Integrating GPS Technology and Air Quality Monitoring for Efficient Environmental Management

Hemant Kumar Mahatara[a]

[a]*Department of Geomatics Engineering, Institute of Engineering Pashchimanchal Campus Pokhara, Nepal*

KEYWORDS

Traffic Management

Environmental Analysis

GPS Technology

Air Pollution Detection

Public Transportation

Air Quality Management (AQM)

ABSTRACT

The goal of this project is to provide dynamic understanding of environmental health by combining real-time air quality monitoring with location data. A flexible device is created to collect environmental and spatial data by combining parts such as the PM2.5 Air Quality Sensor, GSM 800L module, SAM-M8Q GPS receiver, and ESP-32 microcontroller. The gadget connects to a mobile application built with React JS, which makes it easier to send location and air quality data to a central server. Users can access current data through APIs to make well-informed decisions. With the use of gathered data, sophisticated methods such as Inverse Distance Weighting (IDW) interpolation produce heatmaps that visually depict regional differences in air quality. By offering useful information about regions with poor air quality, these heatmaps enable people and organizations to take responsible environmental action. Prospects for the future include integrating machine learning algorithms for predictive analysis and extending sensor capabilities. This multidisciplinary project demonstrates the function of geomatics engineering in data processing and sustainability and environmental awareness monitoring.

A. INTRODUCTION

Cities foster economic growth. However, growing cities also contribute to air pollution and climate change (Kaginalkar et al., 2021). Countries such as India, for instance, have witnessed a steep rise in urban dwellers from about 80 million in 1960 to 471 million in 2019 (World Bank, 2019) and an increase of 416 million is projected by 2050 (United Nations, 2018). In particular for cities in low- and middle-income countries, air pollution is a significant health hazard (WHO, 2018). Air pollution and climate change are closely interlinked through common sources that emit both primary and precursor air pollutants, short-lived climate pollutants (SLCPs, e.g., black carbon, a component of PM2.5, and methane, a powerful but short-lived greenhouse gas) and long-lived greenhouse gases (GHGs, e.g., CO2; Fiore et al., 2015). Here we primarily focus on fine particle pollution, or PM2.5 which result in the greatest burden of disease globally (McDuffie et al., 2021). Improvements in air quality (AQ) and public health are among the largest and most-localized potential co-benefits of GHG mitigation actions, and thus often a key point of engagement for all cities, especially those in low- and middle-income countries, which increasingly seek solutions that achieve multiple policy goals simultaneously (Akbar et al., 2014). However, simultaneously assessing the AQ, health, and climate impacts of GHG and air pollution mitigation actions is challenging, in part because of dramatic differences in the climate and air pollution impacts of various pollutants; the wide variation in quantities emitted by source and by location; and the degree to which specific mitigation actions reduce these emissions (GAHP, 2020).

Improving urban air quality is a global, national and local priority (C40, 2019; CPCB, 2019; Pune Resilience, 2020; UN-Habitat, 2016). The UN Sustainable Development Goals (SDG) for 2030 (SDG2030), such as SDG11, SDG13, and SDG3, are highly relevant for urban resiliency (United Nations, 2015a). In response to these local demands for improved livability, urban environment management is shifting to a decentralized city level approach (Campbell et al., 2018; Landrigan et al., 2018).

In response to these challenges, numerous tools have been developed to aid in integrated assessments and in planning for air quality and climate goals (Anenberg et al., 2016). The evolution in Information and Communication Technology (ICT) in every sphere of life has manifested the smart city framework(Kaginalkar et al., 2021). The recent development of spatial data management in the framework of geographic information systems (GISs) has created a new era of environmental modelling. More powerful computers have made running air quality models at global and local spatial scales possible(Matejicek, 2005). Obviously, the use of GIS has become essential in providing boundary conditions to the air quality models. Certainly, the use of GIS in air pollution modelling can be further extended to processing the surface data. Many models have been coupled with GIS in the past decade to simulate various environmental processes as described by Longley et al. (2001). The interpolations, integrations of land cover surface data, and the GIS analyses focused on small scale spatial models carried out in the kilometer grid are discussed by Lee in the book published by Goodchild (1996) and in the frame of particular studies (Matejicek, 1996, 1998, 1999). In case of large scale air quality modelling, more detailed spatial data are needed to include the impact of buildings

Crossponding Author: Tel: +977-9822975366

Email Address: mahatara.hemant9@gmail.com

and other man made barriers on the distribution of air pollutants, (Janour, 1999; Civis, 2001).

An integrative collaborative mode of working is essential for successfully implementing LAQM within local authorities (Beattie & Longhurst, 2000). In many cases this may involve collaboration between two tiers of local government, with county authorities having responsibilities for transport planning and strategic land use planning in areas covered by non-unitary-authorities (Beattieet al., 1999a)

B. BACKGROUND

A. GNSS Technology

Global Navigation Satellite System (GNSS) include constellations of Earth-orbiting satellites that broadcast their locations in space and time, of networks of ground control stations, and of receivers that calculates ground positions by trilateration. GNSS include two fully operational global systems, the United States' Global Positioning System (GPS), the Russian Federation's Global Navigation Satellite System (GLONASS), as well as the developing global and regional systems, namely Europe's Satellite Navigation System (GALILEO) and China's COMPASS/BeiDou, India's Regional Navigation Satellite System (IRNSS) and Japan's Quasi-Zenith Satellite System (QZSS). The satellite broadcasts two codes – the coarse acquisition (C/A) code, unique to the satellite, and the navigation data message.

In general GPS provides three types of measurements: Pseudorange, carrier phase, and Doppler. By pseudoranging, the GPS user measures an approximate distance between the GPS antenna and the satellite by correlation of a satellite transmitted code and a reference code created by the receiver. Four pseudorange observations are needed to resolve a GPS 3-D position. In practice there are often more than four satellites within view. A minimum of four satellite ranges are needed to resolve the clock-biases contained in both the satellite and the ground-based receiver. Thus, in solving for the X-Y-Z coordinates of a point, a fourth unknown (i.e. clock bias ~Δt) must also be included in the solution. The solution of the 3-D position of a point is simply the solution of four pseudorange observation equations containing four unknowns, i.e. X, Y, Z, and Δt.

A pseudorange observation is equal to the true range from the satellite to the user plus delays due to satellite receiver clock biases and other effects.

$$R = p^t + c\,(\Delta t) + d$$

Where

R = observed pseudorange

Fig 1: Working Principle of GNSS Technology

p^t = true range to satellite (unknown)

c = velocity of propagation

Δt = clock biases

d = propagation delays due to atmospheric conditions

SAM-M8Q GPS Breakout is chosen as the receiver of the GNSS signals which is responsible to accurately locate the points within the earth surface. The SAM-M8Q is a 72-channel GNSS receiver, meaning it can receive signals from the GPS, GLONASS, and Galileo constellations which increases precision and decreases lock time.

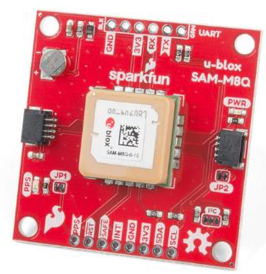

Fig 1: SparkFun GPS Breakout - Chip Antenna, SAM-M8Q (Qwiic)

B. GPRS Technology

General packet radio service (GPRS) is defined as a mobile communications standard that operates on 2G and 3G cellular networks to enable moderately high-speed data transfers using packet-based technologies GPRS Working. In essence, general packet radio service (GPRS) is a packet-switching technology that makes it possible to send data over mobile networks. Multimedia messaging services, internet connectivity, and other forms of data transmission are made use of this. GPRS cellphones, laptops, and portable devices with GPRS modems can all support GPRS. Up to 80 Kbps downstream bandwidths have been reported by subscribers. The second generation (2G) cellular network uses the global system for mobile communications (GSM) as its primary standard; GPRS is an enhanced version. Unlike GSM's short messaging service (GSM-SMS), which has a 160-byte message length limit, GPRS does not allow for this. While most networks run at about 35 kbps, GPRS has a theoretical maximum speed of 115 kbps. Unofficially, GPRS is sometimes referred to as 2.5G. It's a third-generation method of becoming accessible online.

Fig 2: GPRS/GSM 800L Module

Crossponding Author: Tel: +977-9822975366

Email Address: mahatara.hemant9@gmail.com

C. Mobile Application Development using React Native

React Native is an open-source framework developed by Facebook for building mobile applications using JavaScript and React. It enables programmers to create mobile applications that work on both the iOS and Android platforms by utilizing React, a well-liked JavaScript library for creating user interfaces. Developing cross-platform mobile apps with a single codebase is made possible by React Native, which saves time and effort when compared to developing apps specifically for each platform.

The ability to display the geospatial features found on the earth earth's surface on a mobile device is made possible by the integration of geospatial data with the mobile device. The app can display any geospatial data over a basemap, including hospital, road, house, bus station, bus route, and many other features. MapLibre is the source of the basemap used in this application. MapLibre is an open-source library for interactive maps on the web. It is a fork of the Mapbox GL JS library, which is a JavaScript library for rendering interactive maps.

Maps can be integrated into React Native applications with the help of the well-liked third-party library react-native-maps. Through the use of the MapView component, which is available for both iOS and Android, developers can incorporate interactive maps into their mobile applications. GeoJSON (Geographic JavaScript Object Notation) is an open standard format designed for representing geographical features and their attributes. It is a text-based, lightweight data interchange format that uses the JavaScript Object Notation (JSON) syntax to encode geographic data. GeoJSON is a widely used protocol that many GIS (Geographic Information System) software systems support for transferring spatial data between web servers and web clients.

D. PM2.5 Air Quality Sensor

The PM2.5 Air Quality Sensor from Plantower is a state-of-the-art device engineered to measure particulate matter (PM) concentrations in the air, specifically targeting particles with a diameter of 2.5 micrometers or smaller (known as PM2.5). This sensor ensures reliable and precise detection of PM2.5 particles, which are known to deeply penetrate the respiratory system and pose serious health risks upon inhalation. It does this by using sophisticated laser-scattering technology.

One of the standout features of this sensor is its capability for real-time monitoring, providing continuous updates on PM2.5 concentrations. This real-time data allows users to track fluctuations and trends in air pollution levels, enabling proactive responses to environmental changes. The sensor's small size and portability also make it ideal for a wide range of uses, such as wearable device integration, outdoor environmental assessments, and monitoring indoor air quality.

Overall, Plantower's PM2.5 Air Quality Sensor is an advanced instrument for determining air quality and providing information for decision-making processes that protect human health and environmental sustainability. It is essential for organizations and individuals attempting to mitigate the negative effects of air pollution on the environment and public health because of its accuracy, dependability, and versatility.

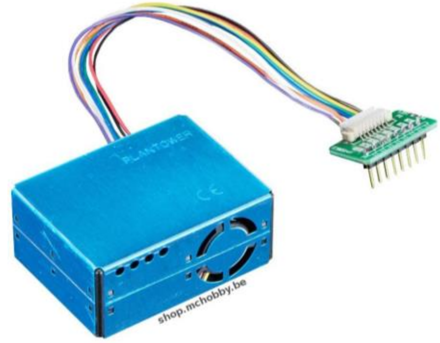

Fig 3: PM2.5 Air Quality Sensor

C. DESIGN AND IMPLEMENTATION OF TRACKING SYSTEM

This paper proposes the design of an embedded system that uses the Global System for Mobile Communication (GSM) and Global Positioning System (GPS) to track and position of our device. Our real-time tracking management system is an open system built with readily available commodity hardware and free and open source software. Our system is composed of four components, a GPS and PM2.5 Tracking Device, a server, database and mobile application. The device's exact location is seamlessly provided by the GPS tracking device. Similarly the presence of particulate matter PM 2.5 is provided by PM2.5 Air Quality Sensor and a microcontroller is used to format and control it. In this system we used ESP-WROOM-32 as the microcontroller.ESP32 is a series of low-cost, low-power system on a chip microcontrollers with integrated Wi-Fi and dual-mode Bluetooth.

A. GNSS Data Formatting

In our project we have developed the device which is imbedded with the SparkFun SAM-M8Q GNSS receiver which is a GNSS receiver and can receive 72-channel meaning it can receive signals from the GPS, GLONASS, and Galileo constellations which increases precision and decreases lock time. The device also contain the General packet radio service (GPRS) module along with the PM2.5 Air Quality Sensor and a microcontroller. In this project we have used ESP-WROOM-32 microcontroller which is really powerful. The main purpose of the microcontroller is to control the signal coming out from the SAM-M8Q GNSS receiver since the GNSS receiver receives the satellite data in NMEA format. NMEA (National Marine Electronics Association) is a standard communication protocol used by marine and terrestrial navigation systems to enable devices from different manufacturers to communicate with each other. The NMEA data format is particularly common in the context of GPS (Global Positioning System) receivers and other navigation devices. One of the example of NMEA sentences is $GNGGA which is given below.

Crossponding Author: Tel: +977-9822975366

Email Address: mahatara.hemant9@gmail.com

$GNGGA 123519, 2815.42533, N, 08358.61071, E, 1, 08, 0.9, 984.4, M,-39.9, M,*47

Where,

GGA	Global Positioning System Fix Data
123519	Fix taken at 12:35:19 UTC
2815.42533,N	Latitude 28^0 15.42533’ N
08358.61071,E	Longitude $83^0$58.61071’E
1	Fix quality
08	Number of satellite being tracked
0.9	HDOP
984.4,M	Altitude, meters, above mean sea level
-39.9,M	Height of geoid(MSL) above WGS84 ellipsoid
*47	The checksum data always being with the *

Given the intricacies involved in transmitting diverse data types through the SIM800L module, the microcontroller undertakes the responsibility of processing both location data from the SAM-M8Q sensor and particulate matter (PM2.5) data from the air quality sensor. Initially, the microcontroller extracts the satellite data received from the SAM-M8Q sensor, employing the built-in library to convert the NMEA message into vital parameters like latitude, longitude, speed, DOP (Dilution of Precision), satellite count, and elevation. Concurrently, it interfaces with the PM2.5 air quality sensor, retrieving relevant data regarding particulate matter concentrations in the surrounding environment. These datasets are then meticulously formatted into JSON (JavaScript Object Notation) format. JSON's lightweight and easily interpretable structure, comprising key-value pairs arranged hierarchically, facilitates seamless parsing and generation, catering to the complexities of transmitting varied data types. This consolidated JSON format encapsulates both location and air quality data, ensuring comprehensive insights for subsequent analysis and transmission purposes. Here is a sample example that shows how the device's combined datasets are represented in JSON.


```
{
  "data": [
    {
      "id": "1319",
      "lat": "28.257350",
      "lng": "83.976493",
      "pm25": "12.5",
      "pm10": "20.8",
      "particles_03um": "168",
      "particles_05um": "72",
      "particles_10um": "35",
      "particles_25um": "18",
      "particles_50um": "8",
      "particles_100um": "2",
      "created_date": "2024-01-30 20:02:45"
    }
  ]
}
```


B. *Database Preparation*

It is imperative to establish a robust database to handle the influx of data transmitted by the tracking device. This database serves as the repository for storing, retrieving, reviewing, and analyzing the collected data. Following formatting, the data is transmitted to the database via the GSM/GPRS 800L module, leveraging its wireless transmission capabilities. Embedded with a Subscriber Identity Module (SIM), the GSM 800L utilizes local networks for data transmission. Renowned for its versatility, the SIM800L GSM/GPRS module acts as a miniature GSM modem, ideal for diverse IoT applications. Its functionalities extend to sending SMS messages, making phone calls, connecting to the Internet via GPRS, and more.

Using a GSM/GPRS module such as the GSM800L, there are a few important steps to make HTTP requests easier. To enable mobile data communication, the module is first turned on and initialized. Next, a GPRS connection is established. The HTTP request is then configured, including parameters like the port and server URL as well as any required headers or authentication data. The actual HTTP request is composed by indicating the headers, the method (such as GET or POST), and, if relevant, the request body. Either AT commands or a communication protocol particular to the module are used to send the request. After transmission, the device waits for the server to respond with HTTP, extracting and processing pertinent data as soon as it is received. It is optional to end the GPRS connection or release the resources.

To facilitate data storage, a local server was established using XAMPP, a versatile platform comprising Cross-Platform, Apache, MySQL, PHP, and Perl components. XAMPP provides developers with the capability to test code locally on their computers, akin to having a mini web server at their disposal. Compatible with both Windows (WAMP) and Linux (LAMP) environments, XAMPP offers a secure space for code experimentation and refinement before deployment. Leveraging the capabilities of the GSM/GPRS 800L and XAMPP, data is seamlessly stored in the local server database.

To make the stored data publicly accessible, an API is generated, facilitating efficient data retrieval and utilization for further analysis and application development.

Crossponding Author: Tel: +977-9822975366

Email Address: mahatara.hemant9@gmail.com

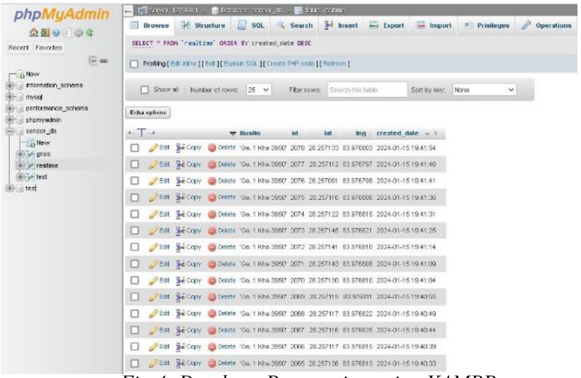

Fig 4: Database Preparation using XAMPP

C. APIs Generation

In the suggested system, the mobile application automatically calls the API as soon as it is opened. Afterward, the API replies by providing the device's present location along with real-time PM2.5 information. This integration makes it possible for users to see the location of the device and the current state of the air quality via the app, which promotes environmental awareness and helps with decision-making. Simultaneously, the gathered data is consistently preserved in the database, guaranteeing its accessibility for interested parties requesting access to past data.

Furthermore, the project encompasses future plans wherein the mobile application autonomously generates heatmaps based on location and particulate matter data. Utilizing interpolation techniques such as Inverse Distance Weighting (IDW) and Kriging, these heatmaps dynamically reflect air quality conditions at regular intervals, typically every hour. By seamlessly integrating this functionality into the mobile application, users gain real-time insights into the air quality landscape, empowering them to navigate their surroundings prudently.

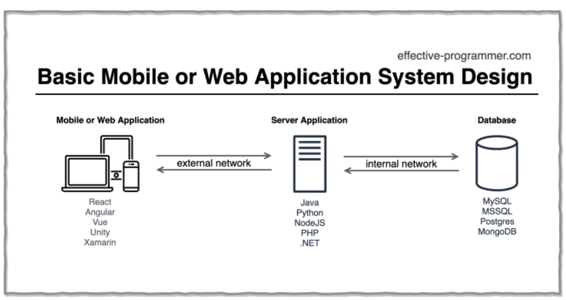

Fig 5: APIs Development for Mero Bus

So when we call an API,

http:// 192.***.***.8/gnss/test_data.php?action=retrieve

Then the SQL coded inside the test_data.php assign the current location along with the air quality data using this code,

retrieveSql = "SELECT * FROM realtime ORDER BY id DESC LIMIT 1";

D. RESULT AND DISCUSSION

The proposed project involves the creation of an all-encompassing environmental monitoring system that integrates cutting-edge sensor capabilities with geomatics technology. The principal objective of the project is to utilize the data provided by the device, specifically concerning air quality, in order to enable well-informed decision-making and environmental development activities.

With sensors like the PM2.5 Air Quality Sensor and the SAM-M8Q GPS receiver, the prototype device shows promise in providing location and air quality data in real time. For those making decisions in the fields of public health, urban planning, and environmental management, this data is extremely valuable. Aiming to improve air quality, stakeholders can formulate policies and carry out targeted interventions by integrating sensor data to obtain insights into the spatial distribution of air pollution levels.

Furthermore, the project's capabilities extend beyond air quality monitoring. There exists potential for integration with additional sensors, such as temperature, humidity, and rain gauge stations, to obtain a more comprehensive understanding of environmental conditions. By incorporating these datasets into the system, users can access real-time information crucial for hydrological modeling, disaster management, and urban resilience planning. Moreover, the integration of flood detection sensors further enhances the system's utility, enabling rapid response and evacuation measures in the event of flooding. Real-time alerts and alarms generated by the device facilitate timely interventions, safeguarding lives and minimizing property damage.

Certainly, the integration of location and air quality data opens up avenues for advanced visualization techniques such as heatmaps, facilitated by interpolation techniques like Inverse Distance Weighting (IDW) and Kriging. These techniques utilize the available data points to generate a continuous surface representation, providing insights into air quality conditions across different locations.

Inverse Distance Weighting (IDW) interpolates values at unknown locations based on the weighted average of nearby known data points, with weights inversely proportional to their distances from the target location. This method assumes that closer data points have a stronger influence on the interpolated value, thereby producing smoother surfaces. On the other hand, Kriging is a geostatistical interpolation method that considers not only distances but also spatial variability and correlation between data points. By modeling spatial dependence through variograms, Kriging produces more accurate and robust estimations, especially in areas with complex spatial patterns.

By applying these interpolation techniques to the combined location and air quality data, heatmaps can be generated to visualize air quality conditions spatially. Areas with higher concentrations of pollutants will be represented by darker shades, while areas with better air quality will be depicted with lighter shades. These heatmaps provide valuable insights for decision-makers and stakeholders, allowing them to identify pollution hotspots, assess spatial trends, and prioritize interventions effectively.

Crossponding Author: Tel: +977-9822975366

Email Address: mahatara.hemant9@gmail.com

Overall, the project offers significant advantages for decision-makers and geomatics engineers alike. It provides a robust platform for data-driven decision-making, allowing stakeholders to proactively address environmental challenges and plan sustainable development initiatives. By harnessing the power of geomatics technology and sensor data integration, the project paves the way for effective environmental planning, analysis, and management in a rapidly evolving world

REFERANCES

- Yee Leung, Yu Zhou, Ka-Yu Lam, Tung Fung, Kwan-Yau Cheung, Taehong Kim & Hanmin Jung (2019) Integration of air pollution data collected by mobile sensors and ground-based stations to derive a spatiotemporal air pollution profile of a city, International Journal of Geographical Information Science, 33:11, 2218-2240, DOI: 10.1080/13658816.2019.1633468

- Beattie, C. I., Longhurst, J. W. S., & Elsom, D. M. (2004). Evidence of integration of air quality management in the decision-making processes and procedures of English local government. *Local Environment*, *9*(3), 255–270. https://doi.org/10.1080/1354983042000219360

- Kaginalkar, A., Kumar, S., Gargava, P., & Niyogi, D. (2021). Review of urban computing in air quality management as smart city service: An integrated IoT, AI, and cloud technology perspective. *Urban Climate*, *39*, 100972. https://doi.org/10.1016/j.uclim.2021.100972

- Kleiman, G., Anenberg, S. C., Chafe, Z. A., Appiah, D. C., Assefa, T., Bizberg, A., Coombes, T., Cuestas, D., Henze, D. K., Kessler, A., Kheirbek, I., Kinney, P., Mahlatji, M., Marshall, J. D., Naidoo, S., Potwana, N., Rodriguez, A., Tessum, C. W., & Thomas, C. (2022). Enhanced Integration of Health, Climate, and Air Quality Management Planning at the Urban Scale. *Frontiers in Sustainable Cities*, *4*. https://doi.org/10.3389/frsc.2022.934672

- Matejicek, L. (2005). Spatial modelling of air pollution in urban areas with GIS: A case study on integrated database development. *Advances in Geosciences*, *4*, 63–68. https://doi.org/10.5194/adgeo-4-63-2005

Crossponding Author: Tel: +977-9822975366

Email Address: mahatara.hemant9@gmail.com