A design of short distance PM$_{2.5}$ monitoring system using a bluetooth module

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Abstract. This paper presents a design of a PM$_{2.5}$ monitoring system based on the Samyoung sensor type DSM501A with the HC-05 Bluetooth data communication module. The sensor is integrated into an Arduino Nano. The measured data are not only displayed on an LCD but also are sent to a computer using a Bluetooth module for the storage. The data are stored in the excel data format and viewed by using the PLX-DAQ add-on. The system was calibrated by using a standard PM$_{2.5}$ measurement device (Kanomax dust monitor type 3443). The calibration procedure was conducted by measuring the PM$_{2.5}$ concentration of the sources. The performance of the system is presented in the optimum communication distance, the concentration range, and the system sensitivity. The result shows that the system works well. The optimum distance between the system and the computer is in the range up to 16 m. The sensitivity of the system is found of 600 μg/m$^3$/minute with the range of the concentration measurement up to 1400 μg/m$^3$ at the room temperature and humidity.

1. Introduction

The earth atmosphere contains of 78% nitrogen, 21% oxygen, variable air vapor, 0.9% argon, 0.04% carbon dioxide and other gases [1]. All of these components are mixed by the atmosphere dynamic into proportion ration in which allowing the human, animal, and plant to life. However, human activity produces other types of substances that very hazardous for the environment [2]. The hazardous product is called air pollutants [3]. The air pollutant comes from many sources such as factory [4], household activity or office [5], [6], and traffic activity [7]. Most of them contain reactive substances that cause health problems and the threat of environmental sustainability [8], [9].

The pollutants may be in the form of particulate matter with a different size distribution [10], such as PM$_{0.1}$ particulate matter with a diameter less than 0.1 μm, PM$_{2.5}$ with a diameter less than 2.5 μm, and PM$_{10}$ with the size less than 10 μm. PM can be produced naturally; however, in the modern era, the PM is mostly generated by human activity such as combustion or smelting process [11]. In term of composition, the PM consists of various types of chemical compounds and have different physical properties. The properties are affected by the place and time of the PM development (ambient condition, source, climate, session, etc.) [12].

PM$_{2.5}$ has become the most concern due to the ability to penetrate the human body and cause several damages in the organ [2], [13]. The aerodynamic diameter allows PM$_{2.5}$ in the airborne to be inhaled by a human [14], [15]. The consequence, numerous diseases are as a result such as asthma, allergy reaction, influenza-like illness [16]. Furthermore, PM$_{2.5}$ is reported to penetrate the cardiovascular
system and spread in the body. As a result, PM$\text{2.5}$ is associated with the development of cardiovascular diseases such as heart problems, red blood cell damage, etc. [17].

Because of the impacts on PM$\text{2.5}$, the concern of better information about the PM raises. A high quality-low cost device is needed to measure the PM$\text{2.5}$ concentration in the air. The device is also necessary for the observer safely. Many PM$\text{2.5}$ measurement devices have been developed to accomplish these purposes. One of the most favorite measurement devices is a handheld type. The handheld type measurement device has a benefit on its mobility and provides better measurement results by less distance between the input and sensor. However, the observer will receive the amount of PM$\text{2.5}$ during the measurement. To avoid the PM$\text{2.5}$ impact on the observer, a device with direct measurement but with a distance data observation is needed. In this study, we aim to develop a PM$\text{2.5}$ measurement system that provides short distance communication and data storage without losing mobility and high-quality data.

2. Methodology

2.1. System design

Samyoung DSM501A was used as PM$\text{2.5}$ measurement module in this study. Samyoung DSM501A performance is proved in terms of accuracy and PM$\text{2.5}$ detection [18][19][20]. The sensor can detect PM$\text{2.5}$ concentration up to 1400 $\mu\text{g/m}^3$ that was made the sensor suitable for high PM concentration conditions.

![Figure 1. The system design.](image)

The onboard LCD module was embedded on the device for direct measurement. The communication was handled by Bluetooth HC-05 module that was integrated into the Arduino nano microcontroller module as a microcontroller. The Bluetooth serves communication with a computer. Bluetooth permits data communication in real-time for display or storage. The communication allows the observer to do the measurement from a distance without any PM$\text{2.5}$ exposure directly. In the computer, the data are saved in the .xlsx format. The .xlsx format is generated by using the PLX-DAQ add-on as the secondary party program. In order to protect the device from an extreme condition such as high temperature or humidity, we use a DHT11 to monitor the measurement location. The system design is shown in the Fig.1.

2.2. System calibration and testing

Before every module was assembled into the measurement device, a simple test was conducted to make sure that every part works well. After the component and the modules were tested, all component was assembled by following the scheme (Fig.1). The final device was calibrated by using a Kanomax 3443 PM$\text{2.5}$ measurement device as the reference. The calibration was done by using a PM$\text{2.5}$ source. The PM$\text{2.5}$ was injected into the chamber with volume of 1.54 m$^3$ for 100 seconds. Further, the designed device and Kanomax 3443 measured the PM$\text{2.5}$ simultaneously. The measurement data were used to determine the correction factor. Later, the correction factor was implemented in the program. The calibration was conducted several times. The similarity was determined by using a linear approach with $R^2 > 0.95$. 
The calibrated device was used in several different conditions to test the performance of the monitoring system. Three conditions were used to examine the device consist of ambient conditions, motorcycle emission, near road area, and construction area. The data result was also used to determine the measurement characteristic of the device. The characteristic of sensitivity, maximum, and minimum concentration was collected in this process.

Furthermore, the communication capability of the device was also examined to find communication delay, maximum distance, and data quality. The test was conducted by sending the concentration, temperature, and humidity in sequential. The ability of the device to send the data in a package was also observed.

3. Results & Discussions

3.1. Monitoring system design
The designed device is presented in Fig. 2. The device has a dimension of 19.0 x 11.5 x 6.5 cm³, respectively, with the weight of 400 gr. An onboard screen is applied that provided information of temperature, humidity and PM₂.₅ concentration. To facilitate the observer, the screen is applied with an angle of 60°. The input is positioned in the upper-left side (1) while the output is in the top of the box (2). The reset button is attached in the upper right side (3). The power source is located in the bottom right side (4). The sample flow is generated by a 9volt van.

![Figure 2.](image)

The internal section is divided into two different sections. First, the sensor section that is positioned on the top side and the circuit section in the bottom. Each section is isolated to make sure there are no measured particulate matters in the sensor section penetrates into the circuit section vice versa. The sensor section contains the DHT 11 and Samyoung DSM501A while the circuit section holds the microcontroller, Bluetooth module, and display module. The device is powered by 12-volt dc source provided by a dc adapter. To protect the sensor, the device is programmed to work in the temperature range of -10°C to +65°C with the maximum humidity of 95%. The programmed command halts when the condition is unfulfilled.

The measurement result is presented directly on the device. Furthermore, the data are also sent to a computer for storing purposes. The data communication for PM₂.₅ concentration, temperature, and humidity are presented in Fig. 3. The daily storage data is 2880 real-time data. In order to protect the data, the system will also provide a backup file.

3.2. Device calibration and test
The calibration data are presented in the Fig 3. The PM₂.₅ measurement result is shown to have a linear response with $R^2 > 0.98$. The data characteristic follows the linearity equation of $y = 0.9851x - 0.4455$. This result indicates that the device is calibrated well with the reference device.

The test on various sources indicates the device work well in the PM₂.₅ measurement. The device can measure the concentration of PM₂.₅ in the ambient condition up to 115.71 µg/m³. The lowest concentration on the ambient is measured at 24.43 µg/m³. The highest concentration changes in the
ambient is found at 75.20 µg/m³. In case of a motorcycle, the maximum concentration is observed of 408.87 µg/m³. In contrast, the minimum concentration is obtained of 20.13 µg/m³ the motorcycle, the concentration can change from 408.87 µg/m³ into 202.53 µg/m³.

![Graph](image.png)

**Figure 3.** System comparison chart with Kanomax 3443.

In the near road area, the maximum concentration is obtained of 103.53 µg/m³. The lowest concentration that collected is 10.61 µg/m³. The maximum concentration change that is observed in the near road area is 87.18 µg/m³. The higher concentration is collected in the construction area with the concentration is higher 1400 µg/m³. The result indicates that the highest PM$_{2.5}$ concentration that is able to measure by the device is 1400 µg/m³. The minimum concentration is observed of 10.61 µg/m³. The device can measure the concentration change 600 µg/m³/minute.

![Graph](image.png)

**Figure 4.** System graph for detecting PM$_{2.5}$ concentrations; (a) ambient condition in the room; (b) motorcycle emissions; (c) construction area and (d) near road area.
3.3. Evaluate the communication system

The data communication is tested in terms of a range, delay and completeness of data during the transmission. The data communication reaches a distance of 20 meters. Furthermore, the delay can be seen in Figure 5. As a result, the data transmitter is related to the distance between the device and the computer. Long-distance causes a large delay time. The device is still connected to the computer up to 20 m. However, the optimum communication of the device is only 16 m. The delay time increases significantly in the distance higher than 16 m.

**Figure 5.** Data communication delay evaluation, (a) sequential method and (b) package method.

Furthermore, the communication stops after the distance reaches 20 m. The maximum distance is obtained for the data communication conducted in the sequential and package manners. The communication using the package data is more efficient in the delay time for the distance of in the range of 1 – 16 m. The average delay time is 0.375 seconds for the data in the package and 0.390 seconds for the sequential data. For the maximum distance, the delay time is 0.475 seconds and 0.410 seconds for the package and sequential data, respectively. The device can send well the data for the distance up to 20 m in terms of the digital value for both methods (sequential and full methods). The data is presented in the Fig.6.

**Figure 6.** The data communication, (a) sequential method and (b) package method.

4. Conclusion

In conclusion, the designed PM$_{2.5}$ monitoring device works well for the concentration in the range of 10.61 - 1400 µg/m$^3$. The device resolution is of 0.01 µg/m$^3$ and sensitivity of 600 µg/m$^3$/minute. The optimum communication distance is up to 16 m. The device system provides real-time data with a maximum number of 2880 counter/day. The data stores in the .xlsx format provide more benefit for further process.

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