Design of PM$_{2.5}$ and PM$_{10}$ measuring instruments for analysis of air pollution distribution patterns in the dramaga area based on internet of things

H Satria$^1$ and S Soekirno$^1$

$^1$Physics Department, University of Indonesia, Depok, West Java, Indonesia

E-mail: hendri.satria@ui.ac.id

Abstract. Particulate Matter (PM) is the main material commonly used to show the degree of air pollution. PM material has an impact on human health and the visibility of the atmosphere. Standard gravimetric measurements and current commercial instruments for field measurements are still expensive and limited at several points in Indonesia. In this research, a low cost PM$_{2.5}$ and PM$_{10}$ measuring instrument was designed, with the application of the Internet of Things (IoT) to support real-time monitoring. This instrument can be used to increase the spatial and temporal resolution of PM data. The system uses the ZH03A which has a correlation of 0.8936 in PM$_{2.5}$ and 0.8873 in PM$_{10}$ through comparison with standard instrument. Sensor data is processed by a data logger which is connected to the internet via the ESP8266 module. This module has sent data to the database with 0% data loss on testing and sent to display the actual PM$_{2.5}$ and PM$_{10}$ values in a website. The results showed a negative correlation on temperature and positive correlation on humidity. The measurement system has recorded the distribution patterns of PM coming from the northwest of Dramaga.

1. Introduction

The quality of the air in the atmosphere is getting worse due to the emission of harmful gases and air pollutants such as particulate matter [1]. Particulate Matter (PM) is the main material commonly used to show the degree of air pollution. PM could from natural sources such as volcanic dust, desert dust particles, and sea aerosols but anthropogenic activities also impacts its emission. Transport, agriculture, industrial processes, and household combustion systems are the main sources of PM contaminants [2]. Aerosols with diameter of 2.5 µm (PM$_{2.5}$) and 10 µm (PM$_{10}$) can affect human health, visibility, and atmospheric air quality [3].

Badan Meteorologi Klimatologi dan Geofisika (BMKG) is one of the institutions in charge of air quality monitoring in Indonesia, one of which is PM$_{2.5}$ and PM$_{10}$. Observation equipment owned by BMKG are still classified as very low when compared to the surface area of Indonesia. Standard gravimetric measurements and commercial instruments in Indonesia are currently expensive and limited for field measurements. In this study, the author will design a low cost PM$_{2.5}$ and PM$_{10}$ monitoring instrumentation with the use of Internet of Things (IoT) as a data transmission method. IoT is proven to be one of the most effective means of systems being designed and when combined with cloud computing can provide a revolutionary method of management and analysis of data derived from PM sensors [1]. Data can be displayed through various electronic devices, where each system has
sensors, loggers and other devices installed on it and connected via network communications [4]. The designed system has the ability to increase the spatial and temporal resolution in PM monitoring depending on the density of the IoT network [5]. The data generated by the sensor is sent to the database and processed with meteorological parameter data such as temperature, humidity, wind speed and direction so that the pollutant distribution pattern can be obtained at the location of the tool installation.

2. Method

2.1 Measurement Site Description
Measurements are divided into 2 locations, first BMKG Kemayoran as a comparison location and BMKG Dramaga as a field test. The first location has coordinate 6°09'21.2"S 106°50'32.0"E and the second one is 6°33'13.4"S 106°44'39.8"E. The instrument was installed in the first location for 5 days to get the correction and regression value through comparison with the standard instrument from BMKG thermo5014i. Instrument is positioned right next to the thermo5014i in the observation field. The main place in this research is the second location where the pollutant distribution pattern analysis is carried out through the installation of instruments for 10 days after the comparison.

2.2 Instrumentation
The low cost sensors assessed in this study were ZH03A which is a manufacturer from Winsen [12]. This sensor was chosen because there were not many uses and performance tests had not been found in the scientific literature. The measurement range of the PM sensors used was 0-1000 µg/m³, with a response time ≤ 90s. The dimensions of the low cost PM sensor used are 50mm x 32.4mm x 21mm [12]. These sensor uses the principle of light scattering to measure the mass concentrations of PM in real-time and separates the length of the light scattering to detect PM\textsubscript{2.5} and PM\textsubscript{10}.

Arduino Mega 2560 is used as a microcontroller that processes data from sensors and other peripherals such as RTC DS3231 and the GPS NEO-6M. Storage media and data transmission using the SD Card Adapter and ESP32 module. The system is equipped with 16 x 4 LCD as a real-time data viewer contained in the box. Internet service is provided by the MiFi which is installed inside the panel and connected to an external antenna as a signal amplifier. All components are connected to each other on a panel box as the enclosure of the data logger system, shown in Figure 1. Panel box is mounted on an iron tripod as a stand and there is a power management consisting of a solar cell, battery and solar charge controller. The overall design of the system can be seen in the Figure 2.

Figure 1. Inside the panel box of data logger
Figure 2. Design of overall system
2.3 Methodology
The methodology included PM instrument output data processing with meteorological data used such as temperature, humidity, wind speed and direction for analysis of pollutant distribution patterns. This condition occurs after the correction value is entered into the ZH03A sensor programming. The schematic of block diagrams and flowcharts for this study are shown in Figure 3 and Figure 4.

![Figure 3. Block Diagrams of system.](image)

![Figure 4. Flowcharts of programming system.](image)

2.4 Statistical Analysis
The comparison is done by collecting the data from system as instrument tested and Thermo5014i as standard instrument. Data were collected and arranged for analysis in a spread sheet under Microsoft Excel, then calculated by the coefficient determination ($R^2$) from results of linear fittings for 1–hour averaged data. The experimental results from instrument which produces PM$_{2.5}$ and PM$_{10}$ data were analysed by combining data of temperature, humidity, wind speed and wind direction using RStudio. The meteorological parameters are obtained from the hourly observation data BMKG Dramaga. Packages used as processing modules in RStudio namely “openair” package made by David Carslaw. The PM$_{2.5}$ and PM$_{10}$ time series data were running with an “openair” package and produced several PM$_{2.5}$ and PM$_{10}$ plots, they are scatter plot, time plot, pollution rose plot, polar plot based on temperature, polar plot based on humidity and correlation plot.

2.5 Database and Web Design
The data generated by measurement instrument will be collected by a database management system which is built with the basic commands of Structured Query Language (SQL) as a liaison between application software and the database server. The data received by MySQL database is displayed on a website based on the Hypertext Pre-processor (PHP) language. This programming language uses a Server-Side system, which is a type of programming language in which the script will be executed by the online server. In this study, the authors created a website with a display like Figure 5.

There are several features on the homepage of the website, including the display of PM$_{2.5}$ and PM$_{10}$ values at Dramaga in real-time, also the graphical form. There is a data download feature with the desired time span, the plot of pollutant distribution pattern can also be viewed and downloaded via this website.
3. Result and Discussion

3.1. Comparison in Kemayoran
Before deployment in Dramaga, we co-located the instrumentation system at Kemayoran observation field to produce the correction value and the coefficient of determination. The instrumentation system is positioned next to the Thermo5014i as shown in Figure 6. Data were taken for 5 days starts from October 1st at 00:00 (GMT+7) with 120 data on hourly concentration average and showed a relationship between PM2.5 and PM10 which is shown in Figure 7. We can see that the increase in PM2.5 levels was also followed by PM10 levels.

The comparison process is carried out in an open area so that pollutant content coverage area is wider, but the mass density is lower because it is affected by the presence of wind. We observed that the hourly time series for PM concentrations measured in the comparison are very similar. Graph of the time series or pattern for both the instrumentation without any ambiguities in them. In other words, no significant variation appeared in the measured PM concentrations between the two instruments [11].

Figure 5. Website Interface from System

Figure 6. Comparison Process.

Figure 7. Time Series Data of PM$_{2.5}$ and PM$_{10}$ when Comparison.
The comparison for 5 days shown a good output value with very strong correlation both at PM$_{2.5}$ and PM$_{10}$. Where PM$_{2.5}$ has a value of $R^2 = 0.8936$ and PM$_{10}$ has a value of $R^2 = 0.8873$. Time series and scatter plots from comparison the ZH03A and Thermo5014i were expected to be highly similar as these were from same measurement method. The scatter plots of PM$_{2.5}$ and PM$_{10}$ comparison is shown in Figure 8.

![Figure 8. PM$_{2.5}$ Coefficient of determination (a) and PM10 Coefficient of determination (b)](image)

However, due to the limited manufacturer’s evaluation results, there is a slight limitation in the consistency of data logging by the ZH03A sensors. In our opinion, the cause of slight variations in the PM measurement could be due to contamination of instrument and instability of the suction fan flow rate.

3.2. Field Measurement at Dramaga
Measurement of PM data in Dramaga area starts from October 7$^{th}$ at 00:00 (GMT+7) to October 17$^{th}$. The time plots of the measured concentrations of PM$_{2.5}$ and PM$_{10}$ are shown in Figure 9. Based on the Figure 9 below, it can be seen that the average PM$_{2.5}$ concentration tended to be stable starting on October 7 to October 16 and began to decline slightly on October 17, 2020. The highest PM$_{2.5}$ range concentration values occurred on October 12-13 with the above 150 $\mu$g/m$^3$ range. When compared with PM$_{10}$ data, it can be seen that the average concentration increased on October 14 and decreased on October 16, 2020. The highest range of PM$_{10}$ values was above 150 $\mu$g/m$^3$ occurred on 11-13 October 2020. This is consistent with the concentration PM$_{2.5}$ where the highest pollutant concentration also occurred on that date.

![Figure 9. Time plot of PM$_{2.5}$ concentration (a) and Time plot of PM$_{10}$ concentration (b)](image)

Figure 10 below shown the distribution of PM$_{2.5}$ and PM$_{10}$ concentrations in the Dramaga area. Based on this figure, it can be seen that the range of magnitudes between the two pollutants is not much different, which is around 0-150 $\mu$g/m$^3$. In the distribution pattern of the two data, it can be seen that there are several outliers that move away from the regression line. However, in general, the
concentration between the two data has a significant relationship, which can be seen from the distribution pattern that is still along the line.

![Figure 10](image)

**Figure 10.** Scatter plot of PM$_{2.5}$ and PM$_{10}$ concentration

From all the data collected, a time variant plot can be made to determine the pattern of PM$_{2.5}$ and PM$_{10}$ concentrations based on time, so that the highest and lowest concentrations can be found. Based on the time variation plot in Figure 11 (a) below, there is an hourly distribution of PM$_{10}$ concentrations, it shown that pollutant concentrations begin to rise in the morning and reach the highest values shown during the day to night at 80-120 µg/m$^3$. Based on the variation of daily time, it can be seen that the highest value is shown on Monday, but then fluctuates gradually downward until it reaches the lowest value on Saturday.

![Figure 11](image)

**Figure 11.** Time Variation plot of PM$_{2.5}$ concentration (a) and PM$_{10}$ concentration (b)

In Figure 11 (b), it can be seen that the PM$_{10}$ concentration distribution pattern is very similar to the PM$_{2.5}$ concentration. For the daily time variant time plot, it can be seen that the highest value is shown on Monday and then gradually decreases until it reaches the lowest value on Saturday.

3.3. **PM$_{2.5}$ and PM$_{10}$ Correlation with Meteorological Parameters in Dramaga Area**

An important factor related to particulate concentration has been previously studied. The correlation between meteorological parameters and particulate concentration has been analysed using models with statistical methods, such as linear regression [6]. The diffusion process in the transmission of air in the atmosphere can bring about air pollutant concentrations [7]. So that the contribution of meteorological...
parameter factors cannot be ignored, even in the same pollutant source, the level of pollution can be much different due to different meteorological conditions [8, 9].

The Pearson correlation analysis was used to measure the positive and negative effects of meteorological parameters on the PM$_{2.5}$ and PM$_{10}$ ratio. The correlation coefficients can be different for each region, which is due to regional heterogeneity [10]. Figure 12 below shows the pattern of the relationship between particulate pollutants and meteorological variables where the X and Y axes show the meteorological parameters and the PM way of reading by looking at the horizontal and vertical lines of the relationship between variables that show positive or negative values per hundred ($\pm$100).

![Figure 12](image)

**Figure 12.** Correlation plot between PM with meteorological variables at Dramaga

It can be seen that between the pollutant data and meteorological parameters, there is a relatively small relationship between the two data, which can be seen from the relatively small correlation results. This can be due to the relatively small amount of data used. On 7-17 October 2020, the highest correlation was shown in the relationship between PM$_{10}$ and PM$_{2.5}$ of 0.86. Meanwhile, the relationship between PM and meteorological elements is shown by PM$_{2.5}$ elements with an air temperature of -0.37, followed by PM$_{2.5}$ pollutants with a correlated air humidity of 0.29. Where the correlation between PM$_{10}$ and air temperature shows a value of -0.29, while the correlation between humidity is 0.20.

### 3.4. PM$_{2.5}$ and PM$_{10}$ Distribution Pattern at Dramaga

From several studies that have been done the correlation value between wind and PM is quite low, but wind can have a direct effect on the ratio due to diffusion speed and transformation efficiency as a carrier of PM$_{2.5}$ and PM$_{10}$. In Figure 13, there is a wind rose plot was depicted in a circular format with a schematic of the frequency of the wind blowing from a certain direction. The length of each crown shows the level of wind speed from that direction, there is no X and Y axes, but is zero at the cardinal points and continues to increase up to the edge of the wind rose. It can be seen where the wind direction in the Dramaga area is dominated from the northwest and west. The highest wind speed ranges from 8 knots. The average wind speed at Dramaga on October 7-17 was 0.8 knots, where calm or calm winds dominate the wind speed there, namely by 69%.
Figure 13. Wind rose plot from wind speed and direction in Dramaga

From Figure 14 below, the rose pollutant depicting pollutants along with wind direction and speed, it can be seen that the pollutants from the west and northwest directions dominate the two pollutant concentrations. Based on the figure, it can be seen that the average PM$_{2.5}$ concentration is 74.612 µg/m$^3$, with the highest pollutant concentration range of 120-140 µg/m$^3$ coming from the northwest direction. Meanwhile, the average PM$_{10}$ concentration was 79.706µg/m$^3$, with the highest pollutant concentration range of 140-160 µg/m$^3$ coming from the northwest.

PM$_{2.5}$ and PM$_{10}$ data correlation analysis with temperature in this study resulted in a negative correlation value and the PM$_{2.5}$ and PM$_{10}$ distribution pattern is on the polar plot Figure 15 below.

In the figure above, it can be seen that the PM$_{2.5}$ concentration tends to be high, namely 30-90 µg/m$^3$ in the temperature range of 21.1 - 23.7 °C, dominated from the west and northwest directions. While in the temperature range 23.7-27.5 °C, PM$_{2.5}$ ranges from 30-60 µg/m$^3$ with predominantly from the west and northwest directions. The concentration of PM$_{10}$ tends to be high at temperatures of 21.1 - 23.7 °C, with a pollutant range of 50-90 µg/m$^3$ in the direction of the dominant pollutants, namely from the west and southeast. In the temperature range of 23.7-27.5 °C the PM$_{10}$ pattern changes, where the wind direction that carries pollutants comes from the west and northwest with the PM$_{10}$ range of 30-60 µg/m$^3$. This indicates that the two pollutant concentrations are higher at lower air temperatures.
In Figure 16 above, it can be seen that PM$_{2.5}$ concentrations tend to be high, namely 40-100 µg/m$^3$ in the RH 79-88 % and 88-93 % ranges, dominated from the southeast and northwest directions. Where as in the RH 54-79 % range, the PM$_{2.5}$ ranges from 50-60 µg/m$^3$ with a predominance from the northwest. The PM$_{10}$ concentration tends to be high at RH 79-88 %, with a pollutant range of 30-100 µg/m$^3$ in the direction of the dominant pollutants, namely from the northwest and southeast. In the RH 83-93 range the PM$_{10}$ pattern changes, where the wind direction carrying pollutants comes from the west and east with the PM$_{10}$ range, namely 40-80 µg/m$^3$.

4. Conclusion

The measurement system has been successfully built with good comparison and field testing results. The ZH03A sensor has been compared with the standard Thermo5014i instrument with a correction value for PM$_{2.5}$ of -0.4656 µg/m$^3$ and PM$_{10}$ of -15.166 µg/m$^3$. The comparison produces a very strong correlation value with details coefficient determination for PM$_{2.5}$ of 0.8936 and PM$_{10}$ of 0.8873. Data from the measurement system is received as much as 100% during comparisons and field testing, this means that the IoT system works very well without any data loss. The database has been well tested to receive and collect data from sensors and RStudio. The system is equipped with a website as the main gui that can be accessed via public IP. The website connection test shows good performance, so that the data is displayed with a very short delay time.

The result of relationship between PM and meteorological parameters is shown by PM$_{2.5}$ elements with an air temperature of -0.37 (negative correlation). PM$_{2.5}$ pollutants with humidity has 0.29 correlated (positive correlation). Where the correlation between PM10 and air temperature shows a
value of -0.29 (negative correlation), while the correlation between humidity is 0.20 (positive correlation). The highest distribution PM$_{2.5}$ and PM$_{10}$ pollutants comes from the northwest with a temperature distribution of 21.1-23.7 ºC and humidity of 79-88% and the highest concentrations of PM$_{2.5}$ and PM$_{10}$ occurred on October 12.

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