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Review RTSRT

Smart Air Quality Monitoring System Using IoT

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Abstract

This paper presents the design and implementation of a Smart Air Quality Monitoring System using the ESP32 Wi-Fi microcontroller integrated with an MQ-2 gas sensor and a DHT-11 temperature and humidity sensor. The system continuously monitors environmental parameters including air quality (smoke, LPG, CO, and other combustible gases), temperature, and relative humidity in real time. The acquired sensor data is transmitted wirelessly to the Blynk IoT platform, enabling users to visualize live readings via a mobile or web dashboard. The proposed system offers a low-cost, portable, and scalable solution for indoor and outdoor air quality monitoring, making it suitable for homes, industries, and smart city applications. Experimental results confirm reliable sensor performance and seamless IoT connectivity, demonstrating the system's potential for early hazard detection and environmental awareness. As the central processing unit, the ESP32 controller gathers sensor data, does preliminary analysis, and guarantees dependable wireless communication via Wi-Fi connectivity. Remote monitoring and rapid access to environmental data from any location are made possible by the incorporation of IoT technologies. Future integration with cloud-based analytics and intelligent decision-making platforms is made possible by the system architecture's energy-efficient design and ease of deployment. Additionally, the information gathered can help identify pollution patterns in certain areas and enable long-term environmental research.

Keywords: Smart air quality monitoring, ESP32, MQ-2 gas sensor, DHT-11, Blynk IoT, IoT, real-time monitoring, wireless sensing

INTRODUCTION

Air pollution has become one of the most pressing global challenges of the twenty-first century. Rapid urbanization, industrial expansion, and increased vehicular emissions have significantly degraded air quality, leading to severe health consequences, including respiratory diseases, cardiovascular disorders, and increased mortality rates. The World Health Organization (WHO) estimates that around 7 million deaths per year are attributed to ambient and household air pollution. Monitoring air quality in real time is therefore essential for enabling timely interventions and informed decision-making by individuals, organizations, and policymakers [1].

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Traditional air quality monitoring stations are expensive, bulky, and have limited spatial coverage. They are typically deployed in fixed locations and are unsuitable for personalized or distributed monitoring purposes. The advent of the Internet of Things (IoT) and low-cost sensor technologies has opened new possibilities for creating compact, affordable, and networked air quality monitoring systems that can be deployed on a large scale [2].

In this project, we propose the design and development of a Smart Air Quality Monitoring System built around the ESP32 Wi-Fi microcontroller. The system integrates an MQ-2 gas

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sensor to detect harmful gases, such as smoke, LPG, CO, and other combustible gases, along with a DHT-11 sensor to measure ambient temperature and relative humidity. The sensed data were transmitted in real time over Wi-Fi to the Blynk IoT platform, where users could monitor the readings through an intuitive mobile or web dashboard [3].

The ESP32 microcontroller was chosen for its built-in Wi-Fi and Bluetooth capabilities, dual-core processing power, and low power consumption, making it ideal for IoT applications. The Blynk platform provides a user-friendly interface for IoT visualization with minimal programming overhead. The combination of these technologies results in a cost-effective, real-time, and remotely accessible air quality monitoring solution [4].

This paper discusses the complete system architecture, component specifications, working methodology, software implementation, and experimental results of the proposed Smart Air Quality Monitoring System. The system demonstrates strong potential for applications in smart homes, industrial safety, greenhouse monitoring, and smart city infrastructure [5].

COMPONENTS AND ARCHITECTURE

The Smart Air Quality Monitoring System was designed using a modular and scalable architecture. Each hardware component as shown in Table 1 has been carefully selected to balance performance, power efficiency, and cost. The overall system block diagram as shown in Figure 1 consists of sensing, processing, communication, and display modules.

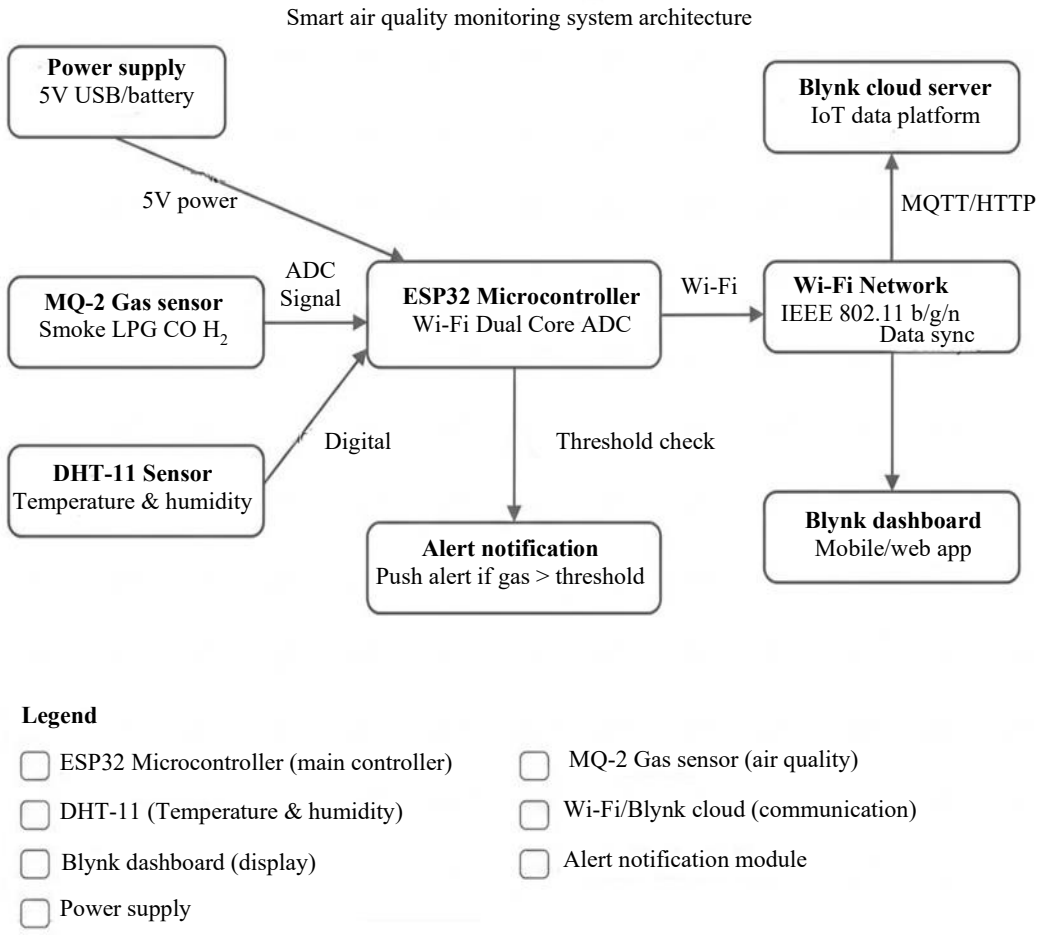


Figure 1. Smart air quality monitoring system — architecture block diagram

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Table 1. Components list.

S.N.	Component	Specification / role	Quantity
1	ESP32 Wi-Fi Microcontroller	Dual-core 240 MHz, built-in Wi-Fi & Bluetooth, ADC, GPIO	1
2	MQ-2 Gas Sensor	Detects smoke, LPG, CO, H2, combustible gases; analog output	1
3	DHT-11 Sensor	Temperature: 0–50°C ±2°C; Humidity: 20–90% RH ±5%	1
4	Blynk IoT Platform	Cloud-based IoT dashboard for real-time data visualization	—
5	USB Power Supply / Battery	5V DC power supply for ESP32 and sensors	1

ESP32 Wi-Fi Microcontroller

The ESP32 microcontroller was used as the central processing unit of the system. It is a low-cost, low-power system-on-chip (SoC) microcontroller developed by Espressif Systems, featuring a dual-core Xtensa LX6 processor running at up to 240 MHz's. The ESP32 includes built-in Wi-Fi (802.11 b/g/n) and Bluetooth (Classic and BLE) capabilities, which eliminate the need for external communication modules. It also provides multiple GPIO pins, ADC channels (for reading analog sensor values), UART, I2C, and SPI interfaces, making it highly versatile for IoT applications [6].

MQ-2 Gas Sensor

The MQ-2 is a widely used semiconductor gas sensor capable of detecting a range of combustible gases and smoke, including LPG, methane, hydrogen, and carbon monoxide. It operates on the principle of chemoresistive sensing, where the resistance of the sensing element changes in the presence of target gases. The MQ2 provides both an analog output (proportional to gas concentration) and a digital output (threshold-based detection), making it well-suited for air quality assessment. The analog output is connected to one of the ADC capable GPIO pins of the ESP32 [7].

DHT-11 Temperature and Humidity Sensor

The DHT-11 is a basic, low-cost digital sensor used to measure ambient temperature and relative humidity. It uses a capacitive humidity sensing element and thermistor for temperature measurement. The sensor communicates data over a single-wire digital interface using a proprietary, one-wire protocol. It measures temperature in the range of 0°C to 50°C with ±2°C accuracy and relative humidity in the range of 20% to 90% RH with ±5% accuracy. Although the DHT-11 has a relatively lower resolution compared to DHT-22, it is adequate for indoor air quality monitoring applications [8].

Blynk IoT Platform

Blynk is a cloud-based IoT platform that enables rapid development of IoT applications with a user-friendly drag-and-drop dashboard interface. The Blynk platform supports both mobile (Android/iOS) and web dashboards, allowing users to visualize real-time sensor data using widgets such as gauges, graphs, and value displays. The ESP32 communicates with the Blynk server over Wi-Fi using the Blynk library, sending virtual pin values that are mapped to dashboard widgets. Blynk also supports event notifications, alerting users when the sensor readings exceed the predefined thresholds [9].

METHODOLOGY

The system follows a continuous sense-process-transmit-display pipeline. The complete workflow is illustrated in Figure 2. The methodology can be divided into the following phases:

System Initialization and Sensor Warm-Up

Upon powering up, the ESP32 initializes its GPIO pins, ADC channels, and serial communication. The MQ-2 sensor requires a warm-up period of approximately 20 seconds to stabilize its internal heater coil and provide accurate readings. Simultaneously, the DHT-11 sensor was initialized, and a connection to the configured Wi-Fi network was established.

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Wi-Fi and Blynk Cloud Connection

After initialization, the ESP32 connects to the local Wi-Fi network using SSID and password stored in the firmware. It then establishes a connection with the Blynk cloud server using a unique authentication token provided during project creation in the Blynk console. Once connected, the device was ready to push the sensor data to the virtual pins on the Blynk dashboard.

Sensor Data Acquisition

The MQ-2 sensor's analog output is read via the ESP32's ADC pin at periodic intervals. The ADC converts the analog voltage to a 12-bit digital value (0–4095), which is proportional to the gas concentration. The DHT-11 sensor's digital data line is read using the DHT library, which decodes the temperature and humidity values. Readings were sampled every 2 s to match the DHT-11's response time.

Data Transmission to Blynk

The acquired sensor values (air quality index from MQ-2, temperature, and humidity from DHT-11) were transmitted to the Blynk server by writing to designated virtual pins (V0, V1, V2). The Blynk.virtualWrite() function was used to push the data. The Blynk timer is configured to call the data sending function at regular intervals to avoid flooding the server [10].

Real-Time Visualization on Blynk Dashboard

On the Blynk mobile/web dashboard, gauge and value display widgets are linked to the virtual pins to show live air quality, temperature, and humidity readings. A graph widget was also added for historical trend visualization. Threshold-based notifications are configured to alert the user when the MQ-2 reading exceeds a critical level, indicating a potentially dangerous gas concentration (Figure 2). Table 2 shows the functional modules and purpose of the smart air quality monitoring system.

SOFTWARE AND PROGRAMMING

The software stack for the Smart Air Quality Monitoring System was built on the Arduino framework, leveraging publicly available libraries to simplify hardware interfacing and cloud communication.

Development Tools and Environment

- Arduino IDE (v2.x) with ESP32 board support package (by Espressif) was used to write, compile, and upload firmware to the ESP32.
- Programming was done in C/C++ within the Arduino framework.
- The DHT sensor library by Adafruit was used for interfacing with the DHT-11 sensor.
- The Blynk library (v1.x) was integrated for IoT cloud communication.
- A Serial Monitor was used during development to debug the sensor output and Wi-Fi connection status.

Firmware Logic

The firmware initializes Wi-Fi and Blynk in the setup() function, then enters a continuous loop() that checks Blynk connection status and runs a timer. A BlynkTimer object calls the sensorDataSend() function every 2000 ms. Inside this function, the DHT-11 is read for temperature and humidity, and the MQ-2 analog pin is read via analogRead(). All three values were sent to the corresponding Blynk virtual pins using Blynk.virtualWrite(). A conditional check on the MQ-2 value triggers a Blynk notification if it exceeds a defined danger threshold (e.g., ADC value > 2000).

Blynk Dashboard Configuration

The Blynk dashboard was configured with three primary widgets: a gauge widget on Virtual Pin V0 for the MQ-2 air quality reading (range 0–4095), a Value Display on Virtual Pin V1 for temperature (°C), and a Value Display on Virtual Pin V2 for humidity (%). A SuperChart widget was added to display the time-series trends for all three parameters simultaneously.

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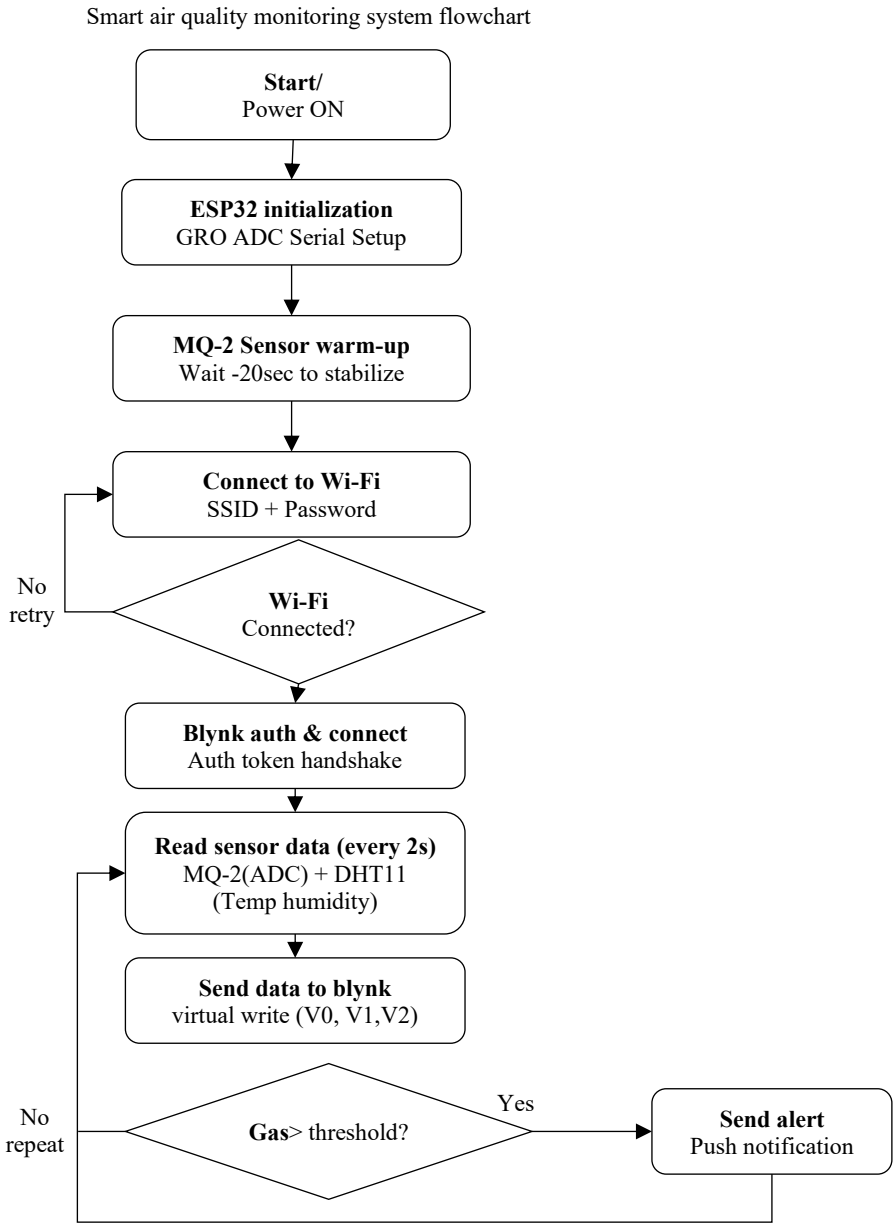


Figure 2. Smart air quality monitoring system — operational flowchart

Table 2. Functional modules and purpose

Module	Description
Sensing Module	MQ-2 and DHT-11 sensors acquire air quality, temperature, and humidity data
Processing Module	ESP32 reads ADC and digital sensor values, applies data formatting
Communication Module	Wi-Fi connectivity for transmitting data to Blynk cloud server
Display/Visualization Module	Blynk IoT dashboard renders live gauges, graphs, and value readouts
Alert Module	Blynk notification events triggered when gas levels exceed safe threshold
Power Module	5V USB supply or battery pack powering ESP32 and sensors

RESULTS AND DISCUSSION

The Smart Air Quality Monitoring System was tested under various indoor conditions to validate sensor performance and IoT connectivity. The following results were obtained:

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- *Air Quality Sensing (MQ-2):* The MQ-2 sensor showed a clear and rapid response to smoke and LPG exposure. Under normal indoor conditions, the ADC readings ranged from 300 to 600. Upon exposing the sensor to a lighter flame, values spiked to over 2500 within 3–5 seconds, demonstrating reliable sensitivity. After the source was removed, the readings returned to baseline within 30–40 s.
- *Temperature Monitoring (DHT-11):* The DHT-11 recorded stable temperature readings consistent with a reference thermometer (±2°C deviation). Indoor temperatures in the range of 27–34°C were measured accurately, confirming the sensor's suitability for room-temperature applications.
- *Humidity Monitoring (DHT-11*): The relative humidity readings ranged from 45% to 72% RH depending on the environmental conditions. The values were consistent with those obtained from a reference hygrometer, with a maximum deviation of ±5%.
- *IoT Connectivity and Blynk Dashboard*: The ESP32 successfully maintained a stable Wi-Fi connection and updated the Blynk dashboard at 2-second intervals. Data was reflected on the mobile dashboard in near real-time with a latency of under 500 ms on a local Wi-Fi network. The SuperChart widget clearly displays time-series trends, aiding the visual analysis of air quality variations.
- *Alert Notifications*: Threshold-based Blynk notifications were successfully triggered when the MQ-2 ADC value exceeded 2000 (indicating potentially hazardous gas levels), providing an effective early warning mechanism.

Limitations

- The DHT-11 sensor has limited accuracy and resolution compared to higher-end sensors, such as the DHT-22 or BME280.
- The MQ-2 sensor requires periodic recalibration as its sensitivity may drift over time.
- The system is dependent on a stable internet connection for Blynk cloud access; local data storage is not yet implemented.
- The MQ-2 sensor cannot distinguish between individual gas types and provides only a composite air quality index.

CONCLUSION

This study successfully demonstrates the design and implementation of a low-cost, real-time Smart Air Quality Monitoring System using the ESP32 microcontroller, MQ-2 gas sensor, DHT-11 temperature and humidity sensor, and Blynk IoT platform. The system enables continuous and remote monitoring of critical environmental parameters through a user-friendly mobile and web dashboard.

Experimental validation confirmed the reliability of the sensor readings and the effectiveness of the IoT communication pipeline. The threshold-based alert mechanism adds a valuable safety feature, making the system suitable for hazard detection in homes, kitchens, laboratories, and industrial environments.

Future Work Includes

- Replacing the DHT-11 with a higher-accuracy sensor, such as the BME280 or DHT-22, for improved measurement precision.
- Adding individual gas-specific sensors (e.g., MQ-7 for CO and MQ-4 for methane) for more targeted pollutant identification.
- Integrating a local data logging system using an SD card or EEPROM for offline data storage and analysis.
- Implementing machine learning-based predictive analytics on historical sensor data for proactive air-quality management.
- Deploying multiple sensor nodes in a mesh network for large-scale spatial mapping of air quality.

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The proposed system serves as a promising and extensible prototype for further research in environmental IoT monitoring, smart city infrastructure, and embedded systems design.

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