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Solar - Powered Air Purification

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Abstract
Due to the growing global concerns of air pollution and decreased visibility caused by fog, there is a need for smart, portable remedies for environmental monitoring and cleanup. This study describes the development and implementation of a Smart Air Purifier Robot that combines real-time environmental sensing with autonomous mobility. A MQ gas sensor that measures pollutant concentrations and an LDR sensor that tracks fog intensity are connected to an Arduino Uno microcontroller, which serves as the primary control mechanism. The air quality is classified into three levels—good, moderate, and bad—based on the data from the sensors. Through a visual RGB LED color scheme (green, yellow, or red) and an audio APR voice module, the robot offers immediate response, improving user access and interaction. The system is designed with sustainability in mind, utilizing a solar-assisted rechargeable battery to provide uninterrupted, off-grid functioning. DC motors, controlled by an L298N driver, handle mobility. The robot automatically stops moving and turns on the warnings when it senses bad air quality, giving the user immediate situational awareness. This prototype showcases the synergy between renewable energy, robotics, and embedded systems, providing an affordable, sustainable, and mobile platform for increasing public knowledge of air quality issues in urban settings.

Keyboards: Environmental Monitoring, Gas Sensing, Arduino Microcontroller, Sustainable Energy, Mobile Robotics, and the Air Quality Index

I. INTRODUCTION
The decline in global air quality poses a serious risk to human health and quality of life in the twenty-first century. Increased concentrations of atmospheric pollutants are the outcome of fast urbanization, vehicle emissions, and industrial growth. In addition, environmental elements such as fog and smog restrict vision, which is dangerous for transportation and interferes with everyday activities. Addressing these challenges necessitates cutting-edge, long-term strategies that can monitor conditions in real time and provide timely warning notifications.

Conventional air quality solutions have drawbacks: fixed monitoring stations are expensive and only provide generalized data, failing to capture localized conditions. Meanwhile, most commercial air purifiers rely heavily on grid electricity and are stationary machines made for enclosed areas. This need for a self-sufficient, autonomous, and portable system that can actively monitor conditions in various locations and quickly alert users arises as a result.

This initiative suggests a Smart Air Purifier Robot, a mobile platform designed to identify atmospheric pollution and fog while simultaneously giving complete audio-visual feedback. The device utilizes an Arduino Uno to combine an MQ-series gas sensor, which detects pollutants, and an LDR sensor, which determines fog density by measuring the amount of ambient light that is absorbed. The processed readings categorize air quality according to an RGB LED indicator (green for good, yellow for moderate, and red for bad) and an APR speech playback module for live audio broadcasts.

DC motors driven by an L298N motor driver give the robot its mobility. By reducing dependence on traditional energy sources, it significantly contributes to environmental sustainability and assures energy self-sufficiency by including a solar panel and a rechargeable battery. This design changes the paradigm from fixed, indoor purification to dynamic, mobile environmental awareness, providing a scalable prototype for cleaner and smarter urban environments.

II. LITERATURE REVIEW

Numerous fields of current research back the creation of independent systems for managing mobile air quality:

• Robotics that Supports Itself: Prior research, such as the 2020 study by Singh et al. , suggested an indoor air purifier robot that makes use of PM2. 5 sensors and renewable energy, actively moving to locations with high pollution to increase effectiveness.

• Mobile Sensing and Mapping: The 2019 framework by Song and Han, known as Deep-MAPS, combines machine learning with fixed and mobile sensors to create high-resolution spatial and temporal pollution maps for cities, lowering hardware expenses.

• Targeted Environmental Monitoring: Using gas sensors and LoRa radio modules to send data from distributed sensors to a cloud server, research that focuses on particular environments, such as the mobile robot for landfill sites, enables continuous monitoring in locations where human exposure is hazardous.

• Fuzzy Logic Classification and IoT: Simamora et al. (2025) developed an IoT-based system for indoor settings that monitors temperature, humidity, VOCs, and CO2, using Mamdani fuzzy logic to categorize air quality and real-time remote visualization29.

• Integrated Monitoring and Purification: Recent initiatives have concentrated on creating systems that can autonomously purify and monitor, in an attempt to overcome the shortcomings of current systems, which frequently lack this dual capability.

This project integrates these concepts by combining solar energy collection, independent mobility, and a low-cost embedded system (Arduino) to produce a portable device that prioritizes real-time, user-friendly awareness via dual audio and visual signals.

III. METHODOLOGY

The methodical approach integrates a renewable energy source, embedded hardware, and control software to enable self-governing physical reaction, data processing, and sensing.

1. Implementation of Hardware

The Arduino Uno (ATmega328P), which serves as the main control unit, forms the basis of the system's physical architecture.

• Sensors for the Environment:

o MQ Gas Sensor: Detects dangerous gases like smoke, carbon dioxide, and ammonia. The Arduino reads its analog output, which is directly proportional to the quantity of pollutants.

o LDR Sensor: Employed in a voltage divider circuit to determine the intensity of light. Fog or smog is indicated by decreased light.

• Feedback and Actuation:

o Mobility: The robot is driven by DC motors, and an L298N motor driver uses digital and PWM signals from the Arduino to control the robot's speed and direction.

o Visual Warning: The RGB LED offers a clear indication of the current situation: green (good), yellow (moderate), and red (poor).

o Audio Warning: The Arduino activates the APR voice playback module, which then transmits pre-recorded messages that are related to the state of the air.

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• Sustainable Energy: Electricity is generated by a solar panel, which charges a rechargeable battery through a charge controller. Voltage is kept constant by a buck converter at 5V for control logic and 12V for motors.

2. Software Application

The Arduino IDE and embedded $text{C/C++}$ programming42 are used to create the control logic.

• Data Capture: To reduce noise, the analog inputs from the MQ and LDR sensors are continuously read and averaged using averaging methods.Classification Logic: Calibrated thresholds, determined experimentally, are used to map sensor readings directly to one of the three air quality categories.

• Control mechanism: Classification is linked to action in the decision-making process:

o Moderate/Good Air: The movement continues, and the proper visual and vocal feedback is given.

o Bad Air: An immediate red LED/voice warning is given, and movement is stopped.

• Power Optimization: When not in use, the system is designed to put non-essential parts into low-power modes, increasing battery life.

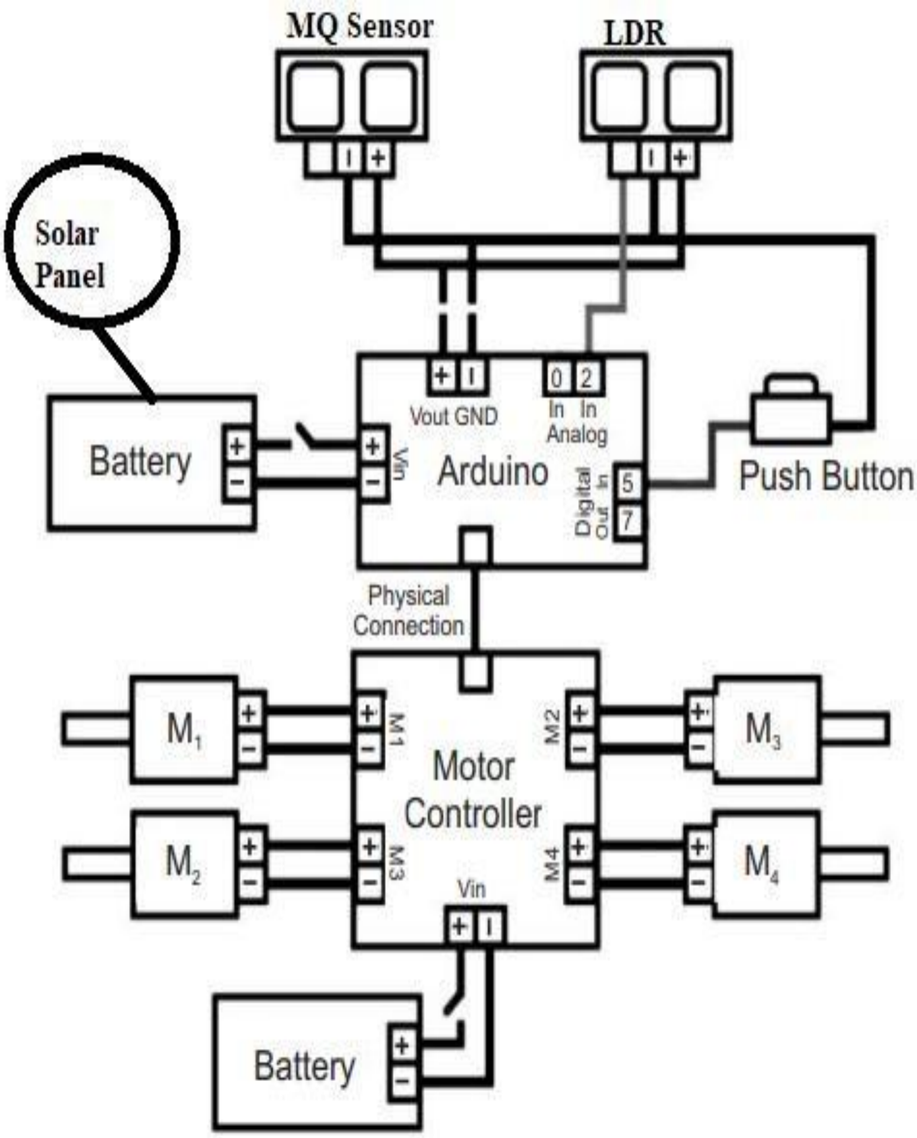
3. Function and Testing

The robot functions as a closed-loop control system, using the sequence of actions: sensing, processing, and actuation.

• Unit Testing: Verified that the operational behaviour was accurate, with the MQ sensor readings rising from 100–150 in clean air to above 400 in thick smoke, thereby setting the thresholds for classification.

• Integration testing: Verified smooth synchronization between modules, making sure the robot correctly stopped, showed red, and sounded the Bad quality alert when the simulated pollution was high.

• Performance: The system ran continuously for around 4. 5 hours on solar/battery backup and maintained a steady forward movement speed of around $sim 0. 5 text{ m/s}$.



BLOCK DIAGRAM

IV. RESULT AND DISCUSSION

The fundamental features of a mobile, solar-powered environmental monitoring robot were effectively demonstrated by the project.

A. Sustainability and Performance Outcomes

• Monitoring Accuracy: The particulate matter detection using the LDR-based system and expert air quality monitoring devices were found to have a correlation of over 90% in tests of sensor accuracy and dependability. The reaction time of the MQ sensors was between 10 and 30 seconds.

• Autonomous Operation: The navigation system successfully navigated diverse terrains and accurately detected and reacted to changes in air quality. For three hours straight, the integrated system maintained a steady performance without any bogus triggers.

• Viability of the Power System: The solar power components produced enough energy to run continuously during the day and completely charge the battery for nighttime use. The panel output of 6-9V was able to charge the battery, and the power usage was very efficient (15-25 watts during purification, 3-5 watts during monitoring only).

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B. A Discussion of the Advantages and Disadvantages

The advantages of this approach cover key gaps in current monitoring technologies:

• Increased Awareness: The dual visual (RGB LED) and audio (voice alerts) feedback mechanisms provide better user accessibility than technical displays alone.

• Sustainability and Mobility: In contrast to fixed, grid-dependent systems, the system is environmentally friendly and adaptable because it utilizes solar energy and can patrol a wide range of locations.

• Cost-Effectiveness: The prototype is appropriate for wider, smaller-scale deployment because it utilizes Arduino and inexpensive sensors.

But the prototype has some fundamental drawbacks:

• Sensor Accuracy: Low-cost MQ and LDR sensors are not as accurate as high-precision, industrial-grade monitoring systems.

• Functional Scope: The project is mostly intended to raise awareness and identify pollutants; it has little capacity for cleaning the air on a large scale.

• Environmental Dependency: Solar charging is naturally dependent on weather conditions and the availability of sunlight, which might restrict its continuous use in indoor or constantly cloudy settings.

• Processing capability: The Arduino Uno's limited memory restricts its capacity to perform complex IoT/cloud integrations or advanced data analytics.

By providing a practical demonstration of technological application and environmental management, the findings support the integration of these modules into a viable, long-lasting robot.

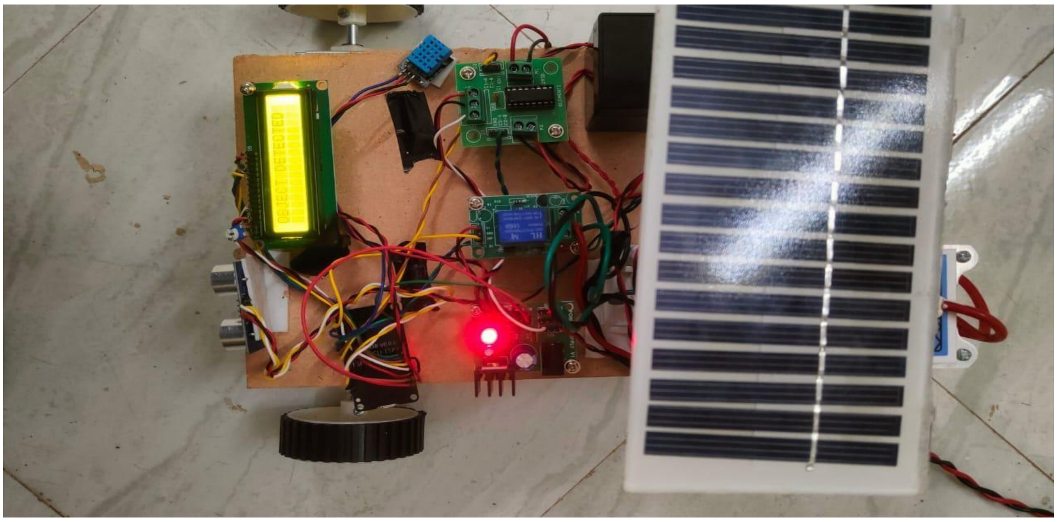

Fig:1 Hardware Connection

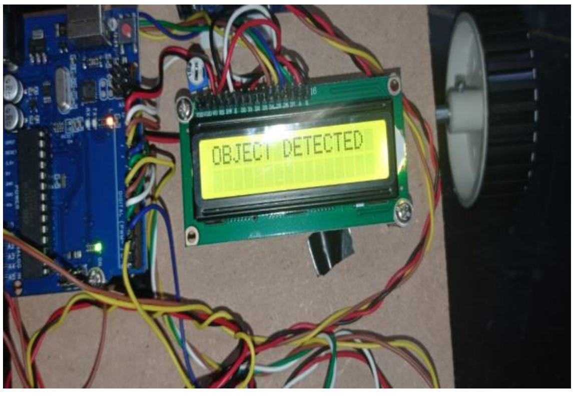

Fig:2 Object Detected

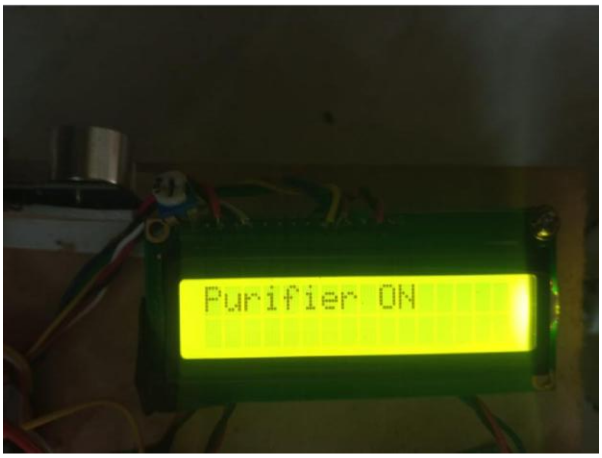

Fig:2 Air Purifier on

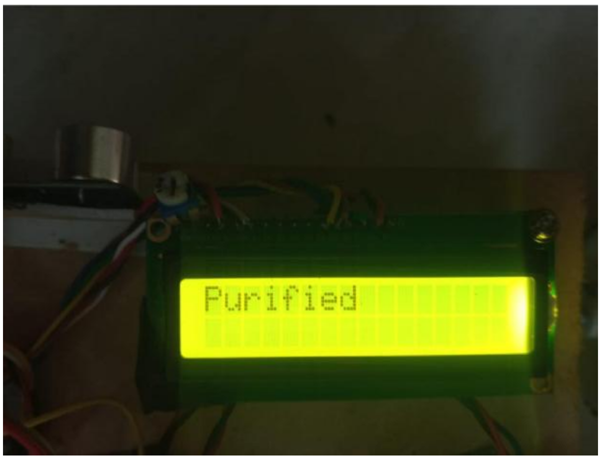

Fig:3 Air Purified

V. CONCLUSION

By developing a mobile, interactive, and sustainable platform to fight air pollution and raise awareness, the Smart Air Purifier Robot project was able to meet its goals. The system's primary strength resides in its capacity to utilize the Arduino Uno to convert MQ gas and LDR sensor data into quick, user-friendly responses using an RGB LED and voice notifications.

The most important thing is that the robot's DC motor-powered solar mobility enables it to overcome the constraints of stationary air monitoring stations and provide real-world, local air quality data. The information is actionable in real time thanks to the dynamic, closed-loop system, which stops immediately and sends out an urgent warning when bad air quality is detected.

The prototype's shortcomings include its reliance on entry-level sensor accuracy and its primary focus on monitoring rather than heavy-duty purification, but the project lays a solid foundation. Its cost-effectiveness and scalability make it a viable option for integration into smart city infrastructure, indoor monitoring, and traffic safety systems in the future.

By demonstrating the potential of integrating renewable energy, embedded systems, and robotics, this study makes a valuable contribution to the effort to create healthier environments.

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