IoT based solar powered air purifier with air quality monitoring system

Aparna Jose, Abraham C1, Akhil K Soman, Ajumal T J, Anandakrishna, Abison Shibu
Department of Electronics and Communication Engineering, Mangalam College of Engineering, Kottayam, India

Abstract. The cornerstone of combating indoor air pollution sustainably lies in integrating solar electricity into air purification systems. This not only addresses airborne pollutants but also reduces reliance on traditional power sources, promoting environmental preservation and cost savings. The system's effectiveness hinges on real-time AQM and advanced filtering techniques, powered by solar energy. By leveraging solar power, it operates ecologically while maximizing indoor air quality impact. Its design emphasizes energy efficiency without compromising purification efficacy, effectively eliminating allergens, pollutants, and Real-time monitoring empowers users to make informed environmental adjustments by tracking various metrics simultaneously. This comprehensive approach fosters sustainability, efficiency, and real-time control, crucial for enhancing indoor air quality. Additionally, its reliance on solar energy aligns with global efforts towards renewable energy adoption, reducing its ecological footprint. In summary, this solar-powered air filtration system signifies a paradigm shift in combating indoor air pollution, embodying the fusion of sustainability, innovation, and health-conscious design for a healthier indoor environment.

Keywords: Internet of Things, Air Monitoring System, Particulate Matter, Volatile Organic Compounds, Air quality index, Wireless Sensor Network, Global positioning system, Air quality monitoring. Revolutions per minute, Cubic feet per minute, Parts per million.

1. Introduction

The urgent issue of air pollution, particularly in regions with unreliable power sources, demands an innovative approach to continuous air quality monitoring and purification. The aim is to develop a sustainable system that not only cleanses the air but also provides real-time information on key metrics such as temperature, humidity, gases, and particulate matter. This endeavour requires leveraging solar power as the primary energy source to ensure the system's autonomy [1]. Combining advanced air quality monitoring features with solar energy presents a significant challenge, but it's crucial for creating a solution that operates independently of conventional power grids. By enabling users to access vital information about their environment, we empower them to make informed decisions for healthier living spaces. Ultimately, the goal is to establish a novel, self-sufficient air purification system that contributes to both environmental and economic sustainability while addressing the pressing

* Corresponding author: aparna.jose@mangalam.in
global issue of air pollution [2]. Air pollution poses a significant threat to the environment, with about 90% of the world’s population living in areas with poor air quality [3]. Exposure to air pollution can lead to various health issues, including lung damage, heart disease, stroke, and respiratory conditions [4]. A cost-effective solution to this problem is the use of solar-powered air purifiers equipped with integrated air quality monitoring systems [5]. These devices utilize solar cells to convert sunlight into power for both the air purifier and monitoring system. Air pollution, largely driven by activities such as mining, construction, transportation, and industrial work, is particularly severe in densely populated cities, leading to respiratory illnesses and other health problems [6]. Despite the availability of various air purifier models, obtaining a sufficient number to adequately address air quality issues is often impractical due to cost constraints and limited funding from government agencies [7]. Therefore, developing more affordable and efficient air purifiers is crucial. Our sun-facing air purifier employs a radial pull mechanism to draw air from the surroundings and pass it through filters, effectively removing odors and pollutants from the air.

2. Methodology

The development of this IoT based system requires careful consideration of sensor selection, the design of an effective hardware architecture, the development of software for data collection and visualization, the integration of renewable energy sources, and extensive testing to ensure accuracy and reliability [8], [9].

3. Synthesis of literature and discussion

3.1 Non–IoT based purifiers.

The publication [10] outlines a comprehensive air quality monitoring system tailored for urban environments, covering sensor development, data collection strategies, analysis methods, and suggestions for managing urban air pollution. Studies examining air quality parameters during lockdowns and COVID-19 impacts [11], as well as discussions on mitigating roadside and street-level pollution [12], were studied. Additionally, proposals were made for removing indoor carbon dioxide using sorption-type air filters [13], and the design of a low-cost, solar-powered air filter to enhance the air quality index was presented [14][15].

Paper [16], explore intelligent air purifier systems with a focus on sensor integration and data processing. In [17] Hossain et al. employ solar thermal collectors integrated with a water storage system to capture solar radiation and heat water, incorporating insulation materials and monitoring equipment for optimized energy efficiency and performance evaluation. The effectiveness of negative ionic air purifiers in maintaining air quality is discussed in [18]. Yoda et al. investigated the effects of air purifier usage on indoor environment and respiratory health among healthy adults, utilizing air purifier technology [19][20] assesses particulate matter levels on building sites, emphasizing influencing variables. Techniques for indoor air cleaning and disinfection, including air ionization and UVGI technology, are discussed in [21]. Gupta et al. conducted experiments to measure the performance of a solar air heater prototype under various conditions, analyzing collected data to evaluate efficiency and thermal stability. Through optimization based on experimental results, they aimed to refine the design parameters for enhanced effectiveness in residential heating applications.
[22]. [23] presents a wireless sensor network- system for live analysis in metropolitan areas.

[24] examines activated carbon's ability to remove sulphur particles from smog, offering insights into smog pollution reduction. Discussions on wastewater treatment approaches, including phenol removal, are found in [25]. [26] investigates the impact of air purifiers on respiratory health of individuals and indoor air quality among healthy adults.

3.2 IoT based purifiers.

Paper [27] introduces ISSAQ, an integrated sensing system for real-time indoor air quality monitoring powered by solar energy. A similar air quality system is proposed in [28]. "Portable Air Purifier with Air Quality Monitoring Sensor" by M. B. Marinov et al. presents a portable air purifier with an integrated sensor for efficient air purification and real-time monitoring [29]. Additionally, A. N. Bhagwat et al. discusses the benefits of energy-efficient air distribution systems for safer air handling units [30].

"Design of a Solar-Powered Air Purifier with Air Quality Monitoring System" describes an integrated air purification framework utilizing photovoltaic panels for electricity generation and sensors for monitoring air quality [31]. The evaluation of indoor air quality monitoring systems, including sensor-based methods and IoT technologies are discussed in [32], complementing the design described. Additionally, [33] assesses the efficacy of a solar-powered air purifier with energy storage capabilities. A reference design for IoT systems is outlined in [34], emphasizing sensor integration and data analytics for efficient monitoring. "Participatory Air Pollution Monitoring Using Smartphones" by D. Hasenfratz et al. explores smartphone-based air pollution monitoring through sensor data and crowdsourcing [35].

"A Survey Paper on Vehicles Emitting Air Quality and Prevention of Air Pollution by Using IoT Along with Machine Learning Approaches" explores IoT and machine learning methods for mitigating vehicular air pollution [36]. Additionally, an IoT-based approach for tracking air freshness is discussed [37], contributing to IoT applications in environmental monitoring. "IoT based low-cost air pollution monitoring system" by G. Parmar et al. proposes a cost-effective system using IoT platforms and sensors for data collection [38]. Similarly, S. Muthukumar et al. emphasizes IoT's role in environmental management through pollution detection and mitigation [39]. The IoT-based system for monitoring pollution and noise levels, introduced in [40], employs data analytics, communication networks, and sensor nodes. S. M. Saad et al. utilizes WSNs to monitor air quality in real-time [41]. This idea is supported by [42], which presents a smart sensor network for thorough environmental monitoring. An IoT-based waste collection system using IR sensors for efficient waste management is discussed in [43], optimizing collection routes based on real-time data.

Paper [44] presents an IoT-based environmental monitoring system for agriculture, tracking meteorological variables like temperature, humidity, rainfall, and wind speed with deployed weather sensors. Integrated with farm-specific data such as crop type and growth stage, this system offers actionable insights for enhanced crop management and irrigation scheduling.
The utilization of air purifier drones for mitigating air pollutants in residential and industrial environments is elucidated by P. Singh et al. [45]. Equipped with air quality sensors and purification modules, these drones autonomously operate indoors and outdoors, actively purifying the air by absorbing particulate matter and VOCs. Supplementing this concept, [46] introduces an air purifier integrated with a monitoring device, facilitating filtration alongside real-time air quality monitoring. Employing filtration technologies like HEPA and activated carbon filters, the purifier effectively removes airborne contaminants while the integrated monitoring device continuously tracks air quality indicators, providing users with pertinent data for informed decisions. Furthermore, [47] explores an IoT-based system for monitoring air pollution levels. Utilizing sensor nodes and communication networks, this system establishes a network of air quality sensors across diverse locations to continuously monitor pollutants such as ozone O3, NO2, and CO. With wireless transmission of sensor data to a central server for real-time analysis, authorities can track air quality trends and promptly implement corrective measures. Dhingra et al.'s study on "IoT-Mobair" outlines a mobile-centric IoT framework for analysis of air pollution [48]. Utilizing GPS coordinates and integrated mobile sensors, this system collects data on air quality, including pollution concentrations, transmitted to a centralized server for analysis, enabling the creation of pollution maps and air quality analyses.

Moreover, "IoT Based Air Pollution Monitoring System" presents a strategy tailored for urban air pollution monitoring [49]. By deploying IoT platforms and sensor nodes throughout urban areas, this system gathers and analyses real-time air quality data, enabling authorities to assess trends and implement pollution control measures effectively.

Similarly, the study by F. N. Setiawan et al. titled "IoT Based Air Quality Monitoring," emphasizes IoT-based air quality monitoring using sensor networks and data analytics. Comprising a distributed network of air quality sensors in cities, this system facilitates real-time monitoring and interventions by transmitting sensor data to a central computer for processing and analysis [50].

4. Problem statement

The urgent issue of air pollution, particularly in regions with unreliable power sources, demands an innovative approach to continuous air quality monitoring and purification. The aim is to develop a sustainable system that not only cleanses the air but also provides real-time information on key metrics such as temperature, humidity, gases, and particulate matter. This endeavour requires leveraging solar power as the primary energy source to ensure the system's autonomy. Combining advanced air quality monitoring features with solar energy presents a significant challenge, but it's crucial for creating a solution that operates independently of conventional power grids. By enabling users to access vital information about their environment, we empower them to make informed decisions for healthier living spaces. Ultimately, the goal is to establish a novel, self-sufficient air purification system that contributes to both environmental and economic sustainability while addressing the pressing global issue of air pollution.
5. Proposed system

5.1 The air quality monitoring system

It comprises multiple sensors, including those for dust, temperature, humidity, and gas levels such as CO, NO2, and VOCs, which continuously monitor the surrounding air. This data is gathered and processed by a microcontroller, facilitating real-time display on an LCD screen. On sensing poor air quality, signalled by the inlet dust sensor detecting levels above 1000 ppm, the filtration system is automatically activated, ensuring prompt mitigation of air pollution.

Fig. 1. Air quality monitoring system

5.2 Air purifier

Within the purifier, there are three key filters: the pre-filter, cabin filter, and activated carbon filter, each playing a specific role in air purification. The pre-filter acts as the first line of defence, capturing larger particles like dust and hair to prevent them from entering deeper into the system. Following this, the cabin filter targets smaller pollutants such as pollen and bacteria, effectively removing them from the air stream. Lastly, the activated carbon filter plays a vital role in eliminating Odors and VOCs by absorbing them. The purification process is facilitated by a fan, which circulates air through these filters, ensuring that the air expelled is clean and fresh.

6. System architecture

6.1 NodeMCU

It is a firmware and development kit designed for creating IoT applications. It utilizes the ESP8266 Wi-Fi module, offering seamless Wi-Fi connectivity and numerous GPIO pins for connecting various components. With support for the Lua scripting language, it simplifies programming and deployment of IoT projects, making it popular for prototyping and DIY endeavours aimed at building internet-connected devices.
6.2 DHT11

It is a digital sensor capable of accurately detecting temperature and humidity. It's compatible with a wide range of microcontrollers, including Arduino and Raspberry Pi, enabling seamless integration for instant measurement of humidity and temperature.

6.3 MQ135

It is an air quality sensor, part of the MQ gas sensor series, is commonly employed for detecting hazardous gases and smoke within the ambient air.

6.4 LCD

It is to display the overall readings and information.
6.5 Arduino UNO

It is a microcontroller board based on a removable, dual-inline-package (DIP) ATmega328 AVR microcontroller.

6.6 Cabin Filter

It removes harmful pollutants, including pollen and dust, from the air.

6.7 Activated Carbon Filter

It helps to improve the indoor air quality by removing harmful gaseous pollutants, VOCs, and odour.
6.8 Centrifugal Fan

It is a mechanical piece of equipment that is in charge of moving air or gases in a certain direction, angle, and flow.

7. Block diagram

In order to power the system, solar panels collect sunlight and transform it into electricity. A charge controller controls this process to avoid overcharging the batteries. The electricity produced is stored in the battery, and voltage stability is maintained by a regulator. A 16x2 LCD display that provides temperature and humidity readings from the DHT11 sensor and...
air quality information from the MQ135 sensor facilitates user engagement. Processor of sensor data and master controller of the system, the Arduino microcontroller is assisted by the ESP8266 Wi-Fi module for remote connectivity. The fan is managed by a relay, which turns it on and off as needed to keep the system cool.

8. Circuit diagram

![Circuit diagram](image)

Fig. 9. Circuit diagram of proposed system

The main power source is connected to the collector, housing the microcontrollers responsible for sensor management. Assembly proceeds with the use of wires to connect various micro devices essential for the prototype. The gas detector is then linked to the collector, integrating a small controller. This controller records gas values, converting analog signals into digital data. Subsequently, these digital values are displayed on the LCD output and transmitted through the Wi-Fi module for further analysis or monitoring.

9. Result and discussion

The ESP8266 Wi-Fi module greatly expands the project's possibilities by giving it access to the internet or Wi-Fi. The MQ135 sensor is perfect for an air quality monitoring project since it can detect a wide range of chemicals, including CO2, alcohol, benzene, smoke, and NH3. Voltage levels are the MQ135 sensor's output, which must be converted to parts per million (PPM) in order to measure gas concentration. When there is no gas present and the circumstances are normal, the sensor returns a result of 90. There is a maximum threshold of 1000 PPM, and 350 PPM is thought to be the safe air quality level. Going beyond this limit may result in health problems including headaches and fatigue. Gas concentrations over 2000 PPM can cause several illnesses including elevated heart rates. Good Quality of Air will be displayed on the homepage and LCD display when the PPM number is less than 1000. The buzzer will ring, the website and LCD display will read "Bad quality of air," and the fan will turn on to purify the air if the PPM number is more than 1000.
10. Calculations

Selecting the right components for an air purifier hinges on accurately gauging the size of the room in question. This determination relies on the CFM (cubic feet per minute) value, which measures the volume of air that needs to be purified within a minute. Once the CFM value of the room is established, the appropriate fan for the air purifier can be chosen based on the same CFM rating. The fan's revolutions per minute (rpm) are crucial for calculating its CFM output, ensuring that it can effectively circulate and filter the necessary volume of air within the specified timeframe. By aligning the fan's specifications with the room's CFM requirements, optimal air purification performance can be achieved, promoting cleaner and healthier indoor environments.

1) Room measurement to determine CFM
   \[ \text{CFM} = \frac{(L \times W \times H \times Q)}{60 \text{ min}} \]  
   \( L = \) Room length
   \( W = \) Room width (sq ft)
   \( H = \) Room height (sq ft)
   \( Q = \) Air Flow rate

2) Fan measurement to determine CFM
   \[ \text{CF} = 3.1416(\pi) \times (0.5 - S) \times R \times A \]
   \( S = \) Fan radius (sq ft)
   \( R = \) Rpm of fan (rad/s)
   \( A = \) Area of fan

<table>
<thead>
<tr>
<th>Dimensional item</th>
<th>Room (L=15sq ft W=15 sq ft H=30 sq ft Q= 4)</th>
<th>Fan (S=150mm=.242sq ft R=2000 A=666.66ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFM</td>
<td>450</td>
<td>540.332</td>
</tr>
</tbody>
</table>

Mathematical analysis for the proposed system:
The amount of the pollutants present in atmosphere is indicated in percentage or parts per million (ppm).
1 ppm = 1.145 mr/m³
1 mg/m³ = 0.873 ppm
1% = 1/100 & 1 ppm = 1/100000
Therefore: 1 ppm = 0.0001%
Conversion from parts per million to percentage is shown in the table below:
Table 2. Ppm equivalent percentage

<table>
<thead>
<tr>
<th>Parts per million (ppm)</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>0.005</td>
</tr>
<tr>
<td>50</td>
<td>0.5</td>
</tr>
<tr>
<td>500</td>
<td>0.05</td>
</tr>
<tr>
<td>1000</td>
<td>0.1</td>
</tr>
</tbody>
</table>

11. Future scope

The integration of smart technologies will revolutionize the capabilities of solar-powered air purifiers. AI (Artificial Intelligence), these purifiers can autonomously analyse air quality data in real-time and adjust their operation accordingly. Machine learning algorithms can optimize purification processes based on environmental conditions, user preferences, and historical data, ensuring optimal performance at all times.

In addition, advancements in materials science may lead to the development of innovative filter materials with enhanced pollutant capture capabilities and longevity. Nanotechnology, for example, could enable the creation of nanofiber-based filters that efficiently trap even the smallest airborne particles.

As the demand for clean air solutions grows, the future of solar-powered air purifiers lies in their ability to seamlessly integrate with existing infrastructure and technologies. This includes compatibility with smart home systems, remote monitoring and control capabilities via mobile apps, and interoperability with other IoT devices for comprehensive environmental monitoring and management.

References

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