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Radio frequency, global system for mobile, and solar based air pollution monitoring cum cleaning truck

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ABSTRACT

This paper proposes a solar-powered, mobile air pollution monitoring and cleaning system mounted on a remote-controlled mini truck, designed for use in highly polluted areas such as near chemical factories, industrial zones, fishing harbors, open drainages, and lakes. The system features a compact air cleaning chamber that purifies air in two stages using charcoal granules and cigarette filter buds. Air is drawn through the filters by two small fans, and the entire setup is housed in a transparent acrylic chamber for demonstration purposes. Two MQ135 air quality sensors are used to monitor pollution levels before and after the cleaning process. These sensors output analog signals, which are converted to digital data using an analog-to-digital converter (ADC) and processed by an embedded system. The measured air quality index (AQI) is displayed on an LCD screen and also transmitted to an authorized mobile phone via a global system for mobile communications (GSM). If the AQI value from the outside sensor exceeds 160, indicating unhealthy air, the purification system is activated automatically, and an alarm is triggered. The system is powered entirely by solar energy, with a solar panel mounted on the vehicle charging a rechargeable battery. This prototype demonstrates a practical, eco-friendly solution to combat air pollution in urban and industrial environments.

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1. INTRODUCTION

One of the biggest environmental hazards to human health is air pollution. Countries can lessen the burden of lung cancer, heart disease, stroke, and respiratory conditions like asthma by lowering air pollution levels [1]. There are many reasons causing outdoor air pollution, mainly due to the big industries, thermal power plants, fuel burning vehicles, open burning of garbage waste, and poor municipal waste management [2] these are the main reasons to damage the climate. Air pollution is the presence of substances in the atmosphere that are harmful to the human's health and other living beings. There are many different types of air pollutants, such as gases like sulphur dioxide, carbon monoxide, ammonia, and methane [3]. Smoke and other chemical vapors delivered from the factories is also a major cause to pollute the air. Air pollution also causes ozone depletion and spoils the natural environment and hence it is essential to purify the outdoor air using possible ways, in this regard this project work is designed using a mini model of truck which is equipped with air cleaning chamber. Indoor air pollution is also matters to spoil the outdoor air because it will be pumped out through exhaust fan and it creates worst toxic pollution problems [4]. Millions of fatalities worldwide are caused by outdoor air pollution alone. According to the concern department survey of individual nations, air pollution is the leading environmental health danger in the world and kills almost

7 million people annually. Ninety percent of the world's population breaths polluted air to some extent, and the problem of air pollution is massive [5]. To lessen air pollution, a variety of pollution management techniques and technologies are available. Even while taking the right precautions at home is necessary to lessen the effects of air pollution, indoor air pollution must also be regulated appropriately in addition to outdoor air pollution. In this project much importance is given for purifying the outdoor air by measuring the air quality through MQ135 sensors [6].

As per the air quality index (AQI) standards, if the air quality percentage is greater than 170, automatically air purifying process will be started [7]. The purpose of the specially made air pollution detection sensor MQ135 is to identify harmful substances in the air, including smoke [8]. This is a fast-responding device; if the air is clean, its output stays constant; if not, it increases in accordance with the concentration of polluted air. Based on this level, its output is calculated and shown as a percentage of pollution, and the program is prepared appropriately. The next separate chapter has a full description of this sen. Now coming to the air purifying chamber, here the air is purified in two steps, in first step activated carbon granules in the form of charcoal granules poured into a mesh type container is used by which the air sucking fan arranged behind this container pulls the air through charcoal pieces [9]. In the second step, Cellulose acetate fiber filter is used. This is the material used in the cigarette buds which is intended to remove the tar and nicotine and in addition it also filters the harmful molecules present in the smoke. These to containers arranged one after another in a small chamber and instrument fans are arranged behind these two filters. Entire system including MQ135 air quality sensors are arranged inside the acrylic chamber and it will be arranged over chassis of moving mechanism. Outputs of both sensors are fed to the analog-to-digital converter (ADC) chip for converting the analog data produced by the sensors into digital [10]. The main processing unit is constructed with 89C51 microcontroller chip, the microcontroller used in this project work is playing major roll. It acquires both sensors' data through ADC and if first sensor out is greater than the set value, means if the outdoor air pollution level is more, automatically it energizes both fans automatically by which the polluted air will be passed through the two filters by which air will be purified [11]. The microcontroller chip is introduced as follows. Instrumentation systems are increasingly being implemented using microcontrollers. Therefore, having a solid understanding of microcontroller-based systems is crucial. Microcontrollers are now a necessary component of all instruments. The functional, operational, and performance-based criteria have undoubtedly improved with the usage of microcontrollers in dedicated systems [12]. The computation and networking capabilities of the micro controller devices were and are responsible for the architectural advances in instrumentation and control systems. Microcontrollers must be viewed as a tool for communication and computation. Understanding microcontrollers is valuable and very satisfying when used to create products that benefit the industry or society at large. Automation and the development of industrial products are directly related to this topic [13]–[18].

In this project work, microcontroller is programmed to perform the function of encoding and decoding techniques, which is essential for any biomedical instrument [19], [20]. Any microcontroller that runs the program that is stored on it. Since the sensor's output will be in the form of analog data, which the controller cannot accept, the program is set up in this way so that the system can perform the task of gathering information from the air pollution detecting sensor. To do this, the data must be decoded into digital form using an ADC [21], [22]. This ADC is connected to a microcontroller chip, which is configured to take the data and translate it into a quantifiable pollution level that can be shown on an LCD connected to the controller chip's output port [23], [24]. This is a summary of the project work, which is covered in more detail in the functional description chapter that follows.

2. SYSTEM ARCHITECTURE AND COMPONENTS

The design of the air pollution monitoring and cleaning truck is based on a carefully chosen combination of components that work together seamlessly to achieve the primary objective: purifying the air in polluted areas. Figure 1 shows the block diagram of the proposed system. The architecture of the system consists of several key components, each playing an essential role in ensuring the efficiency and functionality of the vehicle.

Sensors: at the core of the system are the MQ135 air quality sensors, which are specifically chosen for their ability to detect a broad spectrum of gases, including ammonia, carbon monoxide, alcohol, and smoke, all of which contribute to poor air quality. These sensors are strategically placed before and after the filtration system to assess the effectiveness of the purification process. The sensor at the intake measures the air quality of the surrounding environment, while the sensor at the exhaust measures the air quality after it has passed through the filtration system. The dual-sensor configuration provides real-time data about the improvement in air quality, offering valuable insights into the effectiveness of the system.

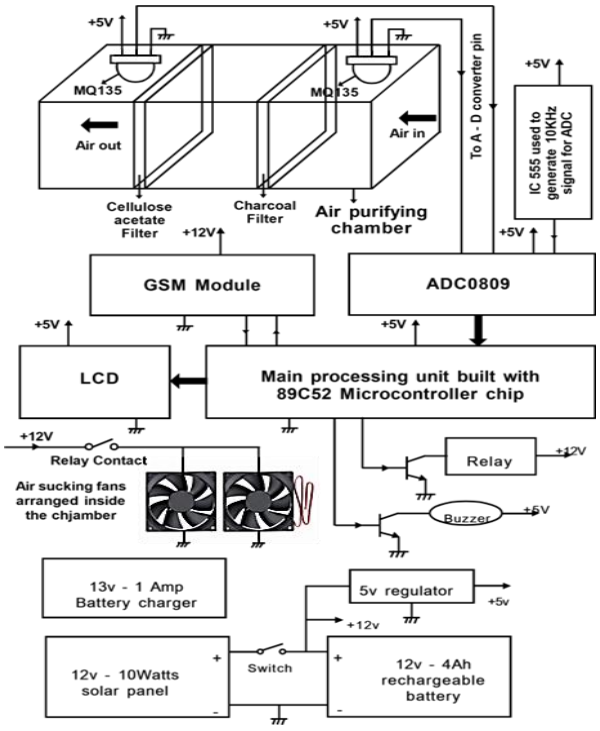

Figure 1. Block diagram of proposed system

Filtration system: the filtration system in this truck consists of two stages, each designed to target specific pollutants. The first stage uses charcoal granules to adsorb harmful gases like carbon monoxide, ammonia, and volatile organic compounds (VOCs), which are common in polluted urban areas. Charcoal has a large surface area that helps trap these harmful gases, preventing them from being released back into the environment. The second stage employs cigarette filter buds, primarily made of cellulose acetate, which are highly effective in trapping fine particulate matter such as dust, pollen, and smoke. The use of cigarette filter buds is a cost-effective solution for removing small particles from the air. Together, these two stages work to purify the air by targeting both gases and particulates. Two fans are used to circulate the air through the filtration system. The first fan draws polluted air into the filtration chamber, while the second fan expels purified air back into the environment. The fans are controlled by the 89C52 microcontroller, which adjusts their speed based on the pollution level, ensuring that the airflow remains optimal for effective purification. The fans play a crucial role in driving the air through the charcoal granules and cigarette filter buds, ensuring that the purification process is continuous and efficient.

The 89C52 microcontroller acts as the brain of the system, controlling the fans, processing sensor data, and managing communication with the global system for mobile communications (GSM). It receives data from the MQ135 sensors, processes it, and determines the AQI. If the AQI exceeds a threshold, the microcontroller activates the filtration system. It also interfaces with the GSM module to send alerts when the air quality reaches hazardous levels. The microcontroller is also responsible for the operation of the remote-control system, which uses radio frequency (RF) signals to navigate the vehicle to different locations. The power supply consists of a 12 V, 10 W solar panel, which charges a 12 V, 4 Ah lead-acid battery. The solar panel ensures that the system can operate independently without relying on external power sources, making it ideal for off-grid locations. The solar panel can generate 0.6-0.8 A of current, which is sufficient to power the various components, including the microcontroller, sensors, GSM module, fans, and remote-control system. This solar-powered design ensures that the vehicle remains operational even in areas with limited access to electricity. The vehicle is equipped with a GSM module (SIM800), which enables remote communication by sending SMS alerts when the pollution level exceeds predefined thresholds. The module communicates with the microcontroller via AT commands, allowing the system to transmit sensor data and alert users in real-time. The remote-control system is based on RF technology, which allows the vehicle to be controlled from a distance. The RF transmitter sends encoded signals to a receiver on the vehicle, which decodes them and activates the motors to move the vehicle. This RF-based navigation system provides the flexibility to deploy the vehicle in areas with high pollution levels and allows it to be moved easily without direct human intervention.

3. METHOD

The method behind the air pollution monitoring and cleaning truck revolves around the integration of sensors, filtration technology, and remote operation to continuously monitor and improve air quality. Figure 2 shows communication and remote control. The system operates in a straightforward manner, using a combination of physical processes (air filtration) and electronic components (sensors and microcontroller) to detect and purify polluted air in real-time. The vehicle's fans first collect outdoor air through an intake system, which channels the air into a transparent acrylic chamber where it undergoes filtration. The first filtration stage uses charcoal granules, which absorb harmful gases, including carbon monoxide, nitrogen dioxide, and ammonia. Charcoal's porous structure allows it to adsorb these gases from the air, significantly reducing their concentration. After passing through the charcoal filter, the air enters the second filtration stage, which utilizes cigarette filter buds. These filters are composed of cellulose acetate, which effectively captures fine particulate matter, such as dust, soot, and smoke particles, from the air.

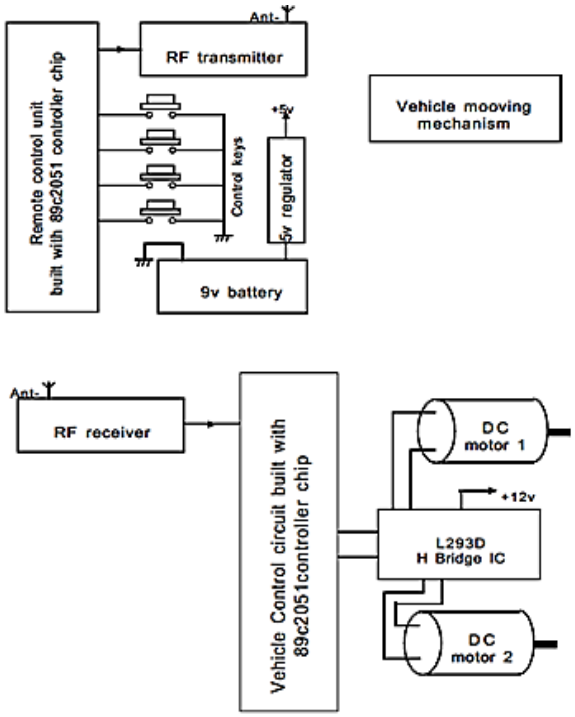

Figure 2. Communication and remote control

3.1. Sensor data collection and processing

The MQ135 sensors are placed both before and after the filtration system to measure air quality at various stages. These sensors provide analog data regarding the concentration of harmful gases in the air. The analog signals are converted into digital signals using an ADC0809, a 8-bit ADC, which allows the microcontroller to process the sensor data. The microcontroller compares the sensor readings with predefined thresholds to determine the AQI. If the AQI exceeds a critical threshold (e.g., 160), the microcontroller activates the fans and the filtration system to improve air quality.

3.2. Air quality display and alerts

Once the AQI is processed by the microcontroller, it is displayed on an LCD screen mounted on the vehicle, providing real-time feedback about the air quality in the surrounding environment. If the air quality is deemed unsafe, the system automatically sends an SMS alert to a designated mobile phone number via the GSM module. The SMS contains the current AQI value and a notification indicating that the air quality has exceeded the safe limit, ensuring that authorities or personnel in charge are alerted immediately.

3.3. Vehicle navigation

In addition to its air monitoring and purification capabilities, the vehicle is also equipped with an RF-based remote-control system that enables operators to navigate the vehicle to different areas. The remote-control system uses a 433 MHz RF transmitter and receiver, along with motor drivers (L293D H-Bridge ICs), to move the vehicle. The operator sends encoded commands from a remote controller, which are received and

decoded by the vehicle's RF receiver. The motors are then activated accordingly, allowing the vehicle to be moved efficiently to locations with high pollution levels. The entire system is powered by a 12 V, 10 W solar panel, which charges a 12 V, 4 Ah battery that powers the vehicle's sensors, microcontroller, fans, and GSM module. The use of solar energy safeguards that the system can function independently in remote or off-grid locations, making it an ideal solution for urban pollution control. The GSM module, using a SIM800 series chip, is integral for remote communication. It uses AT commands to communicate with the 89C52 microcontroller, sending SMS alerts about the air quality in real-time. The GSM module helps notify the user or a designated authority when the AQI exceeds the safety limits. It is connected to a mobile network, ensuring that alerts are sent to the authorized phone number. The RF-based system allows the operator to control the vehicle remotely. The RF transmitter sends encoded signals to the receiver on the vehicle, which decodes them and drives the motors accordingly. This wireless communication ensures the vehicle can be moved to different areas without the need for direct human intervention. The components table shown in Table 1.

Table 1. Components table

S. No	Component name	Specification/model	Quantity
1	Microcontroller	Arduino Uno	1
2	Air quality sensor	MQ-135	2
3	Dust/PM sensor	GP2Y1010AU0F	1
4	Temperature and humidity sensor	DHT11	1
5	GSM module	SIM800	1
6	RF transmitter	433 MHz RF Tx module	1
7	RF receiver	433 MHz RF Rx module	1
8	Solar panel	12 V, 10–20 W	1
9	Solar charge controller	12 V PWM controller	1
10	Rechargeable battery	12 V, 7 Ah lead acid/Li-ion	1
11	DC motors	12 V DC geared motors	2
12	Motor driver	L298N	1
13	Air cleaning unit (fan)	High-speed DC blower	2
14	Air filter	HEPA	1
15	Water spray unit (optional)	DC water pump+nozzle	1

4. EXPERIMENTAL RESULTS

The prototype was tested in an area near a local industrial zone, where pollution levels are typically high. The system successfully detected and purified the air, activating the filtration system whenever the AQI exceeded the threshold of 160. The fans operated efficiently, and the purification process was effective in reducing particulate matter and harmful gases in the air. Figure 3 shows the sensor reading before air purification. The real-time data displayed on the LCD and transmitted via SMS provided valuable insights into the effectiveness of the system shown in Figure 3. The vehicle's ability to navigate autonomously and remotely allowed for targeted air cleaning in high-pollution zones, making it a versatile solution for improving urban air quality. Figure 4 shows the sensor reading after air purification. The use of solar power ensured the system could function continuously without external power sources, making it appropriate for use in off-grid locations. Figure 5 shows air pollution monitoring cum cleaning truck.

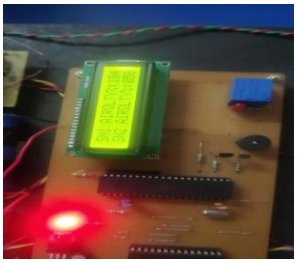

Figure 3. Sensor reading before air purification

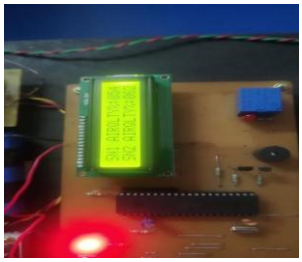

Figure 4. Sensor reading after air purification

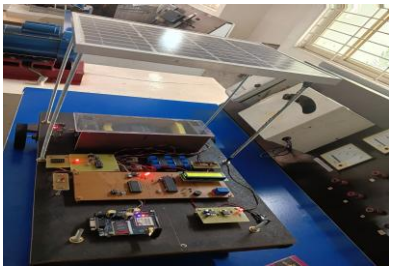

Figure 5. Air pollution monitoring cum cleaning truck

5. CONCLUSION

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exceeded the threshold of 160. The fans operated efficiently, and the purification process was effective in reducing particulate matter and harmful gases in the air. The real-time data displayed on the LCD and transmitted via SMS providing valuable insights into the effectiveness of the system. The vehicle's ability to navigate autonomously and remotely allowed for targeted air cleaning in high-pollution zones, making it a versatile solution for improving urban air quality. The use of solar power ensured the system could operate unceasingly without external power sources, making it appropriate for use in off-grid locations.

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