

IOT-Based ESP32-Driven Real-Time Air Quality Monitoring and Purification

Y. Venkat Vivek¹, K. Umamaheswari², T. Venkata Sai Sriharika³ and R. Nikesh⁴

¹⁻⁴Student, Dept. of EIE V. R. Siddhartha Engg. College Vijayawada, India

Email: vivekvikki743@gmail.com, kunduru.uma@gmail.com, sriharika.bannu@gmail.com, rimmanapudinikesh@gmail.com

Abstract—Indoor air quality significantly impacts human health, comfort, and safety, with pollution sources ranging from combustion byproducts to dust and chemicals. Hence, it's vital to monitor and manage indoor air quality for a healthier environment. Our project proposes a smart air purifier system leveraging an ESP32 microcontroller and various sensors. These sensors detect parameters such as volatile organic compounds (VOCs) like Ammonia, Sulfide, and Benzene, known to degrade air quality, as well as carbon monoxide (CO) levels. Moreover, our system employs a compound pre-filter and HEPA filter for efficient purification, ensuring the removal of a wide range of pollutants and allergens from indoor air, further enhancing its quality and promoting a healthier living environment. Data is transmitted to the Blynk cloud platform for analysis and visualization. Our system prioritizes affordability, user-friendliness, and energy efficiency, making it suitable for both home and office settings to enhance indoor air quality and overall well-being. Additionally, users can seamlessly control the air purifier from their smartphones using the Blynk app, allowing for convenient monitoring of air purification.

Index Terms—ESP32 Microcontroller, Blynk Cloud Platform, High-Efficiency Particulate Air (HEPA) Filter, Indoor Air Quality (IAQ), Pre-filter, Smart Air Purifier.

I. INTRODUCTION

Air pollution has become a pervasive global issue, particularly in major cities, where pollution levels often far exceed health standards. Alongside this, sleep deprivation has emerged as a prevalent problem due to hectic schedules and stress. One potential solution to safeguarding lung health indoors is through the use of air purifiers [1]. Researchers have identified various toxic and harmful substances present in indoor dust, including heavy metals and pesticides originating from household items, toys, and electrical appliances. Exposure to such dust through breathing and skin contact poses a serious threat to human health [2]. Ecological concerns in India are rapidly escalating, with air pollution primarily stemming from vehicular emissions and industrial activities, leading to a plethora of respiratory ailments such as asthma and sinusitis. The air quality in major urban centers like

Kolkata, Delhi, and Mumbai is notably subpar due to the significant emission of carbon dioxide and other hazardous gases by vehicles and industries. Additionally, there is a noticeable decline in indoor air quality within these cities.

II. RELATED WORK

Research into air purification has made significant strides in enhancing indoor air quality and promoting healthier environments. One such development was presented by Hak-joon-kim et al. in 2017, introducing a novel electrostatic air purifier designed specifically for use in passenger vehicles. This advanced device incorporated multiple components, including a carbon fiber brush charger, a metallic collection rod, and an activated carbon fiber (ACF) sheet [3]. The ACF sheet performed a dual function: it applied electrostatic forces to attract charged particles towards the collection rod and simultaneously adsorbed gases. Featuring a cylindrical design measuring 100 mm in diameter and 190 mm in length, the purifier boasted a flow rate ranging from approximately 209 to 360 L/min. However, the study's limitations stemmed from its testing in a controlled 1-meter cube chamber, potentially not accurately mirroring real-world vehicle conditions. The complexity and maintenance requirements of the electrostatic air purifier, including the periodic cleaning or replacement of the ACF sheet, could also lead to operational challenges over time.

Another avenue showing promise in air purification is the adoption of negative ion technology. This technology generates negative ions by breaking down air insulation using high-voltage electric fields, effectively reducing airborne dust and enhancing overall air quality. The high-activity particles produced can react with positive ions and industrial dust to form harmless particles, thereby improving air quality. However, a significant concern associated with this technology is the potential production of ozone as a byproduct. Ozone can pose health risks, especially for individuals with respiratory conditions, necessitating rigorous safety standards and careful management practices [4].

Persily AK emphasized the significance of carbon dioxide (CO₂) concentrations as an indicator for evaluating indoor air quality (IAQ) and ventilation effectiveness in buildings. While CO₂ levels can offer insights into ventilation adequacy and occupant-generated pollutants, they do not provide a comprehensive picture of other potential contaminants such as volatile organic compounds (VOCs) and particulate matter. This CO₂-centric approach may not capture the full spectrum of pollutants affecting IAQ and occupant health, suggesting the need for integrating additional monitoring techniques to achieve a more holistic assessment. Moreover, factors like occupant density and activity levels can influence CO₂ concentrations, potentially leading to misinterpretations of IAQ conditions [5].

Kim, Chu, and Shin's introduced ISSAQ, an Integrated Sensing System designed for real-time monitoring of various indoor air quality parameters, including temperature, humidity, CO₂, VOCs, and particulate matter. While ISSAQ offers comprehensive monitoring capabilities, its complexity, associated costs, and dependency on consistent power sources for continuous operation may limit its practicality in certain scenarios. Additionally, concerns regarding sensor calibration and drift highlight the importance of implementing robust maintenance protocols [6].

The research by Positos et al. in 2017 focused on developing an Arduino-based air quality testing, filtering, and disinfecting device tailored for hospital environments [7]. This study aimed to address air quality concerns in healthcare settings by incorporating real-time monitoring of multiple air quality parameters and potential disinfection mechanisms, such as HEPA filtration and UV-C irradiation [8]. Despite its potential advantages, the device's implementation and maintenance complexities within healthcare settings, along with concerns about its computational capabilities compared to more advanced microcontroller platforms, could potentially hinder its widespread adoption [9].

III. METHODOLOGY

The air purifier development involved integrating various components to enhance indoor air quality effectively. The ESP32 microcontroller was selected for its robust data processing and system control capabilities. The addition of MQ135 and MQ7 sensors enabled comprehensive monitoring of pollutants like ammonia, benzene, smoke, and carbon monoxide, while a fan facilitated air circulation. Assembly required careful wiring and configuration to ensure secure connections among the microcontroller, sensors, and fan. Sensor calibration was crucial to align readings with recognized standards. The airflow system's design, including a compound pre-filter and HEPA filter, optimized filtration efficiency by removing large and fine particulate matter. Programming the ESP32 included developing algorithms for data interpretation, pollutant level determination, and fan speed regulation based on air quality metrics. Rigorous testing confirmed the air purifier's functionality across various conditions. Deployment involved documenting assembly steps, wiring diagrams, and code for future maintenance. A Blynk smartphone app was integrated for remote monitoring and control. Maintenance procedures, such as regular filter inspection and replacement, were established for sustained efficiency.

Ultimately, these combined efforts led to the development of an advanced air purification system designed to deliver clean air in diverse indoor settings, contributing to improved health. A detailed block diagram and schematic overview of the proposed air purifier are provided in Fig. 1 and Fig. 2.

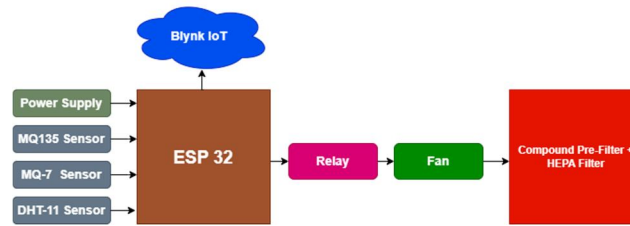


Fig. 1. Block Diagram

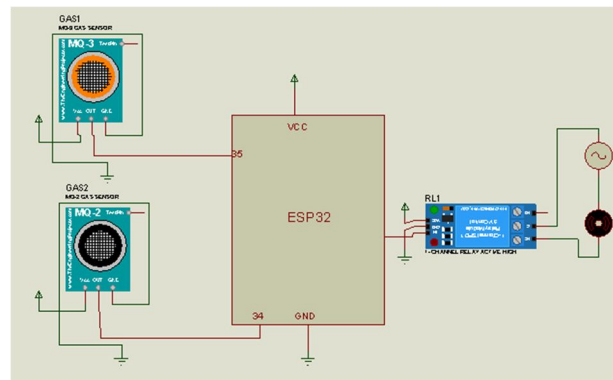


Fig. 2. Schematic Diagram

IV. SYSTEM HARDWARE AND SOFTWARE

A. ESP32

The ESP32 is a versatile module designed for a wide range of applications, from low-power sensor networks to high-demand tasks. It is widely used in various Internet of Things (IoT) applications, including home automation due to its versatility, affordability, and ease of use [10].

The ESP32 stands out among platforms like Arduino and Raspberry Pi due to its emphasis on low-power operation, dual-core processing for efficient multitasking, and built-in Wi-Fi and Bluetooth connectivity. Unlike Arduino's single-core microcontrollers, the ESP32's dual-core Tensilica Xtensa LX6 processor enables better real-time performance, making it ideal for multitasking and timing-sensitive applications. An image of ESP 32 is as shown in Fig. 3

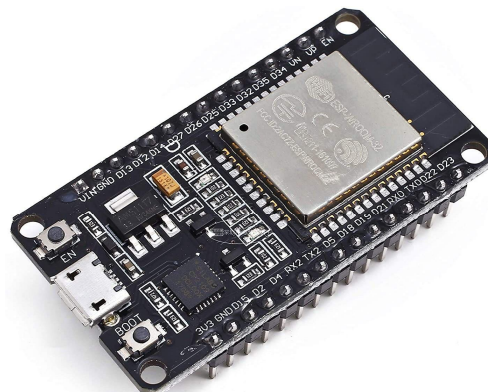


Fig. 3. ESP 32.



Fig. 4. MQ135 Sensor

B. MQ135 sensor

The MQ135 gas sensor shown in Fig. 4 is a versatile sensor widely used in air quality monitoring, especially in air purifiers. It operates based on the chemical reaction between gas molecules and its tin dioxide (SnO_2) sensing element, which changes its conductivity when exposed to certain gases. The sensor typically features four pins: Heater (H) for powering the internal heating element, Analog Output (A) for varying voltage signals based on detected gas concentrations, Digital Output (D) for threshold-based gas detection, and Ground (GND) for circuit completion. It can detect harmful gases like CO_2 , NH_3 , NO_x , and VOCs, triggering air purification processes in purifiers when pollutant levels rise above safe thresholds. Its compact size, affordability, and low power consumption make it ideal for integration into both residential and commercial air purifiers, including IoT-enabled systems for remote monitoring and control of air quality [11].

C. MQ7 sensor

The MQ7 sensor shown in Fig. 5 is a key component in air quality monitoring and air purifiers, specifically designed to detect carbon monoxide (CO) levels in the air.

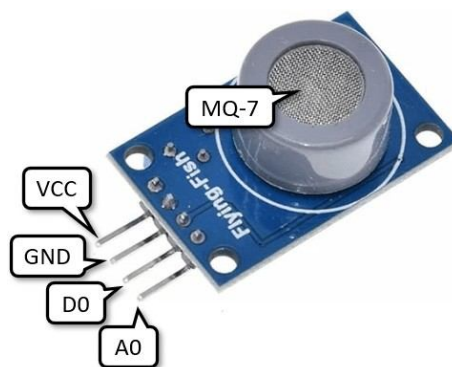


Fig. 5. MQ135 Sensor

Operating on a chemical reaction principle using tin dioxide (SnO_2) semiconductor material, the sensor measures changes in electrical conductivity when exposed to CO. Despite being colorless, odorless, and tasteless, carbon monoxide poses severe health risks due to incomplete combustion of carbon-rich fuels. Integrating the MQ7 sensor into air purifiers acts as a crucial safety measure by continuously monitoring for even trace amounts of CO. Upon detecting elevated CO levels, the sensor prompts the purifier to activate its purification mechanisms, such as ventilation and activated carbon filtration, to neutralize the gas. Its compact design, affordability, and low power consumption make it suitable for various applications, including residential, commercial, and industrial air purifiers. With the rise of IoT technology, MQ7 sensors can be integrated into smart air purifiers for remote monitoring and control, enhancing user convenience and ensuring a safer indoor environment [12].

D. DHT Sensor

The DHT11 sensor shown in Fig. 6 is a cost-effective digital sensor widely used for measuring temperature and humidity in applications like air purifiers. Its integrated capacitive humidity sensor and thermistor provide accurate environmental data, crucial for maintaining optimal indoor conditions. In air purifiers, the DHT11 sensor plays a vital role by continuously monitoring temperature and humidity levels. It helps in optimizing the purifier's performance, preventing issues like mold growth, discomfort, and respiratory problems associated with imbalanced humidity. Additionally, the sensor's temperature readings ensure efficient filtration and system operation, with alerts for temperature anomalies. Its compatibility with microcontrollers and IoT platforms enables smart features, allowing remote monitoring and control of environmental conditions. Furthermore, when combined with other sensors like gas or particulate matter sensors, the DHT11 enhances the purifier's ability to detect and purify a broader range of pollutants, offering targeted purification strategies for improved indoor air quality [13].

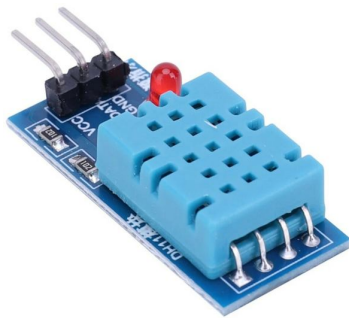


Fig. 6. DHT Sensor



Fig. 7. Relay

E. Relay

A 12V relay shown in Fig. 7 is an electromechanical switch widely used in electronics, including air purifiers, to control higher voltage and current loads using a lower voltage signal. When energized with a 12V input, the relay's coil creates a magnetic field, activating a set of contacts to open or close, allowing or interrupting electrical current flow. In air purifiers, the 12V relay plays a crucial role in controlling the fan or blower motor. Upon receiving a 12V signal from the control circuit, the relay energizes, allowing power to flow to the fan motor and initiating airflow. Conversely, when the purifier is turned off, the relay interrupts the power supply, halting airflow. Additionally, 12V relays provide overcurrent protection in safety circuits, monitoring the motor's current to detect abnormal spikes or surges, and quickly cutting off power to prevent potential damage to the motor or other components. Relays are cost-effective, reliable, and easy to integrate, making them a preferred choice for manufacturers developing robust air purification systems [14].

F. Fan

A 9-inch exhaust fan shown in Fig. 8 is a common component in air purifiers designed for smaller spaces like homes, offices, or specific rooms. These compact fans facilitate air circulation within the purifier, drawing in ambient air for purification.



Fig. 8. Fan

As air passes through multiple filtration stages, the fan creates negative pressure, ensuring a steady flow through the filters to effectively capture and remove pollutants such as dust, pollen, and smoke. Additionally, the exhaust fan expels purified air back into the environment, improving overall indoor air quality. It plays a vital role in maintaining the purifier's efficiency by preventing the buildup of stale air and ensuring continuous circulation to maximize filtration effectiveness [15].

G. Compound Pre-Filter + HEPA Filter

Combining a compound pre-filter with a High Efficiency Particulate Air (HEPA) filter in air purifiers creates a comprehensive filtration system capable of effectively capturing a wide range of airborne contaminants shown in Fig. 9. The compound pre-filter, made of materials like activated carbon, zeolite, and polyester fibers, serves as the initial defense against larger particles, odors, and gases. Activated carbon adsorbs VOCs and odors, zeolite neutralizes chemicals and absorbs moisture, while polyester fibers mechanically trap dust, pet dander, and hair. The HEPA filter, known for its ability to capture particles as small as 0.3 microns with 99.97% efficiency, targets microscopic allergens like pollen, mold spores, bacteria, and viruses. This dual-filtration approach enhances the overall efficiency of the air purification system by extending the HEPA filter's lifespan and ensuring it focuses on capturing smaller, more harmful particles. Together, they provide comprehensive purification, making them ideal for environments with diverse contaminants, such as polluted urban areas or spaces with pet dander and odors [16].

H. Software Platform

The Arduino IDE is a user-friendly platform for programming microcontrollers like the ESP32, commonly used in IoT devices like air purifiers. Setting up the IDE for ESP32 involves installing the board support package and configuring settings. With features like syntax highlighting and code autocompletion, it simplifies coding. The IDE's extensive library and built-in functions facilitate custom firmware development for air purifiers. Its support for ESP32's Wi-Fi enables remote control through apps or web interfaces [16].



Fig. 9. Compound Pre-Filter + HEPA Filter

We integrated the Blynk IoT platform into our air purifier prototype to offer advanced monitoring and control features. Blynk's mobile app and cloud infrastructure enabled us to design a custom dashboard with interactive widgets for real-time monitoring of air quality metrics like purity, temperature, and humidity. Users can also control the purifier remotely through the app, allowing them to customize settings based on their preferences from anywhere [17].

V. EXPERIMENTAL RESULTS

After deploying our air purifier prototype and using the Blynk app for monitoring, we observed significant improvements in air quality metrics. The MQ135 and MQ7 sensors initially detected typical indoor pollutant levels, but activation of the purifier led to noticeable reductions in harmful gases like ammonia, benzene, smoke, and carbon monoxide. The app also indicated minor fluctuations in temperature and humidity, highlighting the purifier's role in maintaining a balanced indoor environment. The images of built prototype are shown in Fig. 10 & Fig. 11.

The Blynk app provided valuable real-time data, confirming the purifier's effectiveness in reducing pollutants and its potential to enhance indoor air quality. This successful deployment, combined with Blynk's monitoring capabilities, offers a promising solution for improving indoor air quality and occupant comfort. The accompanying images showcase the prototype's design and functionality, reinforcing its practicality and potential for broader adoption.

The app's output offers a clear view of the purifier's performance, displaying key metrics like pollutant levels, temperature, and humidity in a concise manner. Its remote control feature allows users to adjust settings and monitor the system from anywhere, enhancing convenience. Screenshots from two different rooms further illustrate the purifier's effectiveness, as shown in Fig. 12 & Fig. 13.

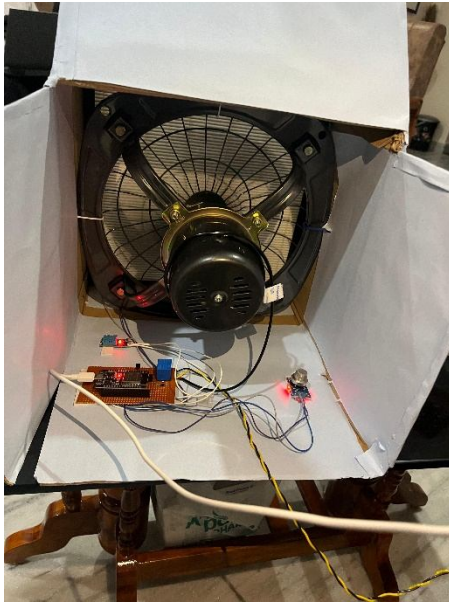


Fig. 10. Prototype Back View



Fig. 11. Prototype Front View

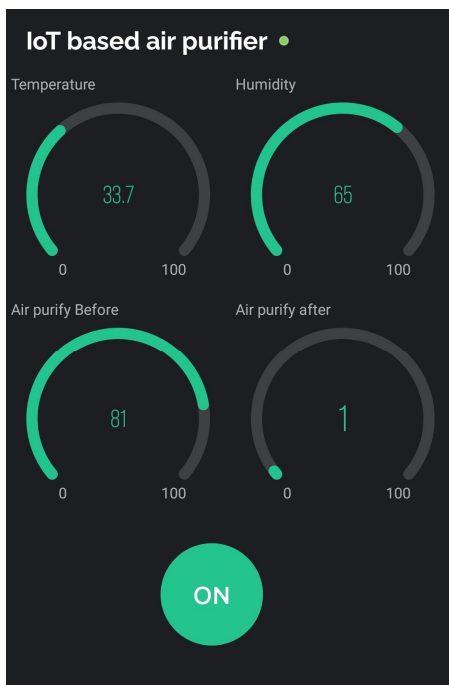


Fig. 12. Blynk IoT Output case 1



Fig. 13. Blynk IoT Output case 2

VI. CONCLUSION AND FUTURE SCOPE

The air purifier prototype, featuring a robust 9-inch exhaust fan for air circulation and real-time monitoring via the Blynk app, has shown considerable progress in managing indoor air quality. The exhaust fan ensures efficient air exchange and pollutant removal, while data from the Blynk app offers comprehensive insights. Purification progress, ranging from 70% to 80%, indicates effective pollutant removal, enhancing indoor air quality significantly. Integration of key components such as the ESP32 microcontroller, MQ135, DHT11, and MQ7 sensors amplifies the system's ability to mitigate indoor air pollutants, ultimately promoting occupant well-being and comfort.

Looking ahead, advancements in air purification technology can focus on optimizing sensor calibration algorithms for improved accuracy, exploring more efficient and sustainable filtration materials, and integrating machine learning algorithms to enhance adaptive capabilities. Further, expanding remote monitoring and control functionalities through IoT protocols and cloud-based platforms can increase accessibility. These innovations represent opportunities for continuous improvement in indoor air quality management, promoting healthier living environments globally.

REFERENCES

- [1] Ari Rabl and Joseph Spadaro. "Public Health Impact of Air Pollution and Implications for the Energy System". In: Annual Review of Energy and the Environment 25 (2000), pp. 601–628.
- [2] Jianhan Zou. "A new type of air purification and automatic cleaning combined machine". In: 201410371775 (2014).
- [3] H. J. Kim et al. "Submicrometer particle removal indoors by a novel electrostatic precipitator with high clean air delivery rate, low ozone emissions, and carbon fiber ionizer". In: Indoor Air 23 (2013), pp. 369–378.
- [4] H. Hsieh. "Negative Ions Generating Circuit Design with Decreasing High Frequency Noise and Apparatus Thereof". In: US20080191145 (2008).
- [5] Yoshinori Sekoguchi, Kenji Furuhashi, and Mamoru Morikawa. "Ion Generator and Air Conditioning Apparatus". In: US20040130271 (2004).
- [6] Andrew K. Persily. "Evaluating Building IAQ and Ventilation with Indoor Carbon Dioxide". In: ASHRAE Transactions 103 (1997), 4072(1–12).
- [7] J. Kim, C. H. Chu, and S. M. Shin. "ISSAQ: An integrated sensing system for real-time indoor air quality monitoring". In: IEEE Sensors Journal 14 (2014), pp. 4230–4244.
- [8] American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc. (ASHRAE). "Standard 62-2001: Ventilation for Acceptable Indoor Air Quality". In: (2001).
- [9] Jude Positos et al. "Arduino-based Air Quality Testing, Air Filtering and Disinfecting Device Design and Effectivity testing for Hospital Rooms". In: INTERNATIONAL JOURNAL OF TREND IN RESEARCH AND DEVELOPMENT 4 (2017). ISSN: 2394-9333.
- [10] Espressif Systems. ESP32 Datasheet. 2021.
- [11] Winsen Electronics Technology Co., Ltd. MQ135 Gas Sensor Datasheet. 2024. URL: <http://www.winsen-sensor.com/d/files/MQ135%20Gas%20Sensor>
- [12] Winsen Electronics Technology Co., Ltd. MQ7 Carbon Monoxide Gas Sensor Datasheet. 2024. URL: <http://www.winsen-sensor.com/d/files/MQ7%20Gas%20Sensor%20Datasheet-V1.4.pdf>.
- [13] Aosong Electronics. DHT11 Sensor Datasheet. 2024. URL: <https://www.aosong.com/asp/down.asp?id=88>.
- [14] Aosong Electronics. Understanding the Role of 12V Relays in Air Purifiers. 2024. URL: <https://www.aosong.com/understanding-12v-relays>.
- [15] Honeywell. Understanding Compound Pre-filters and HEPA Filters in Air Purifiers. 2024. URL: <https://www.airpurifiermanufacturer.com/understanding-filters>.
- [16] Arduino. ESP32 Development with Arduino IDE. 2024. URL: <https://www.arduino.cc/en/Guide/ESP32>
- [17] Blynk. Blynk IoT Platform Documentation. 2024. URL: <https://docs.blynk.io/>.