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Optimization of $PM_{2.5}$ Measurement System Using NOVA SDS011 Sensor

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Abstract. Particulate matters with the diameter less than 2.5 µm or $PM_{2.5,}$ have been known to the health adverse. The developing of a measurement system of $PM_{2.5}$ with a high precision has become a challenge in the last decade. We design the system using a NOVA SDS011 sensor to measure $PM_{2.5}$ concentration. The problem is that the sensor has a capacity to measure particulate matter in the range of 0.3 to 10 µm, meanwhile we would like to design the measurement system of $PM_{2.5}$ with the high precision. Another this that we address is how to optimize the sensor. A factor influenced the sensor optimization is a sample compartment. In this paper, we present the $PM_{2.5}$ measurement system with the different compartments. The $PM_{2.5}$ measurement system was calibrated using the 3443 Kanomax dust monitor. The result shows that the system works well with the compartment is important factor to increase the precision.

1. Introduction

The $PM_{2.5}$ has been known formed naturally or by human activity that are named as natural $PM_{2.5}$ and human-made $PM_{2.5}$ (1–3). The natural $PM_{2.5}$ are created by nature activity such as sandstorm and volcanic activity (4–7). Because of the natural phenomenon is uncommon, the presence of the natural $PM_{2.5}$ are sited on a certain location such as desert or volcano (8). In the other hand, human-made $PM_{2.5}$ occurred more frequently and wider than natural once (9,10). The simple human activity can produce $PM_{2.5}$ such as: cooking known as indoor source (11), motor vehicle, biomass burning, industrial, and mining activity as outdoor sources (12–18).

The concentration of $PM_{2.5}$ depends on the source (19). The concentration of $PM_{2.5}$ has been measured higher in the big city due to several sources (20,21). In the other hand, the low concentration was reported in the rural area (22). The high concentration of $PM_{2.5}$ was also found in the highway, industrial, and mining area (9,23–25) with a number of the sources were identified (26,27). In the big city, the high $PM_{2.5}$ concentration is related to amount of vehicles as well as is on the area near highway (28–30) especially in the rush hours (31,32). The industrial and mining area contribute to $PM_{2.5}$ with the high concentration (33,34).

$PM_{2.5}$ have been known to have an impact on mortality and morbidity (35–40). $PM_{2.5}$ cause respiratory-related disease on children and the people that live closely to the source (41–44). The studies confirm that $PM_{2.5}$ trigger the development of cardiovascular diseases (45,46), non-alcoholic fatty liver disease (NAFLD) (47,48), and the development of tumor growth factor, cancer, and insulin resistance (49–54).

The concentration of $PM_{2.5}$ play a role on the diseases(55,3,56). Due to the importance of the $PM_{2.5}$ concentration measurement, a good measurement device is needed. In this study is aimed to develop a $PM_{2.5}$ measurement device using a low price infrared sensor module that the performance has been tested for $PM_{2.5}$ measurement (57–59)(60) by adjusting the sample compartment to increase the module precision.

2. Method

2.1. Sample Compartment Design

We design three different sample compartments Dsg 1, Dsg 2, and Dsg 3 as presented in Fig 1. The Dsg 1 is an compartment with the dimension of 11 x 9 cm^2 that is divided into two different rooms that are used for placing the $PM_{2.5}$ sensor and the microcontroller. The second design compartment Dsg2 is the modified of Dsg1 by dividing the sensor room into four different rooms for the sensor inlet, the sensor body, the sensor outlet, and the sensor cable and connector. Meanwhile the last design Dsg3 is the developing of Dsg2 by adding a $PM_{2.5}$ filter and a fan. The $PM_{2.5}$ filter is positioned in the front of the sensor inlet while the fan is attached to the sensor outlet.

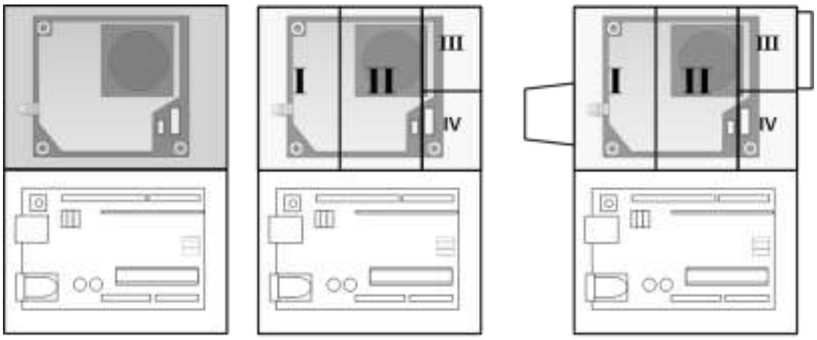

Figure 1. The design sample compartment container design for: (a). Dsg1, (b). Dsg 2, and (c). Dsg 3.

2.2. Evaluation Procedures

In order to optimize the sample compartment, four NOVA SDS011 configurations were tested on this study. The sensor without any compartment, St was evaluated in advance. Next, the sensor was the designed compartments Dsg1, Dsg2, and Dsg3. The test was conducted for 10 minutes in the standard ambient room (temperature of 24^{o}C -26^{o}C with relative humidity of 60% - 61%). The 3443 Kanomax dust monitor was used to calibrate the designed. The data were recorded for every 30 seconds. The system performance is calculated by using the equation (1) as follows

$$System\ Performance = \frac{C_{DM}-C_{DSG}}{C_{DM}} x100\% \qquad (1)$$

In the Eq 1, C_{DM} is the $PM_{2.5}$ concentration that are measured by dust monitor while C_{dsg} is the concentration of designed system.

2.3. Data Validation

The data validation is conducted by comparing the $PM_{2.5}$ measured by the designed system and the dust monitor. The validation was done for the device with the different compartments.

3. Result

The measured concentrations of $PM_{2.5}$ for the NOVA SDS011 sensor without compartment and the three different designed device are presented in Fig.2. The $PM_{2.5}$ concentration measured by the dust monitor is found in the average value of 19.4 μg/m^3, meanwhile the concentration is varied depending on the designed compartment whereas the sensor is placed. The average concentration of $PM_{2.5}$ measured for the condition of the sensor without the compartment (Fig 2.a) is found of 11.8 μg/m^3. The different concentration measured both the equipment is 7.6 μg/m^3. The $PM_{2.5}$ concentration is measured by the dust monitor in the average of 19.1 μg/m^{3}and by the Dsg1 (Fig 2.b) of 5.30 μg/m^{3}with the difference of the concentration is significantly high of 13.8 μg/m^3. The trend is similar for the the Dsg2 (Fig 2.c) with the measured concentration of 21.2 μg/m^{3}and 3.99 μg/m^3 for the dust monitor and the Dsg respectively with the difference concentration of 17.3 μg/m^3. The Dsg3 (Fig 2.d) measure the $PM_{2.5}$ concentration with the average of 21.2 μg/m^3, meanwhile the average concentration measured by the dust monitor is of 15.8 μg/m^3. The difference of the measured concentration between the equipment is 5.3 μg/m^3. Figure 3 present the difference concentration is measured by the dust monitor and the designed system.

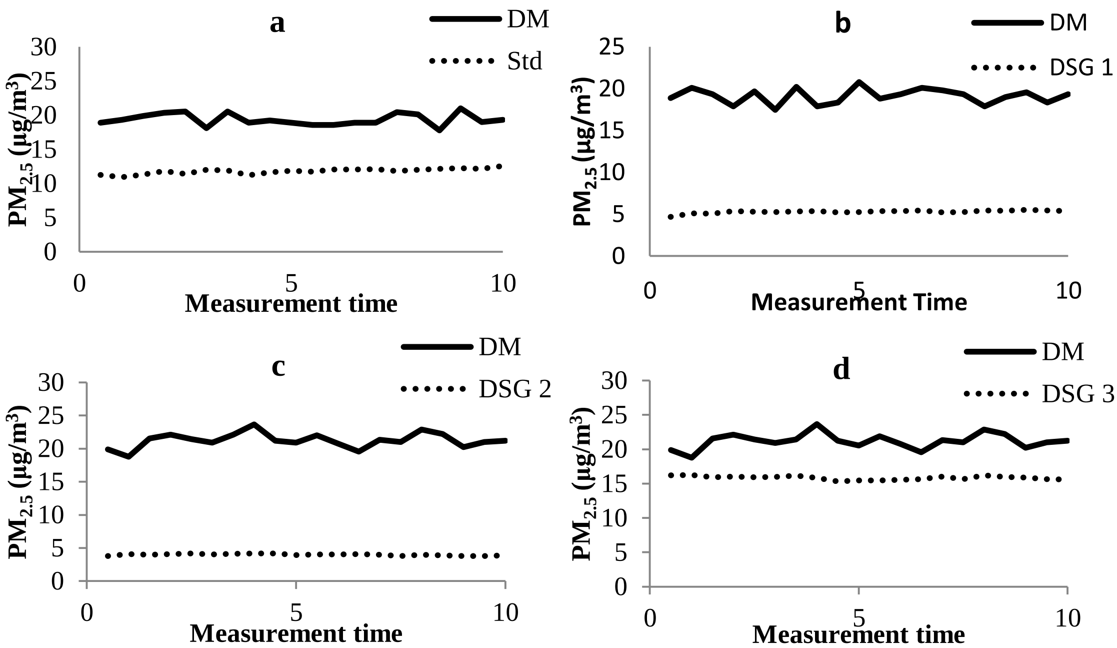

Figure.2. the measured concentrations of $PM_{2.5}$ for different condition

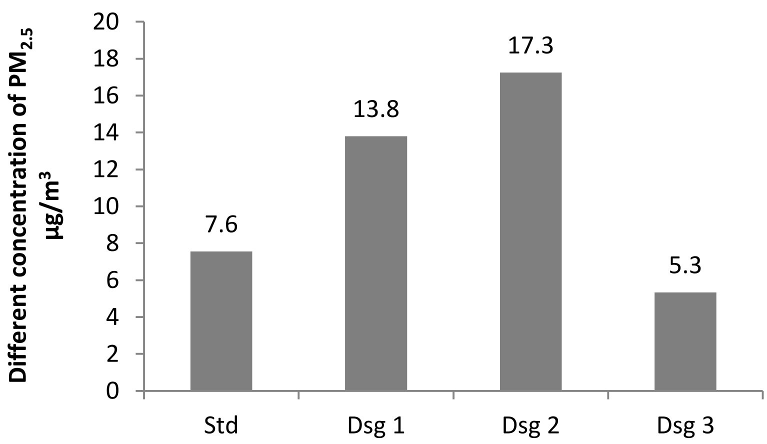

Figure.3. A comparison result of $PM_{2.5}$ concentration in various configurations.

4. Discussion

A NOVA SDS011 sensor is an infrared-based $PM_{2.5}$ measurement device that is commercially traded in unpackaged module. The module detects the infrared intensity change because of the $PM_{2.5}$ block. The NOVA SDS011 module is equipped by a fan that is as function to provide a self-airflow. The limitation of the sensor is there is no filter accomplished in the module as well as the sample sampling. They have an impact on the difference result of the $PM_{2.5}$ concentration using the dust monitor and the designed device. The different concentration is 7.6 $\mu g/m^3$for unfiltered condition. We overcome this problem by designing the compartment using three configuration Dsg1, Dsg2, and Dsg3. Based on these designed system, we obtain the difference of the measured concentration between the dust monitor and the Dsg1 and Dsg2 of 13.8 $\mu g/m^3$and 17.3 $\mu g/m^3$ respectively. The Dsg3 is the best designed system with the difference concentration measured by the dust monitor and the designed system of 5.30 $\mu g/m^3$. The Dsg3 system is very comparable with the calibration equipment. The performance of the designed system is calculated using the equation (1). Based on the equation, we find the system performance is 61 % for the uncontained system, 28 % for the Dsg1 system, 19 % for the Dsg2 system, and 75% for the Dsg3 system. The Dsg3 system has the best performance among others as shown in Fig.4.

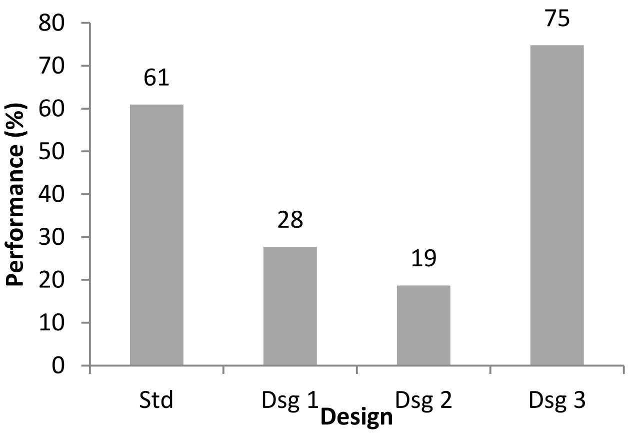

Figure 4. The system performance presented in procentage.

Figure 5 shows the relationship of the $PM_{2.5}$ measured concentration between the dust monitor and the designed system. The $PM_{2.5}$ concentrations are measured by all designed systems are found linearly to those are measured by the dust monitor with the correlation equation of L=-0.12x + 20.9 for the standard system (Fig 5.a), L=-0.40x + 21.2 for the Dsg1 system (Fig 5.b), L=0.75x + 18.1 for the Dsg2 system (Fig 5.b), and L = 1.07x + 4.18 the Dsg3 system (Fig 5.d)respectively.

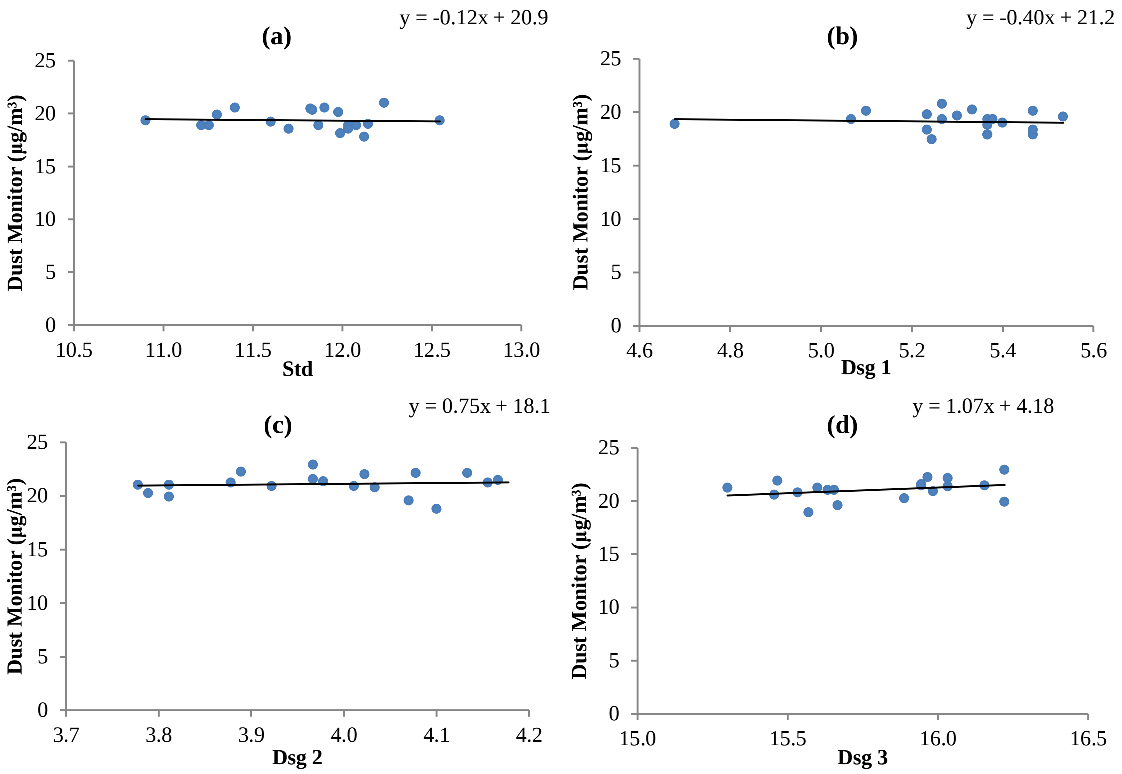

Figure 5. Linearity of the sensor performance for each container configuration

5. Conclusion

In conclusion, the performance of the system for $PM_{2.5}$ concentration measurement depends the configuration compartment where the SDS011sensor is placed. The best design is the system with the configuration of Dsg3 where is the inlet and outlet of the sensor is separated in order to stop re-accounted particulate samples with the performance of 75%. The designed systems are comparable to the validation equipment with the linear correlation.

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