Design and Implementation of a Smart Air Quality Monitoring Station with Blynk-Based Visualization

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***Abstract*—Air pollution is a critical environmental and public health concern, especially in urban areas where the density of population and transportation contributes significantly to the degradation of air quality. This paper presents the design, implementation, and evaluation of a smart, cost-effective air quality monitoring station. Utilizing an ESP32S WROOM 32 microcontroller and sensors GP2Y1010AU0F and DHT11, the system measures PM2.5 concentration, temperature, and humidity. Real-time data is displayed on an OLED SH110X screen and sent to the cloud via the Blynk platform, enabling remote monitoring and timely push notifications when pollutant levels exceed thresholds. This IoT-based system also integrates backup power management, user-configurable warning limits, and manual control features via onboard buttons. The design ensures portability, ease of use, and scalability for deployment in homes, schools, and public spaces.**

***Index Terms*—Air quality monitoring, ESP32, PM2.5, DHT11, Blynk, IoT, OLED display, wireless communication, environmental sensor.**

I. Introduction

Air pollution, particularly fine particulate matter (PM2.5), poses significant risks to respiratory and cardiovascular health. The World Health Organization reports millions of deaths annually due to long-term exposure to air pollutants. Traditional air quality monitoring stations are expensive, stationary, and not easily accessible to individuals. To address these limitations, we propose a portable, low-cost IoT-based air quality monitoring station capable of measuring PM2.5, temperature, and humidity. This system empowers users with real-time data and early warning capabilities via a mobile application and visual/audio indicators.

II. System Requirements and Objectives

The system is designed to monitor environmental parameters such as PM2.5 concentration, temperature, and humidity, with both local display and remote monitoring via a mobile application. This section outlines the user needs and technical requirements essential for the system.

A. User Requirements

In urban areas where air pollution is becoming increasingly severe, users demand a compact, reliable, and user-friendly device capable of monitoring environmental conditions in real time. Specifically, the system must:

- Measure PM2.5 concentration, temperature, and humidity accurately and continuously.
- Display data locally using a 1.3-inch OLED screen with intuitive visual feedback.
- Support real-time remote monitoring via the Blynk mobile application.
- Provide timely alerts when pollution levels exceed safety thresholds (e.g., PM2.5 $> 200\ \mu g/m^3$).
- Allow manual interaction via onboard buttons for data push and warning mode control.
- Be accessible at an affordable cost for both urban and rural users.
- Maintain uninterrupted operation during power outages through a backup battery.

B. Functional Requirements

The system must fulfill the following functions:

- Real-time sensing of PM2.5 (using GP2Y1010AU0F), temperature, and humidity (using DHT11).
- Local display of data on a 1.3-inch OLED screen (SH110X driver).
- Wireless data transmission to Blynk cloud every 2 seconds via ESP32's Wi-Fi.
- Push alerts via Blynk when pollution exceeds set thresholds.
- Manual control via SET and DOWN buttons:
  - **SET button (hold for 3s)**: enters AP configuration mode, allowing SSID/password/token setup via WebUI.
  - **DOWN button (short press)**: triggers manual data upload.
  - **DOWN button (hold 3s)**: toggles auto-warning mode.
- User configuration via Wi-Fi AP mode (SSID: `ESP32_IOT`, IP: `192.168.4.1`).

C. Non-Functional Requirements

- **Sensor accuracy**: PM2.5 ±15%, temperature ±2°C, humidity ±5% RH.
- **Data refresh rate**: 200 ms for PM2.5, 3 s for temperature and humidity.
- **Latency**: OLED update < 1 s, Blynk sync delay < 2 s.

- **Power consumption**: below 3 W; backup battery runtime $\geq$ 4 hours (using 18650 2000mAh).

III. System Architecture

The proposed air quality monitoring system consists of five main subsystems: power supply, sensing, processing, display and output, and user communication. Figure 1 illustrates the block diagram of the complete system.

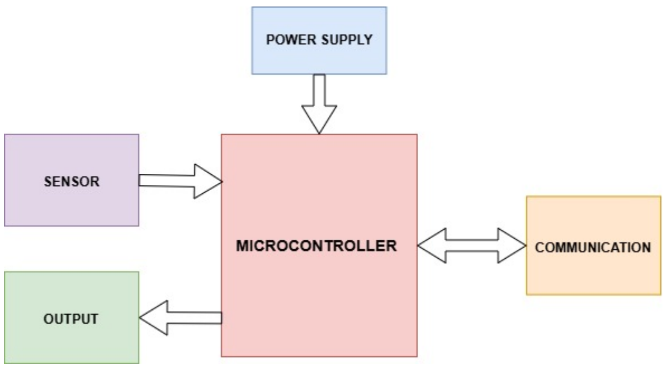

Fig. 1. System Architecture

A. Power Supply Subsystem

The power subsystem includes a 5V/3A adapter as the primary power source, a 15W boost UPS charging circuit, and a 2000mAh 18650 battery for backup. During normal operation, the adapter supplies stable energy to all modules. In case of power outages, the UPS circuit automatically switches to battery mode within 0.5 seconds, ensuring uninterrupted operation for up to 4 hours. Battery status is monitored and displayed via OLED or Blynk alerts.

B. Sensing Subsystem

This subsystem consists of the GP2Y1010AU0F optical dust sensor and the DHT11 temperature-humidity sensor. The dust sensor uses infrared light scattering to detect PM2.5 concentrations and outputs analog signals every 200 ms. The DHT11 communicates digitally every 3 seconds via GPIO, reporting environmental temperature and humidity. These values are used both for real-time monitoring and to determine air quality status levels (e.g., HAPPY, NORMAL, SAD).

C. Processing Subsystem

At the core of the system is the ESP32-WROOM-32 microcontroller. It collects data from sensors, processes the values using a moving average filter, updates the OLED screen, and sends information to the Blynk cloud via Wi-Fi (HTTP/MQTT). The ESP32 also handles user inputs through the SET and DOWN buttons, manages local alerts (buzzer, LED), monitors power status, and stores configuration parameters in EEPROM.

D. Display and Output Subsystem

This subsystem includes a 1.3-inch OLED display, buzzer, and LED indicator. The OLED shows PM2.5 (µg/m³), temperature (°C), humidity (%), power status, and various operation messages using animated icons. The buzzer emits short or long beeps based on button interactions or warnings. The LED blinks to indicate system events such as data upload or alerts, enhancing user feedback.

E. User Communication Subsystem

Users interact with the system via hardware buttons and the Blynk mobile application. The SET button enables Wi-Fi configuration mode, while the DOWN button is used for manual data uploads and toggling auto-warning mode. Remotely, the Blynk app allows real-time data viewing, historical graphs, receiving alerts when air quality exceeds thresholds, and remotely toggling auto-warning functionality.

IV. Hardware Design

The hardware design integrates sensing, processing, power management, user interface, and output components into a compact and energy-efficient air quality monitoring device. Figure 2 shows the schematic diagram of the full system.

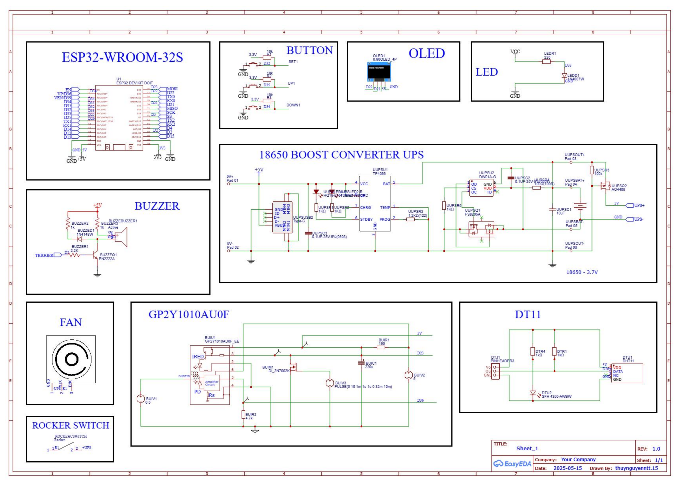

Fig. 2. Complete Circuit Schematic of the Air Quality Monitoring System

A. Sensor Circuit

The sensor circuit includes:

- **GP2Y1010AU0F dust sensor**, which outputs an analog voltage proportional to PM2.5 levels. It is activated using a 10 ms pulse on the IRED (infrared emitter) via a D2N7002 MOSFET. Filtering capacitors and resistors (220 µF, 0.1 µF, and 150 Ω) stabilize the signal.
- **DHT11 sensor**, which measures temperature and humidity. It communicates with the ESP32 via GPIO26 using a one-wire protocol. Signal stability is ensured using pull-up resistors (1 kΩ) and an SFH4350-AWWB diode to suppress noise.

B. Processing Circuit

The central controller is the **ESP32-WROOM-32S module**, responsible for:

- Reading data from sensors (ADC for GP2Y1010AU0F, digital for DHT11).
- Handling user inputs (buttons SET on GPIO32 and DOWN on GPIO34).
- Driving the display via I^2C (SDA: GPIO21, SCL: GPIO22).
- Controlling output peripherals like buzzer (GPIO2) and LED (GPIO33).
- Managing network connections and Blynk communication via Wi-Fi.

C. Power Supply Circuit

The system employs a dual power approach:

- **Main power**: 5V/3A adapter via a DC jack.
- **Backup power**: A single-cell 18650 Li-ion battery (3.7V, 2000mAh) connected to a 15W boost UPS module.

The UPS ensures uninterrupted power by:

- Automatically switching to battery during power loss (switch time ¡ 0.5 s).
- Providing regulated 5V output via a boost converter.
- Monitoring charge/discharge with an integrated control IC and temperature sensing.
- Supporting up to 4 hours of battery runtime under full load conditions.

D. Output and Feedback Circuit

This circuit includes:

- **OLED SH1106 display (1.3-inch)** for showing PM2.5, temperature, humidity, system status, and alert messages.
- **Piezo buzzer** triggered on user actions or warnings with different beep patterns (short for press, double for alerts).
- **LED indicator** used for visual feedback during data transmission or alerts.

E. User Interface Circuit

The system supports both local and remote interaction:

- **SET button**: Hold for 3 seconds to enter Wi-Fi configuration (AP mode).
- **DOWN button**: Short press to push data, long press to toggle auto-warning.
- **Rocker switch**: Powers the system ON/OFF manually.
- **Blynk app**: Enables remote data viewing, alert handling, and control via virtual pins (V0–V4).

V. SOFTWARE DESIGN AND CLOUD INTEGRATION

The firmware is developed using PlatformIO in C++. Blynk is configured with virtual pins for data transmission and control.

- V0 – Temperature, V1 – Humidity, V2 – PM2.5
- V3 – Manual data push, V4 – Auto warning toggle
- Wi-Fi setup via long press on SET button, hosting AP at 192.168.4.1
- EEPROM stores SSID, password, Blynk token, thresholds

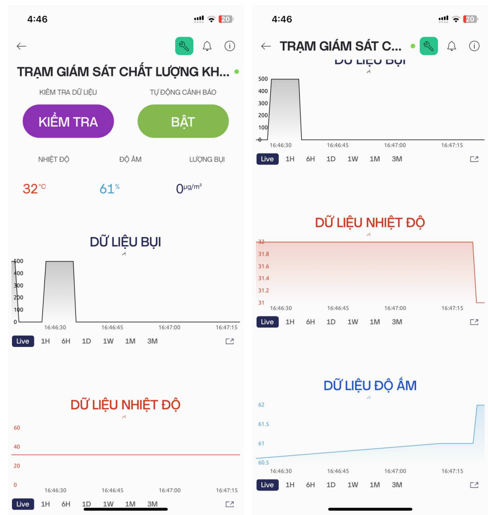

Fig. 3. Blynk Interface for Remote Monitoring

VI. RESULTS AND PERFORMANCE EVALUATION

A. Hardware Evaluation

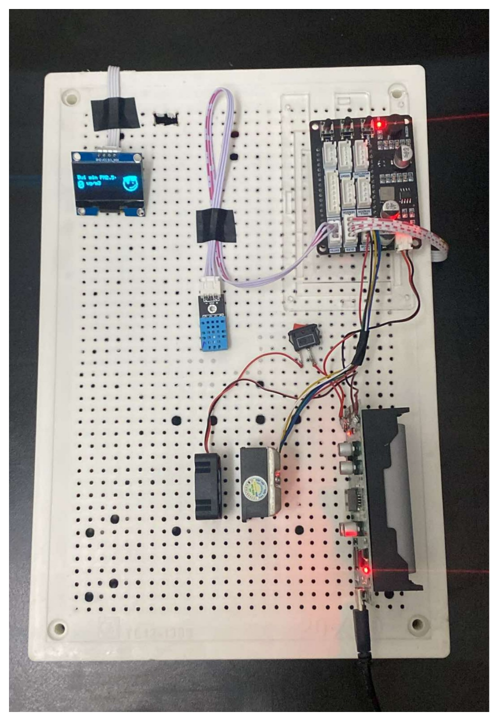

Fig. 4. Output of the working model

All components operated continuously for 24 hours:

- ESP32 maintained stable connection with latency < 2 s.
- DHT11 reported 25.2°C, 59% RH within specification range.
- GP2Y1010AU0F measured dust with deviation $<15\%$.
- OLED refresh and buzzer feedback under 100 ms.
- UPS maintained 4h15m uptime during blackout.

B. *Software Testing*

- Push alerts activated when PM2.5 exceeded 200 µg/m³.
- Manual/auto toggle synced between hardware and app.
- Web interface correctly configured Wi-Fi and thresholds.
- Firmware managed memory efficiently (150 KB heap available).

VII. Conclusion and Future Work

This project successfully demonstrates a robust and user-friendly air quality monitoring solution. It integrates reliable sensors, an intuitive mobile interface, and practical energy management. It is scalable, low-cost, and supports real-time environmental awareness. Future development will explore:

- Replacing DHT11 with more accurate DHT22 or BME280
- Adding CO2 or TVOC sensors
- Supporting offline alerts and SD card data logging
- Enhancing Wi-Fi recovery and app-based configuration tools

References

[1] Espressif Systems, *ESP32-WROOM-32 Datasheet*, 2025. [Online]. Available: https://www.espressif.com/sites/default/files/documentation/esp32-wroom-32_datasheet_en.pdf

[2] Sharp Corporation, *GP2Y1010AU0F Datasheet*, 2025. [Online]. Available: https://global.sharp/products/device/lineup/data/pdf/datasheet/gp2y1010au0f_e.pdf

[3] Aosong Electronics, *DHT11 Datasheet*, 2025. [Online]. Available: http://www.aosong.com/products/DHT11.html

[4] Blynk Inc., *Blynk Platform Documentation*, 2025. [Online]. Available: https://docs.blynk.io/en/