DEVELOPMENT OF A MOBILE FINE DUST AIR QUALITY MONITORING AND ASSESSMENT SYSTEM

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ABSTRACT

Air pollution caused by fine dust is a major global issue and is particularly significant in Vietnam. Fine dust has a serious impact on human health. Despite this, air quality warnings and fine dust monitoring remain inadequate due to the limited number of monitoring stations, and access to information about fine dust is still not widespread. The traditional way of using fixed sensors cannot effectively provide accurate, localized data since the closest sensors can be miles away. This paper proposes a mobile fine dust measurement and data analysis system using IoT technology with the MQTT protocol and GPS for location tracking. Installed on personal vehicles, the system includes a low-cost device to measure fine dust and a smartphone application to display air pollution information. By leveraging an efficient data model, users can access fine dust statistics on a smartphone map and take timely action to protect their health.

Keywords: *Fine dust, IoT technology, GPS, mobile device, MQTT.*

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1. INTRODUCTION

Nowadays, humans face several pollution problems, such as light pollution, water pollution, and noise pollution. Air pollution is also one of the most important things we need to control. According to the World Health Organization (WHO), more than 92% of the global population lives in areas where air pollution exceeds safe levels. In America, urban emissions constitute 52% of total emissions by weight, yet they account for nearly three-quarters of the GAD [10]. Moreover, air pollution can enhance T helper lymphocyte type 2 (Th2) and T helper lymphocyte type 17 (Th17) adaptive immune responses, as seen in allergy and asthma, and dysregulate antiviral immune responses. In Vietnam, approximately 60,000 deaths each year are related to air pollution [14]. As a result, the demand for a system that can measure the amount of dust in the air becomes a significant thing that helps the government and civilization to find ways to reduce the effects of air pollution. However, the situation shows that the current monitoring network is insufficient, relying mostly on stationary stations, leading to data uncertainty. This leads to implementing technological solutions for monitoring, analyzing, and disseminating air quality information to the public as a top priority.

Identifying the causes of dust pollution is crucial for accurate measurement. The main sources of fine dust that frequently affect air quality in urban areas include traffic dust, suspended soil dust, fly ash from honeycomb charcoal stoves and biomass burning, and dust originating from waste. Besides, the amount of dust that belongs to the polluted areas in neighboring countries also contributes to the increase in the dust level of Ha Noi through air masses. It leads to bad effects on the weather in the north. However, the dominant source of emissions comes from more than 7 million vehicles, most of which are motorbikes.

Amidst the rapid advancements of Industry 4.0, the Internet of Things (IoT) has emerged as a leading technological solution for air quality monitoring, data analysis, and public communication. IoT refers to a network of devices that can collect and exchange data. These connected devices include embedded systems, sensors, and network connectivity, allowing them to interact with other IoT devices. IoT has been employed in various sectors. For example, in medicine, telemedicine uses computers, communication networks, medical technology, and equipment so that the patient and experts, medical experts, and grassroots medical men can consult the patient's condition face to face. However, they are in different places [2]. Besides, IoT also helps to optimize the greenhouse environment and resource management [3]. Moreover, IoT is a promising technology in sustainable supply chain management that could significantly change homes and industries. Connected devices will be data-driven, reacting quickly to information and providing valuable feedback. This technology will promote personal independence and energy conservation while minimizing waste [4]. In more detail, air quality monitoring has become a focal point for many research projects and community-based initiatives, as poor air quality is a major concern for cities worldwide. Prolonged exposure to poor air quality poses significant health risks to urban populations. Several studies have explored air pollution treatment, monitoring, and forecasting systems to address this issue. In Russia, researchers have developed an exhaust gas treatment system for mobile and portable asphalt concrete plants [5]. In another way, Korean researchers developed a smartphone application to provide air pollution information, which helps users check the fine dust statistics map and cope with fine dust accordingly [6]. Moreover, the combination of Australia's and France's researchers showed that humidity and noise are the most important factors influencing the prediction of nitrogen dioxide concentrations of mobile stations by using machine learning modeling [7]. Moreover, another research focuses on modeling the air quality pattern in a given region by adopting fixed and moving IoT sensors placed on vehicles patrolling around the region [8]. Furthermore, other researchers increase the ability of data collection on air pollution by using GPS-enabled personal exposure monitors to collect personal exposure readings. Another article presents an experimental study on real-time air pollution monitoring using wireless sensors on public transport vehicles [9].

This paper aims to develop a mobile device capable of collecting fine particulate matter, temperature, and humidity data, analyzing and sending real-time information to users. In this paper, we describe the operational characteristics of the device and present an algorithm for analyzing and predicting pollution levels based on the collected data. The final goal is to propose a viable solution to improve the quality of the environment and promote healthier living conditions.

2. METHODOLOGY

This section details the development process of a mobile fine dust measurement. The crucial idea for this dust measurement system is portability and attaching to transport vehicles.

2.1. System Architecture

The bottom is Data Collection Layer utilizing IoT technologies with sensors and ESP8266, a microprocessor, is able to transmit sensing data through the Internet using MQTT protocol to the central Server.

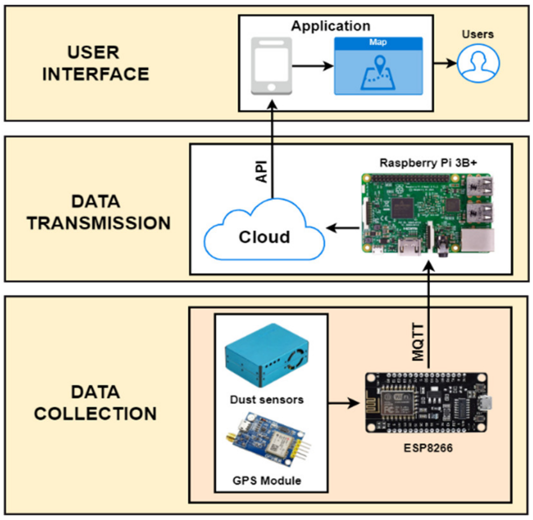

Figure 1. System Architecture

The Center Layer stores sensing and location data in a local database on Raspberry Pi as the central server. A local database will ensure data conversion to ensure the system does not lose any data if the system has network issues. Additionally, this central server will process data to clean, filter, analyze, and predict pollution levels, then upload the results to a cloud server in real-time. The User Interface Layer will use RestAPI to retrieve data from the Cloud and visualize this data on a map application. Users can see forecast pollution levels on various roads.

2.2. Hardware Design

A portable box has been developed to integrate key components for real-time monitoring and data transfer, ensuring efficient measurement of fine dust on transport vehicles. It features a micro dust sensor that measures PM2.5 and PM10 (0 - 999.9μg/m^3), providing essential air quality data. A Raspberry Pi 3B+ is a CPU, connected to LTE via a USB WiFi modem for cloud data transmission and local storage. An ESP8266 manages communication, while an attached GPS module logs location data, enabling precise tracking of dust levels. Powered by a 15,000mAh 18650 battery pack, the system runs for about 7.5 hours on a full charge, making it ideal for extended field use. The box design protects against environmental factors and makes the system simple to install and move on many vehicles. Additionally, it provides easy access to components for maintenance and recharging, making the device both functional and portable.

2.3. Software Development

The mobile fine dust measurement system consists of three core components: data transmission, management, and display. It employs M2M communication [12] with MQTT for real-time, efficient data transmission, cloud computing for scalable data storage and processing, and a mobile app for user-friendly interaction. MQTT's lightweight design and publish-subscribe model make it ideal for IoT, with a Raspberry Pi running Mosquitto Broker to manage data streams securely and efficiently. Data from sensors and GPS modules is stored and processed using Google Cloud, ensuring scalability, real-time analysis, and accurate pollution level reports. The mobile app integrates Google Maps to display fine dust data on an interactive map, letting users track pollution levels across locations in real-time with ease.

2.4. Data Collection and Handling

The box will deploy on vehicles to let them carry it across routes to measure PM2.5 dust. Figure 2 indicates the process of delivering data from the mobile module to the server to handle and visualize to users.

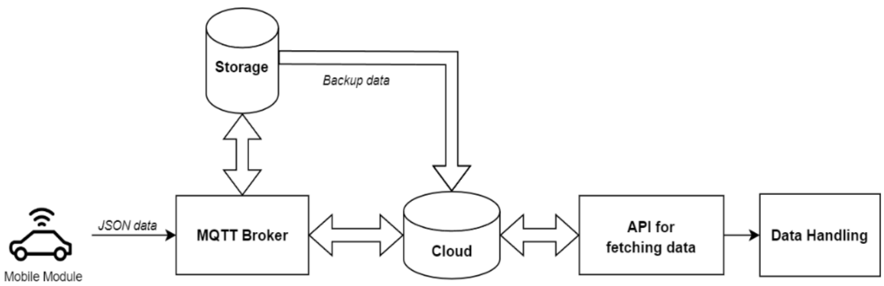

Figure 2. Data Collecting

Sensor data will be organized in JSON data format to pack into a message, then published to the topic on MQTT Broker. The Raspberry Pi is the MQTT Broker and a subscriber to achieve that message. The message will be unpacked, converted to CSV files, and stored in Google Cloud. The Analyzing Server can fetch data from the Cloud using Google Drive APIs to handle data. In mobile measurement applications, data loss can significantly undermine the accuracy and continuity essential for effective monitoring and analysis [13]. Missing data distorts trend analysis and predictive models, limiting the capacity to make timely decisions based on current conditions. The system will simultaneously store data in local storage and the cloud to address these concerns. Combining cloud-based storage with local backups [14] improves data resilience by synchronization, which protects against data loss caused by device faults or network issues.

2.5. Model Prediction

PM2.5 data is collected over time and processed into a time series, then normalized to suit deep learning models. The model uses an LSTM recurrent neural network, which can capture sequential relationships, to learn and forecast PM2.5 values based on past data. The training process uses overlapping sequences to predict the next time step, helping the model detect trends or fluctuations over time. After training, test data is normalized and fed into the model to generate forecasts, which are then converted back to original values for comparison with actual data. Accuracy is evaluated using root mean square error, while results are visualized on plots to clearly show how well predictions match real values, supporting monitoring and decision-making regarding air quality.

3. IMPLEMENTATION AND RESULTS

3.1. Deployment

The deployment process consisted of two phases: initialization and actual deployment. During the initialization phase, the box was powered on, and the Google Cloud interface was used to verify that the system was running smoothly with no issues in data collection. Once everything was confirmed to be functioning properly, we moved on to installing the system on the vehicle.

3.2. Result

Table 1. Percentile Distribution of Fine Dust Values

Metric	Value
25th Percentile (Q1)	The lowest value of 25% of the measured samples is 60μg/m^3.
50th Percentile (Q2)	The median value is 84μg/m^3.
75th Percentile (Q3)	The highest value of 75% of the measured samples is 112μg/m^3.

The data analysis results show that the average value of the measured fine dust is 91.77μg/m^3 (the average of all measurements). The median, representing the distribution's middle value, is 84μg/m^3, indicating that

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most of the data is concentrated around this level. The standard deviation is calculated as 44.76µg/m^3, reflecting the moderate fluctuations of the measured data. The distribution of fine dust values is also analyzed through percentiles (Table 1).

Figure 3 illustrates the change in the PM2.5 index. First, it can be seen clearly that the amount of PM2.5 is high from 10am to 9pm. During this time, this figure is higher than the standard recommended by WHO (50µg/m^3). Besides, this figure reaches its peak at 10am. The air quality is good after 11pm, below 50µg/m^3. And the state of the air becomes worse after 6am. In Ha Noi, from 6am to 9pm, this is the time when work and study activities take place. This leads to a large amount of traffic, causing emissions to become unusually high. In addition, around 10am, it is time for Hanoians to have lunch, combined with the hot and dry weather at noon and the habit of having lunch at restaurants. This leads to large emissions of dust not only from vehicles but also from restaurants. People rest from 5pm to 8pm after a long workday. The need to go out and move around currently increases, leading to increased dust emissions.

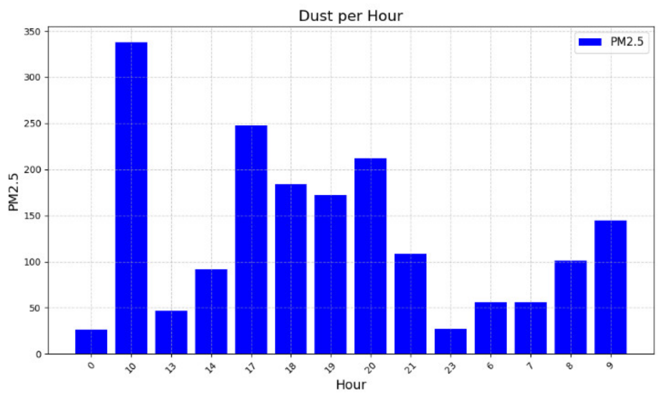

Figure 3. Dust per Hour

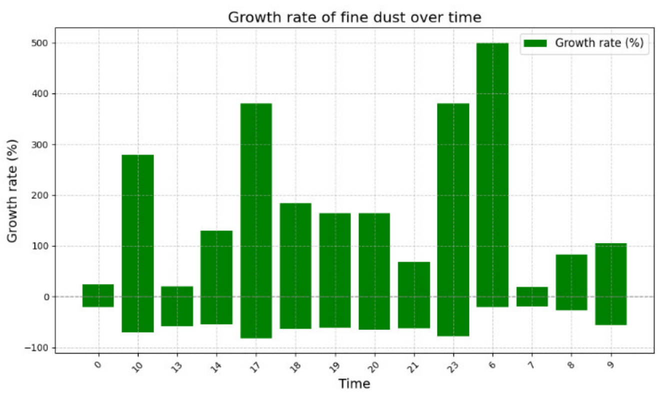

Figure 4. Growth rate of fine dust over time

Figure 4 shows the growth rate of fine dust, and we can see that the rate of fine dust increases significantly at 6am. During this time, most Hanoians started their daily activities, leading to increased travel demand and the use of motorbikes as the main means of transportation. This leads to the highest fine dust concentration currently. Additionally, the remaining periods exhibit a similar trend to that shown in Figure 3.

	Timestamp	Year	Month	Day	Hour	PM2.5	Latitude	Longitude	Date
0	2024-04-11 09:57:00	2024	11	4	9	106	21.034198	105.823118	2024-04-11 09:57:00
1	2024-04-11 09:57:00	2024	11	4	9	100	21.034245	105.823198	2024-04-11 09:57:00
2	2024-04-11 09:58:00	2024	11	4	9	97	21.034258	105.823254	2024-04-11 09:58:00
3	2024-04-11 09:58:00	2024	11	4	9	101	21.034277	105.823304	2024-04-11 09:58:00
4	2024-04-11 09:59:00	2024	11	4	9	104	21.034263	105.823186	2024-04-11 09:59:00
...	...	...	...	...	...	...	...	...	...
475	2024-11-18 21:00:00	2024	11	18	21	98	21.033503	105.769740	2024-11-18 21:00:00
476	2024-11-18 21:00:00	2024	11	18	21	102	21.033803	105.768434	2024-11-18 21:00:00
477	2024-11-18 21:00:00	2024	11	18	21	86	21.034388	105.766384	2024-11-18 21:00:00
478	2024-11-18 21:00:00	2024	11	18	21	67	21.033629	105.767127	2024-11-18 21:00:00
479	2024-11-18 21:00:00	2024	11	18	21	96	21.033139	105.766102	2024-11-18 21:00:00

Figure 5. GPS detection

The integration of GPS technology into the mobile air quality monitoring device has enabled precise location-based particulate matter measurements, fundamentally transforming how air pollution data is collected and analyzed (Figure 5). By continuously tracking the device's geographical coordinates while simultaneously recording PM2.5 concentrations, the system creates a comprehensive spatial-temporal dataset that captures the dynamic nature of air quality across different urban environments.

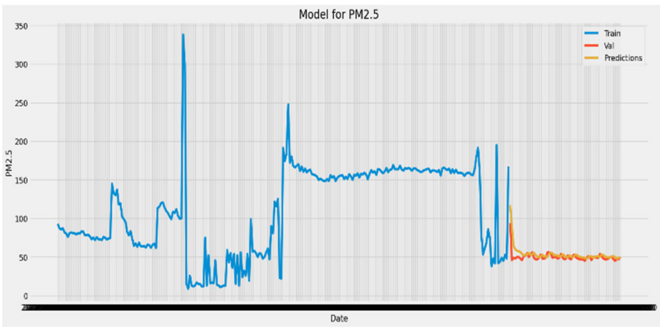

Figure 6. Prediction Model for PM2.5

Figure 6 presents the PM2.5 prediction results, where the training data exhibits numerous high peaks and significant fluctuations, whereas the validation data remains at lower and more stable levels. The prediction curve remains relatively close to the validation curve, exhibiting small oscillations that closely follow the pattern of the actual data. However, at the beginning of the validation period, the prediction curve rises higher than the actual values, possibly due to the influence of large values in the training set. Additionally, the training and validation datasets still exhibit differences in fluctuation amplitude and average value levels. Due to the limited scope of data collection and the absence of diverse factors such as seasonal variations, meteorological conditions, and different environmental contexts, future research will focus on expanding the dataset to include a broader range of variables.

4. CONCLUSION

This study developed a mobile fine dust measurement system using Internet of Things (IoT) technology and GPS tracking to address air pollution in urban Vietnam, particularly in Hanoi. The system's portable and adaptable design allows for the deployment of various vehicles, improving the accuracy and coverage of fine dust monitoring. The results demonstrate that the system effectively collects real-time data on particulate matter (PM2.5 and PM10), temperature, and humidity, even in areas lacking fixed monitoring stations. Data analysis revealed that most measurements exceeded the World Health Organization's safe air quality thresholds, emphasizing the urgent need for effective air quality management. The system empowers users to make informed health decisions by providing localized air quality information. The integration of cloud computing facilitates efficient data storage and processing. Overall, this research contributes to innovative air quality monitoring solutions and underscores the importance of real-time data in combating pollution. Future work will focus on enhancing the system's capabilities and expanding its use to improve public health outcomes.

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