Design and analysis of air quality monitoring system PM$_{10}$ and PM$_{2.5}$ integrated with weather parameters (a case study on Margonda Raya street Depok)

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Abstract. An observation of air quality is very important related to the increasing pollution in Indonesia resulted from the use of motor vehicles, industrial activities, wildfires, and others. It triggers the increase of PM$_{10}$ and PM$_{2.5}$ particulate pollutants in the atmosphere. Meteorological factors influence the fluctuation of PM$_{10}$ and PM$_{2.5}$ concentration. The solution to overcome the problem is the design of IoT-based PM$_{10}$ and PM$_{2.5}$ digital monitoring system that is integrated with parameters of temperature, humidity, wind speed and direction. The design system consists of sensor hardware ZH03A laser dust sensor, SHT11 temperature and humidity sensor, and JL-FS2 wind speed and direction. Data were processed on Arduino ATMega2560-based microcontroller and then sent to the server using internet so that they could be displayed on website. The information system on the website was developed using PHP and HTML. The device had been tested with calibration and comparison methods. As the results of the research, the device could be operated properly and the measuring results were displayed on web in real time to provide air quality information. The correlation of PM source concentrations with meteorological parameters is that temperature (positive correlation), wind speed (positive correlation), relative humidity (negative correlation) and based on the direction of wind, the area is dominated by west winds.

1. Introduction
Depok is one of the cities in Indonesia that has rapid economic growth. However, it causes a decrease in the air quality of the area. Margonda Raya street is one of the connecting-road between the satellite city (Depok) and Jakarta. The large number of universities existed around contributes to the economic growth of this city. Nevertheless, the traffic congestion, the decrease of green field and citizen activities can decrease the air quality index. Research studies about the relation between PM concentrations and meteorological factors had been done before. Research by Chen et al. examined the relationship between PM$_{2.5}$ and meteorological factors in the urban area of Nanjing from 2013 - 2015 [1]. Lie et al. conducted the same analysis in the Sichuan Valley [2]. The relations between the concentration of air pollutants and meteorological factors also varied in each place. Research by Huang et al. found a positive correlation between PM$_{2.5}$ and air humidity in Beijing [3], but the results of a study by Chen et al revealed that a negative correlation in urban areas of Nanjing. [1]. Similar to Li et al, they concluded that a concentration of PM$_{2.5}$ had a weak correlation with air humidity in Sichuan Valley [2]. Previous studies had shown that meteorological parameters such as temperature, humidity, wind speed, and direction show a strong influence on PM$_{2.5}$ concentrations [4,5]. At this
time, the measurement of air quality is still not integrated with the meteorological conditions since the two measurement equipments work separately. Therefore, the results of the measurement less accurate and less efficient. The existence of industrial technology innovation 4.0 is expected to facilitate the air quality problem solving [6]. Based on those concerns, the authors conducted a research entitled Design and Analysis of Air Quality Monitoring System PM$_{10}$ and PM$_{2.5}$ Integrated with Weather Parameters on Margoonda Raya street Depok. The design of this equipment system is used for IoT-based real time air quality monitoring and is integrated with meteorological parameters. This study aims to find out the air quality and to analyze of weather.

2. System Design

Figure 1 shows a diagram block of the system consist a ZH03A sensor which is used to measure PM$_{10}$ and PM$_{2.5}$ mass concentrations, a SHT11 sensor which is used to measure temperature and humidity of surrounding environment, a JL-FS2 sensor which is used to measure wind speed and direction, RTC DS3231 as a time device, Solar Panel 20WP as power supply, and 12V 3AH accumulator battery as an alternative power supply. The process of measurement and data acquisition from sensors and the timing are done in Arduino Atmega2560 microcontroller. Then the output of system will be sent to the cloud server using ESP8266 and will be displayed on web-based display as information for public and the backup storage is in micro SD card Adapter.

![Figure 1. Diagram block of Air quality monitoring System](image-url)
Figure 2. Flowchart for the programming
System

Figure 3. Air quality monitoring
instruments

Figure 2 shows the flowchart for the programming system. The flowchart explains the initialize all components process on Arduino ATMega2560-based microcontroller and then sent to the server using internet so that they could be displayed on website . Figure 3 shows the image of air quality monitoring instruments of \( \text{PM}_{10} \) and \( \text{PM}_{2.5} \) measurement system integrated with weather parameters. The concept of instrument design in this research uses a portable measurement device with 3 meters height to facilitate the mobility of measurement at many points.

3. Sensor Test and Calibration

3.1. Temperature and Humidity Sensor Test

The temperature sensor testing was done through a calibration process of SHT11 sensor and standard sensor which were placed side by side in the temperature chamber. The Standard Sensor Fluke Hart Scientific 5615 has a resolution of 0.001°C and measurement range from -200°C to 420°C. The calibration results of SHT11 temperature data with standard sensor in three set points namely 20°C, 30°C, and 40°C.

The humidity sensor testing was done through a calibration process of humidity data between SHT11 sensor and standard sensor which were placed side by side in the humidity chamber. The Standard Sensor Vaisala HTM333 has a measurement range from 0 ~ 100%. The calibration results of SHT11 humidity data with standard sensors in three set points namely 40%, 60%, and 80%.

The results of temperature and humidity graph resulted from the SHT11 calibration process with standard sensors showing the results of linear measurements and a very strong correlation with the correlation value \( R^2 = 0.9999 \). The average correction of the temperature sensor calibration -0.1572 °C and humidity = 1.68933%. The sensor correction value is still within the correction tolerance range specified by the World Meteorological Organization (WMO) in WMO NO.8 Guide Meteorological Instruments and Methods Of Oservation that are ± 0.2 °C and ± 5%.

3.2. Wind Speed and Direction Sensor Test

The wind speed sensor testing was done through a calibration process of JL-FS2 sensor with standard sensor which were placed side by side in the wind tunnel calibrator type 8420. The Standard Sensor Vector A100LM has a measurement range of 0-75 m/s. The calibration process between JL-FS2 sensor and standard sensor in five set points namely 2 m/s, 7 m/s, 10 m/s, 15 m/s and 20 m/s. The
results of calibration shows linear measurement results and a very strong correlation with correlation value $R^2=0.99991$. Moreover, the average correction of the wind speed sensor calibration is 0.366855 m/s.

The deviation value from the calibration of wind speed sensor is within the range allowed by WMO and BMKG (Indonesian Agency for Meteorological, Climatological and Geophysics) for wind speed, which is ± 0.5 m/s. Thus the sensor is considered approvable for use. Data resulted from the calibration of wind direction sensor which indicates no deviation. The deviation limit determined by BMKG for wind direction is 5°. Therefore, the wind direction sensor can be approved for use.

The wind direction sensor testing was done through the JL-FS2 sensor calibration process which is compared with the output of the wind direction simulator from Jin Yang Industrial Co. Ltd. type JY-601-1. The wind direction sensor is tested using 4 set points namely 0°, 90°, 180°, and 270°.

3.3. Comparison of Particulate Matter Sensors
ZH03A sensor testing was done through a comparison process which had two data outputs namely PM$_{10}$ and PM$_{2.5}$. Data from the ZH03 sensor were compared using Kimoto Aerosol Chemical Speciation Analyzer (ACSA)-14 the National Institute for Environmental Studies (NIES) of Japan which is a partner of the BMKG at Air Pollution Post. The ACSA-14 instrument was used to measure dust particulates of 10 micrometers (PM$_{10}$) and 2.5 micrometers (PM$_{2.5}$).

![Graph](image.jpg)

**Figure 4.** Correlation Graph of ZH03A Sensor PM$_{10}$ and PM$_{2.5}$ with ACSA-14 standard instrument

Figure 4 shows that the lower correlation is found in the parameter PM$_{2.5}$, that is $R^2 = 0.7274$. However, the correlation is quite strong. Meanwhile, the PM$_{10}$ parameter shows a very strong correlation with correlation value $R^2 = 0.9343$.

4. Result and Discussion
The results of PM$_{10}$ and PM$_{2.5}$ sensor data testing were carried out for about several days at the Multidisciplinary Building of FMIPA, University of Indonesia, Margonda, Depok, which is one of the buildings around Margonda Raya Street. The average value of PM$_{2.5}$ is higher than PM$_{10}$ as shown in Figure 5. Still, the pattern formed either by PM$_{10}$ or PM$_{2.5}$ was the same. At 22.00-07.00, the concentrations of both particulates started to decrease, then gradually increased afterwards with the peak at 14.00, then went down again. The concentration of PM$_{2.5}$ is higher compared to PM$_{10}$ since the smaller size of PM$_{2.5}$ make it easier to be detected by the instrument. From the graph above, it can be seen that either PM$_{10}$ or PM$_{2.5}$ has an increase of PM level during the day. It is because the increasing activities in the day time cause the concentrations of PM$_{10}$ and PM$_{2.5}$ to increase.

The obtained data show that the air quality in the area is in the safe category. Since the concentrations of PM$_{10}$ and PM$_{2.5}$ are still in the harmless category. At 23.00-07.00, the concentrations of PM$_{10}$ and PM$_{2.5}$ were in the good category, while at 08.00-22.00 they were in the medium category as shown in Figure 6. The medium category resulted because on weekends people did outdoor activities so that there is an increase on the vehicle use. Nevertheless, the air quality is still categorized safe since it is less than 150 μgram/m$^3$. It means outdoor activities are not dangerous for people and they do not need to wear a mask outside.
The relationship pattern between two meteorological parameters and pollutant particulates can be seen through scatter plots which show the relationship tendency between the values of the two variables. The relationship between those two variables can also be seen from the correlation coefficient values in the following table.

### Table 1. Correlation coefficient values with the mass concentration of PM$_{10}$ and PM$_{2.5}$

| Weather parameters | PM$_{10}$ | PM$_{2.5}$ | Correlation Value $(R^2)$ |
|--------------------|----------|------------|--------------------------|
| Temperature        | 0.866    | 0.837      | Correlation positive     |
| Humidity           | -0.915   | -0.807     | Correlation negative     |
| Wind Speed         | 0.854    | 0.766      | Correlation positive     |

Based on Figure 7 and Figure 8 which show scatter plots between the concentration of PM$_{10}$ as well as PM$_{2.5}$ and the temperature, it can be seen that the patterns of the point distributions show positive trend patterns. It is proven by the linear slope values which show positive values (4.5822 for PM$_{10}$ and 5.6183 for PM$_{2.5}$). It means the increase of PM$_{10}$ and PM$_{2.5}$ concentrations is followed by an increase of air temperature in the area. The correlation coefficient values obtained are 0.866 for PM$_{10}$ and 0.837 for PM$_{2.5}$. Those high correlation coefficient values strengthen the existence of a strong relation between PM$_{10}$ as well as PM$_{2.5}$ and air temperature. In other words, the relation between the concentration of particulate and temperature is strong and directly proportional.
Figure 7. Correlation between Temperature Parameter and PM$_{10}$

Figure 8. Correlation between Temperature Parameter and PM$_{2.5}$

It happened because as the temperature increase, the ambient air layer rose and caused the volume of the layer to increase. Therefore, PM$_{10}$ and PM$_{2.5}$ accommodated in the layer also increased. Based on these results, we need to be concerned and make strategic steps in the future to reduce the rate of pollution in this area in order to withstand the increase of air temperature.

Whereas, scatter plots of the relationship between the concentration of PM$_{10}$ as well as PM$_{2.5}$ concentration and the humidity as shown in Figure 9 and Figure 10 demonstrate negative correlations. It is shown by the patterns of distribution and the negative linear slope values. It means the greater the humidity is, the less the particulate concentration of both PM$_{10}$ and PM$_{2.5}$ will be. It happens because the humidity function is a derived function of temperature which is opposite. The correlation coefficient values are -0.915 for PM$_{10}$ and -0.807 for PM$_{2.5}$. It means the relation between particulate concentrations and humidity is strong and inversely proportional.

Figure 9. Correlation between Humidity Parameter and PM$_{10}$

Figure 10. Correlation between Humidity Parameter and PM$_{2.5}$

The scatter plot results between wind speed and concentrations of PM$_{10}$ and PM$_{2.5}$ in Figure 11 and Figure 12 show that there are positive correlations. This is also supported by the slope values which are also positive. The value of the correlation coefficients are 0.854 for PM$_{10}$ and 0.766 for PM$_{2.5}$. It means the concentration of PM$_{10}$ as well as PM$_{2.5}$ and wind speed has strong relations and are directly proportional. Therefore, the faster the wind blows, the higher the concentration of PM$_{10}$ and PM$_{2.5}$ will be. It is because the wind carries the dispersion of pollutants from other places in the direction of the wind blowing.
Figure 11. Correlation between Wind Speed Parameter and PM$_{10}$

Figure 12. Correlation between Wind Speed Parameter and PM$_{2.5}$

Based on analysis of wind direction in Figure 13, The distribution of PM concentrations at the monitoring location is based on the dominant wind direction distribution of PM$_{10}$ and PM$_{2.5}$ from the West with moderate or blue PM$_{10}$ concentration levels (51-150 μg / m$^3$) and with unhealthy or yellow PM$_{2.5}$ levels (65-150 μg / m$^3$).

Based on Figure 14 shows a web-based data display in which the data are displayed real time every hour. The display was designed using Php language programming and database server used Mysql. Display consists of graphs and tables. The display is user-friendly. Therefore, it is expected that in the future, the data can be used for public.

5. Conclusions

The observation systems of PM$_{10}$ and PM$_{2.5}$ had been designed successfully, calibrated, and compared with standard equipment to generate accurate data. SHT sensor has a correlation value of $R^2 = 0.9999$ for temperature and humidity data. JL-FS2 sensor has a correlation value of $R^2 = 0.9991$ for wind speed and wind direction data with no deviation from the standard equipment. ZH03A has correlation values of $R^2 = 0.7274$ for PM$_{2.5}$ and $R^2 = 0.9343$ for PM$_{10}$. The system has a web-based display in real time.

The results of the system testing conducted at Multidisciplinary Building of FMIPA University of Indonesia show that the meteorological conditions have a significant influence PM$_{10}$ and PM$_{2.5}$ concentrations of an area. This can be seen from the results of this study that show a fairly strong
correlation between PM\textsubscript{10} concentration as well as PM\textsubscript{2.5} concentration and meteorological parameters such as temperature, humidity and wind speed. The results of this study show a positive correlation between PM\textsubscript{10}, PM\textsubscript{2.5}, temperature, and wind speed. The increase of concentration of PM\textsubscript{10} and PM\textsubscript{2.5} is in line with the increase of temperature and wind speed. Meanwhile, humidity has a negative correlation with PM\textsubscript{10} and PM\textsubscript{2.5} concentrations, which means the increase of PM\textsubscript{10} and PM\textsubscript{2.5} concentrations is opposite with increasing humidity. For the parameter of the wind direction, the location of this study is largely influenced by the Monsoon factor.

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