Comparative Analysis between the Shinyei PPD42NS and Plantower PMS7003 Low-Cost Air Quality Sensors

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Abstract: Particulate matter (PM) is a form of air pollution that is considered harmful as these may cause respiratory problems. PM sensors are used to measure PM in the air and vary in costs. There have been many studies done on the accuracies of these sensors based on their price. In this research, a comparative analysis was done between a low-cost sensor, the Shinyei PPD42NS, and a mid-range sensor, the Plantower PMS7003. In previous studies, there were comparisons made between low quality sensors but no direct comparison between these two sensors. The tests were done in an indoor and outdoor environment wherein sensors were placed beside each other to measure particulate matter greater than 1 micron for a continuous span of 10 hours. Results from these tests showed that the Shinyei measurements broadly follow the more expensive Plantower but have more significant deviations over short periods. Larger deviations were noted in the morning and evening periods of testing. Recommendations for further characterization are provided in this paper.

Key Words: Particulate Matter; Air Quality Monitoring; Low-cost PM sensor; Shinyei PPD42NS; Plantower PMS7003

1. INTRODUCTION

Pollution is a problem faced throughout the world and can spread to other parts of the world (National Geographic Society, 2012). Air Pollution can not only bring harm to the environment but also to the health of the population. It is the ninth leading risk factor for death, and it is responsible for 3.2 million deaths each year (Kurt et al., 2016). The statistics from the World Health Organization (WHO) in 2016 shows that 91% of the population of the world reside in places that do not meet the imposed air quality standards, and estimates that in the same year, approximately 4.2 million deaths worldwide were caused by outdoor air pollution (Ambag, 2018).

Particulate matter (PM) is a form of air pollution involving solid materials and liquid droplets. The particles may come from both natural events and man-made sources. These particles range in size and are categorized into two main groups, which are PM 10 and PM 2.5. PM 10 involves particles sized 10 micrometers and smaller, while PM 2.5 involves 2.5 micrometers and smaller. Exposure to these can pose different threats to human health and the environment both short term and long term (EPA, 2018).

Detectors are used by the government to know the quality of air. The Beta Attenuation Monitor (BAM) is most widely used by governments and is considered the standard for detecting particulate matter in the air but is expensive to produce. While low-cost sensors are existent, they are still being developed and are still faulty and inconsistent (European Commission, n.d.). When compared to the standard particulate matter sensors, these cheap sensors are shown to be less accurate (Ahn et al., 2019). Furthermore, these sensors require specific technological components which may not be available in other places of the world.

The urgency to design and manufacture low-cost air quality sensors is widespread. Low-cost air pollution sensors enable high-quality resolutions in real-time and provide new opportunities to enhance existing sensors, as well as engage with the public in active monitoring (Castell et al., 2016). However, the quality of the data gathered is questionable. Studies have reported that low-cost sensors are unstable and often affected by atmospheric conditions (Karagulian et al., 2019).

This study aims to compare the performance between the Shinyei PPD4NS sensor and Plantower PMS7003 sensor in terms of accuracy in measuring particulate matter. Additionally, the capabilities and limitations of the Shinyei will be identified. The tests will be conducted in both an indoor and outdoor environment, and particulate matter will be measured in concentration.

2. PM SENSORS

2.1 Shinyei PPD42NS

The Shinyei PPD42NS uses the light-scattering principle (Tan, 2013). Particulate matter present in the air is measured based on the light scattered by the particles. A heating element is present that causes air to flow in, rise through, and out of the sensor. Additionally, some guidelines are provided when using the sensor, namely that it should be vertically oriented, in a dark area, and be given time to warm up. The sensor outputs a logic low whose time is proportional to the particulate matter concentration. Results from the sensors showed that one had occasional sporadic output compared to the other (Tan, 2013).

Additionally, according to Canu et al. (2018), the Shinyei sensor gives two outputs, P1 outputs information about particles over 1 μm while P2 outputs about particles over 2.5 μm, meaning that it cannot measure certain PM sizes strictly. The sums of the duration of low outputs from P1 or P2 is proportional to the quantity of dust particles. The correlation for P1 is shown in Figure 1.

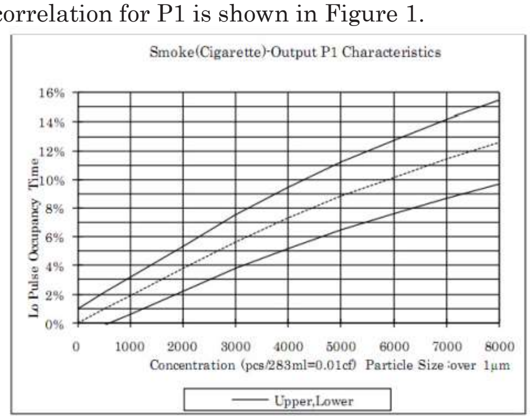

Figure 1. Relation between P1 LPO and PM concentration (Canu et al., 2018)

2.2 Plantower PMS7003

The Plantower PMS7003 uses laser scattering to measure particulate matter. The amount of light scattered due to particles are collected. The equivalent particle diameter and the number of particles with different diameter per unit is calculated by a built-in microprocessor. These measurements are provided in both μg/m^3 and in pieces per 0.1L. The Plantower is known to be effective and reliable in measuring PM (Badura et al., 2018).

3. METHODOLOGY

3.1 Data Collection Setup

Two independent systems to measure the quality of the air were developed. One is based on the Shinyei PPD42NS sensor, and the other based on the Plantower PMS7003 sensor. The Shinyei PPD42NS sensor was programmed with a code provided by SeeedStudio (2015), while the Plantower PMS7003 sensor was programmed with a code provided by Alam (2019). The sensors were set up to measure particulate matter sized greater than 1 μm and tested simultaneously in two different environments around a residence. The indoor test was conducted in a 52 m^3 room with three opened doors and only natural air flow circulating air, while the outdoor testing was done in an open-faced roofed garage.

3.2 Data Collection Method

Both sensors were set-up, connected, then interfaced through an Arduino board. As shown below in Figure 2, the Shinyei sensor was placed vertically for air to flow into the lower hole and out the upper. Additionally, data was not recorded for the first three minutes of connecting the Shinyei to allow it to first heat up its heating element which allows the flow of air in and out.

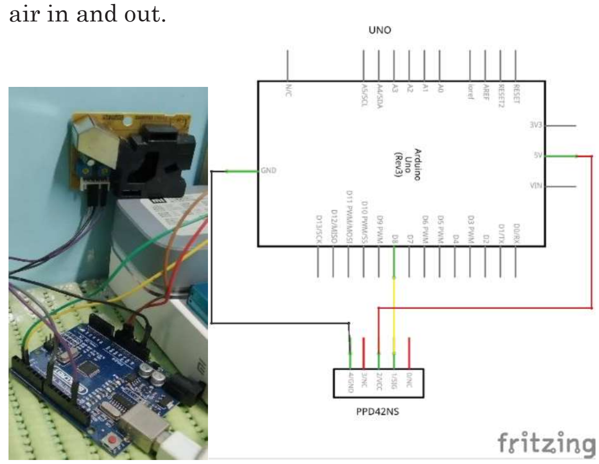

Figure 2. The setup of the Shinyei PPD42NS connected to an Arduino Board (Goram, 2019).

The Plantower was placed near the Shinyei to also obtain readings. Both sensors were interfaced through individual Arduino boards as shown below in Figure 3.

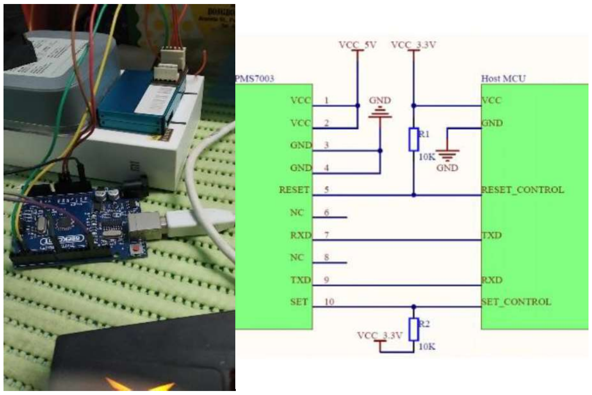

Figure 3. The Plantower PMS7003, connected to the same Arduino board (Zhou, 2016).

Data from the sensors were interfaced through the Arduino board, then transferred to Microsoft Excel to graph the readings.

3.3 Data Analysis Strategy

A conversion in the gathered data was necessary to visualize the readings of the sensors. The Shinyei PPD42NS measures in pieces per 0.01 cubic feet, while the Plantower PMS7003 measures in micrograms per liter of air. Additionally, the sensors send data at different time intervals, specifically, the Shinyei is set to send data in 30-second intervals, while the Plantower is set to 1-second intervals. After converting the data, the PM measurements were smoothened, graphed, and represented through line graphs showing the changes of the PM concentrations on the y-axis with the corresponding time on the x-axis. These graphs were used to compare and analyze the sets of data visually and statistically.

4. RESULTS

As shown below, Figure 4 shows the measurements taken from the two sensors in an indoor environment. The data collected from the Shinyei and the Plantower were done in a 10-hour test.

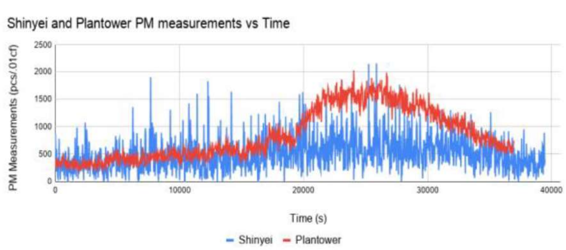

Figure 4. Original Indoor Measurements

The original data gathered is shown, represented by blue for the Shinyei, and red for the Plantower. These measurements are noisy is difficult to be accurately analyzed, hence a smoothening function, specifically through moving average, was done. Shown below in Figure 5 are the smoothened graphs.

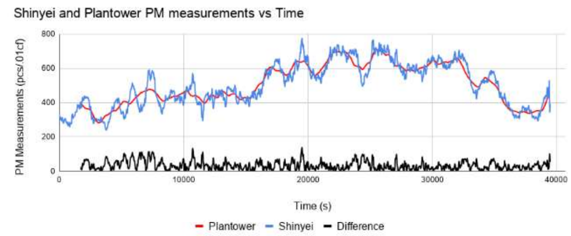

Figure 5: Smoothened Indoor Measurements

The blue line represents the Shinyei's measurements, while the red line represents the Plantower's. Both sets of data were smoothened through continuously averaging 25 data points for the Shinyei, and 15 data points for the Plantower. After time-aligning the data to match the graph, the difference between the two sensors' measurements was found, graphed and represented by the black line. It can be seen in the blue line that the Shinyei follows the trend of the Plantower's measurements throughout the test period, with a root-mean-square-error (RMSE) of 41 pcs/0.01cf.

Figure 6 below shows the PM readings from the sensors in the outdoor environment. These tests were done simultaneously while each sensor was beside each other for a period of 10 hours, starting mid-morning to early evening.

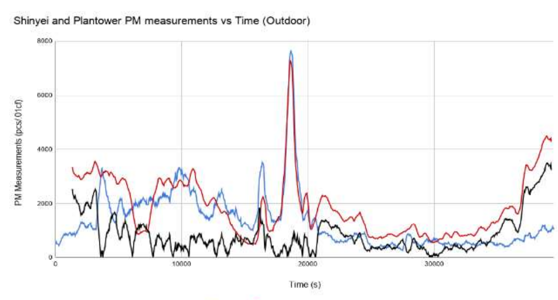

Figure 6: Smoothened Outdoor Measurements

Like the indoor graph, the blue line represents the Shinyei, and the red represents the Plantower. For this set, 15 data points were continuously averaged to attain a smoothened graph. The data was time aligned as well to attain an accurate difference measurement. The graph shows that the Shinyei had lower readings in both the earlier part of the day as well as towards the night compared to the Plantower. The middle parts of the data are similar, however. The large peaks in the middle are nearly identical, with the Shinyei having a slightly higher reading, peaking at 7367 pcs/0.01cf whilst the Plantower peaked at 7257 pcs/0.01cf. The RMSE is 1087 pcs/0.01cf which is attributed both the differences in the morning and evening, as well as the similarities in the afternoon.

5. DISCUSSIONS

Based on the findings, the two sensors are able to produce readings which show that they can be related. This means that the Shinyei PPD42NS can match the performance of the Plantower PMS7003, but only up to a certain degree. Looking back at the time-series graphs of the indoor test, the difference of each point of data is, again, relatively small. This is a good sign as the studies of Kuula et al. (2019) found that the sensor was effective and usable as a complementary to other particulate matter sensors. However, it should be noted that even after smoothening the data, the Shinyei was still noisy in its measurements.

On the other hand, as stated previously, the Shinyei's PM measurements in the morning and evening were significantly lower compared to what the Plantower recorded. The discrepancies during these periods may indicate that temperature and relative humidity might have skewed the sensor's measurements. Jayaratne et al. (2018) and Rai et al. (2017), also believe that temperature and humidity is factor that contributes to the inconsistencies of the Shinyei sensor. Although these factors may also affect the performance of the PMS7003, it can be implied that since the Shinyei is the significantly lower costing sensor, it also has lesser tolerance to environmental influence. To add, this may have not been observed in the indoor test since walls and a roof provide significant degrees of insulation from external environmental changes.

On the other hand, Holstius et al. (2014) investigated another factor, ambient light, which could also be a factor toward the Shinyei's measurements in the morning and night. Additionally, as it was an outdoor experiment, wind may have also factored in. Since the Shinyei relies on a heating element, it relies on air density differences for its airflow. This is more easily affected by wind compared to other sensors in general, which make use of fans for consistent airflow.

That being said, the Shinyei performed well in the afternoon parts of the outdoor test wherein it followed the Plantower's graphs better than in the morning and evening. Additionally, the larger difference in the RMSE values of the outdoor test compared to the indoor is also attributed to higher PM levels outdoors than indoors.

6. CONCLUSION

The Shinyei PPD42NS is a capable low-cost air-quality sensor in terms of particulate matter measurement performance when compared with the Plantower PMS7003. The indoor test showed very promising results in accurately measuring particulate matter, whilst the outdoor test was overall decent as well despite external factors potentially affecting the Shinyei. The lower cost and bare construction allow room for modifications thus providing significant potential. Future research will investigate exposing the Shinyei to controlled PM sizes and testing its performance in more environments with controlled light levels, temperature, and relative humidity. In line with this, the study will continue to improve the Shinyei by identifying limitations and adding corrective modifications, such as fans and filters, to improve its usability and performance in measuring particulate matter.

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