Developing A Low Cost Particulate Matter Measurement System

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Abstract. A low cost particulate matter measurement system has been designed to quantify the concentration in the air. The device has been built up by using a PM$_{2.5}$ sensor. The sensor signal is processed and transferred to an Arduino UNO microcontroller. A long-range wireless communication is attached in the system for a distance measurement. The system has been validated using a 3522 Kanomax dust monitor model. The system was tested in the distance to characterize the performance. The system works properly to measure PM$_{2.5}$ concentration. The PM$_{2.5}$ concentration is presented in the average value of the 30 seconds sampling measurement. The system is controlled by using humidity and temperature sensors to avoid any damage caused by an environment condition. The maximum humidity and temperature for the system is restricted to 70% and 50$^\circ$C respectively. The measurement system is accomplished to a NRF2401 radio module to allow to collect data remotely. In conclusion, the proposed system works well to measure PM$_{2.5}$ in the environment. The system has an ability to measure particulate matter with maximum concentration of 750.0 μg/m$^3$ with the resolution of 0.3 μg/m$^3$.

1. Introduction
Particulate matters (PMs) are solid and liquid suspended in the air that can be produced in two methods naturally and humanly. The volcanic activity and sand storm are the most known natural PM sources [1,2]. In the other hand, traffic, industrial, household activity, and burned forest that human activities produce more PMs [3–6] rather than the natural source [7,8]. PMs concentration was measured in very high level in the highway, roadway intersection, industrial area, and big city with dense population of motor vehicles. In Hanoi, the PMs concentration is strongly affected by the amount of active motorcycle in the road [9]. The PMs concentration is also quantified in very high level and exposes commuter people on public transportation [10]. The concentration of PMs is also found higher in the bigger city than rural area in Swiss [11]. Moreover, a heavy metal compound is reported to composes PM in the industrial area [12,13].

PMs have been identified as dangerous pollutants affecting to human mortality and morbidity [14–16]. Many studies have been reported the impact on human health especially in the respiratory related to the diseases such as: asthma, allergy response, infection, and inflammation [17–30]. Further studies associated the PMs to the organ damage have been observed for liver, cardiovascular, and kidney [31–36], respiratory system, and heart rate [37–39]. In the advanced studies, the PMs has been related to a cancer cell development, tumor growth factor, and insulin resistance [40–47]. The impacts of PMs on health depends on a number of factors such the distance source [48,49], the compounds : reactive oxygen series [50,51], oxygen series [52,53], black carbon, PAH, BTEX, etc [54–57]. All of those compounds...
have been known as toxic substance \cite{58,59,60}. Another factor that have been known is the concentration of the PM that hold a major impact on health \cite{61}. A high concentration is found to responsible for the increase of health issues that were reported in various location on earth \cite{15,61,62,63,64,65,66,67,68}. Based on the studies, it is clear if the PM concentration responsible for the damage on human.

The PM concentration is an important factor in affecting on the human health, it is urgent to measure in order to estimate the effect. The measurement of the PM concentration has been conducted in the past decade \cite{2,69,70,71} for various places \cite{74,75,76,77}. In order to accomplish the study, a good device to measure the PM is urgently needed, meanwhile the commercial equipment costs very high. This study is aimed to design a low cost PM measurement system with a high sensitivity and accurate by taking an advantage a commercially available sensor.

2. Methods

2.1. System Design

A NOVA SDS011 PM$_{2.5}$ sensor is as the primary part of the developed PM measurement system. In order to measures the temperature and humidity, the system is accomplished a SHT 10 sensor. To send the data, a NRF2401 radio communication module is integrated to the system for medium distance measurement purposes. The radio can send data up to 100 meter without any obstacle between the transmitter and receiver. An Arduino UNO microcontroller module was chosen based on the number of usable connector. The measurement result is displayed by using a LED 20 x 4 display module and combined with a I2C module. The system is completed with a mini RTC time module to provide a measurement time. For the data communication, the system has a transmitter and receiver. The transmitter integrates NOVA SDS011, SHT 10, and NRF 2401 into an Arduino UNO that is also used to provide power for the 3 cm outlet fan. In the receiver, we integrate a NRF2401 radio communication and Mini RTC with the Arduino UNO. A LED screen is used for displaying the measurement result.

The transmitter and receiver are able to communicate each other using two different programs. In the transmitter, the program contains of the command to read the NOVA SDS011 and SHT 10 sensor simultaneously. After the data are sent into the microcontroller, the NRF2401 radio module is programed to transmit the data into the receiver. In the receiver system, we set the microcontroller to read the data that were received by the NRF2401. We write the command to read the time data that are provided by a Mini RTC, and the data are displayed in the LED. In the receiver, the measurement data for 30 seconds sampling are averaged before it is displayed on the LED screen.

![The schematic of the PM measurement device](image)

**Figure 1.** The schematic of the PM measurement device

The container design is shown in the Figure 1. The container is separated into two main rooms consist of microcontroller room and sensor room. The separation is purposed to avoid the impact of PM on the
electronic circuit of the microcontroller. In the sensor room, we divide the room into four different compartments. We position the sensor NOVA SDS011 inlet in the compartment I together with the sensor SHT 10. A PM$_{10}$ filter is positioned in the device inlet in order to remove the PM with size more than 10 μm. The compartment II contains the NOVA SDS011 sensor body while compartment III is the outlet of the sensor before the outlet fan sucked the air. The compartment IV is purposed for the sensor cable room that is connected with the microcontroller compartment. The NRF2401 is positioned in the same compartment with the microcontroller while the antenna is placed in the outside of the container. The receiver is designed similarly to the transmitter. The receiver radio antenna is placed on the outside of the box.

2.2. Data Validation
In order to validate the device, we used standard the PM measurement device that was certified before. The device is a 3443 Kanomax Dust monitor. The designed device was validated in three different conditions such as: a normal room, filtered condition, and motorcycle smoke condition. The experimental was conducted in the room with average humidity of 60.0-61.0% and in the room temperature (23-26°C). In the normal room, we tested the device simultaneously with the dust monitor. The data were recorded for every 1 minute (60 seconds) in the ten minutes period of time. We did similarly for the filtered condition test, except adding a PM$_{0.1}$ filter. The PM$_{0.1}$ filter is purposely for measurement in the empty room condition to find the device response in the empty condition (zero particulate). The data was recorded in the same manner with the normal room condition. In the motorcycle PM measurement, we injected the motorcycle smoke into chamber with size of 75 x 55 x 35 cm$^3$ for 80 seconds. The concentration was measured in similar method with the ambient and filtered measurement.

3. Result and discussion
The PM$_{2.5}$ concentration is recorded by the designed system having a similar trend to the displayed value of the Kanomax dust monitor. In the minute one, the designed device measured the PM$_{2.5}$ concentration of 23.3 μm/m$^3$ while the dust monitor was found of 24.6 μm/m$^3$. The PM$_{2.5}$ concentration was observed to increase in the second minute measurement to 23.8 μm/m$^3$ for the designed device and 24.8 μm/m$^3$ for the Kanomax dust monitor. The PM$_{2.5}$ concentrations decreased in the minute of 3 and 4 to 22.1 μm/m$^3$ and 22.8 μm/m$^3$ for the designed device and Kanomax dust monitor. The different concentration was in the minute of 5 where the Kanomax dust monitor recorded 24.0 μm/m$^3$ meanwhile the designed device measured to 22.0 μm/m$^3$. In the minute 6, the Kanomax dust monitor showed the concentration of 23.2 μm/m$^3$ while the designed device displayed the concentration of 22.6 μm/m$^3$. In the minute seventh measurement, the PM$_{2.5}$ concentration was noted in extremely high level by the Kanomax dust monitor with the value reach to 25.6 μm/m$^3$ meanwhile the designed device presented a level of 23.3 μm/m$^3$. In the minute eighth to 10, the concentration gradually reduced to 23.1 μm/m$^3$ on the Kanomax dust monitor and 23.1 μm/m$^3$ on the designed device.

The PM$_{2.5}$ concentration measured by both instrument shows a similar trend with the best fitting of fourth order polynomial approach with $R^2$>0.8 on the designed device and $R^2$>0.7 for the Kanomax dust monitor respectively. The naturally difference is because each equipment has a specific character depending on the used sensor and other parts in the system. By comparing our designed device to the other system is meant to show not only that the designed device can work well, but also to give an evidence of the goodness of the device. The validation test of the device in the filtered condition shows the similar trend of the PM$_{2.5}$ concentration in the third order polynomial as presented in the Fig 2. The consistent result is obtained for the PM$_{2.5}$ concentration measurement by using the designed device and Kanomax dust monitor with the trend of $C = -0.0291x^3 + 0.4808x^2 - 2.3083x + 26.86$ for ambient room, $C = -0.0091x^3 + 0.1435x^2 - 0.7817x + 13.515$ for filtered system, and $C = 0.0057x^3 + 0.0172x^2 - 2.5828x + 46.593$ for motorcycle smoke. In the other hand, the trend of $C = -0.0177x^3 + 0.3392x^2 - 1.8294x + 25.287$, $C = -0.0134x^3 + 0.2289x^2 - 1.2026x + 19.727$, and $C = -0.019x^3 + 0.4075x^2 - 3.6641x + 48.204$
is calculated in the system. The PM$_{2.5}$ concentration for the motorcycle emission is shown in the Figure 2.

![PM$_{2.5}$ concentration on various conditions](image)

**Figure 2.** The PM$_{2.5}$ concentration measured by the designed device and the Kanomax dust monitor.

The device linearity is shown in the Figure 3. In the Figure, the linearity of the system is presented by equation of \( L = 7.92 \ln(x) - 1.80 \). The Figure shown the system is shown a good accuracy to measure PM$_{2.5}$ concentration indoor and outdoor.

![System linearity is approached by logarithmic function](image)

**Figure 3.** System linearity is approached by logarithmic function

In general, the designed device based on the Nova sensor SDS011 usage works well to measure the PM$_{2.5}$ concentration. The sensor has an excellent ability to measure the PM$_{2.5}$ with the maximum concentration of 750 μg/m$^3$ and the resolution of 0.3 μg/m$^3$. The sensitivity sensor need to be paid an attention that will affects to the device. The device sensitivity in measuring the PM$_{2.5}$ concentration depends on the sensor performance. In terms of the designed device has the sensitivity of 1.00 second/data.

**4. Conclusion**

The designed device shows a good performance to measure the PM$_{2.5}$ concentration. The device works well in the various test conditions. The device has an ability to measure PM$_{2.5}$ with of the maximum
concentration of 750 μg/m³ and the resolution of 0.3 μg/m³. The device can be used in the environmental condition with the maximum humidity of 70 % and the maximum temperature of 50 °C. The device performance in the PM$_{2.5}$ concentration depends on the sensor.

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