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Solar Powered Air Purifier with Air Quality Monitoring System

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Abstract: *Rapid urbanization and industrialization have significantly degraded indoor air quality, leading to increased health risks. Conventional air purifiers depend on grid electricity, which increases operating costs and carbon emissions. This study presents the design and development of a solar powered air purifier integrated with an air quality monitoring system. The proposed system utilizes an Arduino Nano controller, MQ-2 gas sensor, HEPA-based filtration approach, and a solar energy subsystem consisting of a photovoltaic panel and sealed lead-acid battery. The system continuously monitors air quality and automatically activates purification when pollutant levels exceed the threshold. Experimental evaluation demonstrates effective detection of harmful gases and efficient air purification with reduced energy dependency on the grid. The proposed model is suitable for low-power, portable, and eco-friendly indoor air purification applications*

Keywords*:* Solar air purifier, Air quality monitoring, Arduino Nano, MQ-2 sensor, HEPA filtration, Renewable energy

I. INTRODUCTION

Air pollution has emerged as one of the most critical environmental and public health challenges of the 21st century. Rapid industrialization, urbanization, increased vehicular emissions, and indoor pollutant sources have significantly deteriorated air quality, particularly in densely populated regions. Poor indoor air quality is strongly associated with respiratory illnesses, cardiovascular diseases, allergies, headaches, and reduced overall well-being. Since people spend nearly 80–90% of their time indoors, maintaining clean indoor air has become an essential requirement for healthy living environments.

Conventional air purification systems are widely used to remove airborne contaminants such as dust, smoke, volatile organic compounds (VOCs), and harmful gases. Most commercially available air purifiers rely on continuous electrical power from the grid, which increases operational costs and contributes indirectly to carbon emissions. In many rural and semi-urban areas, unreliable power supply further limits the effectiveness and usability of traditional air purifiers. Therefore, there is a growing need for energy-efficient, portable, and environmentally sustainable air purification solutions.

Renewable energy, particularly solar energy, offers a promising alternative to address the energy dependency of conventional air purifiers. Solar power is abundant, clean, and sustainable, making it suitable for standalone and off-grid applications. Integrating solar photovoltaic systems with air purification technology can significantly reduce energy consumption from conventional sources while maintaining effective air cleaning performance. Moreover, solar-powered systems are especially beneficial in remote locations where grid electricity is either unavailable or unreliable.

Another important advancement in modern air purification is the incorporation of real-time air quality monitoring. Traditional purifiers typically operate at fixed speeds without considering the actual pollution level in the environment. This results in unnecessary energy consumption and reduced system efficiency. By contrast, intelligent air purification systems equipped with gas sensors can continuously monitor pollutant concentrations and automatically adjust purifier operation based on real-time conditions. Such smart control not only improves purification efficiency but also enhances user awareness regarding surrounding air quality.

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Recent developments in low-cost microcontrollers and gas sensing technologies have enabled the design of compact and affordable smart air purification systems. Sensors such as the MQ series can detect harmful gases including carbon monoxide, smoke, LPG, and other combustible gases. When integrated with microcontroller platforms like Arduino Nano, these sensors enable automated decision-making, display of air quality information, and activation of purification mechanisms only when required. This approach leads to optimized energy utilization and improved system responsiveness.

In this context, the present work focuses on the design and development of a solar powered air purifier with an integrated air quality monitoring system. The proposed system combines a photovoltaic power source, energy storage unit, gas sensing module, microcontroller-based control unit, filtration mechanism, and user alert interface. The system continuously monitors air quality using a gas sensor and automatically activates the purification fan and alert system when pollutant levels exceed predefined thresholds. The use of solar energy ensures reduced dependency on grid power, making the system eco-friendly and suitable for portable applications.

The primary objectives of this study are to develop a low-cost and energy-efficient air purification system, implement real-time air quality monitoring, enable automatic control based on pollution levels, and evaluate the feasibility of solar-powered operation. The proposed prototype aims to provide an effective solution for improving indoor air quality in homes, offices, and small enclosed environments while minimizing environmental impact.

The remainder of this paper presents the literature review, system design methodology, hardware and software implementation, experimental results, and future scope of the developed solar powered air purifier system.

II. LITERATURE SURVEY

1. Foundational Smart Architectures

Early foundational work established the framework for modern systems. The study published in **IEEE Access (2018)** provides a widely cited architecture for "Smart Air Pollution Monitoring," emphasizing the need for a tiered approach: sensing, network transmission, and data visualization. Similarly, research in the **IEEE Sensors Journal (2019)** validates the efficacy of **Wireless Sensor Networks (WSN)** for environmental sensing, proving that low-cost nodes can achieve high-density coverage that traditional government stations cannot match.

2. Real-Time Monitoring and Microcontroller Integration

The use of accessible hardware like Arduino and NodeMCU is a recurring theme for prototyping real-time solutions:

Sarkar et al. (2023) explored the use of **MQ-series sensors** paired with **NodeMCU** for real-time CO_2 analysis. Their work highlights the importance of the ESP8266's Wi-Fi capabilities in ensuring seamless data flow to the cloud.

Purwantoro et al. (2019) focused on the mapping of Carbon Monoxide (CO) using **Arduino-based systems**. This research demonstrated that mobile or distributed microcontrollers could effectively map pollution "hotspots" in urban environments.

3. Application-Specific Systems: Indoor vs. Purification

Monitoring needs vary significantly between indoor and outdoor contexts:

Research in **Sensors (2020)** specifically addresses **Indoor Air Quality (IAQ)**, noting that indoor pollutants often require more sensitive, low-power hardware due to stagnant air conditions.

Moving beyond mere monitoring, the **International Journal of Engineering Research & Technology (2021)** discusses "Smart Air Purifier Systems." This represents the "actuation" phase of IoT, where sensor data directly triggers embedded control systems to remediate air quality in real-time.

4. The Frontier: Edge Computing and TinyML

The most recent shift in the literature involves moving intelligence from the cloud to the device itself. **Ken and Behjati (2025)** introduced **TinyML-based Ozone prediction** using Arduino-class hardware. By implementing machine learning

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models directly on edge devices, they significantly reduced power consumption and latency, allowing for predictive alerts rather than just reactive monitoring.

III. SYSTEM MODELING

The proposed solar powered air purifier with air quality monitoring system is designed as an integrated embedded platform that combines renewable energy generation, sensing, control, and purification mechanisms. The objective of the system modeling is to ensure reliable detection of air pollutants and automatic activation of the purification process while maintaining low power consumption. The system architecture is modular in nature, which improves flexibility, ease of maintenance, and scalability for future enhancements.

The overall system operates on solar energy supported by battery storage, enabling standalone operation without continuous dependence on grid electricity. The control and decision-making functions are handled by a microcontroller-based unit, while sensing and actuation modules ensure real-time monitoring and response to air quality variations.

3.1 Block Diagram Description

The proposed system consists of the following major functional blocks:

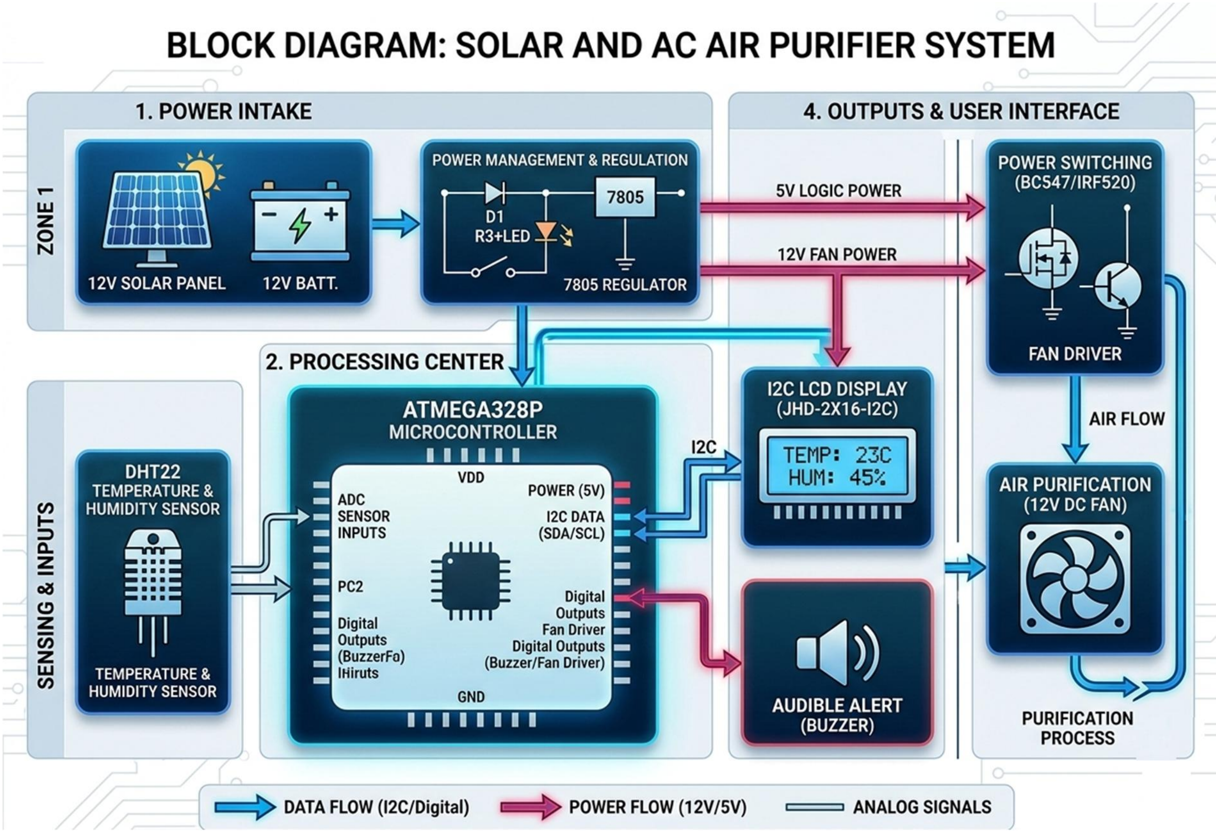

Figure 1 BLOCK DIAGRAM

Solar panel
Battery storage unit
Voltage regulator
Arduino Nano microcontroller
MQ-2 gas sensor
Fan with filter unit
LCD display

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Buzzer alert
MOSFET driver
Each block performs a specific role in achieving automatic air purification with energy-efficient operation.

The **solar panel** acts as the primary energy source of the system. It converts incident solar radiation into electrical energy through the photovoltaic effect. The generated DC power is used to charge the battery and operate the system, thereby reducing dependence on conventional electricity.

The **battery storage unit (12V, 8Ah sealed lead-acid battery)** stores the electrical energy produced by the solar panel. It ensures uninterrupted operation during low sunlight conditions or nighttime. The battery improves system reliability and supports portable applications.

The **voltage regulator** is used to provide a stable and regulated voltage to sensitive electronic components, particularly the microcontroller and sensor modules. Since fluctuations in supply voltage can affect sensor accuracy and controller performance, the regulator plays a critical role in maintaining system stability.

The **Arduino Nano** serves as the central processing and control unit of the system. It continuously reads analog data from the MQ-2 gas sensor, processes the data according to predefined threshold logic, and controls the output devices such as the fan, buzzer, and LCD display. Due to its compact size, low power consumption, and sufficient I/O capability, the Arduino Nano is well suited for this embedded application.

The **MQ-2 gas sensor** is responsible for monitoring indoor air quality. It detects the presence of smoke and combustible gases such as LPG, propane, hydrogen, and carbon monoxide. The sensor provides an analog voltage proportional to gas concentration, which is read by the Arduino's analog input pin.

The **MOSFET driver (IRF520 module)** acts as an electronic switching interface between the Arduino and the fan load. Since the microcontroller cannot directly drive high-current devices, the MOSFET enables safe and efficient control of the purification fan using low-power control signals.

The **fan with filter unit** forms the core purification mechanism. When activated, the fan draws contaminated air through the filter medium (HEPA-type/passive filter concept), where particulate matter and pollutants are captured, thereby improving indoor air quality.

The **LCD display (16×2 I2C)** provides real-time visual feedback to the user. It displays the measured air quality level and system status such as normal air condition or polluted air warning.

The **buzzer alert** serves as an audible warning device. It activates when pollutant concentration exceeds the safe threshold, thereby immediately notifying the user about poor air quality conditions.

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Working Principle

Figure 2 **PROJECT PHOTOGRAPH**

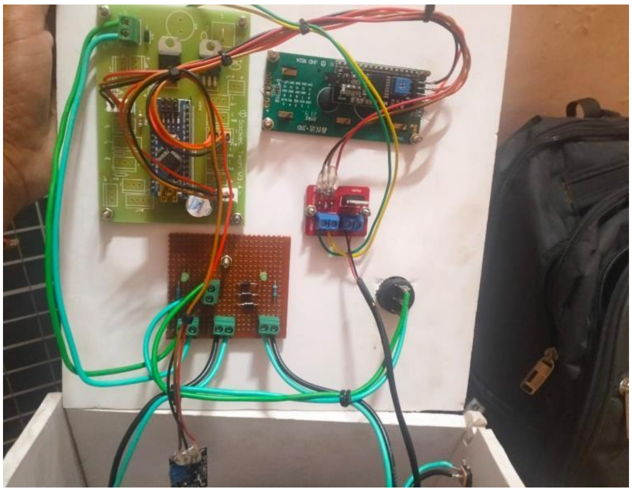

Figure 3 **PROJECT PHOTOGRAPH**

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The working of the proposed system begins with the **solar panel**, which converts sunlight into electrical energy. This energy is stored in the **12V, 8Ah battery**, ensuring continuous system operation even in the absence of sunlight.

The stored energy is passed through the **voltage regulator**, which provides a stable supply to the Arduino Nano, gas sensor, and other electronic components. The **MQ-2 gas sensor** continuously monitors the surrounding air and outputs an analog signal proportional to pollutant concentration.

The **Arduino Nano** periodically reads the sensor value and compares it with a predefined threshold level. If the detected pollution level exceeds the safe limit, the controller activates the **MOSFET driver**, which in turn switches ON the **fan and purifier unit**. Simultaneously, the **buzzer** is triggered to alert the user, and the **LCD display** shows a warning message indicating poor air quality.

When the pollutant concentration falls below the threshold, the Arduino automatically turns OFF the fan and buzzer, and the system returns to standby mode while continuing to monitor the air. This closed-loop automatic operation ensures energy-efficient and responsive air purification.

IV. HARDWARE DESCRIPTION

The hardware architecture of the proposed solar powered air purifier is designed to achieve reliable air quality monitoring, efficient purification, and low power consumption. The system integrates sensing, control, power management, and actuation modules in a compact embedded platform. Careful component selection ensures cost-effectiveness, stability, and suitability for standalone solar operation. The major hardware components used in the system are described in the following subsections.

4.1 Arduino Nano

The Arduino Nano, based on the ATmega328 microcontroller, serves as the central processing unit (CPU) of the proposed system. It is responsible for acquiring sensor data, executing the control algorithm, and driving the output devices. The compact size, low power consumption, and sufficient input/output capability make it highly suitable for embedded air quality monitoring applications.

The Arduino Nano provides 14 digital input/output pins, which are used to control peripherals such as the buzzer, MOSFET driver, and status indicators. It also offers 8 analog input channels with 10-bit resolution, enabling accurate acquisition of analog signals from the MQ-2 gas sensor. The built-in PWM capability allows efficient speed or power control of the purification fan through the MOSFET driver.

Another important advantage of the Arduino Nano is its low power requirement, which aligns well with the solar-powered nature of the system. The microcontroller continuously processes the sensor readings, compares them with predefined threshold values, and accordingly controls the fan, buzzer, and LCD display to maintain acceptable indoor air quality.

4.2 MQ-2 Gas Sensor

The MQ-2 gas sensor is employed as the primary air quality sensing element in the proposed system. It is a semiconductor-based sensor capable of detecting a wide range of combustible gases and smoke. In this project, the sensor is used to monitor indoor air contamination levels and provide real-time feedback to the controller.

The MQ-2 sensor is sensitive to smoke, LPG, propane, hydrogen, and carbon monoxide, making it suitable for general-purpose air quality monitoring. It operates at a supply voltage of 5 V and provides both analog and digital outputs. The analog output is proportional to gas concentration and is used by the Arduino Nano for continuous monitoring and threshold comparison.

Key advantages of the MQ-2 sensor include fast response time, simple interfacing, low cost, and long operational life. However, the sensor has a known limitation: it lacks gas selectivity and cannot distinguish between different gases. Therefore, it is primarily suitable for overall air quality indication rather than precise gas identification.

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4.3 Solar Power System

To ensure eco-friendly and off-grid operation, the proposed system incorporates a dedicated solar power subsystem consisting of a photovoltaic panel and energy storage battery.

Solar Panel

A 10 W solar panel is used as the primary renewable energy source. The panel converts solar radiation into electrical energy using the photovoltaic effect. The generated DC power is utilized to charge the battery and supply the system load. The use of solar energy significantly reduces dependence on conventional electricity and lowers the carbon footprint of the purifier.

Battery

Energy storage is achieved using a 12 V, 8 Ah sealed lead-acid (SLA) battery. The battery stores excess energy generated during peak sunlight hours and supplies power during nighttime or low irradiance conditions. The selected battery is maintenance-free, has low self-discharge, and provides long service life, making it suitable for portable and standalone applications.

The combination of the solar panel and battery ensures reliable off-grid operation and continuous system availability.

4.4 Voltage Regulator (7812)

The 7812 linear voltage regulator is used to provide a stable and regulated 12 V output to the system. Since solar and battery voltages can fluctuate, direct supply to sensitive electronics may lead to malfunction or inaccurate sensor readings. The 7812 regulator eliminates this issue by maintaining a constant output voltage.

The regulator incorporates built-in thermal overload protection and short-circuit protection, which enhances system safety and reliability. By ensuring clean and stable power delivery, the 7812 plays a crucial role in the safe operation of the Arduino Nano, sensor modules, and other electronic components.

4.5 IRF520 MOSFET Driver

The IRF520 MOSFET driver module is used as a power interface between the Arduino Nano and the purification fan. Since the microcontroller output pins cannot directly drive high-current loads, the MOSFET module acts as an electronic switch.

The driver supports PWM control, enabling efficient regulation of the fan operation if variable speed control is required. It can handle load voltages up to 24 V and relatively high current levels, making it suitable for driving DC fans and similar actuators.

By using the MOSFET driver, the system achieves safe isolation between low-power control circuitry and high-power load devices.

4.6 Filtration Unit

The air purification mechanism is based on a passive filtration approach following the HEPA-type concept. The filtration unit is coupled with a DC fan that forces contaminated air through the filter medium.

The primary functions of the filtration unit include:

Removal of particulate matter such as dust and smoke

Improvement of indoor air quality

Safe operation without ozone generation

High purification efficiency for fine particles

Passive HEPA-type filtration is preferred in this system due to its reliability, simplicity, and absence of harmful byproducts. When the fan is activated, polluted air is drawn through the filter, and cleaned air is released back into the environment.

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V. SOFTWARE DEVELOPMENT

The software of the proposed solar powered air purifier plays a vital role in enabling real-time monitoring, intelligent decision-making, and automatic control of the purification process. The embedded program was developed using the Arduino Integrated Development Environment (IDE), which provides a user-friendly platform for coding, compiling, and uploading firmware to the Arduino Nano. Prior to hardware implementation, the circuit behavior and logic were verified through simulation using the Proteus Design Suite. This approach helped in validating system functionality, reducing debugging time, and improving overall reliability.

The software is written in Embedded C and structured to ensure continuous monitoring of air quality with minimal computational overhead. The program follows a loop-based execution model, which is suitable for real-time embedded applications. It continuously acquires data from the MQ-2 gas sensor, processes the readings, compares them with predefined threshold limits, and accordingly controls the fan, buzzer, and LCD display.

During system startup, the Arduino initializes all input and output peripherals, including the gas sensor interface, LCD module, and control pins connected to the MOSFET driver and buzzer. Proper initialization ensures stable communication and accurate sensor readings. The LCD is configured in I2C mode to reduce wiring complexity and microcontroller pin usage.

The MQ-2 sensor provides an analog voltage proportional to the concentration of gases present in the surrounding air. This analog signal is read through one of the Arduino's analog input channels and converted into a digital value using the built-in 10-bit Analog-to-Digital Converter (ADC). The obtained sensor value is then compared with a predefined threshold that represents the safe air quality limit.

If the sensed pollution level exceeds the threshold, the system interprets the condition as poor air quality. In response, the Arduino sends a control signal to the MOSFET driver, which switches ON the purification fan. Simultaneously, the buzzer is activated to provide an audible alert to the user. The LCD display is updated with a warning message indicating that the air quality is unhealthy. This automatic response ensures immediate corrective action without user intervention.

On the other hand, when the sensor reading remains below the threshold value, the system considers the air quality to be within safe limits. In this condition, the purification fan and buzzer remain OFF to conserve energy. The LCD displays a normal air quality message, providing continuous visual feedback to the user.

The entire process operates in a continuous loop, enabling real-time monitoring and dynamic system response. This closed-loop control strategy improves energy efficiency by running the purifier only when required, thereby extending battery life and enhancing the effectiveness of the solar-powered system.

VI. CONCLUSION

In this work, a solar powered air purifier with an integrated air quality monitoring system has been successfully designed, developed, and evaluated. The proposed system effectively combines renewable energy utilization, real-time gas sensing, and automated control to improve indoor air quality in an energy-efficient and environmentally friendly manner. By incorporating a photovoltaic power source and battery storage, the system is capable of operating independently of the conventional electrical grid, making it suitable for both urban and remote applications.

The hardware implementation using the Arduino Nano, MQ-2 gas sensor, IRF520 MOSFET driver, and passive filtration unit demonstrated reliable performance in detecting air pollutants such as smoke and combustible gases. The embedded control algorithm continuously monitors air quality and automatically activates the purification fan and buzzer when the pollutant concentration exceeds the predefined threshold. The LCD interface provides clear visual feedback to the user regarding real-time air status, thereby improving system usability and awareness.

Experimental observations confirmed that the system responds quickly to deteriorating air conditions and returns to standby mode once the air quality improves. This closed-loop automatic operation significantly reduces unnecessary power consumption and enhances battery utilization, which is particularly important for solar-powered standalone systems. The use of low-cost and readily available components further makes the proposed design economically viable for small-scale deployment.

Despite its effective performance, certain limitations were identified. The MQ-2 sensor provides general gas detection but lacks selectivity for specific pollutants, and the purification efficiency depends on the quality of the filter medium. Additionally, solar power availability varies with environmental conditions, which may influence charging performance under low irradiance.

Overall, the developed prototype demonstrates a practical, low-cost, and eco-friendly solution for intelligent indoor air purification. The system has strong potential for further enhancement through the integration of advanced particulate sensors, IoT-based remote monitoring, and multi-stage filtration technologies. With such improvements, the proposed approach can contribute significantly toward sustainable and smart air quality management systems.

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