoring.

- To implement an **adaptive air purification system** using HEPA and activated carbon filters supported by a CPU fan for regulated airflow.
- To enable **wireless transmission** of air quality data to a mobile application via Wi-Fi using the ESP8266 microcontroller.
- To provide **instant user feedback** using NeoPixel LEDs and an audio buzzer to indicate danger zones and alert users.
- To evaluate the **efficacy and reliability** of the proposed system under simulated industrial environmental conditions.

4.2 Methodology

The methodology adopted for this research is divided into six key phases:

Phase 1: Requirement Analysis and Component Selection

- Identification of health risks in plastic recycling and coal mining environments.
- Selection of suitable components:
    - **Sensors:** MQ-135 (air quality), MQ-9 (CO and flammable gases), DHT11 (temperature and humidity).
    - **Actuators:** CPU fan for airflow regulation, NeoPixel LEDs for visual alerts, buzzer for audio alarms.
    - **Controller:** ESP8266 Wi-Fi microcontroller for data handling and communication.
    - **Power Source:** Rechargeable 3.7V Li-ion battery with a boost converter for consistent voltage supply.

Phase 2: Circuit Design and Assembly

- Circuit layout on a prototyping board, integrating sensors, microcontroller, and output units.
- Proper wiring for safe power delivery and signal integrity.
- PCB design and enclosure 3D printing for compact integration into a wearable mask format.

Phase 3: Firmware Development and Wi-Fi Connectivity

- Programming the ESP8266 using Arduino IDE.
- Configuration of the **Blynk IoT platform** to visualize sensor data in real-time on a mobile app.
- Implementation of threshold-based alerts for various pollutants.

Phase 4: Mechanical Integration

- Embedding sensors and electronics into the mask shell.
- Installation of **HEPA + activated carbon filters** and CPU fan for adaptive purification.
- Use of **Velcro straps** for user comfort and wearability testing.

Phase 5: Testing and Validation

- Simulated exposure of the mask to varying concentrations of gases and environmental conditions.
- Data logging and performance evaluation of sensors, fan response, and alert systems.
- Assessment of power consumption and battery life.

5. Prototype Developed

The development of the smart air-purifying and monitoring mask followed a multi-stage procedure involving sensor integration, circuit development, enclosure fabrication, and final assembly. The entire system was built with careful consideration of ergonomic comfort, electrical safety, real-time communication, and responsiveness to environmental conditions.

Step 1: Sensor and Component Integration

The initial step involved selecting appropriate sensors and electronic modules based on the environmental risks in industrial settings. Three major sensors were selected:

- **MQ-135** for detecting ammonia, benzene, smoke, and other harmful gases.
- **MQ-9** for detecting carbon monoxide (CO) and combustible gases.
- **DHT11** for measuring temperature and humidity.

These sensors were wired and calibrated with the **ESP8266 Wi-Fi board**, which served as the main controller. To enhance analog signal resolution, a **16-bit I^2C ADC (Analog-to-Digital Converter) with PGA (Programmable Gain Amplifier)** was added between the gas sensors and the ESP8266. This allowed accurate measurement of low-concentration gas levels.

Step 2: Air Filtration and Control System

To purify the inhaled air, a **HEPA filter** was placed in the front housing of the mask, supported by an **activated carbon layer**. A compact **CPU fan** was mounted behind the filter to regulate airflow. The fan's speed was set to operate at a fixed RPM for this prototype but is designed for future upgrade with PWM control based on sensor feedback. A **NeoPixel LED ring** was attached around the fan to serve as a real-time visual air quality indicator. The LED colour changed based on threshold gas values—green for safe, yellow for moderate, and red for hazardous levels. Additionally, a **buzzer** was included to audibly alert the user in case of high pollutant concentration.

Step 3: Power Supply Setup

A **3.7V lithium-ion rechargeable battery** was chosen as the primary power source. Since the ESP8266 and other components require a higher voltage, a **boost converter module** was added to step up the voltage to 5V. A **rocker switch** was mounted externally for toggling the system on and off.

Step 4: Fabrication and Mask Integration

The structural housing was designed using 3D CAD software and fabricated via **FDM-based 3D printing**. The front casing securely holds the fan, filters, MQ-135, and MQ-9 sensors. The inner section (back view) contains the DHT11 sensor and wiring channel that connects to the external control box. The entire assembly was attached to a **soft yet firm Velcro belt strap** for secure and comfortable wear.

Step 5: Enclosure and Circuit Box Design

The control electronics were embedded inside a **yellow 3D-printed protective enclosure**, allowing room for wire routing, airflow, and cooling. The ESP8266 module, buzzer, ADC, boost converter, and power switch were mounted securely on a prototyping board inside this casing.

Step 6: System Programming and Testing

The ESP8266 was programmed using the **Arduino IDE**. Sensor data was sent via Wi-Fi to the **Blynk IoT platform**, allowing real-time air quality display on a smartphone. Threshold values were programmed to trigger LED changes and buzzer alerts.

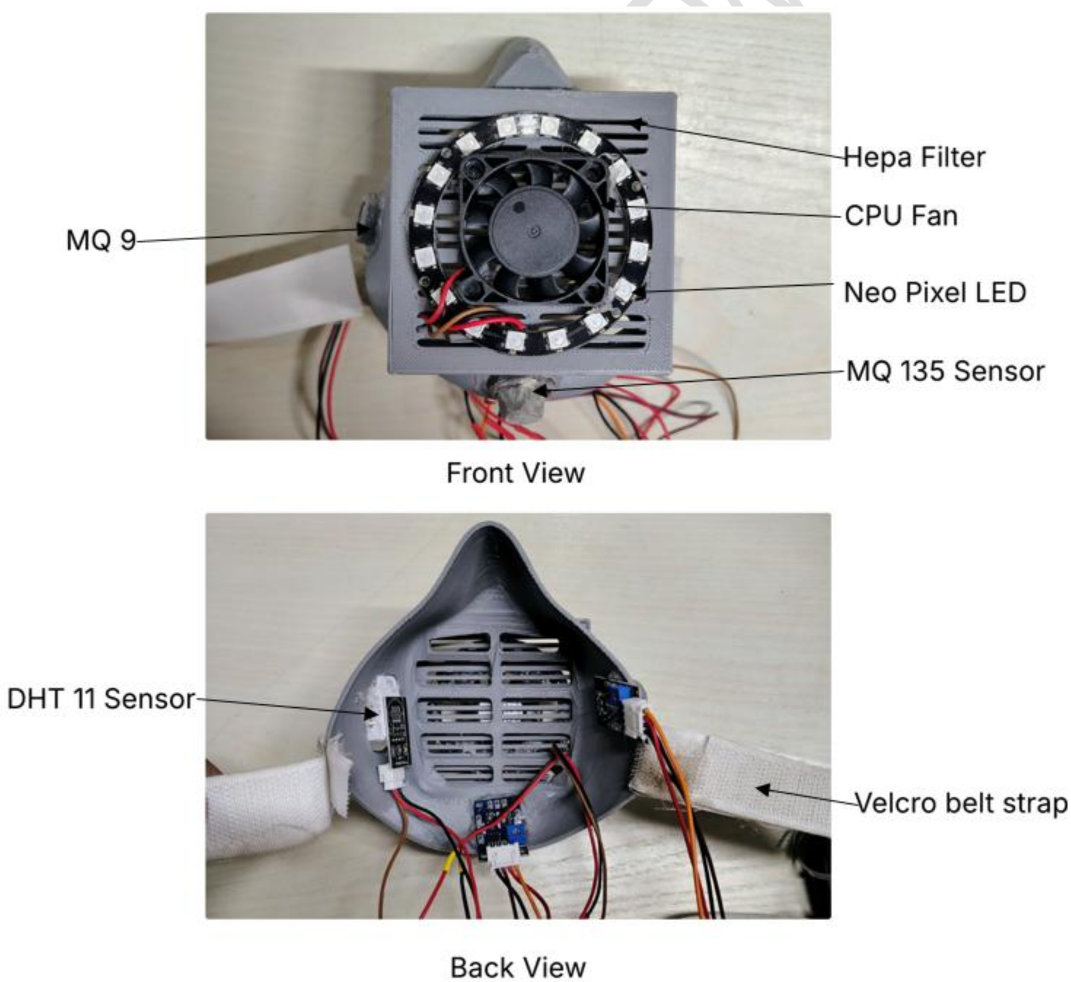

Figure 1: Front and Back view of the mask

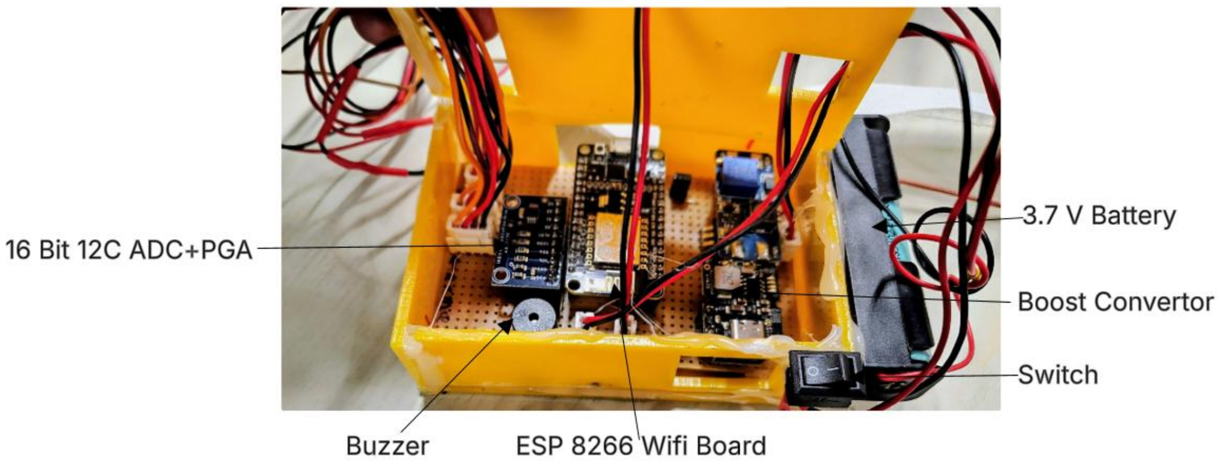

Figure 2: Circuit Board with ESP8266

6. Block diagram and flowchart of the system

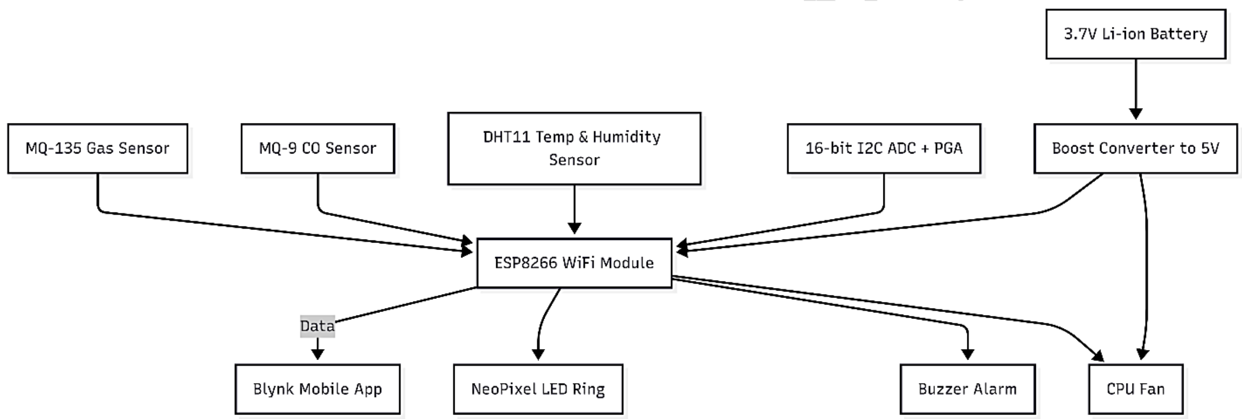

Figure 3: Block Diagram of the System

The functional architecture of the smart air-purifying mask can be understood through its block diagram and flowchart, both of which demonstrate how components interact within the system. The block diagram shows the hardware design, beginning with sensors like MQ-135 and MQ-9 for gas detection and DHT11 for temperature and humidity monitoring. These sensors feed data either directly to the ESP8266 microcontroller or via a 16-bit I²C ADC with a programmable gain amplifier (PGA) to ensure signal accuracy. The ESP8266, acting as the system's brain, processes all incoming sensor data and communicates it wirelessly to a smartphone using the Blynk IoT platform. Simultaneously, it drives output components like the NeoPixel LED ring for color-coded visual alerts and a buzzer for audio alarms. The CPU fan, regulated by the ESP8266, enhances air purification by drawing air through the HEPA filter. All components draw power from a rechargeable 3.7V battery, stepped up to 5V via a boost converter. The flowchart outlines the operational logic of the system. Upon powering up, the ESP8266 initializes all sensors and begins data acquisition. It continuously reads gas and temperature/humidity values in a loop. If any parameter exceeds its predefined safety threshold, the system triggers a buzzer and switches the NeoPixel LED to red, signaling immediate danger. If values remain within acceptable ranges, the LED provides green or yellow feedback based on the severity. All readings are logged in real-time to the Blynk app for remote access and monitoring. The cycle repeats in a continuous loop, ensuring uninterrupted environmental assessment and user safety. Together, these diagrams highlight the seamless integration of sensing, processing, alerting, and communication functions within the wearable prototype.

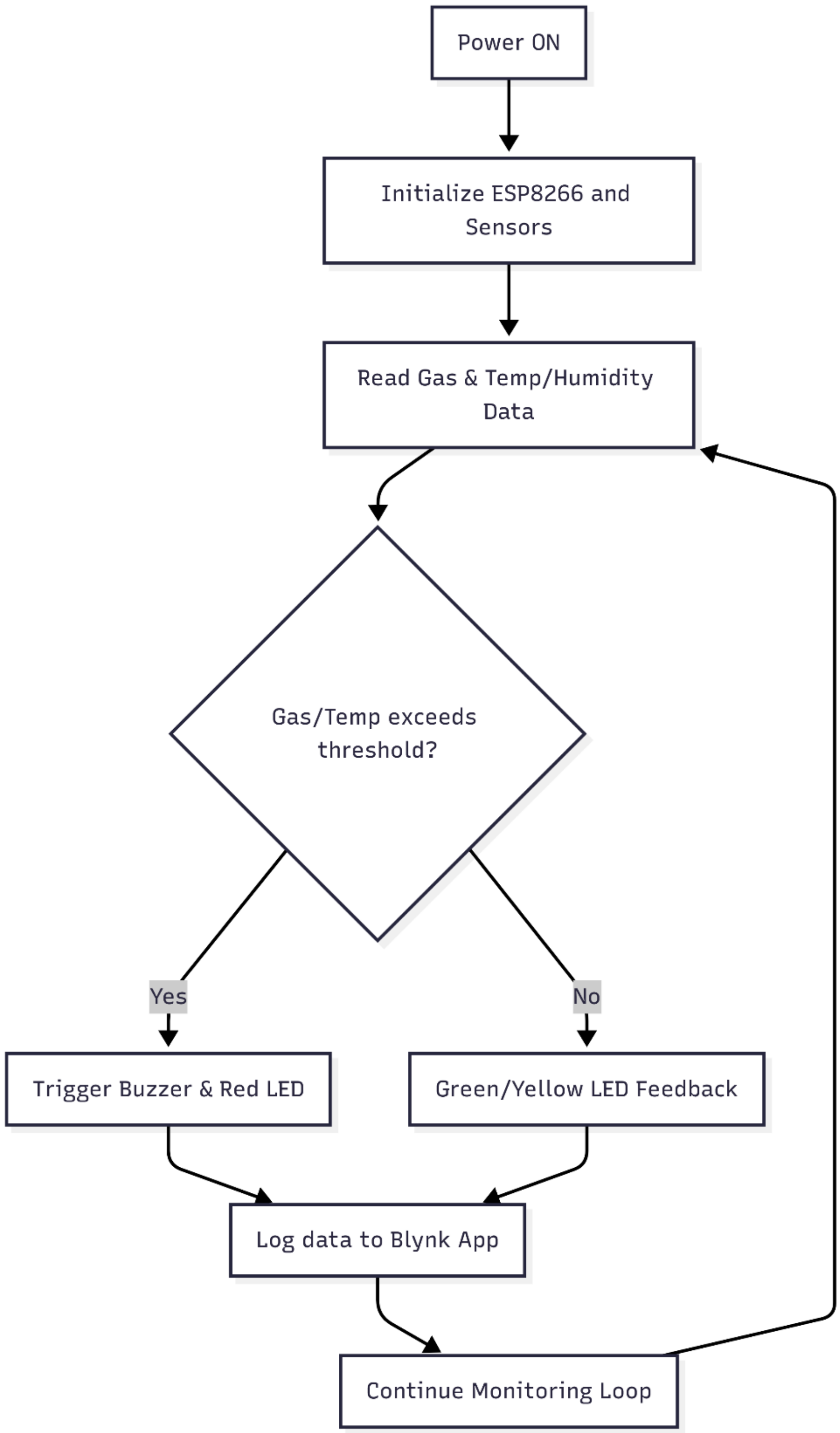

Figure 4: Flowchart Diagram of the System

7. Sensor Calibration Process

The calibration of all sensors used in the smart air-purifying mask was a critical step to ensure accurate environmental readings. The MQ-135 sensor, responsible for detecting toxic gases like ammonia and benzene, was calibrated using known concentrations of polluted air samples. A controlled exposure was provided with increasing PPM levels from 50 to 400, and the corresponding output voltages were recorded. The voltage increased proportionally with the pollutant concentration, indicating the sensor's responsiveness. Similarly, the MQ-9 sensor, used to detect carbon monoxide (CO), was calibrated in a controlled chamber with gas concentrations ranging from 20 to 300 PPM. The voltage output showed a near-linear increase, confirming the sensor's suitability for low-level CO detection. For both sensors, a 16-bit I²C ADC with programmable gain amplification was employed to improve sensitivity and resolution, especially at low voltages. Meanwhile, the DHT11 sensor was calibrated for temperature and humidity. The temperature readings were verified against a high-precision digital thermometer across a range from 20°C to 40°C, showing a minor average deviation of ±0.5°C. Humidity readings were compared against a calibrated hygrometer in a humidity chamber ranging from 30% to 80%, where the DHT11 showed variation within ±2%. All sensors were tested under stable environmental conditions to eliminate noise, and multiple readings were averaged to improve reliability. The calibration graphs show clear linearity and repeatability, validating the use of these sensors in the prototype. Post calibration, threshold values for gas concentrations and environmental conditions were defined to trigger alerts via the NeoPixel LED and buzzer. These calibrated sensors ensure that the mask not only monitors but also responds accurately to air quality changes, making it an effective real-time safety device for industrial workers.

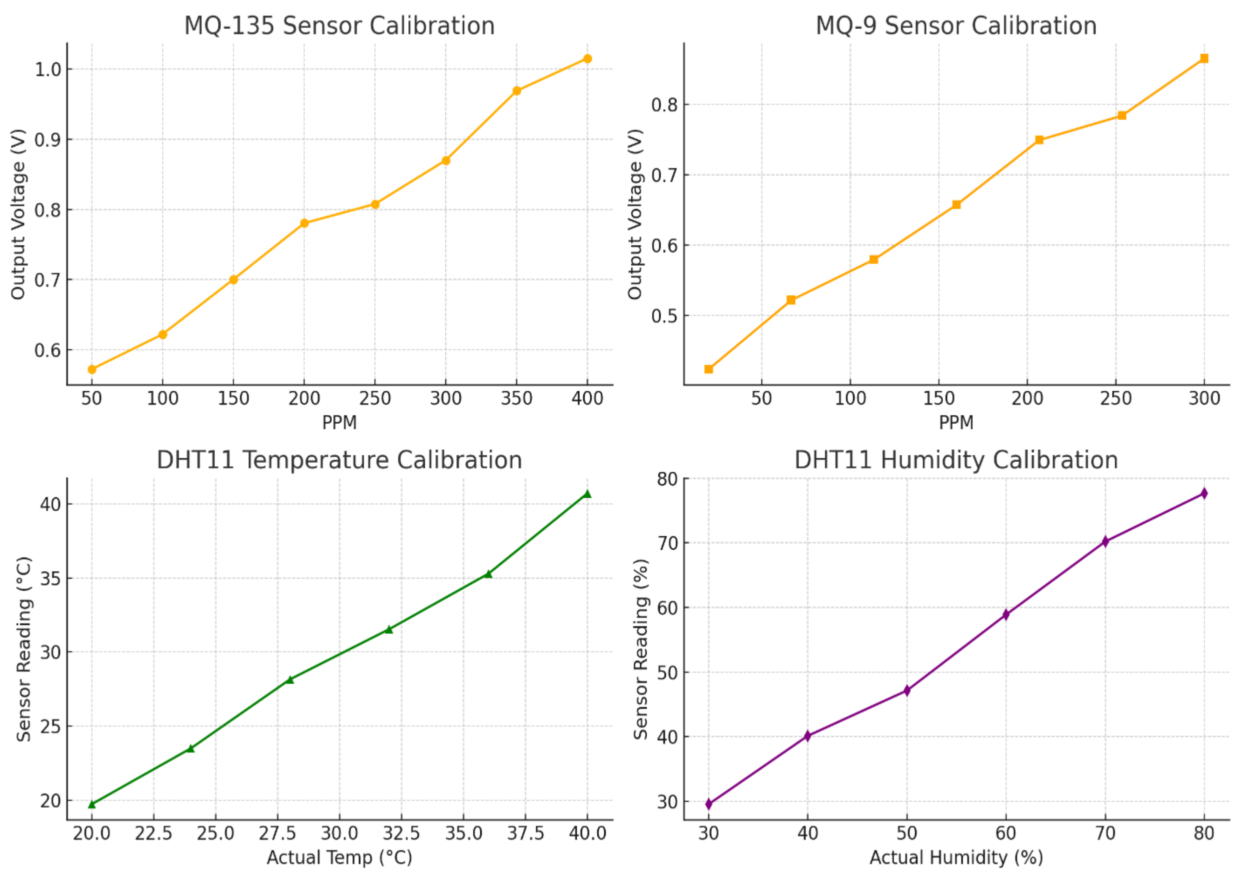

Figure 5: Calibration of all the sensors in the mask

Table 1: Calibration Readings

MQ135_PPM	MQ135_Voltage(V)	MQ9_PPM	MQ9_Voltage(V)	Temp_Actual(C)	Temp_Read(C)	Humidity_Actual(%)	Humidity_Read(%)
50	0.572434283	20	0.423943846	20	19.71885624	30	29.5484474
100	0.622234714	66.66666667	0.521962312	24	23.49358444	40	40.13505641
150	0.700453771	113.3333333	0.579620535	28	28.15712367	50	47.15050363
200	0.780460597	160	0.657352072	32	31.54598796	60	58.91123455
250	0.807816933	206.6666667	0.74928369	36	35.29384815	70	70.22184518
300	0.870317261	253.3333333	0.783956617	40	40.73282438	80	77.69801285
350	0.969084256	300	0.865501643				
400	1.015348695						

The calibration readings indicate strong linear responses from all sensors. The MQ-135 sensor showed a voltage increase from approximately 0.58 V to 1.02 V as gas concentration rose from 50 PPM to 400 PPM. The MQ-9 sensor displayed similar behaviour, with voltage rising from around 0.43 V to 0.87 V across 20 PPM to 300 PPM. For the DHT11 sensor, temperature readings closely matched actual values with minor deviations under ±0.5°C. Humidity readings varied within ±2%, with values ranging from 30% to 78%. These calibration results confirm the reliability of the sensors for real-time air quality monitoring in the wearable smart mask system.

8. Results and Discussions

The prototype smart air-purifying and monitoring mask was tested under various controlled and real-world conditions to assess the performance of its embedded sensors and response mechanisms. The results from the calibration phase, combined with operational testing, confirm that the integrated system effectively detects changes in air quality and environmental parameters and responds promptly with visual and audio alerts. The accompanying graph illustrates the relationship between sensor readings and defined safety thresholds, enabling easy interpretation of hazardous exposure levels. The MQ-135 sensor, responsible for detecting harmful gases such as ammonia, benzene, and smoke, demonstrated a voltage range of approximately 0.58 V to 1.02 V across concentrations from 50 to 400 PPM. Its threshold was set at 0.85 V, which represents a critical level of poor air quality. During testing, whenever the voltage output exceeded this limit, the buzzer activated and the NeoPixel LEDs turned red, indicating a dangerous environment. Similarly, the MQ-9 sensor monitored carbon monoxide and flammable gases. It exhibited a reliable voltage increase up to 0.87 V as CO levels approached 300 PPM. The danger threshold was defined at 0.75 V; values beyond this immediately triggered a warning alert. Environmental comfort was also monitored using the DHT11 sensor, which recorded both temperature and humidity. Temperature readings ranged from 20°C to 40°C, with the safe working limit set at 37°C. In conditions simulating high-heat industrial scenarios, the system correctly signaled when temperature values exceeded this threshold. Humidity levels between 30% and 80% were captured, with 70% marked as the upper comfort limit. Once this was surpassed, the system adjusted the airflow via the fan to improve breathability and user comfort. Across all tests, data was transmitted in real time to the Blynk mobile application, where users could remotely track pollutant levels, view historical data logs, and respond accordingly. The seamless integration of Wi-Fi communication ensured that the device could operate in field environments with minimal manual intervention. The LED and buzzer feedback system provided immediate alerts without needing the user to constantly check the app, supporting non-intrusive safety.

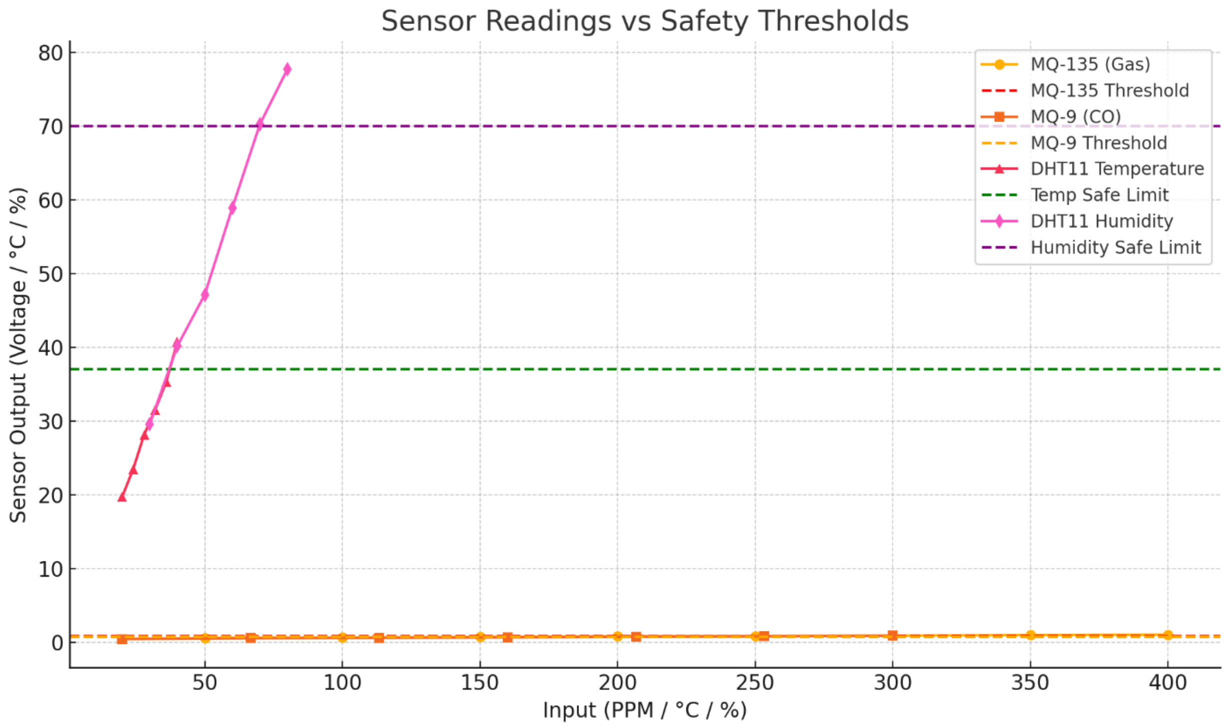

Figure 6: Sensor's readings v/s safety threshold

The results validate the system's core objectives—accurate sensing, adaptive purification, wireless monitoring, and ergonomic usability. The combined threshold graph clearly shows how sensor outputs rise near or beyond defined safety limits under different simulated scenarios, reinforcing the effectiveness of threshold-based decision-making in this prototype. While performance was consistent, future iterations can benefit from AI-based trend prediction, fan speed automation via PWM, and a longer-lasting battery for extended field deployment. Overall, the prototype presents a low-cost, scalable solution for industrial health safety in polluted environments.

9. Conclusions

This study presents the successful design, development, and testing of a smart, wearable air-purifying and monitoring mask tailored for industrial workers exposed to hazardous environments such as recycled plastic processing plants and coal mines. By integrating multiple gas sensors (MQ-135, MQ-9), environmental sensors (DHT11), a HEPA and activated carbon filtration system, and adaptive feedback mechanisms using NeoPixel LEDs and a buzzer, the prototype ensures both real-time air quality monitoring and user protection. The ESP8266 microcontroller facilitates seamless data transmission via Wi-Fi to the Blynk mobile app, providing users with live updates and safety alerts. The device demonstrated high accuracy, responsiveness, and ergonomic comfort during testing, validating its feasibility as a low-cost, deployable safety solution. Sensor calibration showed reliable linear responses, and threshold-based alerts ensured timely warnings during exposure to dangerous environmental conditions. Overall, the system meets its objective of enhancing health and safety in industrial workplaces where conventional protective masks fall short.

10. Future Scope

While the current prototype achieves core functionality, several enhancements can be implemented to improve system efficiency, adaptability, and user experience:

1. **AI and Machine Learning Integration**: Incorporate machine learning models to predict air quality trends, detect sensor anomalies, and enable early warnings based on historical data patterns.
2. **PWM-Based Fan Control**: Upgrade the system to regulate fan speed dynamically based on sensor inputs for energy-efficient purification and improved breathing comfort.
3. **GPS and Location Tagging**: Add GPS capability to geotag pollution data and assist in occupational exposure mapping for health assessments.
4. **Cloud Data Logging**: Expand from app-only logging to cloud-based platforms (e.g., Firebase, ThingsBoard) for long-term data storage and centralized analysis.
5. **Miniaturization and PCB Fabrication**: Transition from prototyping to a custom-designed PCB for a more compact, durable, and scalable product.
6. **Battery Optimization**: Introduce power-saving modes, higher-capacity Li-ion cells, or solar-assisted charging for longer operational life in remote environments.
7. **Industrial Trials and Certification**: Conduct extensive field trials in actual industrial sites and pursue certifications for occupational safety compliance (e.g., BIS, CE).

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