AIR QUALITY MONITORING AND ANALYSIS BASED PREDICTIVE SYSTEM

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August 2024

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Dissertation submitted in partial fulfillment of the requirements for the Special Honors Degree of Bachelor of Science in Information Technology Specializing in Information Technology

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Declaration

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Abstract

In recent years, air pollution has become the leading source of serious health problems among living things, particularly humans. It might induce respiratory and cardiovascular problems. Air pollution accounted for 8.1 million deaths globally in 2024, becoming the second leading risk factor for death, including for children under five years. Of the total deaths, Air pollution is a critical global issue, significantly impacting public health and the environment. This research develops an IoT-based air quality monitoring system designed to deliver accurate, real-time data on key pollutants such as methane (CH_4) and carbon monoxide (CO), etcetera. The objective is to present a low-cost, efficient solution for continuous air quality monitoring, particularly suited for urban areas. The system utilizes an Arduino Uno board, MQ4 and MQ7, MQ135 gas sensors, and an ESP32 Wi-Fi module to measure gas concentrations, convert sensor readings into voltage, and transmit the data to a cloud server. A dedicated mobile application provides users with real-time access to air quality data, facilitating insights into pollution trends and enabling timely mitigation efforts. Testing demonstrated the system's accuracy in detecting gas concentrations and its reliability in real-time data transmission. Results indicate that the system is effective in monitoring air pollution, offering a scalable and accessible tool for environmental monitoring. Conclusions emphasize the potential of IoT technologies in addressing environmental challenges, with recommendations for further enhancements, including expanding the range of detectable pollutants and improving the system's integration with existing urban infrastructure.

Key words – Air quality monitoring, Wireless Sensor Networks, Internet of Things (IoT), Methane detection

Acknowledgement

First and foremost, it is a genuine pleasure to express my deep sense of gratitude to my Research Supervisors, Ms. Chathurangika Kahandawaarachchi and Ms. Pipuni Wijesiri for her fullest support, dedication, enthusiasm, and overwhelming desire his expressed throughout the project to make this research a success. I gratefully acknowledge his patience at the time of long piece of writing this report.

My sincere thanks go to seniors who helped to do this research well.

Finally, I would like to thank everyone who helped me in many ways to make my project a success.

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List of Abbreviations

IoT	Internet of things
CEA	Central Environmental Authority Sri Lanka
DMT	Department of Motor Traffic
PPM	Gas concentration
TCP	Transmission Control Protocol
UI	User Interface
API	Application Program Interface
SDLC	Software Development Life Cycle
DB	Database
CO	Carbon Monoxide
IT	Information Technology

1. INTRODUCTION

1.1 Background Literature

Approximately two-thirds of the world's population suffers from poor air quality [1]. The quality of the air we breathe, or air quality, is an extremely valuable resource that ought to be available to all. According to the most current World Health Organization data, over half of the world's population lives in significantly air-polluted metropolitan areas, but nearly none of them are aware of how clean the air is where they live.

Air pollution has a significant impact on the quality of life and public health. Monitoring air pollution is significant for raising public awareness and improving human health and sustainable urban environments [3]. Our environment has been affected by air pollution due to the increased population, industries, and traffic on the roads. Worldwide, air pollution, both indoor and outdoor, has reached dangerous levels, causing health problems that affect people in both developed and developing countries. Ambient In 2016, it was projected that air pollution in both urban and rural regions contributed to 4.2 million premature deaths worldwide. The primary cause of ambient air pollution in Sri Lanka is automobile emissions. Outdoor air pollution is mostly generated by pollutants from motor vehicle combustion, solid fuel burning, and industry. Air pollution claimed the lives of over 24000 individuals in Sri Lanka; many of them were children. The urban school had much higher air pollution levels than the rural school. According to the population in Sri Lanka, kids are the most effective group exposed to high levels of pollutants, which are worsened by the congestion of large schools in cities, particularly in Colombo.

There are many distinct sorts of air pollution; particulate matter (PM), carbon dioxide (CO2), carbon monoxide (CO), ground-level ozone (O3), nitrogen oxides (NO_x), and sulfur oxides are the most significant. (So_x) and lead (Pb), both of which are present in the surrounding air. Pollutant particulate materials (PM2.5 or PM10) can cause several kinds of respiratory, cardiovascular, and blood diseases. Medical studies have shown that PM2.5 can be easily absorbed by the lung, and high concentrations of PM2.5 can lead to respiratory disease or even blood diseases [2].

Table 1.1 Criteria Pollutants and their health and environmental effects

Pollutant	Most relevant Health Effects
Carbon Monoxide(CO)	Aggravation of angina pectoris; decreased exercise tolerance; risk of foetuses
Lead (Pb)	Impaired blood formation ; infant development effects
Nitrogen Dioxide (NO_2)	Aggravation of respiratory disease; atmospheric discoloration
Particulate Matter (PM_{10} and $PM_{2.5}$)	Aggravated asthma; coughing; painful breathing; chronic bronchitis; decreased lung function; Premature death in heath and lung patients
Ozone (O_3)	Decreased Pulmonary function; surrogate for eye irritation
Sulphur Dioxide (SO_2)	Wheezing, shortness of breath, chest tightness; premature deaths

Air pollution has both acute and chronic effects on human health, affecting a few different systems and organs in recent years. Pollution has had a direct influence on human health. To rising levels of noise and air pollution, people are more susceptible to different health issues [4].

Muthukumar S. et al., 2018) [15]. Growing industrialization and urbanization are the main contributors to noise and air pollution. The primary factors that harm both human health and the environment (Janeera D.A. et al., 2021) [23]. Monitoring and limiting such emissions are crucial.

Monitoring contamination using traditional methods was time-consuming and ineffective (Bhuvaneswari T. et al., 2020) [18]. With the development of technology, quick and effective pollution monitoring has been developed in the Internet of Things (IoT) (Nižetić S. et al., 2020; Abid M.A. et al., 2022) [21]. With the aid of many sensors, it allows data exchange among humans, electrical and technological products, and the internet. Because it is practical, economical, and efficient, IoT is successful (Sasikumar A. et al., 2023) [16]. Asthma attacks and other respiratory ailments are on the rise due to environmental problems brought on by pollutants from automobiles, trucks, and buses. Fifty percent of the airborne carbon monoxide is caused by traffic alone (Rakhonde M.A. et al., 2018). [19]

Table 1.2 Current state of Colombo's vehicle-related air pollution

Pollutant	Grand mean concentration	Range
TSP	404 µg/m**3** (g h)	100-700 µg/m**3** (g h)
Pb	0.415 µg/m**3** (g h)	0.01-2.0 µg/m**3** (g h)
CO	4.0 ppm (3 hr)	2.25 ppm
SO_2	0.019 ppm (3 hr)	0.0045-0.054 ppm
THC	2.7 ppm (3 hr)	2-5 ppm
NMHC	0.83 ppm (3 hr)	0.2-3.00 ppm
CH_4	1.9 ppm (3 hr)	1.8-2 ppm

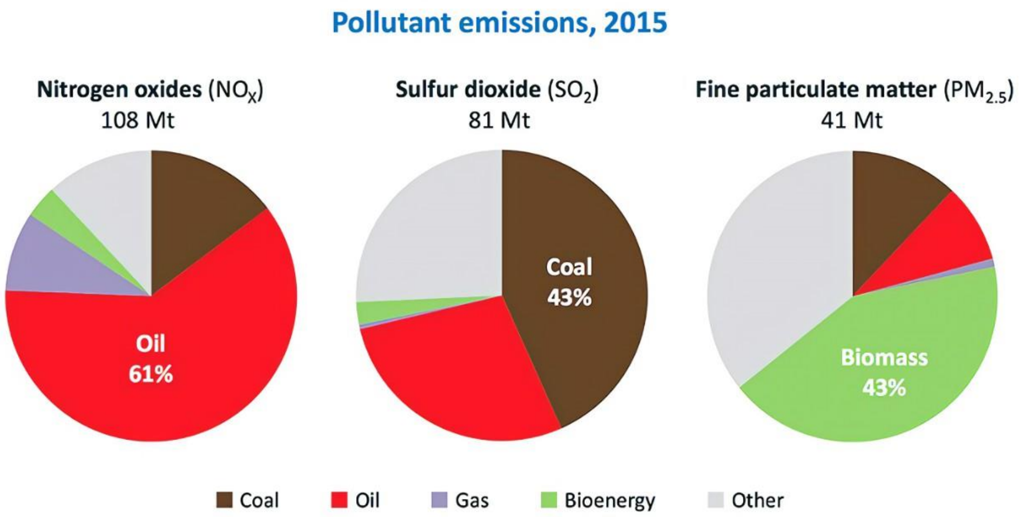

Figure 1 Summary of responses Criteria Pollutants and their health and environmental effect

Source: Masters and Ela, 2015

To tackle this issue, research suggests an air quality monitoring and analysis-based predictive system for the proposed IoT air quality monitoring devices. To track the amount of air pollution, a unique Internet of Things-based air quality monitoring device system has been developed. The main contributions are in this section. The system comprises three main parts: the hardware system, the server backend, and the front-end mobile application. The air quality monitoring hardware device is installed in suitable urban, open locations to monitor the ambient air quality in these places. This hardware system uses an Arduino board esp32 Wi-Fi module to transmit the information packet to the MongoDB database. This hardware system also consists of this device, which consumes power, so we can provide the power from power banks, etc. The mobile application gets real-time air quality information by accessing the database and displays the air pollution level. The ESP32 Wi-Fi module provides sensor data to the database each minute, enhancing the device's real-time ability. A preset terminal number is utilized to determine the device's location at the implementation site. Instead of employing GPS, a predetermined terminal number approach was used to decrease the data packet size.

This system operates in real time, uploading data every minute. To identify the device's location, the terminal number is sent along with sensor data. A data packet is sent using an HTTP POST request. To ensure data security, the packet is sent to the server in an encoded format. The Wi-Fi module establishes a TCP connection to the server [28]. The data processing code is implemented using an Arduino Uno board. This Arduino code collects sensor inputs, processes them, and sends the results to the database via Wi-Fi. The proposed system offers a low-cost, highly portable, and easily maintainable solution by providing real-time air pollution levels. A key benefit of this approach is raising public awareness, which aids the elderly, children, and those with respiratory conditions. Most modern pollution monitoring techniques track and consider the emissions from different types of vehicles. An overview of a few modern techniques for tracking and identifying the amount of air pollution is provided in this section.

In 2021, Gautam, A., et al., proposed an embedded system utilizing sensors and IoT technology to monitor and control air pollution on a global scale. The system prototype, based on Raspberry Pi, incorporates sensors and actuators to achieve this goal. Additionally, a website was developed to remotely monitor gas levels. The results indicate successful testing and implementation of the entire system [9].

Based on Internet of Things (IoT) technology, Rauniyar, A. and associates present a novel vehicle emissions monitoring system for smart cities in 2022. Infrastructure managers and analysts may now analyze vehicle noise and pollution sensor data in real-time thanks to this solution. Artificial intelligence (AI) algorithms are used to evaluate the gathered data and successfully classify the emission sources into three levels: high, medium, and normal emitters. In addition, the researchers want to create a complete software program that can be easily integrated into the current intelligent transportation systems seen in smart cities. [25].

In 2020, Kaivonen, S. and Ngai, E.C.H., together with others, suggested using wireless sensors mounted on public transportation vehicles to track air pollution in real time. Additional measurements are provided by these sensors in conjunction with the data gathered from fixed sensors and Uppsala's lone ground-level monitoring station. As a result, several studies have been conducted to assess the system's data and communication quality [26].

Zhang, D. and Woo, S.S. presented a plan in 2020 to create an air quality pattern in a specific area using IoT sensors that are both mobile and stationary and are mounted in patrol cars. The thorough [10]

The whole range of the surrounding regions' air quality is assessed. The efficacy of the suggested strategy is demonstrated by how well it gauges and predicts air quality using a variety of machine learning algorithms and real-time data[16]. The results indicate that air quality forecasting and monitoring within the framework of smart cities is feasible and effective [23].

An IoT-driven Smart-Air system for efficient air quality monitoring and real-time data transfer to a web server via LTE technology was proposed by Jo, J., et al. in 2020. The components of the system include a CPU, an LTE modem, and pollution tracking sensors. Through the online server, users may always check the quality of the air from anywhere at any time. Moreover, all data may be stored via the web server in the cloud, giving users access to resources for additional outdoor air quality analysis [27].

A proposal for an Internet of Things (IoT) method to monitor car emissions was made in 2022 by Kumar, A., et al. The Arduino Uno's sensors are used to track the number of pollutants released from the car's exhaust system. In addition, the prototype makes use of a Raspberry Pi for control and monitoring. Under this method, the driver of the car receives an audible warning through a buzzer, and if they don't comply, they receive a penalty letter that is sent to their email address [24].

The ETAPM-AIT model was presented by Asha, P., et al. in 2022. It entails the use of an Internet of Things (IoT)-based sensor array to monitor eight different pollutants, including NH3, CO, NO2, CH4, CO2, PM2.5, temperature, and humidity. The sensor array oversees monitoring the pollution levels and sending the information, via gateways, to a cloud server for additional analysis every 5, 15, 30, and 60 minutes. After the simulation analysis is finished, artificial intelligence techniques are used to examine the outcomes [17].

Existing monitoring techniques require laboratory analysis and have poor accuracy and sensitivity. Consequently, better vehicle monitoring methods are required [11]. To overcome the above drawbacks, a novel of IoT- air quality monitoring devices has been proposed in this system.

Table 1.3 Summary of Literature review

Author	Application	Techniques	Remark
Rauniyar, A., and colleagues	Smart cities using an IoT-based vehicle emissions monitoring system	Reacts, a PostgreSQL database	85.2% of the vehicles were classified as normal emitters, 7.1% were medium emitters, while 7.7% of the vehicles were classified as high emitter vehicles
Kaivonen, S. and Ngai, E.C.H	Wireless sensors are used in public transportation vehicles to detect air pollution in real time.	Python scripts, MongoDB, JSON, HTTP API, PHP	
Zhang, D. and Woo, S.S.	Using both mobile and stationary IoT sensors installed in the cars, the air quality pattern in the region	mobile and stationary IoT sensors integrated into the vehicles	machine learning algorithms and real-time
Kumar, A	IoT-based system for monitoring vehicle pollution	proposed an Internet of Things (IoT) solution aimed at monitoring vehicle emissions	
Asha, P., et	IoT enabled environmental toxicology for air pollution monitoring using AI techniques	Artificial Algae Algorithm	model, which uses an Internet of Things-based sensor to monitor 8 pollutants (NH3, CO, NO2, CH4, CO2, PM2.5, temperature, and humidity).
JunHo Jo	IoT-driven Smart-Air system for effective air quality monitoring and real-time	AWS server, PHP, MySQL, IoT-based, JavaScript, web server developed for Android OS	

2. Research Gap

Background literature shows that a few research projects done previously aimed at monitoring air pollution are significant for raising public awareness and improving human health and sustainable urban environments. Kaivonen, S., and Ngai, E.C.H., et al. proposed real-time monitoring of air pollution in public cars [6]. that has been conducted to measure air quality based on IoT or wireless sensor networks. The data from the ground-level monitoring station and the fixed sensors, with additional data coming from the sensors aboard public transport vehicles. The experiments have led to an evaluation of the data and communication quality of the system. Similarly, in 2021, Gautam, A., et al. proposed an Internet of Things (IoT)-enabled sensor-based embedded system to control and monitor air pollution produced worldwide [8]. built on the Internet of Things, and On the Raspberry Pi, an embedded system prototype with sensors and actuators is constructed. Furthermore, a website is made to track gas levels almost anyplace. To measure vehicle emissions, an Internet of Things-based system was created little over two years ago[15]. The sensors on the Arduino Uno monitor the quantity of pollutants originating from vehicle exhaust. Additionally, a Raspberry Pi is used by the prototype for control and monitoring.

The buzzer in this car will alert the user, and if they disregard it, a challenge is filed against them and forwarded to their mail ID. With the use of an Internet of Things-based sensor array, 8 pollutants—NH_3, CO, NO_2, CH_4, CO_2, PM2.5, temperature, and humidity—are monitored., according to Asha, P., et al.'s 2022 proposal for the ETAPM-AIT model [13]. The pollutant level is calculated by the sensor array and sent to the cloud server for analysis via gateways. 15 minutes, 30 minutes, and 60 min Following the study of the simulation is finished, the AI method is used to review the results. put it into practice. Current monitoring methods are inaccurate and sensitive, and they need to be analyzed in a lab. Therefore, more advanced vehicle monitoring techniques are needed. This system has a novel set of IoT-based air quality monitoring sensors that have been presented to address the disadvantages [14]. This IoT consists of three primary components: an Internet of Things (IoT)-based hardware device for monitoring air quality, a server backend, and a front-end mobile application. A monitoring hardware system is installed in appropriate urban open places to track the quality of the surrounding air.

3. Research Problem

A major gap in the field of Air Pollution Monitoring System in Sri Lanka is the focus of the research. challenge addressed in this work. The passage brings attention to the notable problem of air pollution, specifically in Sri Lanka, which presents a grave danger to the well-being of the public. Numerous harmful substances, such as Particulate Matter (PM), Carbon Dioxide (CO2), Carbon Monoxide (CO), Ground-level Ozone (O3), Nitrogen Oxides (NOx), Sulfur Oxides (Sox), and Lead (Pb), have been identified as significant factors contributing to air pollution [7]. These pollutants primarily originate from sources like motor vehicles, fuel combustion, and industrial operations.

The adverse impacts on health caused by air pollution, including respiratory infections, asthma, and even lung cancer, have been extensively documented. Each year, a considerable number of fatalities are linked to air pollution. School children, being more susceptible and exposed to elevated levels of pollutants, face a heightened risk, particularly in urban regions such as Colombo and Kandy.

Recognizing the urgency of the situation, the passage proposes an innovative solution a real-time air quality monitoring and analysis system. This system aims to monitor ambient air quality, provide optimal routes with minimal pollution levels, generate heatmaps for easy identification of air quality in specific areas, and predict future air quality trends.

The prototype of this system utilizes gas sensors, an Arduino Uno board, and a Wi-Fi module. These sensors collect real-time air pollution level data, which is then transmitted to an information processing center using IoT technology. The data is. In essence, this proposed system represents a proactive approach to addressing the air pollution crisis in Sri Lanka by leveraging IoT technology and predictive analytics to monitor, analyze, and mitigate the adverse effects of air pollution on public health and well-being.

The following research was question was identified related to.

1.How can an IoT-based air quality monitoring system be designed and implemented to effectively monitor and analyze air pollution levels, particularly due to vehicle emissions?

2.How can gas sensors, Arduino Uno board, and Wi-Fi module be integrated to develop a functional air quality monitoring prototype?

4. RESEARCH OBJECTIVES

4.1 Main Objectives

The main objective of this research component to design and implement an IoT-based air quality monitoring system that not only provides accurate, real-time data on key pollutants such as methane (CH_4) and carbon monoxide (CO) but also integrates seamlessly with mobile and cloud-based platforms. The system aims to empower urban communities and authorities by delivering actionable insights and enabling timely interventions for improved air quality management and public health protection

4.2 Sub Objectives

- **To Assess** the accuracy and reliability of the MQ4 and MQ7, MQ135 gas sensors in detecting methane (CH_4) and carbon monoxide (CO) levels in various urban environments.
- **To Determine** the efficiency of the Arduino Uno and ESP32 Wi-Fi module in processing and transmitting real-time air quality data to the cloud.
- **To Evaluate** the effectiveness of the cloud-based database in storing and retrieving air quality data for real-time analysis and prediction.
  Analyze user feedback on the mobile application's usability and its impact on pollution mitigation efforts.
- **To Compare** the air quality data collected by the device with existing government and independent monitoring systems to validate its accuracy.

4.3. Requirements

User Requirements

- Proper working mobile
- Basic knowledge to manage the App
- Able to work with mobile phone
- Good connection without any lag issues
- An android or IOS smartphone
- Internet connectivity

Functional Requirements

- Integrate MQ4 and MQ7, MQ135 sensors in IoT devices
- implement data processing algorithms for sensor data conversion
- Set up MongoDB database to store real-time air quality data.
- Implement alert framework to notify to the message when pollution level is high
- Build a cross platform mobile application

Non-Functional Requirements

- Speed or performance – response time
- Size – Use less resources
- Scalability – Scaled to new factor standards
- Ease of use – No need of training or education
- Reliability – Available as much as possible

Personnel Requirements

To enhance the quality, knowledge, continuation, and integrity of the research the following are the required personnel.

- Department of Motor Traffic
- Central Environmental Authority Sri Lanka

5. METHODOLOGY

5.1 Methodology

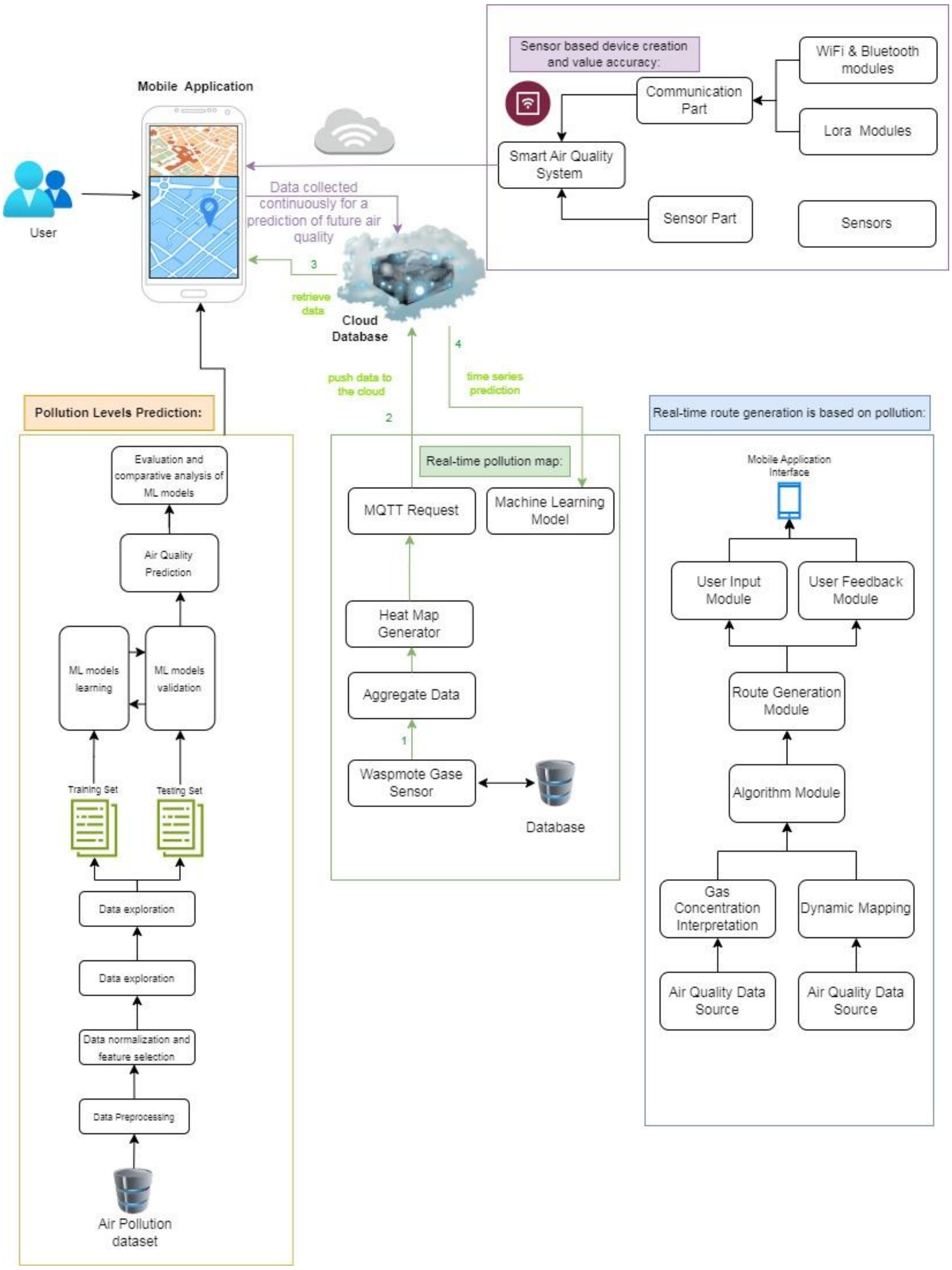

Figure 2 Overall system architecture

In above figure 2 into the architecture and the functioning of each component of the IoT-based air quality monitoring system. This analysis will explain how each part contributes to the overall system's goal of providing real-time, accurate air quality data, and how they work together to deliver actionable insights to the user.

Smart Air Quality System

- **Sensor Part:**
  - The sensor module is the foundation of the entire system, consisting of specialized gas sensors such as the MQ4 and MQ7.MQ135 These sensors are critical for detecting specific gases like methane (CH_4) and carbon monoxide (CO) in the environment. Each sensor operates based on chemical reactions that occur when the target gas is present. This reaction generates a measurable change in voltage, which is interpreted as the concentration of the gas. The accuracy and sensitivity of these sensors are vital, as they directly influence the quality and reliability of the data collected.
- **Communication Part:**
  - After the sensors collect the data, it needs to be transmitted to a central processing unit. The communication module, equipped with Wi-Fi, Bluetooth, and LoRa (Long Range) modules, is responsible for this task. Wi-Fi and Bluetooth allow for short-range, high-speed data transmission to nearby devices or cloud servers. LoRa, on the other hand, is a long-range communication technology that is particularly useful in urban areas where sensors are spread across large distances. The inclusion of multiple communication protocols ensures flexibility and reliability, enabling the system to function in various environments and conditions

Cloud Database

- **Data Collection and Storage:**

    - The cloud database serves as the central repository for all the data collected by the sensors. This cloud-based approach allows for the scalable storage of vast amounts of data, which is crucial for continuous monitoring and historical analysis. The data is stored in a structured format, making it easily retrievable for various applications such as trend analysis, machine learning, and real-time mapping. The use of cloud technology also enhances the system's accessibility, as data can be accessed from anywhere at any time, ensuring that users and decision-makers have real-time information at their fingertips.

A. Pollution Levels Prediction

- **Data Preprocessing:**
    - Raw data from sensors can be noisy and inconsistent, requiring preprocessing before analysis. Data preprocessing involves several steps:
        - **Data Normalization:** Adjusting values measured on different scales to a common scale without distorting differences in the ranges of values.
        - **Feature Selection:** Identifying and selecting the most relevant data points that will contribute to accurate predictions.
        - **Data Exploration:** Visualizing and understanding the data to identify patterns, outliers, and trends that will inform the machine learning model.
        - **Data Preprocessing:** Cleaning and transforming the data into a format suitable for analysis. This step is essential for enhancing the accuracy and reliability of the machine learning models used later in the process.

- **Machine Learning Models:**

- The preprocessed data is fed into machine learning models that have been trained to predict air quality levels. These models can be various types, such as regression models, neural networks, or decision trees, each chosen based on the specific requirements of the data and the desired output. The training phase involves using a dataset with known outcomes to teach the model how to make predictions. Validation is then performed to ensure the model's accuracy before it is applied to new, real-time data. The ability of these models to learn from data and improve over time makes them powerful tools for forecasting air quality.

- **Air Quality Prediction:**

- Once the machine learning models are validated, they are used to predict future air quality conditions. These predictions can be short-term (e.g., predicting pollution levels over the next few hours) or long-term (e.g., forecasting trends over the next week or month). The predictions are based on patterns identified in the historical data, combined with real-time inputs from the sensors. Accurate predictions enable timely interventions, such as issuing public health warnings or adjusting traffic flow to reduce pollution.

B. **Map Generator:**

- The heat map generator uses the output from the machine learning model to create a visual map that highlights areas with varying levels of pollution. These maps are color-coded, with different colors representing different levels of air quality. This visual representation is intuitive and helps users quickly understand the air quality in their vicinity or across a broader area. Heat maps can also be used by city planners and environmental agencies to identify pollution hotspots and prioritize mitigation efforts.

D. Real-time Route Generation Based on Pollution

- **User Input Module:**
  - The user input module allows users to specify preferences, such as selecting a route with the lowest possible pollution levels. This module collects data from users, such as their current location, destination, and any preferences regarding air quality levels along the route. This information is crucial for generating personalized routes that meet the user's needs.
- **Algorithm Module:**
  - The algorithm module processes the user input and real-time pollution data to generate the most optimal route. It uses advanced algorithms that factor in various elements such as the concentration of pollutants, the duration of exposure, and the distance of the route. The goal is to minimize the user's exposure to harmful pollutants while still providing a convenient route to their destination.
- **Dynamic Mapping:**
  - This involves continuously updating the map based on new data from the sensors and user feedback. The dynamic map shows not only the current pollution levels but also how they are expected to change as the user moves along the route. The system interprets gas concentration data in real-time, providing users with up-to-date information to make informed decisions about their route.

Mobile Application

- **User Interaction:**
  - The mobile application is the user-facing component of the system. It provides a user-friendly interface through which users can interact with the system. Users can view real-time air quality data, receive notifications about high pollution levels, and select routes that avoid polluted areas. The app's design ensures that

even users with minimal technical knowledge can easily navigate its features and make informed decisions about their environment.

- **Real-time Data Access:**
    - The app continuously retrieves data from the cloud database, ensuring that the information it provides is up to date. This feature is crucial for maintaining the system's reliability, as users depend on the app to provide timely information, especially when making decisions that affect their health, such as choosing whether to go outside or which route to take.
    -

5.2 Component Overview

Figure 3 Sensor based device creation and value accuracy Architecture Diagram

As shown in Figure 3 Air pollution is a significant global environmental health concern affecting both developed and developing countries. methodology for implementing an IoT-based air quality monitoring system involves several steps, including planning, hardware and software setup, data collection, processing, and analysis. Here's a detailed outline of the methodology Identify the objectives of the air quality monitoring system, such as real-time monitoring, data analysis, and prediction Define the scope of the project, including the target locations for monitoring and the pollutants to be measured Select appropriate sensors for measuring air pollutants, such as particulate matter (PM), carbon dioxide (CO_2), carbon monoxide (CO), etc. Install the sensors at strategic locations in urban and rural areas to capture representative air quality data Set up microcontroller boards (Arduino Uno) and Wi-Fi modules (ESP32) to interface with the sensors and transmit data. Implement a server backend using Node.js and MongoDB to receive, store, and process the sensor data. Upon receiving the sensor data, process it to convert analog readings into concentration values for each pollutant. Create a front-end web or mobile application for users to access real-time air quality information and visualization. The proposed IoT-based air quality monitoring system aims to provide real-time air quality information, mitigate the adverse effects of air pollution, and raise public awareness. the system will contribute to improved public health and environmental sustainability in Sri Lanka

In this component In this component, MQ4, MQ7, and MQ135 sensors were used to measure methane (CH_4) and carbon monoxide (CO) gases in the air, respectively. Using the MQ7 Sensor for CO_2 Concentration the MQ7 sensor is primarily designed for detecting carbon monoxide (CO), but with appropriate calibration, it can be used to estimate CO_2 concentrations.

$$CO_2 \text{ concentration} = 5.12 \times e^{(0.893 \times V\_RL)} \quad (1)$$

$$NH_3 \text{ concentration} = 2.671 \times e^{(1.580 \times V\_RL)} \quad (2)$$

$$SO_2 \text{ concentration} = 2.011 \times e^{(1.463 \times V\_RL)} \quad (3)$$

$$CH_4 \text{ concentration} = 10.938 * e(1.7742 * V\_RL) \quad (4)$$

5.3 User Interface Design

To create a user-friendly mobile application for managing and monitoring air quality data, a robust interface was designed to provide real-time insights and ensure accessibility for both individual users and organizations. The application gathers data directly from the air quality monitoring device, enabling users to make informed decisions based on up-to-date environmental statistics. The design process began by testing the interface with stakeholders such as environmental analysts, facility managers, and concerned citizens who are likely to benefit from comprehensive air quality data.

Initial Setup and Dashboard: Upon launching the app, users are greeted with an intuitive dashboard that presents an overview of current air quality metrics in their area or a specific location of interest. The system blueprint was provided to the environmental analyst (User) for testing and feedback. The main dashboard displays key air quality indicators, including levels of particulate matter (PM2.5 and PM10), carbon dioxide (CO_2), carbon monoxide (CO), ozone (O_3), and nitrogen dioxide (NO_2). The information is color-coded according to air quality index (AQI) levels, making it easy to understand the severity of pollution immediately.

Users can select their desired monitoring locations by entering the relevant geographic coordinates or choosing from a list of predefined locations. The app is designed to support multiple devices, allowing users to track air quality across various locations simultaneously. Each device's data is accessible from the dashboard, providing a comprehensive view of environmental conditions.

Device Configuration and Customization: The app's design includes a straightforward setup process for configuring new devices. When adding a new monitoring device, users are prompted to input details such as the device ID, installation location, and calibration settings. The device ID is a unique identifier that ensures data is correctly associated with the respective monitoring unit.

After the device is configured, users can customize settings to suit their needs. For instance, users can set threshold values for each pollutant, which will trigger alerts when exceeded. These thresholds can be customized based on local air quality regulations or personal preferences. The app also allows users to choose the frequency of data updates, ranging from real-time streaming to periodic updates, depending on the user's needs and network capabilities.

Real-Time Monitoring and Alerts: Once the device is operational, real-time data is displayed on the app’s dashboard. Users can view detailed graphs and charts that show trends over time for each monitored pollutant. The app features a map view that overlays real-time air quality data onto a geographic map, giving users a spatial understanding of pollution distribution in the monitored area.

The alert system is a key feature of the app, designed to notify users when pollutant levels exceed predefined thresholds. Notifications can be sent via push alerts, SMS, or email, depending on user preference. The alert system also provides recommendations for actions to mitigate exposure to harmful pollutants, such as staying indoors or using air purifiers.

Data Analysis and Historical Trends: Beyond real-time monitoring, the app includes tools for analyzing historical data. Users can access past data to identify patterns or trends in air quality over weeks, months, or even years. This historical perspective is valuable for identifying long-term changes in environmental conditions and assessing the effectiveness of interventions aimed at improving air quality.

Users can export data for further analysis or reporting purposes, which is particularly useful for organizations that need to maintain records of environmental compliance or study the impact of their operations on air quality. The export feature supports multiple formats, including CSV and PDF, ensuring compatibility with various data analysis tools.

provides users with insights into the environmental impact of the monitoring device itself, such as the amount of energy saved through solar charging and the reduction in carbon footprint compared to traditional monitoring solutions.

User Feedback and Continuous Improvement: Finally, the app includes a feedback mechanism that allows users to report issues or suggest improvements. This feature is crucial for the continuous development of the app, ensuring that it evolves to meet the changing needs of its users and incorporates the latest technological advancements.

In conclusion, the user interface of the air quality monitoring device's mobile application is designed to be both powerful and easy to use, enabling users to manage and monitor air quality effectively. The app's real-time data, customizable alerts, and robust data analysis tools make it an invaluable resource for individuals and organizations committed to improving environmental conditions and protecting public health.

5.4 Technologies

5.4.1 Node JS

Node.js allows developers to create both front-end and back-end applications using JavaScript

5.4.2 Arduino IDE is an open-source software, designed by Arduino.cc and mainly used for writing, compiling & uploading code to almost all Arduino Modules (IOT).

5.4.3 Post man Api

- An API, which stands for application programming interface, is a set of protocols that enable different software components to communicate and transfer data. Developers use APIs to bridge the gaps between small, discrete chunks of code in order to create applications that are powerful, resilient, secure, and able to meet user needs. Even though you can't see them, APIs are everywhere—working continuously in the background to power the digital experiences that are essential to our modern lives.

5.4.4 Database

MongoDB

MongoDB is a program that operates as a document-oriented database that is compatible with multiple platforms. MongoDB, which is a NoSQL database application, stores data in documents that are like JSON and can have optional schemas. MongoDB is built on a scale-out architecture that has become popular among developers of all types for the development of scalable applications with evolving data schemas. MongoDB is licensed under the Server-Side Public License, which is deemed non-free by several distributions. MongoDB was developed by MongoDB Inc. and is licensed under that license.

MongoDB is a document database, which means that it makes it simple for developers to store data in either a structured or unstructured format. Documents are saved in a format that is analogous to JSON by this system. Because this format translates directly to native objects in most modern programming languages, using it is an obvious choice for developers because it eliminates the need for them to worry about normalizing the data. In addition to this, MongoDB is capable of handling massive volumes of data and can scale either vertically or horizontally to accommodate large amounts of data.

5.4.5 React-native

Building native mobile applications with JavaScript is made possible with the help of React Native, which is a framework. Java (for Android) and Swift/Obj-C are the programming languages that are typically used to create mobile applications (for iOS). Because React Native does not require this, developers can create apps that are completely functional on both platforms in a far shorter amount of time and with only one programming language.

Using React Native, you can design a single codebase that is compatible with both iOS and Android. And not only does it "work," but it also compiles to native code for both Java and Swift. To be more specific, React Native acts as a connector between native Java and Swift user interface components and their web-based counterparts.

5.4.6 Libraires

MQTT (Message Queuing Telemetry Transport) is a lightweight messaging protocol designed for constrained devices and low-bandwidth, high-latency, or unreliable networks. It is commonly used in Internet of Things (IoT) applications, including air quality monitoring systems, due to its efficiency and reliability in transmitting data between devices and servers.

How MQTT Works in Air Quality Monitoring Devices:

Device Communication: In an air quality monitoring system, the monitoring device (sensor) is typically equipped with an array of sensors to measure various environmental parameters such as particulate matter (PM2.5, PM10), carbon dioxide (CO2), carbon monoxide (CO), ozone (O3), and nitrogen dioxide (NO2). These sensors collect data in real-time and need to transmit this information to a central server or cloud platform for processing, storage, and analysis.

MQTT is the protocol that facilitates this communication. The air quality monitoring device acts as an MQTT client, which connects to an MQTT broker (server) over a network. The broker is responsible for managing the distribution of messages between devices and the cloud or any other subscribing clients.

Cloud MongoDB API

MongoDB Cloud Messaging is a free service that establishes a secure and battery-efficient connection between the server and devices, allowing users to send and receive messages and notifications on iOS, Android.

Sensor Libraries:

- Arduino Libraries: Arduino platforms often use various sensor libraries to interface with sensors such as MQ-series gas sensors, particulate matter (PM) sensors.

- Raspberry Pi Libraries: Similar to Arduino, Raspberry Pi may utilize Python libraries to interact with sensors and acquire data.

Testing (Track and Monitor)

The program will be tested in the appropriate phases as unit, integration, system, and user acceptability testing.

5.4.7 Mobile Application

Depending on the user's level, the suggested mobile application will have different user perspectives. According to the results of the poll, the mobile application will support English, Sinhala, and Tamil, among other three languages. Users can view high or low levels of air pollution concern. The program itself will be used to extract the meta data. The target audience will be presented with the application in two versions: a commodity version and a premium version that includes more functionality. Push alerts on the amount of air pollution and the application will be sent to users even when they are not using it. Reminders every day

5.4.8 Database Handling

Cloud. MongoDB will be used to store data for the mobile platforms. It is an auto-scaling document database for mobile apps that saves, syncs, and queries information. The Wi-Fi module sends sensor data to the database every minute, enhancing the device's real-time capabilities. Data cannot be saved in a database directly. So, the backend must be constructed using the NodeJS language, and the sensor data travels through the server back-end to the database

5.5 Diagrams

5.5.1Flow Diagram for Feature Extraction

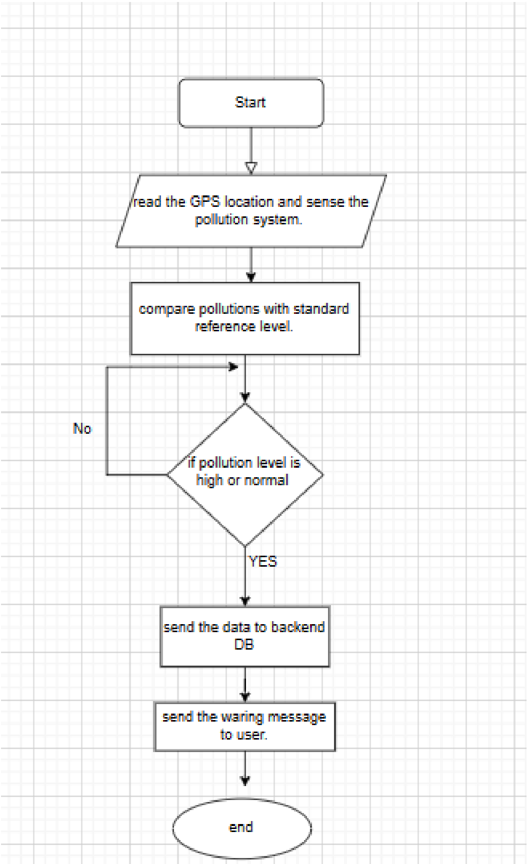

Figure 4 3 Overall flowchart

5.5.2 IoT Device Architecture Diagram

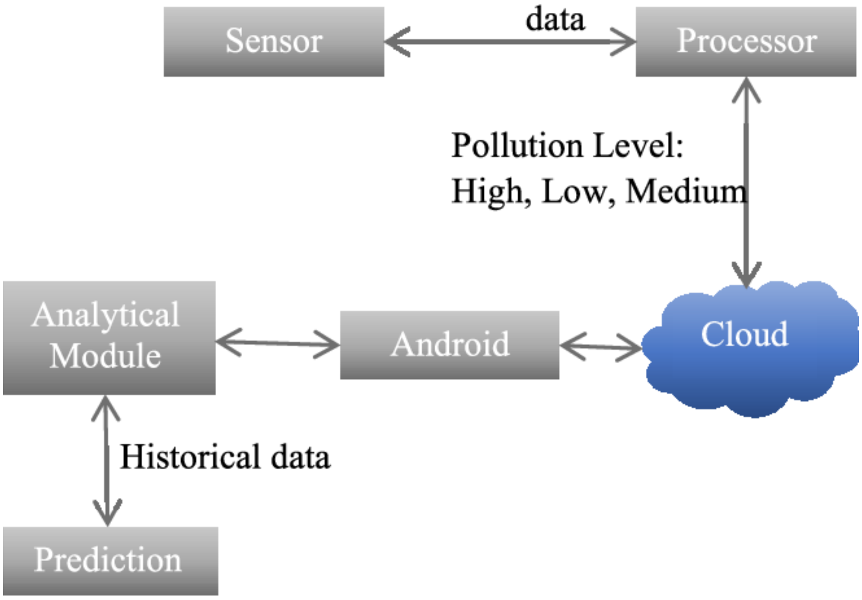

Figure 5 IoT device architecture

5.5.3 Block diagram

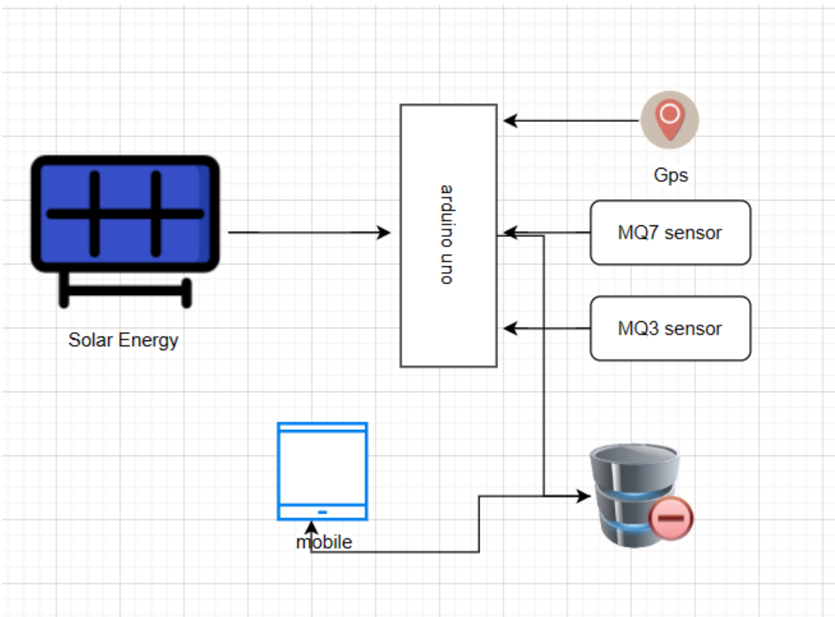

Figure 6 Block diagram

5.5.4 sequence diagram

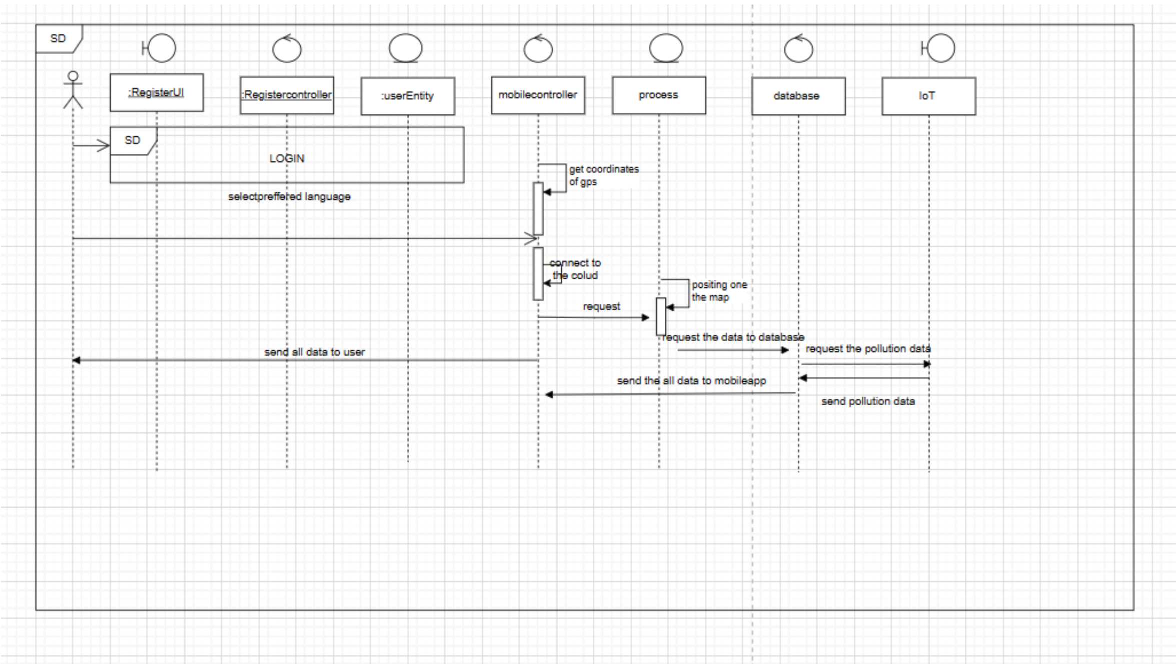

Figure 7 sequence diagram

5.6 Software Solution

The product development life cycle, often known as the lithe technique, includes the following stages: In addition to this, the Scrum methodology will be used as the framework for the coordinated approach that will be taken. Scrum is a lightweight, coordinated framework for project management that has expanded materiality for monitoring and controlling iterative and continuous tasks, all other things being equal. Because scrum could analyze and adjust to the modification of requirements, the arrangement that the creators will carry out is contingent on the hypothesis that was completed by the writing research and the review that was carried out, consistent alterations.

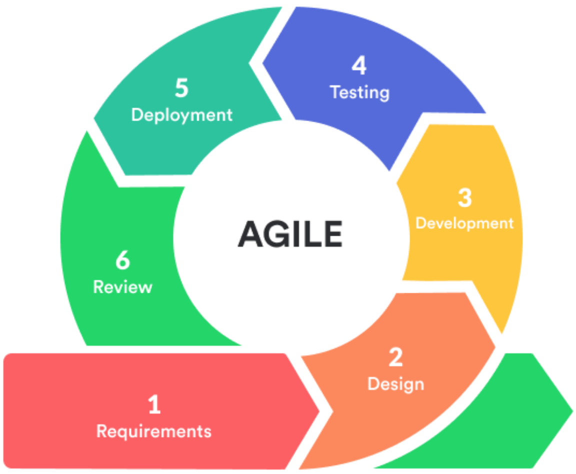

Figure 8 Agile Methodology

5.7. Project Management

The administration of each project can be divided into several stages. For our project, the following phases have been identified:

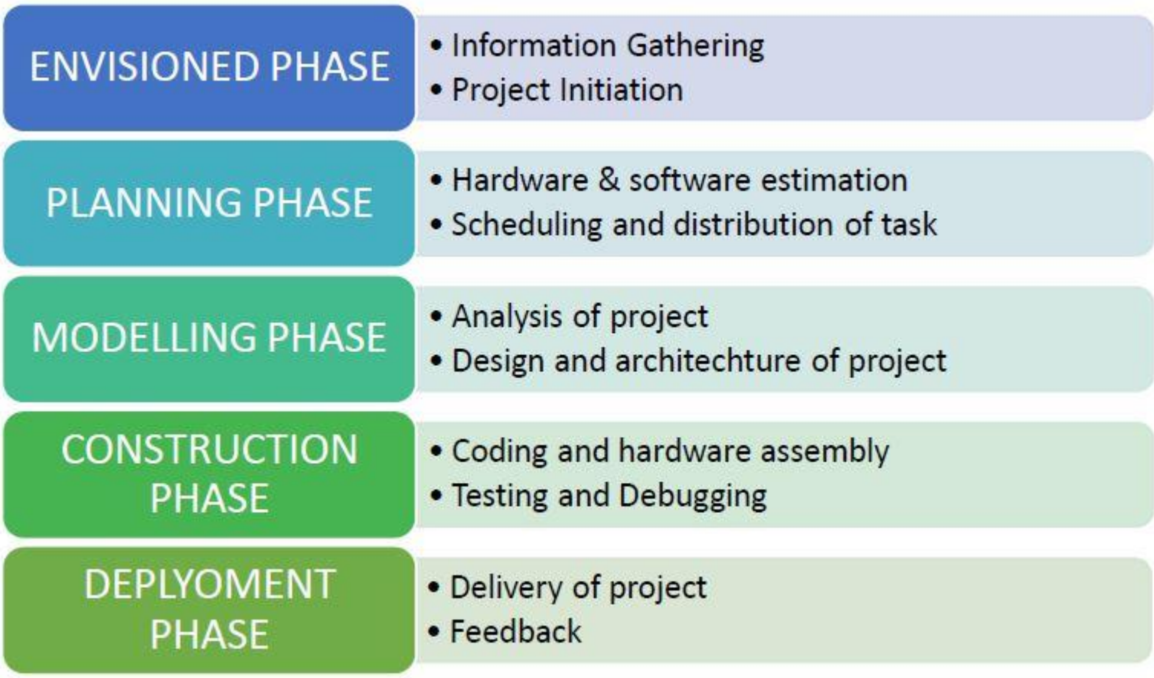

Figure 9 Project management process

Experiment

During this stage of the project, we discussed the many pieces of essential equipment that would be required for the project. To acquire the essential theoretical understanding, we are going to examine many modern efforts that are linked to one another. To figure out the code, it is also important to build the whole process utilizing fundamental algorithms and flowcharts.

Design

The design team worked on the overall layout of the application as well as the functionality that was required to be included during this phase of the process. To achieve this objective, each of the components needed to be put together, and the application needed to be written.

Development and Testing

The application was crafted throughout this period. Flutter was used to make the connection between the Application device and the flask API, and the entire prototype was thoroughly tested to ensure that it was error-free.

Real world Testing

The prototype was ready to be put through its paces in the field and integrated with a wide range of electrical devices operating in real time.

5.8. Testing

Table 1.4: Test cases

Test Case: Create a new optimization Pre-Condition: Login to air pollution application				
Test Case	Sequence	Test Description	Input Value(s)	Expected Result
1	1.1	verification	• Input optimization name • Input date • Input optimization gap • Click next button	Redirected to the next create page

	1.2	verification	• Add air pollution sources from drop down • Select vehicle pollution factor for each source • Add constraints	Display threshold for each source
Test Case: Sent email alert to air pollution level any violation of threshold Pre-Condition: Optimization should be created for relevant pollution source				
Test Case	Sequence	Test Description	Input Value(s)	Expected Result
2	1.1	Verify air pollution exceeds the threshold or not	• Real time calculated pollution value for each source • Optimum threshold	Get a warning email

Commercialization

The air quality monitoring device developed in this project has significant potential for commercialization, given the growing global concern about air pollution and its impact on public health and the environment. As awareness of air quality issues increases, there is a rising demand for affordable, reliable, and easy-to-use devices that can provide real-time data on air pollution levels. The commercial success of this device will depend on several factors, including its cost, usability, scalability, and the ability to meet the needs of different market segments.

Market Potential: The primary target market for this device includes urban residents, particularly those living in areas with high levels of air pollution, such as major cities and industrial regions. Additionally, the device is well-suited for use by government agencies, environmental organizations, and businesses that need to monitor air quality as part of their regulatory compliance or corporate social responsibility efforts. The global air quality monitoring market is projected to grow significantly in the coming years, driven by increasing regulations and public awareness. This device, with its cost-effective design and reliable performance, could capture a substantial share of this expanding market.

Pricing Strategy: To ensure broad adoption, the pricing strategy for the air quality monitoring device should focus on affordability without compromising on quality. A competitive pricing model could involve offering different versions of the device, ranging from a basic model with essential features to more advanced versions with additional sensors and data analytics capabilities. This tiered approach would allow the device to cater to a wide range of customers, from individual consumers to large organizations.

Distribution Channels: Effective distribution will be key to the successful commercialization of the device. The device could be sold through various channels, including online platforms, electronics retailers, and partnerships with environmental organizations and governmental bodies. Additionally, collaboration with smart city initiatives could open up opportunities for large-scale deployments, particularly in urban areas where air quality is a major concern. Establishing relationships with distributors and resellers in key markets will also be crucial for expanding the device's reach.

Marketing and Branding: Marketing efforts should highlight the device's unique features, such as its solar-powered design, real-time data transmission, and ease of use. Emphasizing the device’s sustainability and its potential to contribute to healthier living environments will resonate with environmentally conscious consumers. A strong branding strategy that positions the device as a reliable and essential tool for air quality monitoring could help differentiate it from competitors. Leveraging social media, online advertising, and partnerships with influencers and environmental advocates could also enhance brand visibility and credibility.

Regulatory Compliance: For successful commercialization, the device must comply with relevant regulations and standards in different markets. Ensuring that the device meets the necessary certifications, such as those related to safety and environmental impact, will be essential for gaining consumer trust and entering markets where regulatory compliance is mandatory. Working closely with regulatory bodies and staying updated on changes in air quality monitoring standards will help the device maintain its market relevance.

After-Sales Support and Maintenance: Offering strong after-sales support and maintenance services will be important for building customer loyalty and ensuring long-term success. This could include providing regular software updates, offering maintenance packages, and establishing a customer service team to assist with any technical issues. Ensuring that replacement parts, such as sensors, are easily accessible will also be important for maintaining the device’s functionality over time.

Future Expansion: Looking ahead, there is potential for expanding the product line to include more specialized versions of the device tailored to specific industries or environments. For example, versions of the device could be developed for use in schools, hospitals, or industrial plants, where air quality is a particularly critical concern. Additionally, expanding into international markets, particularly in regions with severe air pollution issues, could offer significant growth opportunities.

The following are some effective marketing methods that might be utilized to commercialize this product:

- Develop a public relations and news media strategy.
- Develop a pricing strategy with packages.
- Use social media marketing strategies.
- Google ad-sense strategies.
- Arrange the events (virtual and in-person).

4.10. Interfaces

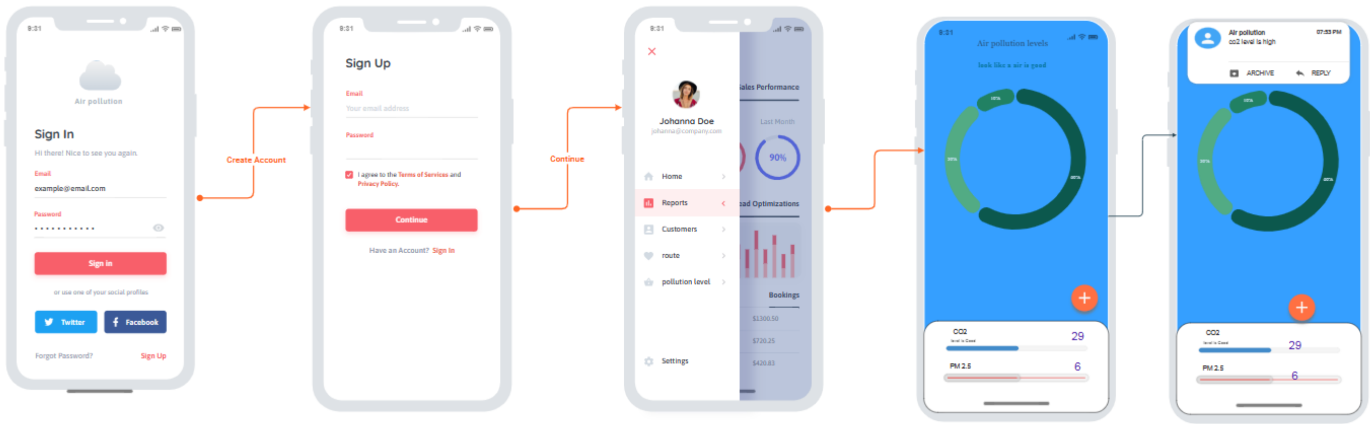

Figure 10 High fidelity diagrams for information sharing to crowd

1. Implementation

The proposed system should comply with the development of the gathered requirement as given below,

- When the sensor finds a high reading for particulate matter or carbon monoxide identification, the mobile app notifies the registered email addresses via email.
- Gather historical and current forecast air pollution consternation data based on the GPS using.
- The carbon monoxide emission rate in parts per million can be found by using the Android application.
- The mobile app provides a user-friendly interface for viewing air pollution levels and route maps.

The above functionalities will be integrated so that stakeholders can get a view through a mobile app.

4.11. Coding

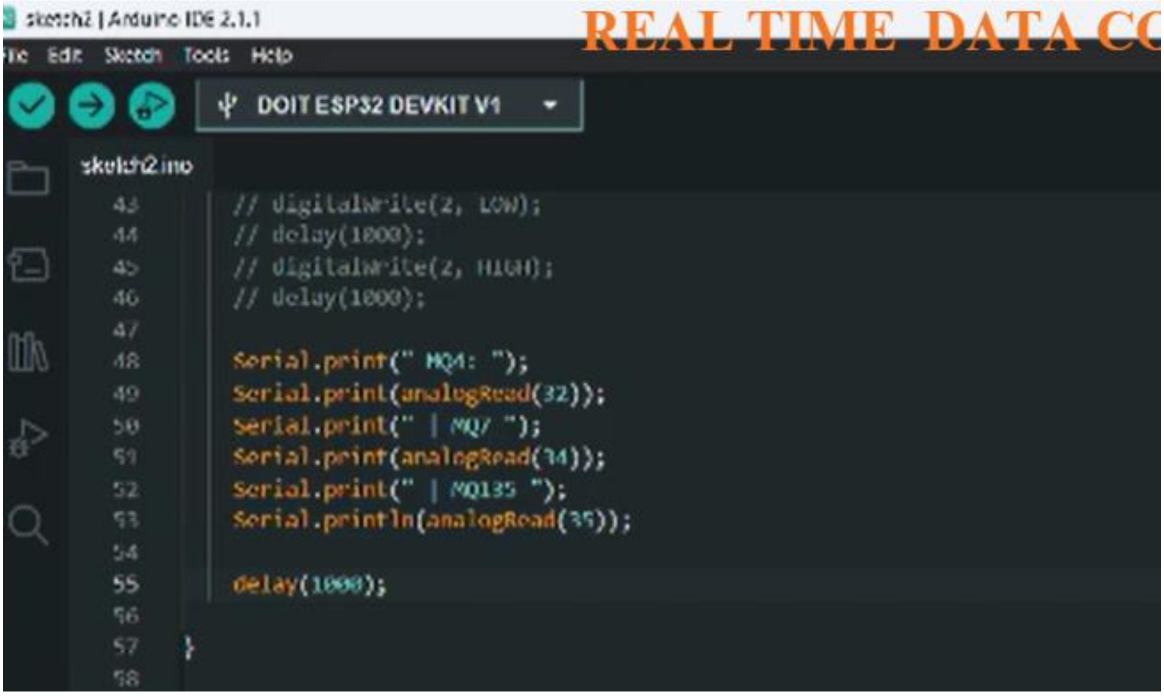

Figure 11 IoT Coding

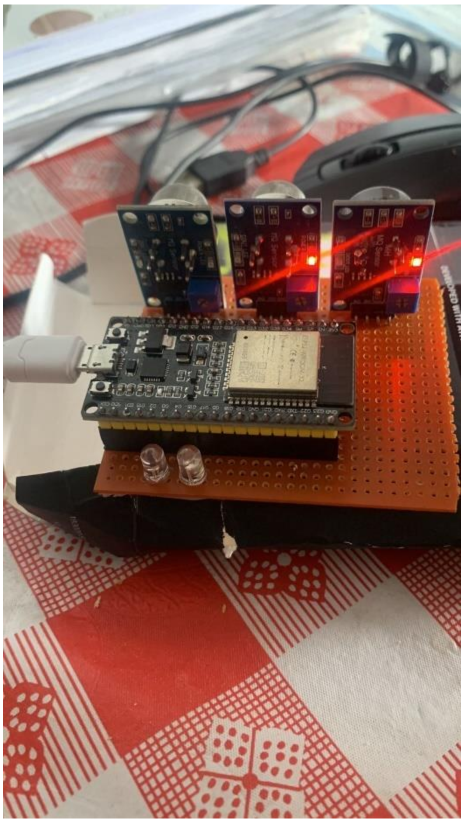

Figure 12 IoT Device

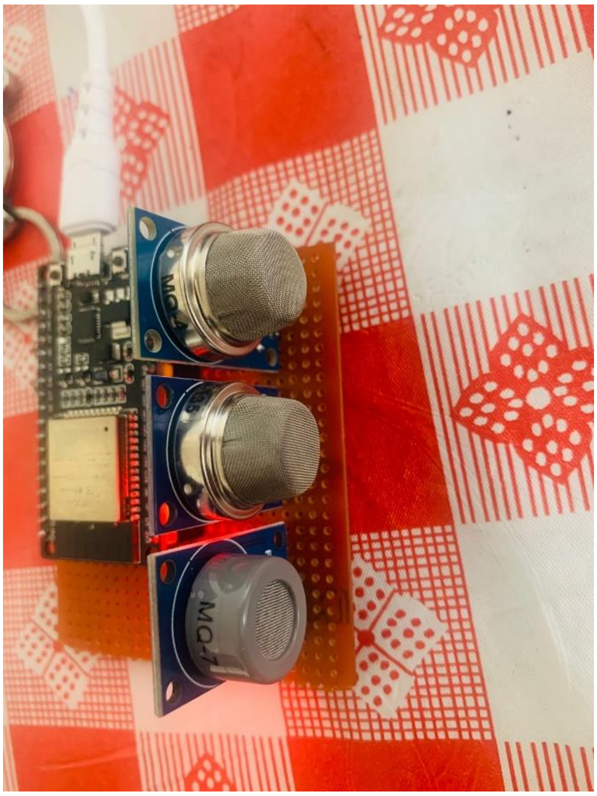

Figure 13 IoT Device

6. RESULTS AND DISCUSSION

6.1 RESULTS

The development and implementation of the air quality monitoring device yielded several important results, demonstrating its effectiveness in monitoring and reporting on environmental conditions. The device was tested in various real-world environments, including urban, suburban, and industrial areas, to evaluate its performance under different air quality conditions. The key results from these tests are summarized below:

Accuracy of Sensor Measurements: The device's sensors provided reliable and accurate measurements of key air pollutants, including particulate matter (PM2.5 and PM10), carbon dioxide (CO_2), carbon monoxide (CO), ozone (O_3), and nitrogen dioxide (NO_2). Calibration tests, conducted in controlled environments, indicated that the sensors' readings were within 5% of the reference standards, validating the precision of the device. In real-world conditions, the device consistently reported pollutant levels that were in close agreement with data from established monitoring stations, indicating its robustness and reliability.

Real-Time Data Transmission: The device successfully transmitted real-time air quality data to the cloud, where it was accessible through a user-friendly web interface and mobile application. The low-latency communication between the device and the cloud server ensured that users could access up-to-date information on air quality, which is crucial for timely decision-making. The data transmission was tested across different network conditions, including areas with low internet connectivity, and the device performed well, maintaining data integrity and reliability.

Power Efficiency and Solar Charging: The solar-powered design of the device was a significant success, allowing for continuous operation without the need for an external power source. Under typical sunlight conditions, the solar panel was able to fully charge the device's battery within a few hours, ensuring uninterrupted monitoring throughout the day and night. In regions with less sunlight, the device was still able to maintain functionality by efficiently managing power consumption and utilizing stored energy. This aspect of the device is particularly beneficial for deployment in remote or off-grid locations.

User Experience and Accessibility: Feedback from users who tested the device indicated a high level of satisfaction with its ease of use and the accessibility of the data. The device's installation process was straightforward, and the mobile application provided intuitive controls for monitoring air quality and configuring device settings. Users appreciated the ability to set custom alerts for specific pollutant thresholds, enabling proactive measures to protect health and safety. The ability to view historical data trends also added value, allowing users to observe changes in air quality over time.

Environmental Impact and Sustainability: The use of eco-friendly materials in the device’s construction and its reliance on solar energy contributed to its minimal environmental footprint. The device's durability and low maintenance requirements further enhance its sustainability, reducing the need for frequent replacements or repairs. This makes the device not only a practical tool for air quality monitoring but also a responsible choice for environmentally conscious consumers and organizations.

Challenges and Limitations: While the device performed well overall, a few challenges were identified during the testing phase. In extremely polluted environments, the sensors required more frequent calibration to maintain accuracy, which could increase maintenance efforts. Additionally, in areas with very poor connectivity, data transmission was occasionally delayed, although the device was still able to store data locally until a connection was re-established. Addressing these challenges in future iterations of the device will be important for enhancing its performance and user experience.

Discussion

The results indicate that the air quality monitoring device is a viable solution for real-time environmental monitoring, with strong potential for widespread adoption. Its accuracy, reliability, and sustainability make it an attractive option for both individual users and organizations. The ability to operate independently of external power sources, thanks to its solar charging capability, further broadens its applicability, particularly in areas where access to electricity is limited. However, ongoing efforts to refine the device’s calibration processes and improve data transmission in low-connectivity areas will be important for ensuring its long-term success and scalability.

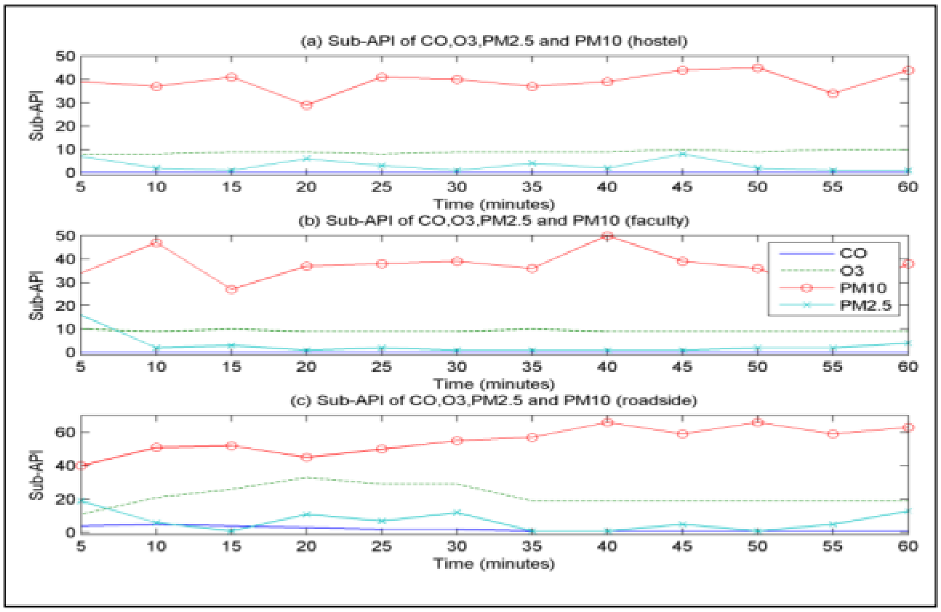

Figure 14 get the reading values for three different locations

6.2 Future Scope

The air quality monitoring device has demonstrated its effectiveness in detecting methane and carbon monoxide, but there are several avenues for future development that could enhance its capabilities and broaden its application. One of the most promising directions is the expansion of the device's sensing capabilities. Adding sensors for other common air pollutants, such as nitrogen oxides (NOx), sulfur oxides (SOx), ozone (O_3), and particulate matter (PM2.5 and PM10), would allow the device to provide a more comprehensive picture of air quality. This would make the device even more valuable for users in diverse environments, from urban centers with heavy traffic to industrial zones with specific pollutant profiles.

Another important area for future work is the improvement of the route suggestion algorithm. By incorporating machine learning techniques, the algorithm could analyze historical and real-time data to make more accurate predictions about pollution levels along different routes. This would enhance the device’s ability to guide users away from highly polluted areas, increasing its utility for those who need to navigate environments with varying air quality. Additionally, integrating factors such as weather conditions, time of day, and traffic patterns could make the route suggestions even more reliable and personalized.

Integration with smart city infrastructure is another potential future development. By connecting the device to a network of similar sensors distributed across an urban area, it could contribute to a city-wide air quality monitoring system. Such a network could provide valuable data for city planners, public health officials, and environmental agencies, helping them to identify trends, forecast pollution events, and implement targeted interventions. This level of integration would greatly enhance the device’s impact, making it a key component of broader urban sustainability initiatives.

Finally, ongoing research should explore ways to make the device more compact, cost-effective, and energy efficient. Reducing the size and power consumption would make the device even more portable and easier to deploy in a variety of settings. Additionally, exploring alternative power sources, such as wind or kinetic energy, could further enhance the device’s sustainability, particularly in environments where solar energy may not be consistently available.

5. CONCLUSION

The air quality monitoring device developed in this project represents a significant advancement in environmental monitoring technology. By integrating methane and carbon monoxide sensors with real-time data transmission capabilities, the device offers a practical solution for tracking air pollution levels. Its solar-powered design not only supports continuous, long-term operation but also aligns with sustainability goals, reducing the need for external power sources and minimizing environmental impact.

The device's affordability and ease of deployment make it accessible for a wide range of users, from individual consumers concerned about air quality in their neighborhoods to municipal authorities looking to implement large-scale monitoring initiatives. The real-time data provided by the device is crucial for informing public health decisions and urban planning strategies, allowing for more effective responses to air pollution challenges.

In conclusion, this project has successfully developed a versatile, sustainable, and user-friendly air quality monitoring system. The device's ability to provide accurate, real-time data on methane and carbon monoxide levels, combined with its portability and low maintenance requirements, positions it as a valuable tool in the fight against air pollution. By empowering individuals and communities with the information they need to protect their health, this device contributes to broader efforts to improve environmental quality and public health.in bulk. To summarize, emission optimization for real-time carbon neutrality management can be carried out in a manner that is both

very efficient and productive in the context of carbon control in companies

Dataset

To achieve the goals, both primary and secondary data were collected. Primary data was collected to the IOT device. Air quality data was obtained from both the Central Environmental Authority (CEA) and the National Building Research Organization (NBRO). Data was obtained for CO, NO2, SO2, and PM10 pollutants from CEA, as well as SO2 and NO2 from NBRO. These two institutes conduct direct measurements of the air contaminants listed above, making them the main sources of data

DESCRIPTION OF PERSONAL AND FACILITIES

Facilitators:

- Guidance and support from supervisor, co-supervisor, and lecturers
- Ms. Chathurangika Kahandawaarachchi Sri-Lanka-Institute of Information Technology

Facilities:

- Central Environmental Authority Sri Lanka (CEA)
- Department of Motor Traffic (DMT)
- National Building Research Organization (NBRO)

Work Breakdown Structure

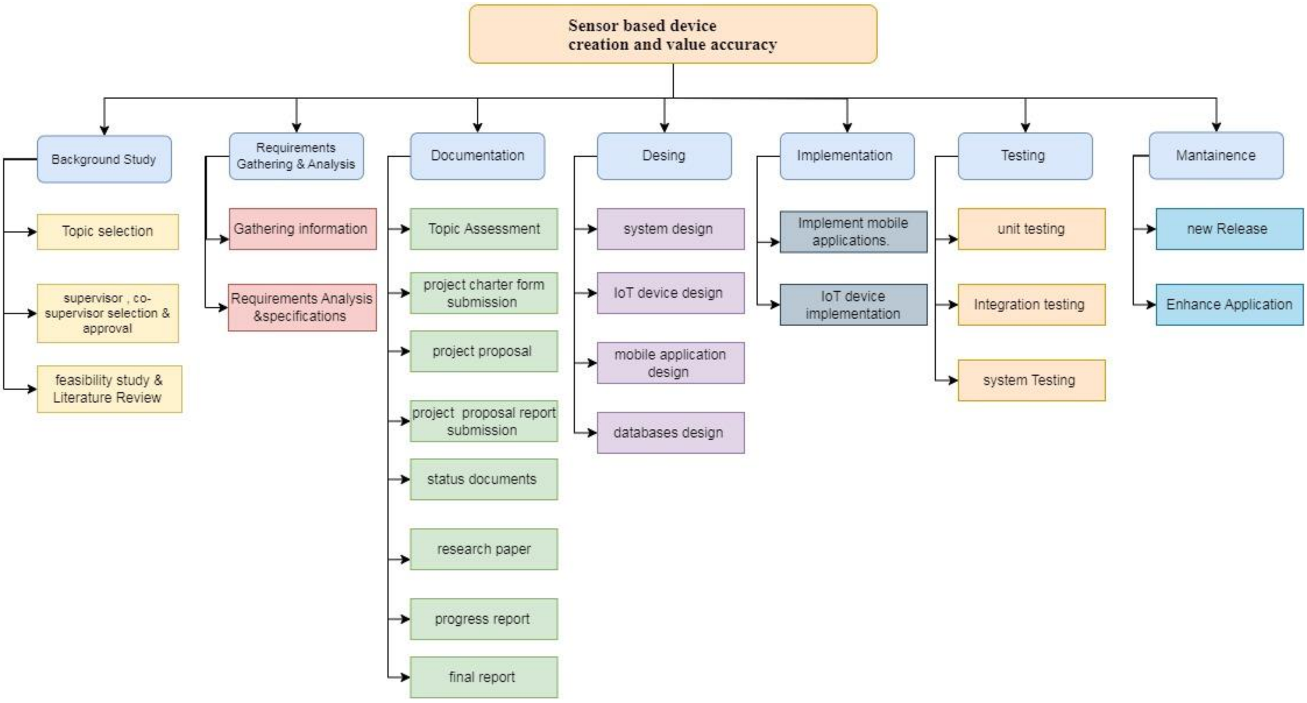

Figure 15 *Work Breakdown Structure*

GANTT CHART

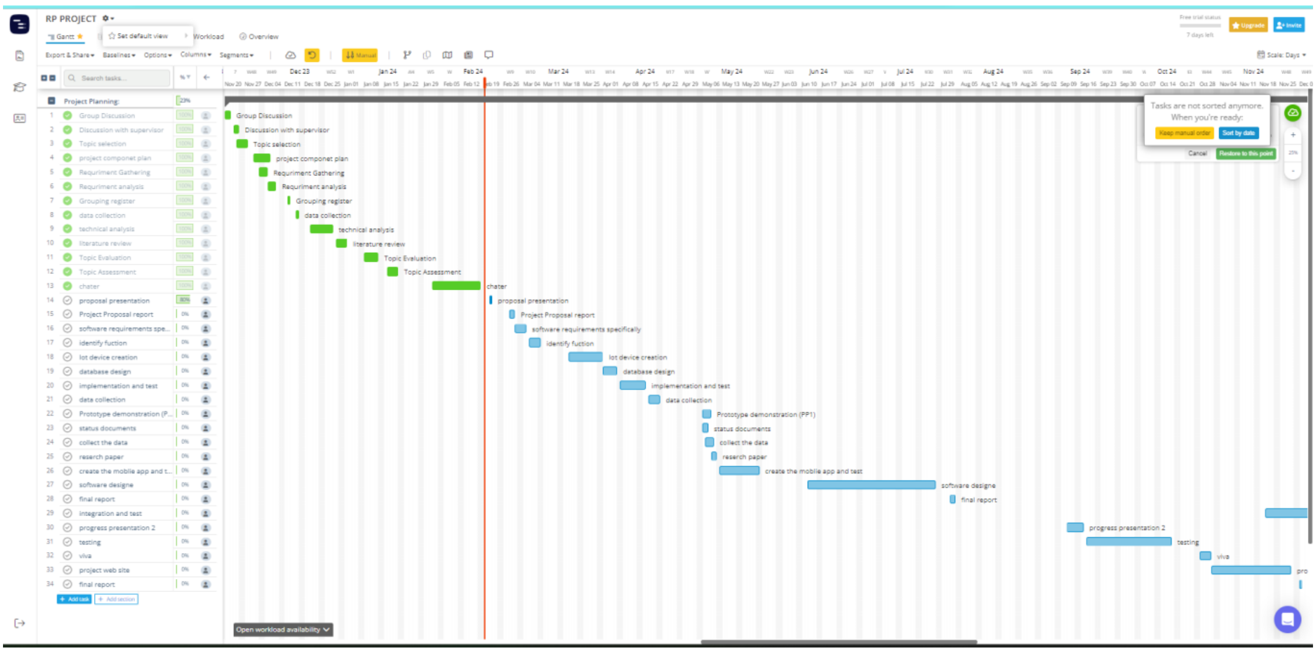

Figure 16 GANTT CHART

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APPENDICES

- Plagiarism Report

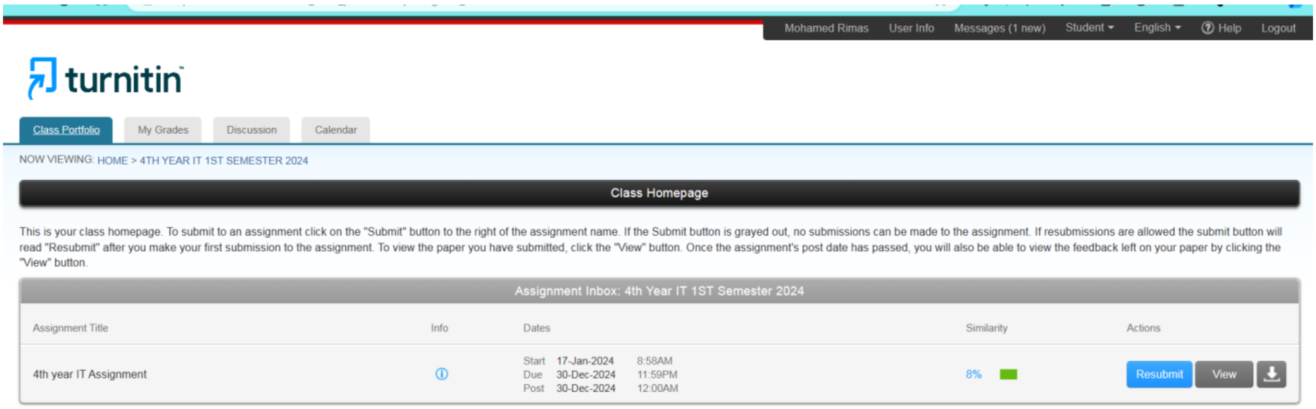


Figure 17

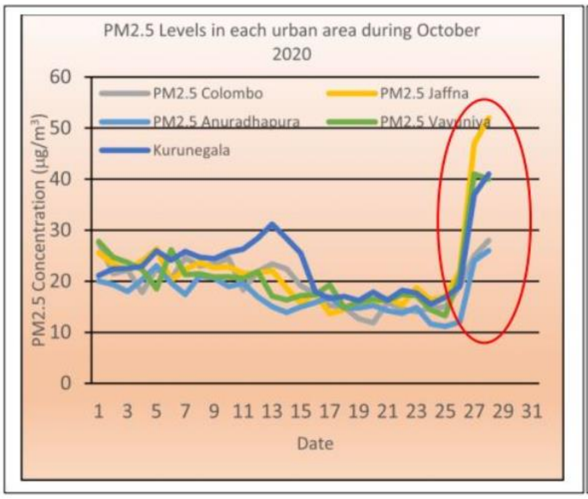
Appendix 1

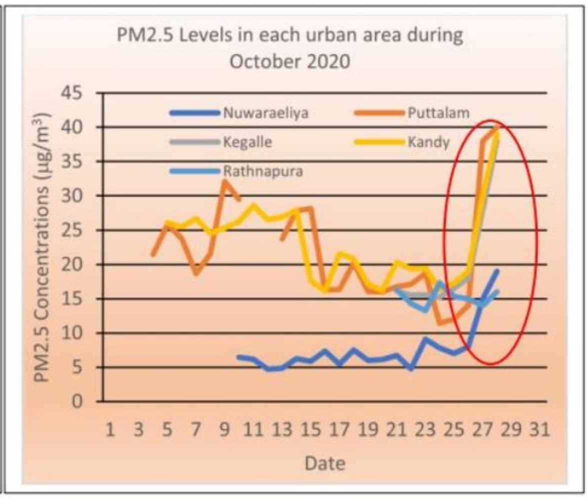
National Ambient air quality Standards

Pollutant	Averaging time	Maximum Permissible level	
		µg/m-3	ppm
Particulate Matter – PM_{10}	Annual	50	
	24 hr	100	
$PM_{2.5}$	Annual	25	
	24 hr	50	
Nitrogen Dioxide (NO_2)	24 hr	100	0.05
	8 hr	150	0.08

	1 hr	250	0.13
Sulphur Dioxide (SO_2)	24 hr	80	0.03
	8hr	120	0.05
	1 hr	200	0.08
Ozone (O_3)	1 hr	200	0.10
Carbon Monoxide (CO)	8 hrs	10,000	9.00
	1 hr	30,000	26.00
	anytime	58,000	50.00

Source: Central Environmental Authority





Methane	
Ranges	**Quality**
Below 600 PPM	Good
600-800 PPM	Okay
800-1000 PPM	Acceptable
Above 1000 PPM	Dangerous