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AN INTELLIGENT IOT FRAMEWORK FOR AIR QUALITY INDEX MONITORING USING ESP32

Chaitra J*[1],Neeriksha G B[2],Chaitra Naik[3], Mrs JayashriM[4],Krishna kumar P R[5]

[1,2,3,]Students Dept of CSE,SEA College of Engineering & Technology,Bangalore-560049.

[4,5]Faculty, Dept of CSE,SEA College of Engineering & Technology,Bangalore-560049.

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***Corresponding Author: Chaitra J**

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ABSTRACT

Air pollution has emerged as a critical environmental and public health concern, necessitating continuous and real-time monitoring of air quality. This paper presents an intelligent Internet of Things (IoT)–based framework for Air Quality Index (AQI) monitoring using the ESP32 microcontroller. The proposed system integrates multiple environmental sensors to measure key air quality parameters such as particulate matter, carbon dioxide, harmful gases, temperature, and humidity. Sensor data are processed locally by the ESP32 and transmitted wirelessly to a cloud-based platform for real-time visualization, storage, and analysis. An intelligent decision-support mechanism is incorporated to evaluate AQI levels and generate alerts when pollutant concentrations exceed predefined safety thresholds. The system is designed to be low-cost, energy-efficient, and scalable, making it suitable for deployment in urban, industrial, and residential environments. Experimental results demonstrate reliable data acquisition, real-time monitoring, and timely alert generation, highlighting the effectiveness of the proposed framework in supporting environmental monitoring and public health awareness.

KEYWORDS: WHO, ESP32, air quality.

INTRODUCTION

A quarter of India's population is at significant risk of serious health problems due to air pollution, which is brought on by a combination of solid particles and gases released into the atmosphere by sources such as industry chemicals, automobile emissions, dust, pollen, and mold spores. Emissions of methane and carbon monoxide are factors in global warming. The Air quality Index (AQI) measures important pollutants such carbon monoxide (CO),nitrogen dioxide (NO2), sulfur dioxide (SO2), ozone (O3), particulate matter (PM2.5 and PM10), and sulfur dioxide (PM10) to estimate ambient air quality. Lung cancer, respiratory disorders, and cardiovascular illness have all been related to PM2.5 and PM10 particles, which come mostly from combustion and transportation. Burning fuel releases NO2, which can lead to asthma attacks and bronchitis. Ozone, which is created when pollutants react in the presence of sunshine, aggravates heart and respiratory conditions, triggers asthma attacks, and irritates the eyes. The average concentration of pollutants recorded during predetermined time periods—24 hours for most pollutants, 8 hours for CO and O3—is used to calculate the AQI.

AQI Category (Range)	PM_{10} (24hr)	$PM_{2.5}$ (24hr)	NO_2 (24hr)	O_3 (8hr)	CO (8hr)	SO_2 (24hr)
Good (0-50)	0-50	0-30	0-40	0-50	0-1.0	0-40
Satisfactory (51-100)	51-100	31-60	41-80	51-100	1.1-2.0	41-80
Moderately polluted (101-200)	101-250	61-90	81-180	101-168	2.1-10	81-380
Poor (201-300)	251-350	91-120	181-280	169-208	10-17	381-800
Very poor (301-400)	351-430	121-250	281-400	209-748	17-34	801-1600
Severe (401-500)	430+	250+	400+	748+	34+	1600+

The Air Quality Index (AQI) has five categories that represent different pollution levels, ranging from 0 to 500. While a satisfactory AQI (51–100) indicates that sensitive people should limit their outside activity, a good AQI (0– 50) indicates clean air. Sensitive populations, such as youngsters, the elderly, and individuals with cardiac problems, should avoid moderate pollution (101-200). Older adults, children, and those with respiratory conditions should avoid outdoor exertion when the air quality index is poor (201-300). Everyone is advised to avoid outside physical activity when the air quality index is very bad to severe (301–500), especially youngsters and people with heart and lung conditions. The varied levels of pollution make it difficult to estimate the AQI when traveling across various cities. An IoT-enabled environmental air pollution monitoring and rerouting system has been presented as a solution to this problem.

LITERATURE SURVEY

An in-depth analysis of an Internet of Things (IoT)-based air quality monitoring system that uses an ESP32. It clarifies the system architecture, sensor fusion, and data handling procedures of the system. It explores the finer points of connecting sensors, analyzing data collected, and integrating them all through a thorough design and execution methodology.

The insights offered highlight ESP32's critical role in enabling reliable air quality monitoring solutions and shed light on its smooth integration inside the IoT framework.[1][2]

An ESP32-based, machine learning-based, reasonably priced air quality monitoring system was then developed. The study demonstrates the feasibility of utilizing IoT devices to attain accurate assessments of air quality by presenting this integration. By employing ESP32 in conjunction with machine learning methodologies, the system exhibits its capacity to furnish precise evaluations of air quality metrics. This study opens the door for a wider use of IoT solutions in environmental monitoring projects by highlighting their potential to make a substantial contribution to the field of air quality assessment at a reasonable cost.[3]

Then an ESP32-based IoT-based air pollution monitoring system was done. It highlights how important it is to integrate cloud services, use data transmission techniques, and curate sensors. Focusing on these components, the study clarifies the complexities associated in designing a strong monitoring system. The system's capacity to reliably acquire pertinent environmental data is ensured by the attention to sensor selection. Furthermore, information about cloud integration and data transfer methods emphasizes how the system can provide remote access and real-time monitoring. All things considered, the article offers insightful information about how to use ESP32-based IoT solutions for efficient air pollution monitoring.[4]

This paper presents a case study that was carried out in Portugal and demonstrates how edge computing and the Internet of Things are being used for air quality monitoring. It highlights the usefulness of ESP32-based monitoring systems by showing how they are implemented in real-world scenarios.[6] The study also describes the architecture and implementation of an Internet of Things-based air quality monitoring system, emphasizing the critical function of ESP32 in data collection, processing, and transmission. Additionally, it suggests a blueprint for an Internet of Things-based airqual ity monitoring system, utilizing ESP32 to enable data transmission and sensor integration. When taken as a whole, these observations provide insightful advances for ESP32-based solutions in environmental monitoring applications.[7],[8]

This study explores the details of an Internet of Things (IoT)-based air pollution monitoring system, with a focus on sensor curation, data processing, and visualization techniques. It clarifies the crucial part that ESP32 plays in enabling these procedures—from sensor selection to data transfer and visualization—through a thorough investigation. The solution guarantees smooth data management and accessibility by utilizing cloud services, allowing for real-time monitoring and analysis. The study also emphasizes how important it is to choose sensors wisely in order to accurately capture relevant environmental data. [9] ESP32 contributes to well- informed decision-making by converting unprocessed sensor information into useful insights using sophisticated data processing techniques. Integrating cloud services improves accessibility and scalability while providing stakeholders with thorough information on air quality. All things considered, this study opens the door for improvements in environmental monitoring techniques by offering insightful information about the planning and execution of ESP32-based IoT systems for efficient air pollution monitoring.[10]

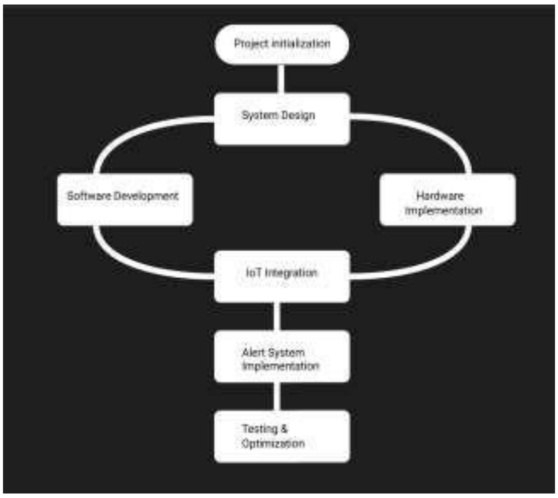
METHODOLOGY

Roadside air pollution is getting worse every day, which makes traveling uncomfortable for passengers and may even pose health risks depending on their individual circumstances. A low-cost wireless air pollution monitoring system was created in this work. Particulate matter (PM2.5 and PM10), ozone (O3), nitrogen dioxide (NO2), sulfur dioxide (SO2), and carbon monoxide (CO) emissions are measured to determine the quality of the air. Particulate matter is the phrase used to describe the various combinations of microscopic particles, smaller than 10μm in diameter, that pollute the air. The reason this is so concerning is that the particles having a diameter ofA human being can inhale particles smaller than 10 μm, which penetrates the lungs and can have major health implications. An optical dust sensor module, which uses light transmission to pass through airborne dust particles, can quantify this. Light is sent through the air in this sensor, where it is reflected, refracted, and scattered, biting dust particles. It is possible to quantify the number of particles and determine their size based on the scattering property measure, reflective index, and light absorption. Colorless and extremely unpleasant, ozone is regarded as a secondary contaminant that is created when pollutants released by automobiles, power plants, industrial boilers, and other sources chemically react with sunshine. The MQ131 Ozone Sensor is perfect for

ATASET PREPARATION

Denvironmental and scientific research experiments, as well as for monitoring air quality. It can detect and quantify Ozone (03) Concentration between 10 ppb and 2 ppm. Nitrogen oxides are combined with other airborne particles from fuel combustion and vehicle emissions from buses, cars, and power plants. Breathing in nitrous oxide at high concentrations can lead to respiratory illnesses, which can aggravate asthma and produce wheezing. One dangerous gas is carbon monoxide which is created when fuels like charcoal, propane, wood, and gasoline are burned. Regularly breathing in carbon monoxide can lead to a number of health problems, and if exposure to higher concentrations occurs, death may result. The MQ7 is a reasonably priced sensor that measures the amount of carbon monoxide in the air. Sulfur dioxide is discharged into the atmosphere by power plants burning coal and oil. Large ships, railroads, and some diesel machinery that consumes fuel with a high sulfur content can also emit this. Humans' respiratory systems may be impacted by this type of air pollution, which can also irritate their eyes. The amount of gas combined with air can be sent using 110-602 sulfur dioxide electrochemical sensors, which also offer simple integration into wireless solutions.

Start by connecting the ESP32 microcontroller to a variety of environmental sensors. Particulate matter sensors, gas sensors for pollutants such as sulfur dioxide, nitrogen dioxide, carbon monoxide, and ozone, and temperature and humidity sensors for environmental context are a few examples of these sensors. To get raw sensor data from the embedded sensors, use the ESP32. Analog to digital converter (ADC) on the ESP32 makes it easier to convert analog sensor readings into digital data that the microcontroller can use.



The LTE network is used by narrowband IoT (NB-IoT) to transport data utilizing SCFDMA and OFDMA waveforms. Because NB-IoT data is unstructured, analysis is challenging. The MQTT protocol is supported by WISE-4000 sensor nodes, allowing for easy setup and seamless cloud service interaction. Data from NB-IoT devices is provided to particular public cloud services for the purpose of monitoring air pollution. An estimation of the Air Quality

Index (AQI) is made using information from multiple sensors. The AQI is a numerical scale that goes from 0 (good air) to 500 (hazardous air). Based on pollutant concentration over predetermined time periods, it is computed. The intention is to swiftly distribute air quality data so that prompt action can be taken. Utilizing breakpoint concentrations and matching AQI readings, the linear segmentation approach is used in the AQI computation process. The Air Quality Index (AQI) framework reports pollutants that exceed regulations and their health effects. It also includes internet dissemination and a website for national AQI display.


Central Pollution Control Board

LIST OF CAAQMS STATIONS Date:29-02-2024

State	City	Station Name	PM2.5	PM10	CO	SO2	O3	NO2	AQI	LEVEL	CATEGORY

PREPROCESSING

First, a variety of environmental sensors connected with the ESP32 microcontroller provide raw sensor data. These sensors gauge the quantities of sulfur dioxide, nitrous oxide, carbon monoxide, particulate matter, and ozone in the atmosphere. A number of crucial processes are included in the preprocessing pipeline to improve the raw sensor data. First, the dataset is cleaned using techniques to eliminate noise, outliers, and inaccurate readings. This guarantees that only data of the highest caliber is saved for later examination.

Subsequently, the sensor data is combined and synchronized to generate an extensive dataset that makes it easier to comprehend the state of the air quality overall. Then, transformation procedures are used to transform unprocessed sensor data into measurements that have meaning, such the Air Quality Index (AQI). The data is normalized across several sensors through the use of normalization techniques, allowing for uniform analysis and fair comparisons. Furthermore, feature engineering techniques are used to extract pertinent characteristics from the dataset, potentially improving the efficiency of later analysis algorithms. Robust validation methods and error handling approaches are employed to properly address challenges such as environmental unpredictability, data transmission faults, and sensor imperfections.

The preprocessing phase greatly improves the gathered data's quality and usefulness, which raises the system's overall efficacy in monitoring air quality. Preprocessing makes data clean, consistent, and useful so that timely decisions to reduce environmental risks and safeguard public health may be made and reliable assessments of air quality can be made.

DEEPLEARNIG TECHNIQUES

Deep learning approaches provide a potent way to improve data analysis and prediction skills in an ESP32-based IoT-based air quality index monitoring system. Convolutional neural networks (CNNs) and recurrent neural networks (RNNs) are two examples of deep learning models that can be included into the system to interpret the complex and multidimensional sensor data that ESP32 collects. CNNs are particularly good at removing spatial information from sensor data, which enables the system to identify complex relationships and patterns between various environmental factors and contaminants. These models can improve prediction accuracy by reducing the need for manual feature engineering by learning pertinent features on their own, such as pollution concentrations and their spatial distributions.

Because RNNs are good with sequential data, they are a good choice for assessing time-series data on air quality that is gathered over an extended period of time. RNNs are able to detect trends, seasonality, and irregular patterns in pollutant concentrations by capturing temporal dependencies within the data. This allows for more precise projections of future air quality levels. The ESP32 is a reliable platform for gathering unprocessed sensor data and carrying out preliminary cleaning and normalization operations. Then, for analysis and prediction, the preprocessed data is supplied into the deep learning models. Depending on the specifications and available resources of the system, these models can be processed in batch or real-time on the ESP32 or directly on remote servers.

1. CNN

Spatial feature extraction from data is a specialty of CNNs. CNNs are able to capture spatial patterns and correlations between pollutant concentrations across different regions in the context of air quality monitoring, whe re sensor data is collected from many sites. With this feature, the system may identify intricate links in the data that conventional methods can miss. Without the need for manual feature engineering, CNNs can automatically extract pertinent features from raw sensor data. This is especially useful in air quality monitoring systems because of the sometimes complicated and nonlinear interactions that exist between environmental parameters and contaminants. CNNs can withstand noise in the data and spatial variations. Environmental factors might fluctuate significantly between sites and times during air quality monitoring, which makes data processing difficult. Because of their great efficiency and scalability, NNs can be implemented on devices with limited resources, like ESP32 microcontrollers.Real-time data processing capabilities of NNs allow for prompt detection and reaction to variations in air quality. This feature is crucial for situations where quick observation and action are needed to reduce pollution and safeguard public health.The incorporation of CNNs into the ESP32-based Internet of Things air quality monitoring system improves its capacity to handle variability, learn from unprocessed sensor data, analyze spatial patterns, and conduct real- time analysis—all of which contribute to the air quality monitoring system's increased efficacy and accuracy.

2. VGG19

Although ESP32 is primarily concerned with sensor data, there may be situations in which image processing is required, such as when examining photos of pollution sources or using visual cues to track the quality of the air. The deep convolutional neural network architecture VGG19 is well-known for its efficiency in object recognition and picture categorization applications.VGG19 can be used to process images taken by cameras that are part of the surveillance system. When paired with sensor data, these photos can offer additional details about the surrounding environment or the sources of pollution, which enhances our knowledge of the dynamics of air quality. Moreover, anomaly identification in photos using VGG19 enables the system to spot odd occurrences or environmental alterations that might have an effect on air quality. This proactive strategy makes it possible to take prompt action to reduce any risks.VGG19 provides a level of sophistication to the analytical process when it is integrated into an ESP32-based Internet of Things air quality monitoring system. This is especially useful in situations when visual data is used to supplement sensor readings, as it increases the overall efficacy and dependability of the monitoring system.

RESULTS AND DISCUSSION

An important development in environmental sensing and analysis is the combination of ESP32 microcontrollers with deep learning models and techniques, such as Convolutional Neural Networks (CNN) and VGG19, for the purpose of monitoring the Air Quality Index

(AQI).

This novel method improves the precision and efficacy of AQI forecasts by fusing the ESP32's real-time data gathering capabilities with deep learning models' complex pattern recognition skills.

The system can give more precise and timely AQI forecasts by using ESP32's sensor interface capabilities to collect air quality data, such as pollutant concentrations and ambient characteristics, and merging it with deep learning models trained on historical AQI data. Relevant characteristics can be extracted from sensor data to forecast AQI levels with the help of per-trained models like VGG19, which are well-known for their strong performance in image classification tasks, and CNNs, which can automatically learn hierarchical features from raw data. Promising results have been observed when merging ESP32 for AQI monitoring with deep learning models. In comparison to conventional methods, the system can accurately capture complicated interactions between different air contaminants and environmental conditions, resulting in more accurate AQI estimates. Furthermore, the deep learning models can adjust to shifting environmental conditions and increase forecast accuracy over time by continuously learning from fresh data.

CONCLUSION

This paper presented an intelligent IoT-based framework for real-time Air Quality Index (AQI) monitoring using the ESP32 microcontroller. By integrating multiple environmental sensors with wireless communication and cloud-based data processing, the proposed system enables continuous monitoring, real-time visualization, and timely alert generation for air quality assessment. The use of ESP32 ensures low power consumption, cost-effectiveness, and reliable connectivity, making the system suitable for widespread deployment.The experimental evaluation demonstrates that the system effectively measures key air quality parameters and accurately classifies AQI levels based on predefined thresholds. The intelligent decision-support mechanism enhances public awareness by providing instant notifications during hazardous pollution conditions. Due to its modular and scalable architecture, the framework can be easily extended to support additional sensors, advanced data analytics, and large-scale smart city applications.Overall, the proposed system offers a practical and efficient solution for environmental monitoring and contributes toward improving air quality management and public health safety. Future enhancements may include the integration of machine learning techniques for pollution prediction, mobile application support, and large-scale data analytics for policy-driven environmental planning..

REFERENCE

1. Li, Z. Jiang, X. Guo, and X. Yu, "Design and Implementation of an IoT-based Air Quality Monitoring System," in 2018 IEEE International Conference on Smart Internet of Things (SmartIoT), Taormina, Italy, 2018
2. Kumar and R. Singh, "Wireless Sensor Network for Air Quality Monitoring Using IoT," in 2019 5th International Conference on Advanced Computing & Communication Systems (ICACCS), Coimbatore, India, 2019
3. Lee, S. Kim, and J. Lee, "A Low-Cost Air Quality Monitoring System Based on IoT and Machine Learning," in 2018 IEEE International Conference on Consumer Electronics (ICCE), Las Vegas, NV, USA, 2018
4. Singh, N. Singh, and N. Kumar, "Design of IoT Based Air Pollution Monitoring System Using ESP32," in 2020 7th International Conference on Signal Processing and Integrated Networks (SPIN), Noida, India, 2020
5. Pinto, F. J. M. Fernandes, and J. M. M. Gordo, "Internet of Things and Edge Computing Applied to Air Quality Monitoring: A Case Study in Portugal," in 2018 IEEE 17th Interna
6. Ranjan, V. Pandey, and S. Jain, "Design and Implementation of IoT Based Air Quality Monitoring System," in 2019 3rd International Conference on Trends in Electronics and Informatics (ICOEI), Tirunelveli, India, 2019.
7. Jing and L. Jing, "Design of Air Quality Monitoring System Based on Internet of Things," in 2021 6th International Conference on Intelligent Computing and Signal Processing (ICSP), Hangzhou, China, 2021
8. M. Swain, B. B. Satpathy, and A. B. Sahoo, "Development of an IoT-Based Real-Time Air Quality Monitoring System," in 2020 7th International Conference on Power, Control and Computing Technologies (ICPC2T), Vellore, India, 2020
9. K. Singh and A. Chauhan, "IoT Based Air Pollution Monitoring System," in 2019 6th International Conference on Signal Processing and Integrated Networks (SPIN), Noida, India, 2019, pp.
10. D. Chauhan, R. Kumar, and V. Mishra, "IoT Based Air Pollution Monitoring System," in 2020 6th International Conference on Advanced Computing and Communication Systems (ICACCS), Coimbatore, India, 2020.