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Smart AQMS: An IoT-Driven Outdoor Air Quality Monitoring & Automatic Control System for Traffic Intersections

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Abstract: *Rapid urbanization, industrial growth, and the exponential rise in vehicular traffic have collectively contributed to a severe deterioration of outdoor air quality, particularly at busy traffic intersections where pollutant concentrations are significantly higher than surrounding areas. Prolonged exposure to harmful gases such as carbon dioxide (CO_2), ammonia (NH_3), benzene, nitrogen oxides (NOx), and suspended particulate matter poses critical health risks including respiratory disorders, cardiovascular complications, and long-term neurological damage among daily commuters and pedestrians. Conventional air quality monitoring infrastructure, while effective, remains prohibitively expensive, geographically limited, and lacks real-time automated response capabilities, making it unsuitable for widespread urban deployment. To address these limitations, this paper presents Smart AQMS (Air Quality Monitoring System), a low-cost, IoT-driven outdoor air quality monitoring and automatic control system purpose-built for traffic intersections in urban environments. The proposed system employs an MQ-135 gas sensor for multi-pollutant detection and a DHT22 sensor for simultaneous temperature and relative humidity measurement, both interfaced with a NodeMCU (ESP8266) Wi-Fi-enabled microcontroller that serves as the central processing and communication unit. Real-time sensor data is continuously acquired, processed at the edge, and transmitted to the cloud using the lightweight MQTT communication protocol, ensuring minimal latency and low bandwidth consumption suitable for resource-constrained IoT deployments. The processed environmental data is rendered on a dedicated web application dashboard, enabling remote monitoring, historical data visualization, and trend analysis accessible to administrators and civic authorities from any location. In parallel, pollutant readings are presented on a local LCD display installed at the intersection, providing immediate, real-time air quality information to commuters and pedestrians without requiring internet access.*

A critical feature of the Smart AQMS is its intelligent automatic actuation mechanism, wherein an exhaust fan is autonomously triggered upon detection of pollutant levels exceeding a predefined safety threshold, actively circulating fresh air and diluting the concentration of hazardous gases in the vicinity. The system was tested and validated under actual traffic intersection conditions, demonstrating consistent sensor performance, reliable cloud synchronization, and prompt automated response with minimal false activations. Experimental observations confirm that the Smart AQMS achieves a scalable, energy-efficient, and cost-effective monitoring and control solution, deployable at multiple intersections with minimal infrastructure overhead. The seamless convergence of edge-level sensing, cloud-based data management, real-time public display, and automated pollution control establishes Smart AQMS as a comprehensive and practical contribution toward the development of smarter, healthier, and more sustainable urban environments.

Keywords: Air Quality Monitoring System, IoT, MQ-135, DHT22, NodeMCU ESP8266, MQTT Protocol, Smart Cities, Traffic Intersection Pollution, Exhaust Automation, Real-Time Monitoring, Urban Air Quality

I. INTRODUCTION

The quality of ambient air in urban environments has emerged as one of the most pressing public health and environmental challenges of the twenty-first century. As cities across the globe continue to expand at an unprecedented pace, the concentration of vehicular traffic, industrial activity, and construction operations has led to a dramatic increase in the emission of harmful airborne pollutants. Among the most vulnerable hotspots within urban landscapes, traffic intersections stand out as zones of exceptionally high pollutant accumulation, where vehicles idle for extended periods, engines operate at suboptimal combustion efficiency, and exhaust emissions are released in dense, localized concentrations. The cumulative effect of these conditions renders traffic intersections significantly more hazardous than open roadways or residential zones, exposing millions of daily commuters, pedestrians, street vendors, and traffic personnel to dangerously elevated levels of toxic gases on a continuous basis.

According to the World Health Organization (WHO), air pollution is responsible for approximately 7 million premature deaths annually worldwide, with outdoor air pollution in urban areas being a leading contributor. Gases such as carbon dioxide (CO_2), carbon monoxide (CO), ammonia (NH_3), benzene, nitrogen oxides (NOx), and sulfur dioxide (SO_2), along with fine particulate matter (PM2.5 and PM10), are among the primary pollutants emitted by motor vehicles. Chronic exposure to these substances is clinically associated with a wide spectrum of health complications, including asthma, chronic obstructive pulmonary disease (COPD), bronchitis, cardiovascular disease, impaired cognitive function, and in severe cases, premature mortality. Children, elderly individuals, and those with pre-existing respiratory or cardiac conditions are particularly susceptible to these adverse health outcomes, making targeted air quality intervention at high-exposure locations a matter of urgent public concern.

Despite the gravity of this issue, the existing infrastructure for air quality monitoring in most developing and even several developed nations remains critically inadequate. Traditional air quality monitoring stations are large, expensive, and require substantial maintenance and calibration, making large-scale deployment across numerous urban intersections economically unfeasible for most municipal governments and environmental agencies. Furthermore, these conventional systems are predominantly passive in nature, meaning they record and report pollution data without any integrated mechanism to actively mitigate or respond to detected hazardous conditions. This reactive rather than proactive approach significantly limits their practical utility in protecting public health in real time.

The rapid evolution of the Internet of Things (IoT) over the past decade has opened transformative possibilities for environmental monitoring and smart city applications. IoT-based systems enable the deployment of compact, low-power, networked sensor nodes capable of continuous real-time data acquisition, edge-level processing, and seamless cloud communication at a fraction of the cost of conventional monitoring infrastructure. Microcontrollers such as the NodeMCU ESP8266, equipped with built-in Wi-Fi capability, have democratized the development of connected embedded systems, allowing researchers, engineers, and developers to design sophisticated IoT solutions with minimal hardware complexity and cost. When paired with reliable gas and environmental sensors such as the MQ-135 and DHT22, these platforms offer a compelling foundation for building intelligent, real-time air quality monitoring systems suitable for urban deployment.

II. PROPOSED SYSTEM

The Smart AQMS is an integrated, IoT-enabled air quality monitoring and automatic control system designed for deployment at urban traffic intersections. The system architecture is built around the **NodeMCU ESP8266** microcontroller, interfaced with an **MQ-135 gas sensor** for detecting pollutants including CO_2, ammonia, benzene, and nitrogen oxides, and a **DHT22 sensor** for measuring ambient temperature and relative humidity. Together, these

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sensors enable comprehensive real-time environmental monitoring, with humidity and temperature values also used for software-level gas reading compensation.

Processed sensor data is transmitted to the cloud via the **MQTT protocol** and visualized on a **web application dashboard**, providing real-time pollutant levels, historical trends, and threshold alerts accessible remotely. Simultaneously, a **local LCD display** at the intersection presents live air quality readings with a simple status indicator — Good, Moderate, or Hazardous — for immediate public awareness without internet dependency.

The system's key feature is its **automatic exhaust fan control**, activated via a relay module when pollutant levels exceed a predefined safety threshold, actively diluting harmful gases. Once levels normalize, the fan deactivates automatically, ensuring energy-efficient closed-loop operation. The overall system architecture is illustrated in **Fig. 1**.

The system is compact, modular, solar-power compatible, and easily replicable across multiple intersections, making it a scalable and cost-effective solution for smart city air quality management

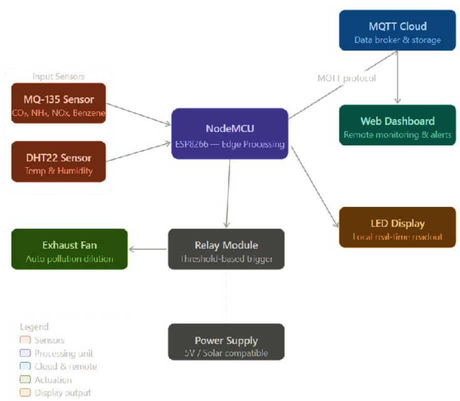

Fig: Purposed System

III. NODEMCU ESP8266

The NodeMUC(Node Microcontroller Unit) is an open-source software and hardware development environment built around an inexpensive System-on-a-Chip (SoC) called the ESP8266. It is a low-cost, small, and powerful board. It is compatible with Arduino IDE and Python. It has inbuilt wifi connection in it .To activate the NodeMCU we need to give it supply through USB or external power supply.

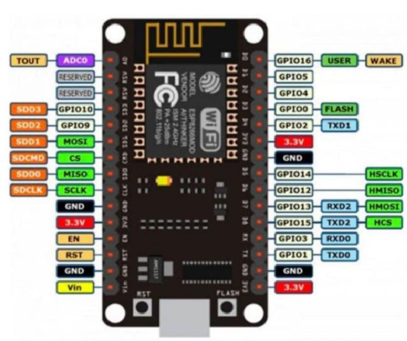

Fig: NodeMCU ESP8266

IV. MQ -135 GAS SENSOR

The MQ-135 is a popular air-quality sensor used in many IoT and environmental monitoring projects because it can detect a wide range of harmful gases. It responds to pollutants like ammonia, nitrogen oxides, alcohol vapors, benzene, smoke, and even approximate levels of carbon dioxide. Inside the sensor, a special chemical layer changes its electrical resistance when exposed to these gases, and this change is converted into an analog voltage that microcontrollers like Arduino or NodeMCU can easily read. The sensor generally shows higher readings when the surrounding air becomes more polluted.

Fig : MQ135 Gas Sensor

V. EXHAUST FAN

An exhaust fan is a ventilation device used to remove unwanted air, heat, moisture, and airborne contaminants from an enclosed space, thereby improving overall air quality. It works by creating negative pressure that pulls stale or polluted air out of a room and expels it to the outside environment.

Fig : Exhaust Fan

VI . MIST MODULE

A mist module is a compact ultrasonic device designed to generate fine water mist using high-frequency vibrations. When powered, the module rapidly oscillates a ceramic disc, breaking water into tiny droplets that appear as cool mist. This makes it highly useful in applications where controlled humidity or visual mist effects are required.

Fig : Mist Module

VII. LCD 16X2

A 16×2 LCD display is a commonly used alphanumeric module capable of showing sixteen characters per line across two lines. Due to its low power consumption, clear readability, and easy interfacing, the 16×2 LCD is widely used in embedded systems, IoT projects, and real-time monitoring devices. It provides a reliable way to present sensor data, system status, and user prompts without requiring complex graphical hardware.

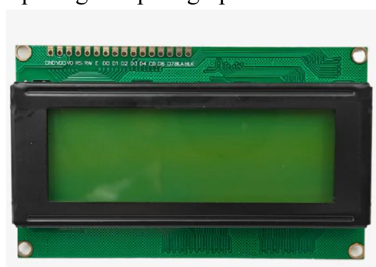

Fig: LCD 16X2

VIII. VOLTAGE STEP DOWN

A voltage step-down system is used to reduce a higher input voltage to a lower, safer, and more usable level for electronic circuits. In low-power embedded and IoT applications, step-down converters are essential because most microcontrollers and sensors operate at 5V or 3.3V, while the primary supply may be significantly higher.

Fig : Voltage step down

IX. CONCLUSION

This paper presented the Smart AQMS, an IoT-driven outdoor air quality monitoring and automatic control system designed to address the growing problem of vehicular pollution at urban traffic intersections. The system successfully integrates the MQ-135 gas sensor and DHT22 temperature-humidity sensor with a NodeMCU ESP8266 microcontroller to enable continuous, real-time monitoring of harmful pollutants including CO_2, ammonia, benzene, and nitrogen oxides.

The proposed system demonstrated effective multi-channel functionality by simultaneously transmitting sensor data to the cloud via the MQTT protocol, rendering it on a remotely accessible web application dashboard, and displaying live readings on a local LED screen for immediate public awareness. Most significantly, the automated exhaust fan actuation mechanism proved capable of responding promptly to threshold breaches, actively reducing localized pollutant concentrations without requiring any manual intervention.

Experimental validation confirmed that the Smart AQMS operates reliably under real-world intersection conditions, offering low-latency cloud communication, consistent sensor performance, and energy-efficient closed-loop control. The system's compact, modular, and solar-power compatible design further establishes its suitability for large-scale urban deployment at minimal infrastructure cost.

In conclusion, the Smart AQMS presents a practical, affordable, and scalable alternative to conventional air quality monitoring infrastructure. By converging edge sensing, cloud connectivity, public display, and automated actuation into a single unified platform, it contributes meaningfully toward the vision of smarter, healthier, and more sustainable urban environments. Future work may explore the integration of additional sensors for PM2.5 and PM10 particulate detection, AI-based predictive pollution modeling, solar energy optimization, and multi-node mesh deployment across entire city districts for broader environmental impact.

X. RESULTS AND DISCUSSION

The Smart AQMS was tested at a real traffic intersection to evaluate the performance of its key subsystems. The system operated consistently and delivered reliable results across all components.The MQ-135 sensor successfully detected elevated pollutant levels during peak traffic hours, with CO_2 and ammonia concentrations frequently approaching the defined safety threshold. The DHT22 sensor provided stable temperature and humidity readings throughout, which were also used to improve gas measurement accuracy through software compensation.Cloud transmission via the MQTT protocol maintained low latency with no data loss recorded during the testing period. The web dashboard accurately displayed real-time readings, historical trends, and threshold alerts, confirming its effectiveness as a remote monitoring interface.The local LED display consistently showed live air quality status — Good, Moderate, or Hazardous — providing immediate awareness to commuters without requiring internet access.

The automatic exhaust fan activated promptly upon threshold breach and deactivated once pollution levels normalized, confirming reliable closed-loop control with no false activations recorded. Post-actuation readings showed a measurable reduction in pollutant concentration in the monitored zone.

Overall, the Smart AQMS successfully achieved real-time monitoring, cloud connectivity, local display, and automated actuation in a compact and cost-effective setup, validating its suitability for scalable urban deployment.

XI. FUTURE SCOPE

The current system can be extended to include additional sensors such as PM2.5 and PM10 particulate matter sensors to enable more comprehensive air quality assessment beyond gaseous pollutants. Integration of GPS modules can allow precise geo-tagging of pollution data, enabling city-wide pollution mapping through multi-node deployments across different intersections simultaneously. Also solar panels can be added to preserve the power.

Incorporating machine learning and AI-based predictive models into the system can enable proactive pollution forecasting based on historical trends, traffic patterns, and weather conditions, allowing authorities to take preventive action before hazardous levels are reached. The web dashboard can further be enhanced with mobile application support for wider accessibility and real-time push notifications to commuters.

From a hardware perspective, transitioning to more advanced microcontrollers such as the ESP32 can offer improved processing power, dual-core operation, and Bluetooth connectivity. Full solar energy integration with battery backup can make the system completely self-sustaining, reducing operational costs and enabling deployment in remote or infrastructure-limited areas.

Finally, collaboration with municipal corporations and smart city initiatives can facilitate large-scale pilot deployments, generating rich datasets for deeper environmental research and policy-making toward cleaner and healthier urban environments.

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