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Design, Develop, Fabricate, and Statistical Quantification of Air Quality System Along with Web Application

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ABSTRACT

Our Air Quality Index (AQI) measurement and analytics system is specifically designed for household, office, or single-room use, addressing concerns related to pollution's impact on respiratory health and visibility. The system incorporates dedicated sensors such as the PM Sensor (PMS5003), the ozone sensor (MQ- 131), the VOC Sensor (MP503), the CO2 Sensor (MH- Z19B), and the temperature and humidity sensor (DHT22). These sensors communicate with a web application server through the ESP8266-01 Wi-Fi module. The sensor values are displayed on a TFT (Thin Film Transistor) display, ensuring continuous monitoring with a time delay. The Arduino Pro Mini Board, powered by an FTDI (Future Technology Devices International Ltd.) chip, facilitates the sensor readings by operating on specific protocols. The ESP-01 module provides internet capability, enabling the system to host a custom web server.

The sensor data is utilized to generate graphs on a dashboard, presenting the air quality information in a visually accessible manner. The displayed values are aligned with the standard guidelines set by the Central Pollution Control Board (CPCB). Moreover, the system supports historical data retrieval through integration with a PostgreSQL database, allowing users to analyze air quality trends over time.

By providing real-time monitoring, comprehensive analytics, and historical data insights, our AQI measurement and analytics system empowers users to make informed decisions to improve air quality and mitigate the potential risks associated with pollution.

Keywords : Arduino, PCB, Altium, Flask, breadboard, ESP8266-01, PMS5003, MQ131, MHZ-19B, ZP07-MP503.

I. INTRODUCTION

The motivation behind studying the air quality system comes from the escalating degradation of our surroundings, resulting in adverse health effects on humans and ecosystems due to suspended particles. Although infrastructure development and technological advancements propel societal progress, they also pose a significant health threat that is often overlooked. When envisioning a future marked by cutting-edge achievements, it is imperative to address the potential scarcity of fundamental necessities that are freely available. Consequently, it is our shared responsibility to navigate this dualistic landscape and prioritize sustainable living practices [1].

This study focuses on examining pollutants such as PM2.5 (Particulate Matter), ozone levels, CO2 gas, and organic compounds, as well as measuring temperature and humidity. The Central Pollution Control Board (CPCB) has established standardized parameters for these pollutants. Through comprehensive monitoring and analysis, we aim to create an environment that promotes the well-being of current and future generations, striking a harmonious balance between progress and sustainable living.

Our emphasis is on PM2.5 particle size, with the dedicated sensor retrieving PM10 and PM1 data as well. These measurements in microns highlight the potential health risks of airborne particles penetrating human lungs and causing respiratory diseases.

The main brain of our project is the Arduino Pro Mini Board, which is integrated into the PCB (Printed Circuit Board), and all the sensors and components communicate through it to establish a connection to the web server. To calculate the AQI level of the environment, we first need to understand the term. So, we have given a small brief about understanding the need and rules to compute the AQI mathematically. The measurement and analysis of AQI levels through our project working flow is shown below in a flow chart in Figure 1.

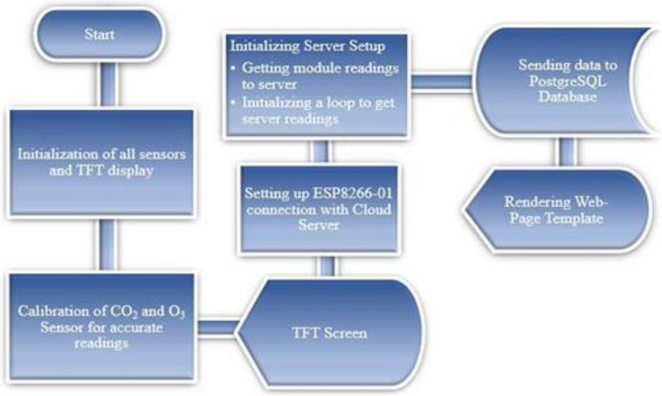


Figure 1 : Workflow of AQI Monitoring System

II. AIR QUALITY INDEX

The Air Quality Index (AQI) serves as a vital communication tool employed by government authorities to raise public awareness about air quality and the presence of various contaminants such as dust, factory emissions, and forest fires. Significant compounds contributing to ozone layer depletion, including CO2, CO, NO2, and SO2, vary in concentration from one country to another, leading to distinct AQI standards set by each nation.

In India, the CPCB sets AQI standards under the Swachh Bharat Abhiyaan initiative. Over 320 monitoring stations in 240 cities measure eight pollutants at 24-hour and 8- hour intervals. The pollutants include PM10, PM2.5, NO2, SO2, CO, O3, NH3, and Pb. Six categories are defined to aid in the understanding of pollutant levels for decision-making and public health protection.
These categories are named Good, Satisfactory, Moderate, Satisfactory, Moderate, Poor, Severe, and Hazardous. According to these ambient concentrations, the health standard is evaluated. The worst case for humans is the hazardous category, which reflects the higher concentrations of contaminants present in the air. These breakdowns can be measured and understood easily in Table 1[2].

Table 1 : AQI Standard Score

AQI Category (Range)	CO_2 (24hr) (ppm)	$PM_{2.5}$ (24hr) (ug/m3)	O_3 (8hr) (ppm)	CO (8hr) (ppm)
Good (0-50)	350-1000	0-30	0-50	0-1.0
Satisfactory (51-100)	1000-2000	41-80	51-100	1.1-2.0
Moderate (101–200)	2000-5000	61-90	101-168	2.1-10
Poor (201–300)	>5000	91-120	169-208	10-17
Severe (301–400)	5000-40000	121-250	209-748	17-34
Hazardous (401-500)	40000+	250+	748+	34+

The project prioritizes PM 2.5 due to its severe health impact, affecting respiratory and brain function. AQI levels are determined based on 8-hour or 24-hour records for various pollutants, with different calculation methods in different countries. India uses 24-hour averages for most pollutants but 8-hour averages for Ozone and Carbon Dioxide in its sub-indices derived from monitoring stations. The AQI table ranges from satisfactory to hazardous, reflecting pollutant levels.

III. DESIGNING OF AQI SYSTEM

The provided diagram in depicts the complete workflow of the AQI system implemented in the project, including the introduction of sensors. Further details about the system and its components are described below.

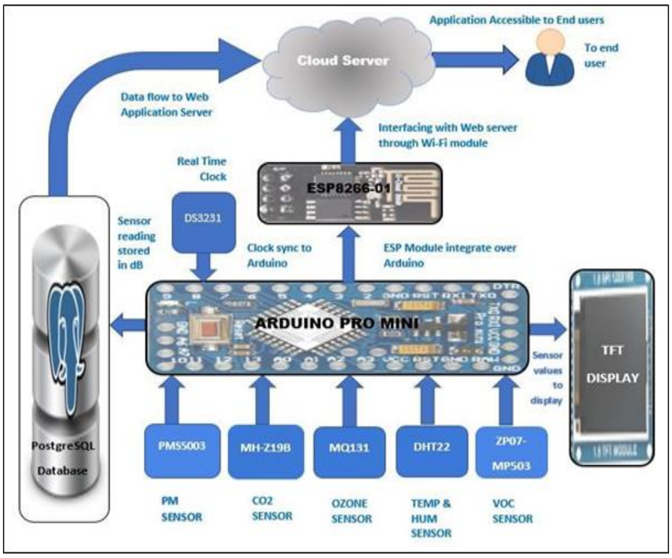


Figure 2 : AQI Monitoring System Block Diagram

A. Sensors Used:

1) MQ-131 sensor: The MQ131 sensor (Figure 3) detects ozone gas through changes in conductivity. It requires 48 hours of heating and calibration, providing readings every 8 hours for up to 5 years [1].

Figure 3 : Ozone Sensor

3) PMS5003 Sensor: The PMS5003 sensor (Figure 4) detects PM2.5, PM10, and PM1 values using laser scattering. It measures the angle of scattered laser light to determine particle diameter and converts it into PM concentration levels using a photodiode [2].

Figure 4: PM Dust Sensor

4) DHT22 Sensor: The compact temperature and humidity sensor (Figure 5) has three pins, low power consumption, and can transmit data up to 20 meters. It operates at 3.3V to 6V, quickly senses conditions in 2 seconds using a Polymer capacitor, and connects to an Arduino board's second-pin[3].

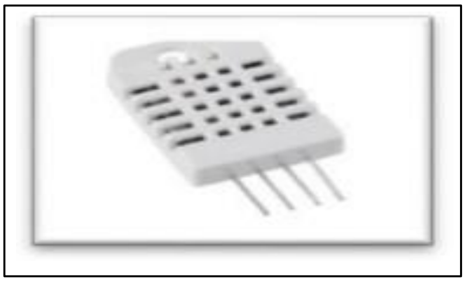


Figure 5 : Temp. & Hum. Sensor

5) MH-Z19B: The MH-Z19B sensor (Figure 6) measures carbon dioxide (CO_2) concentration using non- dispersive infrared technology. It requires a 20-minute preheat time, provides a response in 60 seconds, operates on 3.3V to 5.5V, and has a lightweight design lasting up to 5 years[4], [5].

Figure 6 : CO_2 Sensor

6) ZP07-MP503: The MP503 sensor (Figure 7) measures Volatile Organic Compounds (VOCs) like Benzene, formaldehyde, CO, NH_3, and cigarette smoke. It has good sensitivity, pre-calibration, operates on a 5V power supply, and has a short preheating time[6]. It detects target gases through resistance change and has a lifespan of up to 5 years.

Figure 7 : VOC Sensor

7) ESP8266 Wi-Fi Module: The ESP-01 ESP8266 (Figure 8) Wi-Fi
Transceiver Module combines the TCP/IP protocol stack with 2.4 GHz Wi-Fi access. It can self-host web apps or offload networking, serving as a Wi-Fi shield with ample storage for sensor integration and GPIO pins[7], [8].

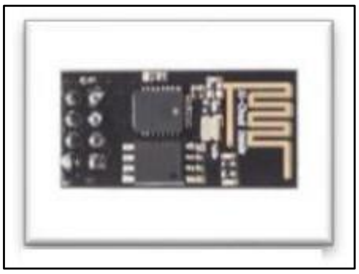


Figure 8: ESP Module

A. Boards (Integrated Circuits):

Arduino Pro Mini: It (Figure 9) is a compact variant of the Uno Board with an ATmega328P chip, 14 digital IO pins, a voltage regulator, and an auto-reset. It serves as a data hub, connecting the ESP module and display, and comes in 3.3V and 5V with 8 MHz & 16 MHz versions respectively, with the latter chosen to meet the sensor requirements.

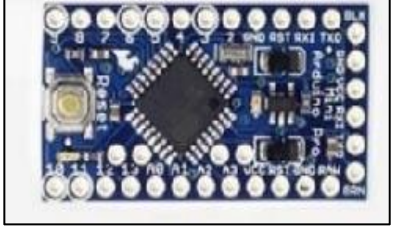


Figure 9 : Arduino Pro Mini

FTDI USB to Serial TTL Converter Module: The FTDI serial converter (Figure 10) enables serial communication with microcontroller boards like Arduino. It operates at 3.3V to 5VDC, provides up to 500mA current, and has breakout pins for easy connection. The DTR pin enables auto-reset functionality during sketch uploading with the Arduino Pro Mini[9].

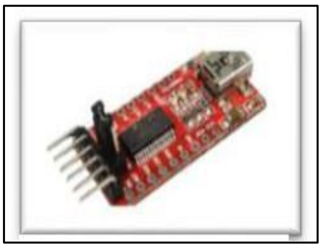


Figure 10 : FTDI Module

DS3231 Real-Time Clock: It (Figure 11) uses a built-in battery and communicates with Arduino boards using the I2C protocol for accurate timekeeping.

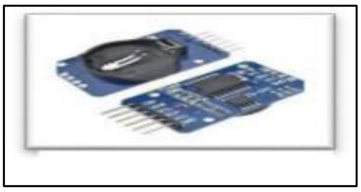


Figure 11 : RTC Module

TFT LCD Display: The 1.8-inch LCD (Figure 12) is an Arduino board shield with a micro-SD slot and uses the ST7735 driver. It has 128x160 color pixels and supports 18-bit color (262,144 shades).

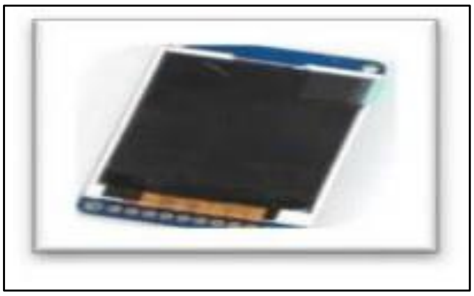


Figure 12: TFT Screen

B. Software Used:

1) Altium Designer: Altium Designer is a leading software for PCB design, allowing the simulation of schematic circuit diagrams and incorporating component libraries. It generates GERBER files for PCB manufacturing.

2) Flask Server: Flask Server hosts web page templates created with HTML, CSS, JS, and Python. It receives data from the Arduino board via Python socket programming, stores it in a PostgreSQL database using psycopg2, and renders the data in graphs and datasheets.

3) PostgreSQL: PostgreSQL is an open-source RDBMS with high scalability. It supports complex workloads and offers flexibility in data types. This project uses PostgreSQL version 12.13, ensuring compatibility with other application software.

4) Arduino IDE: Arduino IDE is a user-friendly software for programming and uploading code to Arduino boards, providing an interface, code editing tools, and a function library for Arduino projects.

5) VS Code Editor: VS Code (Visual Studio Code) is a versatile code editor used for Python and other applications, offering features like syntax highlighting, debugging tools, and an integrated terminal for efficient project development and management.

IV. PROJECT DEVELOPMENT

The system design begins with an Arduino Pro Mini powered by the ATmega328p microcontroller. Various sensors, such as the PMS5003, MQ-131, MH-Z19B, DHT22, and ZP07-MP503 VOC sensor, are connected to the Arduino through their dedicated pins using serial communication. The Arduino board is powered by an FTDI adapter, providing a 3.3V to 5V supply. The Pro Mini has 6 analog pins and 14 digital IO pins, with 6 reserved for PWM outputs.

The sensors' pins are connected to the Arduino, and a display is connected to show the experimental data. The setup is interfaced with the Arduino IDE, where libraries for the respective modules are added to the sketch. The code is compiled and uploaded to the Arduino board.

Data is recorded from the air particles and displayed on the serial monitor of the IDE. To enable internet connectivity, a Wi-Fi module is added and integrated with the existing setup. The module's firmware is updated to the latest version, improving functionality and debugging capabilities. During firmware flashing, the module pins are connected to the Arduino's General-Purpose IO pins.

Once the setup is complete, the hardware is connected to the internet, and the data is stored in a PostgreSQL database. The real-time functionality is displayed on a web page through line graphs and pie charts. Users can access the cloud server to observe the data, compare it with standard readings normalized by CPCB standards, and analyze it date-wise.

The system continuously refreshes the sensor readings in a loop with a certain delay, recording data every 10 minutes. By properly preheating the sensors during initialization, high accuracy, and precision can be achieved. The system provides the mean or average values Of the sensor readings throughout the day whenever the system is active.

Overall, the systematic flow of the setup is presented in the block diagram, enabling real-time data monitoring and analysis.

V. CIRCUIT DESIGN, FABRICATION AND ASSEMBLY

The AQI model was initially tested by connecting each module individually to an Arduino Pro Mini on a breadboard using jumper wires and passive components. After ensuring proper functionality, the connections were compiled together, and a schematic design was created using Altium Designer software. The breadboard setup, including all the sensors and ICs, was documented in Figure 13.

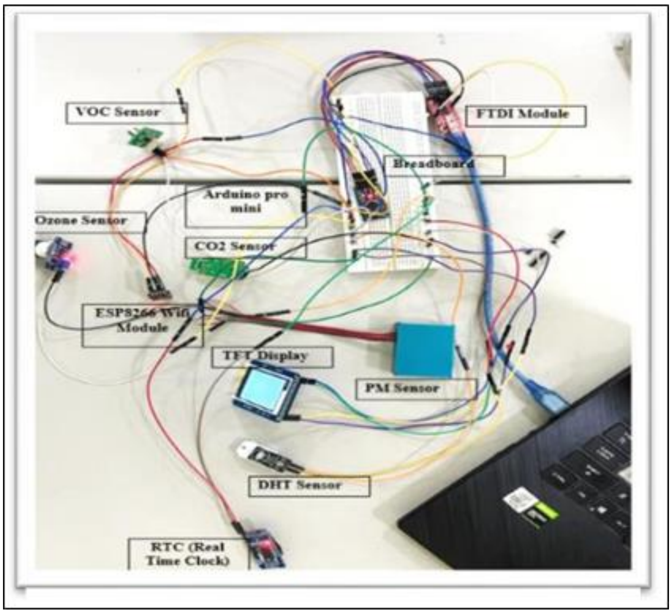


Figure 13 : Breadboard Connection

In Altium Designer, the circuit diagram and PCB designing process begin with creating a schematic diagram (Figure 14). The schematic editor allows to add components, connected them with nets, and defined their electrical properties. The components used in the schematic are linked to their respective footprints.

Once the schematic is complete, the PCB layout process starts. The components are transferred from the schematic to the PCB layout editor, arranging them in the desired positions. The PCB editor provides various tools to route traces, place vias, add planes, and define design rules for spacing, clearance, and other parameters.

After the PCB layout is finalized, the fabrication files are generated. This includes the Gerber files, which provide the necessary information

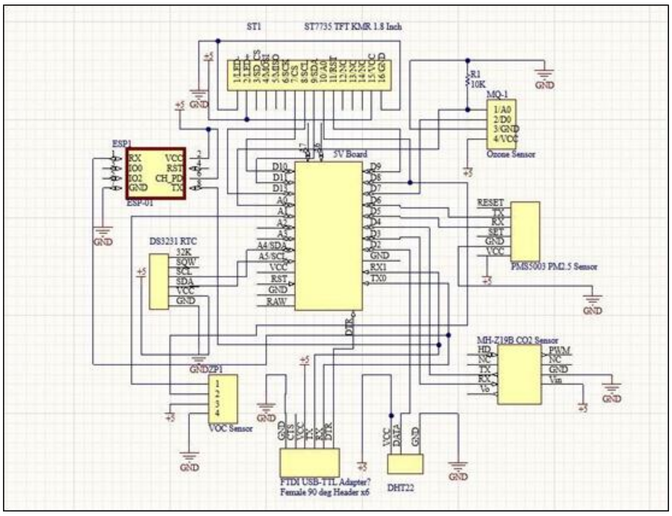


Figure 14 : Schematic diagram of AQI System

For the PCB manufacturing process. The Gerber files contain data for each layer of the PCB, including copper traces, solder masks, silkscreen, and drill holes. So here a glimpse of 3D visualization is shared in Figure 15, created for the AQI system.

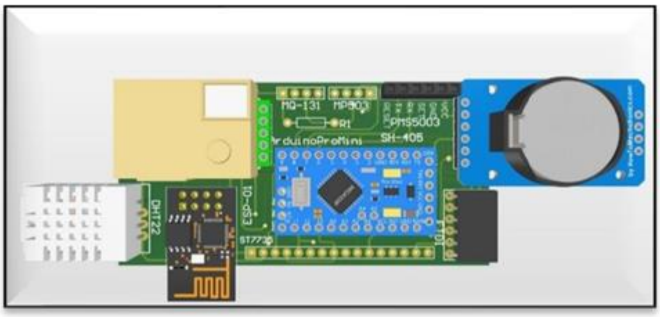
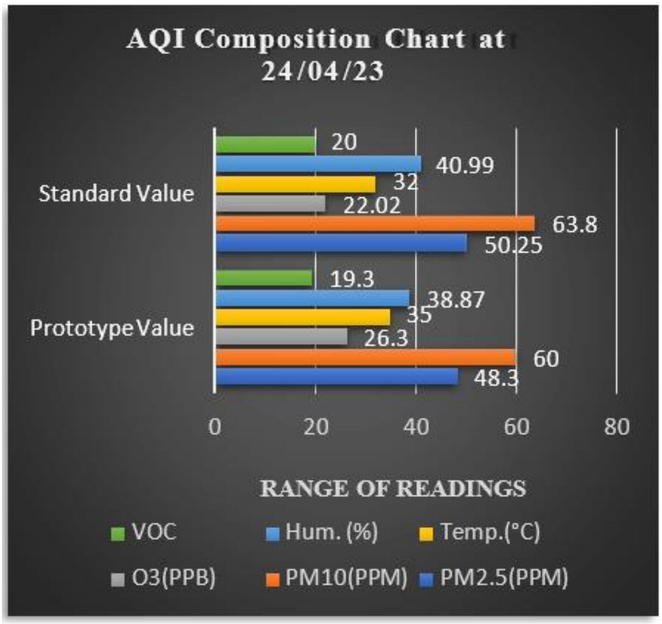


Figure 15 : Top View of 3D design in Altium Software

Altium Designer also supports the generation of other fabrication files, such as the NC drill file for drill hole locations and sizes, the assembly drawing file for component placement information, and the Bill of Materials (BOM) file lists all the components that are used in the design. These fabrication files are then sent to a PCB manufacturer for production, where the PCB is fabricated based on the design specifications.

VI. TESTING OF THE AQI SYSTEM

Table 2: AQI Composition Chart



The AQI (Air Quality Index) model testing took place on 24/04/2023 at different locations in Lucknow city: KV Aliganj, a busy traffic area; Kukrail Picnic spot, a green area with less human activity; and 1090 Chauraha, where a significant number of pollutants can be detected.

At KV Aliganj, various parameters were recorded at intervals of around 15 minutes using a prototype. The recorded parameters include PM2.5, PM10, PM1 (particulate matter), ambient temperature, humidity, volatile gases (such as CO and NO2), ozone, and CO2. The prototype readings were then compared to standard values for PM2.5, PM10, ozone, ambient temperature, and relative humidity.

The difference between the prototype readings and the standard values indicates the variation in readings at different time intervals. By computing the average values of each sensor's readings recorded within 15 minutes, the aggregate AQI score can be determined for that interval. It's important to note that the margin between the standard and model readings can be influenced by various environmental factors.

For analysis, the graphical variance for KV Aliganj Lucknow is shown on a chart (Table 2), which allows the comparison between the reference and practical values to be observed. The values shown on the chart are the average values of each sensor's readings recorded within the 15- minute intervals.

This process is repeated for the other locations as well, which allows the comparison of air quality across different parts of Lucknow city.

By following this procedure, the AQI model provides a means of monitoring and assessing the air quality at different locations in the city and helps in understanding the air pollution levels in real-time. The model's accuracy and effectiveness can be evaluated by comparing its readings with the reference values and understanding any variations due to environmental factors.

VII. WEB APPLICATION DEVELOPMENT

Language and Application: The programming language chosen for the software part is Python, which is widely used for its simplicity and versatility. A rich ecosystem of libraries and frameworks that facilitate the development of web applications is provided by Python, making it an ideal choice.

Flask web framework is as the backend of the application, which is a lightweight and modular framework allowing developers to build web applications fast and resourcefully. It provides the obligatory tools and features for handling HTTP requests, routing, and rendering templates. Its effortlessness and flexibility make it well- suited for small to medium-sized projects.

The application employs PostgreSQL as the database, a powerful and open-source Relational Database Management System that offers strong data storage, and querying capabilities, along with data integrity.
On the front-end side, the application utilizes:

• HTML is the standard markup language that creates web pages and provides the structure and content of the application's user interface.
• Tailwind CSS is a utility-first CSS framework that offers a wide range of pre-built classes for rapidly styling the application's components.
• JavaScript language advances the interactivity and dynamic behavior of the web page, enabling real-time updates and enhancing the user experience.
• Methodology: The application follows a structured approach, combining hardware integration, data processing, and web development.

 Hardware Integration: The various sensors and the TFT display are connected to the microcontroller (presumably an ESP8266-based development board) through appropriate interfaces (e.g., I2C, UART, GPIO). The Python code runs on the microcontroller, which acts as the central processing unit for the device. The code reads data from the sensors and updates the TFT display with real-time information.
 Data Processing: Python's versatility allows easy integration with different sensor libraries, enabling the application to collect data from each sensor accurately. The collected sensor data is then organized and processed to eliminate noise and improve accuracy. It is then ready to be used for visualization and storage.
 Web Development: Flask, a Python web framework, is employed as the back-end to create a web server running on the local device. The server receives the processed sensor data and stores it in a PostgreSQL database. The Flask web framework allows for easy handling of HTTP requests and responses, enabling seamless communication between the device and the web interface.

On the front end, a web page is designed using HTML, Tailwind CSS, and JavaScript. HTML structures the content, Tailwind CSS adds styling for an aesthetically pleasing interface, and JavaScript handles interactive features. The web page fetches data from the Flask server using AJAX requests, providing real-time updates of the sensor readings. The user can view the live sensor data on the web page, offering convenient monitoring and analysis of environmental conditions.

Final Application Outcome:

The final application is an all-in-one environmental monitoring system that combines various sensors, microcontrollers, and web development technologies. It provides real-time statistics on AQI parameters like particulate matter, ozone pollutants, volatile organic compounds, carbon dioxide concentration, temperature, and humidity. The ST7735 TFT display on the device itself allows for quick on-site access to these measurements. Users can easily grasp trends and variations in the data by observing the chart's visual representation in Figure 16.

Figure 16 : Dashboard View

To enhance data interpretation, the application includes a toggle button that allows users to switch between chart and pie chart views. The pie chart provides a concise overview of the data distribution, enabling users to quickly identify dominant factors affecting the environment. This feature offers a simplified visual representation that complements the detailed chart view.

Furthermore, the application provides access to previously recorded datasets stored in the database (Figure 17). A dedicated button enables users to retrieve and analyze historical data. This functionality empowers users to compare current and past data, facilitating trend analysis and long-term environmental monitoring.

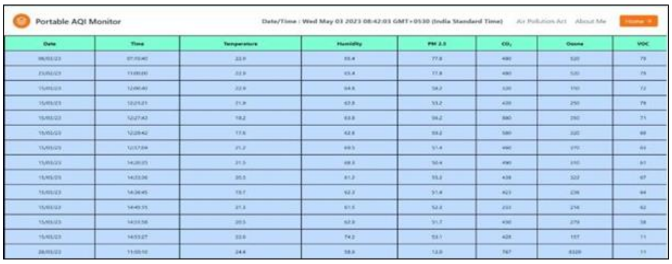


Figure 17 : Dataset View

VIII. RESEARCH OUTCOME

The application's outcome offers valuable insights into the immediate environmental conditions in the monitored area. Users can easily track changes in air quality and environmental factors over time, allowing them to take informed actions for improving indoor air quality and overall living conditions.

This compact and efficient environmental monitoring system finds potential applications in various scenarios, including homes, offices, industrial settings, and public spaces, where continuous tracking of air quality and environmental parameters is crucial for the well-being and safety of occupants.

The final system aims to reform air quality monitoring by developing an advanced device that provides continuous and real-time information on numerous air quality parameters. This device is designed to be compact, cost- effective, and easily deployable in different locations without the need for technical expertise. It offers a user- friendly interface for configuring settings and accessing air quality data effortlessly.

One of the key features of the final system is its ability to promptly alert the public and authorities about high pollution levels. This ensures timely interventions and preventive measures to protect public health. The system also incorporates data analysis capabilities to

identify patterns and trends in air quality, enabling effective air pollution control strategies and policies.
With a focus on sustainability and reliability, the final system operates effectively under diverse environmental conditions. It considers the integration of renewable energy sources or low-power consumption mechanisms to ensure long-term viability and reduce environmental impact.

The implementation of this final system has the potential to significantly contribute to environmental management efforts, public health initiatives, and informed decision- making. By providing comprehensive and accurate air quality data, it can help create healthier living environments, improve overall air quality, and enhance the well-being of communities.

IX. FUTURE SCOPE

The future of air quality monitoring involves GPS technology for improved understanding, prediction, and intervention in pollution. Spatial databases, collaboration with stakeholders, and air purifier integration can revolutionize air quality management and promote healthier environments for a sustainable future.

X. ACKNOWLEDGMENT

We acknowledge the support of the Remote Sensing Applications Centre, Lucknow for funding the research work and the development of the proposed system.

XI. CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

XII.METHODS AND MATERIAL

Arduino

XIII. RESULTS AND DISCUSSION

Arduino is a compu

XIV. CONCLUSION

In this monitoring and management for green environment.
Cite this article as :

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SUSHIL CHANDRA, born in January 1970 in Uttar Pradesh, is a highly accomplished individual with an impressive academic background. He obtained his B.Tech. in Computer Science from IET Lucknow, a Diploma in Export Management from Chennai, and an MBA in Marketing & Finance. Currently, he is pursuing a Ph.D. in Business Administration from Lucknow University.

For the past three decades, Sushil Chandra has been a dedicated professional in the field of Remote Sensing Applications. Since 1992, he has been serving as a Scientist and holds the prestigious position of Head of the CIP & DM Division (Computer Image Processing and Data Management) at the Remote Sensing Application Centre (RSAC) in Uttar Pradesh. His contributions to the field have earned him recognition, including a residential scholarship from the Government of India through UPSC and the prestigious PRASHASTRI PATRA from RSAC-UP for his exceptional work on the occasion of the 20th Foundation Day of RSAC. Notably, Sushil Chandra's expertise and knowledge have led to him being invited as a speaker at G20 Lucknow Workshops Event, where he shared his valuable insights with fellow professionals. His dedication to research and continuous pursuit of knowledge through his Ph.D. studies exemplify his commitment to furthering his field's advancement.

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She is a Software Developer specializing in Mobile App Development at the Remote Sensing Application Centre in Uttar Pradesh, India. Her research focuses on utilizing gyroscopic sensors in the development of Android- based mobile applications, and her paper on this topic was published in the International Journal of Innovative Research in Computer Science & Technology in November 2022. She has also contributed to the field through her involvement in designing and developing a B2C Farming Information System Solution for the Smart Supply Chain of Fruit Crops in Uttar Pradesh. Her work on this project was published in the International Journal of Computer Science and Mobile Applications in January 2020.

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He started his career as a Python web application developer at Cosmo Info Solution in Lucknow, where he developed multiple web applications. Additionally, he freelanced for VelleStudio in Pune, contributing to various web projects. Later, He joined Persistent System in Pune as a Salesforce Trainee, specializing in LWC, Apex, Visualforce, and Salesforce Mobile Developer, earning several Trailhead badges. Since 2022, he has been employed as a Software.

Developer at the Remote Sensing Applications Centre in Uttar Pradesh, focusing on Python development and conducting research. His achievements include winning the first position in the Tech Quiz at Modern Techiesta 2018, and receiving certifications in LibreOffice Suite from the Spoken Tutorial Project at IIT Bombay, Google Colab Machine Learning App, and PHP from Cetpa Infotech Pvt. Ltd.

ROHAN KHARE, a talented individual from Kanpur, India, was born in 2002 and is currently pursuing a BE in Artificial Intelligence & Data Science at ISBM College of Engineering. With a passion for technology and data, he has been interning at Remote Sensing Applications Centre (RSAC) UP and previously at Accrete.ai, honing his skills in data validation. His diverse software projects, including the Covid-19 Predictor and DBMS Supermarket Billing System, showcase his proficiency in C++, Python, JavaScript, HTML, and CSS. Moreover, Rohan's thirst for knowledge led him to complete certification courses in Data Science and the Internet of Things. As an active coordinator of Grand Techno-event 2022 and a celebrated creative writer, he has left his mark on various platforms, making him a promising and multifaceted professional.

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