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Revolutionizing Air Quality Monitoring: A Comprehensive IoT-Based Approach

Md. Ashraful Islam[1], *Mir Md. Mosarof Hossan Showrav[2], Sumaiya Nurim[3]

ABSTRACT: In response to escalating global concerns surrounding air quality, this paper introduces an innovative IoT-based system for comprehensive air quality monitoring. By integrating advanced sensor technology with real-time data transmission, this system offers unprecedented accuracy and accessibility in air quality data, thereby facilitating informed decision-making for researchers, policymakers, and public health officials. The system's design and implementation details, along with its effectiveness under various environmental conditions, are discussed in depth.

Keywords: Air pollution, IoT, Particulate matter, Real-time monitoring, Solar power.

1. INTRODUCTION

The deterioration of air quality has become a critical issue worldwide, prompting the need for advanced monitoring systems. Traditional methods often lack the granularity and real-time data necessary for effective intervention. This study aims to address these limitations by leveraging Internet of Things (IoT) technology to provide continuous and precise air quality measurements.

Objectives and Rationale: This paper specifically targets researchers, policymakers, and public health officials who require accurate, real-time data to make informed decisions regarding air quality management. By addressing the needs of these groups, the system aims to enhance public health outcomes and environmental policy.

The system focuses on tracking harmful gases like carbon monoxide (CO), carbon dioxide (CO_2), ammonia (NH_3), sulfide, benzene (C_6H_6), and particulate matter (PM2.5 and PM10) while also monitoring temperature and humidity. To address these serious health risks, this paper proposes a novel IoT system for real-time air quality monitoring and data collection.

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1 Professor, Department of CSE, UITS
Email: ashraful47@uits.edu.bd, ashraful47@yahoo.com

2 Research Fellow, Department of CSE, UITS

* Corresponding Author: Email: showravofficial@gmail.com

3 Research Fellow, Department of CSE, UITS
Email: nurimsumaiya207@gmail.com

Particulate matter (PM), especially PM10 and PM2.5, can harm children, people with chronic health problems, and asthma sufferers [1, 2]. Carbon monoxide (CO) exposure can cause a variety of health problems, including mental impairment, lung edema, and heart problems [3]. Ammonia (NH_3) exposure can irritate the throat and eyes, cause coughing and phlegm production, and contribute to asthma and chronic lung problems [4]. Benzene (C_6H_6) exposure, mainly from smoking, can affect the immune, reproductive, neurological, endocrine, cardiovascular, and respiratory systems [5].

2. IoT MOTIVATION AND SYSTEMS REVIEW

2.1. Motivation

Almost one in nine fatalities worldwide is caused by air pollution, making it one of the most significant environmental hazards to health [6]. The atmosphere's largest cause for concern, both for the ecosystem and public health in terms of lung and heart problems, is air pollution. Bangladesh, as the world's most populated and developing third-world country, faces increasing challenges in combating air pollution [7]. Awareness of the adverse effects of chemical pollutants has grown substantially in recent years, prompting increased efforts to understand and address environmental pollution. Accurate information and comprehensive toxicological research are essential for guiding further investigation. This study contributes to this growing body of knowledge by proposing practical methods to measure and mitigate air pollution's harmful impacts, aiming to promote a healthier and more sustainable future. In response to the global concerns surrounding air quality and public health, an IoT-based air pollution monitoring system is proposed. This system tracks pollutants such as Carbon monoxide (CO), Carbon dioxide (CO_2), Ammonia (NH_3), Sulfide, PM2.5, and PM10 in real-time, providing valuable data for decision-making [8]. Operating in online, offline, and real-time modes, the system ensures continuous monitoring and data recording, enhancing understanding of air quality dynamics. Additionally, the integration of solar power and GPS technology enables operation in remote areas and precise location tracking during data collection.

In this section, we will examine several additional IoT systems that have inspired the implementation of the project. The table provides a comparison between our IoT system and other notable IoT systems. The primary contributions of our project are outlined below:

1. Design and implement an IoT-based air pollution monitoring system.
2. Development of a monitoring system using cloud storage and ESP32 Wi-Fi for secure data handling.
3. Utilization of IoT technology for real-time tracking of pollutants.
4. Integration of solar power and GPS technology for enhanced functionality, enabling remote operation and precise location tracking during data collection.
5. Implement a handy, cost-efficient and low-power consumed IoT system.

2.2. Related works

In [8], Mohana and Malleswari underscore the importance of IoT devices for real-time air quality monitoring, integrating sensors with platforms like Arduino and Raspberry Pi to enable comprehensive data collection and pollution mitigation efforts.

In [9], Fann, Neal, et al. focus on assessing the health impacts of ground-level ozone (O_3) and fine particulate matter (PM2.5) concentrations in the United States for the year 2005. The study uses the Community Multiscale Air Quality (CMAQ) model and monitored data to create detailed spatial maps of these air pollutants.

Aashiq explores the weather-air quality nexus, introducing a portable IoT device measuring multiple parameters for real-time monitoring via a mobile app and ThingSpeak cloud platform, promising widespread deployment potential. [10].

In [11], Kortoçi et al. advocates a citizen-based monitoring system employing low-cost sensors for PMs, CO_2, and NOx to empower public awareness and policy-making for cleaner air. Their approach provides personalized pollution data, demonstrating sensor accuracy comparable to that of high-end stations.

Dhingra et al. propose a three-phase IoT air pollution monitoring system with gas sensors and Wi-Fi for data transmission. Their system includes an Android app, IoT-Mobair, providing real-time air quality data, route predictions, and health risk assessments, akin to Google Traffic[12].

In [13], Binsy and Sampath introduce an IoT-based smart air pollution monitoring device with user-configurable settings, sensors, a Raspberry Pi 3, and GPS for data collection, accessible via a Bluetooth-enabled Android app and the ThingSpeak IoT platform.

In [14], Kim, Ki-Hyun, Ehsanul Kabir, and Shamin Kabir highlight the health risks of particulate matter (PM) from natural and human activities, emphasizing the need for detailed knowledge to inform policymakers.

Parmar, Gagan, Sagar Lakhani, and Manju K. Chattopadhyay designed an environmental air pollution monitoring system using affordable nodes with Wi-Fi and semiconductor gas sensors to track CO, CO_2, SO_2, and NO_2 [15].

In [16], Tapashetti, Vegiraju, and Ogunfunmi propose a low-cost indoor air monitoring device focusing on CO and HCHO, with scalability for emissions monitoring, facilitating real-time cloud communication and aiding comprehension of air quality dynamics.

Al Nahian et al. link high air pollution in Dhaka to increased rates of preterm births and low birth weight, highlighting alarming pollution levels contributing to elevated risks, notably affecting female fetuses for LBW and males during the second trimester for PTB [17].

In [18], Das et al. introduce an IoT-based Air Pollution Monitoring Device (APMD) with PM 2.5, PM 10, CO, SO_2, NO_2, ozone sensors, and environmental parameters. It utilizes solar energy, and a rechargeable battery transmits data via Wi-Fi/NB-IoT, incorporates GPS for location, and shows accuracy in a 7-day field test, vital for urban air quality monitoring.

In [19]. Shaban, Khaled Bashir, Abdullah Kadri, and Eman Rezk introduce an urban air pollution monitoring and forecasting system leveraging low-cost sensors and the M5P algorithm for accurate predictions, crucial for alert systems in highly polluted areas.

In [20], Ayelee, Temesegan Walelign, and Rutvik Mehta. introduce an Internet of Things (IoT) based system for monitoring and predicting air pollution. The proposed system aims to monitor air pollutants in specific areas, analyze air quality, and forecast air quality conditions.

Hussain, Ayaz, et al. introduce an IoT-based smart bin system that not only manages waste but also forecasts air pollutant levels in the vicinity of the bin. And they predicted the status of the bin and the concentration of carbon monoxide (CO) in the air [21].

In [22], Esfahani et al. unveils a low-cost IoT indoor air quality monitoring system with sensors for VOCs, CO_2, PM2.5, PM10, temperature, humidity, and illuminance, interfacing with a Blynk app for EPA-based air quality index computation, enhancing indoor air quality.

Table 01: Comparison of some promising existing systems with our system.

Existing systems	Comparison with our system
Parmar, Gagan, et al. (2017) [15]	[15] Parmar, Gagan, et al. designed an environmental air pollution monitoring system using affordable, low-cost nodes with Wi-Fi and semiconductor gas sensors. This system proposes a low-cost system to monitor air quality. On the other hand, we propose a low-cost, handly device by implementing Arduino Mega instead of Raspberry Pi, which is more cost-effective.
Kortoçi et al. (2022) [11]	In [11], Kortoçi et al. propose a citizen-based monitoring system employing low-cost sensors for PMs, CO2, and NOx to empower public awareness and policy-making for cleaner air. However, this system has no cloud-based storage system to store the sensor's data. Our proposed system has a cloud-based storage system to monitor and store real-time data.
Das et al. (2022) [18]	[18] Das, Ghosh, Chatterjee, and De present an IoT-based Air Pollution Monitoring Device (APMD) equipped with sensors for PM 2.5, PM 10, CO, SO2, NO2, ozone, and environmental parameters. In comparison, our proposed system extends beyond by incorporating additional parameters such as ammonia, benzene, and sulfide. Additionally, our system features a solar-powered system with a rechargeable battery and includes PM2.5 and PM10 sensors.
Kim, Ki-Hy un et al. (2015) [4]	In [4], Kim, Ki-Hyun, Ehsanul Kabir, and Shamin Kabir underscore the health hazards associated with particulate matter (PM). While their system focuses solely on monitoring PM in the environment, our proposed system offers broader functionality by also enabling the monitoring of hazardous gases in addition to particulate matter.

3. REQUIREMENTS AND SYSTEM OVERVIEW

3.1. Software Requirements

- Microsoft Windows 11 or later.
- Arduino IDE.

3.2. Hardware Requirements

Table 02: Components used in the device.

Categories	Components
Microcontroller Boards	• Arduino Mega 2560 CH340. • ESP32 ESP-32S 30PNodeMCU Development Board Wireless Wi-Fi.
Gas Sensors	• MQ-135 Gas Sensor. • Dust Sensor DSM501A Air Quality Monitoring. • MQ-7 Carbon Monoxide Gas Sensor.
Environmental Sensors	• DHT11 Digital Temperature humidity Sensor Module.
GPS and Location	• NEO-M8N GPS Module with Ceramic Active Antenna.
Power and Charging	• 18650 Li-ion Rechargeable Battery (Blue). • 18650 Battery Holder 3S with wire. • DC Barrel Power Jack Plug Connector 2.1mm x 5.5mm x 9mm. • TP4056 Lithium Battery Charger Module with Protection Dual Functions.
Display and Output	• 16x2 Serial LCD Module Display for Arduino Assembled. • LED 5mm.
Connectivity and Wiring	• Jumper Wire Single 20cm - Jumper Wire Type: (Male to Female, Male to Male, Female to Female). • Mini Breadboard. • MicroSD Card Module.
Energy Harvesting	• Round Solar Panel.
Resistor	• 220 Ω (ohm) resistor

3.4. Index of Air Quality Data

Table 03: PM2.5, PM10 and CO Index [23].

AQI Category	PM2.5	PM10	CO
Good	0 –30	0 – 50	0 – 1.0
Satisfactory	31 – 60	51 – 100	1.1 – 2.0
Moderately polluted	61 – 90	101 – 250	2.1 – 10
Poor	91 – 120	251 – 350	10 – 17
Very poor	121 – 250	351– 430	17 – 34
Severe	250+	430+	34+

Table 04: MQ135 gas sensor Index [24].

AQ	AQI (ppm)
Good	0-50
Moderate	51-100
Unhealthy to sensitive group	100-150
Unhealthy	151-200
Very unhealthy	201-300
Hazardous	301-500

Table 05: Humidity & Temperature Index [25].

Temperature (°F)

Relative Humidity (%)	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Likelihood of Heat Disorders with Prolonged Exposure or Strenuous Activity

Caution | Extreme Caution | Danger | Extreme Danger

3.5. Design Diagrams

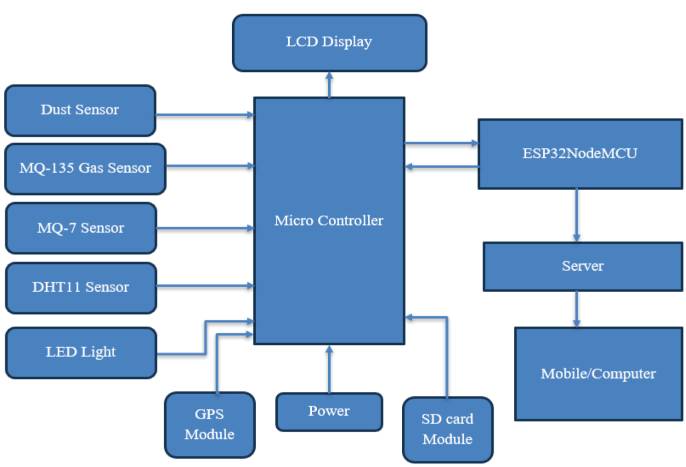


Figure 01: System Block diagram.

3.6. Dataflow Diagram

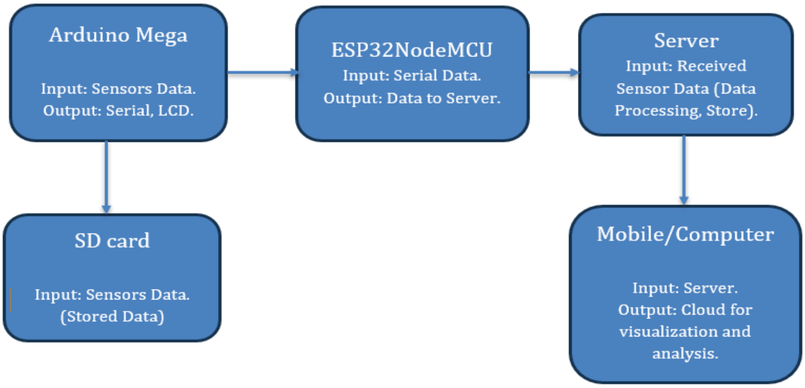


Figure 02: Dataflow diagram.

3.7. Flowchart of the control algorithm

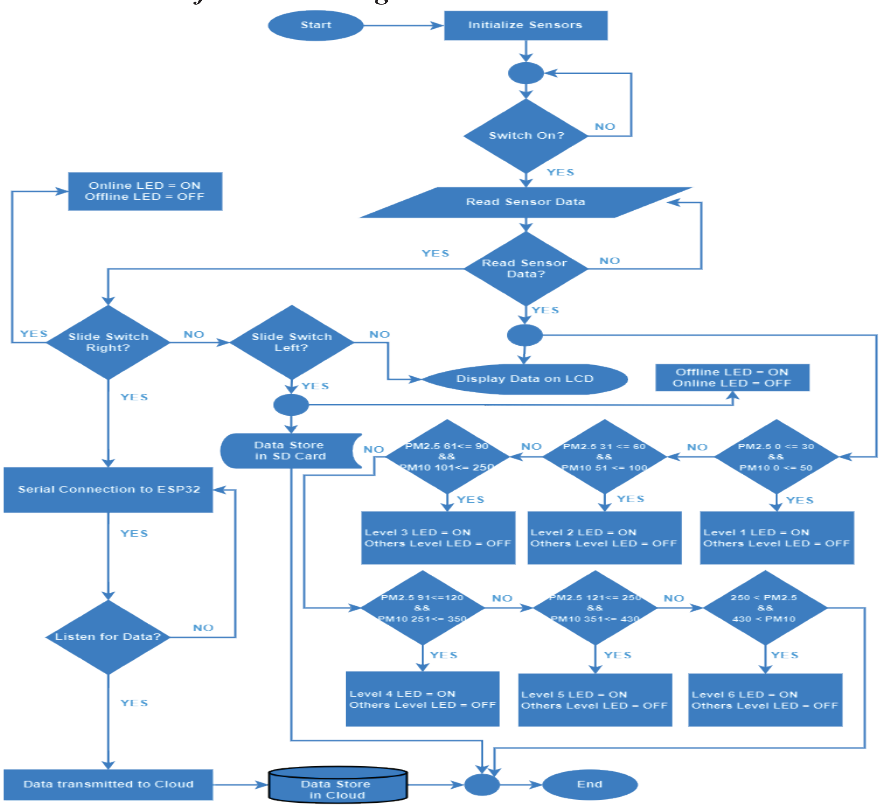


Figure 03: Flowchart for system operation.

4. SYSTEM DESIGN AND IMPLEMENTATION

4.1. Wiring instruction

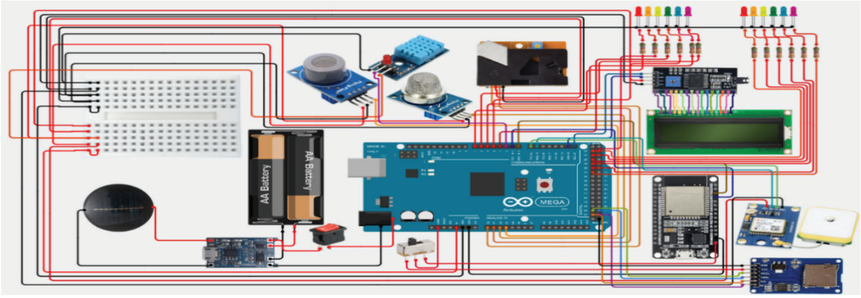


Figure 04: Circuit Diagram.

The proposed IoT-based air pollution monitoring system comprises various sensors, including DSM501A, MQ135, MQ7, DHT11, MicroSD card module and GPS which are connected to the Arduino Mega. Also, some LEDs are added to sense the dust level in the air. A solar panel and rechargeable battery ensure continuous operation, while an ESP32NodeMCU facilitates online data transmission. The detailed wiring instructions and circuit diagram, presented in Fig. 4, guide the implementation process. Additionally, the system's power supply and its comparison with existing systems highlight its cost-effectiveness and innovative features.

4.2. System Model

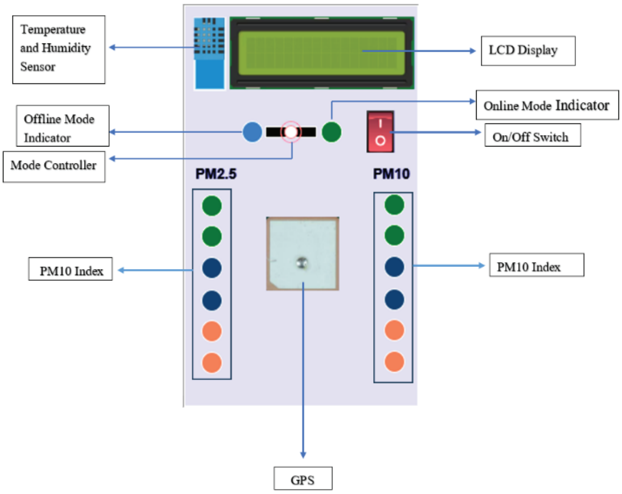


Figure 05: System model front side view.

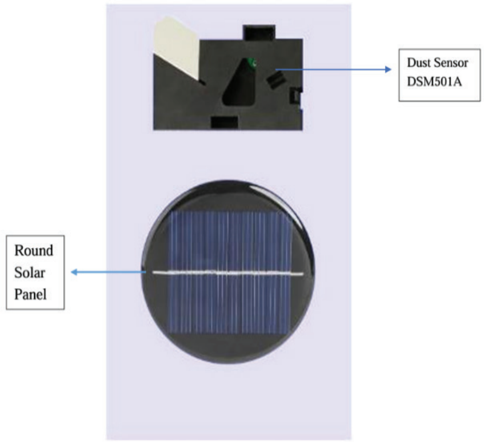


Figure 06: System model back side view.

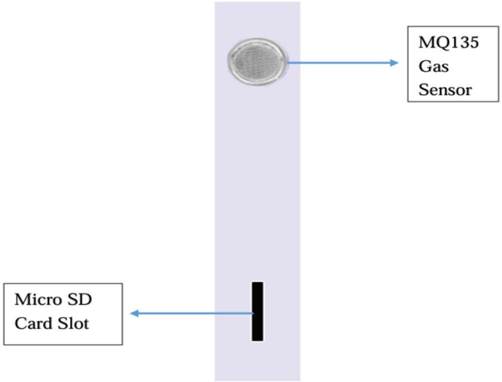


Figure 07: System model left side view.

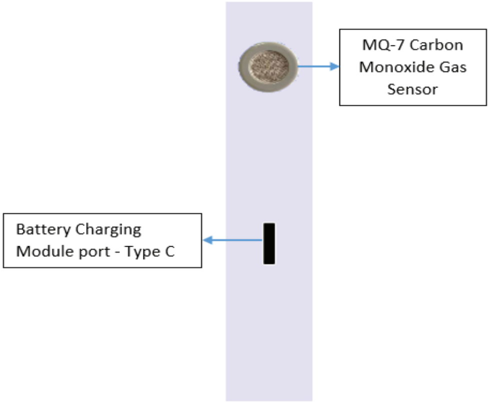


Figure 08: System model right side view.

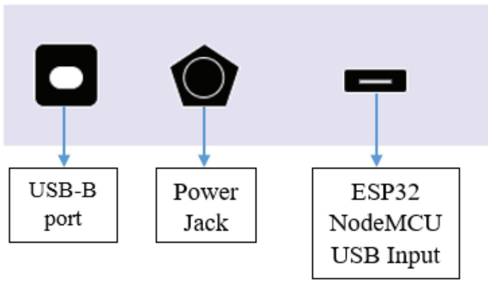


Figure 09: System model down side view.

4.3. Mathematical model

The MQ-135 gas sensor resistance (Rs) is given by the equation:

$$Rs = \left(\frac{V_C}{V_{RL}} - 1\right) \times R_{RL} \qquad (1)$$

where Rs is the sensor resistance, V_C is the supply voltage to the sensor, V_{RL} is the voltage across the load resistance, and R_{RL} is the load resistance.

Specifications/Characteristics	Image
• Operating Voltage: 2.5V to 5.0V • Power consumption: 150mA • Detect/Measure: NH_3, Nox, CO_2, Alcohol, Benzene, Smoke. • Typical operating Voltage: 5V • Analog & Digital Output: 0V to 5V (TTL Logic) 5V Vcc.	

Figure 10: Image and specifications of the MQ-135 sensor.

The DHT11 sensor provides temperature (T) and humidity (H) readings through a 40-bit data stream.

$$H = \text{DecimalHumidity}\left(\frac{IntegerHumidity}{10}\right) \qquad (4)$$

$$T = \text{DecimalTemperature}\left(\frac{IntegerTemperature}{10}\right) \qquad (5)$$

where DecimalHumidity, IntegerHumidity, DecimalTemperature, and IntegerTemperature are obtained from the sensor's data stream. This allows for accurate conversion of the digital output into meaningful temperature and humidity values for environmental monitoring applications.

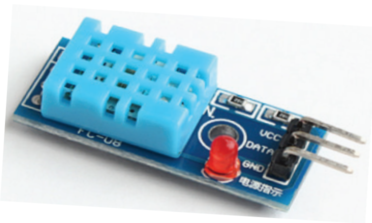
Specifications/Characteristics	**Image**
• Operating Voltage: 3.5V to 5.5V • Operating current: 0.3mA (measuring) 60uA (standby) • Output: Serial data • Temperature Range: 0°C to 50°C • Humidity Range: 20% to 90% • Resolution: Temperature and Humidity both are 16-bit • Accuracy: ±1°C and ±1%.	

Figure 11: Image and specifications of the DHT11 sensor.

Similar to MQ-135, the MQ-7 gas sensor resistance (Rs) is given by the equation:

$$Rs = \left(\frac{V_C}{V_{RL}} - 1\right) \times R_{RL} \quad (2)$$

where Rs is the sensor resistance, V_C is the supply voltage to the sensor, V_{RL} is the voltage across the load resistance, and R_{RL} is the load resistance.

Specifications/Characteristics	**Image**
• Operating voltage (v) DC 5. • Range 10 ~ 1000 ppm. • Characteristic gas 100 ppm CO. • Sensitivity ≥ 3%. • Return time ≤ 30 sec. • Heating resistance ± 31 Ω. • Heating current ≤ 180 mA. • Heating voltage 5.0V ±2V / 1.5 ± 1V • Heating power approx. 350m W • Ambient temperature (°C) -20~+ 50. • Humidity ≤ 95% RH • Oxygen content 21%. • Length (mm) 35. • Width (mm) 20. • Height (mm) 11. • Weight (gm) 20. • Shipment Weight 0.01 kg. • Shipment Dimensions 4 x 4 x 4 cm.	

Figure 12: Image and specifications of the MQ-7 sensor.

The particle concentration (C) from DSM501A is modeled by:

$$C = \frac{K.V}{V_{ref}} \quad (3)$$

where C is the particle concentration, K is the sensitivity factor, V is the output voltage of the sensor, and V_{ref} is the reference voltage.

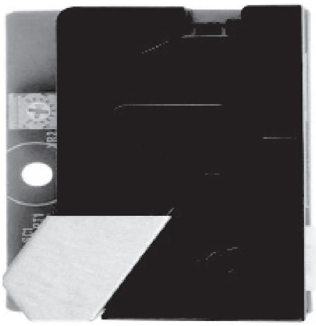
Specifications/Characteristics	Image
• Operating Voltage Range: DC 5V ± 0.5V. • Output Mode: PWM (Pulse Width Modulation). • Output Voltage: Low Level (with particles): 0.7V (max. 1.0V). High Level (clean air): 4.5V (min. 4.0V). • Smallest Particle Measure :1um. • Sensitivity:15,000 / 283 ml. • Operating Current (Max): 90mA. • Humidity Range: Storage Environment: 0-99% RH. Working Environment: 0-95% RH. • Temperature Range: Storage Environment: -20°C to 80°C. Working Environment: -10°C to 60°C.	

Figure 13: Image and specifications of the DSM501A sensor.

5. LIMITATIONS OF THIS PROJECT

The system has been intrigued by the GPS module, which sometimes takes time to connect in challenging environments. The MQ135 gas sensor has a limitation in accurately distinguishing between specific gases, as it is sensitive to a range of pollutants and may need to provide precise identification of individual gases in complex environments. The project encounters occasional data transfer challenges stemming from internet disruptions affecting cloud data transmission. It relies on Google Cloud to store real-time data from air quality sensors, which poses concerns regarding data ownership and reliability.

6. FURTHER DEVELOPMENTS

In future developments, the project aims to develop a software solution based on machine learning techniques that will offer user-friendly access to comprehensive weather data for various locations. Additionally, the system will provide insights into potential environmental health risks, elucidating the correlation between environmental factors and prevalent diseases.

Through cloud-based storage of air quality data, the system ensures its availability for future research endeavors. Furthermore, the envisioned software will provide distinct visualization of gas detection results, particularly focusing on individual sensors such as the MQ135 gas sensor. Alongside this, the project aims to set up a network to help people learn more about pollution. It will encourage more people to care about the environment and get involved in efforts to protect it.

7. CONCLUSIONS

The proposed IoT-based air pollution monitoring system offers a holistic approach to addressing global concerns. By combining technological advancements like solar power and GPS with real-time tracking capabilities, the system aims to revolutionize air quality monitoring. The emphasis on cloud-based data storage ensures informed decision-making and sustainable air quality management, promoting community well-being and a healthier future.

In conclusion, this article provides a comprehensive overview of the proposed IoT-based air pollution monitoring system, emphasizing its innovative features, capabilities, and future development prospects. The integration of advanced technology, cost-effectiveness, and user-friendly design positions this system as a potential game-changer in the field of environmental monitoring.

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