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Advanced IoT-Based System for Air Quality Monitoring and Control in Meteorological station

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Abstract

This paper presents an advanced IoT-based system for air quality monitoring and control tailored for deployment in meteorological stations. The system integrates a NodeMCU (ESP8266) microcontroller with environmental sensors, including the MQ135 gas sensor and DHT11 temperature and humidity sensor, to provide real-time data on atmospheric conditions. The MQ135 detects harmful gases such as carbon dioxide, ammonia, and benzene, while the DHT11 monitors ambient temperature and humidity. Data collected from these sensors is processed by the NodeMCU and transmitted over Wi-Fi to cloud platforms or meteorological databases for remote monitoring and analysis. When pollutant levels exceed predefined thresholds, the NodeMCU activates a suction pump via a relay module to improve air quality by expelling contaminated air. This automation ensures responsive and efficient environmental control without human intervention. The system's compact design, low cost, and internet connectivity make it suitable for widespread deployment in remote and urban meteorological stations. Additionally, it supports continuous environmental assessment, contributing to climate research, pollution tracking, and weather forecasting. The collected data can be visualized on dashboards or mobile applications for real-time access by researchers, authorities, or the public. This smart solution enhances the capabilities of meteorological stations by integrating IoT technology,

ensuring proactive air quality management and facilitating data-driven decision-making in environmental monitoring systems.

Keywords:- Air Quality Monitoring, IoT, Pollution Control, Sensor, Smart City

Introduction

The issue of air pollution has lately become one of the most crucial environmental and health problems in the world. Finally, with increasing concentration of harmful pollutants such as carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and particulate matter (PM2.5 and PM10) the consequence of which has been severe public health, severe environment and finally severe impact on quality of life. However, they are usually static and expensive methods of air quality monitoring that usually do not provide real time and location specific data. These limitations can be addressed by integrating the Internet of Things (IoT) in air quality monitoring system. By utilizing the IoT technology to link low cost, energy efficient sensors, a system that could continually assess air quality at a more scalable, dynamic and responsive network can be created.

An advanced IoT based air quality monitoring and control system are the ones that uses interconnected sensors to collect the environmental data in real time. By deploying these sensors in different indoor and outdoor places, they transmit the data to a centralized cloud platform in which this data is processed, analyzed, and visualized. This information can be accessed by users through mobile apps or web dashboards to obtain a glimpse of the air pollution levels and trends. Additionally, the system can easily be integrated with automated control mechanisms, e.g. air purifiers, HVAC systems or exhaust fans so as to achieve optimal air quality conditions. This IoT—enabled approach is coupled with features such as alert notifications, data logging, predictive analytics, and remote device control, enabling these to boost awareness as well as empowering individuals, communities, and authorities to take pre—emotive and well—informed actions on time. The role of such intelligent systems including automated external defibrillators, smart space construction and even building facades has become important in creating healthier living environments, and promoting urban environmentally sustainable development as urbanization and industrial activities continue to rise.

Project objective

This study is needed due to increasingly serious harm to human health and the environment due to the air quality deterioration in the urban as well as rural areas. The industrialization, urban expansion and vehicular emissions have drastically risen air pollution levels that have led to respiratory problems, cardiovascular diseases and other serious health problems. However, the traditional air monitoring systems are high cost, low mobility and area restricted, which cannot facilitate real time and large-scale air monitoring. The need for solutions to continuously generate and provide data and enabling prompt decision making has emerged as a matter of utmost urgency, in view of the demand of efficient, scalable, and cost-effective solution. It is here that IoT based systems open up an entirely new opportunity. The use of smart sensors that can transmit real time data with cloud-based analytics and remote access provide a broader understanding of the time and location detentions of air quality variation. In addition to providing such systems help to monitor pollution levels, they also allow for automated control responses to the negative effects of pollutants. In addition, they can supply reliable and timely data to support public awareness campaigns, as well as the policy making and environmental planning processes. Next in the current scenario the study is crucial because it tries to fill in the gap between technological advancement and practical implementation in environmental health monitoring. It aims to show how IoT technology is viable and offers advantages to use in air quality management solutions thereby paving way for smart city solutions and more proactive approaches to environmental sustainability.

Literature Review

Barot, V., & Kapadia, V. (2020, July). The problem of air pollution has become a critical global issue and real time efficient monitoring solutions are needed. The traditional air quality monitoring systems are typically expensive and bulky, and have only been deployed to a limited spatial extent. This review discusses how the Internet of Things (IoT), allows for the transformation of air quality monitoring from scale up, cost effective and real time data collection and analysis. The smart system is based on IoT that uses smart sensors, wireless communication, and cloud computing to monitor the pollutants CO, NO_2, SO_2, PM2.5, PM10 with flexibility and accessibility. The various types of these systems can be installed anywhere from urban to industrial to the residential setting, with continuous air quality data being provided through mobile and web-based platforms. This review is present different architectures, sensor technologies, data processing methods, and communication protocols that have been utilized in current IoT based systems for the air quality.

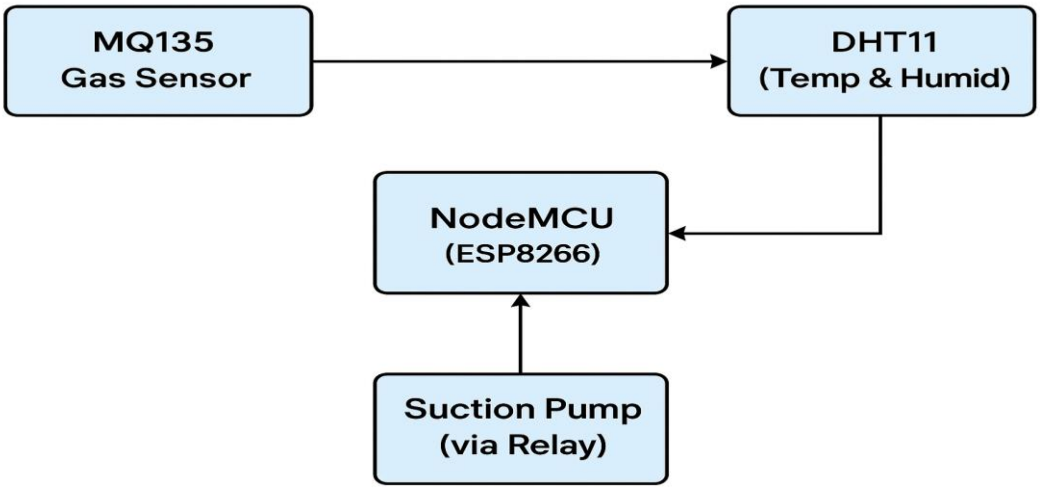
Kumar, S., & Jasuja, A. (2017) That is why this study proposes the design and development of an IoT air quality monitoring system based on Raspberry Pi as the central processing unit. It uses low-cost sensors to measure the pollutants – carbon monoxide (CO), ammonia (NH_3) and particulate matter (PM10) which are then transferred over the internet for real time monitoring. The researchers indicate that the solution relies on using open-source tools and platforms, thus making it affordable and scalable. The data is collected, and is displayed on a web server where environmental remote users can track pollution levels. By deploying this approach, one can have tremendous flexibility at a very low hardware cost. The paper shows the possibility of the Raspberry Pi as a light and effective tool to monitor the environment in real time. Performance and responsiveness of the system is tested in different settings. The result of the study suggests that such IoT systems are a practical alternative to the traditional air monitoring stations, especially in densely populated or resource poor sites. The work is also an advancement of smart city initiatives and helps address the increasing demand for affordable and sustainable air quality monitoring services.

Kumar, A., Kumari, M., & Gupta, H. (2020) In this paper we introduce a system of an IoT based air quality monitoring system capable of detecting and evaluating number of pollutants in the environment. Gas sensors (MQ-135 and MQ-7), a microcontroller and a Wi-Fi module are the integral part of the proposed system which collect and transfer the real time air quality data over the cloud platform. Emphasis is placed on obtaining a low power, robust and energy efficient design capable of long-term monitoring in a continuous manner. It is able to detect toxic gases like CO, NO_2 and other volatile compounds which after logging are analysed remotely on a cloud dashboard. We discuss how the data can be visualised for decision making purposes, triggered alerts when pollutant levels reach some predefined thresholds etc. Performance testing shows how the sensor has reliable accuracy and responsiveness in many environments. The cost and scalability make this system an affordable solution for deployment in both the urban and rural area. The results also support a growing need for data driven pollution control and their value is extended to ongoing efforts in smart environmental monitoring, public health safety, or sustainable urban infrastructure.

Saini, J., Dutta, M., & Marques, G. (2020) In this paper, IoT based IAQ monitoring systems are reviewed systematically. It spans across different types of sensor technology, data collection approaches, communication protocol, and software platforms used in currently deployed IAQ systems. Among key indoor space pollutants that are identified, are carbon dioxide (CO_2), formaldehyde (HCHO), particulate matter (PM), and volatile organic compounds (VOCs). It stresses the need of real time monitoring in homes, schools, offices and healthcare environments as part of priority. IoT integration discussed by the authors allows automatic reaction to air quality degradation implementing air purifiers or ventilation. This review of these challenges includes sensor calibration, data accuracy, power consumption, security. Additionally, the paper discusses several future research directions such as machine learning for data interpretation, and combining the data interpretation capabilities with smart building systems. Through the examination of over 100 studies, the authors are able to shed light on the here and now, as well as what might be, of IoT based IAQ systems. As such, this review is a key source for researchers and developers seeking to design and implement effective, responsive, and user-friendly systems that can promote good indoor environmental quality and improve public health.

Balasubramaniyan, C., & Manivannan, D. (2016) This work is centred on building an IoT based air quality monitoring system (AQMS) using Raspberry Pi as a cheap way forward and compact device. The gases to be monitored are CO, LPG, and the smoke concentration. The system uses MQ series gas sensors to monitor the real-time air quality parameters. Wirelessly transmitting data to a cloud platform, it allows remote access and continuous surveillance. By using Raspberry Pi, it is possible to integrate sensory modules and sensors, therefore the system can be customized for both indoor and outdoor applications. The paper explains how the hardware setup, data acquisition, and integration using open-source technologies in the cloud was done. Due to the low cost and ease of implementation, the system is emphasized by the authors for applications in education, domestic, and industrial areas. The system can also effectively detect air pollution levels and provide timely alerts as confirmed by experimental results. The proposed work adds to the increasing collection of work in smart environmental monitoring and is used as a practical model for later work and real deployment of IoT based AQMS.

Block Diagram



The diagram illustrates a simple IoT-based air quality monitoring and control system using a NodeMCU (ESP8266) microcontroller. The system integrates three main components: the MQ135 gas sensor, the DHT11 temperature and humidity sensor, and a suction pump controlled via a relay.

1. MQ135 Gas Sensor: This sensor detects harmful gases like CO_2, NH_3, and smoke in the air. It sends analog or digital signals to the NodeMCU for air quality analysis.

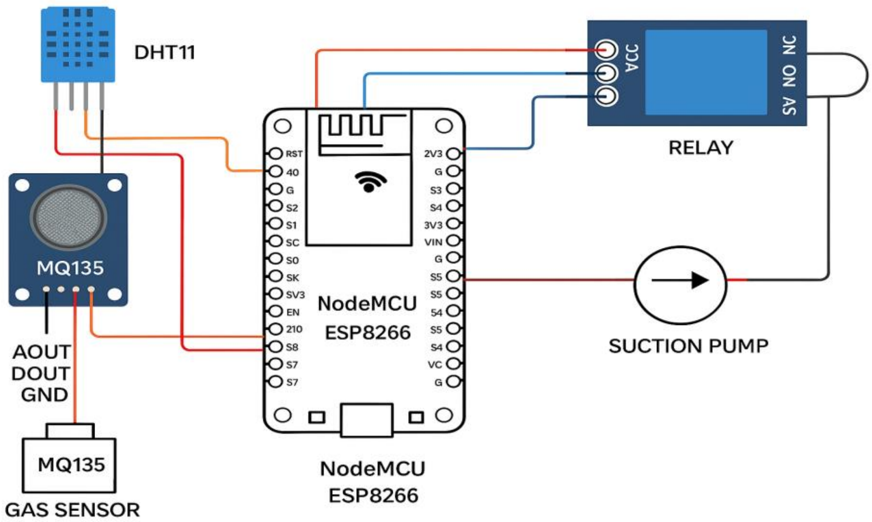
2. DHT11 Sensor: This module measures temperature and humidity. The data from DHT11 is also sent to the NodeMCU for environmental monitoring.

3. NodeMCU (ESP8266): Acting as the system's central controller, it reads data from both the MQ135 and DHT11 sensors. Based on the air quality and environmental conditions, the NodeMCU makes decisions.

4. Suction Pump with Relay: If the NodeMCU detects poor air quality (e.g., high levels of gas), it activates the suction pump through a relay module. The pump works to ventilate or purify the air.

This setup is ideal for smart home or industrial applications where automatic air quality control is essential. The NodeMCU can also transmit data over Wi-Fi for remote monitoring.

Circuit Diagram



The circuit diagram presents a smart air quality control system using NodeMCU (ESP8266), designed to monitor environmental conditions and control a suction pump based on the presence of gases. The setup uses the MQ135 gas sensor, DHT11 temperature and humidity sensor, and a relay module to switch the suction pump. The MQ135 sensor is connected to the NodeMCU's analog input (A0) via its analog output (AOUT) pin to detect gas concentrations. The DHT11 sensor provides temperature and humidity readings and is connected to a digital pin on the NodeMCU (e.g., D4). These sensors receive power from the 3.3V and GND pins of the NodeMCU.

The relay module, acting as an electrically operated switch, is controlled by one of the NodeMCU's digital pins (such as D1). It is powered via the NodeMCU's 3.3V supply (although ideally, it should use 5V for reliability). The relay connects directly to the suction pump, allowing the microcontroller to turn it on or off depending on air quality readings. When the MQ135 detects harmful gases above a threshold, the NodeMCU triggers the relay, which activates the suction pump to purify or ventilate the air. This process helps maintain a safer and more comfortable environment by automatically reacting to pollution levels.

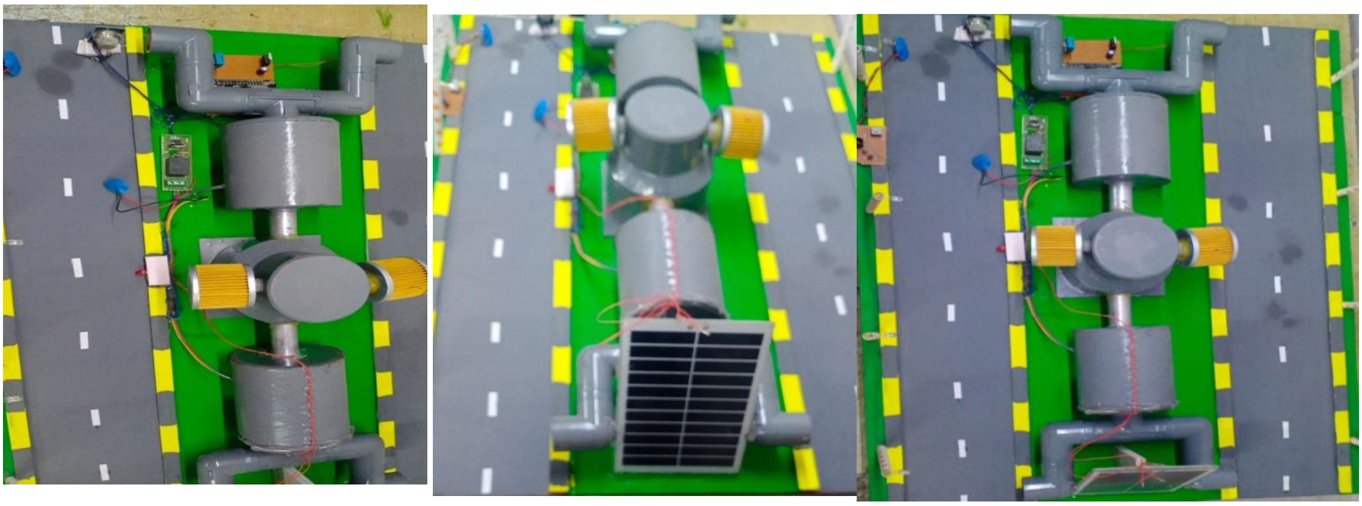
This system is especially useful for smart home or indoor environments where maintaining clean air is critical. Additionally, since the NodeMCU ESP8266 has built-in Wi-Fi, it can be extended to send real-time data to a web or mobile app for monitoring or logging purposes. Overall, the setup efficiently combines sensors, automation, and IoT capabilities to form a compact yet effective air quality management system.

Proposed System

The designed IoT based air quality monitoring and control system to identify and react to indoor pollution level dynamically. It categorizes the air quality in four specific levels depending on the concentration of carbon dioxide (CO_2) in parts per million (ppm) and provides real time environmental control and notification function. It is 'Good', when CO_2 concentration is below 350 ppm. And in this case the unhealthy indoor environment would simply light up a green light, with no audible alarm or corrective action needed.

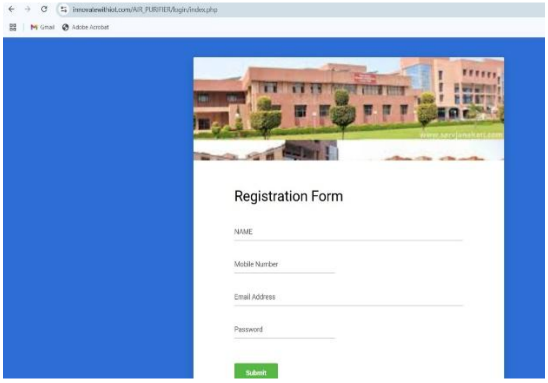
Also, the indicator turns blue and a periodic beep starts to warn users in the case as the pollution goes up to its Moderate range (350–500 ppm). An orange light is displayed in the Low-quality range (500–800 ppm). A medium intensity, continuous sound is triggered and a window is opened automatically to increase the ventilation. At levels above 800 ppm which is "Poor", a red alert is triggered from the system, it continuously rings an alarm, opens the windows, activates the fan, and gives a notice to the user’s mobile application so as to alert the user immediately.

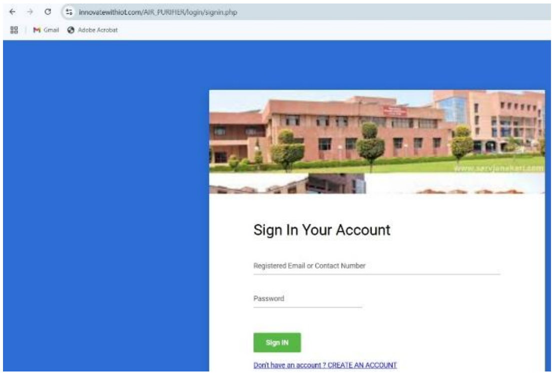
This multi-tiered feedback system not only provides real-time monitoring but also takes automated action to improve indoor air quality, ensuring a healthier living space while keeping the user informed through clear visual and auditory cues.

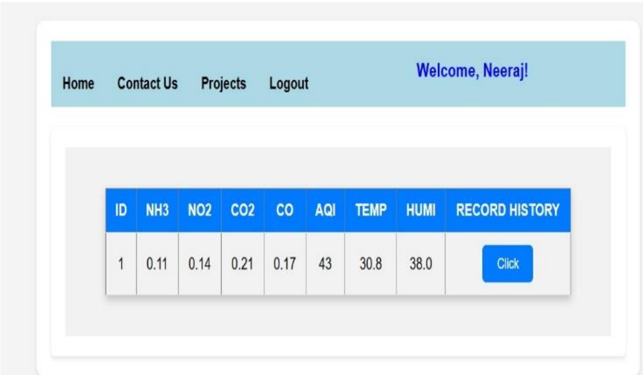


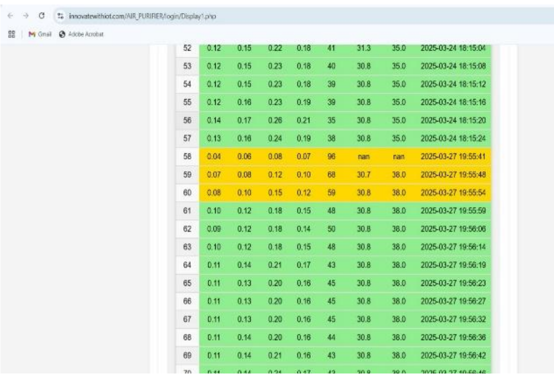
This physical model showcases an integrated setup where multiple sensors, microcontrollers, and mechanical components work together to monitor and respond to air quality levels. The system is built using materials such as PVC pipes for airflow channels, with visible components like air filters, fans, and possibly a gas sensor module attached to a microcontroller (likely an Arduino or Node MCU).

Server Data Analysis









Conclusion

This work proposes a highly promising approach of implementing an advanced IoT based air quality monitoring and control system in region to address the long-standing air pollution issues of the city. Due to high pollution levels, global, Meteorological station demands innovative, scalable and real time solutions for public health and environmental sustainability. This system relies on interconnecting smart sensors, cloud computing and data analysis approach to perform continuous and accurate air quality monitoring in different parts of the place such as residential, industrial and traffic heavy areas. This is implemented through the mobile applications and web dashboards which provide the citizens, authorities and researchers the means to access real time data and to raise awareness and act timely. Additionally, the solution integrates automatic control mechanisms like air purifiers, exhaust systems, and smart HVAC systems to automatically respond to pollution threats after an event has been reported. In order to implement a proactive approach, this is necessary especially in a densely populated area like Meteorological station, where delay in responding has potentially severe health implications. In addition, the long term data which is collected with the system are valuable for trend analysis and policy development based on evidence for environmental planning. In this regard, the proposed IoT based air quality system has a large potential to address the problems related to air quality, empowering the communities, and urban sustainable development in Meteorological station. The adoption could provide an example to other metropolitant cities struggling to encounter the same environmental problem.

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