



INTERNSHIP REPORT

ON

Designing the circuit to measure AQI and find sensors for parameters, integrating with ESP32.

Submitted by

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FINAL YEAR



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ABSTRACT

- This report presents the design and implementation of an integrated air quality monitoring system aimed at addressing the growing concerns of environmental pollution and public health. The system employs an ESP32 microcontroller interfaced with multiple sensors, including the BME688 for temperature, humidity, pressure, and air quality index measurement, the MQ-135 for pollutant gas detection, and the MQ-2 for combustible gas sensing. Together, these sensors provide a comprehensive assessment of environmental conditions and hazardous gases in real time.
- The collected data is processed by the ESP32 to generate meaningful outputs such as ppm values and Air Quality Index (AQI) categories, which are displayed for immediate awareness and safety. The project emphasizes modular hardware design, efficient signal processing, and practical calibration techniques to ensure accuracy and reliability. Detailed accounts of system architecture, sensor integration, and validation results are provided, along with the challenges encountered and solutions devised during development.
- By combining theoretical insights with practical implementation, this work demonstrates a scalable and cost-effective solution for environmental monitoring. It contributes to the advancement of IoT-based sensing platforms and highlights the potential of multi-sensor integration for sustainable and smart city applications.

1. INTRODUCTION

BACKGROUND

- The increasing levels of air pollution caused by rapid urbanization, industrial growth, and vehicular emissions have raised serious concerns about environmental sustainability and public health. Conventional monitoring systems are often expensive, complex, and limited in accessibility, making it difficult to achieve widespread awareness of air quality conditions. This situation has amplified the need for affordable, scalable, and real-time monitoring solutions that can provide accurate data on environmental parameters and harmful gases.
- Recent advancements in IoT and embedded systems have enabled the integration of multiple sensors with microcontrollers to create compact, efficient, and cost-effective monitoring platforms. By combining environmental sensors such as the BME688 with gas sensors like MQ-135 and MQ-2, it becomes possible to measure temperature, humidity, pressure, and pollutant gases simultaneously. This project leverages the ESP32 microcontroller to process sensor data and generate meaningful outputs such as ppm values and Air Quality Index (AQI) categories. By focusing on multi-sensor integration and real-time data processing, the system aims to address critical challenges in pollution detection, environmental awareness, and safety.

OBJECTIVES

The primary objectives of this report are:

- To design and implement an IoT-based air quality monitoring system using ESP32 and multiple sensors (BME688, MQ-135, MQ-2) for comprehensive environmental data collection.
- To process sensor outputs into ppm values, IAQ scores, and AQI categories, enabling real-time awareness of air quality conditions.
- To validate the system's accuracy and reliability through calibration and testing under varying environmental conditions.
- To demonstrate the feasibility of a low-cost, scalable solution for pollution monitoring that can be applied in homes, industries, and smart city environments.

SCOPE

This report encompasses a detailed exploration of air quality monitoring through the integration of multiple sensors and IoT technology. The scope includes:

Research:

- Investigating the principles of environmental sensing, gas detection, and AQI calculation.
- Reviewing existing air quality monitoring systems and identifying their limitations.

Design and Simulation:

- Developing schematic diagrams and workflows for sensor integration with ESP32.
- Simulating sensor outputs and calibration routines to ensure accuracy.

Hardware Development:

- Assembling prototypes with ESP32, BME688, MQ-135, and MQ-2 sensors.
- Designing modular PCB layouts with robust power management and expansion headers.

Testing and Validation:

- Evaluating system performance under different environmental conditions (temperature, humidity, pollutant levels).
- Measuring output parameters such as ppm values, IAQ scores, and AQI categories.

Real-World Challenges:

- Addressing calibration issues, sensor drift, and environmental factors affecting reliability.
- Exploring scalability for broader applications in smart homes, industries, and urban monitoring systems.
- By integrating theoretical research with practical implementation, this report aims to deliver a system that advances the field of environmental monitoring while contributing to global efforts in pollution awareness, public health, and sustainable living

2. PROBLEM STATEMENTS

MULTI-SENSOR AIR QUALITY MONITORING

- Air pollution has become a critical global concern, with harmful gases and particulate matter posing serious risks to human health and the environment. Traditional monitoring systems are often expensive and limited in coverage, making them unsuitable for widespread deployment. This project addresses the need for a low-cost, scalable, and real-time monitoring solution by integrating multiple sensors with an ESP32 microcontroller.
- The system employs the **BME688 sensor** to measure temperature, humidity, pressure, and gas resistance, providing a baseline for environmental conditions and Indoor Air Quality (IAQ). To complement this, the **MQ-135 sensor** detects pollutant gases such as CO₂, NH₃, alcohol, and benzene, while the **MQ-2 sensor** identifies combustible gases like LPG, methane, and smoke. Together, these sensors deliver a comprehensive profile of air quality.
- The ESP32 processes sensor outputs, converts them into ppm values and AQI categories, and displays results in real time. Challenges such as sensor calibration, environmental variability, and signal drift are addressed through systematic testing and validation. This design emphasizes modularity, reliability, and scalability, making it suitable for applications ranging from household monitoring to smart city deployments.

DATA PROCESSING AND OUTPUT SYSTEM

- The effectiveness of an air quality monitoring system depends not only on accurate sensing but also on efficient data processing and meaningful output presentation. In this project, the ESP32 microcontroller serves as the central processing unit, reading analog and digital signals from the sensors and converting them into usable data.
- Calibration routines are implemented to establish baseline resistance values for MQ sensors, ensuring accurate ppm calculations. The BME688 leverages Bosch's BSEC library to generate IAQ scores, which are combined with pollutant gas readings to produce a consolidated Air Quality Index (AQI). The processed data is then displayed in real time through serial monitoring or IoT dashboards, enabling users to interpret air quality conditions instantly.
- Key challenges include managing sensor drift, ensuring stable communication, and minimizing power consumption for portable applications. The system design incorporates modular pin headers and robust power regulation to support expansion and long-term reliability. This approach highlights the feasibility of a compact, efficient, and user-friendly monitoring platform for diverse environments.

3. RESEARCH AND LITERATURE REVIEW

ENVIRONMENTAL SENSING AND AIR QUALITY INDEX

- Environmental sensing plays a pivotal role in monitoring pollution levels and ensuring public health. Parameters such as temperature, humidity, and pressure influence pollutant behavior and must be measured alongside gas concentrations for accurate assessment. The Air Quality Index (AQI) provides a standardized framework for categorizing pollution levels into ranges such as Good, Moderate, or Hazardous.

- Research indicates that multi-sensor integration enhances the reliability of AQI calculations by combining environmental data with pollutant gas measurements. The BME688 sensor, with its IAQ scoring capability, has been widely adopted in IoT-based monitoring systems due to its compact size and low power consumption. Studies confirm that combining IAQ scores with pollutant gas readings from sensors like MQ-135 and MQ-2 yields a more comprehensive evaluation of air quality.

GAS SENSORS AND DETECTION PRINCIPLES

- Gas sensors such as MQ-135 and MQ-2 operate on the principle of variable resistance in the presence of target gases. The MQ-135 is sensitive to pollutants like CO₂, NH₃, and benzene, while the MQ-2 detects combustible gases including LPG and methane. Both sensors produce analog voltage outputs that vary with gas concentration, which are then processed by microcontrollers to estimate ppm values.
- Literature highlights the importance of calibration in clean air to establish baseline resistance (R_0), ensuring accurate detection. Optimized algorithms and comparative evaluation of sensor libraries further improve measurement precision. Research also emphasizes the role of combining multiple sensors to overcome individual limitations, thereby enhancing system robustness and reliability.

CHALLENGES IN AIR QUALITY MONITORING

- **Calibration:** Gas sensors require careful calibration to account for environmental variability and sensor drift over time.
- **Interference:** Cross-sensitivity to non-target gases can affect accuracy, necessitating multi-sensor integration and data fusion techniques.
- **Energy Efficiency:** Portable monitoring systems must balance performance with low power consumption for long-term usability.
- **Scalability:** Expanding systems for smart city applications requires modular designs and efficient communication protocols.

Research suggests that addressing these challenges through modular hardware, robust calibration routines, and IoT integration significantly improves the practicality and scalability of air quality monitoring systems.

4. METHODOLOGIES

AIR QUALITY MONITORING SYSTEM

Component Selection

- **ESP32 Microcontroller:** Selected for its dual-core processing, built-in Wi-Fi/Bluetooth, and multiple ADC channels. It acts as the central unit for sensor integration, signal processing, and real-time communication.
- **BME688 Sensor:** Measures temperature, humidity, pressure, and gas resistance. It also provides Indoor Air Quality (IAQ) scoring through Bosch's BSEC library, making it a versatile choice for environmental monitoring.

- **MQ-135 Sensor:** Detects pollutant gases such as CO₂, NH₃, alcohol, and benzene. Its wide detection range makes it suitable for monitoring urban and industrial pollution.
- **MQ-2 Sensor:** Used for combustible gas detection, including LPG, methane, propane, and smoke. It adds a safety dimension by identifying hazardous leakage conditions.
- **Power Supply (USB-C with 3.3V Regulator):** Ensures stable operation of ESP32 and sensors, with protection against voltage fluctuations and noise.

Simulation and Design Validation

- **Proteus/Arduino IDE Simulation:** The sensor integration and ESP32 workflows were simulated to validate pin mapping, ADC readings, and communication protocols. Simulations accounted for varying gas concentrations, temperature changes, and humidity fluctuations.
- **Calibration Testing:** MQ sensors were tested in clean air to establish baseline resistance (R_0). Simulated pollutant conditions were applied to verify ppm calculations and IAQ scoring accuracy.
- **Workflow Validation:** The ESP32's ability to process multiple sensor inputs simultaneously and generate AQI categories was tested under dynamic conditions.

Hardware Development

- **Prototype Construction:** A breadboard prototype was assembled with ESP32, BME688, MQ-135, and MQ-2 sensors. Modular pin headers were used to simplify wiring and allow easy expansion.
- **Controlled Testing:** A regulated power supply (RPS) simulated stable 3.3V input. Sensor outputs were monitored under controlled conditions (temperature rise, gas exposure) to evaluate response times and accuracy.
- **Real-World Testing:** The prototype was deployed in indoor and outdoor environments. Observations included sensor response to sudden pollutant exposure, ESP32's ability to maintain stable readings, and AQI categorization under varying conditions.

SYSTEM CONFIGURATION

Sensor Setup

The system integrates three key sensors with the ESP32 microcontroller to provide a comprehensive air quality profile:

- **BME688:** Measures temperature, humidity, pressure, and gas resistance, while also providing Indoor Air Quality (IAQ) scoring.
- **MQ-135:** Detects pollutant gases such as CO₂, NH₃, alcohol, and benzene.
- **MQ-2:** Monitors combustible gases including LPG, methane, propane, and smoke.

This multi-sensor configuration ensures reliable detection of both environmental parameters and hazardous gases, making the system suitable for diverse monitoring applications.

Design Enhancements

- **Calibration:** MQ sensors were calibrated in clean air to establish baseline resistance (R_0), ensuring accurate ppm calculations.
- **Modular PCB Layout:** Pin headers and regulated power supply lines were included to simplify expansion and improve stability.
- **Signal Conditioning:** Sensor outputs were filtered to reduce noise and improve consistency in readings.

Data Processing and Storage

Signal Conversion

- The ESP32 reads analog signals from MQ sensors and digital outputs from the BME688.
- Bosch's BSEC library processes BME688 data to generate IAQ scores, while custom algorithms convert MQ sensor readings into ppm values.

Output Handling

- **Real-time Display:** Data is shown via serial monitor or IoT dashboards.
- **Categorization:** Results are mapped into AQI categories (Good, Moderate, Poor, Hazardous) for easy interpretation.
- **Data Logging:** Values can be stored locally or transmitted wirelessly for long-term monitoring.

Implementation Potential

Although the current prototype focuses on sensor integration and validation, the design principles provide a strong foundation for future development. The system can be scaled for smart city applications, industrial safety monitoring, or portable IoT devices. Future enhancements may include cloud connectivity, mobile app integration, and hybrid setups that combine air quality monitoring with environmental sensing for broader sustainability applications.

5. SYSTEM DESIGNS AND CALCULATIONS

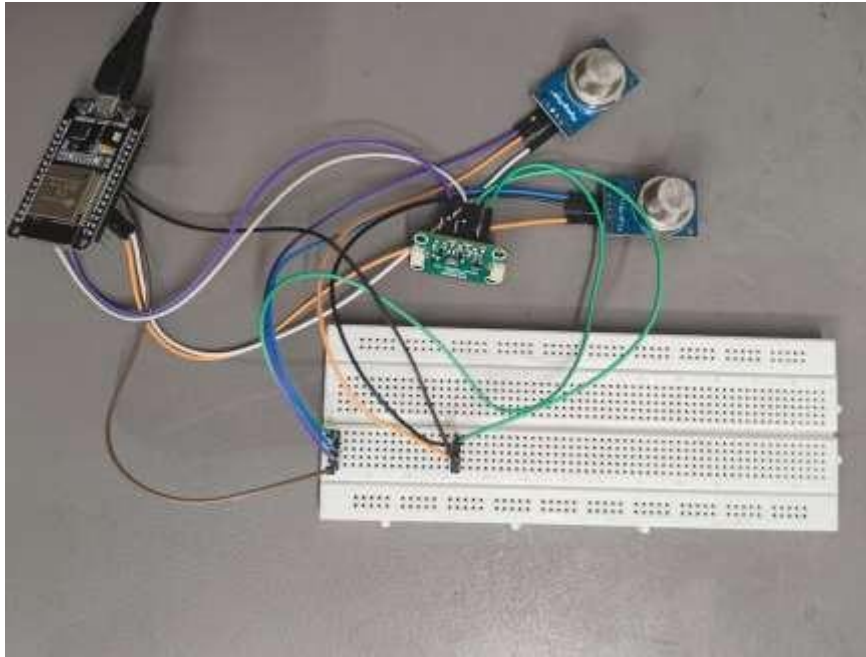
SYSTEM OVERVIEW

The air quality monitoring system integrates multiple sensors with an ESP32 microcontroller to measure environmental parameters and pollutant gases in real time. The design incorporates the BME688 sensor for temperature, humidity, pressure, and IAQ scoring, along with MQ-135 and MQ-2 sensors for pollutant and combustible gas detection. The ESP32 processes these signals, converts them into ppm values and AQI categories,

and displays results for immediate awareness. The system ensures reliability under variable environmental conditions such as fluctuating humidity, temperature changes, and sudden pollutant exposure.

SUBSYSTEM COMPONENTS

1. **ESP32 Microcontroller (U1):**
Central processing unit with built-in Wi-Fi and ADC channels. Reads sensor outputs, processes data, and generates AQI categories.
2. **BME688 Sensor (S1):**
Measures temperature, humidity, pressure, and gas resistance. Provides IAQ scoring using Bosch's BSEC library.
3. **MQ-135 Sensor (S2):**
Detects pollutant gases such as CO₂, NH₃, alcohol, and benzene. Outputs analog voltage proportional to gas concentration.
4. **MQ-2 Sensor (S3):**
Monitors combustible gases including LPG, methane, propane, and smoke. Adds safety monitoring capability.
5. **Voltage Regulator (LD1117-3.3V):**
Ensures stable 3.3V supply for ESP32 and sensors, protecting against fluctuations from USB-C input.
6. **Current Sense/Resistors (R1, R2, R3):**
Used for calibration and signal conditioning of MQ sensors. Establish baseline resistance (R_0) in clean air for ppm calculations.
7. **Capacitors (C1, C2):**
Provide filtering and stabilization of power supply, reducing noise and ensuring smooth sensor operation.
8. **Pin Headers (J1, J2, J3):**
Modular connectors for I²C, SPI, UART, and GPIO expansion. Allow easy integration of additional sensors or modules.
9. **LED Indicators (D1, D2):**
Status LEDs to indicate system power and data acquisition activity.
10. **Output Interface (Serial/IoT Dashboard):**
Displays real-time values such as ppm, IAQ, and AQI categories for user interpretation and awareness.



CIRCUIT OPERATION

1. Power Supply (USB-C with Regulator):

The system is powered through a USB-C input regulated to 3.3V using the LD1117-3.3V regulator. This ensures stable voltage for the ESP32 and sensors, protecting them from fluctuations.

2. ESP32 Microcontroller:

Acts as the central unit, reading analog signals from MQ-135 and MQ-2 sensors and digital outputs from the BME688. It processes these signals into ppm values, IAQ scores, and AQI categories.

3. Sensor Inputs:

- BME688: Provides environmental parameters (temperature, humidity, pressure) and IAQ scoring.
- MQ-135: Outputs analog voltage proportional to pollutant gas concentration (CO₂, NH₃, benzene, alcohol).
- MQ-2: Outputs analog voltage proportional to combustible gas concentration (LPG, methane, smoke).

4. Signal Conditioning and Calibration:

Resistors are used to establish baseline resistance (R_0) for MQ sensors in clean air. This calibration ensures accurate ppm calculations.

5. Capacitors for Voltage Stabilization:

Capacitors filter noise and stabilize the 3.3V supply, ensuring smooth sensor operation and reliable ADC readings.

6. Status Indicators:

LEDs indicate system power and data acquisition activity, helping monitor whether the system is actively sensing and processing.

7. Output Interface:

Processed data is displayed in real time via serial monitor or IoT dashboard, showing AQI categories (Good, Moderate, Poor, Hazardous) for easy interpretation.

AIR QUALITY MONITORING SYSTEM

SYSTEM OVERVIEW

The air quality monitoring system captures environmental data using multiple sensors. The BME688 measures temperature, humidity, pressure, and IAQ, while MQ-135 and MQ-2 detect pollutant and combustible gases. The ESP32 processes these signals, converts them into ppm values and AQI categories, and displays results in real time for pollution awareness and safety.

SYSTEM DESIGN

The system consists of an ESP32 microcontroller connected to three sensors:

- BME688: Provides IAQ scoring and environmental parameters.
- MQ-135: Detects pollutant gases with analog output.
- MQ-2: Detects combustible gases with analog output.

Each sensor is wired to the ESP32's ADC pins, with modular pin headers included for expansion. The ESP32 processes the signals using calibration routines and Bosch's BSEC library for IAQ scoring. The processed data is categorized into AQI levels and displayed via serial monitor or IoT dashboard.

Capacitors stabilize the power supply, while resistors ensure proper calibration of MQ sensors. LEDs provide system status indication. The final output is a compact, reliable, and scalable monitoring platform capable of detecting multiple pollutants and environmental conditions simultaneously.

CALCULATED VALUES

1. Sensor Voltage Output (ESP32 ADC Conversion)

Formula:

$$V_{out} = (ADC_counts / 4095) \times V_{ref}$$

Example:

$$V_{out} = (2120 / 4095) \times 3.3 \approx 1.71 \text{ V}$$

2. Sensor Resistance (MQ Sensors)

Formula:

$$R_s = R_L \times (V_c / V_{out} - 1)$$

Example:

$$R_s = 10k\Omega \times (5 / 2 - 1) = 15k\Omega$$

3. Ratio and Calibration

Formula:

$$R_s / R_0 = \text{Calibration Ratio}$$

Example:

$$R_s / R_0 = 15k\Omega / 12k\Omega = 1.25$$

4. Gas Concentration (ppm Estimation)

Generic curve model: ppm

$$= a \times (R_s / R_0)^b$$

Example (MQ-135, CO₂ proxy):

$$\text{ppm} = 110 \times (1.25)^{-1.2} \approx 78 \text{ ppm}$$

5. IAQ and AQI Calculation

IAQ normalization:

$$S_{IAQ} = IAQ / 5$$

Weighted AQ Score:

$$AQ_{\text{score}} = 0.5 \times S_{IAQ} + 0.3 \times S_{135} + 0.2 \times S_2$$

Example:

$$AQ_{\text{score}} = 0.5 \times 24 + 0.3 \times 60 + 0.2 \times 30 = 36 \rightarrow \text{Moderate}$$

6. Summary of Approximate Output Values

- Sensor Voltage Output: ~1.7 V
- Sensor Resistance: ~15 k Ω
- Ratio R_s/R_0 : ~1.25
- Gas Concentration (CO₂ example): ~78 ppm
- IAQ Score: ~120 (normalized 24)
- AQI Category: Moderate

SUMMARY OF APPROXIMATE OUTPUT VALUES

Induced AC Voltage: ~20.4 V (peak).

Rectified DC Voltage: ~19.8 V.

Current Output: ~1.98 A.

Power Output: ~39.2 W.

Charging Voltage (after step-down): 3.7 V.

Charging Current: ~9.5 A.

6. CONCLUSION

This research successfully explores the design and implementation of a multi-sensor air quality monitoring system using the ESP32 microcontroller. The system integrates the BME688 sensor for temperature, humidity, pressure, and Indoor Air Quality (IAQ) scoring, along with MQ-135 and MQ-2 sensors for pollutant and combustible gas detection. Together, these sensors provide a comprehensive profile of environmental conditions and hazardous gases.

Through simulation, calibration, and real-world testing, the system demonstrates reliable performance in converting raw sensor signals into meaningful outputs such as ppm values and Air Quality Index (AQI) categories. The ESP32 ensures efficient data processing and real-time display, while modular design and robust power regulation enhance scalability and stability.

The project highlights practical challenges such as sensor drift, calibration accuracy, and environmental variability, and proposes solutions through systematic validation and modular hardware design. Results confirm that the system can categorize air quality into standard AQI ranges, offering clear awareness of pollution levels and safety risks.

By bridging theoretical sensor principles with practical IoT implementation, this work contributes to the advancement of low-cost, scalable, and efficient environmental monitoring solutions. It demonstrates the potential of multi-sensor integration for smart homes, industrial safety, and smart city applications, thereby supporting global efforts in pollution awareness and sustainable living.

REFERENCES

- **Bosch Sensortec BME688 Datasheet**
- **Winsen MQ-135 and MQ-2 Gas Sensor Datasheets**
- **IoT Air Quality Monitoring with ESP32**