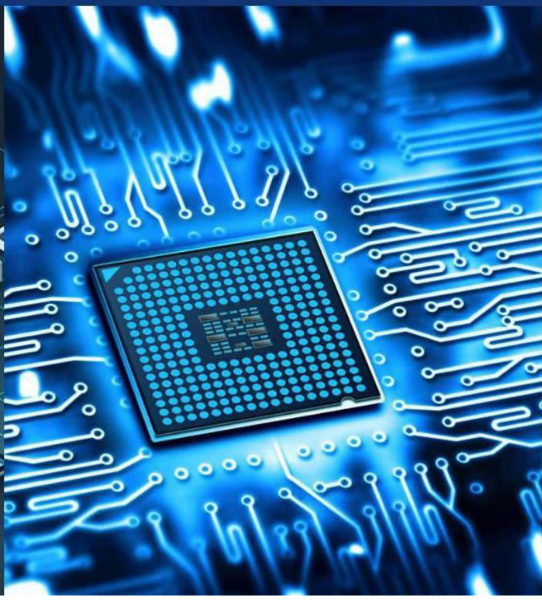
ISSN(O): 2320-9801
ISSN(P): 2320-9798



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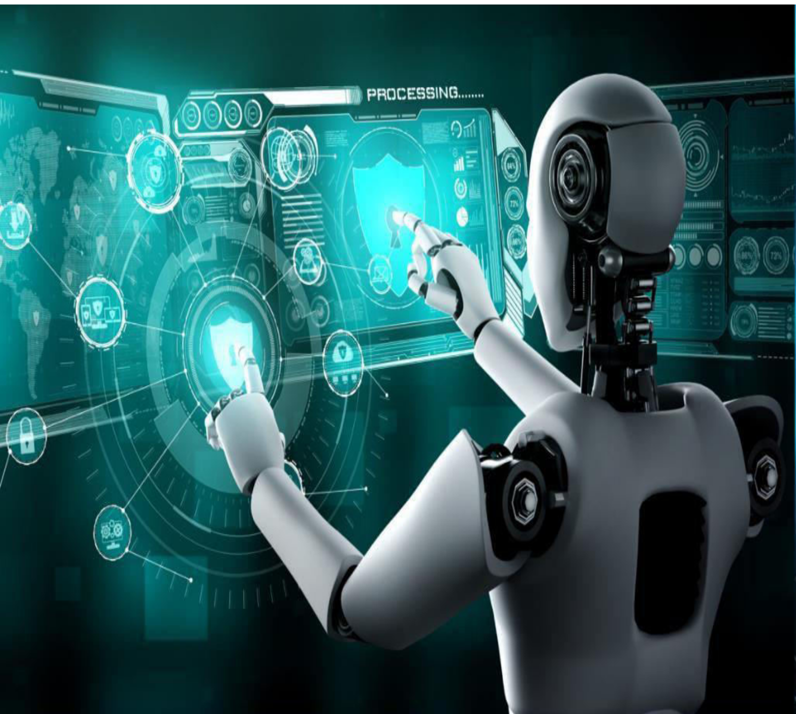

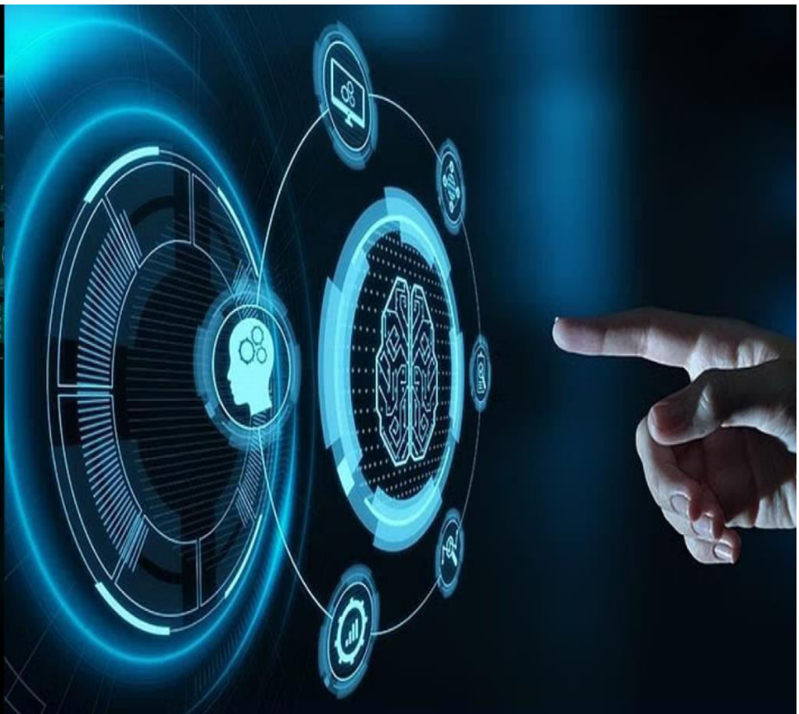

Impact Factor: 8.771

Volume 14, Issue 1, January 2026

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International Journal of Innovative Research in Computer and Communication Engineering (IJIRCCE)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

AI Based Air Purifier Robot System

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ABSTRACT: Air pollution and fog significantly affect human health and visibility, creating the need for smart, portable solutions that can monitor and purify air in real time. This project presents the design and development of a **Ai Based Air Purifier Robot System** that combines mobility with environmental sensing. The system uses an Arduino Uno as the control unit, integrating an MQ gas sensor to detect pollution levels and an LDR sensor to monitor fog intensity. Based on the sensor data, the robot classifies air quality into three levels—good, moderate, and poor—indicated through an RGB LED color scheme. An APR voice module with a speaker provides real-time audio feedback of the air quality status, making the system interactive and user-friendly. The robot is powered by a solar-assisted battery system, enabling sustainable operation without constant reliance on grid power. DC motors with a motor driver allow the robot to navigate, while the onboard relay/MOSFET circuitry controls RGB indication and purification functions. When poor air quality is detected, the robot halts its movement and alerts users through both visual and audio signals, ensuring effective awareness. This smart robotic solution demonstrates the integration of renewable energy, embedded systems, and environmental monitoring, offering a practical prototype that can be extended into scalable air-quality monitoring and purification platforms for smart cities

KEYWORDS: ESP32, MQ-135 Gas Sensor, DC Motors, Relay Module, L298N Dual H-Bridge Motor Driver, Solar Panel, Battery, Robot Chassis, LCD Display, Ultrasonic Sensor

I. INTRODUCTION

- Air pollution and deteriorating air quality have become some of the most pressing global challenges of the 21st century. Rapid industrialization, increasing vehicular emissions, widespread use of fossil fuels, and growing urbanization have all contributed to a significant rise in harmful pollutants in the atmosphere. According to the World Health Organization (WHO), exposure to polluted air is responsible for millions of premature deaths annually and is directly linked to respiratory illnesses, cardiovascular diseases, and reduced quality of life. Apart from human health, air pollution also reduces visibility, contributes to environmental degradation, and accelerates climate change. In addition, fog and smog caused by a combination of moisture and pollutants often impair transportation safety and disrupt daily life. Therefore, effective air quality monitoring and purification systems are essential not only for improving public health but also for building safer, smarter cities.
- Traditional air purifiers are generally static devices intended for indoor use, relying on external sensors and fixed power sources. While these devices can clean air in enclosed spaces, they are not effective in outdoor environments where pollution sources are widespread and dynamic. Similarly, many air quality monitoring systems are limited to fixed stations, providing data only for specific locations. This lack of mobility reduces their effectiveness in providing real-time, location-specific air quality awareness to users. There is, therefore, a strong demand for **smart, portable, and autonomous solutions** that can both monitor air quality and alert users in real time. So, what's the point? Well, traditional systems just don't cut it anymore. They're clunky, and their defences look old next to modern threats. That's why we built something that covers more ground, keeps things hidden, and pushes security a step ahead. contributed to a significant rise in harmful pollutants inthe atmosphere. According to the World Health Organization (WHO), exposure to polluted air is responsible for millions of premature deaths annually and is directly linked to respiratory illnesses, cardiovascular diseases, and reduced quality of life. Apart from human health, air pollution also reduces visibility, contributes to environmental degradation, and accelerates climate change. In addition, fog and smog caused by a combination of moisture and pollutants often impair transportation safety and disrupt daily life. Therefore, effective air quality monitoring and purification systems are essential not only for improving public health but also for building safer, smarter cities.
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Objectives

AI-based mobile air purifier robot that autonomously monitors air quality, detects pollution hotspots, and delivers efficient, low-energy, and sustainable purification in real time.

1. Develop an **AI-based mobile air purifier robot** capable of autonomous operation.
2. Continuously **monitor air quality in real time** using advanced gas and environmental sensors.
3. **Detect pollution hotspots** by analyzing gas concentration patterns through AI algorithms.
4. **Navigate autonomously** to polluted zones for targeted and efficient air purification.
5. Provide effective **air purification in both indoor and outdoor environments**.
6. Implement **intelligent decision-making** to adjust purification intensity based on pollution levels.
7. **Optimize energy consumption** using AI-based control strategies.
8. Ensure **low-power and energy-efficient operation** for extended runtime.
9. Integrate **renewable energy sources**, such as solar power, for sustainable functioning.
10. Enable **continuous operation** with minimal human intervention.
11. Improve **environmental health and safety** by reducing harmful gas concentrations.
12. Design the system to be **scalable and adaptable** for smart cities, industries, and public spaces.

II. METHODOLOGY

1. System Design and Planning

The overall system is designed by defining functional requirements such as air quality monitoring, autonomous movement, purification efficiency, and energy optimization. Hardware and software modules are planned to work in coordination.

2. Hardware Integration

The ESP32 microcontroller acts as the central control unit. Gas sensors (MQ-135) are integrated to continuously sense air pollutants, while the ultrasonic sensor enables obstacle detection and safe navigation. DC motors, controlled through the L298N motor driver, provide mobility, and a relay module manages the air purification unit. A 16×2 LCD displays real-time sensor readings and system status. The robot chassis supports all components, and a 12V battery with a 20W solar panel ensures sustainable power supply.

3. Air Quality Monitoring

The gas sensor continuously measures pollutant concentration in the surrounding environment. Sensor data is processed in real time to assess air quality levels and identify abnormal pollution conditions.

4. AI-Based Data Analysis

AI algorithms analyze sensor data to classify air quality and detect pollution hotspots. Based on learned patterns and threshold levels, the system decides when and where purification is required.

5. Targeted Air Purification

Once the robot reaches a pollution hotspot, the purification unit is activated through the relay module. The system adjusts purification intensity based on pollution severity for maximum efficiency

6. Autonomous Navigation & Hotspot Targeting

When high pollution levels are detected, the robot autonomously navigates toward the pollution source. Ultrasonic sensors help avoid obstacles, ensuring safe and efficient movement in both indoor and outdoor environments.

7 Energy Optimization &Management

Intelligent control strategies are used to minimize energy consumption by optimizing motor speed, purification operation, and sensor usage. Solar energy is utilized to recharge the battery, enabling low-energy and sustainable operation.

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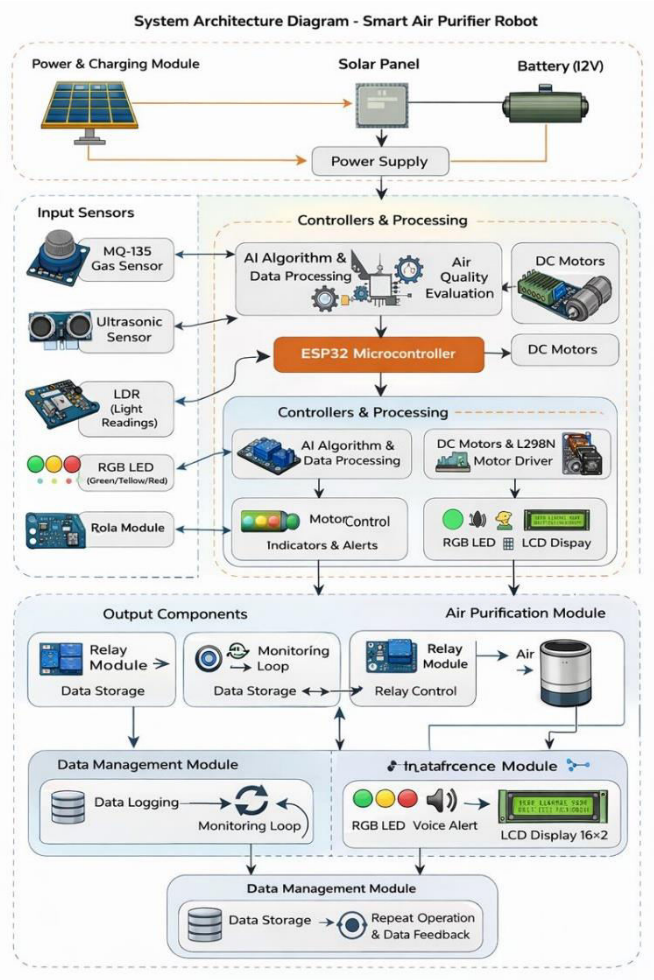
8. Real-Time Display and Feedback

The LCD continuously displays air quality values, system status, and operational modes, allowing easy monitoring of robot performance

III. SYSTEM ARCHITECTURE



Here's how it works:

1. Power & Initialization Layer

- Power supply is provided through a **12V battery with solar support**.
- image with your hidden data or the file you extracted.

Use Case Diagram

- System starts and initializes the **ESP32 / Arduino controller**.
- All sensors, display units, and actuators are checked and calibrated

2. Sensing Layer (Input Unit)

- **MQ-135 Gas Sensor** measures air pollution levels.
- **LDR (Light Dependent Resistor)** supports environmental condition sensing.
- Sensors continuously collect real-time air quality data.

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3. Data Processing & Meter Logic Layer

- The microcontroller processes sensor data.
- Air quality values are compared against predefined thresholds.
- Pollution levels are classified into:
  - **Good**
  - **Moderate**
  - **Poor**
- This classification acts as the **Air Quality Meter Logic**.

4. Decision & Control Layer

- Based on meter readings:
  - **Good Air Quality**
    - RGB LED → Green
    - Robot continues forward movement
  - **Moderate Air Quality**
    - RGB LED → Yellow
    - Robot continues monitoring and movement
  - **Poor Air Quality**
    - RGB LED → Red
    - Robot stops and prepares for purification
    - Voice alert triggers precaution message

5. Indication & Alert Layer

- **RGB LED** visually represents air quality levels (Green/Yellow/Red).
- **Voice alert module** provides audio feedback for air quality status.
- **16×2 LCD display** shows real-time meter readings and system state.

6. Actuation & Mobility Layer

- **DC Motors + L298N Motor Driver** control robot movement.
- Motors respond to air quality decisions (move/stop).
- **Relay module** activates the air purification unit during poor air quality.

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8. Continuous Monitoring Loop

- The entire process runs in a **real-time loop**.
- The air quality meter updates dynamically as environmental conditions change.
- Ensures autonomous and continuous air quality monitoring.

Architecture Outcome

- Acts as a **real-time air quality meter system**
- Provides **visual, audio, and data-based feedback**
- Enables **autonomous, energy-efficient, and intelligent air purification**

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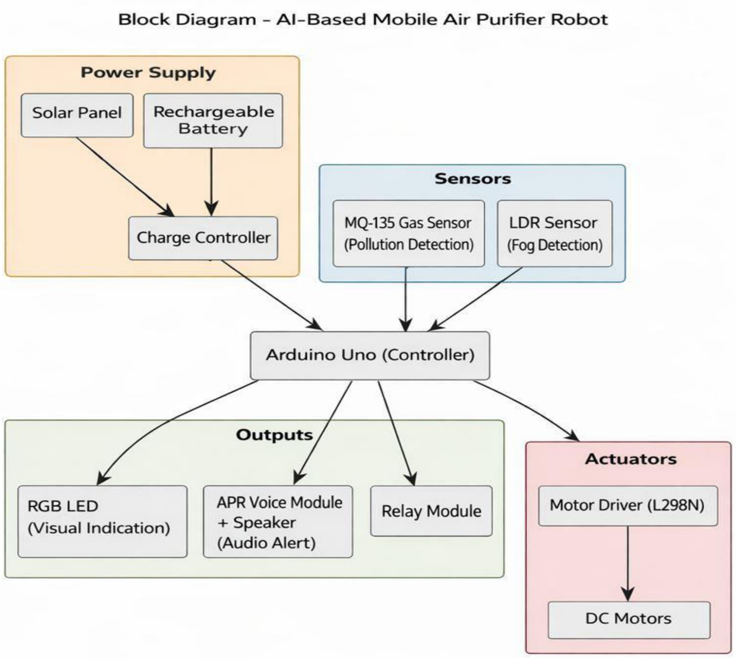
Use Case Diagram

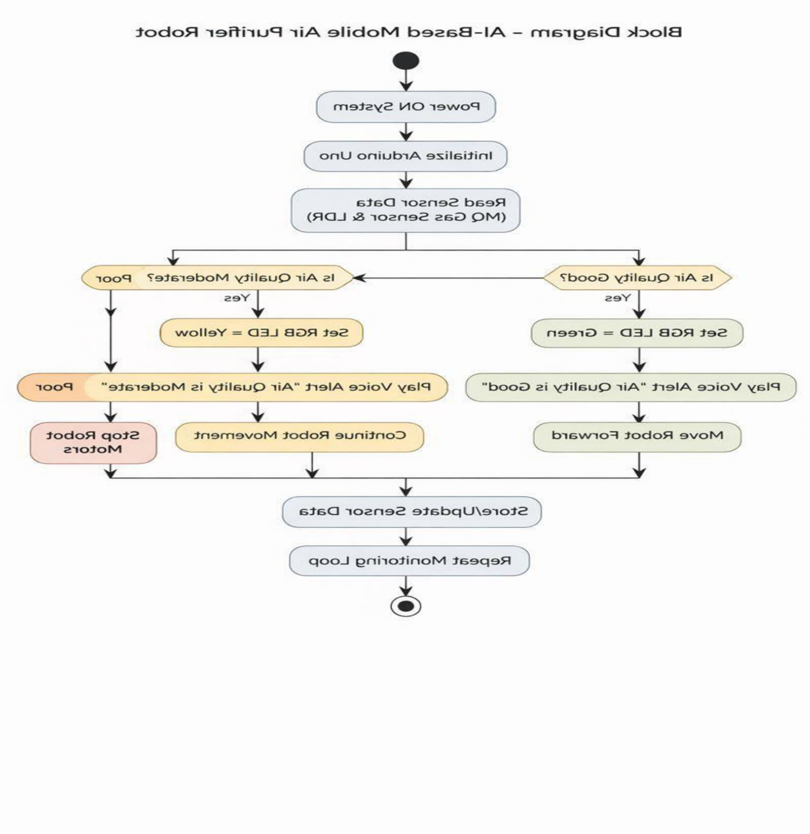


Use Case

- Solar panel and battery provide continuous power.
- Charge controller manages safe power flow.
- MQ-135 sensor detects air pollution.
- LDR sensor senses environmental conditions.
- Arduino Uno controls the entire system.
- Sensors send real-time data to the controller.
- RGB LED indicates air quality status.
- Voice module gives audio alerts.
- Relay module activates air purification.
- Motor driver controls DC motors.
- DC motors enable robot movement.
- System operates autonomously and efficiently.

IV. WORKFLOW

The flowchart represents the working of a smart AI-based air purifier robot. After powering on, the controller initializes and reads gas sensor data to monitor air quality. Based on predefined thresholds, the system classifies air quality as good, moderate, or poor and responds by activating RGB indicators, generating voice alerts, and controlling robot movement. The sensor data is continuously updated, and the monitoring loop repeats to ensure real-time autonomous operation



2. Proposed Methodology (The Logic Flow)

In a research paper, the "Flowchart" is described as the **Algorithm** or **Control Logic**.

- **Initialization Phase:** Upon system activation, the firmware executes a self-test of I/O pins and calibrates the MQ sensor to establish a baseline for ambient air quality.
- **Data Acquisition & Normalization:** Continuous sampling of analog signals from gas sensors, converting raw chemical concentrations into digital values for comparison against safety thresholds.
- **Tri-Level Classification Logic:** A decision-making algorithm categorizes environmental health into three distinct states:
  - **Level I (Optimal):** Safe gas concentrations trigger a green visual cue and unimpeded movement.
  - **Level II (Cautionary):** Mid-range concentrations trigger a yellow warning, signaling the need for increased monitoring frequency.
  - **Level III (Hazardous):** Concentrations exceeding safe PPM (parts per million) limits trigger a red alert and an emergency "Stop" command to prevent the robot from entering high-risk zones.

3. Data Management and Future Scope

This section explains point #5 and #6 of your flowchart in a more sophisticated way.

- **Temporal Data Persistence:** The system maintains a localized data register to track air quality trends over time, facilitating retrospective analysis of pollution spikes.
- **Edge-to-Cloud Integration:** (If applicable) Potential for data transmission to cloud platforms for remote monitoring and large-scale environmental data visualization.
- **Autonomous Iteration:** The system operates on a closed-loop feedback mechanism, ensuring that environmental assessment is performed with zero-latency in real-time.

1. System Behavior Air quality flagged

- The two screenshots demonstrate varying air quality conditions detected by the robot. In the first case, the gas sensor values increase from zero to moderate levels, indicating the presence of harmful gases and a gradual degradation in air quality. In the second case, gas levels remain low, but dust detection occurs repeatedly, indicating particulate

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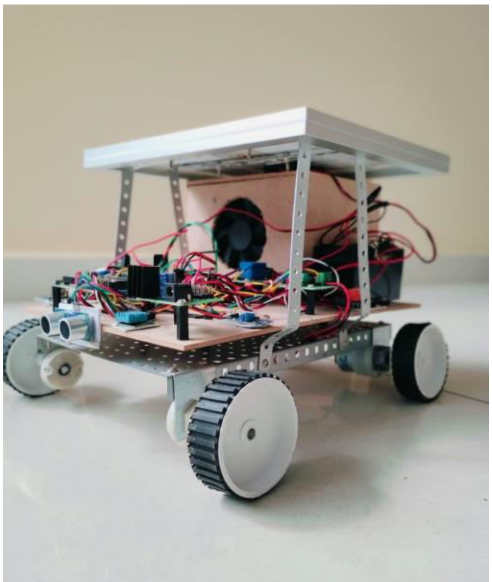
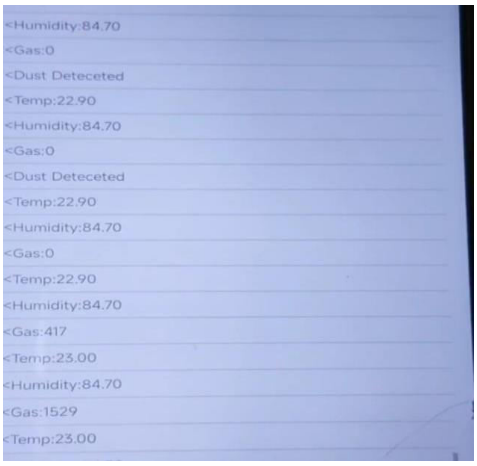
pollution. The system intelligently differentiates between gaseous and dust-based pollution and activates appropriate purification and alert mechanisms based on real-time sensor data.



Overall Robot Prototype View
This prototype shows the complete working model of the AI-based air purifying robot. The robot is built on a four-wheel mobile chassis, enabling smooth movement in indoor environments. A solar panel is mounted on the top to provide renewable energy and support sustainable operation. The structure consists of a two-level platform where the upper section houses the air purification unit and cooling fan, while the lower section contains the control electronics. An ultrasonic sensor is mounted at the front for obstacle detection, allowing the robot to navigate safely. The overall design demonstrates autonomous mobility combined with air quality monitoring and purification.



figer1: Normal / Clean Air Condition

Observed Gas Values:
- Gas: 0
- Gas: **417** (low)
- Gas: **1529** (moderate spike)

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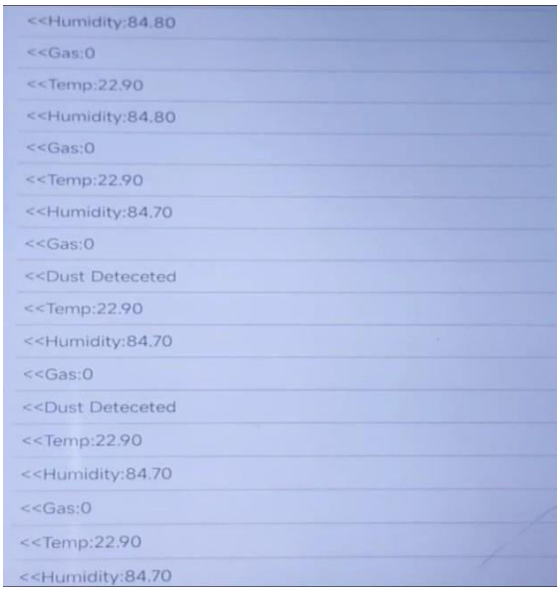
Interpretation:
- Gas value **0** indicates **clean air or no detectable harmful gases**.
- Value **417** indicates **slight presence of gases**, still within safe limits.
- Value **1529** shows **moderate pollution**, **System Behavior:**
- Air quality transitions from **Good → Moderate**
- Robot continues movement
- Purifier may activate at low or medium speed
- Warning indication may appear



figer2: Poor Air / Dust-Detected Condition

Observed Gas Values:
- Gas: **0** (baseline)
- Repeated **Dust Detected** messages
- Stable temperature and humidity

Interpretation:
- Gas sensor reads **low gas concentration**, but
- Dust sensor detects particulate matter (PM)
- Indicates **air pollution due to dust rather than gas**

System Behavior:
- Air quality flagged as **Poor (Dust-based)**
- Purifier fan activates
- Alert message generated
- Robot may stop or slow down in hazardous area

V. RESULTS

Result / Functionality Explanation
- The system powers on and initializes the Arduino Uno microcontroller.
- Sensors (MQ Gas Sensor & LDR) continuously read environmental data to determine air quality.
- Air quality classification:
  - Good → RGB LED turns Green, voice alert says *"Air Quality is Good"*, and robot moves forward.
  - Moderate → RGB LED turns Yellow, voice alert says *"Air Quality is Moderate"*, and robot continues movement.

- ○ Poor → RGB LED turns Red, voice alert says *"Air Quality is Poor, Take Precautions"*, and robot motors stop.
- Sensor data is stored and updated for real-time monitoring and analysis.
- The system runs in a continuous loop, allowing autonomous and real-time monitoring of air quality.
- The flowchart demonstrates integrated decision-making, combining visual, audio, and mechanical responses based on AI-driven environmental sensing.
- Ensures safe, energy-efficient, and sustainable operation of the air purifier robot in indoor or outdoor environments.

VI. CONCLUSION

The **Smart Air Purifier Robot** project has been successfully designed and developed to address one of the most critical challenges of modern times — air pollution and poor air quality. The system demonstrates how embedded systems, renewable energy, and robotics can be integrated to create a cost-effective, portable, and interactive environmental monitoring solution. Unlike conventional air quality monitoring stations that are fixed, expensive, and inaccessible to the general public, this robot provides mobility, sustainability, and user-friendly feedback mechanisms that make air quality awareness more practical and approachable.

At the core of this system lies the **Arduino Uno microcontroller**, which processes data from an **MQ gas sensor** (for pollution detection) and an **LDR sensor** (for fog detection). The processed information is then translated into real-time outputs through an **RGB LED module** for visual indication and an **APR voice module with a speaker** for audio alerts. These dual feedback mechanisms make the system accessible to a wider audience, including those who may have difficulty interpreting technical displays. The mobility of the robot is provided by **DC motors** controlled by an **L298N motor driver**, which allows the system to navigate across different locations, thereby expanding its monitoring coverage. Importantly, the robot is powered by a **solar panel and rechargeable battery system**, ensuring continuous, eco-friendly operation without dependence on grid electricity.

The working principle of the project highlights a closed-loop system where sensor data is constantly monitored and classified into three air quality levels: good, moderate, and poor. For good quality, the RGB LED glows green and a positive voice message is played while the robot moves forward. For moderate quality, the LED glows yellow, the robot continues its movement, and a neutralmessage is played. For poor quality, the LED glows red, the robot halts, and an urgent voice warning is issued. This dynamic response ensures that the robot not only collects data but also interacts with users in real time, making the information immediately actionable.

The methodology adopted for this project ensures modularity, scalability, and reliability. Each component — from the sensors to the actuators and power supply — was individually tested, calibrated, and then integrated into the final system. Special emphasis was placed on sustainability through the use of renewable solar energy, ensuring that the project aligns with global priorities for clean and green technologies. Furthermore, the project also demonstrates the relevance of robotics in environmental applications, showing that mobile systems can be deployed to overcome the limitations of stationary air monitoring devices

VII. FUTURE SCOPE

1. Future Scope and Enhancements

The potential for the Smart Air Purifier Robot extends beyond its current prototype stage. Future iterations will focus on intelligence, connectivity, and hardware sophistication:

- IoT & Cloud Integration: Transitioning to an Industry 4.0 model by integrating cloud platforms (e.g., AWS IoT or ThingSpeak). This enables real-time remote monitoring, historical data logging, and city-wide pollution mapping accessible via mobile applications.
- Sensor Fusion & High-Precision Hardware: Enhancing the sensing layer with specialized modules for PM2.5, PM10, and CO_2. Integrating active air purification systems, such as HEPA filters and ionizers, would transform the device from a passive monitor into an active environmental stabilizer.
- Predictive Analytics (AI/ML): Implementing Machine Learning algorithms (such as Random Forest or LSTM networks) to predict pollution trends based on historical data, allowing for proactive rather than reactive purification.
- Swarm Robotics: Scalability can be achieved through Swarm Intelligence, where multiple robotic units collaborate to scan large urban areas simultaneously, creating a high-resolution heat map of air quality.

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