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Monitoring and Analyzing Air Quality in Several Locations around Medan City Using IoT-Based Integrated Sensors

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ABSTRACT: This research is motivated by the importance of monitoring air quality in industrial and non-industrial areas, especially in the city of Medan, Indonesia. Increasing growth of the industrial sector and use of transportation can increase air pollution. Air pollution caused by emissions of harmful gases such as NO2 and CO, as well as microscopic particles such as PM2.5 has a significant impact on human health, especially causing respiratory and heart disease and premature death. The rapid development of Internet of Things (IoT) technology can detect air quality and transmit sensor readings wirelessly via the internet to an Android or PC. This research aims to design an air quality monitoring tool related to the presence of dangerous gases NO2, CO and levels of microscopic particles PM2.5 with an integrated mics-6814 sensor and PMS5003 sensor based on IoT accurately and in real-time and analyze the results of air quality monitoring in research area. The research methodology involves measuring air quality parameters such as PM2.5, CO, NO2, temperature, and humidity using IoT-based integrated design tools. The research location consists of 3 points, namely around the industrial and residential areas of the Kawasan Industri Medan (KIM) Mabar, the Industrial Area in Tanjung Morawa, and the University of North Sumatra. Numerical data will be tabulated from the results of research carried out for 7 hours in 3 days based on the specified time. The results of this research show that the air quality monitoring system designed can measure temperature, humidity, PM2.5, NO2 and CO levels in real time and accurately. Air quality data collected at several research locations shows different trends. Overall, the air quality in the research area is in the healthy category, having no impact on the health of humans, animals and plants which is linked to Peraturan Menteri Lingkungan Hidup Dan Kehutanan Republik Indonesia. Suggestions for further research include selecting components that are more sensitive in detecting air quality and paying attention to environmental conditions which can reduce deviation values from the sensor.

KEYWORDS: air quality, industry, internet of things (IoT), monitoring, residential

INTRODUCTION

The rapid growth of industry and use of transportation in developing countries, one of which is Indonesia, has resulted in increasing public and government attention to air pollution. One of several industries that is of concern for increasing air pollution is the industrial area in the city of Medan. One of the significant impacts of long-term exposure to air pollution is respiratory disease (Fotopoulou et al., 2016 in Paithankar et al., 2023). If air quality continues to deteriorate, this will be a significant financial burden for the government to face.

Indeks Standar Pencemar Udara in Indonesia based on Peraturan Menteri Lingkungan Hidup dan Kehutanan number 14 of 2020 consists of 7 parameters, that are PM10, PM2.5, NO2, SO2, CO, O3, and HC. Gas emissions have quite high potential for human health and the environment, referring to PP Number 22 of 2021. Air polluted by NO2 and CO gases resulting from industrial processes can pollute the environment around the industry. The body organs that are sensitive to NO2 gas pollution are the lungs. Lungs contaminated with NO2 gas swell, making it difficult for humans to breathe, which can lead to death (Susanto, 2020 in Juliadita et al., 2022). Continuously increasing CO levels or more than 5% in the air will cause blood poisoning and become a barrier to the flow of oxygen in human blood (Wardoyo, 2016 in Rambing et al., 2022).

The main cause of air pollution other than gas is microscopic particles with an aerodynamic diameter of less than 2.5 µm, called Particulate Matter PM2.5, which can bind various toxic compounds and be inhaled by humans (Lei et al., 2016 in Paithankar et al., 2023). The composition that forms PM2.5 consists of sulfates, nitrates, organic compounds, ammonium compounds, metals, acidic materials, and other contaminants which are believed to have bad effects on health (Huboyo and Budiharjo, 2009 in As'ari, 2023), such as disease. respiratory disease, heart and blood vessel diseases, and premature death.

WHO reports that more than 90% of people worldwide live in areas that exceed PM2.5 standards (WHO, 2021) and in 2018 study developed from the global burden of disease project estimated that nearly nine million deaths in 2015 were caused by long-term

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exposure to PM2.5 (Burnett et al., 2018 in Connolly et al., 2022). Temperature and humidity affect the level of air pollution in an area. PM2.5 concentrations are significantly correlated with many meteorological variables, including temperature, humidity, and wind speed, all of which can be obtained through meteorological data sharing sites (SIGFOX, 2016 in Paithankar et al., 2023).
Air quality monitoring devices are an important tool to prevent bad levels of air pollution. Existing air quality monitoring stations do not fully reach various points in areas around industrial areas. Measurement results using existing tools also take a relatively long time, so they cannot provide real-time air quality data. The rapid development of Internet of Things (IoT) technology can detect air quality and transmit sensor readings wirelessly via the internet to Android or PC directly. There are many sensors that can detect air quality in a portable way that can be used.
Low Power Wide area (LPWA) technology, a new type of Machine-to-Machine (M2M) communication, can be used for the communication needs of a large number of air quality sensors spread across a wide detection area. To check air quality, sensors, MCUs, and batteries connected to the Internet of Things (IoT) are needed. This IoT consists of several types of servers built to manage and analyze the data found. Users can access air quality data via the website or mobile app (Paithankar et al., 2023). This technology requires large costs and covers quite a wide range of conditions so it is less efficient if used to detect air pollution on an industrial scale.
One of low-cost sensor that is often used is the PurpleAir II (PA-II) device to monitor particulate matter (PM) levels. Research using the PA-II sensor has been shown to be able to detect indoor and outdoor air pollution. This technology has significant differences from monitoring tools using the Federal Equivalent Method (FEM) or Federal Reference Method (FRM) at the Environmental Protection Agency (EPA) in California or other air quality monitoring stations. This is influenced by data loss due to internet network instability and electrical disturbances (Connolly et al., 2022).
Efforts to collect data on air pollution detection results in industrial areas of Medan City in real-time at low cost are still not facilitated. Therefore, research will be carried out by designing tools that can monitor IoT-based air quality. It is hoped that this research can build public awareness to have a role an important role in monitoring air pollution. The research results in general can empower and educate the public to prevent various diseases caused by air pollution.

METHOD

The research began by carrying out calibration, that is comparing the design tool with a comparison tool from Balai K3 that had been calibrated. Then monitoring data was collected for 3 days. The research location consists of 3 points, there are the area around Kawasan Industri Medan (KIM) Mabar, Industrial Area in Tanjung Morawa, and University of North Sumatra. The equipment that has been designed is placed in the middle between the industrial area and local residential areas. Data from two industrial area points was compared with data around the University of North Sumatra.
One of home at the residents living in the research area was selected for installation of research equipment and consent was requested for data collection. The integrated tools were installed and distributed within a short period of time at the three research locations. The design tool uses a power source from a battery. Numerical data will be collected based on collection time, during 7 hours from 10.00 – 17.00 WIB at the designated location.

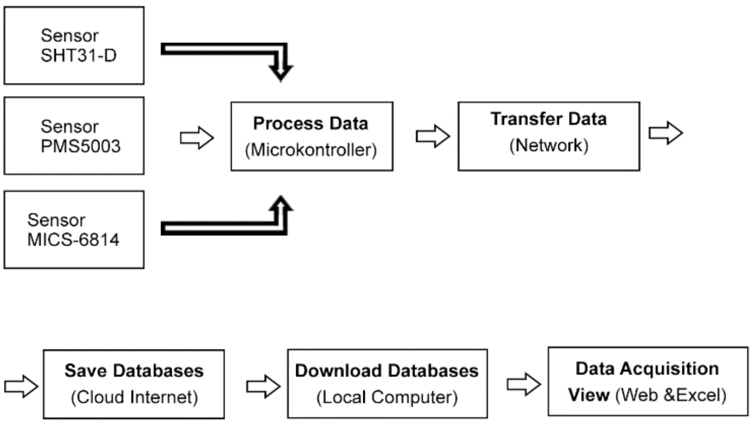

Figure 1. Block Diagram

Figure 1 illustrates how the system works The sensors used in this research are sensor SHT31-D to measure temperature and humidity, sensor PMS5003 to measure air particles with a size smaller than 2.5 microns (micrometers) and sensor MICS-6814 to measure CO and NO2 gases. All data collected by the device is automatically uploaded and recorded on the Blynk IoT server. The result of sensor measurement called database is downloaded from the Blynk IoT site and can be read in the form of tables and graphs in the Excel application. Furthermore, the results of data acquisition can be used as a reference in determining government action to monitor air quality at the research location.

This research uses flowcharts to simplify system workflow. The system that has been assembled in this research initiates each sensor. Each sensor reads values according to its function. The system flowchart can be seen in Figure 2 below.

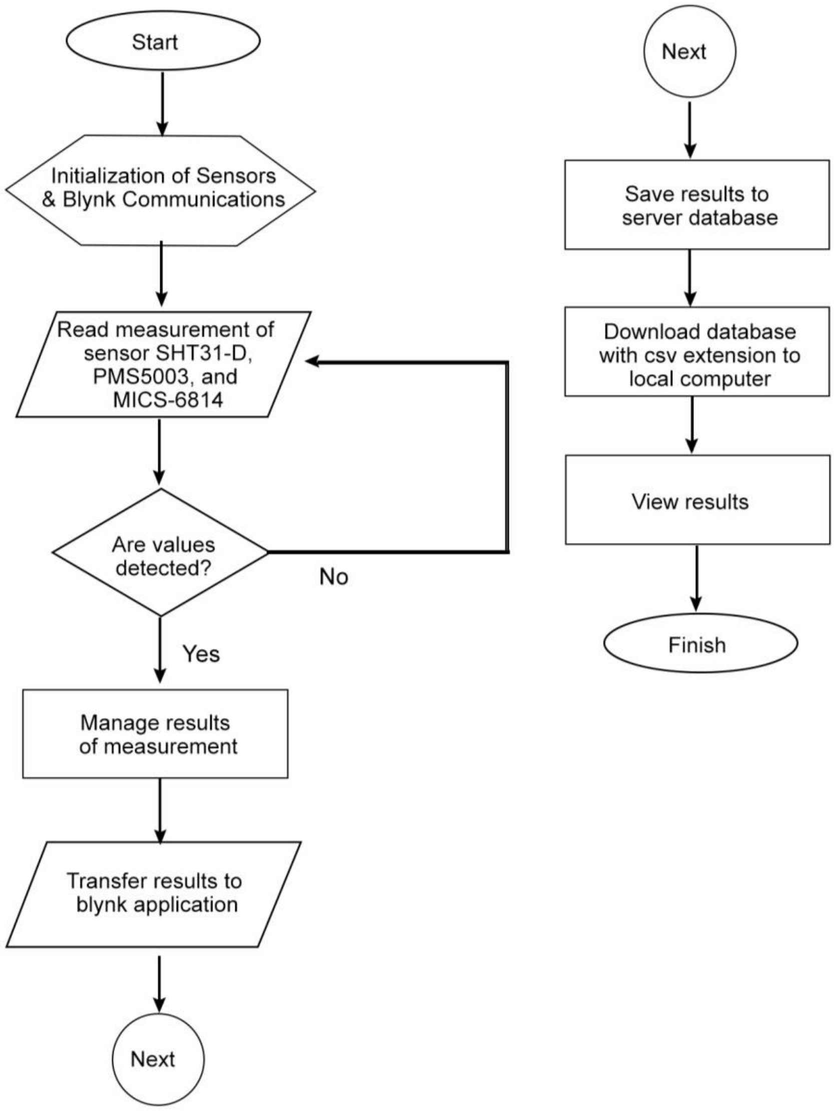

Figure 2. Flowchart

Architecture system is created to make it easier to describe the system layers. Figure 3 depicts a three-tier IoT architecture system consisting of an application layer, a network layer, and a sensor device layer. Air quality sensor devices and the data they detect are the main functions of the air quality monitoring system in this research.

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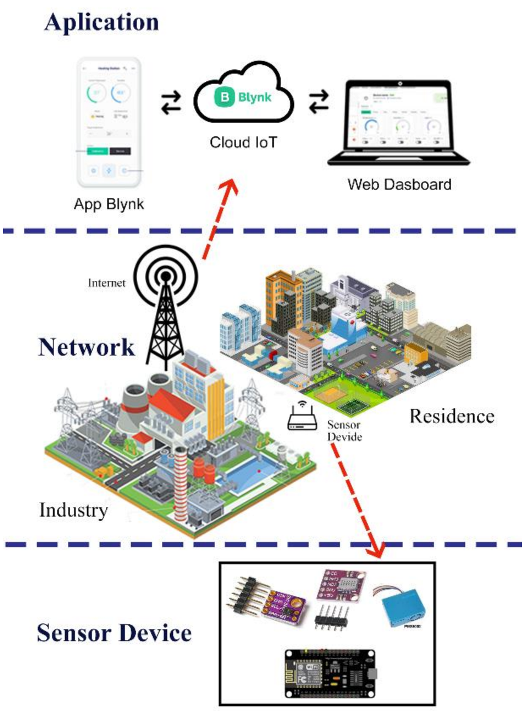

Figure 3. Architecture system

The schematic is designed as a simulation to serve as a reference when creating a real system. A circuit schematic of the device design can be seen in the Figure 4. The 12v battery functions as a voltage source for the system. The voltage at the source is changed from 12v to 5v using a DC step down LM2596. The 5v voltage source from the stepdown is connected to the system or load. System detection results can be displayed and observed from anywhere as long as the system is connected to a network using WiFi from the ESP32.

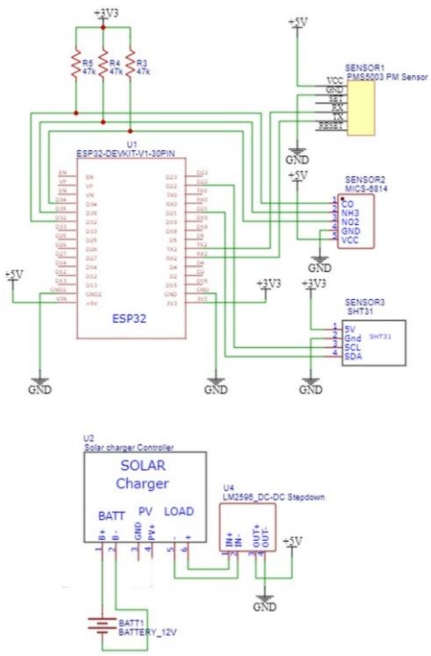

Figure 4. Schematic System

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The collected data can be accessed via mobile devices using the blynk application and the blynk.console website. This application connects to the data manager and displays the detected value information directly. Figure 5 shows an example of presenting information in an application on a mobile device. All parameter values can be seen and will be displayed in graphical form after 1 minute by taking the average value of each parameter.

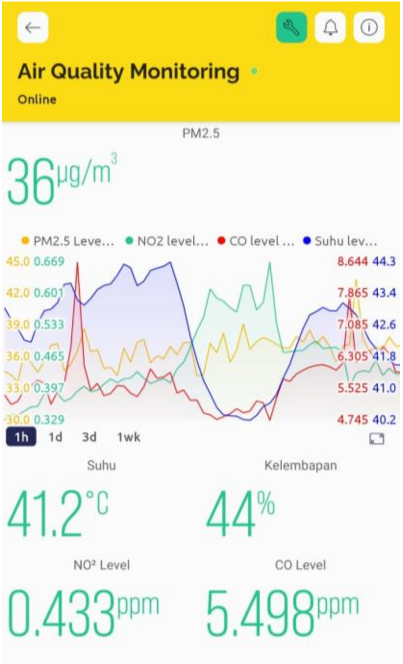

Figure 5. Display of System

RESULT

Testing design tools

The test aims to determine the effectiveness and accuracy of the tool that has been designed as a reference in detecting air quality around industry. The test was carried out by comparing the results of NO2 detection by the Mics-6814 sensor which had been assembled on the design tool with the ECOM D Portable Gas Analyzer instrument. The comparison instrument uses tools from Balai K3 which have been verified. Figure 6 is a display of the comparison tool.

Figure 6. ECOM D Portable Gas Analyzer

The gas tested came from car exhaust gases in Balai K3 Medan. The distance of the gas source from the tool is 1 meter, the time interval for data collection is 4 times in 1 hour. The test results can be seen in Figure 7. This test focuses on comparing the design tool with other tools that are considered comparable (xtrue) to the parameters to be assessed. The equation for determining the sensor error value is as follows:

%error = different of measurement/(true value) x 100

different of measurement= | xcompared tool– xdesign tool|

Through this equation, the difference between comparison tools and design tools can be seen in table 1.

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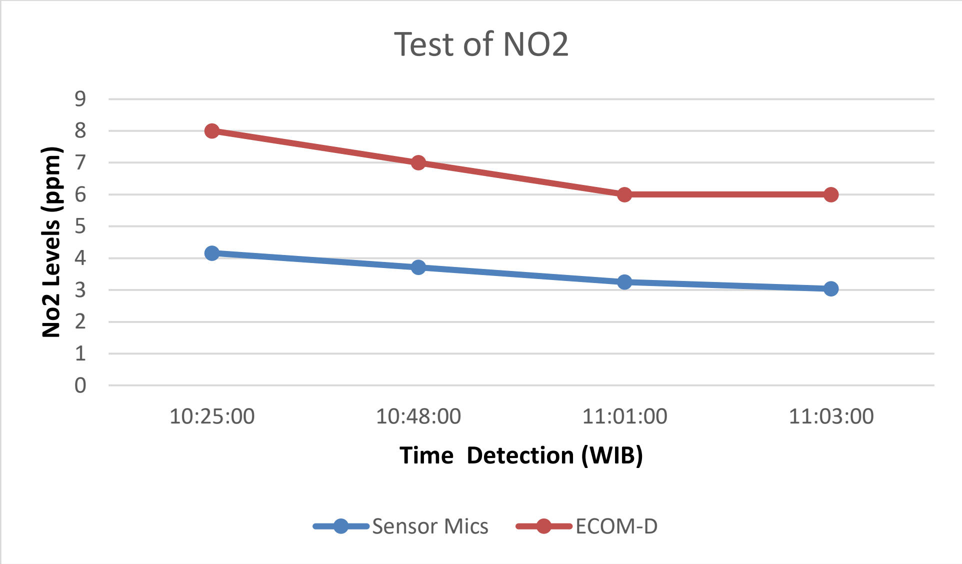

Figure 7. Graph of NO2 value testing

Table 1. Difference and % error in NO2 levels in the design tool and the comparison tool

Time	NO_2 levels in air (ppm)		Different of measurement	%error
	Sensor Mics	ECOM-D		
05/02/24 10:25:00 AM	4,16	8	3,84	48
05/02/24 10:48:00 AM	3,71	7	3,29	47
05/02/24 11:01:00 AM	3,25	6	2,75	45,3
05/02/24 11:03:00 AM	3,04	6	2,96	49,33

The average value of the absolute percentage difference in NO2 is determined by the equation:

Mape (Mean Absolute Percentage Error = $\frac{\sum_{n}^{n}=1|error_n|}{n}$

The sensor that detects NO2 in the design tool produces a measurement error value of 47.54% compared to ECOM D. This is caused by various factors. Differences in function, specifications and components that make up the tools are factors that influence the difference in results. ECOM D has a function to measure levels of gases including O2, CO, NO, NO2, SO2 in chimneys or other stationary emission sources. The NO2 measurement range on ECOM D is 0 – 1000 ppm with a resolution of 1 ppm. Meanwhile, the Mics-6814 sensor is used to measure relative levels of NO2 with a measurement range of 0.5 – 10 ppm.

In this test, calibration of the designed tool is carried out using a comparison tool or standard tool. To determine the calibration value of the design tool, a polynomial regression formula is used with the following equation:

$$Y = b_0 + b_1X + b_2X^2 + \ldots.. b_kX^k + \varepsilon$$

There are :

Y	= response variable
$b0$	= intercept
$b1, b2, \ldots, bk$	= regression coefficients
X	= predictor variables
ε	= confounding factors that cannot be explained by the regression model

Through this formula, the value for calibration is obtained, there is (y = 1,8865x + 0,0716). The results of determining the regression coefficient are entered into listing program on the Arduino as sensor calibration.

CO sensor testing receives the same treatment as NO2 sensors, compare with the ECOM D portable gas analyzer. Comparison of the detection results of the design tool with the comparison tool can be seen in the figure 8. From the equation of a polynomial regression, the formula for calibration is (y = 0,6519x - 0,2856).

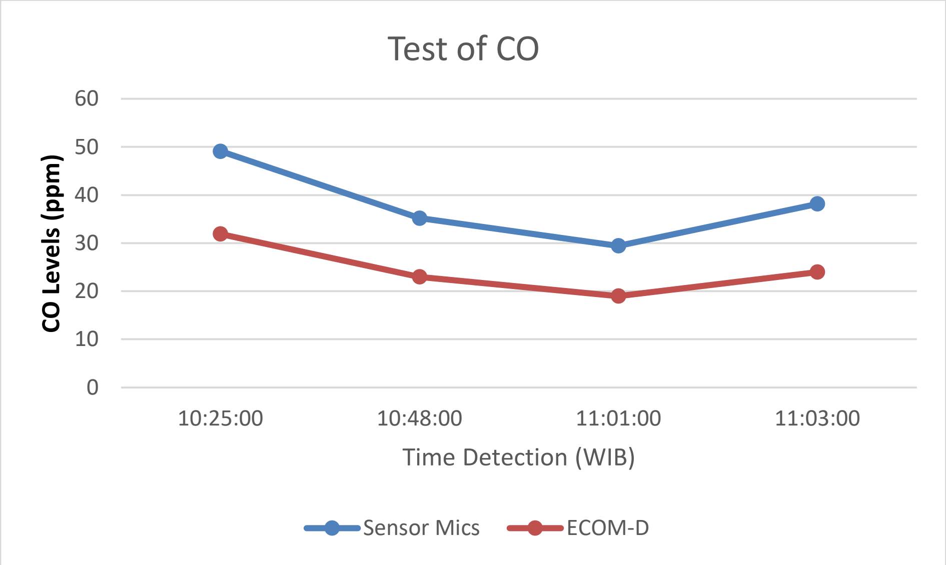

Figure 8. Graph of CO value testing

PM2.5 testing using the PMS5003 sensor was carried out by comparing a tool designed with a 6in1 Air Quality Detector sold on the market. This comparison tool can test PM2.5 with a range of 0-999(µg/m3) and the results can be seen digitally. This tool is generally used to measure indoor air quality.

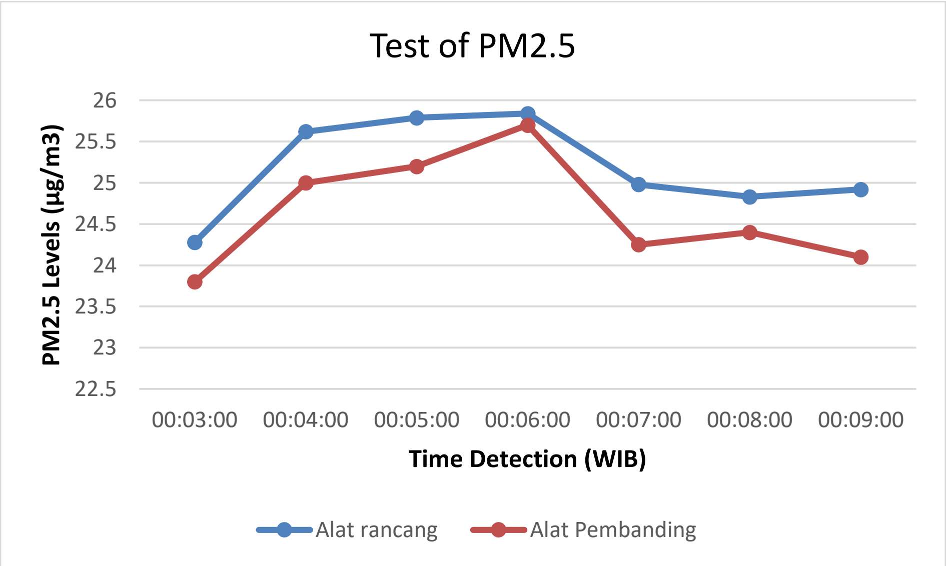

Figure 9. Graph of PM2.5 value testing

The test was carried out by providing fume from burning pieces of paper, then bringing them closer to the same point on the design tool and the comparison tool. These two tools measure PM2.5 levels by scattering light from each tool. Testing took place indoors with sufficient light intensity of around 11W for 7 minutes. The test graph can be seen in figure 9. The formula for determining the PM2.5 calibration value for the design tool is (y = 1,1061x - 3,216). This value is used to listing program too.

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Data Collection at Research Locations

Data collection was carried out at several locations around the city of Medan, that are residential areas around the KIM Mabar industry, around the Tanjung Morawa industrial settlement, and University of North Sumatera. The reason for choosing the research location was to see the effect of industrial activity on air quality in industrial areas which was then compared with areas that were considered clean from air pollution, namely the University of North Sumatra.

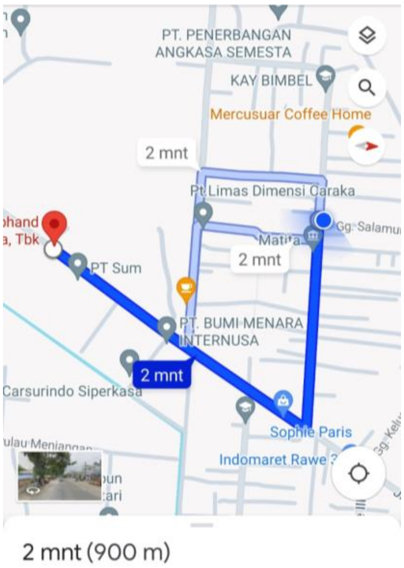

Figure 10. Data Collection Points around KIM Mabar

The research was conducted for 3 days with data collection time of 7 hours at each location. The time chosen for the research was from 10.00 – 17.00 WIB. Air quality monitoring consisting of NO2, CO and PM2.5 is carried out at one of the residential points close to industry. The first point where the research was carried out was in a residential area on Jalan Platina, Medan Mabar, this point is close to PT Charoen Pokphand Indonesia Tbk with a distance of 900 m which can be seen in Figure 10. The design tool detects air quality in the open air which is placed >2 meters above the ground surface.

Figure 11. Data Collection Points around Tanjung Morawa

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The second day of research was carried out around settlements in Tanjung Morawa by choosing a place close to PT. Jafpa. Figure 11 displays the research location and the distance between the research point and the nearest factory. The third day of research was carried out at the University of North Sumatra, the data collection point was between FMIPA and the Faculty of Pharmacy. Air quality monitoring lasted for 7 hours, the design equipment installation was placed at a height of >2 meters from the ground surface. The third research point can be seen in Figure 12. Environmental conditions at each research location are relatively the same, where temperature and humidity are 32-43°C and 38 – 65%.

Figure 12. Data Collection Point at the University of North Sumatra

A. *Results of NO2 Data Collect*

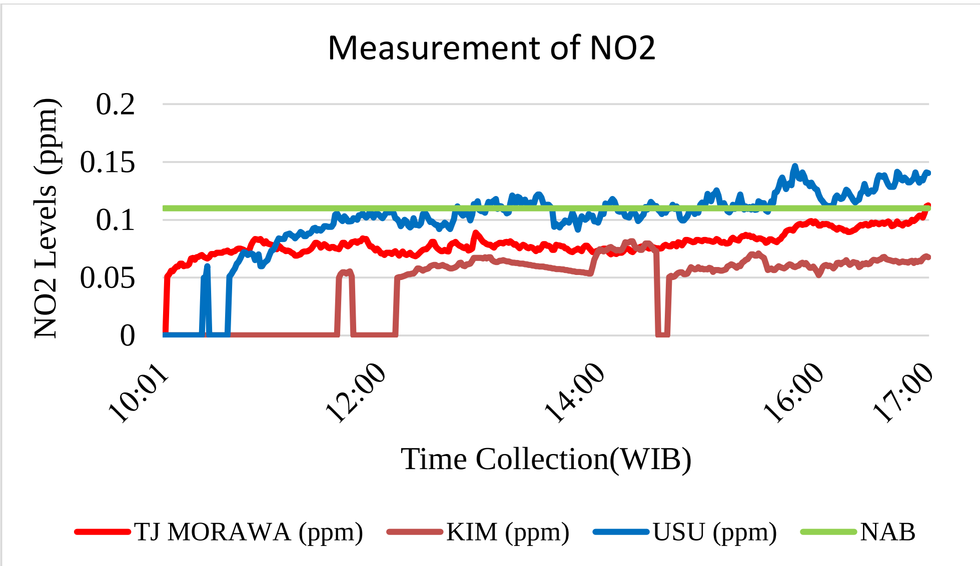

Figure 13. Graph of measurement of NO2 Levels

The results of collecting NO2 concentration data at 3 locations provide different average values at the same collection time. Figure 13 shows that the NO2 concentration measurement results at three different locations are below the NAB (Threshold Value) of NO2 in ambient air. The NAB value is 200 µg/m3 or 0.11 ppm which is calculated based on table 2.1 in the 2020 Peraturan Menteri Lingkungan Hidup Dan Kehutanan Republik Indonesia replacing Keputusan Menteri Negara Lingkungan Nomor KEP-

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45/MENLH/10/1997concerning Indeks Standar Pencemar Udara. The overall results of this measurement are in the medium category, referring to ISPU.

B. Results of CO Data Collect

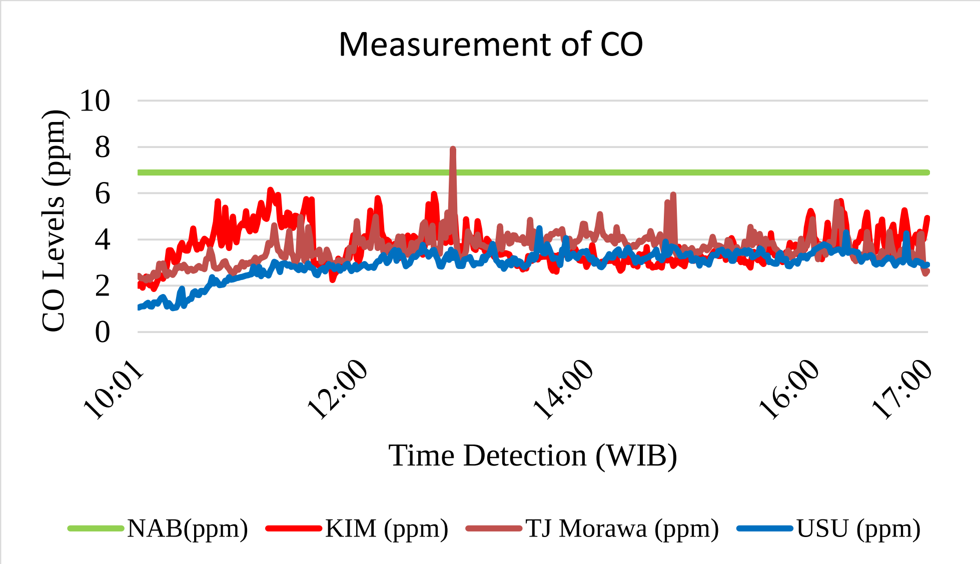

Figure 14. Graph of measurement of NO2 Levels

The average CO levels around USU for 1 hour are lower than locations around Tanjung Morawa and KIM, but overall these 3 locations are still in the healthy category. The detection value of CO levels obtained at each location varies every 1 minute. Detection results at USU ranged from 1.02 to 4.49 ppm. Detection values around Tanjung Morawa ranged from 2.23 – 7.92 ppm and around KIM ranged from 1.86 – 6.15 ppm. Based on the research results, the highest CO levels on average per hour are in the Tanjung Morawa and KIM areas. This is caused by various factors, one of which is combustion fuge from factory machines which are actively working at relatively different times from each other. Even though it is relatively high in these two industrial areas, it does not have a negative effect on humans, animals and plants

C. Results of PM2.5 Data Collect

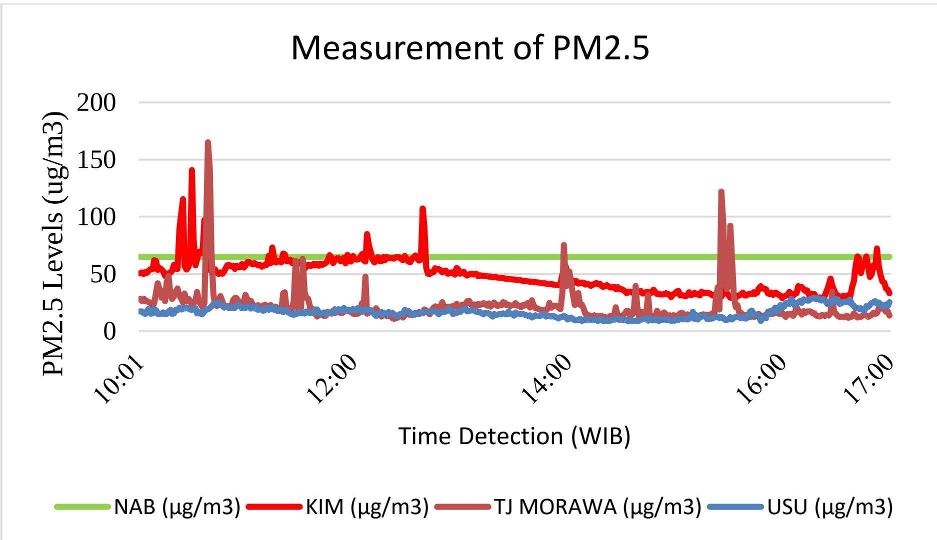

Figure 15 Graph of measurement of PM2.5 Levels

The results of measuring PM2.5 levels at the 3 research locations were relatively below NAB (55µg/m3), except at some times around KIM. The detection results can be seen in Figure 15. The average measurements for 1 hour at consecutive research locations around USU, Tanjung Morawa, and KIM were 16.39 µg/m3, 21.57 µg/m3, and 49.41 µg/m3. Overall, the average detection results for 1 hour are in the medium category or the air quality level is acceptable for humans, animals and plants. PM2.5 values are relatively low in the USU area, this is considered good and has no impact on human, animal and plant health. Activities that produce dust or micro-sized particles 2.5 or PM2.5 are very small in the USU area.

CONCLUSION

The air quality monitoring system designed can measure temperature, humidity, PM2.5, NO2 and CO levels in real time and accurately. The design tool can tabulate air quality data for PM2.5, NO2 and CO levels at the three research locations. The research location is around the KIM Mabar and Tanjung Morawa industrial settlements as well as the North Sumatra University campus area. Data tabulation results can be displayed and processed in the form of graphs and databases on mobile applications and websites with low-cost, wireless networks. The results of the air quality monitoring analysis in the research area as a whole have no impact on human, animal and plant health.

RECOMMENDATION

Suggestions for further research development in overcoming limitations and improving results are by choosing components that are more sensitive in measuring air quality and using comparison tools that have similar characteristics to the design tools. In addition, to improve research results, it is necessary to pay attention to the influence of temperature and relative humidity on the design tool by adding appropriate components and programming algorithms.

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