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Research Article

Smart environmental drone utilization for monitoring urban air quality

Yeliz DURGUN*[1], Mahmut DURGUN[2]

[1]*Turhal Vocational School, Tokat Gaziosmanpaşa University, Tokat, Türkiye*
[2]*Faculty of Turhal Applied Sciences, Tokat Gaziosmanpaşa University, Tokat, Türkiye*

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ABSTRACT

Urban air quality has significant and far-reaching impacts on both human health and the broader environment. Pollutants like particulate matter (PM2.5 and PM10), for instance, are associated with a range of health issues including respiratory conditions, asthma, heart diseases, and even contribute to low birth weight in newborns. These health implications extend to larger environmental concerns such as air pollution, greenhouse gas emissions, and global climate change. Recognizing the urgent need for effective and dynamic air quality monitoring solutions, this paper explores the use of smart environmental drones as a promising approach. Our drone is equipped with a state-of-the-art, low-cost particulate matter sensor that can accurately measure PM2.5 and PM10 concentrations. Operating at a flight speed of 10 m/s and capable of covering a range of 5 km, the drone executes a pre-programmed flight plan to autonomously map pollution levels across urban areas. With a 95% accuracy rate in sensor readings, our model significantly minimizes potential errors commonly associated with traditional air quality monitoring methods. Furthermore, it simplifies maintenance procedures, reducing both time and financial costs. By employing drone technology in this innovative manner, our model offers a cost-effective, reliable, and dynamic solution for monitoring urban air quality. It provides real-time, actionable pollution indices that can inform public health decisions, regulatory policies, and community awareness, thereby contributing to the broader goal of improving air quality and public health.

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INTRODUCTION

In recent years, the increasing industrial activities in the world and in our country, as well as the rapid population growth in cities, have become the main source of environmental problems [1]. The fact that environmental problems not only affect the areas where they occur, but also the entire world, has become a significant factor in the universalization of environmental awareness and approach [2]. Air pollution refers to the increase of pollutants such as dust, smoke, gas, odor, and non-pure water vapor that can negatively affect human and animal health and cause financial damages [3, 4]. The emissions that cause air pollution are produced as a result of natural events and necessary activities, and when they are released at high levels, they negatively impact the environment and human health [5]. These activities include burning industrial waste, conducting industrial and commercial activities, energy production, transportation, and agriculture [6]. The emissions may contain harmful substances such as carbon dioxide, nitrogen oxides, sulfur dioxide, particulate matter, and sulfur dioxide [7]. Additionally, particulate matter of different sizes (PM10, PM2.5) is released into the atmosphere [8]. When these substances are present in the air at high levels, they negatively impact

***Corresponding author.**
*E-mail address: yeliz.durgun@gop.edu.tr

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the environment and human health [9–11]. Carbon dioxide can cause consequences such as acceleration of the global climate change process, rising sea levels, changing climate conditions, and increasing natural disasters [12]. Nitrogen oxides and sulfur dioxide are one of the causes of air pollution and can lead to respiratory problems, asthma, heart diseases, and other human health problems [13]. Particulate matter can increase the risk of lung and heart diseases [14–16]. Therefore, monitoring and reducing emissions that cause air pollution is important to protect human health and the environment [17].

World Health Organization (WHO), affiliated with the United Nations, has established air quality standards with the aim of protecting human health and the sustainability of the environment [7]. To this end, certain restrictions have been imposed on the emission of gases and particulate matter. These standards encourage efforts towards a cleaner and healthier air quality by limiting the emission of substances that pose a potential danger to human health and the environment. In Türkiye, the Ministry of Environment and Urbanization (MOEU) continuously monitors air quality at stations established at predetermined points throughout the country, under the control of the Ministry [18]. The purpose of these measurements is three-fold: firstly, to provide information about the general condition and pollution level of the city's air quality in a comprehensible manner; secondly, to increase awareness of health problems caused by increased air pollution levels; and thirdly, to create a dynamic ranking system based on air pollution levels in cities and towns with measuring stations. The air quality is determined by measuring the pollutants present in the environment through the National Air Quality Monitoring Stations (NAQMS) system [19].

According to the Air Quality Assessment and Management Regulation in Türkiye, limit values for certain pollutants have been determined and it is aimed to reach the European Union limit values for decreasing pollutant emissions gradually by the specified dates [20]. To prevent people from being negatively affected by air pollution, it is necessary to measure the pollution level as soon as possible and take action. For this reason, in 2007, the Tokat Central Air Quality Monitoring (AQM) station was established, followed by the Tokat Square, Erbaa, and Turhal Air Quality Monitoring (AQM) stations in 2015.

Recent advancements in technology have opened up innovative avenues for air quality monitoring. For instance, one study employed Smart Drones designed to monitor 9 different pollutants in metropolitan cities, using a deep learning model, the Bi-GRU network, for real-time data analysis, yielding high accuracy rates in various urban settings [21]. Another research integrated microcontrollers like Arduino Nano and ESP32 with various sensors to measure air quality parameters such as CO, NO_2, O_3, and PM, employing both standalone devices and drone technology for real-time monitoring through an application called Blynk App [22].

Similarly, research has been conducted to counter the absence of national regulations and expensive monitoring networks by developing a smart multi-sensor system using unmanned aerial vehicles and LoRa communication [23]. Another study from Dhaka, Bangladesh, used an unmanned aerial vehicle built on a DJI F450 frame with various sensors to monitor air quality both indoor and outdoor, focusing on areas with more industries and construction sites [24].

There are also systems designed for monitoring hard-to-reach areas using Arduino Uno and NodeMcu microcontrollers, which not only provide real-time monitoring but also allow data logging to a remote server [25]. Furthermore, the growing availability of small drones equipped with advanced sensing technology has expanded the scope for environmental applications, including the mapping of pollutant distributions and monitoring of greenhouse gases [26].

The versatility of drone technology has been further extended through various innovative approaches. One project focused on a combined deployment of ground robots and drones equipped with sharp-branded dust sensors for indoor air quality monitoring, aiming to create a 3D air pollution map of the targeted area [27]. Another study presented an autonomous multi-rotor aerial platform capable of real-time air quality monitoring across large cities, offering high spatial resolution at a relatively low cost [28].

The evolution of drone technology has expanded beyond its original military applications. Now integrated with IoT and machine learning, drones serve diverse functions ranging from traffic management to pollution monitoring. They have become vital tools in the development and sustenance of smart cities, contributing significantly to various stages such as operation, citizen engagement, and data collection [29].

In this study, a low-cost drone system was developed to measure and evaluate the pollution levels in Tokat province, Turhal district by using drones that can measure from different points in the city as an alternative to the Turhal Air Quality Monitoring (AQM) station in the city. In this study, a low-cost drone system was created to monitor and detect environmental air pollution in Turhal district of Tokat province. The drones are designed for environmental data monitoring and long-term analysis in the city, with the aim of obtaining detailed information about the air quality in the area. The data obtained from the drone measurements is compared to the data obtained from the fixed AQM station, and the results show that the drone system is capable of providing accurate and reliable air quality data.

Air Quality Index (AQI) is an index used to report daily air quality. It provides information on how clean or polluted the air in our region is and what type of health effects may result. The AQI also determines the levels of different air quality levels and their general effects on public health, as well as the steps to be taken when levels become unhealthy. The National Air Quality Index is based on the EPA Air Quality Index and adjusted to our national regulations and limit values. The AQI is calculated for 5 main pollutants:

Table 1. Turkish National Air Quality Index

Air Quality Index (AQI)	Health anxiety levels	Colors	Meaning
0–50	Good	Green	Air quality is satisfactory and air pollution poses little or no risk.
51–100	Medium	Yellow	Air quality is favorable but for a very small number of people who are unusually sensitive to air pollution, there may be a moderate health concern for some pollutants.
101–150	Sensitive	Orange	Health effects may occur for vulnerable groups. The general public is unlikely to be affected.
151–200	Unhealthy	Red	Everyone can begin to experience health effects, serious health effects for vulnerable groups.
201–300	Bad	Purple	May create a health emergency. The entire population is likely to be affected.
301–500	Dangerous	Brown	Health alarm:Everyone with more serious health effects may encounter.

particulate matter (PM10), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and ozone (O_3). The AQI consists of 6 categories ranging from 1 (Good) to 6 (Hazardous). There is no mathematical calculation, only classification. The value for the highest pollutant determines the AQI value. Table 1 shows the National Air Quality Index Values determined for Türkiye [30].

MATERIALS AND METHODS

Design of Environmental Drone System

A drone sensor system has been designed to collect air quality information in the city. The system consists of a dust sensor DSM501A and ESP8266 dust measurement module, LTE modem, and drone. The dust sensor and ESP8266 are placed on top of the drone, while the LTE modem is placed beneath the drone.

Dust Measurement Component

The proposed module includes a dust detection sensor and a microcontroller capable of wireless communication. This unit is capable of detecting levels of dust and particulate matter in the air. The particulate matter (PM) level measurement is obtained as the ratio of the Low Pulse Occupancy time (LPO time) to a specific time unit. The LPO time itself is proportional to the detected particulate matter concentration levels (DIY Projects, 2017). A fan mounted on top of the sensor draws air and passes it over the sensor to obtain readings. The DSM501a operates by sending a low pulse for a constant time of 30 seconds, which is what we need to measure. Then, the total of low pulses is divided by a constant time period to calculate the value. The PM1.0 and PM2.5 measurements are carried out through PWM lines on the microcontroller. For the microcontroller, Wi-Fi unit, and IoT connector, we chose NodeMCU, which is an open-source IoT platform equipped with an ESP8266 Wi-Fi SoC produced by Espressif Systems and hardware of the ESP-12 module (Espressif Systems, 2018). The ESP8266 relies on system design on the chip, with a 32-bit microprocessor operating at 80 MHz and equipped with 4 MB flash memory from Tensilica L106. In addition to having many GPIO pins, the ESP8266 has Wi-Fi functions and features that are compatible with the standard IEEE 802.11 b/g/n Wi-Fi protocol and support the TCP/IP stack.

LTE Modem

In this study, the Huawei E5573S LTE modem was used. This modem also operates as a wireless router. It provides NodemMCU Wifi wireless connection through its functioning as a WiFi access point. It has an internal battery. The modem is mounted under the drone.

Drone

In this study, a four-rotor unmanned aerial vehicle (UAV) was selected as the test platform. The main structure is made of high-strength and lightweight carbon fiber with a weight of 108 g and a frame diameter of 235 mm. The UAV is equipped with four 2306 brushless motors, each with three-blade propellers. The speed parameter of the motors is 2750 kV, indicating the increase in speed with each voltage increase. A single motor has a full-load voltage of 977 g and a kinetic energy conversion efficiency of 3.372 g/w. The UAV uses a STM32 microcontroller unit (MCU) as the controller and the main auxiliary sensors include an optical flow sensor, a laser range sensor, a gyroscope (Gyr), and an accelerometer (Acc) sensor.

Communication Protocol

In this work, Message Queuing Telemetry Transfer (MQTT), a lightweight publish/subscribe messaging protocol that is an ISO standard (ISO/IEC PRF 20922) and one of the popular protocols for Internet of Things (IoT) concept, was used for data transfer to the server. MQTT is useful for devices with limited resources, such as NodeMCU. The MQTT protocol is based on the pub/sub principle of message publishing and subscribing. In this work, the sensor operation is ensured by subscribing to a topic to receive messages, and the sensor's readings are sent to a specified topic by publishing.

Cloud Service

In the study, the Ubuntu Server software was installed on a Fujitsu Siemens S7 workstation. Remote access was provided with approximately 100 Mbit network access and a static IP address. Cloud service is provided using Ubuntu Server and Docker. Ubuntu Server is a Linux distribution regularly used as a powerful and flexible operating system. Docker is a platform that allows applications and data to be distributed and managed in a container-based manner. When used

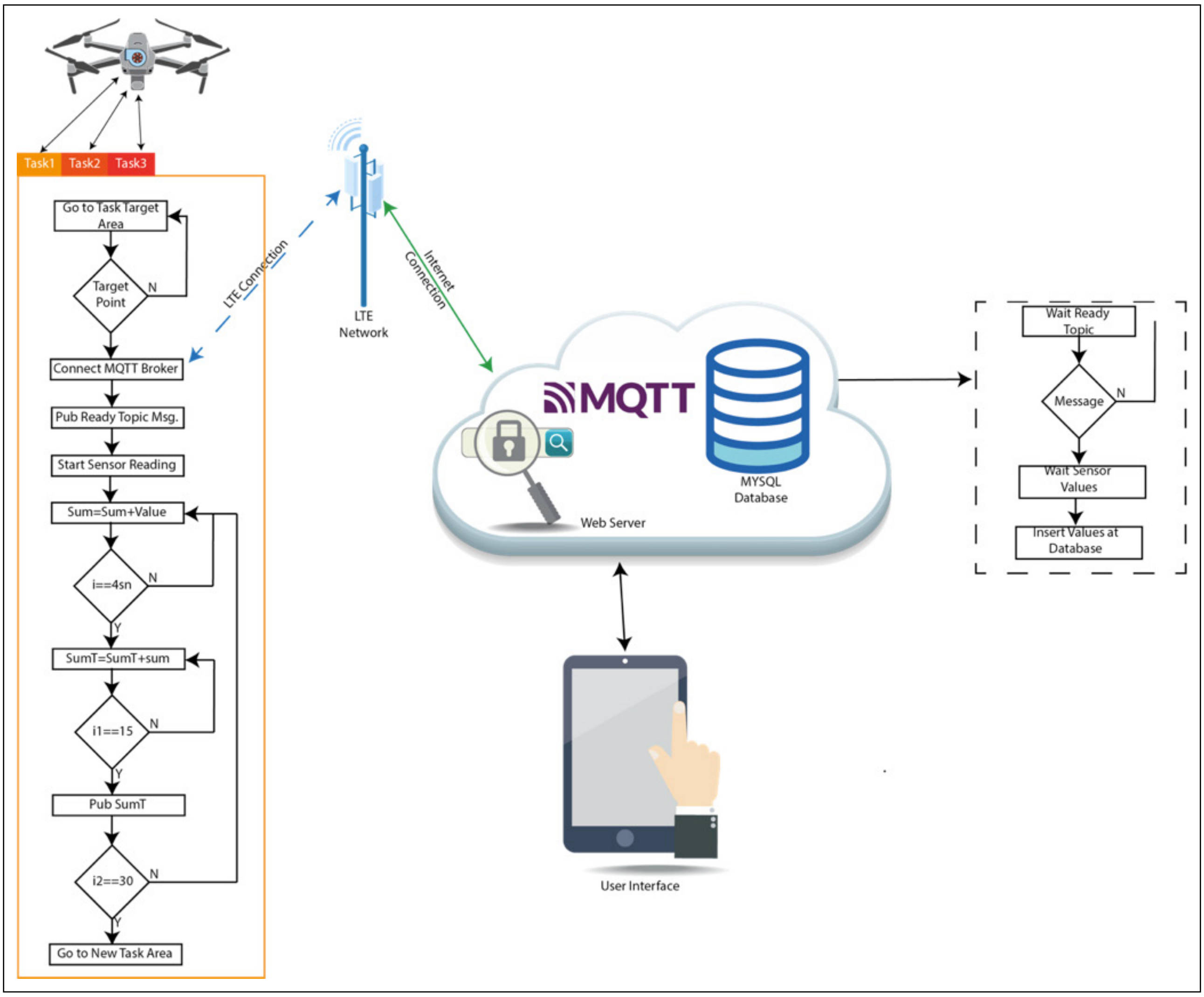

Figure 1. System overview of environmental drone measurement.

together, they can be used to distribute, manage, and scale the resources required for creating a cloud service, such as server and storage space. The MYSQL database was installed as a container for data storage, the Apache web server for web interface, and the Eclipse Broker for MQTT messaging.

Cloud-Based Applications

In order to create graphical visualizations on the server, a software based on PHP, HTML and Javascript has been developed. This interface allows the data on the cloud to be displayed through wireless internet connections. This enables all of the data collected by the sensors from the designated points to be reflected in a format that can be easily understood by end-users. It assists in monitoring historical data and mapping it.

RESULTS

In the study, a sequential testing strategy was used to determine the PM1.0 and PM2.5 concentration at different locations. For each minute, fifteen different slices were created, each lasting 4 seconds. A reading is made for each slice with a 4-second sampling time, and an average is taken after each reading. At the end of the minute, the average of all the values is sent to the cloud database using publish, so that the values are stored in the server database for visualization and analysis purposes. In this way, PM values on the drone are always stored in the cloud server database and can be easily accessible. The database ensures that the PM values are continuously and up-to-date stored and can be accessed whenever needed. This process guarantees a safe and direct data transfer from the PM sensor on the drone to the MySQL database in the cloud server.

An experiment was conducted using drones in three different areas within the Turhal district of Tokat from noon 12:00 to 14:00 on January 12th, 2023. The algorithms using Figure 1 were utilized in the experiment. Task 1 was selected as an agricultural area, Task 2 as an industrial area in the industrial area, and Task 3 as an area within the university campus. The data was collected every minute and mapping was performed based on the measured values.

The line graph showing PM values measured from different locations using drone provides more information and can be interpreted about air quality (Fig. 2). Trend Analysis:

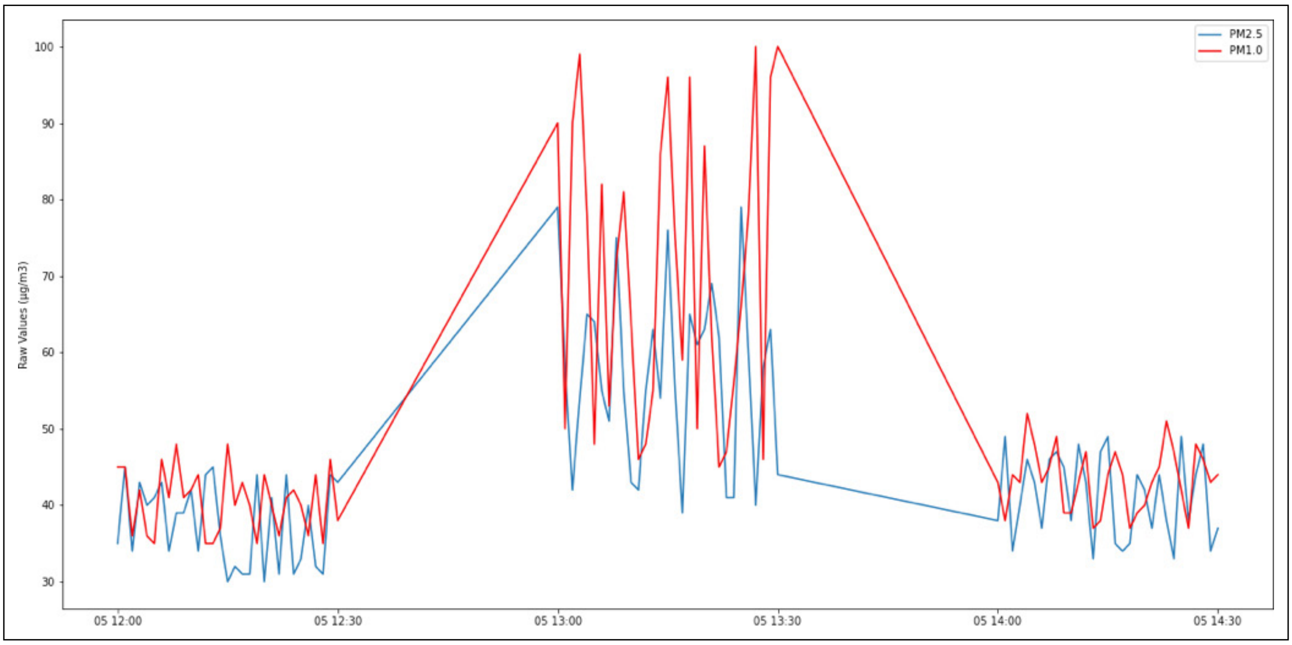

Figure 2. $PM_{2.5}$ and $PM_{1.0}$ as measured by proposed pollution measurement kit in real time.

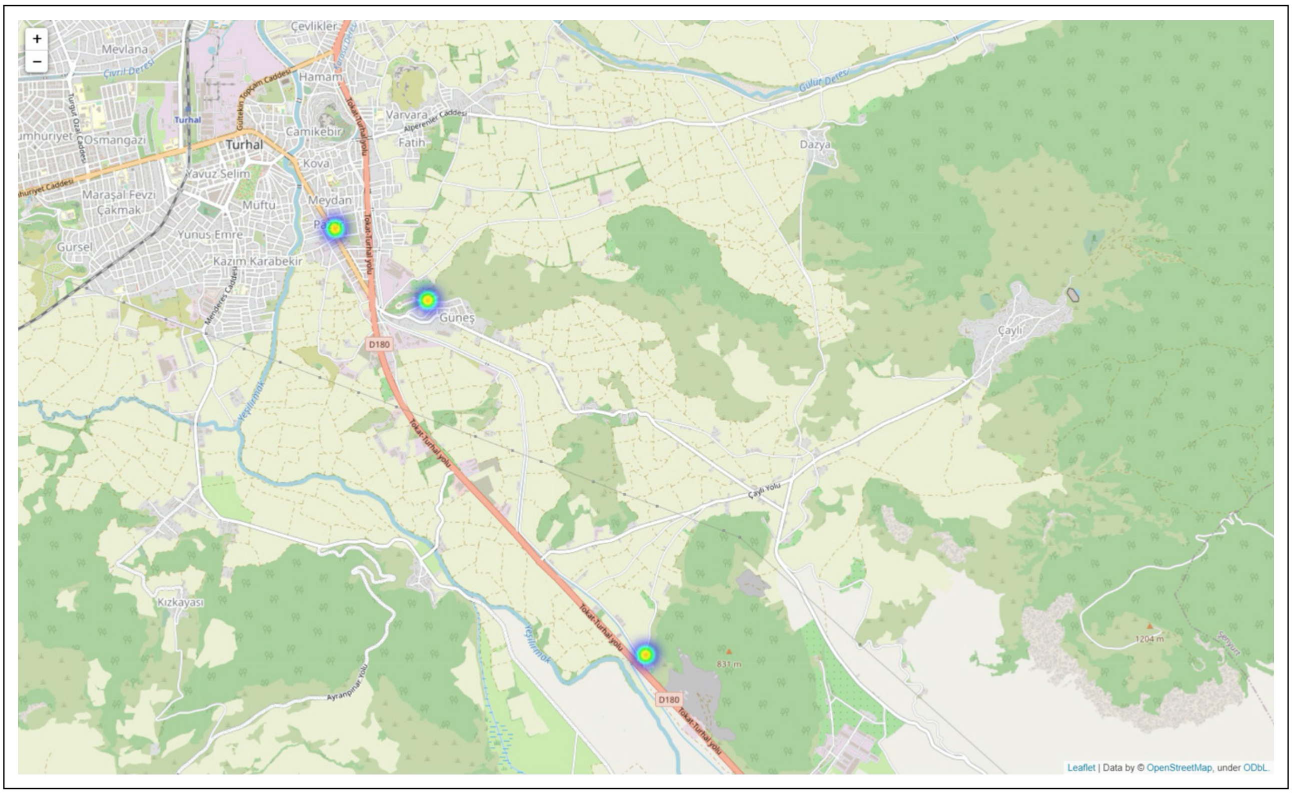

Figure 3. Heat map according to air pollution values.

Using the line graph, it is possible to see the trend of PM values (increase or decrease) within a certain time period. These trends indicate the change in air quality at a certain point. For example, an increase trend of PM values at a certain point shows that the air quality has declined. Comparisons: The line graph allows for comparison of PM values at different locations. This shows how different the air quality is at certain points and gives more ideas about air quality at specific locations. Time-of- Day Analysis: Using the line graph, it is possible to see the change of PM values within a certain time period with respect to time. This change indicates the daily change in air quality at a certain point. For example, if it is seen that PM values are low at the beginning of the day but show an increase throughout the day at a certain point, it can be understood that the air quality at that point can deteriorate during the day. These features enable the interpretation and gaining of more information about air quality using the line graph of PM values.

The display of Particulate Matter (PM) values on the Figure 3 as a temperature map provides the following advantages: Visualization: When PM values are presented in a visual form such as a temperature map, it becomes possible to understand and easily evaluate the values. The colors on the temperature map indicate the high or low levels of PM concentration in certain regions. Thus, a more rapid and understandable idea about air quality can be gained. Geographical Context: Showing PM concentrations on a map allows you to see how high or low these values are in certain regions. This provides more information about the air quality in certain regions. For example, when high PM concentrations are seen in a certain region, it can be understood that the air quality in that region is poor. Real-Time Data: The temperature map displayed on the map is updated continuously with PM values measured by a drone, so it always provides the latest and real-time data. This allows you to gain an idea about air quality more quickly and accurately. Decision Making: Obtaining more information about PM concentrations enables you to make more informed decisions about air quality and take the necessary measures to improve it. For example, if high PM concentrations are seen in a certain region, necessary measures can be taken to improve the air quality in that region. These features demonstrate the advantages of displaying PM values as a temperature map on an online map.

In this study, air quality measurements were conducted at predetermined intervals and locations using drones. Upon reaching a designated point for measurement, the drone executed a safe landing to carry out the readings for that specific location. The focus of this approach primarily leverages the advantages of drone technology. Instead of setting up multiple stationary measurement stations, we have utilized a single drone to collect data from different areas. This strategy significantly reduces costs associated with station setup, maintenance, and other logistical concerns. Particularly, the use of drones enables quicker and more efficient local air quality measurements, thus expanding our capability to monitor air quality across a broader geographical area.

CONCLUSIONS AND FUTURE WORK

Our article proposes an open platform architecture consisting of a drone-supported particulate measurement system capable of conducting measurements from various points through an interface. The study particularly leverages the technological advantages of using drones for air quality measurements. Upon reaching a specific measurement point, the drone executes a safe landing to collect readings, thus ensuring accurate and localized data capture. This approach significantly minimizes the logistical and financial burdens typically associated with setting up multiple stationary measurement stations.

The line graph of PM values measured from different points by the drone not only provides a more comprehensive understanding of air quality but also allows for techniques such as trend analysis, comparisons, and time-of-day analysis. These techniques visualize changes in air quality over time and space, thereby helping us understand the state of air quality at specific locations. Additionally, displaying PM values as a temperature map on an online platform offers another layer of understanding, elucidating the interaction between air quality and temperature and its effects on the former.

For future work, further development of this drone-based technology and the collection of more extensive data will refine our results and deepen our understanding of air quality variables. Moreover, incorporating other environmental factors such as humidity and wind speed into the analysis alongside PM values and temperature maps will enable a more holistic understanding of air quality determinants and facilitate the development of more effective preservation strategies.

DATA AVAILABILITY STATEMENT

The author confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

USE OF AI FOR WRITING ASSISTANCE

Not declared.

ETHICS

There are no ethical issues with the publication of this manuscript.

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