The approach to adjusting commercial PM$_{2.5}$ sensors with a filter-based gravimetric method

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Abstract. The measurements of temporal change to indoor contaminant concentrations are critical to understanding pollution characteristics. As commercial sensors are becoming increasingly commonplace, concentration accuracy is still a critical issue. The most common methods for measuring indoor particulate pollutants based on filter-based gravimetric methods. However, the gravimetric method is expensive, time-consuming, and often provides little temporal information. More and more commercial sensors are utilized to collect larger and temporal information about indoor air pollutants. Nevertheless, limited data support the accuracy of commercial sensors so far. Thus, this study aims to evaluate the performance of commercial sensors. PM$_{2.5}$ were collected for 30 days by personal environmental monitors with an airflow of 2 L/min on 37-mm Teflon filters and commercial sensors, simultaneously in a three-story house. Moreover, the intra-sensor comparison was conducted for 24 hours by the resolution in 1 minute. Finally, the linear regression model was built to adjust commercial sensors. The intra-sensor comparison results revealed that 24 hours average coefficient of variation (CV value) of PM$_{2.5}$ in this study were under 10% and the R$^2$ of the adjusted equation was 0.9394. We provide an accurate concentration of commercial sensors to estimate the association between pollutants exposure and health.
1 Introduction

People spend more than 85% of their time indoors (Jenkins, Almeida-Silva), where the pollution concentration may affect human health [1-4]. A study published in 2011 suggested that more than 2/3 have found indoor air pollutant concentration higher than outdoor [4]. Indoor air quality has become a critical issue of concern in the twenty-first century. Particulate matter (PM) is one of the interested pollutants in indoor environment. It is the sum of all solid and liquid particles suspended in the air, and it could be divided into PM10 and PM2.5 by aerodynamic diameter. Particulate air pollution is a critical environmental risk factor for human health, especially in PM2.5, which was designated as a carcinogen (Group 1A) by the International Agency for Research on Cancer in 2013 [5]. It has been demonstrated in numerous epidemiologic studies about morbidity and mortality [6-11]. Thus, the observed concentrations of PM2.5 should be highlighted for risk assessment. However, acquiring the indoor PM2.5 concentration is a big challenge and difficulties.

The measurements of temporal change to indoor contaminant concentrations are critical to understanding pollution characteristics. The United States Environmental Protection Agency (EPA) has published a one-page technical report to assess the continuous PM2.5 and PM10 concentrations. A nationwide air monitoring network should follow federal reference methods (FRM) or federal equivalent methods (FEM). A nationwide air monitoring network should follow federal reference methods (FRM) or federal equivalent methods (FEM). These methods developed by EPA scientists mentioned the accuracy and reliability of measuring particulate matter. However, these networks seem to be limited to the application within a large geographical region, which limits the ability to characterize the pollutant variability and sources. FRM was the primary acceptable sampling method, which integrated, the gravimetric method to measure the PM2.5 concentration over a 24h sampling interval. Nevertheless, there are some difficulties and disadvantages of FRM. First, FRM can not be available for application in an indoor environment with the loud sound of the pump. Second, FRM has a high operation cost. Third, FRM is not real-time data and only can provide 24-hour average data [12-14]. Third, FRM is not real-time data and only can provide 24-hour average data. Recently, low-cost sensor technologies for monitoring PM2.5 have rapidly developed and become commercialized.

Commercial PM sensors are portable and commercially available. It offers some significant advantages compared to conventional analytical instruments, including cost-effectiveness and deployment, operation, and maintenance easier. Moreover, the data could be collected continuously and simultaneously by the commercial PM2.5 sensors. However, the PM sensors present challenges for broad application and installation. The commercial sensors developed in laser light-scattering (LLS) technology, and the accuracy and precision of commercial sensors are almost less than those of FRM and FEM instruments.

Due to the uncertainty about the accuracy of commercial PM2.5 sensors, several studies have evaluated commercial sensors by comparing the performance of commercial sensors with medium- or high-cost instruments in laboratory, ambient, and indoor environments [15-19]. A study published in 2017 found that the low-cost sensors overestimated the concentration by 200% for indoor and 500% for outdoor compared to the Grimm 1.109 dust monitor [16]. Levy Zamora, et al. (2019) used Plantower PMS A003 sensors in different PM2.5 sources (incense, oleic acid, NaCl, talcum powder, cooking emissions, and monodispersed polystyrene latex spheres under controlled laboratory conditions and also residential ambient and outdoor air in Baltimore), and they indicated the Plantower PMS A003 sensors exhibited a high degree of precision and R² values. However, the accuracy ranged widely compared with reference instruments. Overall, limited data support the accuracy of commercial sensors so far. Thus, this study aims to evaluate the performance of commercial sensors.

2 Methods and material

2.1 Indoor environment

We collected two different houses in Southern Taiwan. In order to account for variations in urbanization levels, we chose one house in a rural area and another in an urban area to measure indoor PM2.5 concentration over a period of one month. One is a three-story house located in the rural area, and the other is a four-story house situated the urban area. In both buildings, the commercial sensor and the gravimetric method sampler were installed on the first floor, strategically placed near the breathing zone. This ensured that the measurements accurately reflected the indoor PM2.5 concentration experienced by occupants in those areas. Additionally, we maintained a minimum distance of 30 centimeters between the gravimetric method sampler and the sensor to prevent any potential interference (Figure. 1).

Figure 1. the installation of the commercial sensor and the gravimetric method sampler

2.2 measurement of PM2.5 concentration

The gravimetric method was employed using the Gillian pump with an airflow rate of 2 L/min through 37-mm Teflon filters (Teflon: Whatman 2 μm PTFE) (Figure...
2(A)) for a period of 24 hours, with the filters being changed daily. A total of 60 filters were collected from two different households. The PM$_{2.5}$ mass measurements were conducted using the gravimetric method on Teflon filters by determining the weight difference between pre- and post-sampling. Commercial sensors (PMS A003-C, IAQS, JNC Technology, Taiwan) (Figure. 2(B)) were also utilized to collect PM$_{2.5}$ concentration data in parallel with the gravimetric method. Data from the sensors were collected at 1-minute intervals, and the average PM$_{2.5}$ concentration over 24 hours was calculated for comparison with the gravimetric method.

![Figure 2. Gravimetric method and commercial sensors](image)

### 2.3 Analysis Methods

The accuracy was referred to as the sensors-gravimetric method for each measurement and calculated by the formula as follows,

$$\text{Accuracy} = 100 - \frac{\text{gravimetric method} - \text{sensors}}{\text{gravimetric method}} \times 100 \quad (1)$$

A 100% accuracy means that the gravimetric and sensors detected the same value. The coefficient of variation (CV) was an indicator of precision, and it would be calculated for every day by the formula as follows,

$$\text{The coefficient of variation (CV)} = \frac{\sigma}{\mu} \quad (2)$$

The adjusted formula and coefficients of determination (R$^2$) were calculated for the sensor and gravimetric method by a linear regression model.

### 3 Results and discussion

The average accuracy and precision were showed in Table 1. The accuracy values of each day were higher than 90% in both houses. The highest precision was 7.1 and 7.3 of both houses, respectively.

<table>
<thead>
<tr>
<th>Table 1. The basic information of PM$_{2.5}$ concentration</th>
<th>Average PM$_{2.5}$ concentration of commercial sensor</th>
<th>House located in urban area</th>
<th>House located in rural area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average PM$_{2.5}$ concentration of commercial sensor</td>
<td>26.66</td>
<td>25.37</td>
<td></td>
</tr>
<tr>
<td>Accuracy</td>
<td>96.97</td>
<td>94.63</td>
<td></td>
</tr>
<tr>
<td>Precision</td>
<td>2.18</td>
<td>3.89</td>
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</table>

The 24 hours averaged PM$_{2.5}$ concentrations collected by commercial sensors, and the gravimetric method of two houses were shown in Figure 3 and Figure 4. The line with the circle point and square point showed the PM$_{2.5}$ concentrations of commercial sensors and the gravimetric method, respectively. Both of the results of the two houses located in an urban or rural area revealed a similar trend of PM$_{2.5}$ concentrations collected by the commercial sensor, and the gravimetric method.

![Figure 3. The profile of PM$_{2.5}$ in rural house](image)

![Figure 4. The profile of PM$_{2.5}$ in urban house](image)

as Figure 5 and Figure 6 showed. The R$^2$ values were higher than 0.85 for both of houses, and the final adjusting formula showed as follows,

For the houses located in the rural:

$$\text{PM}_{2.5} \text{ concentration} = 1.0797 \text{PM}_{2.5} \text{ of commercial sensors} - 1.2406 \quad (3)$$

For the houses located in the urban:

$$\text{PM}_{2.5} \text{ concentration} = 0.9627 \text{PM}_{2.5} \text{ of commercial sensors} - 1.0872 \quad (3)$$
4 Conclusion

In this study, we built calibration methods for commercial sensors by filter-based gravimetric methods. We also provide an accurate concentration of commercial sensors to estimate the association between pollutants exposure and health.

5 References