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Research on Densely-deployed Air Quality Monitoring

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Abstract— *In this paper, the limitations of the existing air quality measurement system were identified, and factors and related cases were studied to overcome them. In the existing measurement system, it is difficult to properly understand the environment in which the user lives because the area to be covered by the measurement station is too large. In addition, since the reliable measurement method is used, the average of the previous hour's data is shared, so it is not possible to quickly grasp changes in air quality that change every minute. Based on the contents examined, it is expected that the elements to be configured so that users can receive and utilize close air quality information in real time at the location where they live is expected to be concrete.*

Keywords—***Air Quality, Fine dust, Air Quality Measurement, Real-time Air Quality***

I. INTRODUCTION

The earth's air quality, including fine dust and ultrafine dust, as well as various chemical components, continues to deteriorate. Interest in this is continuously increasing, and various attempts are being made to solve it. However, the current air quality measurement system has the following limitations, and in this study, basic research was conducted to improve it.

◦ Limitations of regional air quality monitoring stations

- The number of measuring stations is small as it is necessary to secure high installation costs, outdoor collection facilities, and indoor space for constant temperature and humidity measuring instruments
- Due to the nature of the principle of analyzing the collected dust, it is difficult to provide real-time information, so information is provided every hour
- The information provided is not real-time information, but an average value of 1 hour ago, so changes in the current standby state cannot be confirmed
- It is installed at a height of about 10 m from the ground using the roof of the building, so there is a difference in the height of the real living space.
- If a measuring station including a collection facility is configured, a very high installation cost is required per measuring station
- As it requires expert management, it is difficult to manage regularly and respond on a regular basis every year.

◦ Limitations of Handheld Meters

- Due to the limitations of the national measuring station as above, each company and individual will additionally purchase/install and use a simple measuring instrument with different specifications.
- Very low reliability of the simple measuring instrument
- Measured data is shared only with a limited audience, such as the relevant institution or related community.

There are many approaches about dense air quality monitoring such as [1][2], for example.

This paper consists of principals for fine dust measurement, case study of real-time localized air quality, and consideration factors for air quality monitoring. And then I show the design for IoT-based air quality and then conclusion and further woks.

II. METHODS FOR AIR QUALITY MEASUREMENT

There are two main methods for collecting fine dust: manual measurement and automatic measurement.

A. Gravimetric method

The gravimetric method, which corresponds to the manual measurement method, is currently a standard test method for particulate contaminants. The advantage is that it requires a relatively low cost, and the disadvantage is that real-time measurement is difficult, humidity during the process of measuring the weight of the filter paper before and after collection, The error may occur due to the influence of the experimental environment such as temperature and static electricity. This manual measurement method is often used to collect and analyze fine dust using a filter.

B. Automatic measurement methods

On the other hand, automatic measurement methods include beta gauge, light scattering method, and tapered element oscillating microbalance (TEOM).

Beta-ray measurement and light scattering are both optical methods that use light. Beta ray measurement method, also called beta attenuation monitor, has the advantage of being easy and convenient because automatic measurement is possible. Beta-ray measurement is a method of measuring the concentration before and after collection by irradiating beta-rays on a collection tape that is wound over time like a tape.

The beta-ray absorption method is measured in units of at least one hour due to the limitations of the instrumentation method, and since it is a method to measure the concentration after collection, real-time data cannot be used, so it is not suitable for monitoring the environment that changes frequently in a short time.

The principle of the light scattering method is as follows. When light is irradiated to particulate matter suspended in the atmosphere, the light is scattered by the particulate matter. At this time, when light is irradiated to particulate matter with the same physical properties, the amount of scattered light is proportional to the mass concentration. The method of measuring the amount of scattered light using this principle and obtaining the concentration of particulate matter from the value is the light scattering method.

The advantages of the light scattering method include real-time measurement and easy portability, and simultaneous measurement of each particle size such as PM2.5, PM10, and TSP with one device. On the other hand, it measures the number concentration of particles and has the disadvantage that errors may occur in the process of converting it to mass concentration. Although it has the disadvantage of having to accept an error, it is sometimes used as a simple portable fine dust device as shown below due to its good portability. Many types of fine dust measuring devices on the market use this light scattering method.

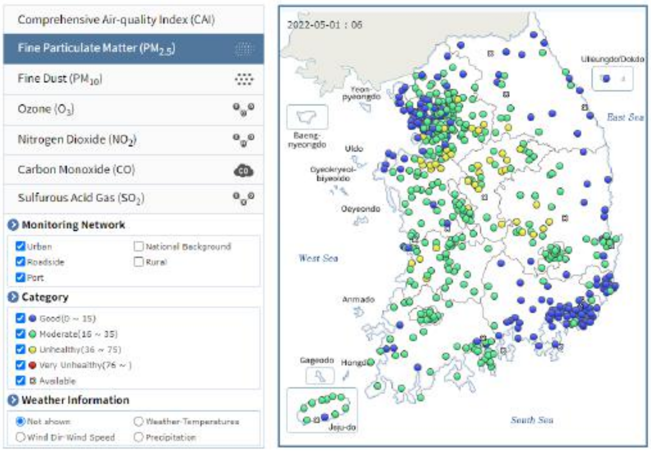


Fig. 1: Reginal deployment for measurement station of air quality in Republic of Korea [3]

National and local measurement stations in Korea mainly use Beta-ray measurement equipment. And they provide SO2, NOx, CO, O3, PM-10, PM-2.5, wind direction, wind speed, temperature, and humidity data. The gravimetric method is also used, but it is not used for real-time numerical disclosure due to the long time required. It is measured once every 6 months for 6 consecutive days and is used as data for the equivalence evaluation of the beta-ray method.

As shown in Fig.1, the number of measurement stations per city is not sufficient and is concentrated in major cities, so the number of measurement stations other than major cities is very small.

III. CASE STUDY OF MEASUREMENT FOR REAL-TIME LOCALIZED AIR QUALITY

Various attempts are being made to measure air quality in real life spaces in Republic of Korea, and the methods used for this are as follows.

C. Public Phone Booth and Base Station

KT (one of mobile service provider) has installed fine dust measurement stations in about 2,000 places across Korea, separate from the national observation network. The fine dust sensor was mainly installed at the height (1~2m) where people breathe, such as public phone booths and base stations. In Seoul, 500 measuring stations were set up for every square kilometer. As a result of the measurement, the number of fine dust in Seoul differed more than double by region during the same time period. By using this information, you can avoid areas and time zones with severe fine dust in downtown Seoul. Anyone can receive real-time information on fine dust from across the country in 10-minute increments through this app, regardless of the telecommunications company that is subscribed. Although this project is increasing the number of measuring stations, it is still being implemented on a trial basis only in Seoul.

D. Taxi or Bus, and Bus station

The first method using a bus is to install an air quality measurement device on top of an existing city bus. Since city buses go around the city, it can provide changes in air quality information at various locations. It uses bus networks for BIS (Bus Information System). BIS uses wireless transmitters and receivers at buses, and then it helps to know how many stops to destination and arrival time at each stop in real time.

Another example of measurement using a car is using a taxi. Since existing data only provides the average value of the previous hour's data collected from several measuring stations, the current air quality cannot be properly expressed. Therefore, by attaching a sensor to the ceiling cap of a taxi, the atmospheric environment, traffic conditions, and floating population were collected and analyzed in real time and compared. A big difference is that taxis transmit real-time information in units of 10 seconds, and the air pollution automatic measurement station discloses the average value of the previous hour in units of one hour.

The other approach is to send a custom car for mobile measuring to a place where there is no air quality monitoring station installed to investigate the air quality. The air quality movement measurement vehicle is loaded with equipment that measures air quality including fine dust on a 45-seater bus and is operated for more than 260 days a year. This bus runs to places frequented by citizens, such as parks, stadiums, environmental resource offices, and sewage treatment plants. This car measures 6 items of air pollutants such as fine dust, ultrafine dust and ozone, and 4 items such as wind direction and wind speed.

In addition, a simple fine dust meter is installed at the bus stop to supplement air quality measurement. Moreover, KICT (Korea Institute of Civil Engineering and Building Technology) installed plant walls at bus stops to verify the effectiveness of air purification through plants [4].

E. Delivery cart and Telecommunication Agency

This social contribution project measures fine dust with an air quality sensor mounted on an electric yogurt delivery cart. The height of the fine dust sensor is 1m, which is the height at which a child breathes. In addition, since it is a service created by a mobile communication service provider, it provides a real-time map of fine dust by adding air quality data collected from more than 1,000 telecommunication agencies across the country to air information received from the Environment Management Corporation. However, this trial service was closed in 2020.

F. Drone

Air quality measurement using drones is mainly used to measure air pollutants emitted from construction sites and industrial complexes. Using drones to closely monitor blind spots in workplaces that are difficult to access or check with the naked eye, and constantly measure fine dust in industrial complexes, strengthen workplace management and supervision, and help reduce air pollution. It is particularly useful for measuring hazardous substances such as sulfur gas or radioactivity that are harmful to humans. In addition, by using the powerful 2D/3D library, it is possible to show the distribution of air pollution or the level of pollution by height.

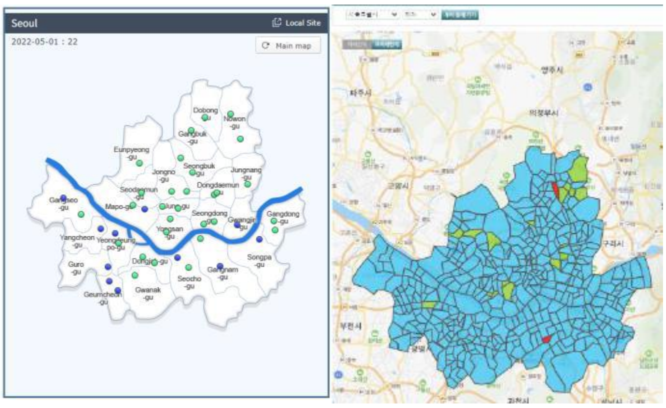
Because equipment and batteries are expensive, and the initial cost is very high. Therefore, they are only used for monitoring industries and construction sites where air pollution can be intensively generated. There are areas that have these drones, but there are areas where they are underutilized, because of the shortcomings that the batteries do not last long and there is a lack of specialized personnel to operate and maintain them.

IV. CONSIDERATION FOR DENSELY-DEPLOYED AIR QUALITY MONITORING

In order to measure the localized and detailed air quality, the following factors should be considered.

A. Densely-deployed monitoring

Administrative districts of large cities in Korea are divided into several 'Gu', and 'Gu' are divided into several 'Dong'. In Fig. 3, (a) measured results from national measuring station, that value is displayed in 'Gu' units of administrative districts. (b) in Fig. 3 shows 'Dong-based air quality monitoring', which it uses data from 350 national measuring stations, 2000 kweather measuring stations, population density, regional characteristics, as well as pollutant emissions information. It is made of more densely-deployed data than (a). However, some of the data shown are from measurements and others can be from estimation.



(a) 'Gu'-based result (Seoul) (b) 'Dong'-based result (Seoul)

Fig. 2: different result for air quality of Seoul [5]

To find optimal deployment, we consider the approach such as the new algorithm, presented in [6]. This aims at finding the best deployment locations for air quality micro sensing units, deployed in a mixed residential or open area region. With the increasing number of air-quality monitoring networks deployed globally, arises the need to properly choose deployment locations to increase the Wireless Distributed Environmental Sensor Networks (WDESNs) monitoring potential.

B. Measurement from the height of human

There are several automatic air pollution monitoring stations in metropolitan cities, but they have the following problems. They are installed in public institutions, community centers, and on the 3rd or 4th floor of an elementary school. It is measured at a height higher than the air directly inhaled by citizens. It is installed in these places because of the safety of the building in consideration of the weight of the measuring station and the need to resolve civil complaints. But residents want to know the quality of the air at the height they breathe.

C. Type of sensors

Sensors used for air pollution monitoring are divided into two categories: Particulate matter sensors (PMS) and GAS sensors (GS) [7].

Low-cost PMS usually works on the light scattering method, where the intensity of scattered light indicates concentration of the PM. In this technique, a target air sample is captured into the sensor's hallow space. Light generated from the laser source interacted with the particles and scattered correspondingly to the size and count of the particles [8].

D. Communication methods

Basic wireless communication protocols can be selected as GSM, WiFi, Bluetooth, and ZigBee. And IoT-based approach includes LoRa (Low power Radio), NB-IoT and LTM-M designed for IoT. Data rate of LoRa is from 10kbps to 50kbps in range of 10km to 20km. Advantages of LoRa are low-power requirement and high range. Limitation of it is low transmission rate, however, it is not enough to convey air quality data. In [9], It is expected that LoRa can enhance the power management and remote communication of low-cost sensors. The first candidate of this research is LoRa considering the possibility of use in my area.

E. Fixed or Mobile nodes, or Both of them

As described above, some devices are installed at fixed locations such as bus stops or schools, and some devices are applied to moving objects such as automobiles and drones. The fixed location device has the advantage of continuously collecting and analyzing data from the same location, but there is a limit to collecting information on various locations. Although the mobile device can collect information from various locations, there is a disadvantage in that the maintenance cost increases according to the movement. Therefore, it is judged that it is appropriate to use a stationary device at the main points where air quality is to be grasped, and to use a mobile device in parallel to obtain additional information [10].

F. Reliability of measurements

Performance certification evaluates five items through indoor and outdoor tests. First, in the indoor evaluation, the so-called 'repeatable reproducibility' is checked whether the simple meter measures the same concentration under the same conditions using following 8 steps of [11].

1) Prior to the test, the internal parameters of the simple measuring instrument subject to evaluation are adjusted so that the standard measuring instrument used for laboratory evaluation and the preliminary comparison test can express the same particle concentration measurement value prior to the test.

2) Ventilate the inside of the test chamber using clean air from which particles have been removed through the HEPA filter, and continue until the concentration of ultrafine dust (PM-2.5) inside the chamber is 5μg/m^3 or less.

3) After generating the test standard particles, inject them into the test chamber and control to reach the target concentration, but the initial concentration cannot exceed 200μg/m^3.

4) The allowable range in the concentration of each of the five equal sections designated in the range of 150μg/m^3 or less shall be the larger of the standard concentration ± 10 % or ± 5μg/m^3. Five equal sections are 100μg/m^3 to 110μg/m^3, 75μg/m^3 to 85μg/m^3, 50μg/m^3 to 60μg/m^3, 25μg/m^3 to 35μg/m^3, less than 5μg/m^3.

5) Acquire the average value measured for 5 minutes in each fine dust concentration section.

6) Obtain a linear regression line using the average value of the data measured and acquired for 5 minutes in each concentration section of step 5 designated in step 4).

7) Repeat steps 3) to 6) 3 times.

8) Calculate the error of the slope of the linear regression line for each measurement order, evaluate the repeatability, and calculate the smallest value as in (1).

$$|d_i| = \left|\frac{a_i - \bar{a}}{\bar{a}}\right| \quad (1)$$

where, i : measurement order (1, 2, 3)

a_i : slope of measurement order (i)

$\bar{a}$: Average of the slope of the entire measurement order

$|d_i|$: |Error| of the measurement order (i)

'repeatable reproducibility' $i = (1 - |d_i|) \times 100$ (%)

Afterwards, in the outdoor evaluation, the 'standard measuring instrument' and prototypes operated by the certification testing institution are operated for 14 days to compare four items: relative precision, data acquisition rate, accuracy, and coefficient of determination.

Equivalence evaluation test standard for continuous automatic measuring of air quality as showed in Table 1.

TABLE I. *EQUIVALENCE EVALUATION TEST STANDARD FOR CONINUOUS AUTOMATIC MEASUREING OF AIR QUALITY*

Elements	Standard
number of meters	3
measurement period	14 days
Accuracy	Over 85%
Linear Regression Slope	0.9~1.1
Linear regression intercept tolerance	-2.25~2.25
Relative precision between measuring instruments	Over 90%
Correlation coefficient value (R)	Over 0.90

G. Maintenance cost and difficulty

According to the case study results, there were cases in which the project was terminated when the system was built with active investment, but had a structure that was difficult to continuously manage or it was difficult to secure a dedicated manpower. From the design stage, it is necessary to design to have a structure that is easy to maintain and to make a manual in detail. This is because maintenance is simple and anyone can learn and manage it easily.

V. CONCLUSION AND FURTHER STUDY

In this paper, I analyzed the limitations of the existing air quality measurement and looked at the considerations to solve them. I focus on the demand for real-time understanding of air quality at the location where people live and study variable methods.

As mentioned above, after considering several factors, the next step in this study is to design to include an air quality measurement function in street lights or security lights as an example for measuring air quality in real living spaces. If it is applied to street lights, it is possible to measure the air quality of large roads, and when applied to security lights, it is possible to measure air quality in a narrower area such as residential areas. To implement this, the security light must include an IoT communication module to enable Internet communication, and an air quality measurement module such as a fine dust sensor is embedded. In addition, a platform server that analyzes the data collected from them is required. The basic function of the cloud server is to show the collected data based on a map or to share statistical data for anyone to see. In addition, the server plans to include a calibration algorithm and an air quality forecasting algorithm to increase the accuracy of air quality data.

In addition, if air pollution information is shared with the city's environmental department, it will be possible to schedule the deployment of a sprinkler car or dust collector car to a highly polluted area.

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